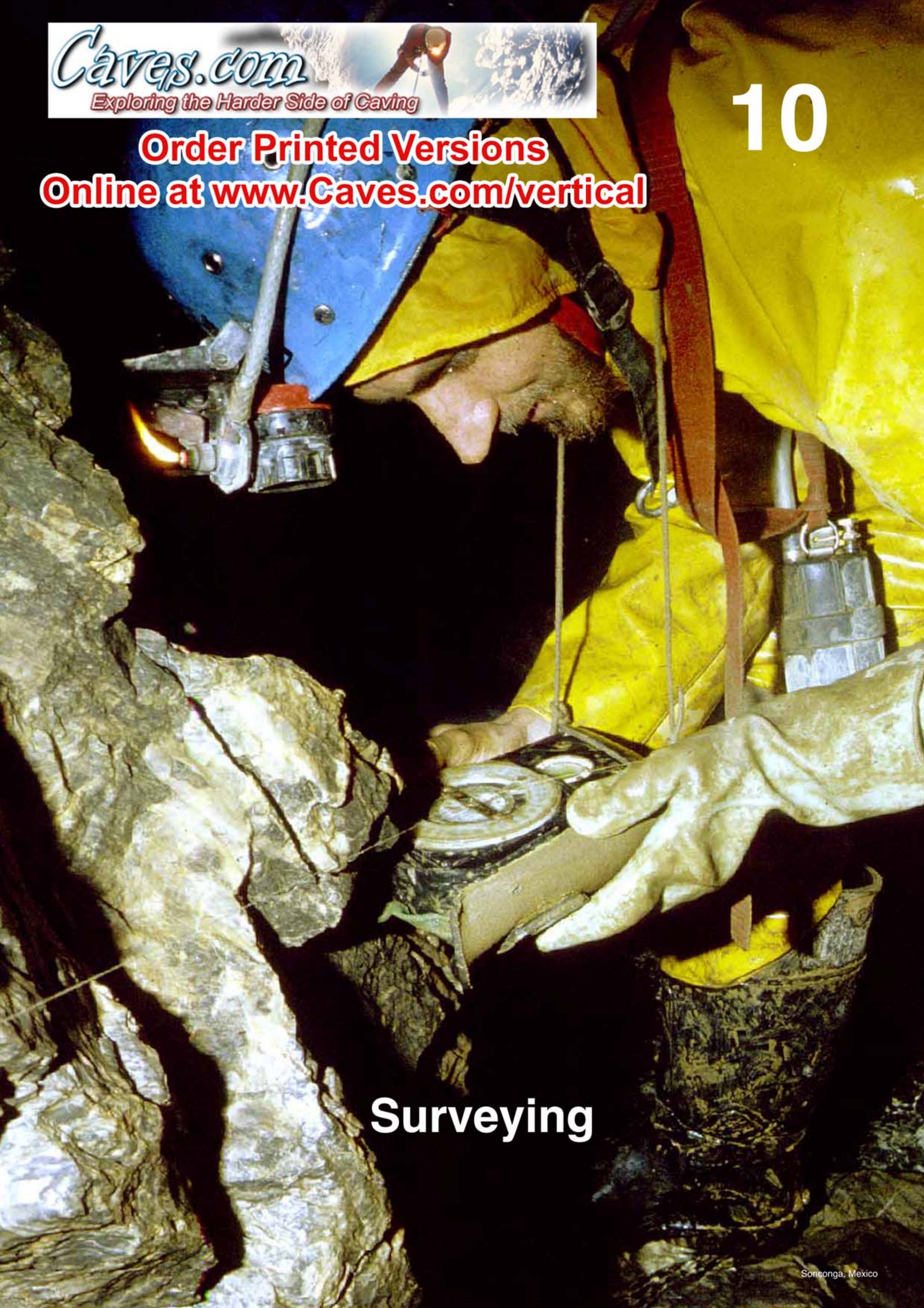
10

Surveying



Soncongà, Mexico

A survey is the only way you can find out how deep your cave is and where it is going. It is a guide that indicates where to look for a continuation or passages that are likely to connect with nearby caves. A high quality survey is 'proof' of a cave, indeed many cavers will not even believe a cave exists until they have seen a good map of it!

Survey instruments

Vertical caves are typically steep, irregular and often confined, not to mention cold, wet and dirty. Obtaining an accurate representation on paper is never simple. In all but the easiest caves, hand-held instruments are the most suitable, if not the only alternative. Sophisticated tripod mounted instruments such as theodolites and total stations are impractical due to their inability to take steep sightings and setting up constraints.

The instruments must be light, compact and easy to carry. They must be fast to use and allow you to take sights in any direction with minimal loss of accuracy. Even so, surveying is painfully slow and takes five to ten times as long as a normal trip through the cave.

Tape and compass

A Suunto KB-14/360RT sighting compass and PM360PCT clinometer with a fibreglass tape are the 'International Standard' for vertical caves. Both the compass and clinometer are neat units in solid aluminium blocks and are robust enough to survive a considerable beating. Contrary to their appearance though, Suuntos are far from waterproof and only a minor dunking or even an unusually humid cave can cause the insides to mist up and render them unreadable. An immediate solution that sometimes works is to warm them over a carbide lamp flame. Careful, the plastic parts do burn and the mist usually reappears as the instrument cools. You can reduce the risk of condensation by warming instruments to or above the cave temperature before you use them – carry them in an inside pocket. Limited waterproofing has been achieved by covering all joints in the instruments with epoxy resin. They then leak more slowly.

