Cave Science

The Transactions of the British Cave Research Association

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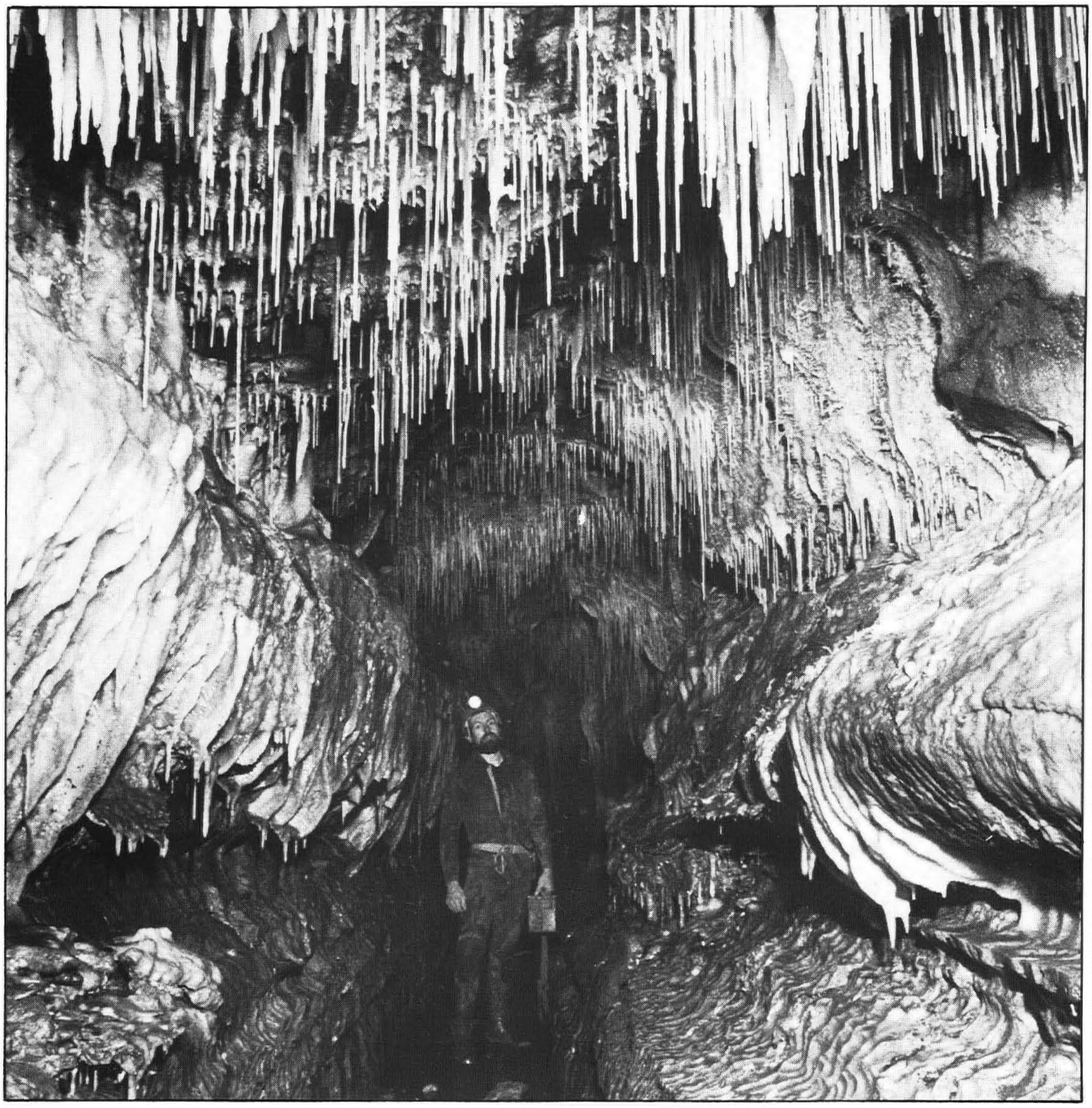

Symposium on Surveying Caves

Cave Science

The Transactions of the British Cave Research covers all aspects of speleological science, including geology, geomorphology, hydrology, chemistry, physics, archaeology and biology in their application to caves. It also publishes articles on technical matters such as exploration, equipment, diving, surveying, photography and documentation, as well as expedition reports and historical or biographical studies. Papers may be read at meetings held in various parts of Britain, but they may be submitted for publication without being read. Manuscripts should be sent to the Editor, Dr T. D. Ford, at the Geology Department, University of Leicester, Leicester LE1 7RH. Intending authors are welcome to contact either the Editor or the Production Editor who will be pleased to advise in any cases of doubt concerning the preparation of manuscripts.

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Cave Science

TRANSACTIONS OF THE BRITISH CAVE RESEARCH ASSOCIATION

Volume 14 Number 2 August 1987

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CAVE SCIENCE Vol. 14, No. 2, August 1987
Transactions of the British Cave Research Association

Symposium on Surveying Caves

FOREWORD

Paul HATHERLEY

The British Cave Research Association held a cave survey study weekend at the University of Sheffield and in Peak Cavern on the 15th and 16th of March 1986. The following papers were presented:

Cave surveying as it used to be ..... B Ellis
Survey method and calculation .... S Foster
Surveying under difficult conditions and divining .... D Brook
Archaeological surveying in caves ... C Hunt
Hydrological surveying .... J Wilcock
Surveying in and beyond sumps .... J Cordingley
Geology and cave surveys .... D Lowe
Draughting techniques and the Peak Cavern Survey .... J Beck
Use of computers in cave surveys .... A Bennett
Expedition surveying .... A White
The surveying of Daren Cilau .... D Ramsey

The idea for this special cave survey edition of Cave Science originated from this study weekend. Grateful thanks are due to the authors, many of whom have contributed to both, and also thanks are due to Charlotte Roberts who organised the study weekend in Sheffield.

It is hoped to repeat the cave survey study weekend in the not too distant future and that the following papers will stimulate further discussion. It is also hoped to include papers on computer applications to cave surveys and the design and use of radio location devices, in future editions of Cave Science - extensive topics which have hardly been touched upon here.

Surveying Caves

Paul HATHERLEY

The cave surveyor in Great Britain performs a thankless task, with few 'sporting' cavers appreciating the hard work which goes into the production of a cave map. Since the Daren Cilau breakthrough of 1984, surveying trips by one small team of cavers commonly exceed fifteen hours (Ramsey, pers comm). However, surveying can be rewarding, if not enjoyable. Some cavers in the USA take cave surveying very seriously and the high profile given to surveyors is illustrated by their 'Compass and Tape'*, a quaterly newsletter devoted to the art and science of cave mapping.

The principle of surveying a cave passage is to measure the distance, direction and angle of inclination along straight lines (legs) between fixed points (stations). The spatial relationship between stations can then be calculated by simple geometry to provide co-ordinates and these points are plotted at a suitable scale on a drawing medium. Measurements are also made from the centre lines and at stations to the floor, walls and roof of the cave and information such as floor deposits are also recorded. These details are drawn around the centre line to form the final map. The layout of this map varies but in Great Britain it will tend to follow that of an engineering drawing, with plan, elevation and sections on the same sheet.

It is not proposed to describe the techniques employed in a cave survey beyond the above summary as these are covered elsewhere in this issue and in 'Surveying Caves' (Ellis, 1976) which will soon be re-published as a thirty-two page booklet.

A competent team of two or three surveyors can, in normal circumstances, take sufficient measurements to record the centre line and passage details of several hundred metres of passage in a few hours. It is impossible to be specific about the rate of cave surveying since it will vary with the survey Grade (see below), location of the passage, the ease by which the passage can be traversed and the temperature and presence of water (Brook, White this issue). It is this lack of appreciation of the environment in which cave surveyors work that can lead to criticism by the surveying profession. Whilst this criticism is justified in terms of the inaccuracy of cave surveys, it is totally unjustified when the reasons for a cave survey are examined.

"The best surveyor is not the one who is extremely precise but the one who makes a survey with sufficient precision to serve its purpose without waste of time or money". (Anon)

This statement is as true today as it was when first published in 'Surveying Caves' in 1976. The reasons for a cave survey were listed then as:

Obtaining a general idea of the layout of the cave

A source of information, e.g. tackle requirements

A route map for finding the way through the system

To postulate further extensions or connections in a cave

A convenient form in which to record scientific or other information

To this can now be added the requirement to record detail of expedition finds for sponsors and the surveying of a cave just for the pleasure of creating a cave map.

The word 'accuracy' is the nearness of the result (or average of a number of results) to the true value. This differs from 'precision' which is the nearness of repeat results to each other, irrespective of their accuracy. The science of Land Surveying aims to achieve precise measurements using instruments which are finely

Footnote*: 'Compass and Tape' from the Survey and Cartography Section of the National Speleological Society. Edited by J. Ganter, RD1 Box 71B, Port Matilda, PA 16870 USA. Available from Lance Lide, SACS Treasurer, PO Box 2601, Little Rock, Arkansas 72203 USA. - $4.00 for 4 issues.

adjusted and surveying techniques such as triangulation which lead to a high degree of accuracy. There is no requirement to achieve such a high degree of accuracy in a cave survey but the overall aim should still be to make as accurate a survey as possible in the time available to meet one or more of the functions listed above.

The graded accuracy of British cave surveys is based on the accuracy of the instrument reading taken between stations and the maximum permissible station position error, not on the instruments or techniques used. The British Cave Research Association survey centre line gradings are explained in Tables 1, 2 and 3. The BCRA grading system assumes that the instrument being used has been calibrated prior to use and that the surveyors are recording the true readings.

One of the main problems of using any kind of sighting instrument is that of parallax. An eye condition called heterophoria can impair the reading accuracy of a Suunto compass. A surprisingly high percentage of people suffer from this condition without being aware of it. The manufacturers of Suunto instruments recommend the following test:

"Take a reading with both eyes open and then close the free eye. If the reading does not change appreciably there is no disalignment of the eye axes, and both eyes can be kept open. Should there be a difference in readings, keep the other eye closed and sight half-way above the instrument body. The hairline now rises above the instrument body and is seen against the target".

The condition may be so bad in some people that it may be inappropriate for them to take part in a cave survey as the instrument observer. It is thus recommended that the test should be carried out on the surface at the same time as calibrating the instrument (see below).

Cumulative errors in a cave survey can be corrected if the instruments are calibrated immediately prior to and preferably after every surveying trip. Calibration is particularly important if a large cave system is being surveyed over several visits and particularly where more than one set of instruments are used. Compass, clinometer and measuring tape calibration is easily carried out on the surface by fixing two

BCRA SURVEY CENTRE LINE GRADINGS

Note: Caving organisations, and others, are encouraged to reproduce Tables 1, 2 and 3 in their own publications; the permission of the British Cave Research Association to reproduce these three tables need not be obtained.

GRADE 1	A SKETCH OF LOW ACCURACY WHERE NO MEASUREMENTS HAVE BEEN MADE
(Grade 2)	May be used, if necessary, to describe a sketch that is intermediate in accuracy between grade 1 and grade 3.
GRADE 3	A ROUGH MAGNETIC SURVEY. HORIZONTAL AND VERTICAL ANGLES MEASURED TO ± 2½°; DISTANCES MEASURED TO ± 50cm; STATION POSITION ERROR LESS THAN ± 50cm.
(Grade 4)	May be used, if necessary, to describe a survey that fails to attain all the requirements of grade 5 but is more accurate than a grade 3 survey.
GRADE 5	A MAGNETIC SURVEY. HORIZONTAL AND VERTICAL ANGLES **ACCURATE** TO ± 1°; DISTANCES **ACCURATE** TO ± 10cm; STATION POSITION ERROR LESS THAN ± 10cm.
GRADE 6	A MAGNETIC SURVEY THAT IS MORE ACCURATE THAN GRADE 5.
GRADE X	A SURVEY THAT IS BASED PRIMARILY ON THE USE OF A THEODOLITE INSTEAD OF A COMPASS.

NOTES:

1 The above table is a summary and is intended only as an aide memoire; the definitions of survey grades given above must be read in conjunction with the additional comments made in the B.C.R.A. book "Surveying Caves". The more important comments are summarised below.

2 In all cases it is necessary to follow the spirit of the definition and not just the letter.

3 The term accuracy, used in the definitions, means the nearness of a result to the **true** value; it must not be confused with precision which is the nearness of a number of repeat results to each other, irrespective of their accuracy.

4 To attain grade 3 it is necessary to use a clinometer in passages having an appreciable slope.

5 It is essential for instruments to be **properly** calibrated to attain grade 5 – details of calibration are given in "Surveying Caves"

6 A grade 6 survey requires the compass to be used at the limit of possible accuracy, i.e. accurate to ± ½°; clinometer readings must be to same accuracy. Distances and station position must be accurate to at least ± 2½cm and will require the use of tripods or similar techniques.

7 A grade X survey must include on the drawing notes on the type of instruments and techniques used, together with an estimate of the probable accuracy of the survey compared with grade 3, 5 or 6 surveys.

8 Grades 2 and 4 are for use only when, at some stage of the survey, physical conditions have prevented the surveyor from attaining all of the requirements for the next higher grade and it is not practical to survey again.

9 The tabular summary above must not be re-published without these notes.

Table 1 Grading of the survey centre line points and taking readings from one to the other in both directions. A suitable correction factor can then be applied to the readings for each particular trip. Instrument calibration is standard practice in the USA and Canada and it is hoped that all British cavers will adopt such good practice in the future.

A factor not taken into account by the BCRA grading system is that of the effect of avoidable mistakes such as omitting a survey leg, reading the wrong value on the instruments, booking the wrong value on the survey sheet and other random mistakes due to inexperience in the use of the instruments, bad techniques and carelessness. Care should always be taken when using a cave map for this reason - a high grade does not necessarily mean an accurate survey.

The majority of cave maps are reduced for publication. Misclosures which result from errors and mistakes during the survey are often adjusted by manual re-alignment without the application of proper arithmetic techniques. Whilst this may be acceptable where the misclosure is small or where the cave map is at a scale of 1:2000 or greater, where a 0.5mm thick line equates to one metre, the effect of such inaccuracies will become apparent when new passage discoveries complete loops or connect adjacent caves and a compilation map needs to be prepared. The temptation for manual adjustment should thus be avoided. The Gaping Gill cave map is a compilation of a number of different surveys and the map indicated that the distance from Ingleborough Cave was considerable. In fact the distance turned out to be a matter of metres. The connection between Gaping Gill and Ingleborough Cave is unlikely to have been forged without the use of radio-location equipment to fix the postulated connecting point. This example illustrates two points; firstly, that many compilation maps in Britain contain gross inaccuracies and, secondly, that the use of radio-location equipment to fix points can significantly improve the usefulness of these maps without the need to carry out major re-surveying of the caves. Improvements can be made to most surveys by fixing several points using radio-location devices and distributing the errors through the rest of the cave passage. It is suggested that any cave maps improved by the use of radio-location should indicate clearly details of the point locations and the error distribution carried out.

The manipulation of cave survey data using computers permits the cartographer greater time to create an art form of the finished drawing. Too often, a British cave map is drawn badly and this does not do justice to the hard work done by the surveying team. In many instances maps show insufficient detail and the following should always be included: name of cave, precise location, BCRA Grade, names of surveyors, date(s) of survey, a grid - preferably related to the Ordnance Survey National Grid system, a proper north point - with an indication of whether grid, true or magnetic (with date) is being used, a proper bar scale to allow for photo-reduction, length, depth and volume (see Worthington, this issue). The surveying of caves is no longer just involved with the measurement of cave passages. It now includes the work of the hydrologist, geologist and geomorphologist and if space permits all relevant information should be recorded on the cave map. Access arrangements for visiting the cave and an indication of loose, flood-prone or otherwise dangerous passage are also invaluable. Lastly, reference should always be made on the map to a written report of the cave survey which should provide sufficient information on the actual survey to allow others to assess its true accuracy and usefulness, notwithstanding its BCRA Grade.

Survey in Dan yr Ogof (photo: Alan Coase)

The skills of the cave surveyor are advancing rapidly but independently throughout the world. The use of computers and radio-location devices are perhaps the two aspects of surveying which have advanced most in the last decade. It would be possible to fill an entire edition of Cave Science with papers devoted to just one of these topics. The International Union of Speleology (IUS) can play an important role in the future development of cave surveying mainly by attempting to establish world standards. International caving magazines should promote cave surveying, and along with specialist publications like Compass and Tape, can act as a forum for future discussion.

The papers in this edition of Cave Science give an indication of the advances made in Britain since the Cave Research Group Symposium on Cave Surveying (1970). It is acknowledged that British techniques differ from the rest of the world and we still have a long way to go to perfect equipment, techniques and above all, presentation of our cave surveys to other cavers, scientists and the general public.

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Ford, T.D. (ed) 1970 Symposium on cave surveying. Trans Cave Research Group of G.B. Vol 12, no 3.

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Class A	All details based on memory.
Class B	Passage details estimated and recorded in the cave.
Class C	Measurements of detail made at survey stations only.
Class D	Measurements of detail made at survey stations and whenever necessary between stations to show significant changes in passage shape, size, direction, etc.

Table 2 Classification of survey detail

Grade	**1A**
Grade	**3B or 3C**
Grade	**5C or 5D**
Grade	**6D**
Grade	**XB, XC or XD**

Table 3 Recommended grading/classification combinations

CAVE SCIENCE Vol. 14, No. 2, August 1987
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Cave Surveying in Britain - an Historical Review

Bryan ELLIS

While the earliest published underground survey that I have traced is one of an Egyptian gold mine that was, apparently, "published" in 1320 BC, cave surveying did not really start until the 17th and 18th centuries and the number of surveys published since then has roughly followed the growth in popularity of caving as a pastime. A study of the Mendip Cave Survey Catalogue shows that for this caving area about 25 surveys are recorded as published before the end of 1919, approximately 15 surveys published in the twenties, 40 in the next decade, 70 in the forties (including the war years), and over one hundred in the fifties; the relative figures are almost certainly similar for the other caving areas.

A fairly comprehensive study of the literature, made with the help of bibliophiles such as Ray Mansfield, Martin Mills and Dave Irwin, has failed to find anything published on how to make a cave survey prior to Arthur Butcher's classic work on the subject published by the Cave Research Group in 1950. There were plenty of standard works on surface and mine surveying but nothing specific to cave surveying, though it is believed that various manuscript notes on surveying methods prepared in the twenties or thirties by C.F.D. Long are in the possession of the Cambridge University Caving Club; there may well be others. This lack of published methods has lead me to the conclusion that most surveys published before 1950, including those in club publications and books, must have been prepared using what are by today's standards very crude techniques. This in turn means that today they would be classed only as grade 1, 2 or at the very best, grade 3 surveys. Butcher opened his work on surveying by saying "Most experienced cavers carry a small pocket compass with them in a cave. With this and ropes of known length (or by pacing) a rough sketch-plan of a cave can be made." Need any more be said? There is at least one exception that must be made to this generalisation, the survey of Ease Gill made in the late forties by Arthur Gemmell; the notes and comments that he published in the early Cave Research Group Newsletters show that he was a very conscientious surveyor and appreciated many of the problems involved. However, this generalisation of mine is pure conjecture and if anyone can provide any information to refute it, or earlier references about how to make cave surveys, I hope they will get in contact with me.

Therefore it is my opinion that cave surveying as a science rather than an art can be said to have its origins in 1950 with Arthur Butcher's "Cave Survey"; this book was almost certainly the first in Britain on the subject and possibly in the world. The contents were republished in virtually the same form in the two editions of "British Caving" that appeared in 1953 and 1962; then in 1966 a revised and enlarged version was published in volume 8 of the Transactions of the Cave Research Group of Great Britain. It says a lot for Butcher's ideas that 36 years later his original recommendations still form the basis of cave surveying in Britain and elsewhere. They were, after all, only modified and expanded but not drastically altered in my own book "Surveying Caves" that was published in 1976, and this book is still the only British one available.

What has developed since 1950? The rest of this paper will attempt to describe the major, and some not so major, changes that have taken place in the following thirty five years.

SURVEYING TECHNIQUES

There have been few changes made in the basic techniques used to obtain the data from which a cave survey is prepared. The only technique that has been introduced on anything like a large scale since 1950 is the one known as leap-frogging. This is where the readings are taken alternately in backward and forward directions along the passage rather than always in the forward direction. This method is both quicker and potentially more accurate. It was certainly being used in the very early sixties and may possibly have been introduced slightly earlier. The idea of taking forward and backward readings on every survey leg, while still considered to be the ideal, is one that has been practised only very rarely. Where there has been an appreciable improvement is in techniques for surveying in specialised circumstances such as under particularly arduous caving conditions, or in areas where large magnetic anomalies exist.

Radio-location is without doubt a development since 1950 but it will probably surprise most cavers nowadays to learn that an electromagnetic direction finding device was in use by U.K. cavers in the mid-fifties. If asked when this technique originated the majority of those attempting an answer would probably quote the work by members of the South Wales Caving Club in the early 1960's but a device was developed by Norman Brooks of the Westminster Speleological Group and tested as early as October 1954. In the following years it was used to check the Stride brothers' survey of August Hole, and the indicated position of Pillar Chamber in Ogof Ffynnon Ddu. The problem with this early device was that it used glass valves which required a 120 volt dry battery to operate them and this made it very heavy and very fragile; I state that from personal experience! By the early 1960's transistors were available to replace valves and electromagnetic transmitters and receivers were designed and built using them. They had the advantages of being smaller, less fragile and require much lower voltages with the result that more powerful and more portable devices were possible. A later development was the facility to transmit speech in both directions which removed the need to keep to the strict transmission timetables that were previously necessary to ensure that both parties were doing the appropriate thing at any one time.

One technique that was discussed by Butcher but which has never been used to any appreciable extent in cave surveying is that of making theodolite traverses. His intention was to produce a more accurate survey line but it has been found to be impractical to use commercial instruments in most cave situations and simplification of the instrument, although tried by several surveyors, does not give the accuracy that is required to produce a better result than that obtained with a magnetic traverse. It has been a technique virtually used only when a magnetic traverse is impractical for some reason or another.

Author's Note. This paper was originally prepared as a lightweight introduction to the more erudite papers that were to be given at the Cave Surveying Symposium held at Sheffield in March 1986. The intention was to provide a history of cave surveying but it ended up more as a personal reminiscence; it has now been rewritten in the form of a review. It is hoped that it will prompt the publication of more information on cave surveying techniques and instruments of the past.

REDUCTION OF SURVEY DATA

The area where the greatest development has taken place in the last thirty years is without doubt in means of reducing traverse data into station co-ordinates. This task which is now so simple to carry out with the aid of the ubiquitous computer was the bane of the surveyor's life until the early seventies when electronic calculators first became available. Before then calculations had to be carried out in longhand using logarithm tables or a slide rule; the fortunate surveyor might have had access to a mechanical (or perhaps even an electrical) calculator but these machines were only capable of performing the four basic mathematical functions, and then only one of them at a time. It was still necessary to look up the values of sines and cosines in trigonometrical tables before carrying out the multiplications on the calculator, followed by a separate step where all the directional changes were added together to obtain the station co-ordinate. There was an alternative in that traverse tables could be used to determine the latitudes and departures in a single step but they were cumbersome and none too accurate. Now the lot can be done in one step using a calculator costing less than £10. One result of this earlier difficulty was that many surveyors did not bother to reduce their data but simply prepared the survey by plotting out the data from their cave notes using a protractor and ruler. In fact this method was the principal one described by Arthur Butcher, with only a brief mention of mathematical reduction. Hopefully all surveyors today determine the co-ordinates of their stations mathematically for all but the simplest of surveys before starting to plot the result; there is no excuse for not doing this nowadays.

PRESENTATION TECHNIQUES

Butcher considered cave surveys as three dimensional engineering drawings and his ideas and recommendations are still followed very closely today; they have been simplified but the principles are unaltered. This is not to say that other methods of presenting surveys have not been proposed since then either for general use or for specialised purposes. Cut away block diagrams to show the layout of the caves have been extremely effective but require a lot of effort and no mean amount of artistic skill to prepare. Other ideas that have been proposed include isometric drawings, simplified diagramatic surveys intended to give just a rough idea of the layout of a cave and even route severity diagrams intended, as the name suggests, only to indicate routes through a cave, the time required, difficulty, etc. and not dimensions or layout. None can be considered to have caught on and virtually all surveys are still produced in the traditional style. Programs for use on simple computers to draw the survey centre line from the survey data have been published but the idea of automatically plotting the passage detail in addition is, in the mid-eighties, still in its infancy and restricted to those with access to large and expensive equipment.

On the question of symbols to be used with cave surveys, Britain has gone in the opposite direction to several other countries. Over the years we have reduced the number of recommended symbols from the list prepared by Arthur Butcher and now publish only the basic symbols; surveyors are expected to devise their own symbols for more specialised purposes, and to publish a key on the survey. Some other countries seem to be publishing ever longer and more complex lists of recommended symbols.

ACCURACY OF CAVE SURVEYS

There has been a considerable increase in the accuracy of surveys produced over the years. To see this it is only necessary to comparer the standard of surveys produced in the eighteenth and nineteenth centuries with those made in the first half of this century, or this latter group with those prepared since 1950. In the 1960's, and to a lesser extent since then, there have been many papers published discussing various aspects of cave surveying and apart from the few dealing with the presentation of surveys, just discussed, most dealt with improving the accuracy of surveys by some means or another. Topics covered have included the calibration of the instruments used, the distribution of closure errors, attempts to improve techniques and hence accuracy, the need to use a clinometer, rationalisation of survey grades, and so on. The majority of these papers originated from Mendip surveyors but this is probably only because with so few proper caves to survey they have had to turn their interest to more theoretical aspects! It is interesting to note, however, that several of the points put forward later by Mendip surveyors, such as the need to use a clinometer even when making a medium grade survey, or the fact that the accuracy of a survey is not necessarily dependant on the caving severity of the passage, were first put forward by northern cave surveyors in the 1940's but ignored when "Cave Survey" was written.

