THE JENOLAN CAVE SYSTEM SURVEYING PROJECT.

PART 2 - TECHNIQUES AND COMPUTING.

Mark H. Bonwick, Russell Q. Bridge, Chris D. Dunne, Julia M. James, David J. Martin and Greg M. Tunnock.

ABSTRACT

The range of techniques used to survey The Jenolan Cave System are presented. The methods of data reduction, plotting and graphics are included. The way in which the plans and sections are going to be produced for publication and used is announced. The methods used for checking accuracy are described.

INTRODUCTION

The Jenolan Cave System Surveying Project - Part 1 (James et al., 1988) contained the history, organisation and an assessment of The Jenolan Cave System Surveying Project. This paper discusses the technical aspects of the survey and presents the methods and instruments used and the computer techniques used to reduce the field data and produce a traverse plot.

INSTRUMENTS AND METHODS

Survey datum

The survey datum point is a surveyors drill hole and wings on top of Camp Rock in the Grand Arch. This station (G0001) was given arbitrary coordinates of E 3000.0, N 7000.0 and Ht 800.0. At a later stage it is planned to tie this point into the National Grid. Both the surface and underground surveys have this datum. A magnetic bearing of 75 degrees between surface survey points G0001 and D0001 (bolthead in roof of pumphouse) provides the baseline for the bearings of the theodolite surveys.

Instruments

A wide range of surveying instruments have been used as different sections of the caves have been surveyed to appropriate standards. The main tourist paths and the surface have been surveyed at the highest possible standard. At the other end of the scale the survey of areas which it has not been possible to enter because of delicate decoration can only be estimated.

Theodolites

Most of the main tourist paths have been surveyed by theodolite with electronic distance measuring (EDM). Included angle techniques are necessary in these areas due to magnetic interference from metallic handrails, wire mesh and power cables.

Sokkisha Set 3 - Most of the underground theodolite work was carried out with a Sokkisha Set 3 (School of Civil and Mining Engineering, University of Sydney) with an SDR2 Electronic Field Book, essentially a data logger/computer. This instrument has infra-red electronic distance measurement (EDM) and a resolution of 1 mm for distance and 1 second for angles. In terms of accuracy, the standard deviation is +/- (5 mm+3 ppm) for distance measurement and +/- 4 seconds for angles.

Nikon NTD-3 - This did not have the data logger/ computer and therefore was not as convenient for the sketcher. This instrument was used for the Jubilee-Imperial main traverse and for the surface survey. It has the same precision and accuracy as the above Sokkisha Set 3. Angles were manually reduced.

Civil Eng. 'ancient theodolite' (Cooke, Troughton & Simms V 208) - This instrument was used for the wire sections of the Righthand branch of the Jubilee cave. This instrument has a resolution of 1 minute. However, in restricted passages the lighter, more mobile forestry compasses are much easier to use. Angles were manually reduced.

Underground theodolite survey team - A party would comprise;

- theodolite operator
- forward tripod operator
- rear tripod operator
- data recorder
- passage detail and station cross section sketcher

Advantage of instant XYZ coordinates - The Sokkisha Set 3 computer calculates rectangular station coordinates as each leg is surveyed. These are recorded in the data logger's memory and also on booking sheets by the data recorder as a backup and for the sketcher who may be several stations behind the instruments. High grade sketches can then be made immediately to scale. Having rectangular coordinates available in the cave for plotting improves both the rate and quality of passage sketching. The other instruments can only produce angle and distance and the sketcher is required to mentally reduce this in order to scale the sketch.

Tripod placement - The rate determining step both in this and other theodolite surveying is usually the tripod placement. The function of the forward tripod operator is to set up the tripod at each new station, mark the survey station and measure the height of the prism above the station. Both tripod operators must light the prisms to allow instrument readings to be taken. When a set of readings at a station are complete the rear tripod operator passes his tripod to the forward tripod operator in a leap frogging system. Where party numbers were limited the rear tripod and data recording functions were combined. The data recorder also records passage left, right, up and down data at each station.

Occasional problems were encountered with the tripods in narrow or low passages. These were usually solved by innovative tripod placements. In at least one instance a low section was surveyed by placing a tribrach directly on the passage floor. In narrow cave passages it was not unusual for a tripod to block access and passages where this was likely to occur were surveyed at times when there were no tours. Tourists occasionally had to climb around tripods.

Theodolite stations - All theodolite stations were permanantly marked. This was necessary to allow a survey to be continued at a later date and so that tripods could be reset if accidently bumped. In the cave on the northern side of the system these were usually drill holes in the concrete paths. In the Southern caves masonry nails were driven into the concrete or rock. The nails were found to be much easier to relocate as some drill holes tended to fill up with dirt or muddy water and disappear, whilst others proved virtually indistinguishable from drip holes in the path.