After each day's surveying, bring the Suuntos out of the cave and dry them in the sun, jar of silica gel or carbide. At special request to the manufacturer it is possible to buy them with small screw-in plugs in the side that you can remove to simplify drying. Other compasses such as the Silva 54NL and a similar Suunto KB-77 model have a direct sighting lens on top of the instrument that cannot mist up, making them far superior to the KB-14. Complimentary clinometers are also available.

Suunto kit

Suuntos are easy and fast to read in the full light of day, but once underground you need a good light to see the face of the dial clearly. In most cases it is necessary to externally light the face of the instrument. A removable back-up or hand held electric is ideal for this as it is safer and easier than removing your helmet for each reading.

Cavers often place a light hard up against the instrument to make the dial easier to read and while this is fine for the clinometer, the electromagnetic effect and steel components and magnetic switches in the lamp will affect the compass. Carbide lamps too, may have enough steel pieces to upset a compass. Keep any lamps, battery packs or generators a safe distance away.

Always read the left side of a Suunto clinometer – the right is a percentage scale. Also remember that the scale on the compass is backwards (right to left). Read sighting compasses with one eye only to avoid the possibility of a 3° or more parallax error.

Most compasses only work well in a horizontal plane, or close to it. When you're taking a steep reading there is no option but to sight to an imaginary point above or below the station. This is easier to do when sighting up rather than down and for the sake of accuracy, avoid steep down-sights.

Use a 30 m PVC coated fibreglass tape in an open reel so that it will not clog with mud. Steel tapes are heavy, break easily, difficult to use and may affect compass bearings.

Laser distance measurers

Hilti PD-32

Tapes are rapidly being replaced by laser distance measurers. They are very accurate, fast, sufficiently robust (although, clearly, not as robust as a tape!), and very expensive. The original is the Leica 'Disto'. As time goes on, more and more copies and new versions with more features are appearing, such as the Hilti illustrated. It is small, fast so that you don't have to hold it on target for long and has an excellent optical sight for use in sunlight where the laser spot is often impossible to see. As I write, Leica has released the 'A8' with a built-in clinometer. It's not cheap and still has no compass. Like anything, you must use them correctly. You can measure a distance to almost anything, so be careful that you are actually taking a distance to the station. The survey notebook makes a good target. Lasers require extra care as they can damage your eyes. The target holder should close their eyes or look away, while the instrument man should avoid shining the laser at people's faces. They are probably more dangerous while they are actually measuring rather than when they are only 'pointing'.

Topofil

Topofil kit

In its simplest form a topofil consists of a small box that contains a roll of thread and distance counter. A topofil offers some advantages over a tape:

- It is lighter.
- No distance limit between stations, which is ideal for big pitches.
- The thread is sighted along, increasing the accuracy of high angle compass shots.

More advanced topofils use a compass and clinometer adapted to read along the thread laid from one station to the next. These are a separate unit or mounted in the topofil box provided it contains no magnetic components. Commercially available topofils specifically for caving use are restricted to the Vulcain. The Vulcain model is a complete unit with detachable compass, however they are only sporadically available from the Club Vulcain in Lyon, France and as such are hard to get. This rarity and design limitations make constructing one a reasonable alternative.

Unlike Suuntos, topofils have no optical sighting, therefore there is never a problem with them misting up or the need to put your head in strange positions to read them. They are fast to use, can be operated by a single caver and with practise offer a degree of accuracy unequalled in other hand-held survey instruments.

Topofils have more working parts than tape and require a light touch to run well. If you use it roughly the thread can break or snag as it pays out and you need to open the instrument to insert a new roll of cotton when the old one runs out.

Topofils leave a thread line throughout the cave that you must collect on your way out. Use cotton thread so that if you accidentally leave any behind it will eventually rot.

Electronic instruments

iDigital 'topofil'

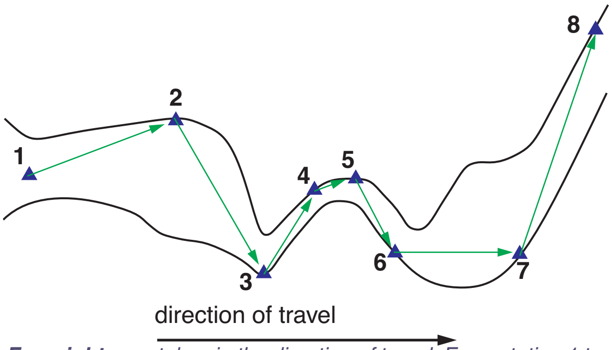
TopoScan

As an experiment, I have mounted an electronic clinometer and electronic compass onto a Disto. The unit is something like a 'digital topofil', without the thread. Once calibrated, the clino and compass 'sight' along the laser beam. Shine the laser at the target, press the hold button on the clino, then the hold on the compass, then take the distance. You can now read off the instruments at your leisure rather than at some awkward angle. The procedure is simpler than Suuntos, and not as easy as a topofil, but you don't have to look after a thread. You also still risk the possibility of a transcribing error between the instruments and the book. Hopefully you'll make fewer errors transcribing the digital readouts than you would for analogue instruments.

