The Art of Computerised Cave Mapping

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[This is a revised (2000) version of a paper published in the Proceedings of the ASF Conference, Quorn, 1997]

For the last five years all my cave maps have been prepared and printed (almost) entirely with a computer and exist completely as computer CADD files which I can modify and print from as required. But getting a map to that stage involves several steps and initially spending a significant amount of money. Here I will describe the process involved in producing a cave map via a computer (See Figure 1 for a summary of the steps).

First survey your cave

This involves a team of 2-4 people, who use tape, compass and clinometer (and other optional devices) to survey a base line through the cave and to locate points that assist the sketcher in drawing a picture of the cave. The survey is the mechanical part and necessary to maintain accuracy of the sketch and the overall map. However, the important job is the sketching (to scale) of the wall outlines, floor and roof detail, cross-sections etc. This requires a certain artistic flair, supported by rough measurements.

The techniques and art of the physical survey could fill a book (and have done so) and I will not go into that here. Several books on the subject have been published by both the NSS and the BCRA (see list at the end of this paper). If your club library does not have one perhaps you should talk to your librarian.

Computerising the survey data.

There is now a good range of cheap or even free software available for converting cave survey data to co-ordinates (see web page listed at end of this paper). These allow you to type in your survey data (station names, length, bearing etc.) and then convert that to a set of grid co-ordinates which can be accurately plotted (no more playing around with ruler and protractor). The better programs will also make automatic adjustments for magnetic declination and instrument corrections, and will adjust loops for misclosures. They will then display the final survey plan as a line map on the screen. This allows you to check for gross errors (such as a back bearing entered as a forward bearing). They may also let you display side views (profiles). Finally, they will print the survey lines in both plan and profile views for you at whatever scale you want, along with station names, a scale bar, and other extras you might ask for.

Generating grid co-ordinates.

Data entry: First enter details of survey team, date, and instrument corrections. Then type in the survey data using the data entry part of the program. You will typically enter station names (from & to), length, bearing (fore or back), vertical angle, floor and roof height and wall distances, and

