

Issue 39

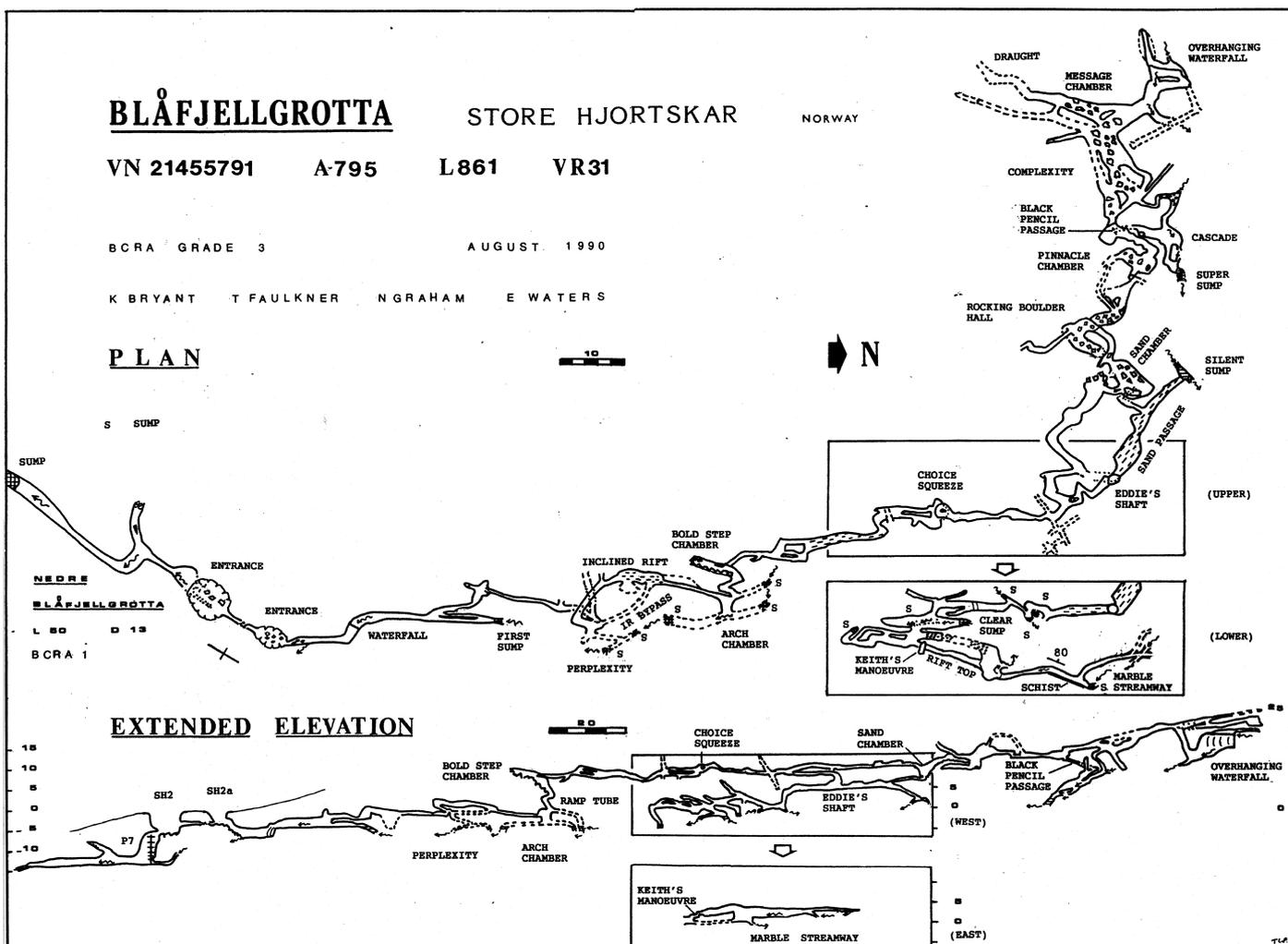


COMPASS POINTS

March 2008



BCRA



Techniques for rapid surveying of small caves An electronic inclinometer

COMPASS POINTS INFORMATION

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The group aims, by means of a regular Journal, other publications and meetings, to disseminate information about, and develop new techniques for, cave surveying.

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courtesy of Doug Dotson, Speleotechnologies.

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Cover image: Survey of Blaafjellgrotta, Norway, courtesy of Trevor Faulkner. This cave was surveyed in three visits in 1990 using the techniques described by Trevor in this issue.

Editorial

A running theme in recent issues of *Compass Points* has been the development of electronic instruments for surveying. This theme is continued in this issue with Ian Todd's contribution about the latest version of his electronic inclinometer. It is clear that this continues to be a hot topic. However, I was also pleased to be able to include Trevor Faulkner's contribution about the practicalities of managing a surveying project. I am always on the look-out for similar case histories, and would like to encourage readers to write about their own surveying projects so that we might all be able to pick up a few useful tips.

Standing Orders

The BCRA Treasurer informs us that there are some people who are paying Bank Standing Orders to BCRA under an old arrangement. BCRA has not accepted Standing Orders as a valid method of paying membership for two years. Unfortunately, because of the nature of these payments, BCRA is unable to cancel them nor is it able to trace them via the issuing bank. If there are any Compass Points subscribers who are still paying a standing Order to BCRA (e.g. for the now-obsolete category of Associate Membership) we would be grateful if you would contact your bank to arrange for the cancellation of the payment. Any such payment that is received by BCRA will not entitle you to any membership benefits and will be treated as a donation.

Payments by credit card

It seems likely that BCRA will be forced to withdraw its facility for accepting payment by credit card because of new regulations introduced by the credit card companies, which are intended to reduce fraud. The regulations place strict limitations on how the customer's data can be handled. The merchant's procedures must be audited and there are heavy fines for non-compliance. For a small volunteer-based organisation such as BCRA, the simplest course of action is therefore to cease to operate a credit card account, relying instead on customers using on-line facilities provided by third parties. Therefore, henceforth CSG can no longer accept subscription payments by credit card that are made by post or telephone.

As an alternative, CSG now has a paypal account which can be used to pay for subscriptions to Compass Points. If you wish to pay for your subscription by this means, the account is CSGsubs@wotcc.org.uk. Note that this account cannot accept credit card payments.