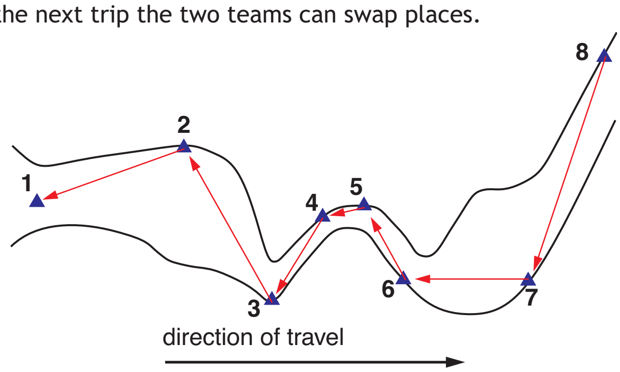
The ultimate cave surveying instrument is the much more sophisticated and even more experimental. 'Toposcan' is made by a French/Quebec group. It combines the three instruments into a single unit. A single press of button sends the distance-compass-clino reading directly to your Palm PDA—no more transcribing errors. With a Toposcan it should at last be possible to survey at a reasonable speed, if you can find one.

Tactics and procedure

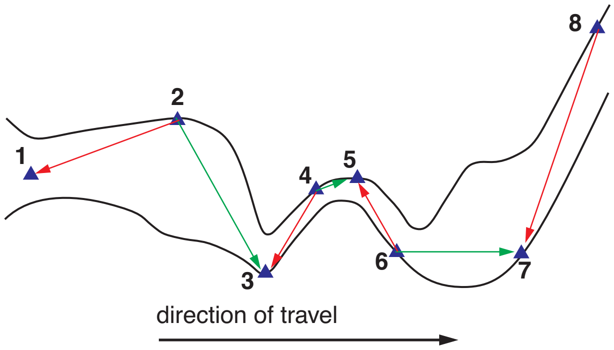
'Survey what you explore' is a good rule and one that has caused many an argument when broken. A reasonable compromise is to have one or two cavers rigging and a survey team following along behind them. On the next trip the two teams can swap places.



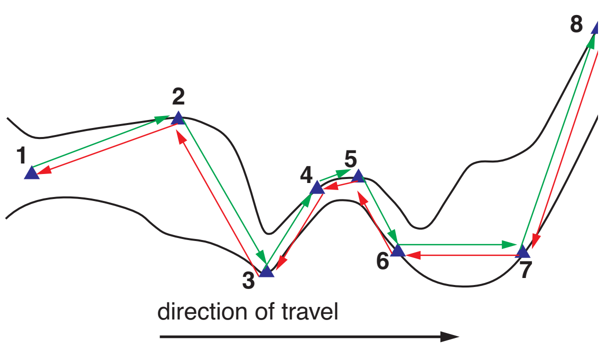
Foresights *are taken in the direction of travel. From station 1 to 2, then 2 to 3, 3 to 4, etc. It is the simplest, least confusing method of gathering data, especially when using tape and compass.*



Backsights *are taken facing opposite to the direction of travel. From station 2 to 1, then 3 to 2, 4 to 3, etc. This is the preferred method for topofils.*



Leapfrog *is taken in both directions alternately. From station 2 to 1, then 2 to 3, 4 to 3, then 4 to 5, etc It gives the maximum survey speed for tape and compass and minimises systematic errors.*

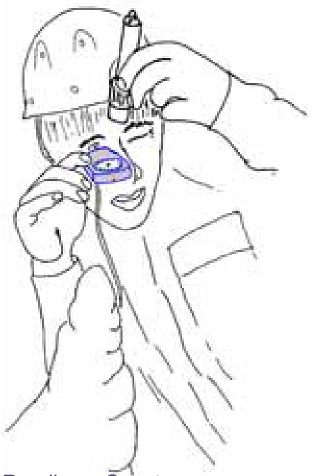


Fore *and* ***Backsights*** *are taken in both directions from each station. From station 1 to 2, the 2 to 1, 2 to 3, 3 to 2, to 4, 4 to 3, etc. For maximum accuracy.*

For ease of understanding the data and its later reduction, it is best to maintain the survey direction. If you begin the survey at the entrance of a cave you should continue down the cave, starting each new day's surveying at the end point of the day before or some other known point along the way. Surveying down one day then the next day going past the end point and surveying back to it leads to confusion. Consistently surveying from a known point keeps survey data as a continuous series instead of a collection of little pieces that you have to tack together or reverse to calculate the total displacement from the starting point. It's not that the data is 'wrong', just that easier to understand data means fewer problems later outside the cave.

The data you collect will be easier to understand and therefore mistakes are less likely if you take all survey sights in the same sense; either all forward sights looking in the direction of travel or a series of backsights looking back along the cave just traversed, but not a mix of both. If you're forced to take a sight in the opposite sense, note it well in the data and avoid mentally reversing it in the cave. A mistake could well be undetectable except that in the final map, when something looks wrong.

Tape and compass



Reading a Suunto compass

Reading a Suunto clinometer

A team of three is the ideal for a tape and compass survey: one to read the instruments, one to manage the tape and a third to take the notes and sketch the passage. If you use a Disto instead of a tape, the instrument reader can also use the Disto and the ideal team becomes two.

The note-taker is the 'boss' and in easy passage the survey will move only as fast as the sketcher can sketch, while in difficult passages the instrument reader will be the rate determining factor. When there are only two surveyors the note-taker handles an end of the tape as well.

Tape and compass surveys are usually done as a series of forward sights. In essentially 'down' caves however, it is far better to survey facing uphill, taking 'backsights' so you can read the compass more easily.

