

# Compass & Tape

Volume 15 Number 3 Issue 51



Newsletter of the Survey and Cartography Section of the  
National Speleological Society

## Survey and Cartography Section



**The Survey and Cartography Section (SACS)** is an internal organization of the NSS that is devoted to improving the state of cave documentation and survey, cave data archiving and management, and of all forms of cave cartography.

**Membership:** Membership in the Section is open to anyone who is interested in surveying and documenting caves, management and archiving of cave data and in all forms of cave cartography. Membership in the National Speleological Society is not required.

**Dues:** Dues are \$4.00 per year and includes four issues of *Compass & Tape*. Four issues of the section publication are scheduled to be published annually. However, if there are fewer, then all memberships will be extended to ensure that four issues are received. Dues can be paid in advance for up to 3 years (\$12.00). Checks should be made payable to "SACS" and sent to the Treasurer.

**Compass & Tape:** This is the Section's quarterly publication and is mailed to all members. It is scheduled to be published on a quarterly basis, but if insufficient material is available for an issue, the quarterly schedule may not be met. *Compass & Tape* includes articles covering a wide range of topics, including equipment reviews, techniques, computer processing, mapping standards, artistic techniques, all forms of cave cartography and publications of interest and appropriate material reprinted from national and international publications. It is the primary medium for conveying information and ideas within the U.S. cave mapping community. All members are strongly encouraged to contribute material and to comment on published material. Items for publication should be submitted to the Editor.

**NSS Convention Session:** SACS sponsors a Survey and Cartography session at each NSS Convention. Papers are presented on a variety of topics of interest to the cave mapper and cartographer. Everyone is welcome and encouraged to present a paper at the convention. Contact the Vice Chair for additional information about presenting a paper.

**Annual Section Meeting:** The Section holds its only formal meeting each year at the NSS Convention. Section business, including election of officers, is done at the meeting.

**Back Issues:** SACS started in 1983 and copies of back issues of *Compass & Tape* are available. The cost is \$1.00 each for 1-2 back issues, \$0.75 each for 3-6 back issues and \$.50 each for more than six back issues at a time. Back issues can be ordered from the Treasurer.

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## INSIDE

### Ultrasonic Cave Mapping

by W.I. Sellers and A. T. Chamberlain.....4

### Canvas Map Makers Guide

by Paul Burger.....12

### The Transit Survey Myth

reprinted from *Compass & Tape*, Vol. 5, No. 1

by Bill Mixon.....18

**ISSN: 1074-596**

**Front Cover:** Graphic by Linda Heslop

**Back Cover:** Kijahe Xontjoa, map generated by  
Toporobot for  
Projecto Cerro Rabon, Mexico

Published in **May 2002** by the Survey and  
Cartography Section of the National Speleological  
Society.

Publishing Editor: Patricia Kambesis  
Circulation Editor & Printing: Bob Hoke

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### SUBMISSIONS

All types of materials related to cave survey and survey data, cartography, and cave documentation in general, are welcome for publication in *Compass & Tape*. Manuscripts are accepted in ANY form but are most welcome on 3.5 inch diskettes either IBM compatible or Mac format or via email. Typed material is next best although we will accept handwritten material as long as it is legible. Artwork is any form. shape or size is also welcome. Send all submission for *Compass & Tape* to:

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# Ultrasonic Cave Mapping

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## Abstract

Surveying the internal structure of a cave is an important part of any archaeological or palaeontological investigation of a cave locality. However, using standard topographical surveying techniques is often difficult due both to the irregular nature of the structure and to the difficult working conditions. This study uses a novel method based on ultrasound reflections to produce an accurate 3D model of Kitley Shelter Cave, an archaeological cave in Yealmpton, Devon. This model enables the cave system to be visualised leading to a better understanding of the site and its taphonomy.

## Introduction

### Cave surveying techniques

Caves are generally either surveyed in a topological fashion recording the bearing, inclination and length of the passages or more exhaustively using standard interior surveying techniques to record the positions of the walls of the passages [Worthington 1987, Ellis 1988]. Neither of these options are ideal for use in palaeontological research [Hunt et al. 1987, Grady 1994]. The first option does not allow a comprehensive visual impression of the cave to be recorded, while the latter approach is time-consuming and may encounter difficulties due to access problems and the prevalence of ill-defined, curved surfaces which are difficult to specify precisely without fixing a number of artificial marker points to surfaces. However, with time and care these difficulties can be overcome and there are excellent surveys of archaeological caves - for

example, the survey of Kent's Cavern in Devon (Proctor & Smart 1989).

The automated scanning system described in this paper can get around many of these problems. It is reasonably quick and it produces profiles of the passageway at known distances into the cave system. This approach allows a full and accurate 3D reconstruction for later visualisation.

There are a number of computer packages to help cave surveying. These are mainly designed for topological surveys and help with loop closure and error distribution. Some also have 3D visualisation features, although these are generally for displaying survey line data rather than passage reconstructions based on sections (for a review see Wookey 1994).

### Ultrasound scanning

A number of options are available for automatically calculating the distance of an object from a point [Gibson 1996]. The most accurate systems use electromagnetic radiation (either radar or laser sources). Laser sources are highly dependent on the precise reflective properties of the target object and are unsuitable when used on rough, bare rock surfaces. Radar is considerably better, but suitable equipment is neither cheap nor easily portable. Sound waves are a suitable alternative for range finding where exact precision is not required [Gibson 1991a]. Ultrasound transducers are relatively inexpensive, and usually, ultrasound beams reflect well off rock surfaces. The lack of precision is due to the difficulty in obtaining a narrow ultrasound beam and the problem of shaping a precisely defined sound pulse.

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## Survey Site

The Kitley caves are located in Devonian limestone at Western Torrs Quarry in Yealmpton, South Devon (National Grid Reference SX 57505125). The quarry, now abandoned, is located in the side of a natural limestone bluff which overlooks a narrow steep-sided valley formed by the river Yealm. An extensive cave system, the Kitley Show Caves, is open to the public but many more caves and fissures penetrate the limestone on both sides of the river Yealm, including the Kitley Shelter Cave which is the subject of the present study.

Kitley Shelter Cave is located at a high level within the limestone outcrop, and prior to archaeological excavation the cave was partially filled with cave breccias, flowstones and unconsolidated cave sediments. Since 1994 an archaeological research project, led by the University of Sheffield and the University of Wales Lampeter, has investigated the archaeological and palaeontological remains in Shelter Cave. During the research excavations the locations of archaeological finds and faunal remains have been recorded using local reference datums consisting of bolts drilled into the cave roof. It was realised that an accurate survey of the accessible part of the cave was desirable in order to gain a visual impression of the cave and to determine the spatial relationships between finds in different parts of the cave system.

## Materials and Methods

The basic approach used for the survey system is a rotating ultrasound emitter mounted so that the beam scans the walls of the cave in a vertical plane. The system is able to calculate the distance of the wall from the emitter at any point in this sweep and so is able to calculate the profile of the cave in the scanning plane. By moving the emitter through the cave system a set of profiles is built up as a stack of slices. These slices can then be reassembled in a CAD program to reconstruct the 3D shape of the cave system.