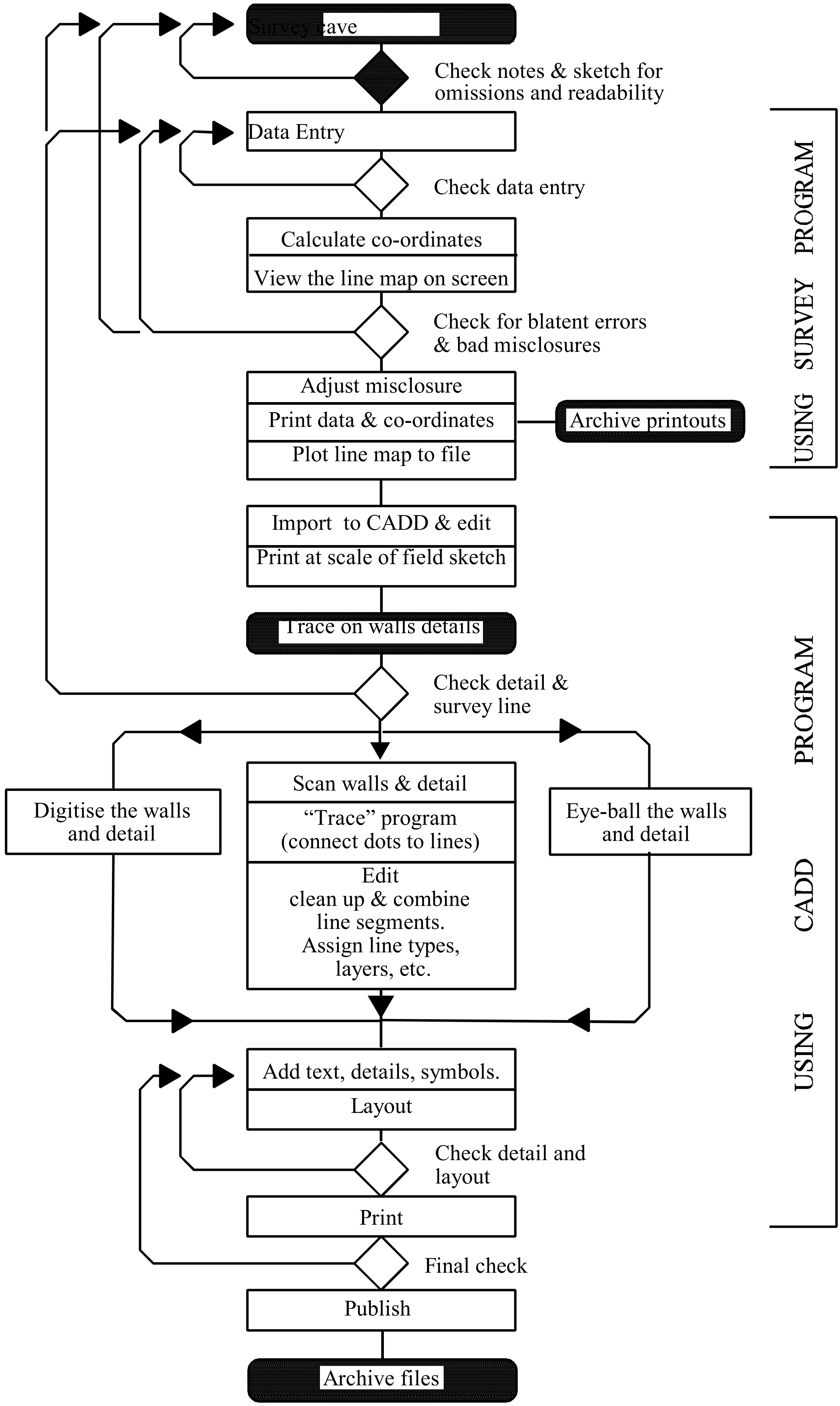

Figure 1: Steps in making a map.
Shaded boxes are non-computer activities. Diamonds are check points.

possibly comments describing what natural object or mark you used as a station. Print this out and check it carefully against the original. Fix any typing errors. You also enter the grid co-ordinates and elevation of any known stations (typically the tag at the entrance), or you can let the program use 0,0,0 as a default.

Reducing the data to co-ordinates: The program should do this automatically and will give you a list of x,y,z co-ordinates for each survey station (i.e. eastings, northings and elevation). It may also pick up discrepancies between fore and back sights, misclosures, and "hanging" chains that do not connect to the main survey (perhaps you miss-typed a station name?). It will probably also give you a total length of survey line - which is an approximation to the "length" of your cave - and the extent of the cave, including its vertical range.

Adjusting misclosures: The program may offer to do automatic closure corrections, but don't do that yet. First, inspect the results (see below) then come back to this step. You may be able to fix some of the errors and re-calculate the co-ordinates to eliminate the problem. Adjusting for misclosure simply spreads the error over adjoining stations so it is less obvious, and it is then easier to fit the base line to your field sketches. But the error is still there, and the adjustment may well be moving accurately located stations to less accurate positions. Automatic closure adjustment does not "fix" the error, it merely hides it. But if you main objective is just a picture of the cave this is probably OK.

Viewing and plotting the survey lines.

The program should let you view the survey on the screen as a line map (or print off a copy). Check it against your field sketches. Look also for major misclosures in loops where a chain of survey legs joins back onto itself, or into the main survey at another point. Minor discrepancies can be adjusted for by the software, but if there are major errors check first that the data has been entered correctly. Otherwise you may have to go back to the cave and resurvey that part.

What constitutes a "major error" depends both on your own level of pride, and also on the intended use of the map. Most cave maps are just done to give people an idea what the cave looks like, or to help in underground navigation - in which case a few metres error isn't going to bother anyone. But if the intention is to dig an access tunnel into the back of a tourist cave, or to make a connection between two nearby caves, or to blow up parliament, then better accuracy is needed. As a rule of thumb for typical cave maps, if the error is less than 1% of the loop length, then you can go ahead and adjust it out of sight.

