The Techniques of Cave Surveying

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I. Introduction

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 shrortness 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 achievment 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 arbitary.

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 percent.

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 strivin; 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.

Ⅱ. Equipment

The standard method of surveying measures distance, compass direction and inclination, using three instruments (those 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 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 (ultransonic 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 it most frequently used. Once the circumferences of the two windows are sealed with silicons 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 topofilthread 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.

Machanical 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 eleswhere (Machin, this volume). There is now a quarterly newsletter Speleonics, devoted to cave 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 the 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.

Ⅲ. 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 cave ("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 verical 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 on 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 littel data available on the accuracy of pace and compass surveys, but with careful measurements misclosures of only a few percent 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.

Both the Roppel (part of the Mamoth 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 pubilished for either cave, but they are likely to appear at a scale of 1:2,000 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.

Ⅳ. Survey Standards for Cave Men

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.

V. 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 indifferent countries do in fact agree. Muller (1981) published a set of 83 symbols, with explanations in six languages, after comparing German, Swiss, Austrian, French, British, Spanish, Italisn 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).

Ⅵ. Survey Data and Record Lists

The longest mapped cave in the world has been Mammoth Cave (USA) ever since the first survey in 1935, which showed 13km of passage. With their multitude of long, shallow caves, it is quite natural for Americans to be interested in length 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 the largest chamber for non-calcareous caves. All of these lists encounter problems of definition. For chambers, when does a wide passage become a chamber? Should on 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 bouldet 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 amy 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 (Hallidany, 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 limenstone 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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