## Schematic diagram of the system

The ultrasonic scanner consists of an ultrasound emitter and receiver mounted on the spindle of

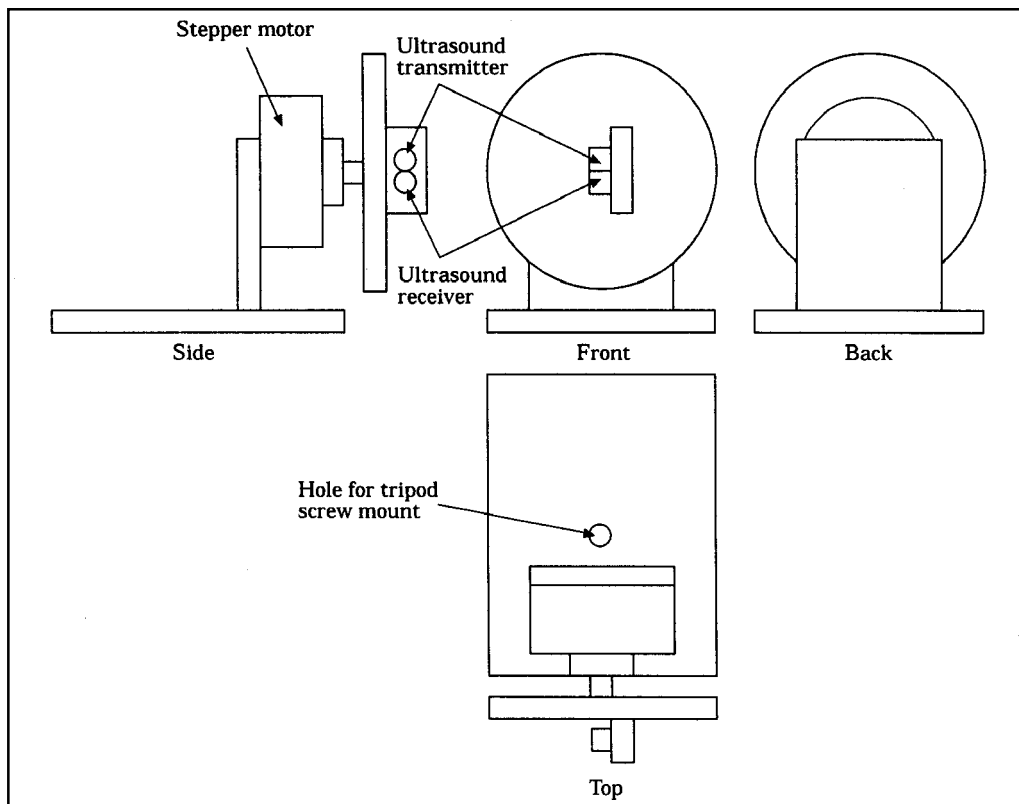
a stepper motor. The stepper motor and the ultrasound transmitter are controlled via a laptop computer which also reads the signal picked up by the ultrasound receiver. The emitter sends out a pulse of ultrasound and the echo is picked up by the receiver. The time taken for the echo to arrive depends on the distance from the transmitter to a solid object such as the wall of the cave. The stepper motor then rotates the transmitter and receiver through  $7.5^\circ$  and the process is repeated. A complete circular scan is built up in very much the same way as radar with the computer storing the ultrasound echo at each of the 48 scan orientations and then plotting them on the screen as a radial map. Figure 1 shows a diagram of the mechanical aspects of the system. Figure 2 shows a schematic of the electronics. Full plans, including printed circuit board designs, can be obtained from the authors.

## Description of the process

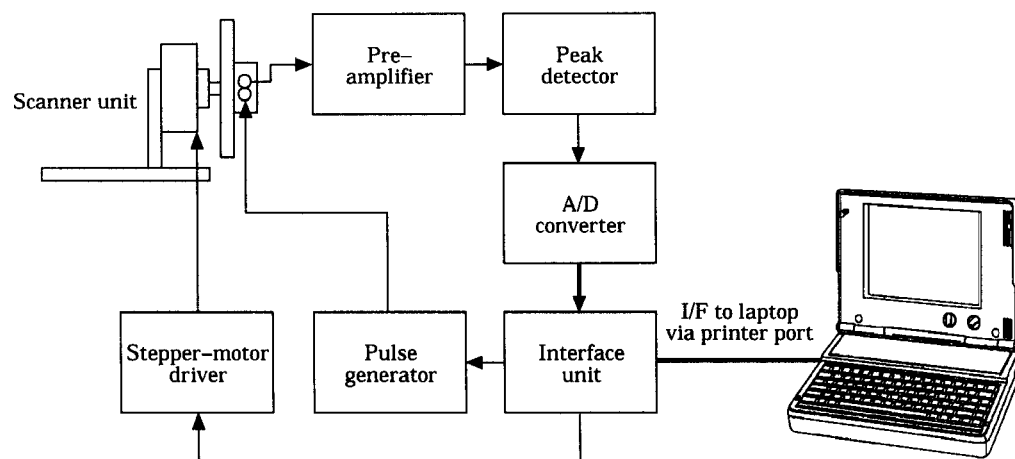
The scanner produces a radial scan perpendicular to the axis of the stepper motor. To produce an accurate 3D reconstruction both the position and orientation of the axis needs to be known. To map a cave system, a zero point at the entrance is first defined using standard surveying techniques. Then a series of secondary markers are set up at convenient places within the cave and surveyed by measuring their distance, bearing and inclination from each other and from the zero point as convenient.

The scanner unit is then moved through the cave. It is set up at convenient points at approximately 0.5m intervals and the bearing and inclination of the spindle recorded. In this particular case, the spindle was always held horizontal, though there is no particular requirement to do this. The position of the spindle was defined by the distance, bearing and inclination from one of the previously surveyed markers.

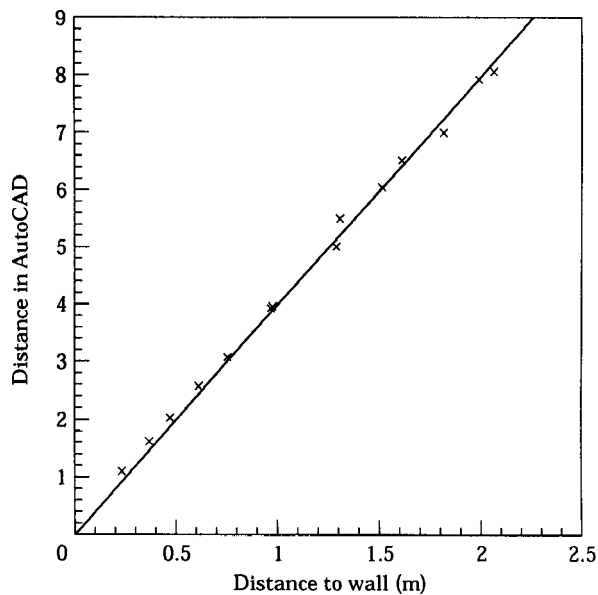
Once the six degrees of freedom of the centre of the scan have been defined, the scanning process is automatic and takes about a minute. The actual time taken to complete a single scan depends on the number of echo traces taken for each segment (repeated echoes are software integrated to improve the signal to noise ratio). The scan can be displayed immedi-



**Figure 1.** The design of the scanning head. An ultrasound transmitter and receiver are mounted on the spindle of a stepper motor. This allows a pulse of ultrasound to be directed radially and the echo signal recorded at  $7.5^\circ$  intervals.



**Figure 2.** Schematic diagram of the data capture system. The computer program controls the position of the stepper motor and sends out ultrasound pulses in known directions. The echo signal is recorded for each ultrasonic pulse and used to build up an image of the cave walls.



**Graph 1:** The relationship between scans of known distances and the distances in arbitrary AutoCAD units after tracing. The equation of the best fit straight line through the points is  $y = 4.020 x$  with  $r^2 = 0.9976$ . This relationship was then used to calibrate subsequent measurements.

ately on the computer screen allowing visual confirmation that a useful image has been obtained.

The resolution of the system is independent of the distance to the reflecting surface and is currently approximately a distance of 5cm with an angular resolution of  $10^\circ$  (see Graph 1 and Figures 4 and 5). The latter value is constrained by the beam width of the ultrasound transducer and the former value by the difficulties in precisely defining the edge of the pulse. Reducing the transmitter beam width will reduce both these values as would improved software. There are, however, constraints on size and portability of the equipment that mean that a realistic limit to the precision of this approach would be an arc of  $1^\circ$  and a distance of 1cm. The maximum measurable distance depends on the ambient noise level and the sound reflection properties of the cave, but preliminary test showed that the prototype could identify echos from walls more than 10m away in ideal conditions.