Most of the better programs will let you rotate the view and look at it from the side (a projected profile) as well as above. Rotating the side view as you watch is fun, and gives you a good feel for the 3-dimensional shape of the thing.

You will probably cycle through the calculate-view-correct-adjust steps several times until everything looks OK.

Adding details to the map with CADD

The cave survey program should let you plot the stations and survey lines as both plan and side views, along with title blocks and scale bar etc. But you only get the skeleton formed by the survey line - adding the walls and other detail is another matter. Most cavers go to manual drafting methods here, drawing in the detail by hand and adding hand lettering or Letraset etc. But using a CADD[1] program makes life a lot easier - albeit a bit more expensive.

In CADD any mistakes can be removed at the press of an *Undo* button. You can quickly add predefined objects such as north arrows, scale bars, etc and move things around to get the most pleasing layout. You can change the shape of a wall by grabbing a control point and dragging it about on the screen. Newly surveyed passages can be merged in (from separate files, or directly). If you are doing an area map you can suck in the wall lines from a series of pre-existing cave files and position them according to their 'real-world' co-ordinates (assumes that in the co-ordinate calculation and align stage you used actual AMG grid-references - but even if not, you can still pick up the cave outlines and drop them at the approximate location.). Figure 2 in my paper on the Mt Eccles caves in the *Vulcon Proceedings* started that way - each of those little cave silhouettes was originally a separate full scale cave map.

The key to efficient CADD work is to organise your data into "*layers*"; the electronic equivalent of multiple sheets of tracing paper - you can 'hide' or 'display' layers at will or do global changes to them such as changing the thickness of all lines in your 'Walls' layer. Put the grid and traverse lines on separate layers & hide them - you can redisplay them again if you need them for reference. Have a 'TEMP' layer for construction lines and text messages to yourself (such as a reminder list of which layers should be hidden before plotting !) If you think you might be plotting two versions at different scales you might want two text layers, with different sized lettering - display whichever one is relevant before plotting. If there is a special cave passage that you do not want the great unwashed public to find out about you can put it on a separate layer and only plot it on versions for your washed (**?**) mates. This is also useful if you want to add a location diagram for club records but not for publication - one of my Vulcon map files had a hidden layer that showed the relation between a known cave and one I wasn't talking about ! It is printed in the version held by VSA.

Only one layer is *"active"* at any time, and anything you draw goes on that. Any editing actions (e.g. erasures) will only effect the current layer - unless you switch on an "*All Layer Edit*" mode.

A typical set of layers which I use in my cave maps is given here. The colour is used to help see what is what on the screen (they all plot as black, unless you have a colour printer), a * indicates a layer which is usually hidden when printing the map.

TEMP *		(construction lines, messages, & misc. things)
Grid *		(normally only in the early stages)
Survey lines *	[Dark Red]	(as imported from the Cave Survey program)
Walls	[Magenta]	
Sections		
Detail	[Grey]	
Text	[White, note, I use a Black background]	
Fill & hatches		(these are easier to manipulate if on a separate layer)
Construction lines for flood-fills & hatches *		
Surface details		(sometimes you might want to see these, sometimes not)
Water	[Blue]	

An alternative to CADD programs are "Draw" or "Paint" programs (referred to here collectively as DRAW). These are cheaper, but less satisfactory. The problem is that they are oriented to free-hand sketching or the production of text and diagram displays such as sales charts and brochures. They are good for artistic layouts, but fall down when it comes to precise location of points (essential for a cave survey) and sophisticated editing of objects. In a DRAW program you locate an object (say a survey line) by moving the mouse pointer and clicking (approximately) where you want it on the screen. In CADD

[1] CADD = Computer Aided Design and Drafting.

you can, instead, type in the actual co-ordinates in real-world units or as an angle [2] and distance from the previous point. In CADD you can also *"snap"* a new point accurately to an existing point or object (essential if you want a closed cave outline that you will later fill in for a silhouette effect). DRAW programs are better for fancy text effects, such as bending a line of text to follow a curved wall line. The fill patterns in DRAW programs look better, but suffer from the fact that they are predefined dot patterns and cannot be enlarged or rotated to suit the scale of the drawing. The cheaper DRAW packages do everything as a "bit-map", i.e. in dot patterns rather than lines with the ends defined as co-ordinates. This means they cannot be easily scaled to larger size without getting nasty jaggy effects.