Forthcoming Events

Hidden Earth 2008

The UK's national caving conference, Hidden Earth, is scheduled to take place on 26-28 September 2008. The venue will be Prince Henry's Grammar School, Otley, West Yorkshire. Full details will be published on the Hidden Earth website:

<http://www.hidden-earth.org.uk/>

Arthur Butcher award

Each year, BCRA presents an award for, broadly speaking "excellence in cave surveying". The winner receives a cash prize of £100, a trophy that they keep for a year. The Award is judged and announced at the National Caving Conference.

In 2007, the award was presented to Phil Underwood for his "Shetland Attack Pony" electronic compass/clinometer. Phil is not the only person to have worked on such a device, but he has produced a well-thought-out and robustly built unit which has the potential to allow more accurate surveying, especially in difficult conditions. It achieves this by reducing the station position errors and by storing readings in the device to allow later downloading, thus reducing transcription errors.

Phil was also awarded the CREG award, which recognises special contributions in the field of cave radio and electronics. The citation notes that Phil is one of several people who have been experimenting with instrumentation such as this, but Phil receives his award not only for the development of the device but for writing about it in Compass Points and the CREG journal. Phil's project shows innovation as well as significant mathematical, software and hardware skills and gives to cavers a highly-useful tool which, in combination with the continued developments in survey-drawing software that are happening, will make it easier for cavers to produce higher-quality cave surveys.

Surveying software updates

This is the regular round-up of recent updates to some popular cave surveying software packages.

A new version of **Compass** [1] was released on 1st June 2007, and now supports the ability to display extended elevations. Several options are provided to control how these profiles are produced. For example, the user can control the angle of the plane to which the cave is flattened. There have also been some updates related to the release of Windows Vista. Most of the software works correctly, with the exception of CaveX. Vista users should use the new CaveXO program. This includes most of the functionality of CaveX, with the exception of joystick controls and the ability to load and save X files. These features will be added in the coming months. The old help files do not work with Vista, so new versions have been made created. Printed manuals for all Compass programs have also been made available.

The latest build of **Walls** [2] was released on 28th September 2007. The SVG update function has been revised to work round problems present in recent versions of Adobe Illustrator. Two levels of additional prefixing were also added that assists when merging large survey projects.

[1] Compass: <http://www.fountainware.com/compass>

[2] Walls: http://www.utexas.edu/tmm/sponsored_sites/tss/Walls/index.html

Terrain data tool

Mike McCombe

I have recently developed an application to create terrain data for Survex from the results of the Shuttle Radar Topography Mission (SRTM). Coverage is >99% of the land mass between 60°N and 56°S, with the missing bits mostly being in mountainous areas where steep faces were shadowed from the oblique radar by surrounding peaks.

The tool lets you select a rectangular area in a variety of coordinate systems (OSGB, Irish Grid, UTM, Lambert Coordinates, Austrian grid...) and saves the result as a .svx Survex data file. It is written in Java and should run OK on Windows, Linux, Solaris etc. If anyone is interested in playing with it you can download it from:

<http://uk.geocities.com/mikemccombe@btinternet.com/terraintool.htm>

You will also find some installation instructions and driving instructions.

2007 Cave Technology Symposium

David Gibson

Back in April 2007, BCRA's Special Interest Groups got together to organise a symposium. Cave surveying, electronics and the use of explosives in caving were discussed.

In retrospect, the symposium organised by BCRA's Cave Surveying Group, Cave Radio & Electronics Group and Explosives Users Group bore some similarity to the "regional meetings" that BCRA used to organise in the 1980s and 90s. That wasn't a specific goal we had in mind when organising the event, but with the presence of the Hidden Earth technical team, the Video and AV show we put on and the catering on offer, it *was* rather like a one-day mini-version of Hidden Earth, which is just what the old regional meetings used to be. Perhaps the new streamlined BCRA can revive these?

The event, on 14 April 2007, was arranged to coincide with CSG's field meeting at the nearby Orpheus Caving Club in order to provide something of a guaranteed audience, and took place at Hulland Ward village hall, which is near to Ashbourne in Derbyshire.

Allan Richardson helped me with the pre-event planning and arm-twisting. Les Williams, David Cooke and Andy Morse travelled up from the Mendips with the Hidden Earth technical gear (video projector, sound system and huge projection screen), Jenny and Boyd Potts manned the reception desk and the kitchen hatch, producing drinks and bacon sandwiches on demand, and Ann Whilding supplied a very sticky chocolate and banana cake. A buffet lunch of sandwiches was supplied at the Nags Head, close by. Grateful thanks to all these people, and to all the speakers and, indeed listeners who turned up.

Thirty three people signed-in for the event; a few others appeared to manage to avoid doing so. There were twelve presentations, plus a showing of Martin Baines's film *Voyage* and John Robinson's AV *Fourpence a Day*.

Poster papers and cave surveys were on display, together with a range of BCRA publications for sale and items of equipment. The presentations were organised into five sessions – cave radio, surveying, photography, explosives and equipment. The event seemed to go very well, with a large number of audience questions and discussion. Organising an event like this does not take much effort, since most of the contribution comes from those who attend. The main requirement is therefore to persuade enough people to want to take part.

There were two surveying related presentations. Phil Underwood presented the electronic surveying device that has been the subject of articles in recent issues of *Compass Points* [1] and the CREG journal [2][3]. The device that is accurate to 1°, and features a laser pointer, digital display, and USB interface; and he has developed a novel method of calibrating such devices. After explaining the concept and the design process, the instrument was put through its paces and the Cave Surveying Group arranged for further trials to take place underground the next day, as part of their field meeting.

The second surveying related presentation was by Trevor Faulkner, who put forward a minimalist approach to surveying and drawing that could be undertaken with a small team and without specialist software. He claimed that the end result could be indistinguishable from surveys produced by more elaborate procedures. Naturally this led to some lively debate amongst the surveyors and software experts present. This presentation forms the basis for an article in this issue.

There were also two posters relating to surveying. Wookey presented "Data management of large surveying projects". This included some very nice surveys drawn with Tunnel (SteinbrückenHöhle and surroundings) and Therion (Terikan river system and Whiterock Cave, Mulu) from large datasets. He gave a very short talk explaining that it is now possible to do all the drawing electronically as well as the data processing, and that top-quality free tools exist for this purpose which work on all three major computing platforms. The second poster was "Digital compass and clino" by Mike McCombe. This latter project has also been described in a previous issue of *Compass Points* [4].

References

- [1] Underwood, P. (2007). Calibrating a combined electronic compass/clinometer, *Compass Points*, 37, 5-7.
- [2] Underwood, P. (2007). A combined electronic compass/clinometer, *Cave Radio and Electronics Group Journal*, 66, 12-14.
- [3] Underwood, P. (2007). Calibrating the electronic compass/clinometer, *Cave Radio and Electronics Group Journal*, 69, 10-12.
- [4] McCombe, M. (2007). Electronic compass/clino update, *Compass Points*, 37, 3.