As with the presentation of surveys, there has tended to be a simplification of the grading system used to indicate the expected accuracy of cave surveys. This followed from a realisation that the finer discussions over relative accuracy of surveys were only of interest to cave surveyors and most certainly not of interest to the average survey user! As far as the latter are concerned surveys are of low, medium or high accuracy, and no more. One small change has been to indicate the probable accuracy of the detail in addition to that of the centre line; this is done by means of a suffix letter. There has been a change away from the simplified view that one could gauge the accuracy of a survey solely from the instruments used rather than from how they were used. It is very gratifying to notice that surveyors from most countries around the world now quote their estimate of accuracy by means of the B.C.R.A. grading system.

SURVEY INSTRUMENTATION

In the fifties, being relatively soon after the second World War, there was an abundance of fairly simple surveying instruments available cheaply from government surplus dealers. These included the mark III liquid filled prismatic compass, the Abney level, the Watkin clinometer and surveying tapes - all very suitable for the making of relatively accurate cave surveys, certainly a vast improvement on the "pocket compass and pacing" that, presumably, had been the norm before.

Compasses

The ex-government mark III prismatic compass soon became the instrument most commonly used by cave surveyors. They were readily available in both dry and liquid filled versions but only the latter was really practical for use underground; with the other it was necessary to wait for ever and a day for the needle to stop oscillating. The price at that time was £4 - £5 (or to put this in perspective, about the cost of seventy five pints of beer) so, although not cheap, they were not outlandishly expensive, in fact if one advertised in "Exchange and Mart" it was possible to pick them up at about half that price. They are excellent instruments, very robust, accurate, relatively cheap (when purchased ex-WD), compact and very easy to use in daylight. Unfortunately they had not been designed for use underground. The principle is that while looking through a slot at the near side of the compass one lines up the distant station with a sighting line marked on the raised lid, and at the same time you look at the compass card through a prism below the slot. The problems when using these compasses for cave surveying are in illuminating the card below the prism so that the bearing can be read, and cleaning the prism itself when it becomes coated in mud or condensation. One's tongue is usually the most effective method of dealing with the latter, but attempts to solve the former have given rise to some intriguing inventions that attempt to prevent electrical fields from the illumination affecting the compass. The other problem with the ex-WD prismatic is trying to take accurate bearings on survey legs that slope at more than about +20° or - 15°; but then the Suunto instruments are even worse in this respect. One method used to overcome this problem was to fix a glass or Perspex rod horizontally across the sighting line so that the target light was refracted to the prism but it is very doubtful if this was any more accurate than struggling without it. (Incidentally, this same idea has recently been suggested for use with Suunto compasses to overcome the same problem.)

The only other compasses even vaguely in common use at this time were the Silva-type compass (quite a good instrument for lower grade surveys) and the ex-government 06A hand-bearing prismatic. The former are still available of course; the latter were much larger instruments only graduated in two degree divisions but the prism could be tilted which meant that readings on upward sloping legs could be made much more accurately. It also had built in illumination. Bulky and heavy, but accurate and a very easy instrument to use. The Brunton compass, beloved by the Americans, has very rarely been used in the U.K.; one caving club who did own such a thing considered it to be too expensive to take underground!

By the very end of the 1960's the Suunto compass had been introduced to cavers by northern surveyors and its use rapidly spread to other areas. Largely because of its relative ease of use but aided a little by the fact that by this time prismatics were becoming hard to obtain at an acceptable price, it soon became the most commonly used instrument despite, as one contemporary surveyor wrote, its high purchase price of £6! These are still, of course, the instruments most commonly used today.

Clinometers

The Abney level was another instrument available ex-WD at roughly the same price as prismatic compasses though they were a little more difficult to come by. Although called a "level" these instruments are really clinometers. They are reasonably robust and to use them underground does not present any additional problems beyond the obvious one of illumination. The principle of use is that one looks through a sighting tube at the target and at the same time looks (by means of a mirror occupying half of the sighting tube) at a spirit level bubble. The bubble is movable and is altered until it is central in the field of view. The angle of slope can then be read against a scale. It is a relatively easy instrument to use but it becomes progressively more difficult to make accurate readings as the angle of slope increases and, although calibrated from +90° to -90°, the maximum angle is about ±45° when used as a hand-held instrument. Some surveyors modified it so that it could be mounted on a tripod when it became an even better instrument, easier to use accurately and it could be used on lines of sight at virtually any angle.

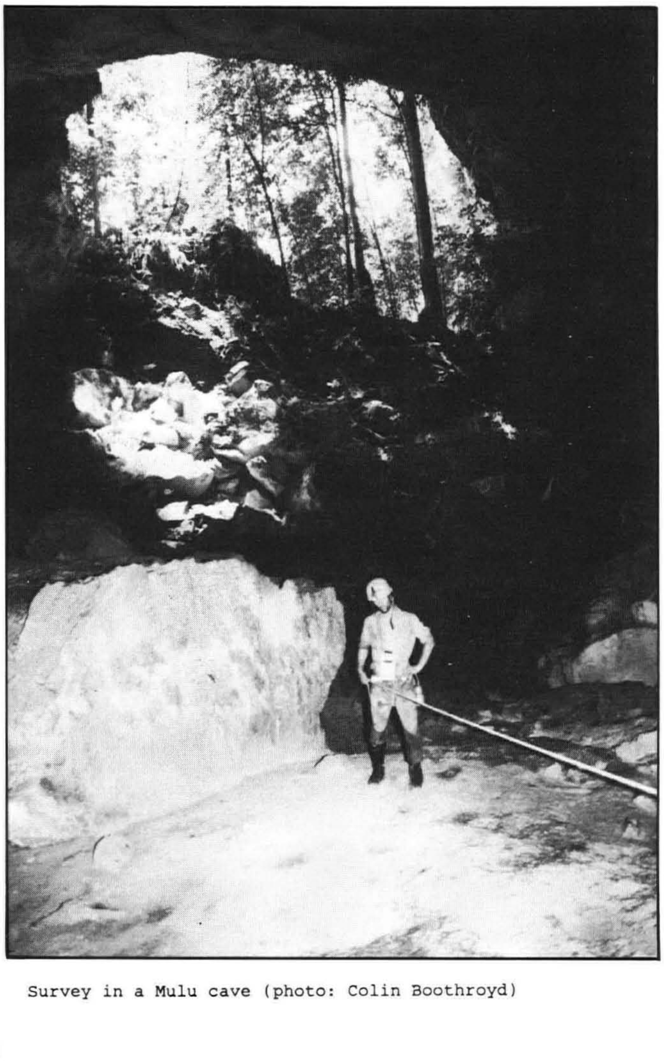
Another instrument that was occasionally available on the government surplus market was the Watkin clinometer. This is based on a pendulum instead of a spirit level and has a scale calibrated from -45° to +45°, sometimes marked directly in tangents of the angle. It is used by looking through a pin hole on one side of the case and out through sighting wires on the other; there is a concave mirror occupying half of the field of view and the scale, fixed to the pendulum, can be seen in this. Once the instrument has been sighted on the station the scale is locked and the reading made in "comfort". While quicker to use as a hand-held instrument than the Abney level, the method of sighting is relatively crude and the precision is probably not as high. They were useful when making surveys where speed had a higher priority than accuracy.

As with the compasses it was in the late 1960's that Suunto clinometers became known to the cave surveying community and swiftly became the most commonly used instrument; they still are.

Virtually the only other clinometers used in the early post-war years were home-made ones. A typical instrument consisted of a 15 cm aluminium alloy ladder rung that had cross wires inserted at one end and a plug with a pin hole through it at the other. Along the side was fastened a semi-circular school protractor over which moved a weighted brass pointer "driven" by gravity. The tube was sighted on the distant station, the pointer clamped by the judicious use of a finger and then the instrument moved so that the reading could be made! During this period, until the introduction of Suunto instruments, few northerners bothered to use any form of clinometer when making cave surveys.

Combined Instruments

Over the years efforts were made by several surveyors to combine a compass and clinometer into a single instrument; one such was designed by me in the mid-1960's when a prismatic compass and an Abney level were rigidly mounted together in what was called a Survey Unit. The idea was to remove many of the problems associated with using the instruments independently. The Abney was used to sight on the distant station and this one sighting sufficed for both the clinometer and the compass reading so the latter could be taken on very steeply sloping legs. The spirit level of the Abney was set by looking from above the instrument instead of through the mirror and so it was possible to take precise readings in the vertical range +80° to -80°; the difficulty of illuminating the bubble was also removed. A larger prism was



Survey in a Mulu cave (photo: Colin Boothroyd) fitted to the compass and this made both illumination and reading easier. The complete instrument was used mounted on a tripod and this gave a further increase in precision. However it must be admitted that outside a small band of Mendip surveyors it never caught on and its demise was hastened by the appearance a few years later of the Suunto instruments.

A commercial version of the same idea is known as the Verschoyle Transit. But for one defect it would probably be the best instrument available for cave surveying, even today. It consists of a 7.5 cm diameter compass scale graduated to 0.5°, a spirit level and a folding sighting arm. The compass scale and spirit level can be seen, by means of a prism, at the same time as looking along the sighting arm and the two readings are made against the same reference. A pointer attached to the sighting arm moves over a semi-circular scale and the inclination is read from this. It does suffer from the same problem as the Abney level in that it becomes progressively more difficult to make readings through the prism as the angle of slope increases but this can be overcome by mounting the instrument on a tripod and setting the bubble without using the prism - as was done with the Survey Unit. If only the compass were liquid filled it would be close to the ideal instrument for cave surveying.

Another combined instrument made by cavers appeared on the market some years later in the seventies, the Topofil. This attempts to overcome the sighting problem, and at the same time measure the inter-station distance, by using a thread pulled between the stations. Again, this instrument has failed to catch on except with a small band of surveyors. Why? Is it conservatism on the part of cave surveyors or, in this case, doubts about the inherent accuracy of the system? I suspect that it is a combination of both reasons.

Astro compasses, originally used to take bearings of stars from aeroplanes, were modified in the early 1950's by at least two cave surveyors who added a simple sighting tube so that they could be used as a "cave theodolite". As stated earlier, theodolite traversing has never caught on with British cave surveyors largely because it has been realised that very precise instruments are required for this type of traverse; astro-compasses and other home made cave theodolites certainly did not reach the required standard.

Length and Depth Measurement

An instrument developed by members of the University of Bristol Spelaeological Society in the late forties was known as the Spelaeobathometer. It consisted of one hundred feet of pressure tubing filled with water and had a pressure gauge at one end directly calibrated to show the depth (in feet) of the gauge below the other end. It was claimed to be accurate to within one foot and to provide a rapid but reasonably accurate method of levelling through a cave. This might be an idea worth resurrecting! Members of the S.W. Essex Technical College Speleos also experimented with a water level in the early 1960's but this time as a straight level without the pressure gauge.

"Fibron" tapes, consisting of glass fibre reinforced PVC, were not introduced to cave surveying until the mid-sixties, and earlier the only measuring tapes available were those made of linen (which stretched or shrank at the slightest provocation), those known as "metallic" tapes (linen tapes incorporating strands of copper and which were not much better than cloth tapes), and steel tapes. These last had the disadvantages that they rusted if great care was not taken of them, were prone to kink if one was not careful when using them, and broke if they were trodden on. There was also the possibility of introducing errors on a magnetic traverse if the tape was allowed to get too close to the compass; but this danger was not as great as many thought.

CONCLUSION

If the review given above is anything like a true record, then it can be seen that the vast majority (about 95%) of the British cave surveying development took place over a period of approximately 25 years that started around 1948. It started with people like Arthur Gemmel and Arthur Butcher, and was developed by surveyors practising in the 1950's and 1960's. Virtually the only developments since then have been in fields of using computers to assist surveyors, and improvements in radio-location equipment. Is anyone going to dispute this? If so, then I hope details will be brought to my attention so that the record can be corrected.

Author's Postscript

Literally as the manuscript of the above article was being run off I came across an earlier article describing how to make cave surveys. This was published in 1947 in the Bulletin of the National Speleological Society of America and therefore pre-dates Butcher's paper by three years, although it is contemporary with the discussions in the early C.R.G. Newsletters. Although relatively short this paper does deal with many problems of cave surveying and the presentation of surveys without going into great detail.

As my paper is a review of cave surveying in Britain it does not materially affect what has been written; Butcher was a committee member of the Cave Research Group and therefore it is just possible that he may have been aware of the American paper when he wrote his own work but it is almost certain that general knowledge of it in the United Kingdom would have been very restricted.

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Review of Cave Surveying Techniques

Steve WORTHINGTON

The main purpose of this article is to compare different mapping techniques, so that an appropriate one may be chosen for a particular cave. Ultra-accurate techniques such as using tripods are not discussed here, as their application is limited to a small minority of caves. Most modern mapping is carried out under time restraints, due to the shortness of an expedition or the difficulty of a cave; thus, rapid mapping techniques are emphasised here.

One can broadly define three reasons why caves are mapped:

a) to compute the length/depth of a cave for "record" purposes,
b) to produce a map of the cave for route-finding, scientific purposes, or as a work of art,
c) to locate passages accurately so that connections or new entrances can be made by further exploration, digging or blasting.

Each of these requirements imposes different demands upon the cave surveyor, and will be considered in turn.

Length and depth lists of caves are becoming increasingly popular and provide a satisfaction of achievement and a competitive spur. In many long caves, it seems that the calculation of length is the main reason for mapping. An extreme example is the Mammoth System, where the total cave length is published annually (1985: 500,506m), yet the most recent maps are 1908 (for 56km of Mammoth Cave) and 1964 (for 53km of the Flint Ridge section). Only computer-generated line plots with no passage information have been published in recent years. It is interesting to note that American cavers often record how many survey stations they set on a particular trip, rather than how many metres of passage they mapped: this attitude rewards effort rather than luck, and it encourages the mapping of constricted passages with short legs. The calculation of the depth of a cave is relatively simple, though with large entrances (e.g. Sotano de las Golondrinas, Mexico) the choice of datum is often arbitrary.

With long cave systems, the data is usually fed into a computer, which will generate a precise surveyed length. But with large data bases it becomes increasingly difficult to keep track; for instance, in Hölloch (Switzerland) the current length of 133,050m follows a purge of over 11km of data from the resurvey of passages; thus the length of the cave had been overestimated for many years.

Having carefully eliminated all duplicate surveys from your data, do you now have an accurate length? Not at all. You first have to decide whether to follow the principle of continuity or the principle of discontinuity (Caving International, 3 p35). To follow either method strictly would be so tedious that I doubt whether either has been implemented in an extensive cave, yet in a cave with wide passages and chambers the difference could be several per cent. Next, what about that 20m oxbow that you sketched? You may not have produced numbers for your computer to add up, but it's a passage on your map and so should be part of the cave length. Then what about big passages? Should you zig-zag from wall to wall to give good passage definition, take the shortest route, follow one wall, or map down the centre? The last choice is the most logical for accurate length, but the other methods may be easier to use. When you've resolved all these problems and calculated a precise length, is it right? If you want your confidence shaken, get someone else to remap any section of the cave, preferably using different techniques. Most likely their results will differ by at least 1%. Thus if one is mapping a cave to calculate its length, there seems little point in striving for better than 1% accuracy in one's survey.

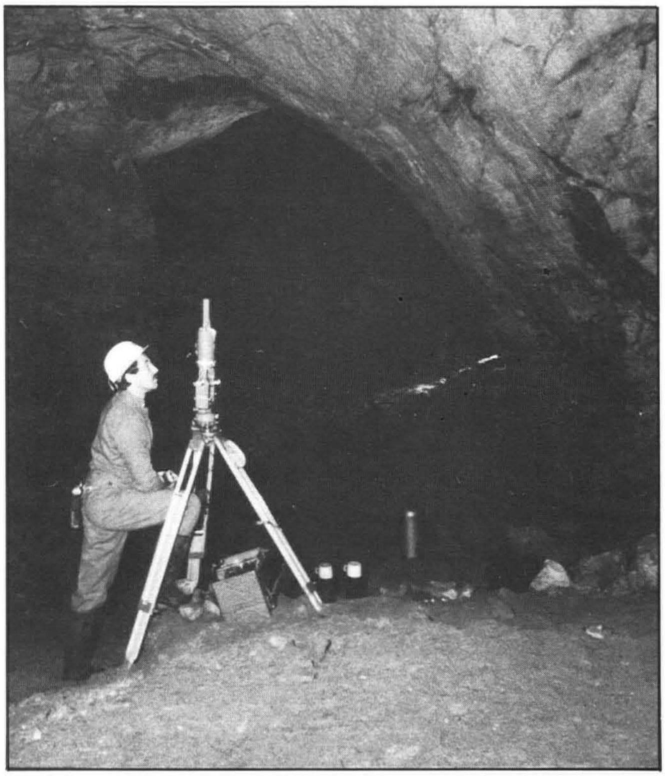
To produce a good cave map requires careful drawing of passage detail. The National Speleological Society (USA) has encouraged this for many years by presenting awards at their week-long annual conference for the best cave maps; the result is that some American maps achieve the highest cartographic standards anywhere, with meticulous attention to the portrayal on individual boulders and formations. For route-finding purposes, a map should emphasise those features that a caver is likely to notice, such as deep pools, climbs, pitches, ducks, sumps and squeezes. For scientific purposes it is most useful to have an accurate, well-drawn map, but most scientific projects will require additional information in specific parts of the cave.

To locate passages for connection purposes, it is useful to have an accurate map, but nowadays radio-location is commonly used in many countries and will give better information than the most accurate mapping.

EQUIPMENT

The standard method of surveying measures distance, compass direction and inclination, using three instruments (though these may be mounted together as in a topofil). These will be considered in turn.

Distance may be measured by tape, topofil or telemetry. Thirty metre long fibreglass/PVC (Fibron) tapes are most commonly used, though 15m tapes are lighter and cheaper and are preferable in most circumstances. A topofil (Foster, this



High-grade survey with a gyrotheodolite in Alderley Mines (photo: Paul Deakin) volume) may come in one of three forms; it may just measure distance e.g. Topofil TSA (although it is easy and inexpensive to add a protractor and spirit level to the case to measure inclination); it may measure distance and inclination (e.g. Topofil Dressler); or it may measure all three parameters (e.g. Topofil Vulcain).

Telemetry (ultrasonic rangefinder) (Breish and Maxfield 1981; Torode 1984; Mixon 1984) has been little used in caves, due largely to high prices and the delicate nature of existing instruments, but improvements in microelectronics assure a more popular future for these instruments. It works best with relatively short survey legs (<10m), because it is difficult to aim precisely at a distant survey station and because accuracy diminishes with distance. However, this device enables heights in high passages to be measured for the first time, and passage cross-sections and chamber dimensions can be measured speedily and accurately.

For measuring compass direction, a Suunto compass is most frequently used. Once the circumferences of the two windows are sealed with silicone adhesive, these light, durable instruments are water-resistant and almost ideal for cave surveying. There are two methods of reading the scale; for normal station-to-station usage the scale with 0.5 degree gradations is read, but the scale with 5 degree gradations is used when aligning the compass with a topofil thread or when a pace-and-compass survey is being made. In the latter case, if a straight line is engraved along the centre line of the top of the compass to facilitate alignment, then the scale can be read to an accuracy of one degree. Other types of compass such as Brunton (U.S.A.) and Topochaix (France) are still used, but they are bulkier, more expensive and less suitable than the Suunto for cave use.

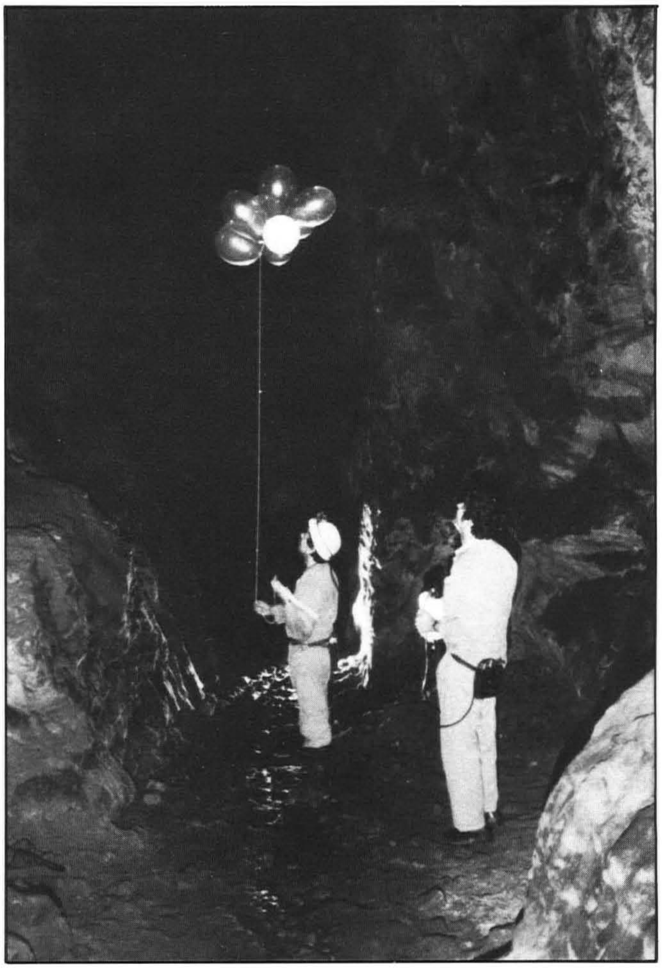
For measuring inclination, the Suunto clinometer is the most popular instrument. Some topofils have a protractor mounted on them, and some care is needed to achieve an accuracy of one degree. Alternatively, a Suunto clinometer may be aligned along a thread.

Mud and water seem to have an affinity for survey notes, so water-repellent paper, or, better still, plastic is recommended, such as the Duksbak waterproof survey pad*. Plans, elevations and cross-sections should be drawn to an appropriate scale so that detail can be included. Surveyors in Sistema Purificacion (Mexico) carry ruler and protractor and draw up what is essentially a finished map of both plan and elevation at 1:500 as they proceed through the cave. This technique is likely to detect instrument blunders and ensures a sufficient amount of passage detail is recorded, but surveyors in cooler caves are unlikely to have the necessary patience. Mechanical pencils with 0.5mm leads work well, the models with retractable tips being the best. Even so, for emergencies it is worth carrying one or two inch-long pencil stubs taped to the webbing on the inside of one's helmet.

Radio-location equipment with two-way voice communications are now common in Britain and elsewhere (Machin, this volume). There is now a quarterly newsletter Speleonics*, devoted to cave

Footnote*: From R.D. Penhall Ltd., Vancouver, B.C., Canada. It has 10cm by 17cm plastic pages with a 2mm/10mm grid on one side, and 30 lines with six columns printed on the other side. The six columns can be used doe station number, tape, compass, clinometer, distance to left wall/distance to right wall, distance to roof/distance to floor; the gridded opposite page can then be used for plan, elevation and cross-sections which should be oriented and to scale (e.g. north up the page, one grid square = 1metre). The pages can be used in the ring binder supplied (which is rather bulky for carrying inside one's suit), or a loop of cord a metre or so in length can be passed through two of the holes in the plastic sheets so the pad can be hung around the neck.

Footnote*: Speleonics was adopted by the Technical and Material Commission of the IUS at the Barcelona Congress as an international forum for caving electronics, Subscriptions ($6 for 4 issues) are available from Joe Giddens, PO box 170274, Arlington, Texas 76003, USA.



Using helium-filled balloons to survey roof height (photo: Paul Deakin)

radios. There are substantial differences between radio-location equipment from different countries, as a wide range of frequencies can be used (Davis, 1970). Canadian equipment is based upon a design by Pete Hart (Westminster Speleological Group), and use a frequency of 114.3 kHz, with a band width of 1.5kHz. Two-way voice communication has succeeded to depths of 220m, and a 13m diameter aerial is currently being constructed for communication to the surface from an underground camp at a depth of 700m in Sotano de San Augustin, Mexico. On the other hand, most American cave radios use a much lower frequency, about 3.5kHz, with a narrow band width of 3-30 Hz. At this frequency only one-way voice communication is possible but more accurate locations and further distance penetration are possible. Other countries use different designs such as current injection at low frequencies at Holloch (Switzerland), and double side band usage in Sweden.

Since the most popular instruments for surveying are Suuntos and tape, the range of techniques that may be used will be examined next.

TECHNIQUES FOR SUUNTO AND TAPE SURVEYS

The best technique to use on a particular mapping trip should depend on the accuracy required in the final map, the number of people and the amount of time, and the instruments available. It is more important to devote time to survey the principal passage of a cave accurately than to take readings accurately through short side passages or oxbows, yet this is often not done. There are three techniques in particular that may be varied during a survey that will affect speed and accuracy.

First, survey stations may be fixed or "floating". Fixed stations are commonly suitable projections on a wall, or cairns. They must be carefully chosen so that it is possible to read the instruments from them, and frequently this involves considerable effort. The soot from a carbide flame is commonly used in North America to mark both the station position and station number. This considerably aids navigation through complex caves ("follow the P survey till you get to P123, then turn left down the Q survey"), but in many countries this is considered unacceptable pollution. A compromise used in Switzerland is to mark the station position with a small spot of nail varnish.

A much simpler method is to use the "floating" station, which is at eye height when the surveyor is standing (or kneeling, or lying) at a suitable position in the passage. For correct vertical control, unless one is using the leapfrog technique, it is important to sight on the equivalent height on the other surveyor, or, if one sights on the light (which is easier), then one needs to make a vertical correction for every leg.

Second, Suunto readings may be taken either only in one direction (as foresights, backsights, or by leapfrog), or one can take both fore- and back-sights. The latter technique ideally needs an extra person, so that the foresight on one leg can be taken immediately after the backsight on the previous leg, but it means that instrument reading errors can be picked up immediately and corrected.

Third, a pace and compass survey is much faster than any of the above methods, and, like a topofil survey, it only requires one person. The length of one's pace can be calibrated on the surface for walking, stooping and crawling. Slope measurement depends on the situation; body lengths are suitable in steep passages. In big, low-angle stream passages, where there are pools, the vertical drops of the stream can be estimated, and may yield a more accurate result than a clinometer reading. (A clinometer reading of 1 degree on a 30m leg gives a vertical difference of 0.52m; many stream passages have more gentle gradients than this; there have been instances in such streamways where a Grade 5 survey shows the stream as flowing uphill.)