Postscript (2000): Draw programs are improving. I now tend to import a HPGL file output from SMAPS direct into Corel Draw (v7) and do all the detail there.

But the best part of CADD is the editing and management of objects. You have a sophisticated array of tools for selecting sets of objects (in DRAW, building a selection group is more tedious). CADD lets you iteratively add and subtract objects from the selected group, and also set filters so the selection process will only effect (e.g.) all straight-line objects that are coloured red and in the "WALL" layer. Having done that you could then remove from that selection any that have a specific line type and then do something with the remainder.

The Steps in making the computer map

Transferring the survey line map from the survey program to CADD.

Tell your survey program to plot the line diagram using a HPGL format (i.e. tell it you have a pen plotter - they all use HPGL), but plot **to a File**, not to paper. If the survey program can export in other CADD readable formats (such as DXF) you should go that way and jump straight to the next step. My survey program (SMAPS) only knows HPGL, which is why I am describing that way in detail.

Before plotting the file - set the program's plot options so that as well as the survey lines and stations it plots a grid of crosses at (say) 10m intervals - you will use these for control later on. If it has an option to plot different parts of the map, or different cave levels, in different colours this is useful, but do **not** use dot or dashed line types if it offers them as an option. Each dot and dash will go across as a separate line object, which makes for a big file and complicates things when you get inside CADD. Select a plot 'scale' that approximates the intended final scale or larger - the larger the better from accuracy point of view[3]. Select a "paper size" big enough to hold the whole plot in one go. (A0 is pretty safe !) This is just to ensure that the program does not split the plot over several "pages", which confuses things later on !!!

You may also want to plot one or more horizontal views to other files to assist in construction of projected elevations.

Importing the survey line file to CADD.

How you import the plot file depends on your CADD program. My CADD program, Generic Cadd, has a separate program that reads a HPGL format file and converts it to CADD file format. I think most

[2] Angles in CADD are confusing to cavers. They use the mathematical convention of measuring anti-clockwise from east - we are used to bearings that go clockwise from North !
The conversion is: **Angle = (90 - Bearing).**

[3] HPGL has a theoretical plot accuracy of 1/1000 inch, so plotting at 1:1000 means all locations are rounded to the nearest (real world) inch - which is ample accuracy for our purposes.

(decent) CADD programs can suck in HPGL; they all can read DXF format (if they can't, don't buy them). If you imported via HPGL use the grid crosses as a guide to re-scale the drawing so that 1m = 1m (i.e. a "Real World" scale of 1:1). Tidy up this imported version in CADD - removing any unwanted lines and text that the survey program insisted on including. If your survey program plots different parts of the map in different pen colours you might want to use those colours as a basis to select and shift the objects to different CADD "layers".

Adding the wall detail.

From CADD, print the survey lines & grid crosses (on paper this time) at whatever scale your field sketches are drawn at. This requires a plotter, or an appropriate printer driver for your CADD program - Windows based CADD will just use the windows drivers, but sometimes you can get better results from third party drivers. Depending on the size of the cave and scale of your sketches you may have to plot several sheets. Having an A3 size (or better) printer or plotter is a distinct advantage here [4].

We now go old-fashioned. You put your field sketches under the plotted sheet (on a light table, or taped against a window, or plot onto tracing paper if your printer can handle that). Manually trace off the wall outlines and any other detail that needs to be accurately located. This is just an interim version, it does not have to be tidy (unless you intend using a scanner - in which case your fingerprints will also get scanned). Trace any cross-sections also. Note, this works best if you used a ruler and protractor in the cave to assist in accurate sketching. This step is essentially the same as what you would do in the old non-computer method.

Getting the wall detail into the CADD program.