Press Round-up

Cave surveys, cave size, and flank margin caves

This article, by John Mylroie, is the principal feature in Issue 60 of Compass and Tape - the newsletter of the Survey and Cartography Section of the National Speleological Society, which was published in December 2007.

The article discusses conventions for describing cave size in a way that allows meaningful comparison of the extent caves with very different morphology. Surveyed length is the usual metric, and this is suitable for describing the extent of linear caves for which the passage length is very much greater than the width or height. This measurement is also useful when considering maze caves, and when interpreted in conjunction with the areal extent of the cave can provide a measure of passage density. However, in many cases it is not always obvious that the surveyed length is a useful indicator of the extent of a particular section of cave. A commonly occurring example is the problem of how to measure the surveyed length in a large chamber. This might be surveyed by means of a single line around its perimeter or a series of splay shots from a central point. In both cases it is questionable whether the total length of the survey legs gives a useful measure of the the caves extent. The occasional large chamber in a predominantly linear cave does not alter the overall measure of cave length significantly. However, if the cave comprises a large chamber and little else, defining a meaningful cave length can be problematic.

This issue is discussed with reference to the flank margin caves of Puerto Rico, the Bahamas and the Mariana Islands. These caves are dissolution features formed by the mixing of fresh water and salt water in coastal limestone bodies, with no significant water flow. Due to this mode of formation, these caves tend to comprise a series of chambers. As the caves tend to have very low ceilings at the edges, the preferred mode of surveying is to shoot splays from a central point to map the extent of each chamber. Whilst it may be possible to divide such caves into a number of linear segments and thus derive a measure of cave length, it is not clear that this would be a useful exercise.

Monica Roth, a graduate student at Mississippi State University, set out to determine the areal footprint of the caves. The map was scanned and its perimeter delineated using a program from the National Institutes of Health that was developed to map cell interiors. Interior columns were identified and their areas subtracted from the total area, whilst their perimeters were added to the total perimeter. Analysis of the resulting data showed that the area of flank margin caves is linearly related to the perimeter, with area-to-perimeter length ratios consistently in the range 4-4.5. Much lower and more variable ratios are obtained for typical stream caves. This result has contributed to an understanding of the mode of formation of these caves. Furthermore, feedback on the use to which the surveys will be put has been given to the surveying teams who can adjust their strategy accordingly. For example, they realise that accurately identifying the position of isolated bedrock columns and pillars is important to the later analysis of the survey.

The overall conclusion is that the appropriate measure of cave size is dependent on the morphology of the cave in question. For linear caves, surveyed length remains a useful measure. In the case of flank margin caves, plan area is more meaningful. This is in part because these caves tend to develop on discrete levels associated with the freshwater-seawater mixing level giving characteristic low, wide chambers. In other settings where the caves are not so restricted in the vertical dimension, a method for characterising the cave volume in three dimensions may have to be devised.

Sustainable mapping of caves

Phillip Häuselmann and the UISIC have prepared a paper presenting the whys and hows of good surveying practice. It was published in Issue 10/11 of Speleology, cover dated August/December 2007.

The article sets out to present some guidelines for how to perform a survey that is complete, of high quality and sufficiently well documented that it can easily be supplemented with new finds without having to be done again in its entirety. First, the authors set out the basics of good surveying technique: using good quality, properly calibrated, instruments; accounting for sources of systematic error; using stations that can be re-found and at which the passage dimensions are measured; and drawing a detailed and accurate sketch. The subject of marking stations is controversial as some object to marking the cave in any way. The principal author's preference is for marking and labelling points at critical junctions discretely such that they can be found only if actively searched for.

To be complete, the survey should include plan, extended elevation and cross sections, and should be accompanied by a written description. All elements should be provided for all caves, even if it isn't immediately obvious that the particular view offers any useful insight into the nature of the cave. The plan view is often the most useful for navigating round a cave, showing as it does the width and orientation of the passages and their relationships to each other and other caves. This latter point is also true for predominantly vertical caves, so plans should always be drawn as even with limited lateral extent any preferred orientation of cave development and the relationship to other caves in the area can become apparent.

The extended elevation and cross sections give details of the shape and vertical extent of the passage that is not obtainable from the plan view. The authors argue that extended elevations are preferable to projected elevations because, for projected elevations, information is lost for passages orientated perpendicular to the plane of the elevation. Furthermore a projected elevation can be derived from an extended elevation whilst the reverse is not true. Projections have the advantage of allowing the relationship between cave passages and surface features to be easily seen. Elevations and cross sections offer much more information about the genesis of the cave than can be obtained from the plan: vadose and phreatic passages can be easily distinguished, and different levels of cave development identified. Hence elevations and cross sections provide useful information even for predominantly horizontal caves.

The written description is intended to cover observations made by the surveyors that cannot easily be ascertained from the map itself – for example geological and biological notes and hazard assessments.

The advantage of a high quality drawing over a rough sketch is obvious when detailed scientific studies are to be conducted, but are also more useful for sport cavers. For example, detailed sediment maps can be a useful aid to identifying suitable sites for searching for continuations of known passages. In the cave it is important to sketch to an appropriate level of detail, which will be determined by the scale the final survey will be drawn to if known. If the final scale is not known, it is better to err on the side of recording too much detail as the level of detail can be reduced at a later stage while absent detail cannot be created later.

The authors make the case for publishing completed surveys, or at least archiving them with a trustworthy body on condition of secrecy should this be considered necessary. If you own the only copy of a survey and it becomes lost or destroyed, all the work that went into creating it will have to be duplicated. The authors also advise that all the original data and survey notes should be archived. Finally, it is advised that paper copies should be made for long term storage rather than relying on digital media that may be unreadable in the relatively near future.

Overall, this article offers a concise description and justification of good cave surveying practices.

The effect of binocular vision disorders on cave surveying accuracy

This article – by Mark Dougherty – was printed in Cave and Karst Science (vol. 33, no.2, pp 51-54). A summary is presented here.

Binocular vision disorders are relatively common and can have a detrimental effect on compass and clinometer readings taken with conventional sighting instruments unless suitable precautions are taken. This article sets out to highlight the effect on survey accuracy, and suggests practical measures that can be taken to mitigate their effects.