There is little data available on the accuracy of pace and compass surveys, but with careful measurements misclosures of only a few per cent can be achieved; the 0.6% misclosure of the 1660m Tigris Tunnel survey by Waltham (1976) is equivalent to the lower limit of Grade 5 accuracy, but is probably exceptional.

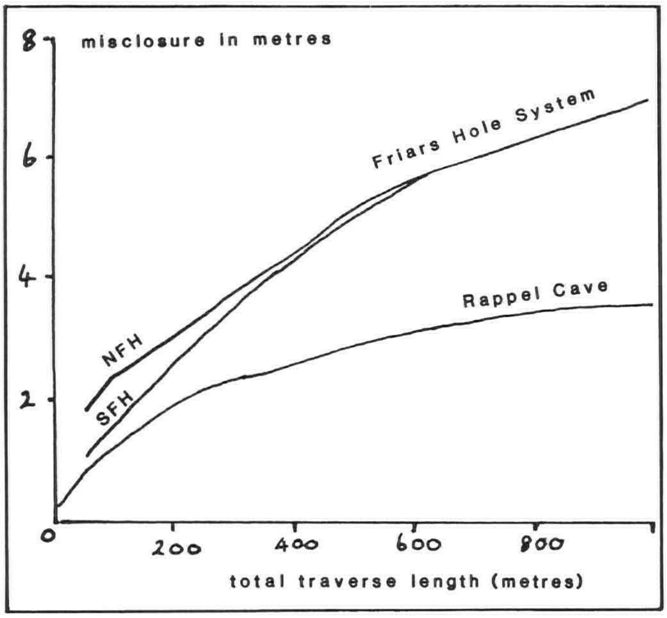


Figure 1 Misclosure plotted against length. NFH = Northern Friars Hole; SFH = Southern Friars Hole

Some loop misclosure results are shown in Figure 1. Both the Roppel (part of the Mammoth System) and Friars Hole data include over 50km of passage and 300 loops. The Roppel data shows what can be achieved with hand-held Suuntos, using fixed stations and fore- and back-sights. The southern Friars Hole data was mapped using fixed stations, fore-sights and compass readings to the nearest degree. The northern Friars Hole data is the least accurate of the three sets; floating stations, fore-sights and compass readings to the nearest degree were used. On short loops the northern Friars data is significantly less accurate, due to station error when using floating stations. In both Roppel and Friars Hole, radio location has been used to further increase the accuracy of the survey. Maps have not been published for either cave, but they are likely to appear at a scale of 1:2000 or less; at that scale at least 90% of misclosures will be less than the thickness of a drawn line.

It is thus worth considering what degree of accuracy is required for a cave survey before one starts to map it. In particular, if radio location can be used then a more rapid mapping technique can be justified.

SURVEY STANDARDS FOR CAVE MAPS

The grading system originating with the Cave Research Group of Great Britain and somewhat modified by BCRA (Ellis, 1976) is used not only in Britain but also in many other countries, and provides an international standard. Nevertheless, the majority of cave surveys bear no indication of grade or precision, even in this publication. The letter suffixes are useful and clear in meaning, but are used even less. The most popular survey grade is 5b, though grade 4 surveys are popular, especially when topofils are used.

There is often a considerable loss of accuracy between the survey notebook and the final map. This comes in two stages; data reduction and drawing of the draft map, and secondly in inking and publishing of the final map. Mistakes in transcription, coordinates calculation and drawing are easier to rectify if a computer is used, and programs are now available for microcomputers that include least-squares loop closure and plotting capabilities*. On published maps, both magnetic and true north are rarely shown, there is often confusion about what a solitary "N" refers to, scale bars are often too small and there may be distortion of the map during printing. The final result is an accuracy of much less than 1%. Finally, surface surveys are often neglected, and neither the location nor the altitude of the cave are given.

CARTOGRAPHIC STANDARDS AND SYMBOLS

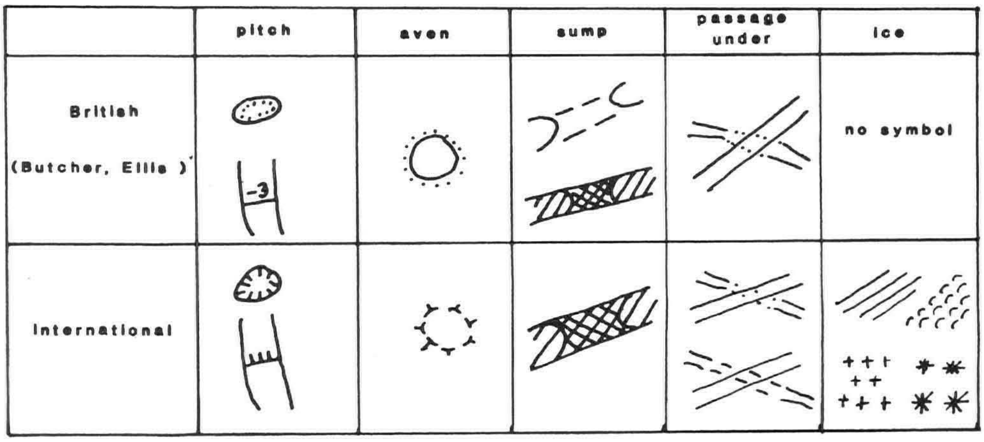
It would save confusion if there were standard IUS symbols for passage detail that were used by all. The majority of basic symbols used in different countries do in fact agree; some of the major differences are shown in Figure 2. Muller (1981) published a set of 83 symbols, with explanations in six languages, after comparing German, Swiss, Austrian, French, British, Spanish, Italian and American symbols, together with earlier IUS recommendations. Some other sets which may be of use are by Marbach and Rocourt (1980), Delannoy (1981), Hedges et al. (1979) and Sprouse and Russell (1980).

SURVEY DATA AND RECORD LISTS

The longest mapped cave in the world has been Mammoth Cave (USA) ever since the first survey in 1835, which showed 13km of passage. With their multitude of long, shallow caves, it is quite natural for Americans to be interested in length

Footnote*: e.g. SMAPS, available in CP/M and MSDOS versions. The latest MSDOS version requires 256k of memory. The program is available for $35 US from Doug Dotson, Department of Computer Science, Frostburg State College, Frostburg, Maryland 21532, USA.

Figure 2 British and international symbols



as the most interesting statistical attribute of a cave. Plans are always published, but elevations rarely appear. Conversely, the world depth record has passed between ten caves in six countries in the European Alps, and there are a dozen or more other countries to which the depth record could pass. There is a wider interest in depth, well expressed by the appearance of two editions of the Atlas des Grandes Gouffres du Monde (Courbon 1972, 1979) before long caves were included in the third edition (Atlas des Grandes Cavites Mondiales, Courbon and Chabert, 1986).

However, there is a third criterion by which caves may be measured and compared, and that is volume. The IUS has hoped to compile a list of cave volumes, but the data is fragmentary, as only Soviet caves have consistently calculated cave volumes. In the new era of computer manipulation of survey data, passage dimensions can be recorded more frequently so that the computer can generate three-dimensional models of the cave. It is a simple step to calculate cave volume roughly and perhaps this will become routine in a few years. Certainly, a "big volumes" list would emphasise the scale of caves in tropical countries, with extreme examples such as Gua Payau, Sarawak (length 2km, volume c.12Mm³) greatly exceeding Friars Hole System, USA (length 68km, volume 1.7Mm³).

Record lists are also given in the Atlas des Grandes Cavites Mondiales for the largest chamber (by floor area and volume), for deep shafts, and for non-calcareous caves. All of these lists encounter problems of definition. For chambers, when does a wide passage become a chamber? Should one include chambers with daylight (Gaping Gill), or which have been partially unroofed (Sotano de Golondrinas) or totally unroofed and now have either overhanging walls (Mynie) or steep slopes (Luse)? What is the size of a ledge which will break one pitch into two? If it is continuous rigging then is Gouffre Touya de Liet a single 1200m pitch? Caves in conglomerate, chalk, granite, quartzite, gypsum, basalt and salt are reasonable, but what about boulder caves and caves in ice? T.S.O.D. Cave (USA) has 4km of survey between boulders in a scree slope, which many would contest as being a cave. Caves in ice are remarkably dynamic, and any map is likely to be out of date before it is drawn up. But there are certainly many long and deep caves below glaciers; notable examples are Paradise Ice Cave, USA, which has varied in length between 0.5km and 13km (Halliday, 1979) and the Upper Kverkfjoll River Cave (Iceland), in which 3km of passage was mapped in 1984 to a depth of 525m (Favre, 1985). Perhaps when all caves in limestone have been fully explored and mapped, future cavers will spend their time continuously remapping some of the world's great ice caves.

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Cave Surveying in Difficult Conditions

Dave BROOK

Most cave surveyors would aim to achieve a minimum standard of BCRA grade 5 in caves of average difficulty but often the standard is drastically lowered when the going becomes arduous. Any survey is better than none but with some forethought a reasonable standard of cave survey can be maintained in quite appalling conditions.

The definition of what is 'difficult' about caving is very different when considered from a surveying point of view. Long exhausting crawls in homely sized passages are very easy to survey even though one member of the team may have to traverse much of it backwards. Short abrupt squeezes also constitute no problem, nor do airy or desperate climbs, providing the surveyors are capable of overcoming them. It is most important that the team is physically and psychologically ready for the task it has taken on and it is advisable for at least one member of the party to have previously visited the section to be surveyed. Clearly this is not always possible especially on expeditions where passages are being explored and surveyed on the same trip. In this case it is particularly important to be well prepared because it may not be possible to return and finish a survey which had to be abandoned.

Logistics play a central role in expedition or arduous system surveying. The surveyors should carry as little equipment as possible and survey inwards until stopped by time, exhaustion or an obstacle. If not exhausted they can then assist by bringing out tackle, surplus equipment or rubbish. One long trip will survey far more passage than two trips of half the length and if time is running out and a return trip is unlikely it is advisable to dispatch one person with a compass and notepad to carry out grade 2 or 3 surveys of all areas not covered by the line of the main survey.

The most physically awkward passages to survey are considerable lengths of tortuous tubes or rifts where removable limbs would be a great advantage. These are most easily surveyed by those who have visited them previously but in extreme cases a mixture of fore and back sights will have to be used and the readings shouted forward to a place where recording and sketching is possible. Because of their small dimensions, changeover errors in these situations are of little consequence since passages such as these are only a tiny fraction of the total cave system.

Water in caves poses many problems to the surveyor and plastic notepads are a must for very aqueous sections. Waterfalls and rapids make aural communication impossible so workout a memorising system with the instrument reader before you enter the noisy section. As with very tortuous passages the instruments can be difficult to read in areas of low airspace and it is advisable to take each measurement more than once and repeat it on open sights as a double check. This process requires great dedication and if the near sump conditions persist the accuracy will suffer.

Large bodies of water which are deep pose special problems. Boats would seem to be one answer but have been found to be less than ideal. They are difficult to keep on station even when moored and mooring points rarely correspond with ideal survey stations. If untethered the whole exercise becomes farcial and time consuming; a great source of entertainment but a poor method for producing an accurate survey. A much better technique is to equip the team with good wetsuits and flotation aids, provide them with waterproof survey gear and launch them at the problem. Stations are not always in the ideal spot since they must be located on wall and roof projections or in shallow areas and on islands or boulders. All the equipment must be firmly attached to the team or the task will come to a premature and costly end. Large lakes are handled in a similar manner to the problem of large chambers. A complete traverse of the walls should be supplemented by several cross ties if this is possible with a single tape. The alternative is to leave markers (preferably lights) on the stations and carry out a triangulation exercise. Clinometer readings for survey legs on the water surface are superfluous but the depth should be plumbed using a heavy karibiner on the end of the tape.

All cases mentioned so far create problems for the survey team but if tackled with the right equipment the results will be of an acceptable standard. Thick glutinous mud is another matter. It can totally overwhelm the team if no water is available to remove it. Instruments gradually turn into blobs of mud and plastic pads become so smeared that it is impossible to see what is being written. Many a despondent surveyor has washed off his pads to reveal a mass of gibberish! The only approach is to keep the hands and equipment free of mud for as long as possible and pray for a supply of water to materialise. The techniques is to traverse the cave without using your hands at all, which puts a heavy strain on the elbows. Should mud obscure the instruments or pad it must be removed with a cloth or a careful lick - such is the dedication of the fanatical cave surveyor. The tape can usually be read by wiping the required area between the thumb and forefinger but great care must be taken that the higher digits are correct. Open reel tapes are a must in these conditions but even these can become almost impossible to rewind. At this stage the caver's wellington boot comes into its own since it usually contains enough water to lubricate the mud on the tape.

Less common hazards encountered by the cave surveyor are a legion but the application of a little common sense and much stoicism will overcome them all. My own experiences include bad air (detected in good time by our carbide lamps), being bombarded by bats and swifts in bottlenecks, attacked by cave snakes and covered in a mass of giant earwigs searching for a warm blooded host.

In future improved equipment should ease the surveyors task in difficult situations. As electronics become smaller and more reliable one can foresee remote sensing, distance measurement and coordinate logging being possible. At present such concepts are hardly feasible, very expensive and unreliable in wet conditions but induction position and communication devices and small ultrasonic distance measurement devices are a reality. One day it should be possible to merely progress through a section of difficult cave pressing a button at the desired survey stations and have the coordinates recorded in a box of tricks in ones helmet - a surveyors dream!

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Cave Surveying on Expeditions

Tony WHITE

It has become a standard requirement of a caving expedition to produce surveys of caves it explores. This is necessary as a record of work done, reference information for future use and to substantiate claims - it is no good saying that you have discovered the biggest, deepest or largest unless you've surveyed it. In addition, and of considerable importance to the explorers themselves, cave surveying assists exploration. For this to be most effective the survey must be drawn up in the field, preferably between exploration trips. It is with this in mind that you must assess your survey methods, how to plot your results and what equipment you should take.

WHAT TYPE OF SURVEY?

The type of survey will depend upon your objectives:

RECONNAISSANCE. Here the objective may not be to fully explore caves but to investigate an area superficially for a future, more thorough, expedition. Manpower will be low and time will be better spent covering more ground rather than producing highly accurate surveys. Often a pace and compass survey will be sufficient. In areas where maps are reliable or unobtainable an altimeter is invaluable and is certainly the quickest and easiest method of calculating the depth potential of a system.

A WELL EXPLORED AREA OR SYSTEM. Here your objective will be to find more passage. A Grade 5 survey will be expected if you are successful but there is little point in taking the drafting office with you unless you are confident of substantial new discoveries. If your objective is to bottom a known system then it is worth having survey equipment to hand, just in case, but plotting with a protractor and calculator will suffice.

FULL SCALE EXPEDITION. Although your objectives may include both the above, here you will mainly be concerned with the discovery of lots of new cave passage. Grade 5 is the standard and the correct equipment for survey and drawing up can make the expedition far more productive, enable details to be checked in the field and enable a report to be produced with maximum speed on your return.

METHODS OF SURVEY

Detailed description of the various techniques and their merits are given in the standard texts (Ellis, 1976, 1984). However the combination of unknown factors, extremes of condition and scale, and limited time may result in a compromise between speed and accuracy. So a few additional points are necessary

Design of survey book

Speed and accuracy can be enhanced by the design of the survey notebook and the method of sketching.

The left page is set out in tabular form (Figure 1.). This immediately shows up any missing items and also allows easy transfer of data to a computer. Columns are ready printed for distances to left and right walls, roof and floor.

The right page is printed with a 1cm grid for the sketch. This can allow the sketch to be drawn directly to scale and direction. Choose the scale at which you wish to draw:

e.g. 1: 500 for small caves
1:1000 for most caves
1:2000 for large caves

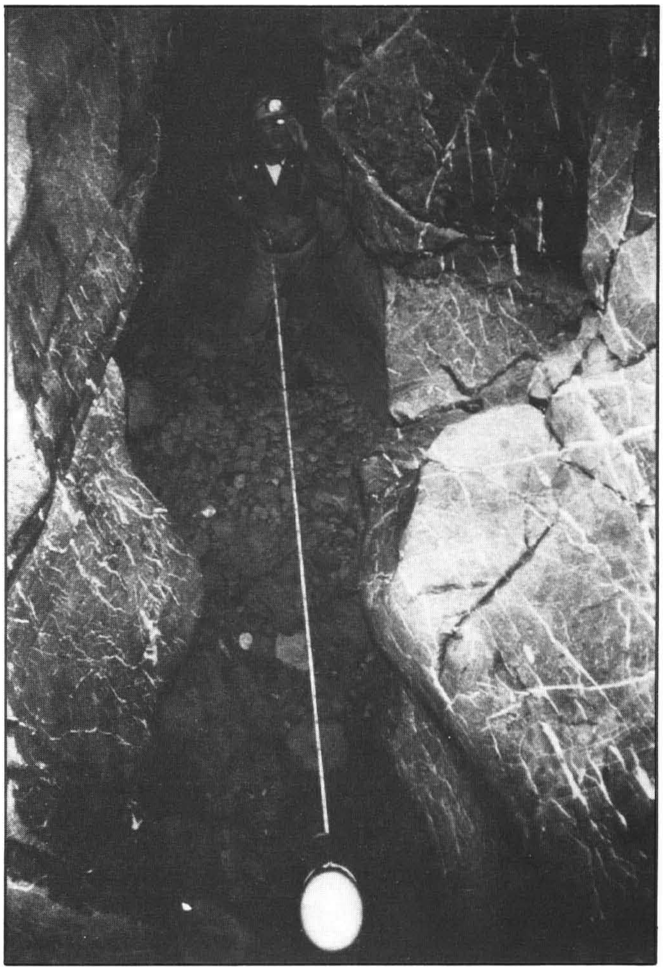
and mark a magnetic north direction. Once the measurements have been called and noted, plot the leg length and direction very roughly by eye. Mark on the wall distances and sketch in the details. If the drawing runs off the page, continue the drawing elsewhere but maintain the orientation (Figure 2.).

This method may at first be slightly slower than the traditional rapid sketch but the resulting drawing is far more accurate. This is of particular importance in complex passage areas. The sketch may be good enough to transfer directly onto the finished survey by tracing.

In or Out?

Individual preferences vary as to whether it is better to survey in or out of the cave when exploring. In a vertical system logistics may demand a separate party or for the exploration team to survey out when not overladen.

Surveying out offers the advantage of a greater understanding of cave morphology and therefore better placing of survey stations, more accurate sketching etc. In a flood liable cave this knowledge of the system could prove



Anglo-Chinese survey project in the caves of Guangxi (photo: China Caves 85)

Footnote: This article is a modified version of that published in "Caving Expedition" edited by R. Willis and published by the Expedition Advisory Centre, London, in 1986. Permission for reproduction is gratefully acknowledged. This also contains an appendix with program listing for the Casio fx-3600P and Sharp PC1500.

invaluable to your safety. Surveying out has the disadvantage that, unless you are able to estimate the time you will require very accurately, you are likely either to cut short your explorations early or to overrun your time and perhaps leave the survey hanging.

Surveying in may lead to temporary confusion in complex areas. However it is more exciting if it is an exploration trip. In a complex system with loops and multiple entrances it is more efficient since many passages will not require a return visit.

Complex systems

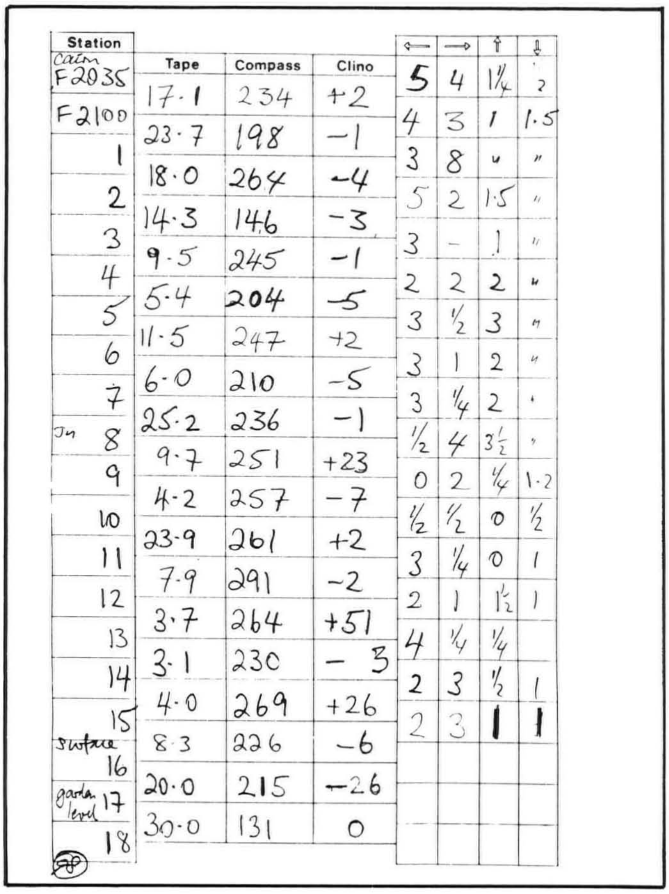
Where several survey teams are working in a system confusion can easily arise. Sticking to the golden rule that "explorers survey their own finds" generally works well since the corollary is "if it's got footprints in it, then it has been surveyed".

Picking up the ends of another party's survey can be made easier if markers are left at relevant junctions and where they finished. Small pieces of waterproof paper cut out of the survey book are ideal and can hopefully be removed later. Write on it the number of the station and, if the marker is not on the station, its location, e.g. "1.6m up", or "end of stal".

In the evening when drawing up it is important to draw the cave walls, not just the survey line. Let the survey sort out the complexity and hopefully indicate connections and extensions.

Deep water

Fixed points are necessary so utilise places where it is possible to hang onto walls. Some extra flotation, especially for the instrument reader will make his life easier not to mention longer. Sight TO awkward stations and FROM the easier ones. Water level can be used as a height control, so you can dispense with the clinometer, but do remember to drop verticals to the water surface at each end.



Station	Tape	Compass	Clino	←	→	↑	↓
Cairn F2035	17.1	234	+2	5	4	1¼	2
F2100	23.7	198	-1	4	3	1	1.5
1	18.0	264	-4	3	8	"	"
2	14.3	146	-3	5	2	1.5	"
3	9.5	245	-1	3	-	1	"
4	5.4	204	-5	2	2	2	"
5	11.5	247	+2	3	½	3	"
6	6.0	210	-5	3	1	2	"
7	25.2	236	-1	3	¼	2	'
Jn 8	9.7	251	+23	½	4	3½	'
9	4.2	257	-7	0	2	¼	1.2
10	23.9	261	+2	½	½	0	½
11	7.9	291	-2	3	¼	0	1
12	3.7	264	+51	2	1	1½	1
13	3.1	230	-3	4	¼	¼	
14	4.0	269	+26	2	3	½	1
15	8.3	226	-6	2	3	1	1
surface 16	20.0	215	-26				
garden level 17	30.0	131	0				
18							

Figure 1 Left page of notebook

Rivers

Noise is the problem so it is useful if the instrument reader has paper to note down his readings, which are transcribed into the survey book after each leg. The tape is less likely to snag if the tape operator is upstream.

Large passages and chambers

Top priority is a good light and preferably a high power spotlamp. One method of surveying rapidly through a high passage if time is short is shown in Figure 3. The survey line is run close to one wall and an extra person explores the opposite wall, preferably making a sketch himself. He parks himself at strategic positions so that the survey team can take instrument readings on him. The distances are calculated by triangulation. This method has the advantage that the surveyor can see both sides of the passage at the same time and get a much better feel for the size and shape of it. If later they find they have some spare time the other wall could be surveyed properly. In general try to keep the triangle length/base ratio less than 3/1.

Big pitches

If against a wall measure between rebelay points, or on long sections it may be possible to have extra fixed stations on the walls.

On free-hanging pitches there are several methods of varying accuracy:

Measure the rope. Probably the most frequently used technique. You tie a knot in the bottom and measure it after you pull the rope up.

Join two tapes together.

Low stretch wire has been used by the Americans (Steele, 1982).

Topofil. Probably the best solution for most situations.

Tandem method. (Figure 4). Jo prusiks up one tape length, marks a station on the rope with a piece of string or even a safety pin with a streamer on it! Measure leg A. Rob goes up to the mark, Jo

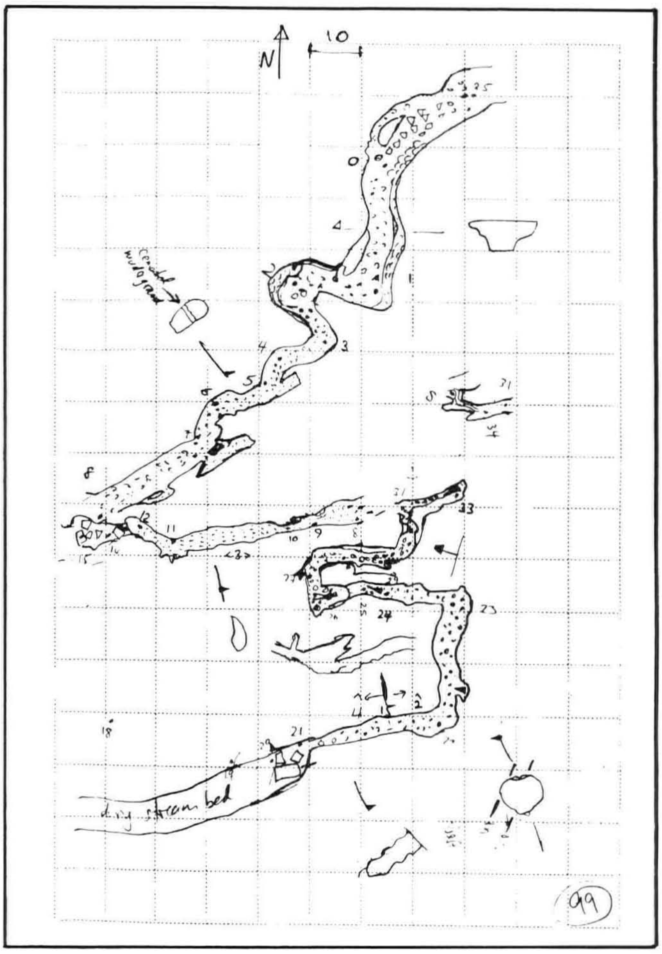


Figure 2 Right page of notebook

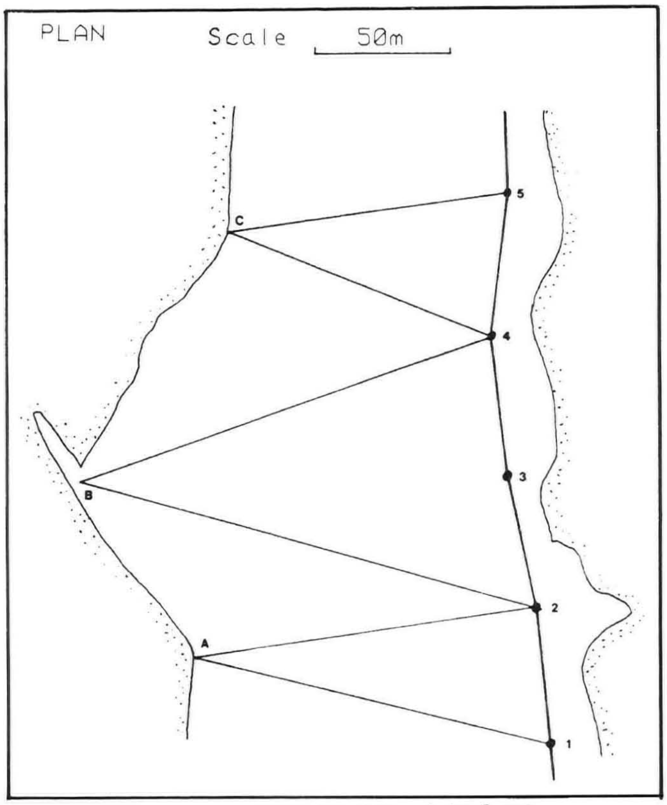


Figure 3 Surveying a large passage. 1 to 5 are main survey stations, and only sightings are made to an extra person at A, B, and C, who sketches his side of the passage

continues and they measure leg B, etc. Then pitch length = A+B+C+D.