You have to make a decision here as to how much money you want to spend and what hardware is most useful to you. The alternatives are using a digitiser, a scanner, or just eyeballing it. Digitisers and scanners are expensive, but they are only one (albeit essential) step in the process. If you have access to one at work you may be able to use it at work or borrow it for the weekend. Perhaps your club could consider buying one. Digitisers have come down in price - I saw a 12"x12" one in a Dick Smith shop the other day (1997) for $350 - so they are now quite competitive with scanners. Postscript 2000: Scanner sare now quite cheap and easy to use and digitisers seem to be getting scarce again.

(a) Digitising it: Go out and buy a Digitiser Tablet of at least 12"x12" size (preferably A3 size if you can afford it). But first make sure that your CADD program can USE a digitiser (and THAT model of digitiser). Some cheap CADD programs (and most DRAW programs) only use Mice; others claim to know about digitisers but only use them as an expensive mouse substitute. If you are running Windows you will need a WINTAB driver - with luck it will come with the tablet when you buy it (ask first).

What you are looking for is the ability to "*align*" the drawing on the tablet so that as you move the tablet pointer the program converts the position of the pointer to the real-world co-ordinates of your CADD file.

Put your outline map on the digitiser tablet and tape or weigh it down so it cannot move. "Align" it to the CADD drawing using reference points of known co-ordinates (the grid crosses, or survey points at diagonally opposite corners of the drawing). Your CADD manual will tell you how this is done. Usually

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[4] I do not recommend the small desk-top pen plotters; they are very slow, and the standard felt-tip pens produce lines that are too thick for detailed work. If you want colour plots get one of the new colour bubble-jets (Canon has one that can print on A3 for about $800).

you select a point of known co-ordinates on the CAD screen then click the cross-hairs on the same point on the paper and repeat this for two or more points.

If you are converting someone's pre-existing map to CADD this is where you start. Align it using the scale bar as reference, and also digitise the north arrow as well as everything else and use those as a guide to scale and rotate the drawing to north inside CADD.

Select an appropriate layer, line type, colour and line width and start digitising (tracing) the lines on your drawing into the CADD file. For cave walls you will use a '*curve*' line rather than a series of straight lines[5]. This involves starting at the end of each wall segment and working along it clicking the puck[6] button on the line whenever there is a bit of a bend. Some programs allow you to hold a button down and just move the cross-hairs along the line; the program puts in control points wherever it thinks they are needed - usually a lot more than you really need and so it makes for larger files.

(b) Scanning it: Buy a scanner ($500+ for an A4 flat-bed in 1997, Only $200 in 2000) or use a scanner service at an office services shop (about $5 for each A4 sheet, plus extra if you need it converted to a special format). As with a digitiser, make sure that your software knows how to talk to the hardware or can import the resulting file formats from someone else's scanner.

This is initially faster than the digitiser at getting the info into the CAD program, but it is less satisfactory in the long run. The output from a scanner is a bit-map, or raster data (lots of little dots). You have to run this through a "trace" program - which you may have to buy[7], or perhaps the office shop will have one and charge you to use it. It makes decisions as to what groups of dots represent lines and generates a vector file of line segments which can then be imported into CADD (via DXF or HPGL in the same way as you imported the survey line map). You then have to tidy up the scanned version within CADD.

The problem with automatic 'tracing' is that you have to spend a lot of time tidying up. The 'trace' program will often split what should be a single straight or curved line into a series of shorter line segments, and you will have to recombine those itno a single line before you can easily convert them to whatever layer, line-thickness etc you want to use in CADD. It generally proves easiest to redraw a new line over the top of the scanned version (on another layer) in the same manner as you do with a digitiser, but using the mouse. You will then need to re-scale and rotate the drawing to face north - using control points of known co-ordinates as a guide.

Mind you, the time spent in editing the scanned file, might not be too much more than that in digitising a very complex map from a tracing. And you can do other useful things with scanners (scanning photos, text recognition etc), but not much else with a digitiser (except use it as an expensive mouse).

Note (2000): Most CADD and DRAW programs will now let you import a scanned bitmap and display it on a separate layer behind your drawing. You can then use the mouse to manually trace the detail onto other layers - much as described above for a digitiser tablet.

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[5] You may find you have a choice of several curve types: I prefer '*spline curves*' as they follow the control points in a more sensible fashion and are easier to edit.