## Data processing/software

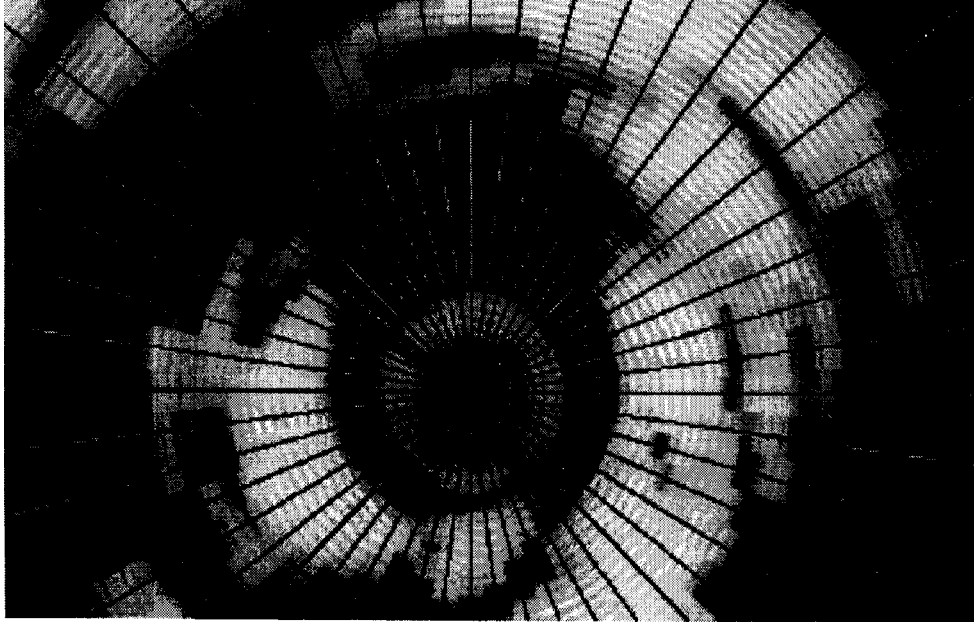
The software can be divided into two parts: data capture and data analysis. The data capture software is responsible for controlling the scanner and storing the ultrasound echo data. Echo digitisation occurs in real time, so parts of the software had to be written in machine code to maximise the data throughput. This results in the digitisation speed being dependent on the actual running speed of the host computer and therefore the device needs to be calibrated by recording several scans at known distances from a solid object. In this case, this was done by arranging the scanner at known distances from the wall of a house. Graph 1 shows the results of this calibration exercise.

The data analysis stage takes the raw data files from the data capture program and ultimately produces an accurate 3D CAD model of the cave. This is presently a fairly time consuming process, but there is potential for several of the stages to be automated.

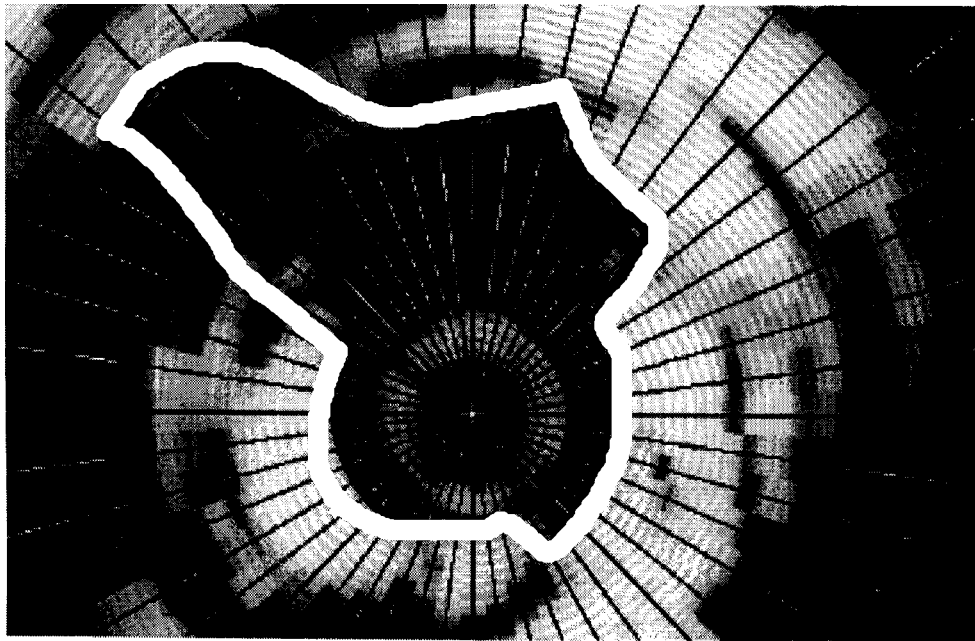
Firstly, the radial scans are converted into a standard rectangular coordinate based TIFF picture file. This is then read into the graphics package Canvas [Canvas, Deneba Software 1993] which handles both bitmap and object based drawing. The central point is then marked and the outline of the cave is drawn by hand as an overlay. A set of 48 radial lines are used as a drawing aid. These hand drawn vectors are then saved as a DXF (data exchange format) file that can be read by AutoCAD [AutoCAD, Autodesk Inc. 1996].

In AutoCAD, the vector outline is scaled using the factor calculated from the calibration experiments and then rotated and translated so that the position and orientation of the axis of the scan matches that recorded from the cave. Each separate scan outline is converted to its original cave coordinates and can be imported into a single 3D AutoCAD file.

The outlines can then be used as surface boundaries which are spanned by surfaces to "skin" the wire-frame structure, producing a 3D surface model of the cave.



**Figure 4.** The raw output from the scanner program. The diagram should be interpreted in very much the same way as a radar. The distance from the centre represents the echo time, and the brightness of the shading represents the strength of the reflected signal. The superimposed 48 point star indicates the centre of the beam.



**Figure 5.** The raw output overlaid with a trace representing the estimated position of the wall of the cave. This is generally the first large reflection signal.



## Results

### Plan of Shelter Cave

Figure 6 shows the plan of Kitley Shelter Cave obtained using standard surveying techniques. The section of the cave surveyed by ultrasound scanning is indicated.

### Sample cross-section scan

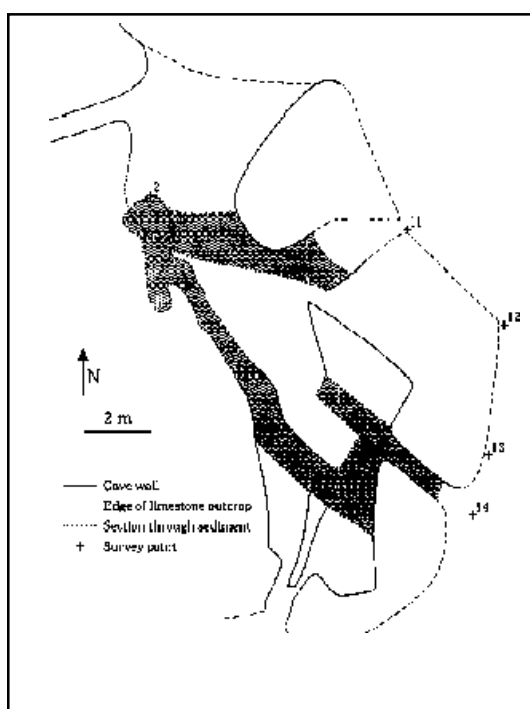
Figures 4 and 5 show how the cross-sectional profile is built up. Figure 4 shows the raw data from the scanner, superimposed onto a 48 point star so that the beam centre can be clearly identified for each of the scans. Figure 5 shows how the cave walls are identified on this “radar” picture and drawn on as an overlay. Note, on figure 5, the wall at the 10 o'clock position is poorly defined, and there is some interpretation “by eye”.