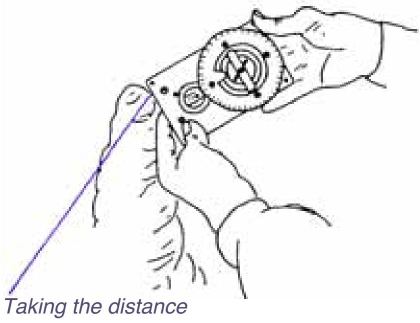
Begin the survey at a cave tag or marked point at the entrance. The tape reader waits at the entrance while the instrument reader runs the tape down the cave and finds a 'station' from which the tape reader is visible as well as providing a good view toward the next station.

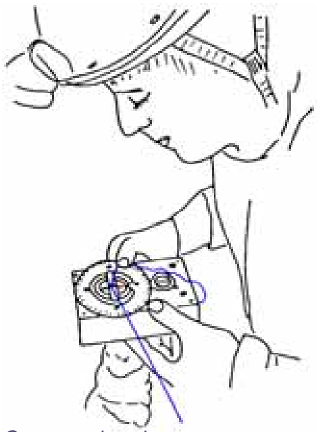
Measure the distance and perhaps move the forward station a few centimetres so as to coincide with a full decimetre on the tape. The tape reader calls out the measurement to the note-taker who repeats it.

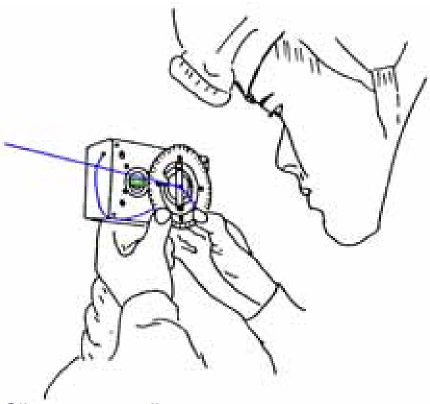
The tape reader 'lights' the station by holding a light on or behind it or by putting a finger on it and lighting that. While lighting the station they call out 'left', 'right', 'up' and 'down' estimates and rewinds the tape. Meanwhile, the instrument reader sights the compass and calls the figure to the note-taker, who repeats it, then the same for the clinometer. Before moving on they make sure that the note-taker knows where the station is so that they can include it on the sketch. The instrument reader then moves to the next station where the tape reader points out the station's precise location, leaves the end of the tape and moves down the cave in search of the next station. The note-taker travels either between or behind the other two surveyors.

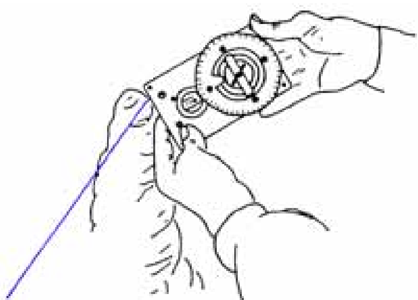
Using a topofil

Topofil


Taking the distance


Compass bearing


Clinometer reading


Finding the correct position on the thread

A topofil survey is most efficient with two surveyors: one to read the topofil and the other to take notes. When a team is short-handed you can do a topofil survey alone with no loss of accuracy although it will be slower.

Topofil surveys run easily down a cave taking a series of backsights and leaving a trail of thread behind. If the thread breaks on a pitch or difficult passage you can leave that one sight for the return trip rather than having to do the pitch an extra time.

The instrument reader begins by pulling out enough thread to tie off to the entrance station then calls out a 'first topo' to the note-taker, who repeats it, then runs out a straight line of thread to the next station. Preferably choose a small projection you can later wrap the thread around, that also has a view forward. After calling out the distance, hold the topofil above the station or in line between the stations and take a compass reading and call it to the note-taker. Next, hold the instrument beside or in line with the station and take the inclination. The note-taker repeats all readings. Be careful to ensure that the thread is not snagged between stations and do not allow it to sag while taking clinometer readings.

After you have taken the readings, wrap the thread around the station two or three times by pulling sufficient thread as stretch from the leg that you've just measured.

Find the exact point on the thread by making a mud mark on it at the correct point when the distance is taken or by running the topofil past the station until the thread begins to run and taking the point on it where it passes the station. If there are no projections to tie the thread to, anchor it with a rock or ask the note-taker to hold it.

New ways of surveying

New faster surveying instruments are shifting the balance so that the sketcher doesn't have a hope of keeping up. If you want a really detailed sketch you don't have much choice but to travel at the speed of your team artist. One option is to just neglect the sketch and use the left, right, up and down data to computer generate the map. For large caves that will be drawn at scales larger than 1:1000, this may well be adequate. Another approach is to enter your data directly into a Palm PDA using Auriga software and plot as you go. All you record on paper is the sketch and the Auriga plot helps a lot with that. With practise, this could save you some time in the cave, and considerable time in the drawing up phase. If you have time and resources you can take the data and mark the stations on one trip, then return with a print of the line plot and sketch-in the details.

Thirty minutes later, against the same wall, as the instrument man and I fade off into the calm world of hypothermia-induced sleep, we begin to dream of rainbows, lollipops, and the cave collapsing on the sketcher. When we finally awake, another 30 minutes has gone by and the sketcher has at last caught up with the survey. Disappointed by the lack of sweets, happiness, and dead sketchers, we carry on to the next station. —Brandon Kowallis, NSS News, August 2006.