[6] A ***puck*** is the tablet equivalent of a mouse - it has cross-hairs and buttons. Some tablets use a pointed pencil-shaped thing instead.

[7] ***Corel Draw*** comes with a *trace* program built into it.

(c) Eyeballing it: Can't afford a digitiser or scanner? Use your mouse as a cheap-skate alternative. When plotting the base-line map, include a fairly close pattern of grid crosses. When tracing the wall detail onto the plot, pencil in the grid also (join the crosses).

Now you sit in front of the CADD (or DRAW) screen with the mouse, and eyeball in the walls and other detail using the grid and survey lines as a visual guide. It is slow and not very accurate but it is cheaper than the alternatives, and if your field sketches are pretty ratty anyway the loss of accuracy may not matter. Mind you, if your field sketches are ratty your eyeballing will probably also be ratty! It helps if you have a good graphics bio-computer mounted behind your eyes, but there was a lot of variation on that production line and they don't sell upgrades. Accuracy will improve a bit with practice but, as with sketching, the skill is largely innate.

Now use CADD to add text, symbols and other details.

Now add text, pre-defined symbols for stalactites etc, fancy North arrow, your club logo, and so on. You need to decide fairly early what scale the final drawing will be plotted at, as that determines what size letters and symbols you use[8]. Do a test print with just a few symbols and text lines to see what it looks like. An alternative is to re-scale the whole drawing to the final scale - a 2mm letter is then drawn as 2mm. With a DRAW program you may have to do that. The disadvantage of that is possible future confusion when you come to merge two adjoining caves (at different plot scales) or adding new passages. I prefer to do everything at "real world" scale.

This stage can be a bit tedious if you have a lot of floor detail (such as rubble piles) that needs hand drawing with the mouse, but it is great for the text side of things - my hand lettering has always been abysmal and Letraset takes ages. You will only get up to speed after a fair bit of experience in the CADD package you use. If you make a mistake just press the Undo key. No worries about spilled ink !

Cycle through a series of test plots and editing stages.

Up till this stage it has probably taken longer than drawing the map freehand would have (assuming you can do neat hand-lettering). But from here on CADD comes into its own. Any mistakes can be removed at the press of a button. You can take pre-defined symbols from a library and place them with a single mouse click. You can play about with the layout - moving things about to get the best look. And if there is a major new discovery in the cave that runs off the edge of the map sheet, you can add it in with minimum effort instead of re-doing the whole drawing from scratch. Soon we will be able to buy digitised versions of the topographic maps, and import surface contours and other info into the cave map.

Finishing up.

Print the final map. Spot a last-minute spelling mistake, fix it, and plot again! Send it off to the publishers or whoever is going to use it. Archive your survey data & sketches with your club records: photo copy the original sketches & field data (complete with mud-stains) and also give them a printout of the entered data from the computer (which is more readable but may have data entry errors !!).

Archive the computer data and CADD files onto disk or tape and store in a safe place. Some day soon you will be e-mailing the CADD files and the survey data to your club records keeper.

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[8] If plotting at 1:500, a 2mm letter will need to be 1000 mm high in "real world" scale !

Some books on cave surveying

Brian Ellis: Surveying Caves. *British Cave Research Association.*
[Out of print?]

Brian Ellis: An introduction to Cave Surveying. *British Cave Research Association.*
[a cut down, but updated version of the above]

George Dasher: On Station. *National Speleological Society.*
[USA - a very comprehensive book, and good value for money].

Thompson & Taylor: The Art of Cave Mapping. *National Speleological Society.*
[USA, - another comprehensive book]

See also the **ASF Cave Survey and Map Standards** document, including map symbols, which is on pages 18-1 to 18-20 of the *Australian Karst Index*.

Other sources of information

For an annotated list of available cave survey reduction software see the BCRA web page at:
http://www.sat.dundee.ac.uk/~arb/surveying/software.html

For the electronic text of the ASF Cave Survey and Map Standards and a list of map symbols go to:
http://www.caves.org.au/standards/mapping/stdsurv.html