If a person has perfect binocular vision both eyes point in exactly the same direction. A person whose eyes have a tendency to drift relative to one another in the absence of a visual cue to stay aligned has a phoria. This can clearly be a problem when using sighting instruments when one eye is focussed on the target station and the other is focussed on the scale of the instrument.

The most common phoria is heterophoria in which one of the eyes has a tendency to move in the horizontal plane. The condition is divided into two subclasses: esophoria and exophoria, which refer to the case where the eye drifts inwards or outwards respectively, as illustrated in Figure 1. If this disorder is sufficiently severe it can affect the accuracy of compass readings if it is not identified, but will have no effect on clinometer readings. Although the precise proportion of the population that suffer from this disorder to such a degree is unknown, the numbers appear to be significant. Hyperphoria refers to the analogous (much rarer) disorder in which the eye drifts in the vertical plane. In this case, clinometer readings may be affected whilst compass readings will be correct.

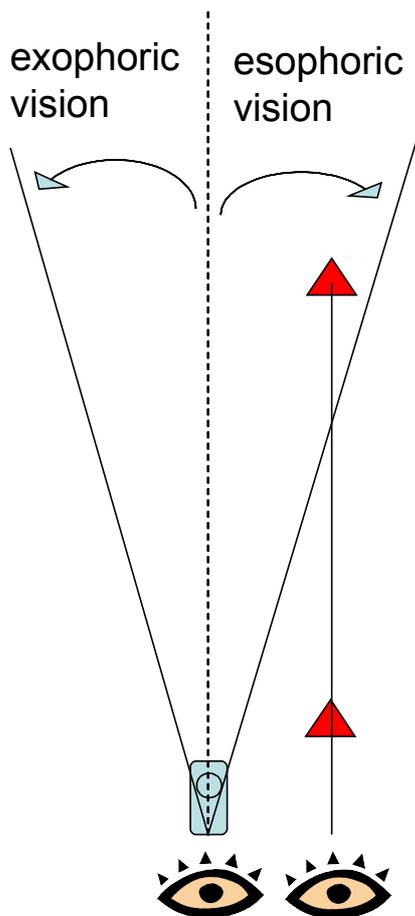


Figure 1: Exophoria and esophoria.

The author suffers from fairly severe esophoria. When performing a sighting on a tree sighted at a distance of 15m, the difference between compass readings sighted with his right and left eyes was 8°. This example provides an illustration of the potential scope of the problem. It is suggested that cavers should ideally test their eyes for heterophoria and hyperphoria by sighting compass and clinometer on a distant point with each eye in turn and looking for consistent differences between the readings.

A number of simple methods for coping with the problem present themselves:

- measure each leg twice, once with each eye, and average the results;
- turn your head on its side when reading the instrument that would be erroneously recorded such that the axis in which your eye drifts is always in line with the rotation axis of the instrument;
- sight with one eye over the top of the instrument;
- wait until the reading has fully stabilised before recording it, since for people with a mild phoria the eye eventually stabilises on the direction parallel with the other eye.

The use of instruments with a built in laser sight that has to be aligned on the distant station also eliminates the problem.

It may be tempting to assume that the issue can be addressed by performing an instrument calibration to determine the magnitude of the problem, then noting the eye with which each reading was taken during the survey and applying the appropriate correction. However, the angle of convergence or divergence is not constant and can vary according to several factors.

- The problem is often worse under high illumination levels, so if calibration is performed in bright sunlight the corrections obtained may not be applicable to readings taken underground. It is therefore advisable to perform calibration in lower lighting conditions that more closely approximate those experienced in the cave.
- Tiredness can exacerbate the effect, so that the error increases over the course of a long surveying trip.
- The amount of convergence or divergence between eyes may be variable on the distance to the sighting object. The author found that the 8° difference when sighting on an object 15m distant was reduced to 4° when sighting on a closer target 3m away.

Overall, it is clear that using one of the methods to mitigate the effect of a phoria is preferable to relying on calibration readings. If it becomes apparent that a someone with a phoria has operated instruments in a cave, it may be possible to correct for the effects if they perform a calibration on multiple targets at different sighting distances under subdued lighting conditions. The correction can only be applied if it is known that the surveyor generally sights with one eye or the other so that the correction can be applied in the right direction.

The author concludes that binocular vision disorders are potentially a very serious source of errors in cave surveying if they are not identified and their effects mitigated. He suggests that the following clause be added to the notes that supplement the BCRA surveying grades:

“To obtain grade 5, the surveyor(s) reading the instruments must be either known to not suffer from binocular vision disorders, or active precautions against such errors must be made.”

An electronic inclinometer

Ian Todd

This article describes the development of an electronic inclinometer (“clino”), a surveying device designed to be used in the instrumentally hostile environment of cave exploration, and discusses its use and performance in practice.

History

Back in about 2000, integrated circuit accelerometers, magnetometers and laser pointers had become available, and were affordable for the amateur experimenter. I conceived of the idea of building a solid state surveying tool, the InCompass, having a built in compass, an inclinometer and a laser pointer for sighting on the target survey station. Using an accelerometer gives not only the tilt angle to the next survey station, but knowing the tilt angle, the compass can be “electronically gimbaled” to give an accurate reading when tilted, unlike a conventional compass which must be held level. The InCompass project is still not finished but work continues. This article isn’t about the InCompass project, but about a spin off that the surveyors at South Wales Caving Club (SWCC) have found very useful; the electronic clinometer.

Dave Edwards and I worked together at this time at a London university, and I talked him into joining me on the compass project. Neither of us had any experience with microcontrollers at this stage. Initially we concentrated on just getting the accelerometer to be a sensor attached to a PIC microcontroller (PIC16F84), with an LCD display to show the output. We used a lookup table stored in some non-volatile external memory, to give us an output in degrees. This was in essence our first electronic clinometer.

Working independently, Dave then changed the display for an LED display, and boxed the instrument in a Perspex case to make it as rugged as possible (see Figure 1). He offered this to the SWCC surveyors for trial, and never got it back! They found it both easier to use than a traditional clino, and more accurate, and have used it ever since. The development of this prototype was described in an article in issue 33 of Compass Points [1].

Just before Christmas 2006, an approach was made by someone who had heard that SWCC had an electronic clino, and wanted to build one for himself. Unfortunately the one we had was really a prototype, and the documentation we had was mostly in our heads, and fading with time. So on that occasion we couldn’t really help him. Subsequently two other people at SWCC also expressed an interest. This gave me a kick-start to get back into the project, which I hadn’t touched for a while.