Survey stations

Choose stations that give as long a sight as possible in each direction as well as being easy and comfortable to reach while taking the sight. Don't, however, exceed 30 m and for accuracy, try to stay below 20 m. Stations should always be a fixed point on the wall, roof or floor. This minimises station error and makes it possible to accurately mark points for future use.

In complex caves, cave systems or areas with several separate caves, systematise the station labels or names so that each survey is readily identifiable. Do this by assigning a unique alphanumeric label for each station.

Eg. N 2 7 0 6

where:

N = letter to indicate the cave or area within a cave

2 7 = two digits to indicate the day of the expedition or date and thus identify each section of the N survey

0 6 = two digits to indicate the station number within the N27 survey

When you survey more than 100 stations in one day change the date numerals. ie. The station after N2799 could be NB700 or N2800. All this information is not needed for each station in the field. What is required is that you mark each page of data clearly with the appropriate letter and number. In simple or isolated caves it is sufficient to assign station numbers only. Other labelling schemes that provide unique station numbers also work. One thing to avoid is to split a series and use the same series of labels in two distinct sections of caves. This easy leads to confusion as it is quite natural to assume that like numbered items will be near each other.

Mark some stations such as those at junctions and the end of a day's surveying. Do so in some semi-permanent manner such as a strip of note paper or flagging tape tied to the station or a cairn built with one of its rocks bearing the station number written in carbide. There is no need to go through and label each station nor is it necessary to write station numbers on the cave walls. When you label a station write the complete station number so as to make it readily identifiable should another survey connect to it.

Before entering a cave to continue a survey, note down the tie-in station and the correct series of station labels you will use that day.

Surface surveys

At the cave entrance, 'tie' the survey to a permanent station whether it be a tag, painted number or point chipped into the rock. Later you can locate the exact position of the cave entrance by surveying to some known point such as another cave tag, local bench mark, trig point, corner of a building marked on a topographic map of the area or fix the point using GPS.

In some areas it is valuable to survey to the resurgence of the cave be it proved or only suspected so as to give a more precise estimate of depth potential than is available from some topographic maps.

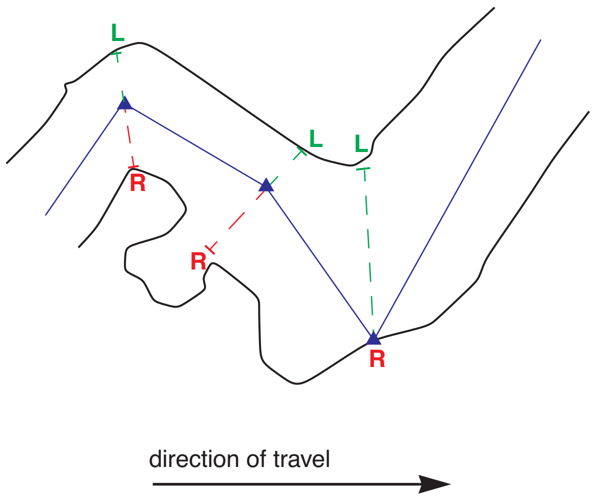
Use Suuntos or more accurate instruments for surface survey and only use topofils to measure the distance component. Even a light crosswind will displace a topofil thread enough to give a compass error of several degrees.

In open country it may be difficult to use fixed stations that are not on the ground. Rather than lay on the ground for each leg, sight to a vertical stick with a bright mark on it at the same height off the ground as the instrument reader's eye level. Take length measurements with a tape, topofil or rangefinder. Laser distance measurers can be difficult to see in bright sunshine. For accuracy avoid the temptation to use long sights—keep survey legs to a maximum of 30 m.

Data collection

The notes and sketches that a surveyor makes should be of such a standard that someone can draw up the map with no prior knowledge of the cave. To this end, note your data systematically and consistently. A reliable method is to use a small pad with removable sheets of waterproof paper printed with boxes to format the data on one side and a grid to make sketching the passage shape easier on the other.

The minimum data you must collect in the cave is station number, distance, bearing and inclination. To these, add estimates of left, right, up and down (LRUD) distances to the walls, roof and floor. There is no recognised convention for these. However it is most reasonable to take LRUD data while facing in the direction the survey is travelling. Remember, they are estimates that reflect the general passage form and should be the average distance to the walls, roof and floor from the station.



Left and right data convention

Another convention you must decide on is the exact direction of left and right. The option that involves minimal notes and gives a good representation is to take the left and right data in the direction that bisects the angle between the two sights. Up and down are best left as true verticals.

LRUD data are essential for good computer graphics and give scale to the sketches, making drawing up of the final map easier than relying on sketches for information that is difficult to show. eg. If the surveyor is sketching a plan as he goes, the up and down data automatically give a passage height.