Despite the marks being at different positions for each stage, the total is actually the length of the pitch. The reason is that the sections B,C and D when they are measured are under the same tension as when section A was measured (give or take a bit of rope on the ground).

What if they are different weights? Say Rob is heavier than Jo. Then the total figure would be a little too high. So Rob gives Jo all the tackle to carry up the pitch.

A way of eliminating that error is if Rob gets on the rope first and hangs just off the ground. They mark the rope at ground level. Rob gets off, and when Jo starts up they measure the mark again. Plug this extra correction factor into the formula and it's done.

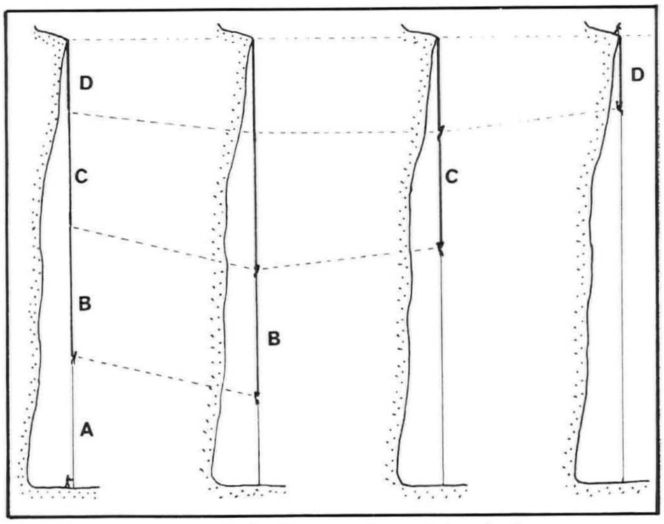


Figure 4 Tandem method of surveying a big pitch

If L = uncorrected length calculated above, and T = tandem length (B+C+D in this case), and S = difference in stretch measured at the bottom, then:
Pitch length = L-(SxT)/L

The method relies on the elastic properties of the rope and any inelastic effects such as slippage of fibres or sheath could effect the result. It does however give people a good excuse for resting on the rope.

METHODS OF PLOTTING

GRAPHICALLY. Using a protractor and ruler. The traditional method which is convenient for a few legs. For large complex surveys it is slow and less accurate. It is usual to use a calculator to work out the horizontal and vertical components of each survey leg.

HAND PLOTTING COORDINATES. A programmable calculator or computer is useful for calculating coordinates.

MACHINE PLOTTING. Using a computer with a linked plotter.

For all the above methods, if you have an area map with a grid, then as soon as you begin, estimate grid references for all your cave entrances and plot them to grid north. This will allow every point in the caves to be easily related to the map, the separation between caves is immediately apparent and any discrepancies in position are likely to be quickly seen, allowing checking and correction while you are still in the field.

WHAT IS REQUIRED?

For Surveying

Compass. Grade 5 surveys require a compass graduated to 1 degree. The standard for years has been the Suunto KB-14/360RT, which is small, robust and easy to read when handheld. Regrettably they are liable to leak and must be sealed around eyepiece and top-plate before use in wet conditions.

A possible alternative is the Silva 54NL, a map compass with a direct sighting facility for more accurate measurements.

Pace and compass surveys can be done with the KB-14 but another model, the Silva type 7NL, is easier to use for mapwork and general surface navigation, is lighter and more likely to be carried at all times on a recce trip. Even on a Grade 5 survey it is handy for the notetaker to have one of these instruments to take rough bearing to improve the sketch.

It may be worth considering the Suunto MC-1 mirror compass for rough surveys. This has a built in clinometer which could be useful for estimating heights and depths.

Compasses are balanced for the magnetic dip of a particular latitude. If incorrect for your expedition area the needle or card will not pivot horizontally. Usually the whole instrument can be tilted to compensate but if severe, or if you are obtaining new instruments, get them balanced correctly.

Clinometer. Essential for Grade 5 but not for rough surveys. Again the accepted standard has been the Suunto PM5360PCT, graduated to 1 degree. It also has a per-cent scale which has the dual function of estimating heights and confusing the inexperienced. It leaks and must be sealed before use.

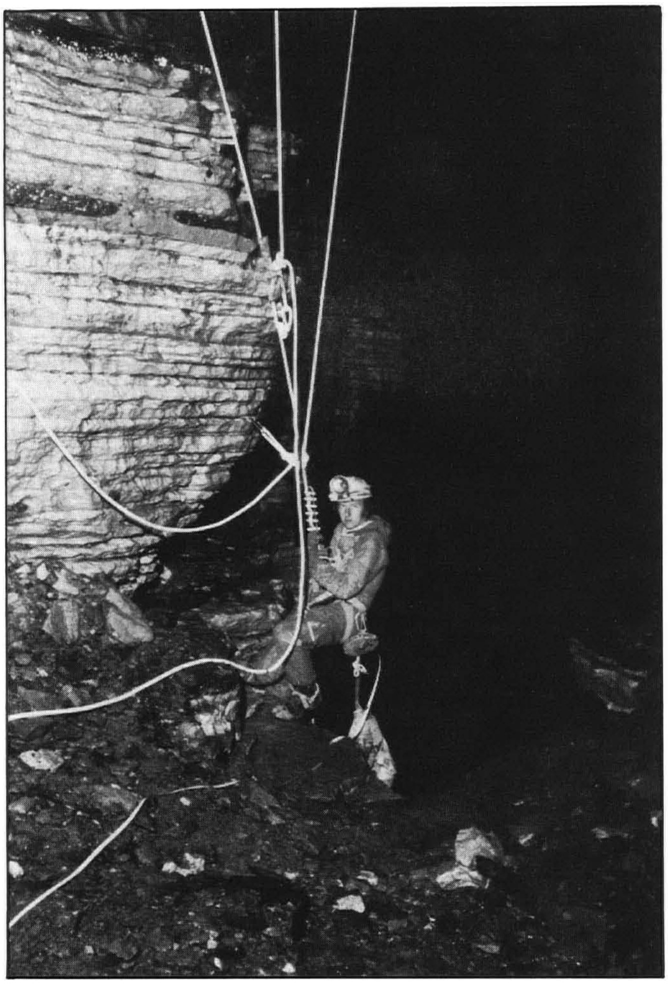
Survey Books. Wiggins Teape produce a laminated plastic material called "Synteape", in various grades, of which FPG 130 grade is ideal. It is totally impervious to water, takes ballpoint ink and pencil very well and with a little care, can be easily washed clean of mud. Loose sheets (preprinted as in 14.3 above) can be bound together in a plastic cover using a two hole binder. The book and pencil can be attached to, and carried in a pvc wallet hung around the neck. I personally prefer a 0.5mm HB clutch pencil, even in water.

Measuring Tape. A 30m glass reinforced plastic tape in an open reel is ideal, such as the Rabone Chesterman 701/55. With heavy use and especially in river caves, it can be shredded or broken, so consider taking spares. For very large caves, surface survey and vertical caving a 50m tape is useful. An alternative is to use a Topofil measuring device which uses a biodegradable cotton thread, or an electronic distance measuring instrument if a cheap, reliable handheld instrument can be obtained.

Altimeter. Not essential but useful. The Thommen TX is small and light enough to be carried anywhere. It is graduated in 10m intervals. If used singly, local pressure variations are a problem but, even so, it can provide considerable information with little effort. If the party uses two altimeters then accurate altitudes can be obtained - one instrument being kept at camp and its readings recorded at half hourly intervals, the second instrument is used in the field to take measurements at the desired sites. The plotted variations in readings from the static instrument may then be used to calibrate the other readings in order to remove the effect of local pressure variations through the day.

Sundries. Waterproof containers for carrying the instruments underground. A container of drying agent (e.g. silica gel or carbide) with room for the instruments if they do succumb to moisture.

Sufficient complete sets of survey gear should be taken for the maximum number of teams surveying at any one time (roughly one set for every three team members) but spares should also be allowed, especially if going on an extended trip.



About to descend a deep shaft in Greece, trailing a tape to a survey station part way down (photo: Tony Waltham)

For drawing up

Paper. For hand plotting by protractor use a rectangular grid and a 1mm grid for plotting by coordinates. Take large sheets folded or rolled in a tube for protection, and A4 graph pads for small caves and extensions to the main site.

Pencils. Hard pencils are only good for tearing your paper when you are working under pressure; use an HB and keep it sharp.

Erasers. Use soft ones.

Rulers. For most purposes you won't need one longer than 10cm but a 30cm ruler may be worth taking.

Protractor. If hand plotting, take a 360° protractor, otherwise a small one is adequate.

Drawing Board. You will need something flat for resting on but weight and bulk will undoubtedly restrict you. If you are going to an area where wood is abundant, try taking some thin sheets of rigid white plastic. If nailed to a table frame these give an easily cleanable table to eat off, draw surveys on and, with a bright lamp underneath, a light table.

Binder. To store survey sheets.

Logbook. Multi-purpose, vital for keeping a record of who does what and when, also useful for pasting or stapling in odd sheets of paper and computer print-outs.

Sundries. You might also consider taking: scissors, paper glue, adhesive tape, small stapler (and staples), tracing paper, acetate film, coloured fine marking pens, drawing pins, and large sheets of paper or polythene onto which to draw the survey as it grows - display this near the eating table to stimulate ideas of what, why and where to work next.

Calculator or Computer?

Calculator. For geographical plotting it should have sine and cosine functions. For coordinate plotting, many programmable ones are suitable. The Casio fx-3600P has just sufficient programme steps to convert the raw data into eastings and northings for the plan, and height and projection coordinate for a projected elevation.

Computer. This may do a little or a lot more than a calculator. For example it could print out a permanent record of the data and coordinates, perform adjustments to close loops, plot the survey line and elevation, and record data on tape or disc. More powerful machines are getting smaller and more robust all the time. Two examples of machines which have been successfully used on several expeditions are:

Sharp PC1251. A calculator sized unit which can be inserted into a combined printer/miniature tape recorder. It is programmable in BASIC, appropriate software has been written by Mike Meredith. Options are: 1. Set magnetic declination. 2. Enter starting coordinates. 3. Reverse data. 4. Enter readings and print results. Coordinates are plotted manually on graph paper.

Sharp PC1500 plus CE150 plotter. Size 330 x 115 x 50mm, weight 1.4kg, standard available memory is 1850 bytes. Has a miniature QWERTY keyboard and a 26 character scrolling LCD display. It has a 5cm drum plotter with four colour ball-point pens. The recorder is, if required, a separate unit. Software written in BASIC by Paul Dyson was used on this machine with a 4K RAM module on the Muller '82 Expedition (Martin, 1984). Since an 8K module is available the software has been modified and extended. A 16K module is now also available. Station labels have five alphanumeric characters, the first three containing coded information such as the cave, surveyor or instrument set used and the date; the final ones are normally numeric.

Options are: 1. Start, print date and time. 2. Input data (a) read from tape. (b) enter from keyboard. After the first label is entered, all others will be generated with the numeric part increasing or decreasing. Measurements can be reversed if backsights. 3. Print out raw data and give total length surveyed. 4. Enter magnetic declination, coordinates of each starting point and calculate coordinates for all points. 5. Print out coordinates. 6. Set scale and plot plan. 7. Plot a projected section. 8. Record data onto tape.

Since most surveys will not fit onto a 5cm strip, the first leg is plotted down the centre of the strip, its orientation and coordinates of the first point are printed. Susequent legs are plotted correctly in relation to the first. If the pen runs off the strip a new plot is begun with the uncompleted leg re-oriented. This results in a series of plots on different orientations. These are transferred to a sheet of graph paper by hand plotting the first and last points of each strip then overlaying the strip and pricking the other points through onto the graph paper with a pin. This is faster than it sounds.

Power supply: this machine is powered by a built in rechargeable battery pack, charged from a 9v source. Dry cells (eg. two MN-1203 or six D-cells) are an alternative to the mains adaptor which is supplied, so take a plug and connectors.

FUTURE DEVELOPMENTS

It is clear that the use of portable computers can be of considerable benefit to expedition groups. The systems described above will undoubtedly require rapid modification in the light of advances in equipment design. Several 10cm plotters are now available and, although bulky, have obvious advantages. Sharp now make a drum plotter, the CE515P, which can take an 11cm roll or paper up to 21cm wide, this will enable printing and plotting on A4 sheets or fanfold paper. Other manufacturers make combines processing unit/10cm plotter/miniature tape drive units which look suitable for expedition use.

One problem to consider with such automated processing facilities is that manual plotting can seem so tedious in comparison, that groups working away from the base camp leave all their data unprocessed until they return to use the computer. Because of this, if the computer is too bulky to be taken to the camp where the action is taking place - you might be better off without it.

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Surveying In and Beyond Sumps

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There are several reasons why cave divers should take the trouble to record survey data underwater. Perhaps the most important is that of increased safety (Yeadon, 1981) because it promotes a greater awareness of the surroundings. Apart from adding interest to a cave dive, the information collected is often an invaluable aid to further exploration. In deep sumps, an accurate knowledge of the dive profile is needed for the planning the future operations. The increasingly worrying problems of sump rescue will be eased if good surveys of sumps are available. Finally, as has been shown in the past (Yeadon, 1977), well produced underwater surveys are helpful in gaining sponsorship for major projects.

SUMP SURVEY METHOD

Experience has shown that with a minimum of effort and a little knowledge of surveying theory, it is possible to produce reasonably accurate surveys of sumps. The basic method has been described by Lloyd (1970, 1975, 1976). It is a compromise between speed and accuracy. Attempts at improving the accuracy tend to slow the diver down such that a "law of diminishing returns" applies. In other words, to obtain a small gain in accuracy requires a much more complicated and time-consuming technique.

Before making a survey underwater it is essential that a line tagged at suitable intervals is laid in the sump. This is normally the guideline laid on the initial exploration dive and must not be slack. The instruments used are normally carried by all divers, whether or not surveying is intended, for safety reasons. They consist of a wrist-mounted "Formica" slate and pencil, a normal divers compass and a good depth guage (preferably calibrated from time to time against a vertical shot line, tagged at regular intervals, in open water).

The first station chosen should be the final station of any previous survey done in the passage leading to the sump. If there is no previous survey to tie into, a station should be chosen close to water level. Whichever is the case, the diving line must coincide with it. The compass is held against the line and the bearing recorded. The diver then enters the sump, following the line until it changes direction (at a belay or wall corner) and counting the tags to estimate the distance travelled. This is also written on the slate, together with the depth at the second station. The new bearing of the next section of the line is then recorded before repeating the procedure at the second deflection of the line (ie the third station). If the distance between any two stations is greater than about 20m., it is preferable to split the survey leg with another extra station, to maintain accuracy.

Other passage details may be recorded at this stage but it is often a good idea to do this on a different dive in order to concentrate on getting the main line done accurately. This is the most important part and the surveyor should not try to do too much at once. More details can always be collected on a subsequent dive and if a positive effort is made to do this, the temptation to guess the position of walls etc. (at the drawing stage) is reduced. On more than one occasion the exploration of important sites has been held up because divers have not used a systematic approach when checking large murky sumps for other ways on.

If possible, stations should be chosen at permanent features in the sump (eg a recognizable boulder or a stalactite in an airbell) so that if the old line is torn out by floods before the next survey session, it is possible to continue with the survey when a new line is laid. If a sump is relined, the old line can be measured before it is discarded. The furthest point reached along the line on a survey dive should be clearly marked (eg with a piece of twisted wire) for continuation next time. Finally, although underwater surveying is a fascinating occupation, normal cave diving safety procedures must never be overlooked, just because the diver's mind is on something else!

Errors

To describe any survey as "good" or "bad" demonstrates a lack of understanding of surveying theory. The important thing is to appreciate the limitations of the technique (Cordingley, 1984) which has been used. None of the existing B.C.R.A. grades of accuracy describes the above method well but the results should be considered as approximately between grades 2 and 3. There is a need for divers to practice both the reading and making of underwater surveys to ensure that errors arise solely from the limitations of the instruments used, rather than from their own poor technique.

The main source of error is directional. Both the lining up and the reading of the compass need care. Most diving compasses are only graduated at every 5°, so the bearing has to be estimated to the nearest degree. Although day to day calibrations are probably un-necessary (Stanton, 1984 a & b; Abbott, 1984) both the observer's ability to read the compass and the instrument itself should be periodically checked against a known true bearing. The difference between the recorded bearing and the true bearing is the correction factor which must be applied to all observations made. The diver should also be aware of errors caused by the proximity of steel equipment (bottles, knives etc) or the magnetic fields created by the bright diving lights which are gaining in popularity.

Errors of distance should be fairly small. Experience has shown that when divers guess the distance of lines they have laid, they almost invariably over-estimate. When tagging a line, the distance from the start of the line (in metres) should be written on each tag, to avoid confusion underwater. Unlike a normal cave survey. The total distance of the sump can then be read off directly, which forms a useful check on the sum of the length estimations made whilst underwater. Shorter distance between tags can be obtained by rough "hand over hand" one metre estimations along the line, a technique which becomes more reliable with practice. Station position error is minimised if the line has been frequently belayed previously.

Levelling errors are also small in a sump survey. A good quality depth guage (calibrated as previously described) is probably more reliable than a clinometer in a dry passage with the added advantage that any errors are not transferred to all subsequent stations. The two ends of a sump will always be at exactly the same level, no matter how long it is. However the water surface in airbells is occasionally below sump level (as at Ink Sump in Peak Cavern, Derbyshire) or even above it (as in the "Torricellian Chamber" in Buxton Water Sump also in Peak Cavern).

If possible, loop closure should be carried out, with the misclosure quoted as a percentage. If a loop has been formed by both ends of a sump being connected by dry passages which have been surveyed to a high grade, then it is probably wisest to distribute the error solely through the sump. If no natural loops occur, a closed loop

Survey in Wookey Hole 20
(photo: Peter Glanvill)

can be created by resurveying the sump on the return journey. A misclosure of about 2-3% is typical.

PROCESSING THE DATA AND DRAWING THE SURVEY

Pencil notes on a diving slate are in a very temporary form; a few minutes of transport in a gritty diving bag will soon erase all trace of them! They should be transferred to a notebook immediately after the dive. However, access to original survey notes is often valuable at the drawing stage, so it is also worth trying to preserve them. A permanent record is later made by simply photocopying the slate before cleaning ready for the next dive. Other relevant information is also better recorded immediately at the dive site, such as the date, calibration information, visibility, water levels etc.

Before drawing the survey, all numerical data should be reduced to co-ordinates in the normal way (as described elsewhere in this publication). It is a simple matter to adapt a computer programme to accept depth information instead of clinometer readings (R.J. Bury, personal communication). A line survey is then constructed either as a plan, elevation or both (depending on the intended use of the survey) before passage details are added. Walls must not be drawn in as solid lines unless they have been definitely observed and their distance from the main line estimated. Any other useful information should be included, such as cross joints, side passages, permanent stations, radio-location points, depths (on the plan view), faults, decompression points, flow markings, dip of limestone beds, floor deposits, direction of water flow etc., depending on the scale of the drawing. The position of the diving line is often worth showing if the route taken by divers is not obvious or straightforward.

Like any survey, it should also bear a title, scale, Grid North arrow and some indication of it's likely accuracy. A detailed underwater survey is more clearly drawn without the cross-hatching which cavers normally use to depict sumps. Any symbols which are used must also be accompanied by a key.

SURVEYING BEYOND SUMPS

Ideally, this should be carried out to B.C.R.A. grade 5. However, it often takes considerable organisation to get a team through a long sump especially if it is in a remote location. The number of trips which can be had beyond the sump may be limited by long periods of poor weather etc. To be practical then, there is obviously a need for a faster, more efficient method. Again there will inevitably be some trade off in accuracy due to logistics; It is better to have a reasonable survey of major extensions beyond sumps than to have a highly accurate survey of only a small part. A useful compromise is to perform a grade 2 (pace and hand-held compass) survey, with key stations pinpointed from the surface using a radio-location device such as Bob Mackin's "Molefone" or the "Ratbag Locator" (Smith, 1986). The errors in the survey legs between each located point can then be distributed, with the end result being quite acceptable. The above can be carried out by a solo diver, for example during the recent extensions to Notts Pot, Yorkshire, beyond the downstream sump, the writer surveyed 1,500m of passages over about five hours using this method.

If the use of a location device is not possible (due to lack of availability, excessive depth, proximity of mineral veins or ferromagnesian minerals in lava beds etc) and a full grade 5 survey is impractical, another useful technique to maintain some degree of accuracy involves using the diving line. A 10m length of line is cut from the reel (previously measured when it was tagged) and tied to a lead weight (removed from the belt). The diver lays this out along the passage floor, takes a back bearing along it then pulls the weight in before repeating the procedure (Cordingley, 1986a and 1986b). Shorter legs can be measured using a little ingenuity (eg fold the 10m length into half or for strands etc). In level passages this approximates to B.C.R.A. grade 3, as the compass can be lined up more reliably than when trying to "sight" along to the next (as yet undetermined) station. No extra equipment is needed other than that which an exploring cave diver is already carrying and the method is fairly rapid.

AVAILABILITY OF SURVEYS MADE BY CAVE DIVERS

Most divers who make surveys submit them for publication in the Cave Diving Group Newsletter, which is widely available. Another useful source of these is in the regional sump indexes, produced occasionally by the C.D.G. for each major caving area. These surveys are not always very detailed, as the scale is small. Accounts of the more important discoveries made, along with larger scale surveys are sometimes prepared for the journals of the caving clubs of which divers are members. The most reliable source however is to contact these divers concerned directly, who will usually be able to supply larger drawings and more importantly, the original survey data.

THE FUTURE

Continental and American divers (Exley & Maegerlein, 1982; Thiry, 1985) often make sump surveys which are more accurate than those produced in Britain. Because their diving conditions are often much better than ours they are able to work in pairs using normal tapes and sighting compasses. This approach is not likely to be adopted in British sumps due to the generally poor visibility. Apart from variations on the normal technique (Cordingley, 1986c) divers will probably rely more and more on electronic devices. Radio-location will become more common as an aid to correcting normal underwater surveys. Perhaps the most promising innovation currently being developed for use underwater (N. Bennett, personal communication) is an automatic survey unit. The diver must still count the tags on the line, but the device records the station number (shown on a display), bearing, dip, depth, distance to roof, walls and floor, and temperature. These last two might have applications as "side passage detectors". To record the above data the unit is held at arm's length like a pistol, before a button is pressed to store the information. This reduces paralax errors and errors arising from the proximity of magnetic materials (diving bottles etc). All data is stored on a microprocessor and it's final processing is done later on a home computer.

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Application of Computers to Cave Surveying

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The reduction of cave survey data is an essentially straightforward but repetitive mathematical task which can be carried out to advantage using virtually any type of computer from a programmable calculator upwards. The obvious benefits are speed and accuracy in reducing and adjusting the raw data to obtain the x,y,z coordinates (eastings, northings and elevations) of the surveyed points. Additionally, depending on the functionality of the software (program) and power of the hardware (computer), the user may be able to build up a data base of surveys, plot out on paper scaled plans and elevations of the cave and possibly even see a three-dimensional model of the cave, in perspective or some other projection, as an aid to understanding the spatial relationships of cave passages.

At the present time, computer hardware for cave survey applications can be classified into three main groups. At the bottom end of the range the programmable calculator of a few years ago has been superseded by what is perhaps best termed the 'pocket computer'. Typically these cost under £100, are programmable in BASIC and come with a few kbytes of memory. Additionally, they may have an interface for a printer and some kind of magnetic strip storage device. The mid-range group comprises 8-bit home micro-computers and the more powerful 16-bit personal computers (P.C.s). The former have typically 32 or 64 kbytes of memory and store data on either audio-cassettes or flexible ('floppy') disks. The latter are usually available with a minimum of 128 kbytes of memory and use floppy disks or hard (Winchester) disks for data storage. Some micros and most P.C.s support industrial standard operating systems and software packages and can output to printers and graph plotters. Prices vary from a few hundred to a few thousand pounds. Finally, at the top end of the range are the 32-bit mini-computers and larger machines, used for scientific and business applications. These have very fast processors, many megabytes of memory and often gigabytes of hard disk storage. Graphical output can be obtained from plotters for paper sizes up to twice A0, whilst high resolution colour displays (typically 1024 x 850 pixels) can provide interactive graphics including , with the more expensive devices, 'hidden line' and 'colour shaded' three dimensional views in real time. For all but the most demanding tasks in cave surveying the 'pocket computer' and home P.C. are quite adequate.