### Assembled traces

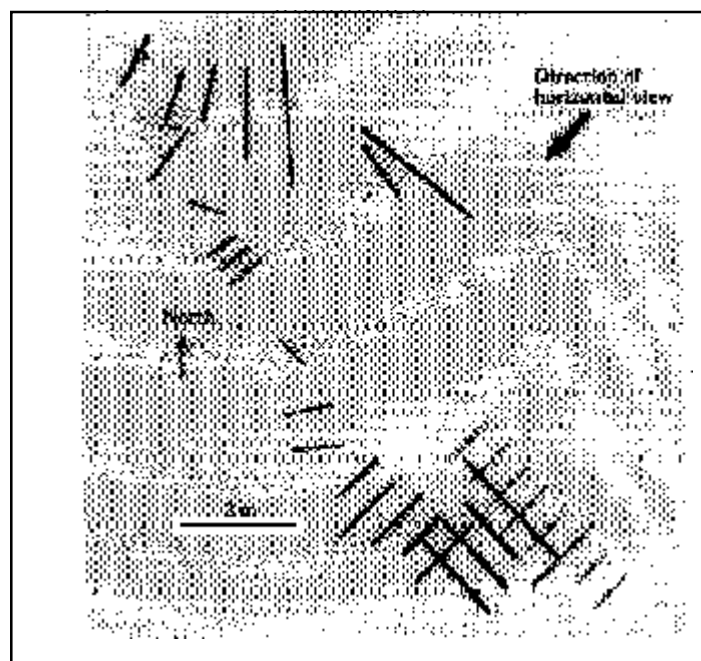
Each profile is recorded along with the surveyed position and direction of the stepper motor axis. This defines the position of the centre of the scan and the orientation. The scale information is obtained from the calibration curve. This information is used to shift, scale and orient the profiles in AutoCAD. Figures 6 and 7 show the correctly oriented scans. Once the profiles are oriented, the wire frame model can be converted into a surface model - a process known as “skinning”. This produces a realistic looking 3D rendered model of the cave system that can be viewed from any particular orientation (figure 8), and with the right software, can even be walked through.

### Discussion

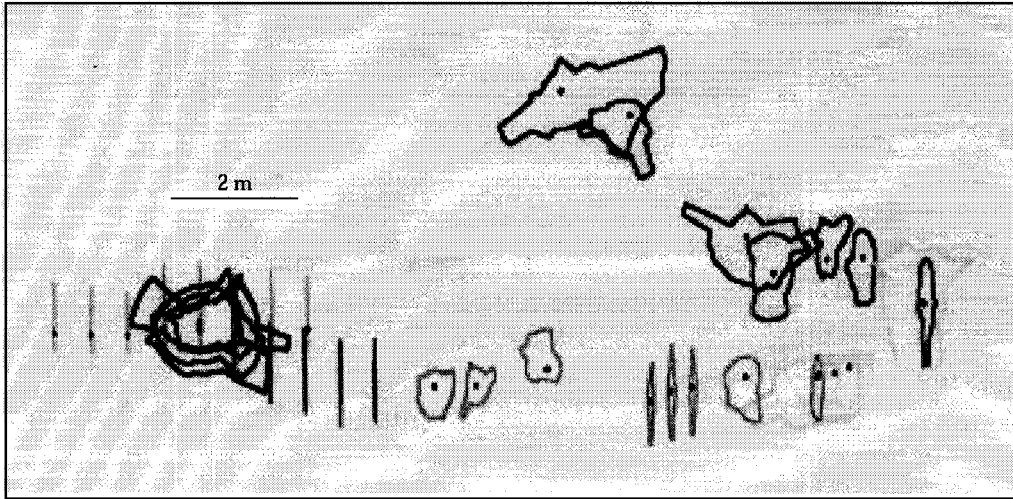
As mentioned before, accurate surveying is a vital part of palaeontology. The ultrasound scanning technique presented here allows accurate surveying and visualisation to be performed in restricted spaces relatively quickly.



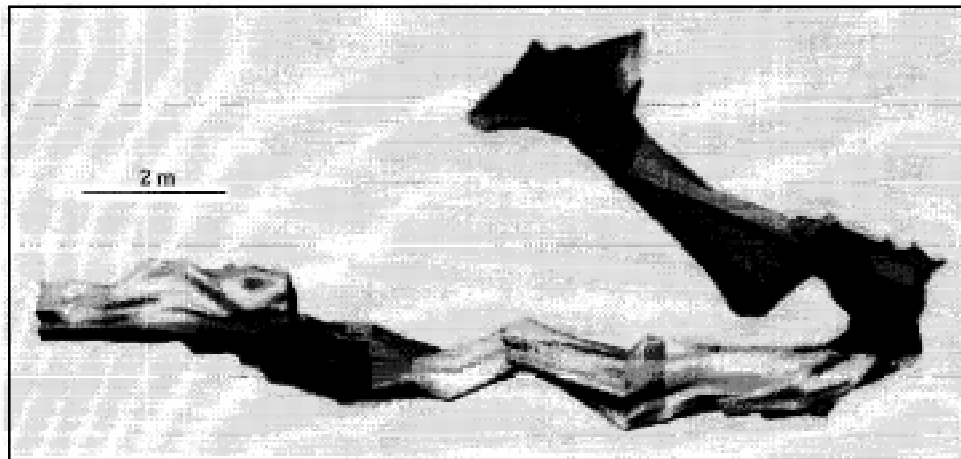
**Figure 6** Plan of Kitley Shelter Cave obtained by traditional surveying means. Stipple indicates the parts of the cave surveyed with the ultrasound scanner.



**Figure 7.** Plan view of the set of vertical profiles correctly scaled and oriented in AutoCAD. The arrow shows the direction of the horizontal view in Figures 8 and 9.



**Figure 8.** This figure shows an elevation of the profiles viewed from the direction indicated by the arrow in figure 7. The change in altitude at locations from within the cave is apparent.



**Figure 9.** Fully rendered 3D representation of Kitley Shelter Cave obtained by “skinning” the vertical profiles. Direction of view as in Figure 8.

The visual display of the surface of the cave system (figure 8) is a useful aid in the interpretation of the geomorphological and taphonomic processes that may have influenced the movement and deposition of sediments, fauna and artefacts within the cave. The 3-D model provides information about the directions and gradients of the segments of cave passage, the maximum volumes of sediments that can be contained within the cave, and the locations of points of constriction where movements of large clasts may have been ob-

structed. Given appropriate fluid dynamic modelling software, the 3-D model could also be used to simulate sediment flow within the cave. In addition, at Kitley Shelter Cave the locations of finds and sections through the cave sediments were recorded by measuring their coordinates along three orthogonal axes relative to datum points fixed to the roof of the cave. These locational data can be incorporated easily into the AutoCAD model of the cave to allow the display of the position of the finds within the cave system.

The surface of the cave wall could have been recorded in a similar fashion to the individual finds (i.e. manually, using measurements from datum points in the x, y and z dimensions). However, this would have been extremely time consuming as it would have required 144 measurements (x, y, and z displacements for each of the 48 radial positions) for each profile of the cave wall recorded to achieve the same density of information as the ultrasound scan. The time required for basic data processing and manipulation is considerably higher for the scanning method, although there would be no difference if the traditional survey had the same amount of information as the ultrasound one.

The use of ultrasound in caves will disturb bats. The 40kHz transmitter used is very close to the echolocating signal of brown long-eared, Daubenton's, whiskered, Brandt's and pipistrelle bats (genera *Plecotus*, *Myotis* and *Pipistrellus*). However, any human activity in a cave will disturb bats and cave surveying in general should not be undertaken during sensitive times of the year such as the hibernation period (personal communication K. Jones, Roehampton Institute).