Contents Index

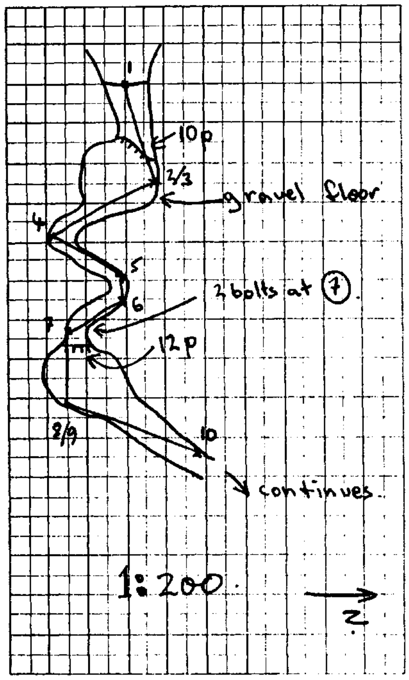
Survey data sheets

CAVE Nada Cave							DATE 15/5/88
SERIES N2701 – 10							SHEET 1/1
SURVEY BY A.W.							
STN	TOPO	COMP	CLINO	←	→	↑	↓
N2701	062	—	—	1·2	1	0	1·5
2	119	250	20	0	4	1·5	10
3	217	0	90	0	4	11·5	0
4	281	330	-15	1·4	0	3	2·5
5	328	208	41	0	0·8	4	2
6	344	262	-8	0	0·8	4	2·5
7	389	332	52	1	0	5	1·5
8	435	270	-20	3·5	0	10	12
9	555	0	90	3·5	0	22	0
10	637	198	-7	0	1·2	1·5	1·2

Topofil

CAVE Nada Cave.					DATE 15/5/88		
SERIES N2701 – 10					SHEET 1/1		
SURVEYORS AW					Backsights		
STATION	~~TOPOFIL~~ TAPE	COM-PASS	CLINO ±	←	→	↑	↓
N2701	5·7	250	20	1·2	1	0	1·5
2	9·8	0	90	0	4	1·5	10
3	6·4	330	-15	0	4	11·5	0
4	4·7	208	41	1·4	0	3	2·5
5	1·6	262	-8	0	0·8	4	2
6	4·5	332	52	0	0·8	4	2·5
7	4·6	270	-20	1	0	5	1·5
8	12·0	0	90	3·5	0	10	12
9	8·2	198	-7	3·5	0	22	0
10				0	1·2	1·5	1·2

Suunto



Sketch

Table 10:1 Cave map symbols

▲	marked survey station		mud
sketch / topofil	change of survey grade		flowstone
a a'	cross-section plane	old new	stalagmite
	unsurveyed passage	old new	stalactite
	abrupt change in floor		flowing water
	sloping floor		standing water
	boulders or blocks		sump
	rockfall		airflow
+ + + + +	crystals		doline
o o o o o	gravel		shaft
	sand	marble → slate	change in rock type
10p	pitch (with height)	5c	climb (with height)

After Anderson, 1978. For official international symbols, see: www.carto.net/neumann/caving/cave-symbols/

Draw sketches of the cave passage as a series of small plans or occasionally sections, with all stations and pitches marked to simplify the drawing up. As a check, keep the plans to scale and orientation so that you will notice a wrong figure from the instrument reader in the first instance. Draw cross-sections, perhaps at a larger scale, to show passage shape or help explain a complex piece of passage. Note a provisional tackle list along with the sketch.

Take down sketches and data with a soft mechanical or self-sharpening pencil. Carry the pad, pencil, spare pencil, marking pen and flagging tape in a pouch that hangs around your neck.

If you make a mistake during note taking, cross it out neatly and rewrite it. Never obliterate an original, as it may useful in sorting out a more serious problem later. Sketches on the other hand may become an unreadable mess if you do not erase errors.

At the end of each days surveying remove the used data pages from the pad so as not to risk losing them in the cave on a later survey trip and transcribe the numerical data into a master data book or computer so as to give a duplicate copy.

Be sure to include information such as members of the survey party, full name of the cave, date and instruments used on the first page of any series of data or attached as a separate title page.

Plot a traverse line as soon as possible and have the person who took the original notes draw on the wall detail. Mark pitches, climbs and squeezes and write up an accompanying tackle description or note the information beside each pitch. The original note taker should do as much as possible so that the final drawing up will be as easy and accurate as possible.

Standard symbols

Only the neatest of note takers can use the full range of symbols in their original cave sketches and have them correctly interpreted later. Use a few written words and an arrow to indicate where and save the pretty symbols for the final drawing. Large caves are often presented at scales of 1:1000 or more so it is impossible to note much more than the passage outline, water, airflows and the occasional large block.

Survey accuracy

Precision is the reproducibility of data and is reflected by the fineness to which the instruments can be read; theoretically half of the smallest unit marked on the scale. Topofils should be readable to half a degree in compass and clinometer and half a centimetre in distance. With Suuntos and tape this is a quarter of a degree for the compass and half a degree for the clinometer and usually half a centimetre for the distance. In any survey, the station error (distance the instrument actually is from the station) and movement in the hand-held instrument is so great that anyone who reads to that precision is fooling themselves. It is only reasonable to read to the nearest degree and nearest 5 cm when you are surveying **carefully**.

Accuracy is the distance a surveyed point lies from the 'truth'. It is largely affected by the skill of the surveyors and the precision of the instruments.

Any survey point lies within an area of uncertainty, the size of which you can estimate. The simplest means of checking the accuracy of a survey is to map a closed loop and calculate the difference between the two end points that are supposed to be the same. This difference is the 'misclose' and is rarely zero. A loop that closes within acceptable limits is probably alright, one that is outside the limit suffers from one or more gross errors.

Estimating survey accuracy

You can estimate the theoretical accuracy of a survey using Random error curves for Suunto and topofil surveys on page 181. These give an expression of the possible accuracy that the instrument and survey can produce given certain parameters but cannot take into account gross errors such as how well the instruments were really read, excessive station error, data collecting errors, magnetic errors or systematic errors.