Programmable calculators and pocket computers

Ten or fifteen years ago scientific programmable calculators suitable for cave surveying applications were difficult to program, had limited memory, offered little or no storage facilities (for either software or data) and were expensive. The present day devices by comparison have enough memory to be able to hold and analyse data for perhaps 100 survey stations, a good days work for any surveying team. Moreover, because they are programmable in BASIC, and can usually display about 20 characters on the 'screen', software can be written which has a 'friendly' user interface (i.e. displays prompts, error messages etc.). The attachment of a small printer can provide hard copy output of data in numeric and sometimes graphical forms. Some machines also offer an industry standard serial interface permitting programs and data to be transferred to and from other computers. Being battery operated these small computers are ideal for expedition use as has been clearly demonstrated by White (1987). The essential steps in writing software for machines at this level have been presented by Reid who has supplied a BASIC program for a Hewlett-Packard device but which could be converted to run on many other types of hardware (Reid 1983).

Home micro-computer and personal computers

The advent of the 8-bit micro-processor (a computer on a chip) brought computing into the reach of almost everyone. The introduction of the IBM PC to a certain extent legitimised this type of hardware by setting de facto industry standards for operating systems, magnetic media formats and display management, and as a result most hardware vendors have been forced to follow suit. This standardisation, combined with the low cost and high availability of this class of hardware makes it an ideal choice on which to develop cave surveying software at a level above that which the pocket computer will allow. Micros and P.C.s have the following benefits:

i) They support industry standard operating systems, scientific programming languages and storage media

ii) They have sufficient memory and disk storage capacity to permit the reduction of large amounts of survey data (many hundreds of stations)

iii) They offer sophisticated keyboard and display management, permitting software to be written which allows the user to make selections from menus and/or function keys, and input and edit data in tabular form on the screen

iv) They offer sophisticated keyboard and display management, permitting software to be written which allows the user to make selections from menus and/or function keys, and input and edit data in tabular form on the screen.

v) They have sufficient memory and disk storage to permit the adjustment (closure) of complex networks

vi) They offer comparatively high resolution graphics displays

vii) They can support a wide range of printers and plotters to provide scaled plans and elevations on paper, which can be used as a basis for drawing up the final survey

viii) By virtue of (i) software and data should, in principle, be easily transportable between different users' hardware.

The best example known to the author of P.C. software for cave surveying which incorporates many of the features outlined above is SMAPS (Survey Manipulation Analysis and Plotting System) written in the U.S. by Douglas Dotson. This runs on a wide range of hardware under CPM, MS/DOS and UNIX operating systems. The data is input and modified by a comparatively easy to use editor (although programming the function keys could have avoided the need to remember so many 'control codes') and stored in a well-structured filing system as individual traverses or more complex networks. Multiple closed loop adjustment is performed by a least squares method with the option to fix certain stations as desired. SMAPS version 3 does not provide any screen graphics, but does allow the output of scaled plans and elevations to a range of printers offering useful features such as the ability to include or exclude survey legs (e.g. surface traverses) used for closure checks. Whilst the data editor accepts passage cross section dimensions, if the user chooses to input them, SMAPS makes no use of this information. However, it does provide the ability to read and write ASCII 'dump' files of both raw and reduced data in a fixed format. Thus data reduced by SMAPS could be used by other software to generate a 3D solid model of the cave. SMAPS has a sizeable user base in North America but is not currently available in the U.K..

Unfortunately, the author is not aware of any cave surveying software developed in this country which is comparable to SMAPS both in terms of functionality and ease of use, and in its general availability. Nevertheless, a few interesting ideas and programs have appeared recently.

Ellis (1987) has rather ingeniously made use of a number of popular commercial spreadsheet programs including 'SUPERCALC2', 'LOTUS 1-2-3' and others to accept cave survey data, reduce it and perform closures of single loops. Although the software is not specific to cave surveying it has the advantage of being able to output reduced data in a file having a format which could be accepted by other P.C. graphics packages to generate scaled drawings.

Irwin (1987) continuing his long-standing interest in the difficult problem of network adjustment, has recently written a suite of three programs on the Amstrad PCW8256 to carry out this task. These facilitate the input, editing and reduction of survey data, followed by the adjustment of either single loops or complex networks, taking into account fixed stations as required. No graphical output is currently available and rather unfortunately the hardware uses non-standard disks and offers no communications interface, so that data transfer to other types of hardware is not possible.

At the 8-bit micro end of the range at least one system running on a BBC machine has been exhibited at a recent BCRA conference whilst an interesting network closure program has been developed by Warren and Warren (1986) which runs on rather esoteric home built hardware.

32-bit Computers

When John Wilcock (1976) wrote the section on computers in 'Cave Surveying', ten years ago, most of the software he described ran on large 'mainframe' devices. Many of these have probably been melted down for scrap by now and, one suspects, the software lost. The computing power of some of these old machines is now available on the larger P.C.s and for many applications of cave surveying, this is quite adequate, although network adjustment may be slow. If one wants to build 3D 'solid' models of cave systems, i.e. ones which recognise that a passage has a volume rather than just a length and direction, and view such models in a variety of 3D projections (perspective, isometric, axonometric etc.) then even some of the more powerful P.C.s may be inadequate. The combined advances in Computer Aided Design (CAD) software and in 32-bit mini-computer hardware, particularly with respect to the VLSI chip and Winchester disk technology, have given rise to what is now commonly referred to as a graphics workstation. A typical workstation would be linked to a computer having a powerful processor (1 Mip or greater), a few Mbytes of memory, and a fast access, hard disk storage system with a capacity in excess of 50 Mbytes. The display would be a high resolution (typically 1024 x 850 pixels) 19 inch (50cm) colour graphics monitor capable of producing pictures of outstanding definition, often much better than from a domestic TV set. A 'single user' device could be purchased from around £20,000 and this type of facility is to be found increasingly in university and polytechnic computing and engineering departments, as well as in the design sections of many commercial organisations. Sadly, cave survey software to utilise the features of this class of hardware is scarce. The techniques required to build and view a 3D model, such as that of a cave, are complex and mathematical. They are described in general terms in a number of standard texts on computer graphics (Newman & Sproull, 1979; Rogers, 1985; Angell, 1981; and Foley & Van Dam, 1982). The author has developed some software in this area but the only complete package at present seems to be the Swiss system TOPOROBOT written by Martin Heller (1983). TOPOROBOT has been successfully used to analyse data from and generate 3D models of a number of large Swiss caves including the Holloch and Siebenhengste systems as well as the Flint Ridge-Mammoth complex in the U.S.A.. In order to obtain a good model some care must be taken in recording passage cross section detail (as distances to left and right walls, and to floor and roof) and in choosing the positions of survey stations at verticals and passage junctions. Most of this information should be recorded as a matter of course when surveying, and in any case the additional effort is rewarded by impressive 3D views of the cave system either as a colour shaded model or with hidden lines removed. Using these techniques enormous benefits are to be gained in terms of understanding the 3D spatial relationships of complex caves. A TOPOROBOT user group exists but unfortunately does not extend to the UK, despite a number of attempts to contact the author of the software, each eliciting no reply. It is to be regretted that the product of Mr Heller's considerable talents cannot be appreciated in this country and applied to the large cave systems of Yorkshire and South Wales.

The future

Undoubtedly the trend for computer hardware to become physically smaller, more powerful and cheaper will continue. The IBM PC and its many clones have led to a number of important de facto industrial standards for operating systems and storage media. This in turn has led to increased portability of both software and data between computer systems. Thus the P.C. has at last provided a low cost, high performance environment on which sophisticated cave survey software can be made available to a large number of people.

To date much effort has been expended by individuals and small groups in surveying caves and writing software to analyse this data. Much of the original data has since been lost, and many of the computers used are no longer available. The only records of the work done are the final surveys. We are currently witnessing a massive amount of re-surveying in South Wales and Yorkshire, with the extension and linking of many caves. One can only speculate as to how much of this could have been avoided were the original data still extant. Increasingly, cave survey data is being processed by computers and stored on computer magnetic media. The need for a commonly agreed format for data exchange between computer systems and for a central archive for cave survey data is now of paramount importance in order that this information may be available for use by future generations of cavers. It can only be hoped that some central organisation such as the BCRA, will address itself to this problem in the near future.

With regard to the cave surveying software currently available in this country, it is the author's opinion that there is a lot of scope for improvement in terms of functionality, ease of use and portability. SMAPS and TOPOROBOT have been cited as two particular examples of what is achievable. If others exist, the author would be interested to learn of them. Most, if not all of the techniques required to perform the more complex mathematical operations in network adjustment and 3D visualisation and modelling are already documented. It now requires an individual or group with the expertise, hardware and enthusiasm to incorporate these into a software package which is freely available to as many cavers as possible.

Finally, now that the technique of modelling cave passages in 3D has been developed, the logical progression is to generate a 3D computer model of the ground surface under which the cave systems lie. The 3D cave models could then be located precisely with respect to the terrain model, and the whole 'assembly' viewed in a variety of 3D projections so that the spatial relationships of the caves with each other and with the ground surface might be understood more clearly. As a further extension to this model one could include additional surfaces for important geological horizons for the area, if sufficient data were available. This technique could be of use to both explorers and cave scientists. The author has begun to investigate this application area but currently lacks adequate cave survey data from which to work.

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Network Traverse Closure with a Micro Computer

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In an earlier paper (Irwin & Stenner, 1975) a method of closing a network of closed traverses was described requiring only a desk calculator and other equipment readily available to the cave surveyor working on home-based facilities. Since that time use of the pocket calculator and the home computer have become commonplace. The method advocated by authors is ideally suited to be adapted for the home computer. In 1984 the author wrote a simple database version of this program to be used with the Texas TI99/4A computer with a usable memory of 14600 bytes to illustrate that a large memory computer, though desirable, is not a necessity. A number of computer programs have appeared in print but these only produce information for open traverse work and the closure of a single traverse (Reid, 1983).

The aim of this paper is to present programs that are written in the fairly universal computer B.A.S.I.C. language. The author has used the Amstrad PCW 8256 to finalise the programs. The actual language is Locomotive Software's Mallard BASIC. The computer is supplied with a V.D.U. and a printer and therefore both facilities are fully incorporated into the programs. The storage of the data is on a 3 inch floppy disc.

Because of the limited memory of the PCW 8256 when using BASIC (32.6K) the whole operation requires it to be presented as three database programs in which a prepared file from program SURVEY.PT1 is transferred to program SURVEY.PT2 to handle the network traverse lines and the data from this file is transferred into program SURVEY.PT3 for final co-ordinates. Program SURVEY.PT1 by itself will enable the surveyor to obtain the co-ordinates for open traverse lines. The author carried out proving trials for these programs using the field data gathered for the St. Cuthbert's Swallet survey, a cave containing some 120 separate closed traverses. The programs are being transferred to the Amstrad 6128 and trials are continuing using O.F.D. survey data (Geh, 1987).

The author is prepared to supply copies of the programs on disc or as a printout thus enabling the user to modify the program to suit his needs. The Texas database programs (4) are also available but only on cassette tapes should any reader possess this hardware. A disc drive and printer is still available for this computer from a company at Honiton, Devon; although the cost is fairly prohibitive by modern standards.

TRAVERSE NETWORKS

The method adopted by Irwin and Stenner for the St. Cuthbert's survey has already been outlined (Irwin & Stenner, 1975). Briefly, one picks a suitable origin and compares the co-ordinate change between that and a second point across the traverse network. Whichever route is chosen the co-ordinate changes should be the same. They won't be! One could of course compare the co-ordinate changes around the network from the same point. A convenient way to do this is by dividing the survey lines up into sets of co-ordinates between passage junctions. The junction to junction co-ordinates, for convenience has been called a LINK. By summating the links in any route (or line) though the network a the difference of each set of co-ordinates from the origin and mean point can now be inspected. Most results will be close together but a few will be outside the limit that you would consider satisfactory for closure. The curves published in (Irwin & Stenner, 1975) will help. An inspection of the routes will probably show up links that are common to a number of routes. This example of simple self inspection eliminates sections of the cave where gross errors may be suspected. Repeating the procedure omitting the suspect sections will improve the accuracy of the closure. From the final set of compared co-ordinates the main line can be closed. More than one line can be closed from the same set of results provided that each line has a different combination of links. The remainder of the passages (i.e. open traverse lines) can then be closed onto the fixed points of the already closed lines. A more detailed discussion on this subject may be found in Irwin & Stenner (1975).

THE PROGRAMS

The programs are in no way intended to be the textbook example of how a computer program should be prepared but an amateur's approach to solving a problem that works satisfactorily for his own personal use. The three programs are intended to help the surveyor to: a) prepare the field data in a form to enable a network traverse to be closed quickly; b) translate the program easily to his own variant of the BASIC language (consequently easily recognisable string and number names have been allocated, usually variants of the main name. e.g. nor,n,north all refer to northing etc.); c) the screen instructions are designed so that the user can use the programs without being in any way conversant with BASIC programs; and d) to act as a general purpose surveying program. There is a fourth program - 'HELP' that demonstrates the procedure both by illustration and notes (available from the author on request).

PROGRAM FACILITIES

Although the programs have been devised to cater for the more complicated multiple traverse systems they can also be used as a general purpose computer program that will satisfy the needs of most surveyors. It will solve the open traverse system, processing up to 80 survey legs at a time, by simply entering the data together with the start of co-ordinates that will align the surveyed passage to the cave grid and when recalled from file the computer will calculate the ordinates, summate and present them on the screen and, if required, print them on continuous or single sheet paper. Menu numbers 1 and 2 of program SURVEY.PT1 will fulfil most people's needs.

Another common requirement is to produce an extended elevation; this facility is included in Menu 5 of program SURVEY PT1 and a recall of this data in Menu 6. Menu 5 enables these values to be tabulated for the lines of sections of lines. Suitable prompts are included to aid the user.

Summarising, the general calculations required for an open traverse cave may be obtained from program SURVEY.PT1 menus 1,2,5 and 6. All of these facilities have the printer option included.

Access to all program facilities is via a menu. Every operation is listed in a viewport on the screen to remind the user of the current action. Each of the options on the menu screen is briefly described below (OT= open traverse and CT= closed traverse applications).

<u>Program 1 (filename: SURVEY.PT1)</u>

menu:1 ENTER FIELD DATA & SAVE (OT & CT):

Input: cave name; line/link number + series name, altitude, northing, easting, magnetic deviation,

slope length, horizontal length (for extended elevations)
Field data: station number, compass, clino, slope length

Note up to 80 stations can be accommodated between junctions. The total number of entered sets of station data is given so that you are able to end the input at a convenient point. To ensure that no confusion arises from 000 degrees and 360 degrees compass entries, ALWAYS use 360 degrees for north. 0 degrees is a special case, When taking a plumb-bob reading the compass bearing is not required; in all such cases when prompted enter zero. A correction facility is available should a typing error occur. The information is then saved given a suitable filename. The author uses a filename FDATA (field data) for his own purposes. The field data should be entered in groups that will form links, therefore enter all station data that lie between junctions as separate files.

If program SURVEY.PT1 is being used for open traverse caves enter the O.S. or cave grid co-ordinates of the first survey station of the first survey line. Obviously the start co-ordinates for subsequent lines will be entered with the relevant start data. Enter zero for the start of link data. The final grid co-ordinates for an open traverse line is given on the printout of Menu 2 (Summated Co-ordinates).

Any file can be corrected by using the Amstrad editing utilities RPED.SUB (for files up to 200 lines) or ED.COM (for large files). In fact files may be created using these facilities if it is found to be more convenient than putting them into file via the program SURVEY.PT1. These facilities may not be available on other machines; the manuals should be checked. If the editing facilities are not available adequate checking must be carried out at the field data input stage otherwise there will be no option but to re-enter the relevant data.

menu:2: RETRIEVE FIELD DAT & LIST CO-ORDINATES (OT & CT):

all data saved on menu 1 is retrieve, lists field data, lists station to station co-ordinates, and summates co-ordinates, lists each on screen and optional printout.

NOTE: If the data is for open traverse passages then the summated co-ordinates will already be aligned to the cave survey grid and may be considered final co-ordinates ready for plotting.

menu 3: ACCUMULATIVE JUNCTION DATA (CT):

NOTE: A separate file is created to accumulate the link data for closed traverses assessment. The program is designed to enable the user to add to this file after he has obtained each set of summated co-ordinates. Depending upon the complexity of the system it is advisable to prepare a schematic diagram of the network so that a full record of the filename and link numbers is readily to hand. The screen prompts are self explanatory. Up to 50 links can be accommodated.

menu:4 RETRIEVE DATA (CT):

enables link data to be screened for checking purposes.

menu:5 EXTENDED ELEVATION DATA & SAVE (OT):

takes data computed to menu 2 and extracts relevant data, saves, tabulates on screen and optional printout.

menu:6 RETRIEVE EXTENDED ELEVATION DATA (OT)

retrieves extended elevation data checking purposes only.

<u>Program 2 (filename: SURVEY.PT2)</u>

as program SURVEY.PT1 menu 4, data screened and printed.

NOTES: Each link has been given a number. Record these on a schematic diagram of the network and create lines from the combination of links available. Ensure that your checks are in the same direction as the co-ordinates for each link otherwise their polarity will be wrong. The program cannot reverse the directional sense of the links. The user can of course create two links for each junction by simply reversing the sign of each ordinate. The number of links created by the forward process is probably adequate for checking and obtaining a reasonable value for the mean point.

menu:2 CREATE MAIN LINES (CT):

input link numbers to form lines, screens and printout line link combinations, summates line co-ordinates and determines mean point, obtains differences of each line end from mean point, tabulates horizontal, vertical and total slope misclosure as actual lengths and percentage of total line length, determines correction factors for each leg, saves correction factors, all data screened and printed.

NOTE: Having tabulated the link combinations for each line on the schematic diagram these can now be entered following the prompts on the V.D.U. screen. Up to 50 lines can be accommodated. Following this activity, the computer will continue and present on the screen in lists of five lines the slope misclosure, % error and correction factors (prepared for immediate use, i.e. polarity has been reversed) for each line. These results are also printed. The correction factors are then saved on a file CF ready for continued use on program SURVEY.PT3.

menu:3 CREATE INTERMEDIATE LINES (CT):

input start and end co-ordinates of compared points, input link numbers to form lines, screens and printout line link combinations, obtains differences of each line from end point, tabulates horizontal, vertical and total slope misclosure as actual lengths and percentage of total line length, determines correction factors for each leg in lines, saves correction factors.

<u>Program 3 (filename: SURVEY.PT3)</u>

menu:1 RETRIEVE FIELD DATA (CT)

as program SURVEY.PT1 menu 2 but only calculates station to station co-ordinates.

menu:2 RETRIEVE CORRECTION FACTORS (CT):

enters into memory data saved in SURVEY.PT2 menus 2 or 3

menu:3 FINAL CORRECTION TO GRID CO-ORDINATES (CT):

lists uncorrected station to station co-ordinate, input start grid co-ordinates, applies correction factors, summates to final grid co-ordinates, lists on screen and optional printout; saves data.

NOTE: With the station to station co-ordinates and the correction factors in the computer memory the co-ordinates can be modified. First the user will be asked if the relevant data has been entered into memory, if not the menu screen will appear. Then the user will be asked which LINE number is to be corrected. This ensures that the right correction factors are used. Don't forget to use the same correction factors for each link! If more than one line is to be corrected then simply keep loading the links and correcting with the appropriate correction factors. The screen prompt will ask for the start co-ordinates. Correction of each set of ordinates will be carried out and presented on the screen. An optional printout is given. The data is then filed under GDATA (Grid Data) and is ready for plotting.

menu:4 RETRIEVE GRID DATA (CT):

enters grid data into memory for checking purposes, optional printout.

Following the closure of the main line(s) the remainder of the network can be closed. If there are areas of the network still left bordering into the closed lines then these should be treated in the same way as for the closure of the main lines. In this case the user will load the junction data into program SURVEY.PT2 and use the INTERMEDIATE LINES facility as shown on the menu screen. In this case the comparison of various lines will be between two fixed points on the closed line(s). The use of the intermediate lines facility simply implies that it will not work out a mean point expect the user but enter the start and end point to co-ordinates of already established stations.

If radio location devices are used to fix the positions of important areas of the cave it is of course a simple matter to survey the surface points and tie them into the cave entrance. The fixed points may then be used to close any closed traverse networks by using the Intermediate facility in SURVEY.PT2.

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Using a Spreadsheet to Reduce Survey Data

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There must be many cave surveyors who know little about computers and programming but still have access to them, perhaps using one in connection with their work. One of the most common types of commercial computer program is the "spreadsheet" (examples are VisiCalc, SuperCalc, Lotus 1-2-3 and FlashCalc) and a surveyor who has access to such a program can easily use it to convert raw survey data quickly and accurately into station co-ordinates without understanding anything about programming. In fact, even someone who does understand programming will probably find it just as easy to set up this spreadsheet as it is to write or copy a program in a language such as BASIC. The program given here is written for use with SuperCalc2 but virtually identical programs have been run on all four of the programs listed above and there is no reason why it should not run on any other spreadsheet provided that trigonometrical and logic functions are available; that is, on any but the most simple type. It is possible that very minor changes will be necessary to run it with some of those other programs.

In the form given here the program will deal with:- (a) instrument readings taken in both forward and backward directions; (b) instrument calibration adjustments for the compass and clinometer (but, deliberately, no corrections are made on vertical legs); (c) closed survey traverses by calculating the closure errors and then distributing the errors equally to each non-vertical survey leg (this will require running the program a second time); (d) any value of co-ordinates for the initial survey station; and (e) if it is a long traverse the running totals can be carried forward from one set of calculations to the next. However, if these functions are not required (e.g. if the instruments have not been calibrated (shame!)) they can be ignored and the program still used in exactly the same way. A glance at Figure 1 will show that in addition to the station co-ordinates being available (lines 26-28), one can find the total traverse distance from the start to each station, and the running totals of change in easting, northing and depth (lines 30-33). If you don't think you are ever going to want this latter group of figures and want to save a little time in the initial setting up of the program (or space on the sheet) then these four lines could be omitted. But is is hardly worth it.

All that is necessary is to prepare the template (i.e. the blank form of the spreadsheet prepared ready for the purpose in hand) as described in this article, and this is only done once. Then to reduce a set of survey readings the data is entered into the template, the "!" is pressed (with most spreadsheets) to cause the calculations to be carried out, and in a few seconds the station co-ordinates will be available. If the data was for a closed traverse the results will show the three dimensional closure errors and these figures can then be added to the spreadsheet and the figures recalculated

	COLUMN A B C D	E	F	G	H	I	J	K	L	M	N	O
ROW 1	SURVEY DATA CALCULATIONS	DATE:		SURVEY OF:								
2	======================	----		---------								
3		East.	North.	Depth	|	Calibration of		| Running		Total Trav Dist:		
4	Enter starting co-ordinates here:				|	Instruments		| Totals		Total Change E.:		
5	* If data for previously closed	- - - -	- - - -	- - - -	- - |	Compass:		|	B/F	Total Change N.:		
6	traverse, enter misclosures here:				|	Clino.:		|		Total Change Ht:		
7	********************************	*******	*******	*******	*******	*******	*******	*******	*******	*******	*******	*******
8	Readings from Station Number											
9	Readings to Station Number											
10	Enter "1" if a Back Reading											
11	--------------------------------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
12	Comp Rdg-360 for N,blank if vert.											
13	Clinometer Reading											
14	Slope Distance Measured											
15	++++++++++++++++++++++++++++++++											
16												
17	Corrected Compass Reading	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
18	Corrected Clinometer Reading	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
19	Horizontal Distance	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
20	Change in Easting	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
21	Change in Northing	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
22	Vertical Change	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
23	++++++++++++++++++++++++++++++++	+++++++	+++++++	+++++++	+++++++	+++++++	+++++++	+++++++	+++++++	+++++++	+++++++	+++++++
24	Station Number											
25	--------------------------------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
26	Easting Co-ordinate											
27	Northing Co-ordinate											
28	Vertical Co-ordinate											
29	================================	=======	=======	=======	=======	=======	=======	=======	=======	=======	=======	=======
30	Traverse Distance (total)	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
31	Change of Easting from Start	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
32	Change of Northing from Start	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
33	Vertical Change from start	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
34	********************************	*******	*******	*******	*******	*******	*******	*******	*******	*******	*******	*******

Figure 1.

with the closure errors distributed around the traverse. Only two conventions are necessary when using this spreadsheet - a due north bearing must be entered as 360°, and on a vertical survey leg the space for the compass reading must be left blank; it is also necessary to enter a figure "1" on one line if the readings were taken in a backward direction.

The number of survey legs that can be calculated on each spreadsheet display will depend on the amount of available memory in the computer. Shown here is one "unit", the width chosen so that it will just fit an A4 sheet, or the usual 8.25" wide continuous computer stationery, when printing in 132 column mode. There is no reason why the table cannot be made as wide as you like, especially if a wider printer is available. Similarly, the heart of the program (i.e. lines 8 to 33 inclusive) can be repeated below the unit as many times as desired within the memory limitations of the computer; it is just possible to incorporate one such repeat on an A4 or (11") sheet.

<u>Preparation of the template</u>

The template is shown in Figure 1. To set up this template, the first step is to set the column widths as follows:-

- Column A - 24 characters wide,
- Column B - 1 character wide
- Column C - 8 characters wide
- Column D - 1 character wide
- Columns E, etc. - 8 characters wide

Second, type in all the text shown in Figure 1 except the ".00"'s that appear in columns E to O inclusive. These labels do not make the spreadsheet work but do enable you to enter data in the correct spaces, and to see what the results are!

The third stage is to enter all the mathematical functions and logic operators that cause the spreadsheet to do what is required. The formulae to be entered in various cells are given in Table 1 but it should be noted that these are specifically for use with SuperCalc; some other spreadsheets have different names for their functions and operators, e.g. with SuperCalc the operators are written as "If", "Abs", "Count", etc. whereas for both VisiCalc and Lotus 1-2-3 they are written as "@If", "@Abs", "@Count", etc. As with any program, these must be entered as written.