There are two areas where improvements could be made in the prototype scanning system. Firstly, the main cause of inaccuracy in ultrasonic surveying is due to the width of the ultrasound beam. This can be ameliorated by either using a narrower beam [Gibson 1991b], or by using an array of receivers rather than just a single one so that different parts of the beam can be resolved. This requires considerably more sophisticated equipment, but is in principle achievable by increasing the cost of the unit and by improving the data capture hardware and software [Altes 1995]. Similarly, using wideband sonar techniques can also allow improved spatial resolution [Wehner 1987]. The second area for improvement is the reconstruction software. Currently, much of the processing of the scan image needs to be done by hand and could be automated using image recognition style algorithms. Image recognition is notoriously unreliable, but the problem in this case is quite well circumscribed and the position of the first large echo could be automatically detected to automate the identification of the position of the reflecting surface.

In conclusion, the results obtained from this relatively cheap system are very encouraging as they provide accurate 3D models of the complex geometry of a cave system in a comparatively short space of time.

## Acknowledgments

We would like to thank John Varley and David Ross at the Centre for Human Biology, University of Leeds for their help in constructing the prototype. Research at Kitley Caves has been supported by the British Academy. The assistance of John Wright and the landowner, Michael Bastard, is gratefully acknowledged.

## References

- Altes RA. Signal processing for target recognition in biosonar. *Neural Networks*. 1995; 8:1275-1295.
- AutoCAD. 13. San Rafael, California: *AutoDesk Inc.* 1996.
- Canvas. 3.5. Miami, Florida: *Deneba Software*. 1993.
- Ellis B. An introduction to cave surveying. *BCRA Cave Studies Series No. 2*. London: BCRA. 1988.
- Gibson D. Accuracy problems in ultrasonic and light-beam rangefinders. *Journal of the BCRA Cave Radio and Electronics Group*. 1991a; 6:9.
- Gibson D. Improving directivity in ultrasonic rangefinders. *Journal of the BCRA Cave Radio and Electronics Group*. 1991b; 6:9-10.
- Gibson D. Electronics in surveying. *Journal of the BCRA Cave Radio and Electronics Group*. 1996; 23:25-26.
- Grady F. Collecting in caves. In: *Vertebrate palaeontological techniques*, Volume 1. Editors: Leiggi P, May P. Cambridge: Cambridge University Press. 1994, pp77-81.
- Hunt CO, Brooks IP, Coles GM, Jenkinson RDS. Archaeological surveying in caves. *Cave Science - Transactions British Cave Research Association*. 1987; 14(2):83-84.
- Proctor C, Smart P. A new survey of Kent's Cavern, Devon. *Proc. Univ. Bristol Spealaeol. Soc.* 1989; 18:422-428.
- Wehner DR. *High resolution radar*. Norwood: Artech. 1987.
- Wookey. Survey software. *Compass Points, BCRA*. 1994; Issue 3. <http://www.chaos.org.uk/survey/cp/CP03/CPoint03.htm>
- Worthington S. Review of cave surveying techniques. *Cave Science - Transactions British Cave Research Association*. 1987; 14(2):56-59.

# Canvas Map Makers Guide

*by Paul Burger*

## Introduction:

The purpose of this guide is to help beginning digital cartographers lay out and draw cave maps electronically. Many of the suggestions here are my personal preferences, including line weights and layer names, and can be changed to meet the needs or preferences of the cartographer. The guide assumes that the user is at least generally familiar with the Windows operating environment, Windows-based programs, and the basics of cave mapping and cartography. Some familiarity with drawing programs is helpful, but not necessary to use this guide. The guide will not teach you all of the tools available in Canvas. Use the one-line and manuals to find tricks and shortcuts for some of the more common tasks.

## Why Digital?

Digital cartography increases the flexibility of cave maps. Updating and adding new passages to digital maps is relatively easy and faster than with conventional pen-and-ink maps. Digital maps are easier to scale for multiple purposes (wall maps vs. publication maps) and are much easier to integrate into GIS, web sites, digital documents and other forms of electronic publishing. Photographs and color geology can easily be added to digital maps to present more information than conventional maps. In general, digital cave maps are more dynamic and adaptable than other types of maps.

## Drawing vs. CAD Programs

There has been a great deal of debate about what kind of programs work best for drafting cave maps. CAD systems (AutoCAD, IntelliCAD, Microstation) are great for maintaining real-world coordinate systems and are easily integrated into GIS. Drawing programs (Canvas, Illustrator, CorelDraw)

contain more freehand and image editing tools. However, the biggest advantage drawing programs have over the CAD programs is their shorter learning curve. Traditional cartographers can learn to use drawing programs much faster than trying to learn the specialized lingo and skills of technical drawing.

## Getting started

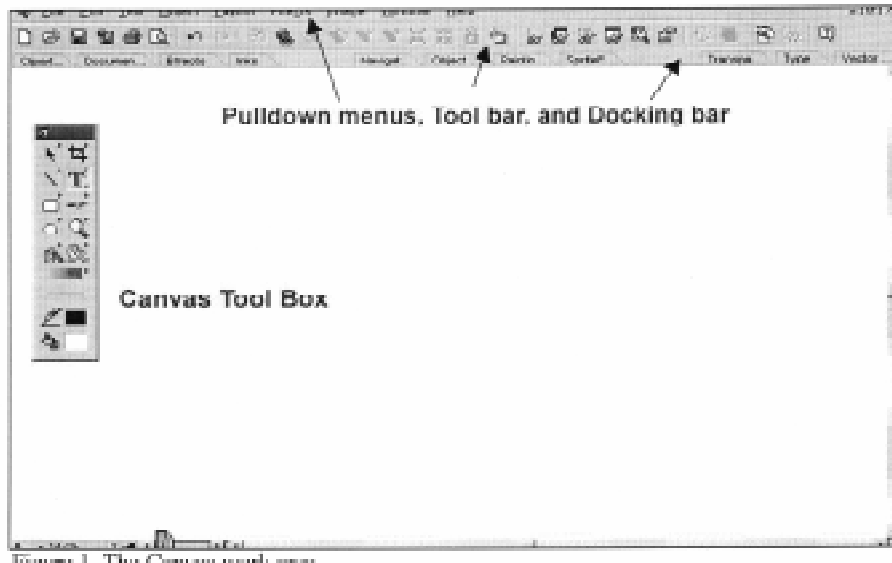
Start Canvas using the start menu. A new drawing will automatically appear in the window. If you want to continue to work on an existing drawing select **Open** from the **File** menu. A dialog box will appear so you can select a file. If you make a mistake in a drawing and want to start over, select **New** from the **File** menu. A selection box will appear with several drawing options, illustration, publication, or presentation. Select the **Illustration** option for doing cave maps.

## The Menus and toolbars

The top of the work area contains three parts, the menu bar, the toolbar, and the docking bar (Figure 1). The menu bar is a set of pulldown menus with commands and tools. The Toolbar contains buttons you can click to choose commands, tools, inks, strokes, and styles. To display the Toolbar: select **Window>Palettes>Show Toolbar**. To hide the Toolbar: select **Window>Palettes>Hide Toolbar**. The docking bar allows you to keep palettes such as the document setup palette, and macro box “docked” at the top of the screen, so you don’t have to go through the pulldowns or Tool Box to get to your most-used features.

## Document set-up and layout

To set up the blank page, go to the **Layout** menu and select **Document Setup**. A dialog box will appear that gives you the options for setting up the



**Figure 1.** The Canvas work area

drawing environment. You can choose any standard paper size by selecting it in the illustration size pulldown menu. You can also define your own map size using the custom option in the illustration size pulldown menu and then typing in the dimensions manually. These settings can be changed later without affecting your drawings if you decide you need more or less space later.