Markers from old surveys, particularly the survey through Lucas, Orient and Baal for the Binoomea Cut, were used when convenient. Even if the old survey marks were not convenient for a main traverse station they were usually surveyed in by a radiation for reference.

Surface Survey - An important difference of the surface survey from the underground survey was the use of triangulation (and trilateration - measuring distances). In contrast, the underground survey, including the underground theodolite survey was almost entirely traversing, i.e. progression from station to station one leg at a time.

Because of the relatively long survey legs involved in the surface survey (up to 850m), it was desirable to establish a network of stations where the connecting legs form a series of braced figures. To illustrate: a rectangular figure where the diagonals have also been measured, is a stronger figure, mathematically, than one where only the sides have been measured. Thus, from a given station readings might be made to two or three or even four other stations.

Again because of the longer length of most of the surface survey legs, the placement of tripods often involved a circuitous walk between stations (up to three times the line of sight distance) and, in general, readings could not be taken till all tripods were in place. Rather than leave the booker and reader idle and then, in turn, tripod operators for long periods, it was common to use a survey team of only two or three people.

Surface survey stations, where they are on rock, have been marked with a drill hole and wings; otherwise a surveyor's peg has been placed. Two-way radios were an advantage when working on some of the longer survey legs.

The present northern and southern extremes of the surface survey are, respectively: the Spider Cave entrance tag and station S0005 opposite the entrance to Binoomea Cut. Station S0006, on top of Lucas Rocks is 150m above Camp Rock (the survey datum point) and is the second highest station. Another, slightly higher station is nearly a kilometre away to the north beside the Six Foot Track on the edge of Binoomea Ridge.

Surface theodolite survey team - A party would comprise;

- instrument operator
- data recorder (booker)
- tripod operator

Depending upon the placement of some surface survey stations, a tripod "minder" was more often necessary than an operator. For example, station S0014 on the roadway on de Burgh's Bridge near the Grand Arch needed a "minder" to keep vehicles from demolishing the tripod.

Forestry Compass

Ushikata forestry compasses were used in many of the narrow tourist sections where magnetic interference was a problem. These instruments were made available to the Project by Keith Oliver and Hills Speleological Society. They are a tripod mounted instrument with a compass, inclinometer and a telescopic sight and are used to conduct included angle surveys. These were usually read to a precision of 0.5 degree. Distance measurement was by fibreglass tape read to the nearest 0.05 m. Forward and backward sights were taken to specific levels on wooden sticks with tape measures glued to them (a staff in surveyors parlance). Stadia techniques were not used. Survey stations were marked with drill holes.

Forestry compass survey team - A party would comprise;

- compass operator
- forward staff and tape operator
- rear staff operator
- data recorder
- passage floor detail and station cross section sketcher

Where party numbers were limited the data recording function was combined with either the sketching or rear staff operation. Passage detail was normally sketched by neglecting the magnetic anomalies and using forward bearings as true bearings. This obviated the need to calculate included angles in the cave but resulted in some less than correct sketches.

Calibration - These instruments were not calibrated. Calibration of the inclinometer is not warranted as the reading at each station is dependent upon the accuracy to which the instrument is levelled (usually achieved by a spirit level attached to the instrument).

Tape, Compass and Clinometer

Most side passages were surveyed using conventional tape, compass and clinometer surveys. Suunto instruments, KB-14 compass and PM-5 clinometer, and fibreglass tape were almost invariably used. These were read to the nearest 0.5 degree and 0.05 m respectively.

Suunto survey team - A party would comprise;
- instrument reader
- tape operator
- data recorder and passage floor detail and cross section sketcher

Surveys were usually conducted as a series of forward sights. Where a survey started in an area where magnetic interference was possible backsights were often taken to the tie in point to keep the compass as far from the interference as possible. On several occasions these instruments were used for included angle surveys.

Survey stations were not usually marked unless a junction or point to be continued from at a later date required marking. Plastic track marking tape held in place with a rock or tied to a suitable feature was the most commonly used method. Marking pens were used to write the station label on the tape.

Calibration - Compasses were calibrated by having two people sight each compass between two points in the upper car park at Jenolan. This data was used to determine a mean bearing, deviation from mean for each compass and standard deviation. Two compasses out of eleven had a deviation from the mean in excess of the standard deviation. A new mean was calculated with these two compasses excluded from the data set. The resulting standard deviation was 0.5 degrees. Calibration constants for each compass were determined using this mean. The compass with the worst error (-2 degrees) was withdrawn from service. Clinometers were calibrated by setting each one on a flat plate and having two people take a sight. The clinometer was then turned through 180 degrees and the sights repeated. Calibration constants for each instrument were determined from this data.