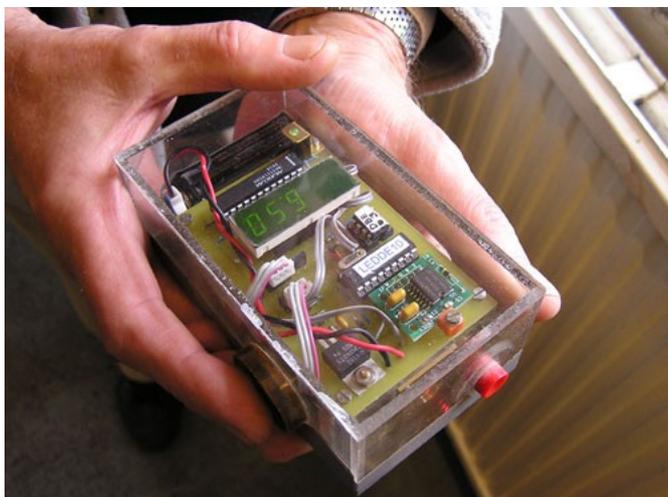


Figure 1: The Prototype Inclinometer, completed by Dave Edwards with LED display and Perspex case.

Recent developments

The first new units built were basically tidied up versions of Dave’s unit. A fresh PCB was laid out and three boards were made commercially. These boards worked out at about £17 each. Of the three units, the two for our club surveyors worked well, but the third unit built for my further experimentation was unstable and inaccurate. After a lot of head scratching, it turned out that the Analog Devices ADXL202 accelerometers had quite variable characteristics, unit to unit, and my unit had little change of the output pulse width with temperature. Dave had developed a clever method of using changes in the ADXL202 output pulse width to detect the current temperature and used a lookup table to apply corrections. By chance the third unit had little change with temperature, and so the corrections were very coarse.

This third board was then modified. The original PIC16F84 was swapped, for a newer, pin compatible microcontroller, the PIC16F87. This has much more internal memory, so that the look up table didn’t require the external memory any more. At the same time the resolution of the lookup table was improved to one tenth of a degree. The PIC16F87 had an internal capture and compare module, which could more accurately measure the duration of the accelerometer output pulses. The resistor which determines the accelerometer total output period (T_2 in Figure 2) was replaced with a couple of components that made the unit much more sensitive to temperature changes. This improved the accuracy of the calibration corrections and the original instability in readings disappeared. At this point the design was considered to be fully working. I subsequently upgraded all three units to use the PIC16F88, which while functionally like the PIC16F87, also has an A-D (Analogue to Digital) converter, which meant we could measure the supply battery voltage.

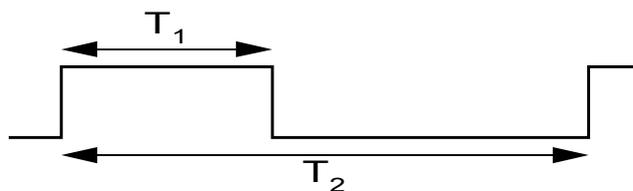


Figure 2: Accelerometer output. The duty cycle of the ADXL202 output varies with acceleration. The device is temperature sensitive and the inclinometer design applies temperature compensation according to the output period T_2 .

Out of interest I decided then to do a complete redesign around the PIC16F876 microcontroller which, like the PIC16F87 and 88, has more internal memory than the PIC16F84. It also has more control lines available than the PIC16F87/88, which made it possible to dispense with the LED driver integrated circuit, and drive the four digit display directly from the PIC. As well as the Capture and Compare module this PIC has an A-D module. This is used to continuously monitor the battery supply, warn when it is getting low, and prevent further use once the voltage has dropped to the point at which the voltage regulator can no longer supply a steady voltage to the accelerometer. Circuitry was added to isolate the battery from the whole circuit except during a measurement.

The PIC turns the power off when a reading is finished. This should extend battery life considerably. Considerable changes were also made to the software, putting functions like keyboard debouncing, capture and compare, the A to D, and display multiplexing into the interrupt routine.

The original clino had to have a set of calibration values programmed into the external memory during manufacture. This was less than ideal. The new version has the calibration routines built in, and can be calibrated at each of two different temperatures by the end user. These values are stored in the PIC, and calibration values are then automatically calculated for other temperatures while the unit is in use. This procedure is described later in this article. This final version is referred to as InclinomETer Version 2.0, and is shown in Figure 3.



Figure 3: The InclinomETer Version 2.0, showing the laser port and trigger switch.

Practical build considerations

Full details of how to build an InclinomETer Version 2.0, including circuit diagrams and sources of components, can be found on the project website [2]. The procedure was also described in an article in the CREG journal [3]. You are free to do as you wish with the software and circuit, but you may NOT use it for commercial gain without first obtaining my permission. A brief discussion of some practical issues is presented here.

The clino is contained in a plastic instrument case with battery compartment, and all components are mounted on a single sided Printed Circuit Board. It is quite possible to make this board yourself, and I include the full-scale artwork on the web page for those who wish to make their own. The mounting holes for the laser will need filing out on a home made board to enable alignment of the mounting block, but would be routed out during commercial manufacture.

The PIC processor will need to be programmed, which requires some simple hardware, but unless you really want to get involved, it is easier for me to do it for you. Just send the PIC to me, with stamp and addressed packaging for the return. (Please note that this offer applies to cavers only.) For anyone interested, the assembler file of the program, the generated hex file and some necessary include files are available on the web page [2]. The PIC should be mounted in a DIL socket, so it can be removed if necessary for re-programming if a change of program becomes necessary. For those who are familiar with PICs, the PIC can be programmed *in situ* using In Circuit Serial Programming (ICSP) and a connector is provided.

Manufacture of the mounting block for the laser pointer is a bit of a problem as it needs someone with machining facilities to make a neat job. A drawing of the block is shown in Figure 4. This block hangs beneath the PCB, and the laser is held in place by a grub screw. The type of cheap laser used here has a beam that may come out at quite an angle relative to the body of the laser. So the idea is to rotate the laser in the mounting block until the off axis beam is as near horizontal as possible, and then tighten the grub screw. Then swing the block left or right on its mountings until the beam is straight ahead. Minor errors in getting the beam horizontal can be corrected in software as described below. Probably the most accurate way to set the beam level, is to use a water level. This is just a length of transparent hosepipe, the longer the better, filled with water. One end is held near the laser exit port and the water level adjusted to be level with the laser beam. The angle of the laser beam is then adjusted until it is also level with the water in the distant end of the hose. The laser beam is then exactly horizontal.