### Suggested layers

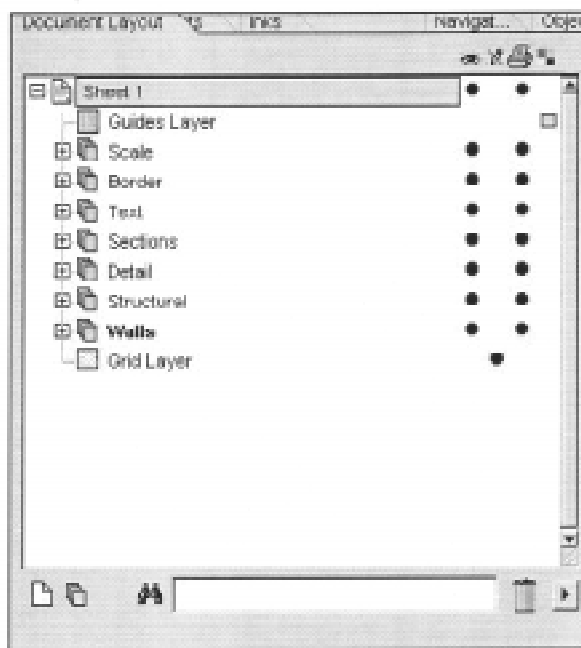
It is best to keep different types of information on different layers. This helps to avoid cluttering the screen with too much information during drawing and it helps to create different types of maps later on. To create, delete, or modify layers, go to the **Layout** menu and select **Document Layout**. The document layout palette (Figure 2) will then appear. Click the + sign next to the text that says Page 1 and the list of layers will appear. Click on the layer name (Layer 1 is the only layer in the new drawing) and then click the **New Layer** button at the bottom of the document layout box. To change the name and other parameters of a layer, double-click the layer name. Below is a table of layer names that I use and what they contain:

In general, it's best to keep the bitmap as the bottom-most layer since everything will be drawn over the bitmap. The order of the other layers is not as important and can be customized to your needs.

### Creating bitmaps

In order to create a digital cave map, you will need an original pencil drawing of the map or passage first. You can either scan in the pencil version of the map or digitize it directly from a digitizing table. The following procedures are for scanning and digitizing on-screen using the mouse.

If you are dealing with a small cave that fits on only one or two survey pages, you can just scan the original notes into the computer. For a longer cave, I suggest drafting the pencil version of the map on gridded paper first and then scanning in the pencil map. It is possible to assemble larger cave maps using scans of original notes, but that requires importing the line plot into the computer and a lot of manipulation of the notes that is currently easier by hand. It is recommended that you draft on gridded paper (mylar, velum, etc.) so that you can reassemble the map from the scanned pieces.



Name	Contains
Walls	passage walls, bedrock pillars
Structural	symbols representing changes in ceiling heights, slopes, pits, domes, dropoffs, etc
Detail	floor detail such as sand, mud, bedrock, formations, breakdown
Cross sections and ceiling heights	ceiling height circles and passage sections
Elevations	passage elevations
Stations	survey station symbols and station labels
Text	passage labels and other text items
Scale	scale and north arrow
Bimaps	the scanned and assembled bitmap of the cave or cave passage

Each scan will result in a bitmap image to be saved on disk. I generally use either the TIF or JPEG file formats since they give the best quality for the smallest file sizes. These bitmaps will be reassembled in Canvas later.

### Assembling bitmaps

Unless you have a map scanner, you will probably have to scan your pencil map into the computer in smaller pieces. If possible, try and keep the page straight in the scanner. This will speed up the process

of assembling the map in the computer. Otherwise you may have to rotate the bitmaps so that north is the same direction on each one.

Go to the **Layout** menu and select **Document Layout**. The document layout palette (Figure 2) will then appear. Click on the layer named *Bitmap* to make it the active layer. Click on the drawing space to make it active and then select **Place** from the **File** menu. A document dialog box will appear. Choose the format you want to input and then the first bitmap image of your pencil drawing. Make sure that the

## Drawing the Cave (Plan View)

### Line Weights

- 1.5 Walls including bedrock ceilings in the profile and cross-sections
- 1.0 Structural details and floors in the profile and cross-sections
- 0.5 Floor detail on plan, profile and cross-sections

I also use rounded corners and ends for all of the line.

option to “Place on Current Layer” is checked. An angular cursor will appear on the screen that will allow you to place the bitmap. Click on the drawing and Canvas will import the bitmap. Repeat these steps for every bitmap you have scanned in.

Using the gridlines on the scans, move the bitmaps back together. You may have to rotate the bitmaps slightly to make them fit. Go to the Effects menu and select Rotate. In the rotate dialog box, you can type in the exact angle of rotation. It may take several tries to get the correct rotation. When you have assembled all of the bitmaps together, select them all by dragging a box around them with the cursor. You may have to zoom out using the magnifying button on the toolbox to see all of the bitmaps. After they have been all selected, go to the **Object** menu and select Group. This will make all of the bitmaps into one object that you can move around the space. This will also prevent you from inadvertently disassembling the bitmaps as you work.

### Setting up the map

Try to center the assembled bitmaps on the page. You may have to go back and change the page dimensions using the page set-up procedures described above. Leave enough room to put in passage names, ceiling heights, elevations, etc. You are now ready to begin drawing the cave map.

### Walls

It doesn't matter what order you digitize the map features in, but it is best to only work with one layer at a time. I generally do the walls first, then the structural features, and then the floor detail. Go to the **Layout** menu and select **Document Layout**. The document layout palette (Figure 2) will then appear. Click on the layer named *Walls* to make it the active layer. On the toolbox, make sure that the fill is set to no fill, the line color is set to black and that the line weight is set to 1.5.



### Curve Tool

Select the curve tool shown above and begin tracing the walls. Each left mouse click you make will add a point to the line. Double-click a point to end the line. If you accidentally close the line and didn't mean to, just double-click the line, select the curve tool, and keep drawing.

### Structural

Go to the **Layout** menu and select **Document Layout**. The document layout palette (Figure 2) will then appear. Click on the layer named *Structural* to make it the active layer. On the toolbox, make sure that the fill is set to “no fill”, the line color is set to black and that the line weight is 1.0.



## Line Tool

For some of the structural detail (such as floor drops, domes, pits, etc.) use the curve tool to draw the overall shape and the line tool to make the hatchures. For changes in ceiling height, you can draw a dashed line and then add the hatchures using the line tool.

### Details

Go the **Layout** menu and select **Document Layout**. The document layout palette (Figure 2) will then appear. Click on the layer named *Details* to make it the active layer. On the toolbox, make sure that the fill is set to no fill, the line color is set to black and that the line weight is set to 0.5.

For symbols such as breakdown and flow-stone, use the curve tool. For standard symbols, you may want to use some built-in symbols, which Canvas calls macros. The macros can be found on the toolbox (Figure 3) as the symbol that looks liked shelved books.

In order to set up the macros for the first time, drag the symbol into the work area as shown in Figure 4. In the lower right corner, select the arrow and Canvas will display several options. To load an existing set of symbols, select Append Set and Canvas will display a file dialog box and you can select the

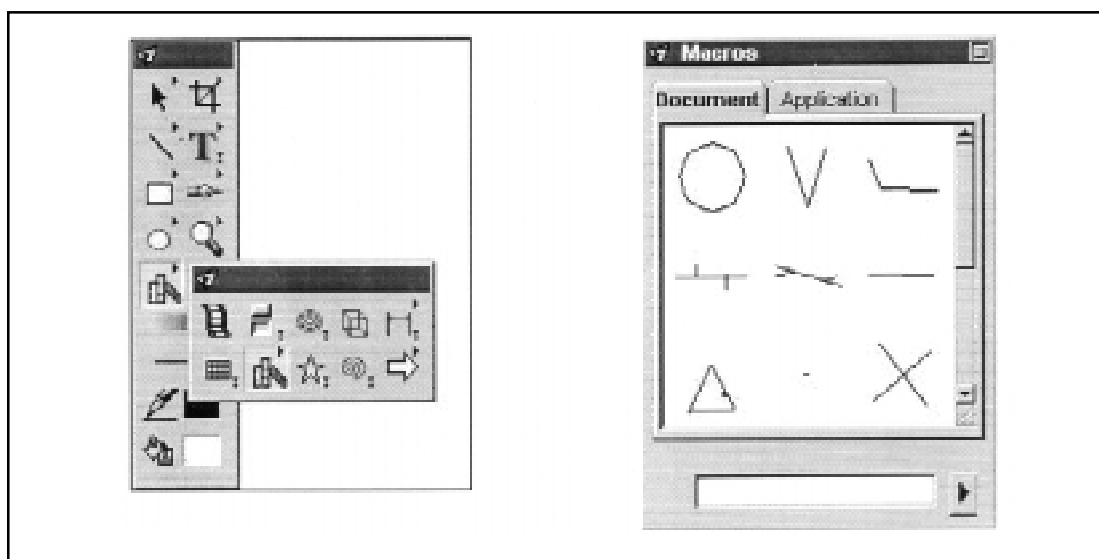
pallet that contains the symbols. Canvas 5 uses a \*.pal extension and version 6 and 7 use a \*.mcr extension.