Various lines need to be formatted in order that the figures are displayed, or not displayed, in the required style. Thus, lines 15 and 16 which are intermediate calculations, should be formatted so that the contents are hidden from view, i.e. not displayed. One does not wish to know the results of these calculations and their display is likely to cause confusion. Line 24 should be formatted so that the contents are displayed to the nearest whole number but it will display a blank if the answer is zero, and lines 26, 27 and 28 should be formatted to show the contents to two decimal places but display a blank if the answer is zero. These formats should

Cell Ref	Format	Cell Contents
E 15	Hidden	If(E8=0,0,If(E10=1,E12+J5+180,E12+J5))
C 16	Hidden	Count(E12:O12)
E 16	Hidden	If(E13=90,90,If(E13=-90,-90,E13+J6))
E 17		If(Abs(E13)=90,0,If(E8=0,0,If(E15>360,E15-360,E15)))
E 18		If(E8=0,0,If(E10=1,E16*-1,E16))
E 19		If(E8=0,0,Cos(E18*Pi/180)*E14)
E 20		If(E8=0,0,Sin(E17*Pi/180)*E19-If(E12=0,0,E6/C16))
E 21		If(E8=0,0,Cos(E17*Pi/180)*E19-If(E12=0,0,F6/C16))
E 22		If(E8=0,0,Sin(E18*Pi/180)*E14-If(E12=0,0,G6/C16))
C 24	Type 1	If(E10=1,E9,E8)
E 24	Type 1	If(E8=0,0,If(E10=1,E8,E9)
C 26	Type 2	E4
E 26	Type 2	If(E8=0,0,C26+E20)
C 27	Type 2	F4
E 27	Type 2	If(E8=0,0,C27+E21)
C 28	Type 2	G4
E 28	Type 2	If(E8=0,0,C28+E22)
E 30		If(E8=0,0,O3+E14)
F 30		If(E8=0,0,E30+F14)
E 31		If(E8=0,0,O4+E20)
F 31		If(E8=0,0,E31+F20)
E 32		If(E8=0,0,O5+E21)
F 32		If(E8=0,0,E32+F21)
E 33		If(E8=0,0,O6+E22)
F 33		If(E8=0,0,E33+F22)

Format Type 1 - cell contents shown to the nearest whole number but give a blank display if the result is zero.
Format Type 2 - cell contents shown to two decimal places but give a blank display if the result is zero.

Table 1

a) Closure error determined

Figure 2.

SURVEY DATA CALCULATIONS ======================= DATE: 15/3/86 ---- SURVEY OF: TESTING SWALLET: Main Oxbow Passage. ---------

	East.	North.	Depth	Calibration of Instruments		Running Totals	
Enter starting co-ordinates here:-	1078,63	-78,64	673,60				Total Trav Dist:
* If data for previously closed				Compass:	-8,25	B/F	Total Change E.:
traverse, enter misclosures here:-				Clino.:	-1,00		Total Change N.:
							Total Change Ht:

Readings from Station Number		21	21	23	23	25	25	26	28	28	29	30
Readings to Station Number		20	22	22	24	24	26	27	27	29	30	31
Enter "1" if a Back Reading		1		1		1			1			
Comp Rdg-360 for N,blank if vert.		35	275,5	26	270	23	297		117,5	201	306,25	360
Clinometer Reading		-7	3	34	4	13	-11,5	-90	9	-17	-10	-6
Slope Distance Measured		7,55	4,73	,71	2,54	6,36	9,27	5,14	8,21	6,43	7,13	4,72
Corrected Compass Reading		206,75	267,25	197,75	261,75	194,75	288,75	,00	289,25	192,75	298,00	351,75
Corrected Clinometer Reading		8,00	2,00	-33,00	3,00	-12,00	-12,50	-90,00	-8,00	-18,00	-11,00	-7,00
Horizontal Distance		7,48	4,73	,60	2,54	6,22	9,05	,00	8,13	6,12	7,00	4,68
Change in Easting		-3,37	-4,72	-,18	-2,51	-1,58	-8,57	,00	-7,68	-1,35	-6,18	-,67
Change in Northing		-6,68	-,23	-,57	-,36	-6,02	2,91	,00	2,68	-5,96	3,29	4,64
Vertical Change		1,05	,17	-,39	,13	-1,32	-2,01	-5,14	-1,14	-1,99	-1,36	-,58
Station Number	20	21	22	23	24	25	26	27	28	29	30	31
Easting Co-ordinate	1,078,6	1,075,3	1,070,5	1,070,4	1,067,9	1,066,3	1,057,7	1,057,7	1,050,0	1,048,7	1,042,5	1,041,8
Northing Co-ordinate	-78,6	-85,3	-85,5	-86,1	-86,5	-92,5	-89,6	-89,6	-86,9	-92,9	-89,6	-84,9
Vertical Co-ordinate	673,6	674,7	674,8	674,4	674,6	673,2	671,2	666,1	665,0	663,0	661,6	661,0
Traverse Distance (total)		7,55	12,28	12,99	15,53	21,89	31,16	36,30	44,51	50,94	58,07	62,79
Change of Easting from Start		-3,37	-8,09	-8,27	-10,78	-12,36	-20,93	-20,93	-28,61	-29,96	-36,14	-36,81
Change of Northing from Start		-6,68	-6,90	-7,47	-7,83	-13,85	-10,94	-10,94	-8,26	-14,23	-10,94	-6,30
Vertical Change from start		1,05	1,22	,83	,96	-,36	-2,37	-7,51	-8,65	-10,64	-12,00	-12,57

Readings from Station Number		32	32	34	35	35	36	38	38	20		
Readings to Station Number		31	33	33	34	36	37	37	39	39		
Enter "1" if a Back Reading		1		1	1			1		1		
Comp Rdg-360 for N,blank if vert.		194	21		188	341	96		156,25	278		
Clinometer Reading		3	0	90	12,5	1	5	-90	4	-4,5		
Slope Distance Measured		2,90	5,79	6,04	3,56	4,07	25,80	17,64	10,43	3,93		
Corrected Compass Reading		5,75	12,75	,00	359,75	332,75	87,75	,00	148,00	89,75	,00	,00
Corrected Clinometer Reading		-2,00	-1,00	-90,00	-11,50	,00	4,00	90,00	3,00	5,50	,00	,00
Horizontal Distance		2,90	5,79	,00	3,49	4,07	25,74	,00	10,42	3,91	,00	,00
Change in Easting		,29	1,28	,00	-,02	-1,86	25,72	,00	5,52	3,91	,00	,00
Change in Northing		2,88	5,65	,00	3,49	3,62	1,01	,00	-8,83	,02	,00	,00
Vertical Change		-,10	-,10	-6,04	-,71	,00	1,80	17,64	,55	,38	,00	,00
Station Number	31	32	33	34	35	36	37	38	39	20		
Easting Co-ordinate	1,041,8	1,042,1	1,043,4	1,043,4	1,043,4	1,041,5	1,067,2	1,067,2	1,072,7	1,076,7		
Northing Co-ordinate	-84,9	-82,1	-76,4	-76,4	-72,9	-69,3	-68,3	-68,3	-77,1	-77,1		
Vertical Co-ordinate	661,0	660,9	660,8	654,8	654,1	654,1	655,9	673,5	674,1	674,4		
Traverse Distance (total)		65,69	71,48	77,52	81,08	85,15	110,95	128,59	139,02	142,95	,00	,00
Change of Easting from Start		-36,52	-35,24	-35,24	-35,26	-37,12	-11,40	-11,40	-5,88	-1,97	,00	,00
Change of Northing from Start		-3,42	2,23	2,23	5,72	9,33	10,34	10,34	1,51	1,53	,00	,00
Vertical Change from start		-12,67	-12,77	-18,81	-19,52	-19,52	-17,72	-,08	,46	,84	,00	,00

b) Closure error distributed

SURVEY DATA CALCULATIONS ======================= DATE: 15/3/86 ---- SURVEY OF: TESTING SWALLET: Main Oxbow Passage. ---------

	East.	North.	Depth	Calibration of Instruments		Running Totals	
Enter starting co-ordinates here:-	1078,63	-78,64	673,60				Total Trav Dist:
* If data for previously closed				Compass:	-8,25	B/F	Total Change E.:
traverse, enter misclosures here:	-1,97	1,53	,84	Clino.:	-1,00		Total Change N.:
							Total Change Ht:

Readings from Station Number		21	21	23	23	25	25	26	28	28	29	30
Readings to Station Number		20	22	22	24	24	26	27	27	29	30	31
Enter "1" if a Back Reading		1		1		1			1			
Comp Rdg-360 for N,blank if vert.		35	275,5	26	270	23	297		117,5	201	306,25	360
Clinometer Reading		-7	3	34	4	13	-11,5	-90	9	-17	-10	-6
Slope Distance Measured		7,55	4,73	,71	2,54	6,36	9,27	5,14	8,21	6,43	7,13	4,72
Corrected Compass Reading		206,75	267,25	197,75	261,75	194,75	288,75	,00	289,25	192,75	298,00	351,75
Corrected Clinometer Reading		8,00	2,00	-33,00	3,00	-12,00	-12,50	-90,00	-8,00	-18,00	-11,00	-7,00
Horizontal Distance		7,48	4,73	,60	2,54	6,22	9,05	,00	8,13	6,12	7,00	4,68
Change in Easting		-3,25	-4,61	-,07	-2,39	-1,47	-8,45	,00	-7,56	-1,23	-6,06	-,56
Change in Northing		-6,77	-,32	-,66	-,45	-6,11	2,82	,00	2,59	-6,05	3,20	4,55
Vertical Change		1,00	,12	-,44	,08	-1,37	-2,06	-5,14	-1,19	-2,04	-1,41	-,62
Station Number	20	21	22	23	24	25	26	27	28	29	30	31
Easting Co-ordinate	1,078,6	1,075,4	1,070,8	1,070,7	1,068,3	1,066,8	1,058,4	1,058,4	1,050,8	1,049,6	1,043,5	1,043,0
Northing Co-ordinate	-78,6	-85,4	-85,7	-86,4	-86,8	-92,9	-90,1	-90,1	-87,5	-93,6	-90,4	-85,8
Vertical Co-ordinate	673,6	674,6	674,7	674,3	674,4	673,0	670,9	665,8	664,6	662,6	661,2	660,5
Traverse Distance (total)		7,55	12,28	12,99	15,53	21,89	31,16	36,30	44,51	50,94	58,07	62,79
Change of Easting from Start		-3,25	-7,86	-7,92	-10,32	-11,78	-20,24	-20,24	-27,80	-29,03	-35,09	-35,65
Change of Northing from Start		-6,77	-7,08	-7,74	-8,19	-14,30	-11,48	-11,48	-8,89	-14,95	-11,75	-7,20
Vertical Change from start		1,00	1,12	,68	,76	-,61	-2,66	-7,80	-9,00	-11,03	-12,44	-13,07

Readings from Station Number		32	32	34	35	35	36	38	38	20		
Readings to Station Number		31	33	33	34	36	37	37	39	39		
Enter "1" if a Back Reading		1		1	1			1		1		
Comp Rdg-360 for N,blank if vert.		194	21		188	341	96		156,25	278		
Clinometer Reading		3	0	90	12,5	1	5	-90	4	-4,5		
Slope Distance Measured		2,90	5,79	6,04	3,56	4,07	25,80	17,64	10,43	3,93		
Corrected Compass Reading		5,75	12,75	,00	359,75	332,75	87,75	,00	148,00	89,75	,00	,00
Corrected Clinometer Reading		-2,00	-1,00	-90,00	-11,50	,00	4,00	90,00	3,00	5,50	,00	,00
Horizontal Distance		2,90	5,79	,00	3,49	4,07	25,74	,00	10,42	3,91	,00	,00
Change in Easting		,41	1,39	,00	,10	-1,75	25,83	,00	5,64	4,03	,00	,00
Change in Northing		2,79	5,56	,00	3,40	3,53	,92	,00	-8,92	-,07	,00	,00
Vertical Change		-,15	-,15	-6,04	-,76	-,05	1,75	17,64	,50	,33	,00	,00
Station Number	31	32	33	34	35	36	37	38	39	20		
Easting Co-ordinate	1,043,0	1,043,4	1,044,8	1,044,8	1,044,9	1,043,1	1,069,0	1,069,0	1,074,6	1,078,6		
Northing Co-ordinate	-85,8	-83,0	-77,5	-77,5	-74,1	-70,6	-69,6	-69,6	-78,6	-78,6		
Vertical Co-ordinate	660,5	660,4	660,2	654,2	653,4	653,4	655,1	672,8	673,3	673,6		
Traverse Distance (total)		65,69	71,48	77,52	81,08	85,15	110,95	128,59	139,02	142,95	,00	,00
Change of Easting from Start		-35,24	-33,85	-33,85	-33,75	-35,50	-9,66	-9,66	-4,03	,00	,00	,00
Change of Northing from Start		-4,41	1,15	1,15	4,55	8,07	8,99	8,99	,07	,00	,00	,00
Vertical Change from start		-13,22	-13,37	-19,41	-20,17	-20,22	-18,47	-,83	-,33	,00	,00	,00

present the results to a satisfactory degree of precision for most purposes but individual surveyors may wish to change them to suit their own purposes.

Once all the formulae in Table 1 have been entered into the correct cells it will be necessary to copy (replicate) the contents of the right-hand cell on each line, from line 15 downwards, into the rest of the cells on that line. Relative values will be required when replicating, except for those that will contain the various initial and correction values which are, of course, constants. These are cells E4, F4 and G4; E6, F6 and G6; J5 and J6; O3, O4, O5 and O6. If the spreadsheet has been extended downwards formulae will have to be copied on to the corresponding new lines, with appropriate corrections being made to the left-hand cell on each new line to accommodate values carried forward from the block of calculations above.

Finally, all cells other than those into which values are entered (i.e. all the cells listed in the previous paragraph together with the cells on lines 8-10 and lines 12-14 columns E, F etc to the right) should be protected to prevent inadvertently overtyping them when making entries. If the whole spreadsheet is changed from automatic to manual recalculation it will very appreciably speed the entry of data. The order of calculation should be set to 'row-wise'. Embellishments, if the facilities are available, are to remove the border (to make it look prettier) and switch on the 'tab' and 'next option' modes so that the cursor moves automatically to the next unprotected, non-blank cell when entering data.

When the template is complete it should be saved to disc because the same template is re-used for every set of figures. Then when survey data is available it is only necessary to reload the template and enter the data into the relevant cells (the data for each station is entered into individual columns) and one calculation will produce all the required results. These can be printed out for ease of use.

Figure 2 shows the spreadsheet in use; on the left-hand sheet the instrument calibrations and survey data for a closed traverse have been entered and the provisional station co-ordinates calculated. At the bottom right-hand corner of the sheet will be found the difference in each dimension between the initial and final stations of the traverse; as this was a closed traverse these should each have been zero. That they are not shows there is a closure error, and the differences are that closure error. On the right-hand sheet the closure errors have been entered and the figures recalculated. A glance at the calculated differences will show that these are now zero - the error has been distributed around the traverse.

Although a fairly comprehensive template has been described here, anyone with experience of using spreadsheets will be able to adapt it to their own individual needs. It has already been mentioned that the precision with which co-ordinates are quoted can be changed to suit different needs; if preparing figures from which to plot the survey then answers to the nearest whole number would be best, whereas if the co=ordinates are to be used to determine other station positions then one or two decimal places might be more appropriate. In the template given here traverse closure errors are distributed equally to each non-vertical survey leg (the simplest method) but the surveyor may wish to use some other criteria. If the spreadsheet used has an 'execute' command or 'macro' facilities these can be used to 'mechanise' procedures such as printing off the results. And so on, the possibilities are numerous. I set out to give enough information to help those who have access to spreadsheets know little about how to design a template; I hope I have also sown a seed in the minds of those more used to them.

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Cave Surveying with the Topofil

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The Topofil is made by the Groupe Vulcain, a speleo club based in Lyon, France. It was purchased from them in 1981 and at that time cost approximately £60 of which £30 was for the compass alone. The following section should be read in conjunction with the diagram of the instrument. The three major functions of cave surveying are distance measurement, compass bearing, and inclination or slope angle.

<u>Distance measurement</u>:

The measuring system uses a cotton thread from a bulk reel (500m or 1000m) instead of the traditional measuring tape. As cotton is removed from the reel it is guided onto and around a calibrated wheel; from which it passes through another set of guides, over the centre of a large diameter compass and hence out through an opening in the front of the unit. As the calibrated wheel rotates it moves a revolution counter such that each centimetre of cotton pulled out from the front of the unit registers one unit on the revolution counter.

To make a distance measurement between two survey points the following procedure is followed: (a) the initial reading of the rev counter is taken (Do); (b) the cotton is gripped firmly where it leaves the unit; (c) the next survey station is reached either by pulling out cotton and holding the topofil on station or vice versa; (d) at the next survey station the rev counter reading is taken (D1).

The distance between the two survey stations is thus D1-Do. Over run of the bulk reel is prevented by a simple tensioned plastic strip. Care must be taken not to snap the cotton and also not to allow it to sag (this is the same as for a tape).

<u>Compass bearing</u>

Holding the unit level the centre line on the compass is aligned with the taut survey cotton. The compass bearing is read directly off the compass through a small magnifying lens. The same problems exist as with using other instruments when the inclination is greater than ± 15°. As the unit is moved to the horizontal great care must be taken to keep the compass centre line aligned with the survey thread.

<u>Inclination</u>

The topofil provides an ingenious solution to the measurement of slope angles. The cotton is held firmly against the front of the unit to stop any further cotton being removed from the bulk reel (and hence increasing the rev counter reading). The taut cotton is hitched around a small hook situated in the centre of a large protractor on the 'bottom' of the unit. The survey thread is pulled taut and the box aligned such that the bubble of a small spirit level on the top edge is central. The unit is thus vertical and with the cotton just off the surface of the protractor the slope angle can be read off the protractor scale. In awkward positions it is often possible to press the cotton onto the scale and then read the angle in a more comfortable position.

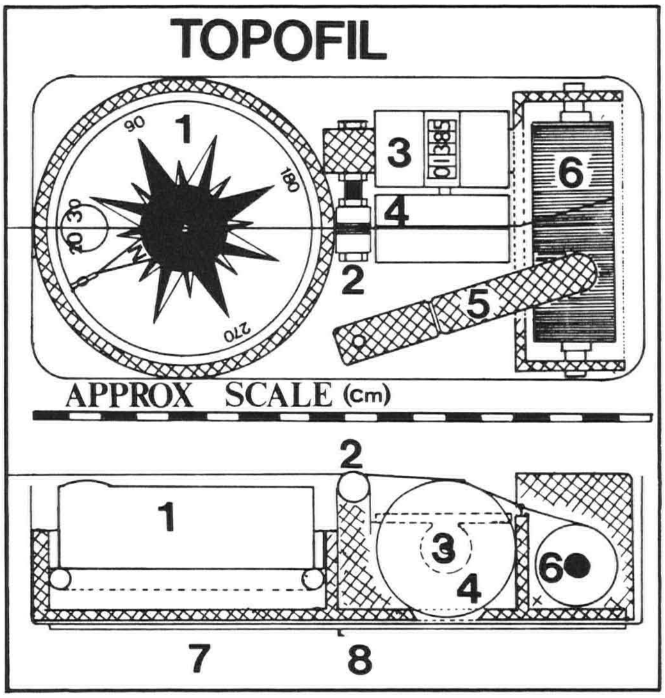
The cotton is then snapped near the unit and can either be left as an aid to route finding or can be recovered and disposed of outside the cave. Providing care is taken the rev counter reading should not change and hence the next reading that would be taken would be (D2) and the distance would be (D2-D1). If any movement has occurred than a new (Do) must be recorded (see Table 1).

<u>Replacing the cotton reel</u>

The outer cover is removed by unclipping the neoprene strap. The whole unit, which is based on a PVC board, is removed. The stainless steel bar upon which the cotton reel revolves is slipped to one side and the new reel inserted. The cotton is hooked under the first guide looped once around the nylon wheel attached to the rev counter, pulled between the two guide washers and thence over the compass. The unit is placed back inside the aluminium case and after leading the cotton out of the front of the box the unit is again ready for use.

Table 1

From	To		Distance
		10560 (Do)	
1	0	10694 (D1)	1.34m (D1-Do)
1	2	10926 (D2)	2.32m (D2-D1)
		10942 (D2)	
3	2	11582 (D3)	6.40m (D3-D2)



Key to Topofil diagram

1. Large diameter compass with magnifying lens.
2. Guide for cotton. Two brass washers sprung loaded with neoprene discs.
3. Revolution counter, firmly mounted to PVC base.
4. Nylon wheel coupled to rev counter; calibrated such that 1cm of rotation moves rev counter 1 unit.
5. Tensioning device, held in tension with rubber band fixed to base. One end is on a PVC pivot post; the other is on a bulk cotton reel. A small felt pad on the cotton reel end ensures smooth running.
6. Bulk cotton reel, free running on a stainless bar. All hatched areas are PVC. The outer case is of aluminium and the lid is of aluminium with clear perspex areas above the compass and rev counter. The lid is held on with a neoprene strap.
7. Large diameter (16cm) plastic protractor.
8. Small brass hook.

Materials of construction

None of the materials used - PVC, neoprene, foam rubber, brass and aluminium - are affected by immersion in water. The perspex viewing areas on the lid can be washed or licked clean if they become too muddy. The only points of weakness on the unit are the 4 attachment lugs, but even these stand up to a lot of rough treatment. An added extra is a neoprene case for carrying the unit before and after surveying. This can also be used to carry spare pencils and even a notebook.

Accuracy

From experience it is easy to obtain an accuracy of BCRA Grade 4 with the topofil and with a little care and regular practice Grade 5 should be possible in all but the most arduous situations. It is usually possible to read the unit even in quite muddy situations and the problems of misting encountered with Suunto instruments do not occur.

Initial checks

Distance measurement: on a flat draught-proof surface a number of measurements should be made and checked against a reputable surveying tape. If the unit is reading more than it should, then a light sanding of the calibrated wheel will rectify this. If it is reading under, then the wheel has to be built up which is much more difficult as this build up must be evenly distributed about the wheel.

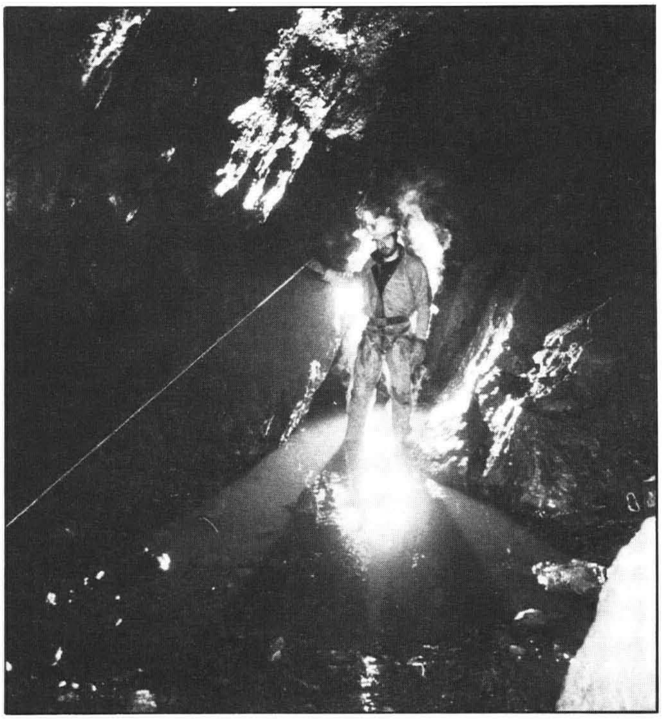
Compass bearing: The checks required to ensure that a compass has no intrinsic faults and also to allow for magnetic anomalies near the cave are very well explained in 'Surveying Caves' by Bryan Ellis (1976). In the topofil unit the compass is mounted in a tubular section of PVC and held in place by an inner ring of neoprene. The base of the compass rests on a ring of tubular neoprene. This ensures a firm grip whilst cushioning the compass from knocks. When removing and replacing the compass (this should not be necessary very often) it is important that the magnifying lens is to the front and that the inscribed sighting line runs parallel to the edges of the box. A check on the forward and back bearings taken between two stations will indicate whether it has been resighted correctly.

Inclination measurement.
Other then gross physical damage to the unit, the protractor and spirit level set-up should not cause any problems. Again a check of the forward and back inclination readings can be made between two survey stations.

Advantages in vertical systems

A common situation in many alpine systems is a large shaft or a series of pitches very close together separated by only small ledges essentially vertical probably split into many sections with intermediate belays. In the first case the easiest way to carry out the survey is to use only vertical legs (on the pitch) and horizontal legs (for the ledges). This not only reduces the error in using angles close to vertical but also makes the calculation and plotting of the survey much simpler. This method, whilst not of the very highest order of accuracy, is perfectly acceptable when used in deep cave systems of a high order of technical difficulty.

With conventional tape-and-compass techniques, providing the vertical sections are not in excess of the length of the tape (30m or perhaps 50m), all is well. One problem I have encountered involved the use of a steel tape. I was abseiling down first, taking the tape reel with me, and after each section of pitch, the note taker above me simply dropped his end of the tape. This proved very distressing, with up to 30m of steel tape whistling around my head. Although this was a particularly silly situation, the same problems can occur with Fibron tapes where the risk is more that the tape will get entangled with the rope. If it is assumed that the leapfrogging is not possible the alternative is for the highest surveyor to have the tape reel and to wind in the tape after each leg. This is not only slow and tedious but there is also the risk that the tape will get snagged. When the pitches get longer than the tape then the fun really starts, especially with free hangs. Some sort of intermediate survey point must be made. This should stay fixed to the rope but not be impossible to remove. Some sort of inner tube loop or bulldog clip would probably be best. However, a Topofil survey can be a single caver affair, which can be a bonus in loose shafts! Assuming that the shaft is essentially vertical but split with rebelays, the technique is as follows: the topofil is attached to the surveyor and he ties the cotton onto the top belay, noting the rev counter reading and carefully starts to abseil. A possible, but risky, method is to abseil one-handed and hold the topofil in the other hand. At the next belay the rev counter reading is taken and the cotton is fastened to the rebelay. The rebelay is then passed and the process continues. If ledges are encountered then the thread can be tied to the main rope and a horizontal leg made. The only extra measurement is a compass bearing. Although the actual surveying is quite simple a very high degree of competence of SRT is required as a smooth descent and passing of rebelays is required if the cotton is not to be broken. Problem can occur where the cotton left on the pitch can become entangled with the rope and ball up to form quite a large obstacle to the next man down. It is also very embarrassing to run out of cotton part way down a large free-hanging drop. Prussiking back up to the last belay, and then changing to another cotton reel usually ensures that this does not happen again, at least for a while.