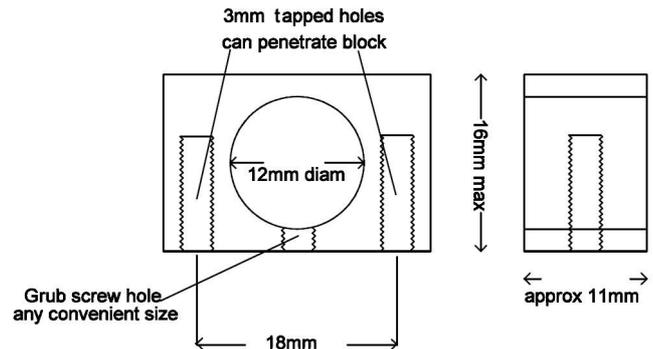


Figure 4: The Laser Pointer Mounting Block. The height of the 12mm hole in the block is not critical.

The trigger switch is the other mechanical problem. The unit only has the one switch for both turning the unit on, and for use as a trigger to take a measurement. To avoid disturbing the clino as the trigger is pushed, the trigger should only need a very gentle push. The switch should not be mounted on the top of the unit, as pushing the button will tend to lower the beam slightly. Maybe the switch should be very sensitive but have some mechanical protection to avoid turning the unit and the laser on accidentally during transport. This might also help prevent the ingress of water and cave dirt. I don't have a good solution to this problem so far, so please let me know if you think of something ingenious.

Temperature compensation

The ADXL202 accelerometer chip is sensitive to temperature, and so the instrument must be calibrated to give accurate results. This involves taking a pair of measurements at a high temperature, and a pair at a lower temperature. (In the airing cupboard and in the fridge, maybe.) The actual temperature does not need to be known, but the unit should be given plenty of time to temperature stabilize.

For the first measurement, at each temperature, the unit is pointed vertically up. This subjects it to a -1g acceleration due to gravity. For the second measurement it is pointed vertically down and experiences a +1g acceleration. The difference between the obtained readings is therefore caused by a known 2g change in acceleration. These values are then stored in the device and used to calculate the correct calibration values for any other temperatures, including temperatures outside of range of the two calibration temperatures.

Before a calibration can be performed, a jumper is used to short out the 2-pin connector on the bottom left corner of the circuit board. This applies power continuously to the circuit. Having fitted the jumper, put the lid back on the instrument case (just hold it with a rubber band, to save putting the screws back in). The lid will keep the internal temperature more stable during the actual calibration.

Hot and cold calibrations are performed independently, and either can be done first.

On fitting the battery the device will power up, and enter a calibration routine with prompts presented on the display. Following these prompts will result in the unit being calibrated at the two temperatures and also provide the opportunity to enter an offset to correct for mechanical misalignment between the laser pointer and the accelerometer.

When calibration is complete, the jumper link on the circuit board should be removed, and parked on just one pin. The unit now cannot enter calibration accidentally. The instrument is now ready to use and shouldn't require frequent calibrations - however, periodic checks of accuracy are advised.

Method of use

When in normal use, with the jumper link removed, the battery is effectively disconnected from the circuitry, until the button is pressed. The laser will now be turned on, and the display will show the continuously updating angle from horizontal. When the laser beam is pointing at the target survey station, hold the unit as steady as possible, count to 3 (to allow for settling), and push the button gently. The laser will turn off, and the angle when the button was pressed, will be held on the display, which will flicker gently to indicate a held reading. The display automatically inverts when the unit is inverted to allow easy reading.

After recording the value in the log book, another press of the button will disconnect the battery again. In this way battery life should be maximised. In use, the output voltage of the 9V battery will slowly decrease. A 5V regulator ensures that the voltage supply for the accelerometer remains constant.

When the battery voltage drops to 7.5V, the bottom left hand segment of the display will flash. The unit is still usable, but this is a warning that the battery will soon run out. When the battery voltage drops to about 7V, it is close to the point at which the regulator can no longer maintain a 5V output. This is sensed by the PIC, and the display will read "FLAT". The unit cannot then be used until a replacement battery is fitted.

Practical benefits

The prototype inclinometer that preceded the InclinomETer Version 2.0 has been in regular use by SWCC members since 2002, and the new instrument has been available since March 2007. The surveying projects for which the instruments have been used include the OFD survey, and also some very low passages in the old firestone mines in East Surrey. In the latter case, the passages in question have been dug out over backfill, so steep legs are commonplace when a roof fall is encountered. Particular advantages that have been identified over conventional sighting inclinometers include the following:

- It can be held on or next to the survey station, with the laser pointing to the next station. This eliminates the need to look through the inclinometer in an awkward position, which can be a source of error, and also the inconvenience of lighting the instrument from the side. The optical compass is not as critical on position, as one "merely" has to line up the two survey points, the vertical distance above or below them not being relevant.

- When the button is pressed the inclinometer displays the elevation in an easy-to-read way complete with plus or minus, so eliminating the problems of reading the wrong scale or mistaking the mark either side of ten as nine or eleven depending on whether it is pointing up or down.
- The locking of the reading and easy to see figures makes it very quick to use and gives great confidence in the quality of the data.
- It is more accurate, reading to point one of a degree. A loop closure error of only 70 cm on a loop of 860 metres has been reported, and vertical loop closure errors well below 1% are consistently achieved.
- By making the surveying much easier, the amount that can be covered in one session is increased by it both being quicker and less tiring, particularly where the passages are awkward. Using a laser rangefinder has also improved the speed and accuracy for much the same reasons.

Overall, the electronic inclinometer has proved to be very popular amongst SWCC surveyors, and the development of a combined compass and inclinometer is awaited with anticipation.

Conclusions

The electronic inclinometer described in this article has been in development for a number of years. This article has focussed on some recent refinements to the design. Electronic instruments offer a number of advantages over traditional instruments in the cave environment. This inclinometer has seen extensive underground use over a period of years and has proved to be robust.

Acknowledgments

My thanks go to my friends who have helped me with this project, particularly Trevor Woolvin who helped both with the circuit design and software, and built my PIC programmer. Also Frank Vine for the use of his amazing homemade CNC PCB drilling machine. Brian Clipstone and Graham Christian provided testimonials on the performance of the inclinometer underground.

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Rapid and solo surveys of short caves

Trevor Faulkner

The south Nordland area of Norway has many short caves, often found in remote locations scattered over a wide area. In this article, Trevor Faulkner advocates the adoption of rapid surveying techniques sufficient to achieve BCRA Grade 3 to facilitate the documentation of these caves.