The symbols appear in the macro box. To use them, just click on the symbol you want and then click on the part of the map where you want it. To place the same symbol many times, make sure you have “retain selected tool” selected in your **Preferences** under the **File** pulldown menu. If “Retain selected tool” is selected, every time you click the left mouse button, the selected symbol will appear.

If you want to create your own symbol, draw it using the drawing tools, group all of the part of the new symbol together, and then drag it into the macro box. Remember, if you want to make your new symbol part of the master symbol set, you will need to click on the arrow on the lower right of the macro box and choose “Save Set.”

### Cross Sections and ceiling heights

Drawing the cross-sections is the same as drawing other parts of the map except you use different line weights on the same layer. I use 1.5-point lines for the bedrock ceiling, 1.0-point lines for continuous floor, and 0.5-point lines for the floor detail (Figure 5). I also add floor detail to the sections using macros. After I have drawn the cross-section, I group



**Figure 3:** Macro Tool in toolbox



all of the parts of the section together into one symbol to make it easier to arrange the pieces in the final drawing.



Use the Text tool to place the ceiling heights on the cave map. Then use the Circle tool to draw the circle around the text. If you hold down the shift key while sizing the circle, Canvas will draw a perfect circle and not an ellipse. Once you have the text and circle drawn and centered on each other, group them into one object and place where you want.

### Text

Use the Text tool to place text on your cave map. I usually use an Arial font for text that is part of the map, because it is easier to read than most of the other fonts. Be sure to include the entrance, name of the cave and general location (state, county), the dates of survey, the list of mappers, your name and copyright notice, and other details such as cave length and depth.

### Drawing the Cave (Profile View)

Use the curve tool and macros to draw the profile. If you are drawing profiles in the same space as the plan view put the bedrock features (ceiling, etc) on the *Walls* layer and put the other information on the *Details* layer. I use the same pen-weighting scheme as I do for the cross-sections. Put any text you want on the profile onto the Text layer.

### Assembling the Final Map Technical details

For the final map, you will need to add a north arrow and scale bars for both the plan view and the profile. You will also need to create an explanation for all of the symbols you have used on your map. I find

it easiest to make a master explanation on a separate drawing with all of the common cave symbols. I then place a copy of the explanation into my current map and remove all of the symbols that I don't use.

### Moving things around

Once you have all of the pieces of your map in the drawing area, you will probably want to rearrange things to make the layout look better to win the Medal at the annual NSS Cartographic Salon. Moving things is fairly easy, but you have to be careful about how you group objects to move them. There are two basic ways of moving things around without messing up your map.

On the **File** pulldown menu, select **Preferences** and check the box that reads "Select Across Visible Layers." With this box checked, can select the whole plan map and then move it. At this point, you have to be very careful about how you grab the selected objects with the mouse. If you click wrong, you will move only one piece of the map and will have to madly scramble up the undo button. Another way is to group the plan (or profile) together before moving it.

First, on the plan map, select all of the items on the *Walls* layer and group them together. Repeat this with all of the layers on your plan map. Now repeat this process on all of the layers of your profile map. Doing this will allow you to put your drawing objects back on the right layers later.

Make sure you have "Select Across Visible Layers" checked in your preferences. Now you can group all of your grouped layers together on the plan map (or profile). Keep in mind that when you do this, all of the groups will be brought into the active layer. Now select all of your grouped layers by dragging a selection box around them. Group these together and now your plan map is one object that you can move around. Repeat the process for your profile map. Shift stuff around and win that medal.

# The Transit Survey Myth

by Bill Mixon

Reprinted from *Compass & Tape*

Volume 5, Number 1

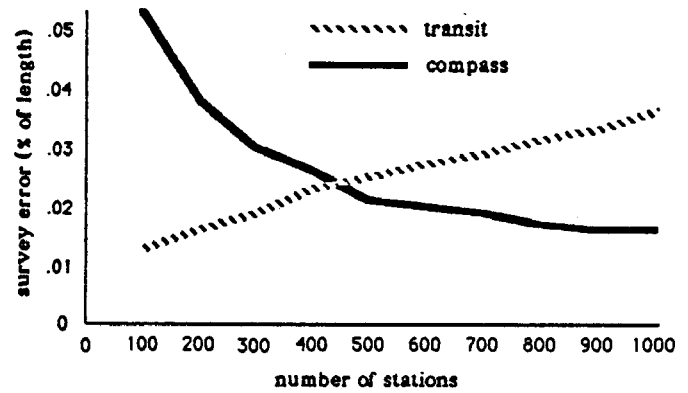
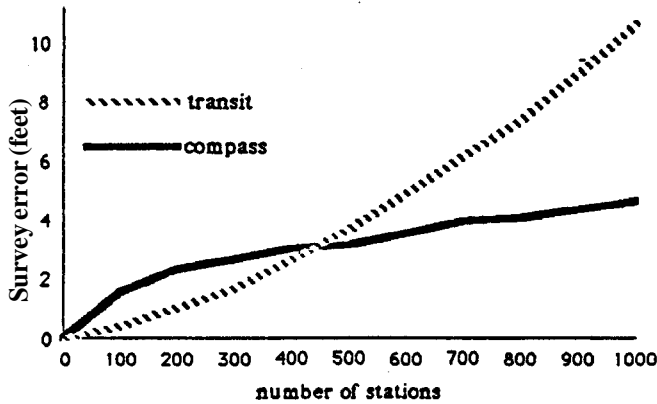
While reading the report of the Bighorn Caverns Project, which remapped that Montana cave in 1985-1986, I was reminded of the mistaken respect many cavers seem to have for transit surveys. This is no doubt due to the deceptive precision involving in reading angles to, say, the nearest half-minute of arc, which is commonly and easily done with those instruments. \*\* I believe “transit” surveys are in fact usually done with theodolites, but I am not sure just what cavers mean by a “transit survey;” that is, one in which turning angles measured with a surveying instruments substitutes for the compass and clinometer, but that otherwise resembles an ordinary cave survey. Large-scale land triangulations are another question entirely. The fact is that a cave survey of any substantial length will be more accurate when done with conventional compass and tape than with fancy surveying equipment.

To demonstrate that fact, I ran a simple numerical experiment on a computer. I calculated the accumulated error in the survey of a random horizontal cave with both instruments. The cave had one thousand survey stations, with each true distance selected randomly and uniformly in the range 10 to 50 feet and each true azimuth selected randomly and uniformly in the range of 0 to 270 degrees. Restricting the range of azimuths makes the cave actually go somewhere;

qualitatively similar, but a bit less dramatic results are gotten if the angles are distributed around the entire circle. To each distance measurement in the compass survey, I added a random error between plus and minus 0.1 feet; to each distance in the transit survey, I added a random error in the range of plus or minus 0.01 feet, assuming use of a real surveyor’s chain. To each compass reading I added a random error between plus and minus 0.5 degrees; to each transit angle I added a random error between plus and minus 0.5 minutes, sixty times smaller than the assumed compass error. The total survey error at each hundredth station was calculated. I ran one hundred such experiments and averaged the results. (Aren’t computers nice?) The result is tabulated below.