Use the curves to estimate the expected accuracy of an open survey as well as to check if the misclose in a loop is within acceptable limits.

You can expect a perfectly executed survey to lie within the theoretical range and in practice this is usually the case for the vertical while the plan is usually within twice this value. Surveys lying up to twice the theoretical value for the elevation and three times for the plan are still regarded as acceptable even though they are obviously affected by some gross error(s). This difference between the magnitude of the acceptable error in plan and elevation is due to the comparative difficulty in getting accurate readings from a compass as compared to a clinometer.

You can eliminate most of the potential gross errors in a survey by taking back-bearings on each leg with a separate compass and clinometer as a check on misread instruments.

Altimeter

In most vertical caves it is not possible to survey a loop that takes in the extremities of the cave, though minor loops will at least indicate if the surveying is generally up to standard. Use an altimeter as a control to take a series of readings at known stations on the way down and back up the cave and if possible leave a second altimeter on the surface to record pressure variations caused by weather changes. A good altimeter 'survey' should give readings that are within ±25 m of a good survey.

There are several variables to take into account when you do an altimeter survey. The pressure difference either side of a strongly blowing squeeze can give altimeter errors up to 100 m. Fortunately, this is a local phenomenon and reading quickly return to normal as you move away from the disturbance. One thing to specially take note of is the temperature adjustment that any altimeter requires—even a temperature compensated altimeter. An altimeter can only read the weight of air pushing on it. It 'knows' the altitude it is at based on a standard column of air that has a standard temperature gradient. As you climb a mountain the temperature often drops tens of degrees. As you climb up cave, it's temperature may drop two or three degrees.

Table 10:2 **Standard temperatures**

Altitude (m)	Temperature (˚C)
0	15.0
200	13.7
400	12.4
600	11.1
800	9.8
1000	8.5
1200	7.2
1400	5.9
1600	4.6
1800	3.3
2000	2.0
2400	-0.6
2800	-3.2
3000	-4.5

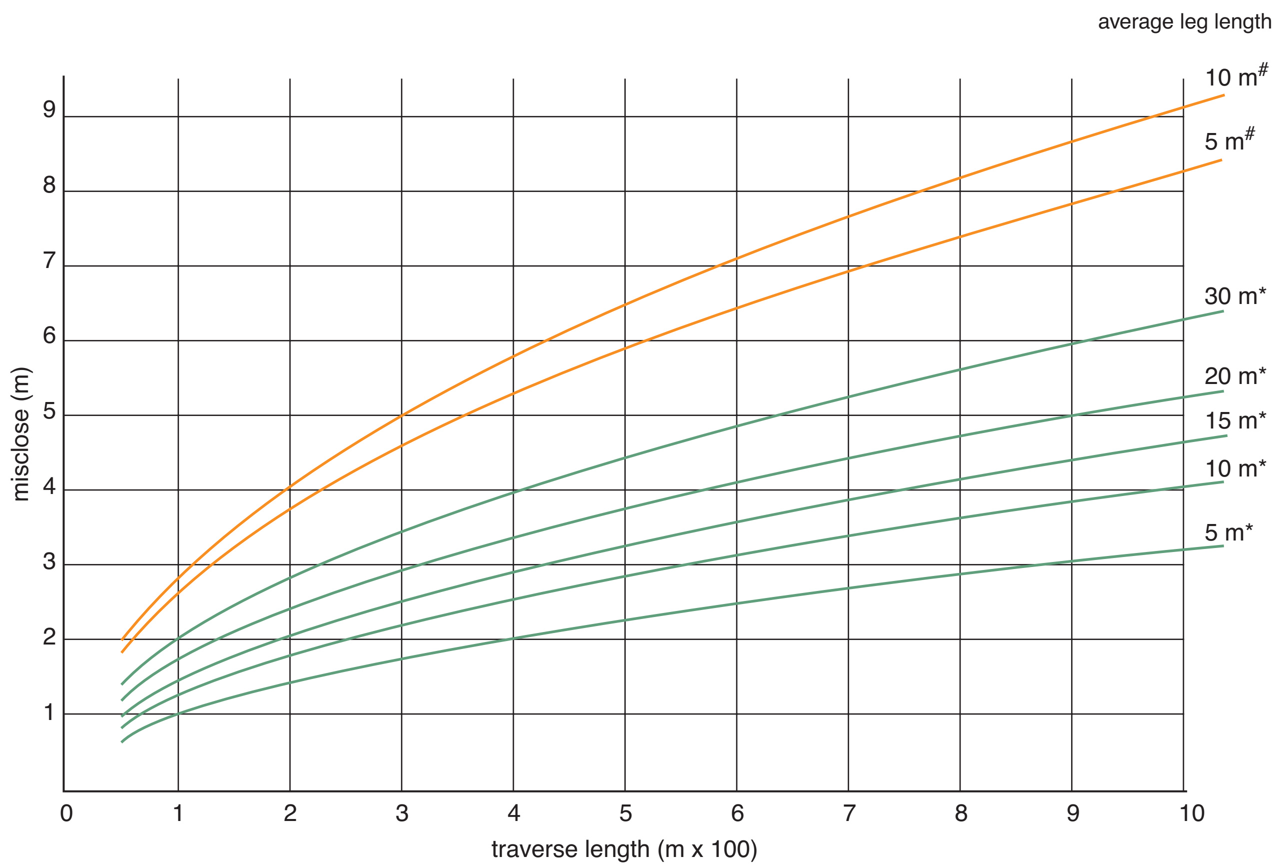
If the sum of the temperature offsets from the normal temperatures (from Table 10:2) at two different altitudes is 1 ˚C, the altitude difference calculated by your altimeter is 0.2% off the real altitude difference (Suunto, 2003).