Introduction

The principles of cave surveying were described by Ellis (1976) [1], who proposed BCRA Grade 5 as the normal standard. However, this can be inconvenient during cave exploration with a small team, or with inexperience, shortage of time, inadequate instruments, or the discovery of many short caves, as is the case in south Nordland, Norway. This area contains some 661 scattered marble stripe karst outcrops and has over 728 well-recorded caves that reach a maximum length of 1.9km and a maximum depth of 180m [2]. However, the mean length is only 80m and the mean depth is only 9.0m, so that the temptation after walking a long way to discover only a relatively short cave is to explore the cave without surveying it. This article proposes that, rather than to leave the cave unsurveyed, perhaps for a long time, it may be better to make a rapid “approximate” Grade 3 magnetic survey during original exploration before returning to base camp. Such a survey may then be used quite adequately to identify special features about the cave and its development.

Rapid surveying

Rapid techniques were introduced by Paddy O’Reilly in the inspirational surveying of 25km of passages in OFD 2/3 in South Wales within two years [3]. They allow caves to be surveyed by three, two or even one person at a rate over 10 stations per hour, which is twice the normal Grade 5 rate in the author’s experience, so that up to 1km can be surveyed per day, even in small passages. It is most efficient to “survey into unexplored passage”, but surveying might be delayed until the start of the return to the entrance. The best team size is three: the main surveyor, who makes all the notes and will eventually publish the completed survey, an assistant who decides on the best position for the next survey station (Figure 1), and an explorer who decides where to go at passage junctions.



Figure 1: The surveyor’s assistant identifies the next forward survey station in Marimyntgrotta, Norway. [Photo by Alan Marshall]

Instead of sighting to a lamp at the next (forward) survey station through the eyepiece of an expensive compass, the reading of the magnetic bearing is combined with that of measuring the distance between the two stations. This is achieved by aligning a simple orienteering compass horizontally along the tight tape measure and rotating the bezel until the magnetic north coincides with 0°, when viewed from above. The bearing is then “fixed” on the compass and can be written down with the distance (perhaps measured to 2° and 5cm respectively) without being forgotten. The time-consuming sighting with a clinometer (which is mandatory for Grade 5) is completely avoided, by the surveyor and his assistant each estimating the vertical range (VR) between the two stations when the tape is still tight and agreeing the result to the nearest 0.1m. The data and sketches (including key cross-sections) are carefully entered into a cave survey note book that should be waterproof and that must be prepared in advance, to speed up the work underground and to ensure that no readings are missed (Figure 2). Stations are not permanently marked, to avoid cave disfigurement, but should be chosen as prominent cave features or as cairns. They should be easily relocated from the sketches and from the Left, Right, Up, Down (L, R, U, D) estimates if the survey is continued later from the same point. It is often important to correlate surface and underground features, and a similar rapid technique can be used to create local surface surveys.

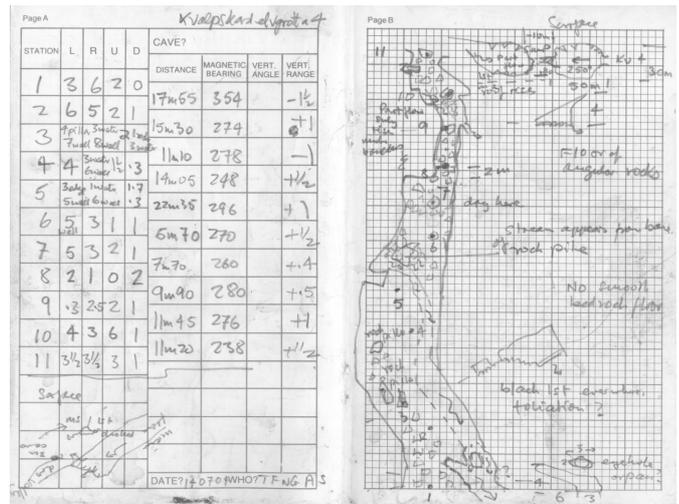


Figure 2: Survey data entered into the survey notebook.

Solo surveying

Very occasionally, a single person may locate a new or unsurveyed cave during field work, and the rapid technique can be adapted to solo surveying. The solo surveyor then combines the three roles described above. The first station is identified (perhaps under the drip-line at the centre of the entrance) and the loose end of the tape measure is held in this position under a stone. The surveyor then walks (or crawls!) forward to the second station, estimates the VR, measures the distance and then measures the bearing as before, except that this is treated later as a back-bearing. For consistency, cross-section sketches are also best viewed “backward”. The tape is then pulled away from the stone and the process repeated. Although solo surveying and solo caving are not recommended, if there is no alternative, three good lights should be carried, and a “no risks” policy adopted.

Calculations

The minimalist approach can also be extended to the calculation and drawing processes. It is easy to design a standard three-part spreadsheet that records information about the cave and the surveyors in the first part, tabulates the original measurements in the second part and calculates station coordinates from Pythagoras and simple trigonometric functions in the third part (e.g. as described by Gibson, 2002 [4]). The total leg length is calculated from the sum of the original distance measurements, to which can be added manually any extra unsurveyed side passages and oxbows from the sketches (less any duplications), to create the total cave length. It has been a convention in British surveys of Norwegian caves that this total cave length includes the heights of all avens and the depths of all shafts. The vertical range of the cave is calculated by subtracting the height of the floor below the lowest station from the height of the roof above the highest station, again with any necessary manual adjustments. An example spreadsheet for a short cave is shown in Figure 5 (overleaf). It is visually convenient to include the calculated grid or true north bearing (calculated from the magnetic bearing and the local magnetic deviation) and the plan distance for each leg in the second part of the spreadsheet, and the original L, R, U, D measurements in the third part. The approximate volume of the passage between two survey stations = distance \times (L+R) \times (U+D) and this is also included for each leg in the second part. The total cave volume is then estimated as the sum of these leg volumes. The mean cross-sectional area of the cave passages = total volume / total leg length. This extra information may be useful when comparing caves and when considering their speleogenesis.

Drawing

When drawing up the survey, the spreadsheet chart facility can be used to plot the station positions for plan and elevation, to decide final scales and orientations, and even to plot the grid for a final (manual) drawing, which rarely needs to be larger than A4 size. Figure 3 is an example of "work in progress" prior to final decisions about a published survey. This treatment is less ambitious than that of Gibson (2002) [4]. In the author's opinion, a cave survey should always include both a plan view and an elevation (even if the elevation is very simple), because the necessary data should always be available from the notebook and the derived information greatly assists understanding the cave relative to its local geology, topography and hydrology.