The slight irregularity reflects the fact that random walks are seldom “typical,” that is, while their average properties can be calculated, the spread is quite large. More than 100 trials would have smoothed the curves more. The results, which are also shown in the accompanying graphs, are nevertheless clear and perhaps rather surprising. Despite 10 times better distance measurements and sixty times better angle measurements, the transit does little better after only a couple of hundred stations, and actually is worse, by an accelerating margin, after five hundred. What is going on?

Number of Stations	Average Error in Feet	
	Compass	Transit
100	1.6	0.4
200	2.3	1.0
300	2.7	1.7
400	3.1	2.7
500	3.2	3.7
600	3.6	4.9
700	4.0	6.1
800	4.1	7.4
900	4.4	9.0
1000	4.7	10.7



The answer lies in the way angles are actually obtained in the transit survey. After somehow determining the direction from the first station to the second (more on that later), the instrument is placed at the second station and the difference in the directions to the first and third stations is read, which allows calculating the actual direction to the third station. Then the difference in directions from the third station to the second and fourth is read, from which is derived the azimuth between the third and fourth, and so on. An error in any direction measurement influences all subsequent azimuth calculations, since every azimuth is calculated as, essentially, the sum of all preceding angle readings whereas in a compass survey, the azimuth errors, though larger, each affect only one left of the survey. It is the accumulation of azimuth errors over many stations that accounts for the fact that transit surveys become less accurate as they proceed, whereas the random compass errors tend to cancel out to some extent. So a compass survey becomes more accurate, percentage-wise, the longer it gets.

Of course, my simulation doesn't really reflect the true accuracy of the typical cave survey. Compass surveys more often quote errors, where closures are available, of around 0.5 percent, not less than one-tenth of that. This is presumably due to blunders – reading or recording errors, misunderstandings among party members about station locations, and the like – and non-random errors that result from, for instance, using uncalibrated compasses or stretched tapes. Also, I am assuming that there is no station-position error that is the instrument is always placed exactly at the point just sighted to. In the case of compass surveys, random station-position errors behave like compass or distance errors; they tend to partially

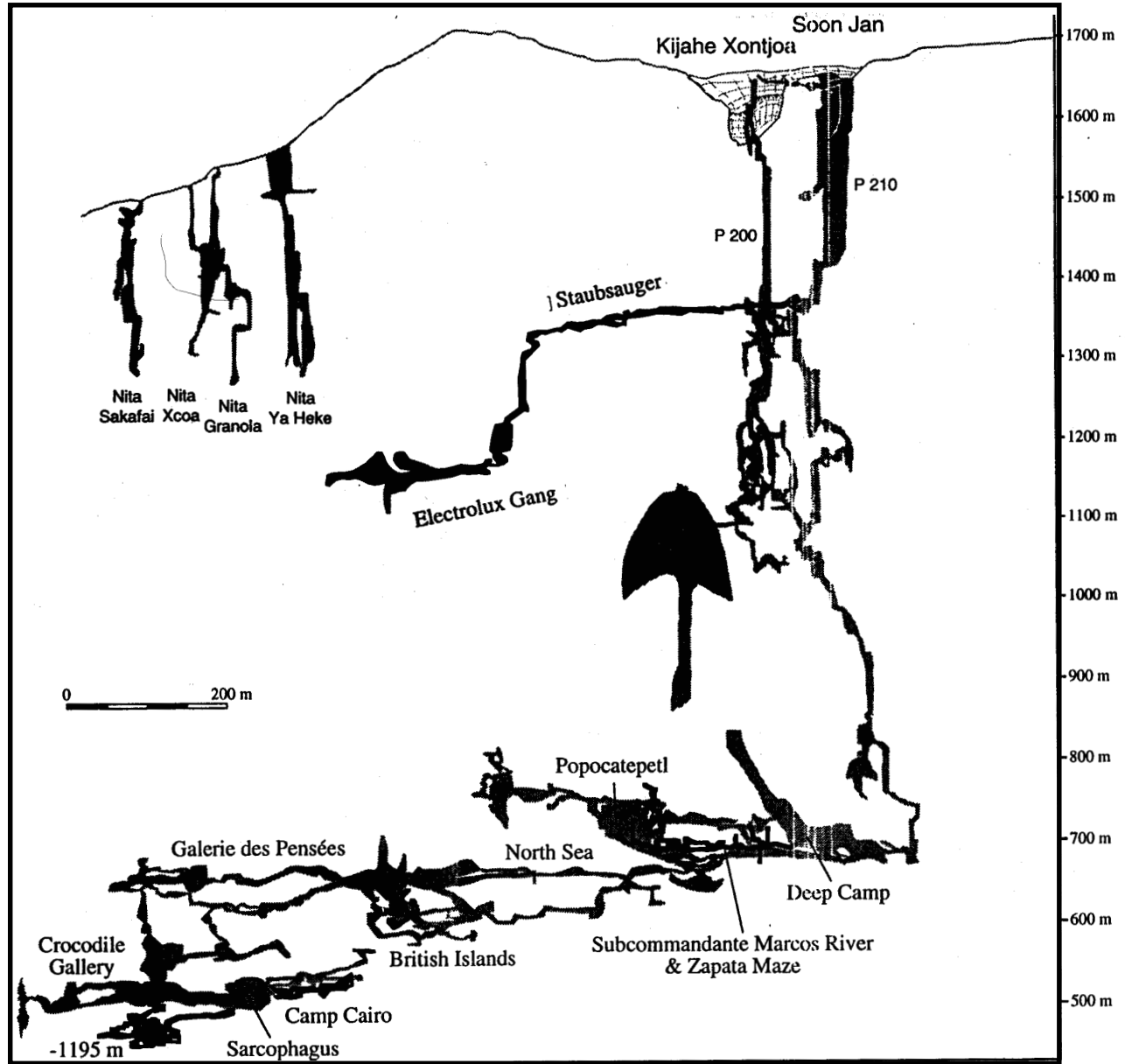
cancel. In a transit survey, station position errors contribute an extra component to the angle errors, which accumulate. Whether transit surveys come closer to even their theoretical accuracy is doubtful. I find it hard to believe that station-location errors of under one-hundredth of a foot are attained under cave conditions, for instance, and of course a single angle blunder has drastic results.

Since any direction error in a transit survey affects every subsequent shot, the direction of the *first* shot is very important. In a compass survey, the first shot is just another shot. But if a compass is used to give the direction of the first shot in a transit survey, then the absolute positions of distant points in the survey will be seriously affected. For instance, a quarter-degree error in the first direction would along result in an error of 23 feet in the position of a point one mile away. This will not affect closures within the cave, of course, which can be good, in that promising locations for connections and such will not be spoiled, and can be bad in that a false impression of overall accuracy will be obtained from in-cave closures. I wonder how many transit surveyors actually make sure their first angle is as good as all of the others, which would require a carefully timed sighting on the North Star.

I doubt if very many cave surveyors have seriously considered making a transit survey five hundred stations long. They needn't feel guilty about their laziness.

**\*\*(Editor's Note:** The distinction between transit and theodolite seems to be rather vague in the surveying and civil engineering literature. Transit often refers to a telescope-sighted compass, with graduations read by vernier. Theodolites tend not to have compasses, have either graduations read with microscopes or digital readouts and are used as Bill describes – John Ganter, editor, *Compass & Tape*, Vol. 5, No. 1, 1987)

## Profile of Kijahe Xontjoa Cerro Rabon, Mexico



plot by Toporobot