Thread Measurement Devices

Most of the Imperial Riverway and some side passages were surveyed using topofils built by Al Warild. These instruments comprise a thread length counter, compass and clinometer mounted together as a single unit. A counter reading is recorded at each survey station as cotton thread is spooled out between the stations. The length of the survey leg is calculated by taking the difference in counter readings.

Topofil Survey Team - A party would comprise;
- topofil operator
- data recorder and passage floor detail and cross section sketcher

Surveys were typically conducted as a series of backsights and all thread was removed. Survey stations were not normally marked.

Range Finders

In passages that could not be entered a 'Ranging 120' optical range finder was used to measure distance.

Underwater Surveying

Underwater surveys were carried out using a calibrated diving line, divers compasses and depth gauges.

Data Sheets

Tape, compass and topofil data was recorded on a standard form originally developed for the Muller '82 expedition. Special data sheets were designed for recording data from other instruments. A data header page was used to record the section of cave, date, surveyors and instruments.

COMPUTER DATA REDUCTION

Mainframe Computing - During 1987 the survey data was processed on a Unisys 1100 series mainframe computer. A Fortran program written by David Martin in 1982 to handle the Atea Kananda data was modified to accept Topofil and included angle survey data. Some traverse plots were produced on a 750 mm wide Calcomp drum plotter.

PC computing - At the start of the project consideration was given to using SMAPS Version 3 (Dotson, 1985). Whilst this integrated program provides a user friendly data entry and least squares loop closure facility it had several major disadvantages for this project: it did not support thread measurement or included angle data; it did not calculate coordinates for left, right up and down data; and did not support plotters. Whilst the data file structure used by this project is unique the coordinate calculation program could easily be modified to create

SMAPS compatible files. The data file structure was designed with this possibility in mind.

In December 1987 the survey data and Fortran data reduction program were transferred from the mainframe to an IBM AT personal computer. The program was extensively enhanced during the early part of 1988. Large plots are handled by transferring ASCII MS-DOS format plotting files to a Hewlett Packard CAD system (Figure 1). Checking plots at A4 and A3 may be generated on a HP7475A plotter using the Autocad computer aided drafting (CAD) package. A text editor (SPFPC) is used for entering and editing data.

Data from the Sokkisha SDR2 was initially processed using the 'SURVIS' survey information system (Foresight Systems and Datacom Group) consisting of seven modules. A Fortran program was written to convert files generated by this system to the format used on the IBM AT.

Traverse plotting - A plotting program was developed by Greg Tunnock on a Hewlett Packard CAD system comprising a HP9000 model 350 and HP7580 plotter capable of handling A1 sheets. Time on this computer system was provided by J.N. Almgren. Plots are normally generated at a scale of 1:200. Solid lines are used to represent the traverse lines and dotted lines represent the left and right or up and down data. The station label and a symbol may be drawn at each survey station.

On-site data entry - Data entry at Jenolan became possible in March 1988 with a Hewlett Packard HP75D micro computer which stores data in battery backed memory or on magnetic strips. It is later transferred to an MS-DOS format floppy disk for processing by the IBM AT. The software, developed by Mark Bonwick for the Chilchotla 87 Mexico expedition, features user friendly data entry and co-ordinate calculation modules for both tape, compass and topofil data. A Think Jet printer provides hard copy output to facilitate proof reading and field plotting.

Contour plots - Contour plots of the major chambers Grand Arch, Devils Coach House, Carlotta Arch and the Exhibition Chamber will be produced using the SURVIS system.

Computer graphics - When the data gathering and reduction is complete it is proposed to produce three dimensional graphic models of the system using software developed by Keir Vaughan-Taylor.

Traverse Closure

Where a loop contains both high accuracy theodolite data and lower accuracy magnetic data the closure is usually on the basis that the adjustment is restricted to the magnetic survey legs. This is justified as closure errors in loops surveyed entirely with the Sokkisha equipment are typically less than 50 mm. The high grade theodolite survey effectively constrains the coordinates of many junctions in what is quite a complex network. The closure problem is then reduced to a number of fairly small simple networks. Closed junction coordinates for these networks are determined using methods similar to those given by Irwin and Stenner (1975). More sophisticated treatment of the misclosures, such as least squares adjustment, is unlikely to improve the final product as most misclosures are small.