Topofil survey (photo: Steve Foster)

Conclusion

The topofil is a very useful compact addition to a cave surveyors equipment and whilst the very highest standards of accuracy are more difficult to attain, it is ideally suited to deep vertical cave surveys. It is in one form or another used by many European cavers and part of or all of many caves like Schneeloch, 56, and BU56 have been surveyed using this method.

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Aerial Photographs for Cave Studies

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Aerial photographs, particularly vertical aerial photographs, of various scales are of use to the caver or cave scientist in the field and also as an indoor tool for locating possible sites of interest or interpreting the geological and geomorphological features of an area. When two adjacent vertical air photographs (known as a stereo pair) are viewed through a suitable stereoscope an apparently 3-dimensional image of the overlapping parts of the two prints is visible. Stereoscopes may be small folding gadgets which you can carry in the pocket or may be large and sophisticated optical instruments, with a number of intermediate alternatives. Find the one that is available and suits your purpose, and learn to use it.

The 3-dimensional image is useful in itself in displaying the topography of the area viewed, often with some vertical exaggeration, such that dolines, blind or pocket valleys and shafts are readily visible. Beyond the initial impression, however, the photographs can provide abundant additional information, some of which might not be apparent on the ground. Different rock types can be distinguished (though not necessarily identified), the dips of sedimentary sequences can be observed or deduced, lineaments indicative of faults or joints often stand out, even where they are masked by superficial deposits or vegetation, and abandoned stream courses may be visible through younger alluvial deposits. In fact, most features which are visible on the ground can be identified or deduced from suitable aerial photographs. Learning to recognise the features requires practice and an appreciation of the criteria available, but a basic level of usefulness will be obvious at first glance. It is not intended here to describe how to interpret aerial photographs, since no matter how much is written, the ultimate data recovery depends upon the experience of the user. It is, however, useful to obtain and study stereo pairs of an area you know well on the ground, comparing the obvious features visible on the photographs, the tones and textures of the image, with what you know is present on the land surface.

With a suitable mirror stereoscope, the more sophisticated type of instrument mentioned above, it is possible to measure differences of altitude directly from stereo pairs. Such measurements can be absolute, by reference to a point of known altitude on the photographs, or merely relative between various points within the area of interest. With experience the photographs can be contoured at any desired vertical interval, but to the caver the technique is likely to be of most use in measuring differences of altitude between entrances or sinks and risings.

Aerial photographs in the field

In the field aerial photographs can be of direct use in at least four ways:

1. Singly or in stereo pairs as an aid to navigation, to complement existing topographic maps or in areas where maps do not exist. Use of a pocket stereoscope allows the 3-dimensional landscape on the photographs to be compared directly with the actual landscape features.
2. For spotting potentially interesting areas or individual sites within a larger field reconnaissance area.
3. As a base map for marking the locations of sinks, risings, cave entrances or distinctive features which might facilitate navigation by follow-up teams.
4. As a base map for geological, geomorphological, vegetational or topographical mapping.

If the photographs are to be used as in 1 and 2, or if they will subsequently be used for photo-interpretation, it is preferable to keep them clean and unmarked. Annotation of the prints with hard pencil, 'biro', or fibre-tip pen (even the so-called water-soluble types) will leave irritating marks, even if the notes are erased later. Markings with soft pencil and wax (chinagraph) pencils are messy, crude and easily rubbed off by accident. A number of possible ways are available to preserve the photos and yet record data neatly and indelibly:

a. If costs are not a problem, have a second set of prints and annotate these in the field using a sharp pencil. It is useful to specify matte rather than a glazed finish when ordering the photos, since this surface takes pencil more readily. Any important pencil notations should be made permanent with drawing ink as soon as possible.

b. Half way to the above - duplicate alternate photos along a run. The standard 60% overlap should ensure that the whole area is covered, but small areas may be missing if the camera aircraft crabbed or veered on its flight path. Additionally this method uses the edge areas of each photograph, where distortion is at its greatest. This can complicate later map production unless the data are transferred back to less distorted parts of the intermediate prints.

c. Supply each photograph with a clear acetate overlay (such as overhead projection film). Attach the overlay firmly along one edge only with masking tape, so that it can be folded back, and mark the print's collimation marks (fiducal marks) and principal point (these features are described below) on the overlay. The overlay can then be annotated using pencil, fine-point fibre-tip pen or a Rotring type drawing pen.

d. Modern photo-copy machines can produce superb copies of good quality aerial photographs. The contrast of the copy can often be modified to suit particular needs - a somewhat 'paler' copy can be chosen to facilitate annotation, or a more contrasty copy to emphasise darker areas against the generally white limestone outcrops. These paper copies can be annotated using any kind of pen or pencil and if fine detail is not visible they can be quickly compared to the original, unmarked, prints. An additional degree of distortion is built into this method, but since, ideally, the field data should be transferred back to the original photo and hence to a planimetric map for publication, there is no real problem. Good quality photo-copies can be viewed stereoscopically and will give an acceptable, though possibly slightly distorted, stereo image. Finally these copies, being relatively cheap and easily reproduced, can be cut up to produce photo-mosaic maps, utilising the relatively less distorted central areas of adjacent photos.

Data Transfer

On a normal map a 3-dimensional landscape is portrayed in two dimensions. Each point on the actual land surface is shown as occupying a position projected vertically downwards onto a plane below the level of the lowest point on the map. Though there are complications to this simple picture due to curvature of the earth's surface and other factors, it is reasonable to assume that within a limited area a planimetric map is a scale-true representation of the country it shows. Most aerial photographs on the other hand are not scale true. Putting aside problems such as distortion due to the optical properties of the camera lens system, there are a number of other reasons that scale is variable on aerial photographs. Only the centre of each print shows the land surface at that point projected vertically down onto the plane described above. All other points are projected into slightly displaced positions, and the amount of displacement increases with increased distance from the photo centre. Without going into the detailed geometry of this, and other, distortion it is sufficient to know that within reasonably acceptable limits, all points on radial lines drawn from the photo centre exhibit the same angular relationship to the photo centre as they would to that point imposed on a planimetric map. This property allows a fairly long-winded but essentially reliable method of fixing points (e.g. cave entrances) seen on an aerial photo onto a suitable map. The method is known as radial line plotting. Even more long-winded, but sometimes necessary, it is possible to plot points along a line (e.g. geological boundary) and interpolate the line onto the map.

Example - to plot the position of a cave entrance from aerial photos to a topographical map.

You will need:

a. A stereopair of aerial photos, each print showing the location to be plotted. Any scale will do.

b. A map of the same area with as much topographic detail as possible. Again, any scale will do (i.e. the photos and map do not have to be the same scale).

c. Tracing paper, drafting film or similar material.

d. Pencil, ruler, chinagraph pencil if available.

The procedure is straightforward and soon becomes second nature:

1. Locate the principal (centre) point of each photo. This is simply accomplished by joining the collimation marks (fiducal marks) which are found either at the photo corners or at the half-way point on each side margin. The point where the joining lines cross in the centre of the print is best marked by scribing a small cross using a sharp stylus or scalpel. Put a ring around the cross with a chinagraph pencil to make it more easily visible.

2. Look at the first photo and the map and pick out (at least) three points recognisable on both, preferably at widely spaced angles to each other. This is obviously more difficult in remote areas with poor maps, but bends in streams, stream junctions, peaks, lakes and so on are quite suitable. If more than three points are available, so much the better since it will enable the accuracy of your other locations to be checked.

3. Having chosen the points, place a sheet of tracing paper over the photo and either mark the principal point or pierce a hole through its position on the tracing paper. Draw lines from the principal point outwards through the chosen topographical points, running the lines to the edge of the overlay.

4. Place the tracing paper over the map and position it so that the radial lines pass through the chosen points on the map. This should only happen in one position! Pierce through and mark the position of the principal point on the map, with a circled dot and the photo number to identify it.

5. In the same way locate the principal point of the second photo on the map. There are now two identifiable principal points marked on the map.

6. Return to the first photo. Position the overlay and draw a radial line from the principal point through the position of the cave entrance.

7. Place the overlay on the map, aligning it by means of the marked principal point and radial lines.

8. On the second photo overlay draw a radial line through the cave entrance position, as described in 6.

9. Place the second overlay on the combined map and first overlay.

10. Where the two cave entrance radial lines cross is the required position. Pierce through the intersection and mark the position on the map.

This technique is pretty well foolproof and a great improvement on guesswork. There are commercially available gadgets called radial line plotters which make the same operations somewhat less tedious.

Other methods of data transfer are available. You can look at the photo and map and then sketch features using instinct and experience. This is called "eyeballing" and is really a last resort. Slightly more satisfactory, especially in areas with little relief variation, is to use a gadget such as a "Sketchmaster" which uses a half silvered mirror to superimpose the photo image optically onto the map. This works best with photo and map of similar scale, though a degree of enlargement or reduction is possible. Away from the photo centre there are problems due to various distortions, some of which can be minimised by tilting the apparatus, but this can only be done for small areas and if there is enough recognisable topography to match. In difficult circumstances a number of points can be plotted using radial lines to act as a framework for "Sketchmaster" transfer.

Much more sophisticated is another machine known as (for instance) a "Stereosketch". This apparatus superimposes map and stereo image and it is simply a question of marking off the lines or points. The more sophisticated the machine, the easier and more accurate the transfer.

All things considered, if it is just a question of accurately locating expedition finds from air photo to map, radial line plotting is the most cost-effective and accurate technique.

Aerial photo scale

Along one side of each aerial photograph is a title strip which gives such information as print number, run number, date and time of flight, altitude of photography and focal length of the lens used. To find the scale of the photograph divide the focal length of the lens by the flying height (in the same units!): thus if the plane was flying at 20000 feet and the camera had a 6 inch lens, the scale is 0.5 divided by 20000 = 0.000025 or 1:40000.

Obtaining aerial photographs

In some countries or parts of countries air photos are unavailable for reasons of security, elsewhere they may be exhorbitantly expensive (if of good quality) or of poor quality. Know in advance the approximate scale of photo you would prefer, depending upon the size of the area to be studied and the degree of resolution required. Contact the appropriate agency, enclosing a recognisable sketch map of your area of interest (with scale, north arrow and recognisable topography), and ask for details of available cover and a flight plan or photo centre plot. Also request details of cost per print, finish available and delivery time - it's not much use if the photos arrive after you've left the country.

Overseas the best approach is directly to the local (usually government) map making department (equivalent to the Ordnance Survey) or local Geological Survey. Even if these bodies do not hold aerial photo coverage, they might be able to give details of any flights carried out on behalf of mining or oil companies. Aerial photos of many countries have been produced by British survey firms or the Ministry of Overseas Development but usually copies will only be supplied with the written approval of the government involved.

In the United Kingdom aerial photographs can be obtained from the Ordnance Survey in Southampton, and from private firms such as Clyde, B.K.S. and Hunting. Also, many local authorities now hold photographic cover.

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Archaeological Surveying in Caves

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and R.D.S. JENKINSON

The history of archaeological cave excavation in Britain goes back to the early 1800s, when Dean Buckland (Buckland, 1823) conducted excavations at Kirkdale Cave, Craven. Since that time, hundreds of cave archaeological excavations have taken place. In many early cases, excavation and recording techniques were woefully inadequate and very few of the results were properly published. At Creswell Crags, on the Derbyshire and Nottinghamshire borders, for instance, most of the very extensive archaeological deposits in Church Hole Cave were removed in just eight hours work. Out of a total of 62 known excavations at Creswell in the period 1873-1975, only five formal excavation reports were published, together with a number of reports on specific finds from the caves and assorted newspaper articles (Jenkinson, 1984).

Research into the detailed litho- bio-magneto- and chronostratigraphy of cave sediments has reinforced the point made by a previous generation of excavators, most notably A.L. Armstrong (Armstrong 1929), that in favourable circumstances long and complex depositional sequences containing an unrivalled wealth of archaeological and palaeoenvironmental information may be preserved in caves. For instance, a very large proportion of all British Palaeolithic human and animal fossils are from caves. 92 species of bird are known from Pin Hole Cave alone (Jenkinson, 1984). Many caves contain long and detailed pollen records, in addition to their archaeological and vertebrate material (Hunt & Gale, 1986). These important archaelogical and environmental records are contained in sediments which may yield further evidence concerning palaeoenvironments to sedimentological and magnetic mineralogical techniques (for instance, Lawson, 1982; Jenkinson & Gilbertson, 1984; Gale, 1984, 1985; Gale & Hunt, 1985; Yates, 1985). The sediments and their contained archaeological and environmental records may be dated by the U/Th disequilibrium method (Gascoyne et al., 1978; Ivanovich & Harmon, 1982, radiocarbon, magnetostratigraphy (Noel, 1982; Gale, 1984; Gale & Hunt, 1985) or classical biostratigraphical techniques such as palynology (Marshall & Whiteside, 1980; Gale, Hunt & Smart, 1985) or mammalian palaeontology.

In recognition of the extremely detailed nature of the cave record at Creswell Crags and its great potential importance for archaeology, sensitive recording and excavation methods have been adopted there to maximise the information retrieved while minimising disturbance of the caves and their deposits. They are outlined below. It is emphasised that few of these techniques are new and that not all of them would be suitable for use in other situations.

Cave Survey

Prior to more detailed archaeological investigation of any deposit it is necessary to record the extent of the site and its extant deposits. This is particularly important for cave sediments, which can be far more complex than those encountered in an external context. Such deposits have great potential as detailed records of prehistory and history. The methods in use at Creswell Crags are essentially simple with much of the ground plan being established by 'off-set' survey with standard Fibron 30m tapes. Due to the restricted nature of some of the passages it was found to be easier to record the survey in note form to be drawn up at a later date. The resultant plans record not only the basic plan of the cave, but also the position and extent of any deposits (including those attached to the cave walls) and any disturbance of the deposits. Frequent profile and cross sections are also necessary. These again would generally be drawn by offset from a (usually) horizontal datum line. A water level, calibrated by reference to a datum placed in the cave entrance area, is used to establish levels within what are broadly horizontal cave systems. In the heavily excavated caves at Creswell Crags the mapping of the cave sediments was of prime importance since it allowed the establishment of stratigraphical relationships within the surviving sediment sequences and thus the identification of key sites for excavation. Unfortunately, in some areas thin flowstones had formed over the sections left by the early excavators, so excavation had to take place 'blind'. Some patches of sediment were so isolated from one another that it was impossible to infer their position in the stratigraphy without use of dating tools such as U/Th or palynology.

Some geophysical prospecting has taken place at Creswell Crags in order to find previously unknown caves and to extend the plans of filled caves (Samson and Jenkinson, 1979). This proved to be successful for cave systems that were a relatively short distance below the surface.

Cave Excavation

The necessity of sampling only a small part of the surviving cave sediments in Robin Hoods Cave and Pin Hole Cave and the recognition of the extremely detailed stratigraphies in these oaves led to the excavation of small quantities of sediment in considerable detail. In Robin Hood's Cave, planning permission was given for a small number of excavations 100 mm wide by 100 mm long and of indefinite depth. In cases where standing sections existed, material was excavated down the free face in units of 100 mm. In other areas, where deep fills of chambers were suspected, cores up to 3.4m deep were taken using commercial U4 sampling tubes driven into sediment using a hydraulic pit-prop braced against the roof of the cave (Jenkinson et al., 1983). Cores of undisturbed sediment recovered by this method were analysed in 100 mm units in the laboratory.

Analysis of the 100 mm thick units recovered from Robin Hood's Cave showed that in some cases these units of excavation were insufficiently fine and that there was some mixing of faunal and palynological assemblages. Accordingly, when excavations started in Pin Hole Cave in 1984, a more detailed excavation and recording system was devised (Brooks, 1985). An area of the cave 1.2 m long x approximately 1.7 m wide is currently under excavation. The basic 'unit of excavation' is a 100 mm square dug to a depth of 10 mm. This may be subdivided when two or more 'contexts' are found within any 'unit of excavation'. Control is provided by a horizontal datum board fixed over the excavation area. The datum board is marked with the horizontal site grid and strung with plumb-lines from the corner of each 100 mm square. In this way, very tight control over horizontal measurements may be achieved. Depth measurements are taken from the same datum board, giving tight vertical control. The contexts recognised and all finds down to 1 mm (including bones, artefacts, mollusca and charcoal) are planned in situ and a three-dimensional coordinate taken for each end of the find. Any voids encountered during the process of digging are cast using inert latex rubber to record their shape in detail. All sediment excavated from the cave is conserved in its contexts within its 'units of excavation' after it has been sorted for the occasional small finds missed by the excavators.

A detailed sampling strategy has been used for pollen, mineral magnetism, sedimentology and magnetostratigraphy. Samples are taken from a designated 'sampling square', or the closest 'unit of excavation' thereto if the sample square is blocked by a large boulder or it is otherwise unsuitable. A square adjacent to the 'sampling square' is used to supplement the quantities of sediment if insufficient is available. Further samples are taken around large bones for pollen analysis, since the large quantity of organic material in bones seems to help the preservation of pollen grains. Every 0.5m down the profile, a transect of samples is taken across the cave to help assess lateral variability.

The vast quantity of data accumulated by this type of research can only be fully synthesised using powerful numerical techniques. Computer programs and statistical models to handle the information from Pin Hole Cave are currently being developed at Sheffield University.

Although this type of cave excavation offers information of unrivalled quality, this information can only be won at considerable cost, both financial and in terms of the sheer time expended. Eighteen months of full-time excavation in Pin Hole have resulted in the excavation of a depth of 1.10m of sediment.

Conclusions

The use of this type of detailed excavation technique allows a very detailed picture of changing environments and of taphonomic and sedimentation patterns within a cave to be built up. Together with accurate survey of the surviving sediment it provides a unique archaeological opportunity to study the past in potentially greater and more continuous detail than any other method.

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Hydrology and Cave Surveys

John WILCOCK

All cavers are familiar with water, be it muddy aqueous crawls, exhilarating wading in master caves, dramatic waterfalls, gour pools, or underground rivers which can swell to dangerous proportions under flood conditions. A small fraternity, the cave divers, have made water so much their environment that they venture into the silent world of the flooded phreatic tubes, undertaking marathon trips which in the eyes of less venturous cavers are comparable achievements to the ascent of Everest. All these watery environments must be recorded on a cave survey, at least so far as they affect cave exploration, but cave scientists are interested in many other aspects of water which affect the speleogenesis of the cave, and these details have an equal claim to be indicated on large scale scientific plans.

Recording information on underground water

The recording of the characteristics of bodies of underground water is as much cave surveying as measuring distances and directions. Bull (1984) and Drew and Smith (1969) have presented excellent summaries of the available techniques for the tracing of this subterranean drainage. Hydrologists are interested in at least the following properties of the water: Source; Destination; Water levels under different antecedent rainfall conditions; Temperature at different months of the year; and Chemical Characteristics.

Ordinary cave explorers will be interested in at least the first two of these properties, source and destination, while cave scientists will be interested in the others. Thus cave surveyors should produce two versions of their plans and sections, a small scale summary (with much detail omitted) for the tourist explorer, and a much larger scale "scientific" version, including all the details of the original survey, perhaps on a scale of 1:1000 (1cm representing 10m), with plenty of blank space for scientists to record their observations.

Non-intensive hydrological recording

The kinds of information which hydrologists will want to record for water tracing on regional non-intensive level are: Name of system or cave; Control information (name and person making the entry; date of entry); Origin of information (name of person making test; club; date of test); Description of test (dye or tracer used; quantity); Inflow description (NGR of test site; name of swallet; exact time of insertion; inflow comments - e.g. colour, temperature, stage, weather conditions); Outflow description (NGR of rising; name of rising; throughflow time; outflow comments - e.g. colour, temperature, stage); Meteorological and other comments; and Test summary (test result - positive, negative, inconclusive; reason for inconclusion; finish time - if inconclusive).

These data may be recorded in a computerised database, or in paper files, but it may also be relevant to record summaries of positive traces on an area plan, showing the locations of all the sinks and risings, and probably the outlines of the known cave passages as well. Test results within the cave are probably restricted to what is known from inflow and outflow of water, e.g. visible dye, temperature, actual flow levels (with dates and related to the external weather conditions and antecedent rainfall over the past weeks), and proven connections with surface sinks and risings or with other appearances of streams within the cave. It may be appropriate to record these brief details on a large scale "scientific" plan of the cave.

Intensive Hydrological Recording

Intensive recording will include all the non-intensive categories above, plus the following: Administrative details (test area; county, etc.); Environmental data (soil; ground; aquifer comments); Inflow characteristics (quantitative flow in cumec; hydrograph; tracing method; colour by Hazen value; pH; air, soil and water temperatures; conductivity; antecedent rainfall; chemical parameters; total hardness; parameter accuracies; derived parameters such as saturation index, partial pressure of carbon dioxide, relative entropy and ionic ratios); Outflow characteristics (as for inflow characteristics, plus detection device; detector assay method; number of detectors; quantitative trace measure in ppm; exact timings of observations and flow-through time; comments specific to detector site; relationship to inflow site - eastings, northings and height); and Bibliography. There is too much information to appear on a plan, but there may be coded references to data held elsewhere.

Special Surveying Techniques for Hydrologists

Hydrologists may find the following techniques useful for adapting standard cave plans for scientific purposes: Transparent overlays - these are good for showing changing flood characteristics, but are not very practical for publication: Insets - small additional plans; boxes and arrows with detailed comments - both are more practical than overlays, as they may be written on a blank large scale survey in the cave, or overprinted on a standard survey for publication; and Flood level indications - important where flood water invades normally dry passages, forming temporary ducks or sumps.

Symbols for the Depiction of Water

The classic symbols were recommended by the Cave Research Group of Great Britain, selected from suggestions by experienced British cave surveyors, and from American, French, and other European sources (Butcher, 1962, p. 524). These were perpetuated and modified by the British Cave Research Association (Ellis, 1976a, p.9; Ellis, 1976b, p.25). The most relevant are reproduced here (Fig. 1). All can still be recommended, with the exception of the later sump symbol (Fig. 1 (c)), which now seems to have gone out of favour - the cross-hatched version with continuous passage outline (Fig. 1 (d)) is preferred. The use of a comment box with continuous straight arrows to explain scientific observations is recommended (Fig. 1 (g) and (i)). Continuous arrows should be used for known water connections (Fig. 1 (i)), whilst wavy arrows should be used exclusively for flowing water (Fig. 1 (b)). Surveys of totally flooded passages are becoming much more common: the problem here is that if the conventional cross-hatched symbol (Fig. 1 (d)) is used throughout, other details of the passage are obscured. It is therefore recommended that the initial cross-hatching be retained at the ends of the sump, but that within the sump the cross-hatching be gradually faded out, eventually leaving a blank passage outline suitable for the marking of other features (Fig. 1 (e)). This convention, if generally adopted for flooded passages, the usual medium of the cave diver, would be comparable to the convention adopted in the sport of orienteering, where white paper on a map means forest, the usual medium of the orienteer. A new convention for the illustration of flood levels is introduced in Fig. 1 (g).

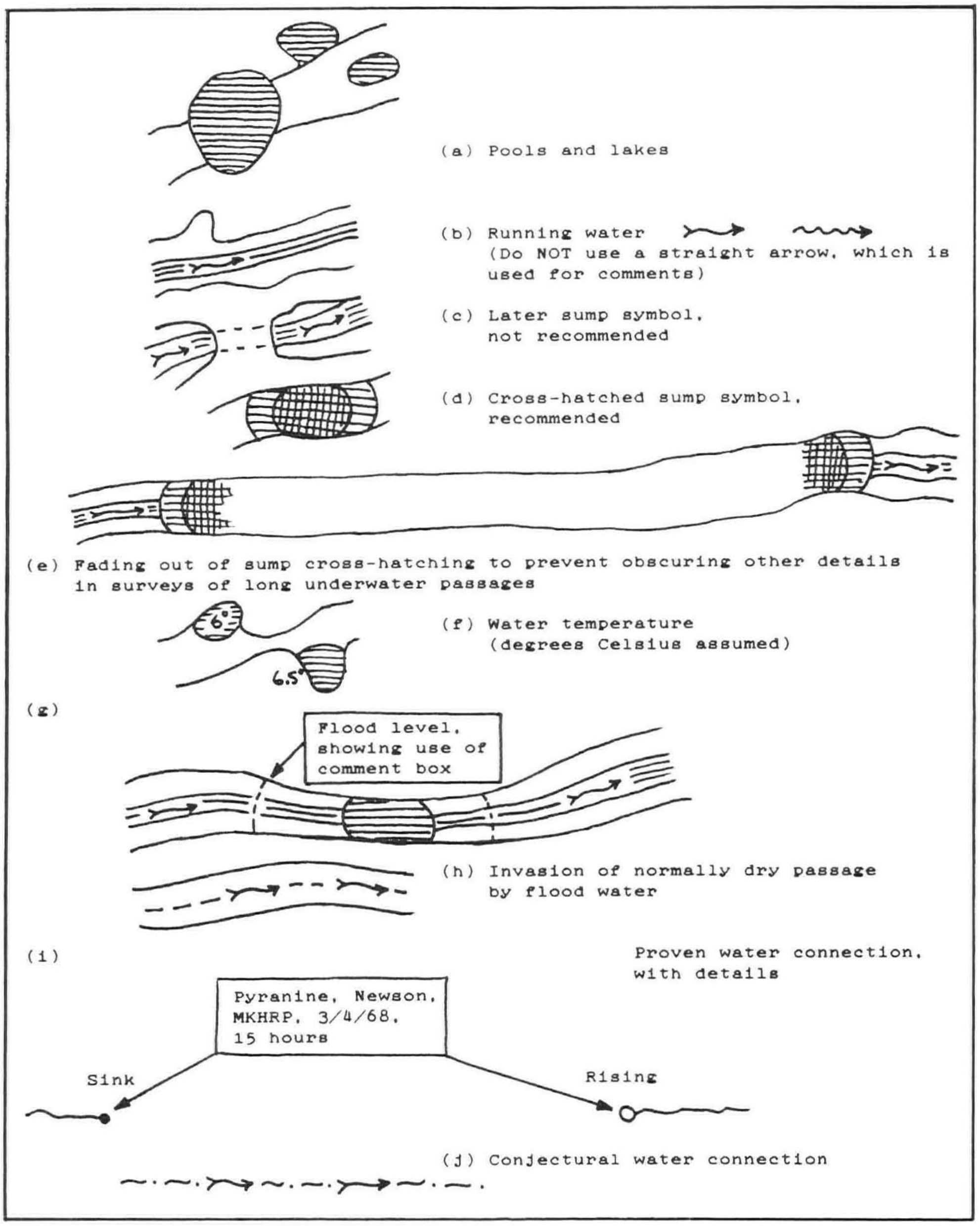

Figure 1 Symbols to illustrate water in caves

Conclusion

This brief survey of the mapping techniques for the representation of water in caves has presented a range of conventional symbols, and has recommended the introduction of a few new conventions. It is hoped that cave scientists will use these symbols increasingly for the portrayal of their observations on large scale plans of caves.