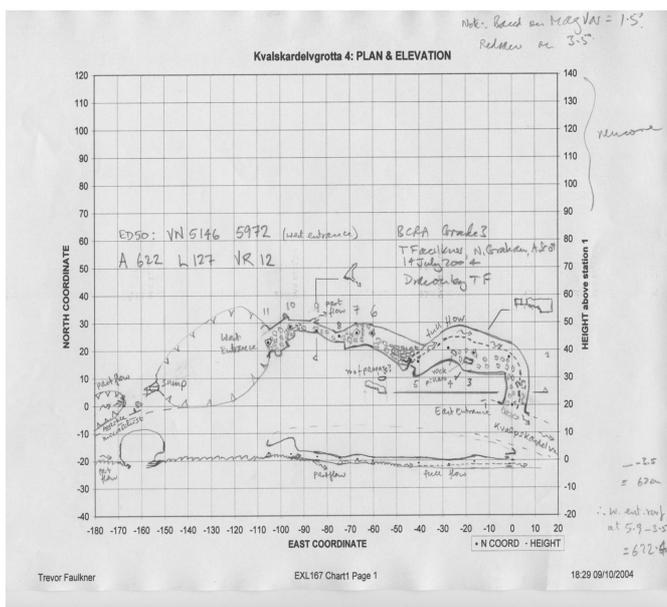


Figure 3: A partially-completed survey of a short cave produced by rapid techniques.

Conclusions

The "rapid" technique ensures that the surveyor keeps control at all stages of data collection and processing, whilst placing the original data in a digital format that is archivable, easy to amend and easy to debug by visual inspection. The use of a simple spreadsheet in cave surveying avoids reliance on complex software, about which the surveyor may have limited knowledge and expertise and which may be too "facility rich" for a short cave. The spreadsheet presentation format chosen by the surveyor is easily transferable to his next cave survey by retaining the formulae whilst nullifying the raw data and starting again. The final output commonly achieves a horizontal misclosure of 1-2%. If large and/or gross errors arise, these can commonly be removed by manual intervention without using complex error distribution algorithms. Because the VRs rely on human estimates, the initial elevation accuracy could be the weakest part of the survey. However, this might be improved by subsequent revision of the original VR data from observations of water levels and flows and from altimeter and/or GPS readings at entrances. In the author's experience, the published A4 drawing may be indistinguishable from one produced by more elaborate procedures.

So far, ~21km of passage in over 88 caves up to 1.9km in length and commonly >100m long have been surveyed to "Rapid Grade 3" standards in south Nordland, in 17 expeditions of 3-weeks duration with a typical team size of four people, and the author has completed five solo surveys. We should spread the message further that cave surveying is an easy process and, as well as being a duty of explorers fortunate enough to find new caves, it is fun and fast to do (with a little practice), often leads to extra passages being found, and can be combined with rapid photography, even by the surveyor himself, by using a disposable camera in small passages (Figure 4).



Figure 4: Surveying in a small passage in Marimyntgrotta.

This article is based on presentations given at the 2007 BCRA Cave Technology Symposium and at the Baltic Speleological Congress in Visby, Gotland, Sweden on 15 August 2007.

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CAVE SURVEY SPREADSHEET

VERTICAL RANGES USED (ESTIMATED)

DIMENSIONS IN METRES

CAVE	Kvalskardelvgrotta 4		
LOCATION / KOMMUNE	Susendal / Hattfjelldal		
COORDS	VN 5146 5972	(West entrance)	(ED50)
ALTITUDE	622m	(West entrance)	
1:50000 MAP	Susendalen		
BCRA GRADE	3		
DATE	14 July 2004		
SURVEYERS	Trevor Faulkner, Nigel Graham, Adrian Scott		
MAGNETIC VARIATION (DEGREES EAST OF GRID NORTH)	3.5		

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ORIGINAL MEASUREMENTS:

FIRST STATION	SECOND STATION	DISTANCE APART	MAGNETIC BEARING	VERTICAL RANGE	GRID BEARING	PLAN DISTANCE	LEG VOLUME
1	2	17.55	354.0	-1.5	357.5	17.49	315.9
2	3	15.30	274.0	1.0	277.5	15.27	504.9
3	4	11.10	278.0	-1.0	281.5	11.05	832.5
4	5	14.05	248.0	0.5	251.5	14.04	252.9
5	6	22.35	296.0	1.0	299.5	22.33	491.7
6	7	6.70	270.0	0.5	273.5	6.68	107.2
7	8	7.70	260.0	0.4	263.5	7.69	184.8
8	9	9.90	280.0	0.5	283.5	9.89	59.4
9	10	11.45	276.0	1.0	279.5	11.41	96.2
10	11	11.20	238.0	0.5	241.5	11.19	548.8

TOTAL LEG LENGTH 127.30 (Sum of legs)

APPROX. TOTAL VOLUME

3394.3

STATION NUMBER	N COORD	E COORD	HEIGHT above station 1	LEFT	RIGHT	UP	DOWN	CUM. PLAN DISTANCE	CUM. VOLUME
1	0.0	0.0	0.0	3.0	6.0	2.0	0.0	0.00	0.0
2	17.5	-0.8	-1.5	6.0	5.0	2.0	1.0	17.49	315.9
3	19.5	-15.9	-0.5	7.0	8.0	2.0	3.0	32.75	820.8
4	21.7	-26.7	-1.5	4.0	6.0	1.5	0.3	43.81	1653.3
5	17.2	-40.0	-1.0	5.0	6.0	1.7	0.3	57.85	1906.2
6	28.2	-59.5	0.0	5.0	3.0	1.0	1.0	80.18	2397.9
7	28.6	-66.1	0.5	5.0	3.0	2.0	1.0	86.86	2505.1
8	27.7	-73.8	0.9	2.0	1.0	0.0	2.0	94.55	2689.9
9	30.1	-83.4	1.4	0.3	2.5	2.0	1.0	104.43	2749.3
10	31.9	-94.7	2.4	4.0	3.0	6.0	1.0	115.84	2845.5
11	26.6	-104.5	2.9	3.5	3.5	3.0	1.0	127.03	3394.3

bold Start of new survey run

HIGHEST STATION 2.9 :STATION 11
 LOWEST STATION -1.5 :STATIONS 2,4

APPROX. MEAN CROSS SECTION 26.7

VERTICAL RANGE 4.4
 Extra at 10 5.5
 Extra at 3 2.0

CAVE VERTICAL RANGE 11.9

TOTAL LEG LENGTH 127.3

TOTAL CAVE LENGTH 127.3

Figure 5: A survey spreadsheet for a short cave.