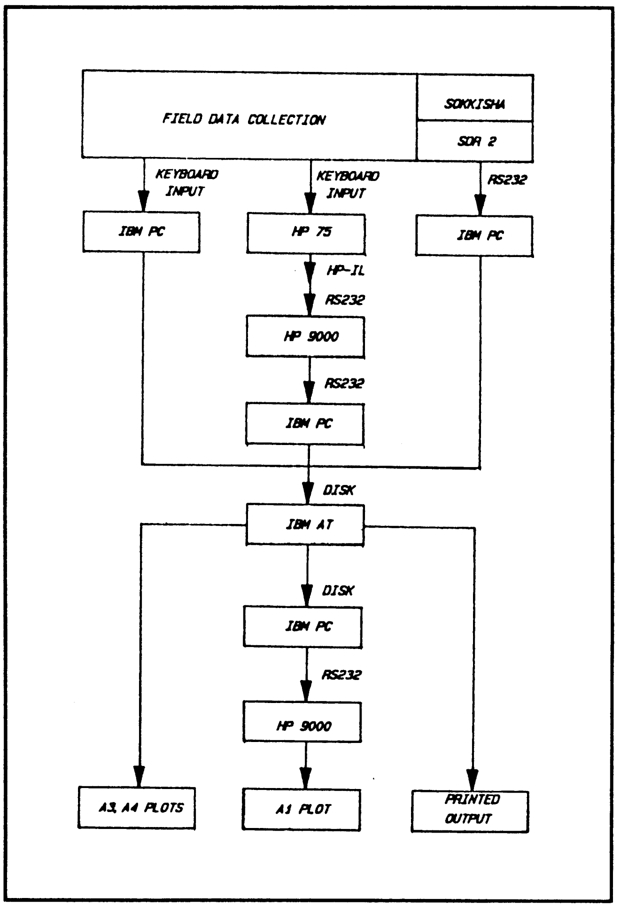

Figure 1 - Flow Chart for Computer Applications.

CHECKING SURVEYS

Radio Direction Finding

RDF is being used by Mark Bonwick and Ron Allum to locate on the surface the extremities of passages which have not been surveyed by theodolite traverse; surface points are then located by surface theodolite traverse.

Cave to surface RDF has been attempted for the following locations; Red Cave, Alabaster Hall, Water Cavern sump, Victoria Bower and Imperial Riverway Sump 7. The initial attempt at locating Victoria Bower resulted in a 43 m horizontal discrepancy. The surveys indicated that the vertical separation between the surface and underground points was about 1 m. With this small separation the point located was in fact a false null. This exercise was repeated and the results are still being evaluated.

Cave to cave RDF has been used for the following; Water Cavern to Sump 4 and Imperial Riverway to Spider. The misclose between the Sump 4 RDF fix and the surveyed coordinates is 3.1 m. The accuracy of the Spider - Imperial RDF fix cannot be established until the connection is surveyed.

Loop Closure

Other checks on survey accuracy are provided by loop misclures. All loops surveyed entirely with theodolites have closure errors less than 100 mm. Some sections of survey with other instruments have been resurveyed where an unacceptable misclose has been encountered. Unacceptable misclures have resulted from; tie-in station labels incorrectly booked, forestry compass bearing booking errors, and magnetic interference.

Sketch checking

Sketches are drawn to scale and then taken into the cave for checking and improving.

PRESENTATION OF RESULTS

From the computer data it will be possible to generate the depth of the cave, the traverse length of the cave system, the plan length for the cave system, an approximate volume; a new figure for an Australian cave.

The plan of the known system will fit on a sheet 800 mm x 600 mm at a scale of 1:2000. This will be published as a line drawing which also shows surface features. The plan will be drawn at 1:500 for development, tourist and exploration information and published as two sheets. Plans with passage cross sections at 1:200, detailed contour maps of all the major chambers and their features at 1:200 and a 1:500 projected section (North - South) are planned for scientific studies.

The survey data is sufficiently complete for it to be used for three dimensional computer graphics representation and possibly for the preparation of a model.

It is hoped to publish the survey as a book complete with descriptions of the cave, photographs and artists sketches.

ACKNOWLEDGEMENTS

See The Jenolan Cave System Surveying Project - Part 1 History, Organisation and Assessment (James et al., 1988).

John Almgren, J.N. Almgren Pty Ltd, for computer facilites.

BHP for computer facilites.

Wollongong University for computer facilites.

Dr Richard Coleman, School of Civil and Mining Engineering, University of Sydney for surveying equipment and computer facilities.

REFERENCES

DOTSON, D., 1985 **SMAPS, Survey Manipulation, Analysis and Plotting System - Users Manual, Version 3.** Department of Computer Science, Frostburg State College, Maryland.

IRWIN, D.J. and STENNER, R.D., 1975 Accuracy and Closure of Traverses in Cave Surveying. **Trans. Brit. Cave Res. Assoc. 2(4):151-165.**

JAMES, J.M., MARTIN, D.J. and TUNNOCK, L.K. 1988 The Jenolan Cave System Surveying Project - Part 1 History, Organisation and Assessment. **This issue.**

MATHEWS, P.G., **1985 Australian Karst Index.** The Australian Speleological Federation, Melbourne.