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Geology and Cave Surveys

D.J. LOWE

Contrary to the opinion of many, caves are not random features which are the chance result of interaction between any old limestone and water. In fact just about every limestone cave is where it is and in the form it takes for reasons of geological structure and rock composition. Factors such as surface topography, water-tables, base-levels and solution chemistry are inseparably bound to the geological considerations, but largely irrelevant if viewed outside the geological context. Geology is the fundamental influence on the mode and extent of cave formation in a given area - some rocks will be cavernous, others will not, no matter how much it rains or how far down the hill "resurgence" level lies. The structural element of geological control or guidance is by far the most important. Caves do not simply end and any apparent termination, whether it be a narrowing, a lowering, a sump or choke, is there for a reason. If geological reasoning is applied to detailed geological observation, a way on, or around, can often be located. On the scientific side, a seemingly complex and inexplicable speleogenesis can generally be resolved if the structural and lithological guides and controls are recognised, and can be integrated with erosional and depositional events affecting the area.

A well-produced cave survey can provide the ideal "base-map" for detailed geological mapping and data recording. However, in small systems or in caves explored on expeditions there may be no obvious need, or no opportunity, for a geologist to return with the topographic survey and append geological detail. It is therefore a good idea if a number of fundamental geological features are observed and noted by the cave surveyor and, if these features are clearly seen and non-controversial, that they be included on the finished survey.

Cave surveying is, arguably, a complicated and demanding enough procedure without adding to the difficulties, and even those who claim to be geologists sometimes "forget" to bother; the author is no exception. The intention here is to point out the features which are easy to spot, significant in terms of speleogenesis or extension-potential and straightforward to record; the items which can turn a basic cave survey into a more useful and powerful tool for scientist and explorer alike. Additionally a number of suggestions will be made concerning the best way to record these data underground and add the information to a finished survey.

Rock-type (lithology)

It is often not really feasible for a geologist, let alone a non-geologist, to distinguish different types of limestone in underground exposure, even if hammer and lens are available. However, it is worth noting obvious lithological differences, such as dark or pale limestones or bands rich in fossils, and the presence of chert nodules. Non-limestone bands (shales, sandstones, coal seams and various types of volcanic rock) are more obvious and easier to pick out, if not positively identify. These should be noted whenever observed, with particular care being taken to record horizontal as well as vertical extent. The importance of this will become apparent in the survey production section.

Bedding planes

These are the generally horizontal or sub-horizontal discontinuities between separate beds of rock. Sometimes they are planar (as the name suggests), but they can also be wavy or highly irregular. Sometimes they are marked by partings or beds of another rock-type. For example two beds of essentially similar limestone might be separated by a thin leaf of "shale" or a thin smear of "mud". Not all bedding planes are horizontally extensive, but some are major features and worth recording, as described later.

Dip

The dip of the rock succession is the angle that the beds form with the horizontal and the direction the slope takes. True dip is the steepest dip on a bedding plane and can only be towards one direction at the point of measurement. Lesser angles on the same bedding plane are termed apparent dips and apparent dips of equal magnitude are present on either side of the true dip direction. A line at rightangles to the true dip direction is termed the strike and since a strike line joins points at the same height on a bedding plane, there is no dip along this line - or, expressed another way, the true dip is the maximum dip on a bedding plane and the various apparent dips tend towards zero as the 90° from true dip to strike is rotated in either direction. By definition there is no dip if the beds are horizontal whilst if the beds are vertical there is no dip direction, only strike. Another complication is that beds can, in extreme circumstances, be overturned in large fold structures, but for most cave explorers this situation will be rarely, if ever, encountered. Bearing in mind that bedding planes are not always planar (!), measuring the dip angle and direction is not always easy, even with clinometer and compass ready to hand, but if reliable measurements can be taken and recorded, they can be very useful. Failing that, a general direction and amount of dip can often be estimated as the survey progresses, and the general sense of the dip shown on the survey. With detailed observation of major bedding planes and partings throughout a cave it is possible to work out accurate dips from the survey data, using the relative three-dimensional positions of at least three points on the same bed. This technique can be highly misleading if there are any faults, however.

Faults

A fault is any fracture in the rock mass along which movement has taken place. The movement may be vertical, horizontal or at any angle between, or the rock on both sides of the fracture might simply have pulled apart. Faults may be open, with voids and hence potential water routes, or they may be sealed by various minerals, clay or rock waste. Amounts of displacement on a fault line can vary between the very small and the very big, but generally in underground exposure throws measured in metres or tens of metres would be the largest recognisable, generally only being demonstrated by a displacement of a recognisable geological horizon. Even if no displacement is visible a fault can often be recognised by secondary characteristics such as brecciation (broken rock material preserved in the fault plane), gouge (clay dragged along the fault plane) or slickensides (grooves scoured in the walls of the fault plane and running parallel to the direction of movement). Cave passages can run along fault planes, pitches can drop down them or there can be a combination of the two, but elsewhere faults have no effect at all on cave passage formation. When a fault is recognisable underground the things to record are the direction it trends, the dip of the fault plane, if any, both amount and direction, and the magnitude of the throw if this is apparent. Depicting the faults on a survey is problematical, particularly in complex 3-dimensional systems, but several suggestions are made below.

Joints

Contrary to popular belief, few joints are produced by the limestone drying out and shrinking, at least not totally, but as a secondary effect associated with faulting or folding. In theory there is no displacement on a joint, this being the only property to distinguish it from a fault. In fact some "joints" seem to have moved and some "faults" have no discernible displacement, but in both cases the effects on cave formation are similar. The comments regarding survey of faults also apply to joints.

Mineral Veins

The majority of features in this category are simply joints or faults with a loose or tight infill of mineral matter. The mineral may be an ore, a mixture of ores (commonly galena and sphalerite), less valuable gangue (such as calcite, quartz, fluorite or baryte) or mixtures of all these. Veins of this type can be plotted in the same way as joints and faults: the minerals present should be noted wherever possible. Other mineral bodies are cave passages filled with ore and/or gangue, cave passages which predated the mineralization or which were dissolved by the mineralizing fluids. If these have been worked out they may look like caves. If they haven't been worked they probably look like cave passages full of ore and you should forget about surveying and think in terms of filing a claim!

Other features

Drift deposits should also be noted when possible and indeed many are recorded as a matter of course by most surveyors. Floor deposits such as boulders, gravel, sand, silt and mud can all be marked and if they have a significant thickness or

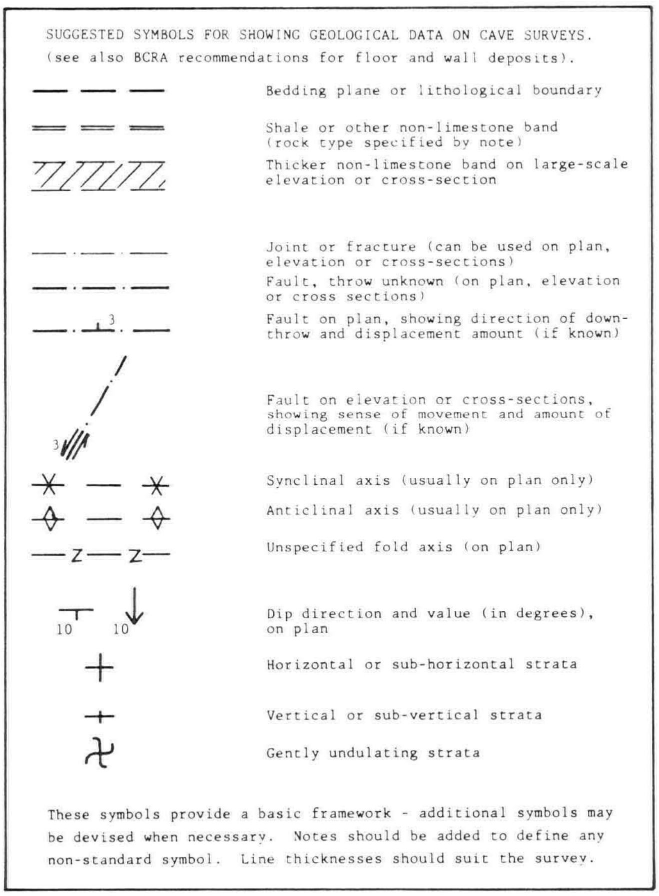

Figure 1

notable features such as laminations or grading, these should all be recorded. Speleothems on floor, walls or roof can also be recorded, and any inter-relationship of these with the sediments mentioned above should be noted.

Below, the three basic parts of a good cave survey, plan, elevation/s and cross sections are considered with suggestions of how the various geological features described above can most usefully and clearly be included in the finished drawing.

Plan

In systems with only one significant level of passage development, whether this be sub-horizontal or following a steeply-dipping bed, the plan is the most suitable place to show detail of dips and fault or joint lines. Dip may be shown by arrow symbols (Fig. 1) which point in a down-dip direction with the angular value shown in degrees, or by a dip bar (Fig. 1) which has a longer line corresponding to strike and a shorter 'tick' pointing down dip. Positioning of these symbols on the plan may not be crucial, particularly if the dip indicated is generalised, but ideally the head of the arrow, or dip bar, should be as close as possible to the position of the dip recording. To be slightly more sophisticated different symbols can be used for true dip and apparent dip, whilst additional symbols (Fig. 1) may be used to indicate horizontal (ie angle too small to measure), vertical or undulating/wavy bedding.

The type of line used to indicate faults and joints on cave surveys should be standardised and alternatives are suggested in Figure 1. Note that in some instances a fault may not be identified positively, so the categories "joint or fracture" and "fault" are recommended. Lines used to indicate bedding planes or geological boundaries on the elevation (see below) must be of different type and, within the limitations of the drawing, use of the various symbols must be consistent on the separate survey elements.

In multi-level systems or systems with deep vertical sections it is still possible to indicate fault or joint lines, but if space allows the same fracture can be shown, with suitable labels, at different levels on the plan. Fractures visible at different levels should only be shown as parts of the same structure if exposure is continuous (for instance in a shaft) or if the measured dip of the fracture and surveyed depth between passages indicate a probable geometrical tie-in.

Elevation

In a single passage system geological detail may be fairly easily shown on either a projected or an extended elevation. In more complex systems the type of elevation chosen will dictate which information can be shown - in general it is more difficult to show geology meaningfully on a complex projected elevation, though if the structure is perceived prior to drawing, it might be possible to choose a projection which will show it advantageously (Figs. 2 and 5). Generally, extended elevations would not be used on a complex survey, unless to illustrate individual passages, and in this case some geological data could be added. The problem on any elevation is one of indicating geology which is 3-dimensional on a 2-dimensional surface and maintaining the correct geometrical relationships.

Faults and joints are most easily and realistically shown if the elevation is drawn approximately at rightangles to their trend (Fig. 2). Elevations which cut the fractures obliquely will show them with dips which are smaller or larger than the actual value, due to extension or foreshortening by the projection. A note on the drawing can be useful, to draw attention to this, and should include the true measured or calculated dip if possible.

Similar comments apply to dip and bedding features. Bedding-controlled passages will only appear at their true (maximum) dip value if the section is drawn along the strike. If a long bedding-controlled passage is foreshortened on a projected elevation, a dip appearing steeper than the true value will be produced, whilst passages on bedding planes could also be running at shallower, apparent, dip angles. For these reasons it is probably best not to mark dips as such on a projected elevation, unless they are known to be a reflection of the true dip. Bedding planes (or non-limestone partings) can still be shown, however, giving an impression of the dip direction without indicating values. The corollary of this is that true dip readings should be shown on the plan, wherever possible. On extended elevations passages running down dip will always appear at the correct dip angle and dip symbols and values may be validly shown. The disadvantage here is that the elevation will include non-bedding plane passages and the same bedding plane may appear at progressively lower (or higher) levels, particularly where the passages meander slightly on the bedding plane.

Lithological changes may also be shown on the elevation, be it projected or extended, but care must be taken not to cause confusion on complex surveys. The best approach is probably to indicate the position of the observed lithological change by using a bedding plane (or

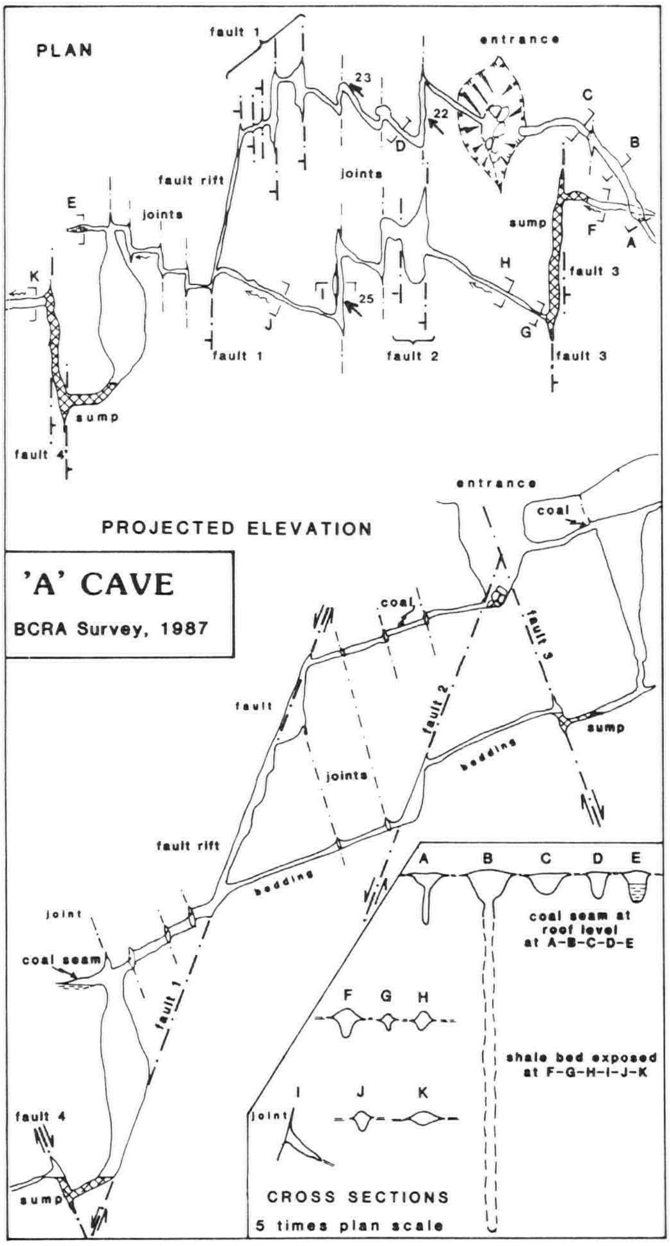

Figure 2. Survey of an imaginary cave, illustrating the inclusion of basic geological data.

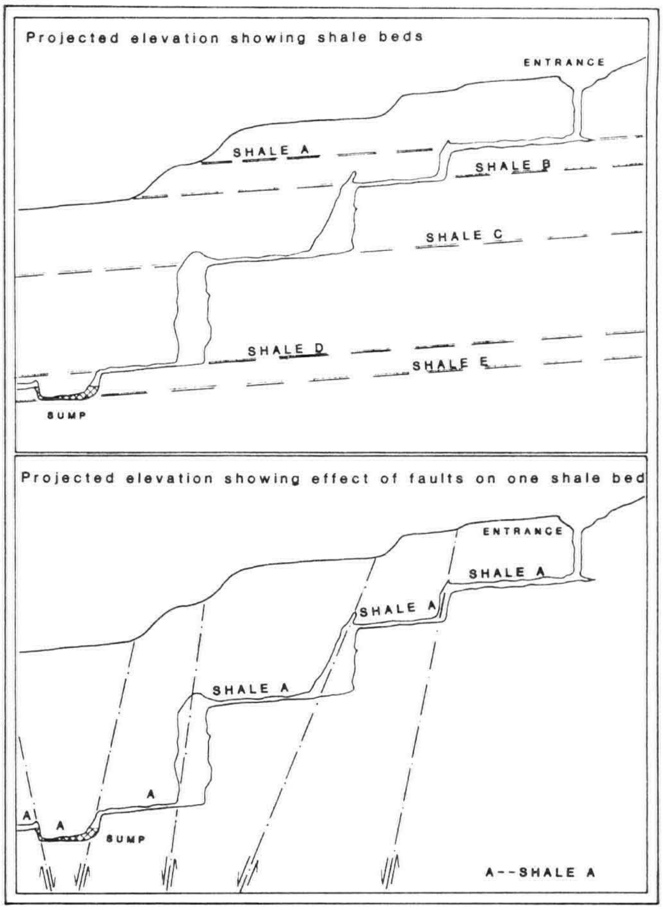

Figure 3. Elevations of an imaginary cave, showing extremes of shale band interpretation and emphasising the need for detailed observation of marker bed exposures.

shale band etc) symbol and adding notes, such as 'dark limestone', 'pale limestone', above and below the boundary. If the same boundary is visible in several locations it may be possible to use lines connecting the various exposures, but this will depend upon the type of projection and the complexity of the survey. Such lines should not be drawn unless there is a certain correlation and unless it is sure that no significant fault lies between the exposures. Figure 3 shows two extreme interpretations of scattered shale exposures in a cave system. On the one hand every shale noted in passing vertically down the cave has been considered as a stratigraphically lower horizon and on the other hand faulting has been deduced between the scattered exposures on the assumption that only one shale is present in the sequence. In a real situation a mixture of these two extremes is most likely and, as mentioned above, it is essential that the surveyor tries to observe the horizontal extent of such beds rather than merely recording widely spaced exposures. Often the individual horizon will be recognisable either by its lithology, its relationship to rocks above and below or by its influence on passage shape.

Cross-sections

The cross-section (or simply section) is grossly underused by the cave surveyor and cave geologist. It can be sketched underground, with geological detail added, without complicating the main survey sketch and can then be fitted into blank areas of the finished drawing at enlarged scale (if necessary). Notes can be added to those sections requiring clarification without interfering with the detail shown on the plan and elevation.

Where passages follow faults or joints these structures stand out well on a cross-section. Likewise simple bedding planes, shale bands, coal seams, fossil bands and other changes of lithology can be simply shown. The passage shape itself can give an indication of lithological variation, some beds being more prone to solution or corrasion than others.

Sections can also be a very useful guide to the sequence of speleogenetic development. In Figure 2, for instance, sections A, B and C show a passage which developed in the phreatic zone by solution along a bedding plane. At a later stage a joint across the passage was opened up and eventually this pirated a part of the drainage. After a change of base level and the establishment of a vadose regime, the passage at point C was abandoned as the stream descended the joint, forming a shaft. Later still the vadose trench cut back from the original joint forming a deep vadose rift at point B. The head of the shaft on the survey is a considerable distance back from the original joint and at point C vadose downcutting is still going on. In this situation the original bedding plane-guided roof remains along the entire passage and a traverse at roof level would pass over the more recent vadose route to the untrenched phreatic tube at point A. A similar situation is shown at point E, deeper in the cave, where the phreatic continuation is shown silted, but offering an obvious 'dig' and potential by-pass to the downstream sump.

The geological data can be shown on the cross-sections using standard symbols, as on the plan and elevation, but also there is generally abundant space for notes and labels (Fig. 4). As an underused element of the finished survey, there is ample scope for experiment to find a suitable approach, without breaking established conventions.

Late stage additions

There are a number of geological features which would not necessarily be readily identified

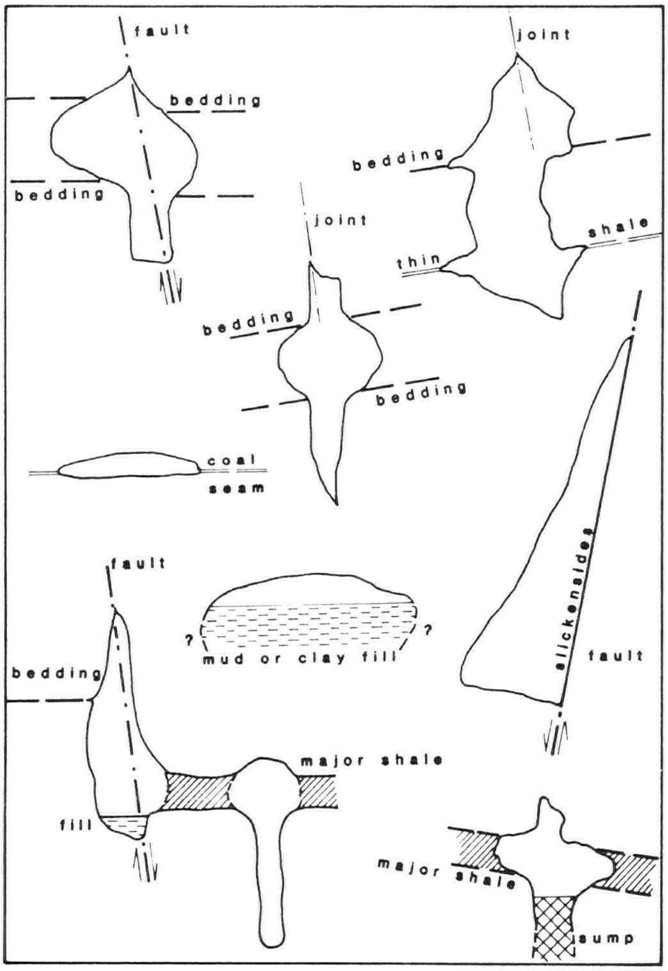

Figure 4. Examples of cross-sections with geological data.

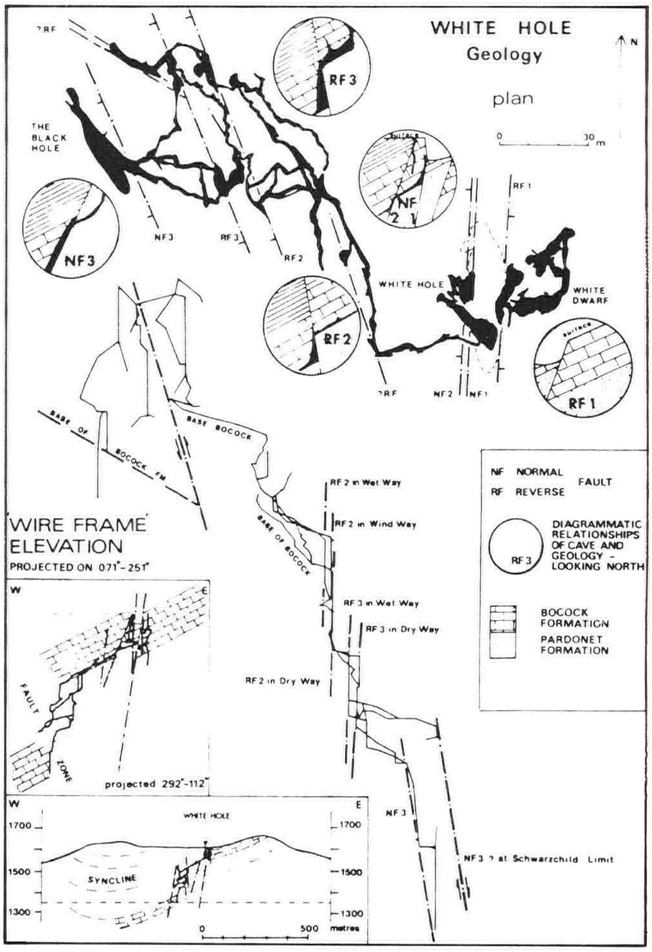

Figure 5. Geology of the White Hole (Canadian Rockies) showing one approach to depicting faults at different levels and in difference passages. The elevations are computer generated.

during surveying, but which can be recognised and inserted on the final drawing. Approximate lines of anticlinal, synclinal or other fold axes may be shown on the plan or a suitable projected elevation. Similarly the sense of throw of a fault may be added on plan, elevation or cross-sections if the displacement of recognisable beds becomes apparent on drawing the survey and, in the same situation, the actual amount of displacement can be noted on the plan.

Conclusions

The above comments are biased towards the depiction of geological information in a useful form on traditional cave surveys. With increased use of computer graphic facilities many possibilities of improving the presentation will soon be found. Figure 5 (previously published in Cave Science Vol. 12 No. 2, page 42, 1985, and hence using slightly different symbols to those recommended above) shows an early attempt to utilise computer graphics. A stick elevation of the White Hole was rotated by the computer to provide the most advantageous viewing direction - close to the strike and looking along the major fault lines. More sophisticated box models can be generated and rotated by the computer, and it is only a matter of time before geological data are being inputted and the computer used to generate a more 3-dimensional depiction of the relationship between cave passages and geology.

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