To temperature compensate altimeter depth readings:
• Calculate offset between the normal and measured temperature for each point
• Add the two differences
• Altitude error = sum of offsets x measured altitude difference x 0.002.

For example, the figures below are from a recent trip with a surface control:
entrance alt= 2232, temp = 20: offset = 19.5
camp 2a alt = 1377, temp = 13: offset = 6.9
so, 26.4 x 855 x 0.002 = 45
855 + 45 = 900 m (surveyed depth is 901 m)

While I can't advocate mapping a cave with an altimeter alone, if you encounter a discrepancy between the altimeter and traditional mapping, you can narrow down the location of the problem and check the survey.

Random error curves for Suunto and topofil surveys



Good survey:
station error ± 5 cm, distance error ± 5 cm, compass/clinometer error ± 1°.

\# *Rough survey:*
station error ± 20cm, distance error ± 20cm, compass/clinometer error ± 2°.

Systematic errors

Systematic errors are those inherent in the design or calibration of the instruments as well as the way you read them. Systematic errors are not random but accumulate, making the accuracy of the survey worse with increased length.

A wrongly calibrated tape for instance, adds to or subtracts from each measured distance, making the cave bigger or smaller than it really is. A poorly calibrated compass will give a constant error that has the effect of turning the north arrow on the finished map through the number of degrees it is out of calibration. Similarly a maladjusted clinometer will affect the overall angle of the map, reducing or increasing its depth and possibly 'causing' streams to flow uphill. If you survey the entire cave with the same instruments it only requires a minor adjustment in the final drawing up, but when several instruments are involved, all with different calibrations, it can result in considerable confusion. Surveying a test loop will not easily detect these systematic errors. Comparison with a standard is the best way.

Systematically misreading instruments can also accumulate errors. A surveyor sighting with a Suunto to the light of an assistant of the same height adds 15 cm to the vertical difference between the two stations and this accumulates for the length of the survey. A 200 m leg survey would be 30 m out from this error alone!

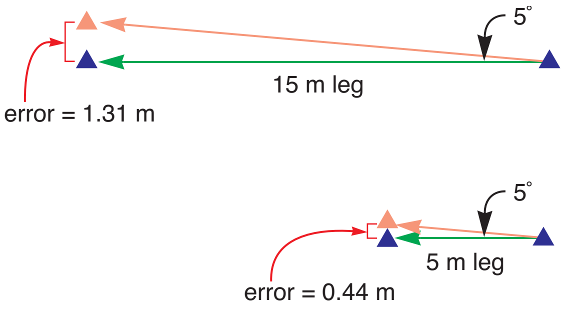
Check your instruments before a surveying project and periodically during it to ensure that they really do point north, horizontal and measure distance correctly. Test compasses against each other. Check clinometers quickly by putting them on a flat surface, taking a reading, turning them through 180° and taking a reciprocal reading. Test surveyors and instruments by surveying a known non-horizontal test triangle in both directions.

Note any errors in the instruments and correct them if possible. Otherwise, clearly mark the original notes and allow for the deviation by adding or subtracting it as a zero error when you calculate the data.

Minimising errors

Random errors tend to compensate for each other as the number of survey stations increases. Compensating errors may allow a rough survey to give a good closure even though each individual point on the map is well displaced from where it should be. This is not to say that you should ignore random errors. There are several procedures you can follow in order to minimise both random and systematic errors.

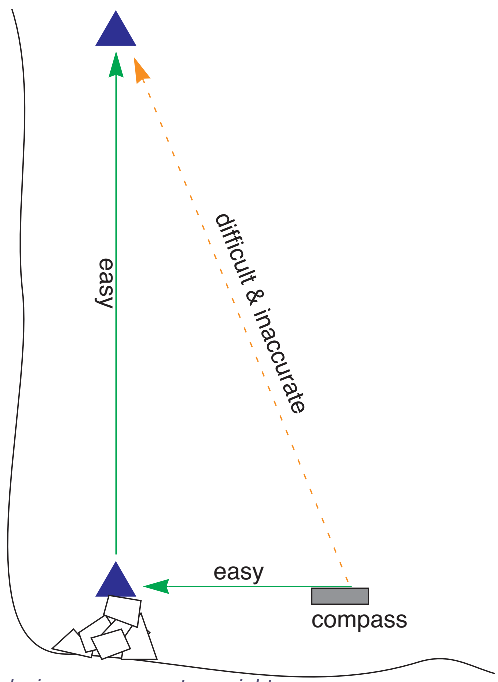
Leg length



Comparative error in short and long survey legs

Long leg length magnifies compass and clinometer errors and gives less accurate final displacement than a series of short sights. If you're using a topofil or rangefinder, avoid the temptation to take sights longer than 30 m. The optimum leg length is a compromise between station error and instrument reading precision (see Random error curves for Suunto and topofil surveys on page 181). Roughly located stations favour long survey legs while low compass precision favours short survey legs. On pitches where the difficulty of getting any sight may outweigh the need for accuracy, try to keep the pitch length as a true vertical.

High angle readings

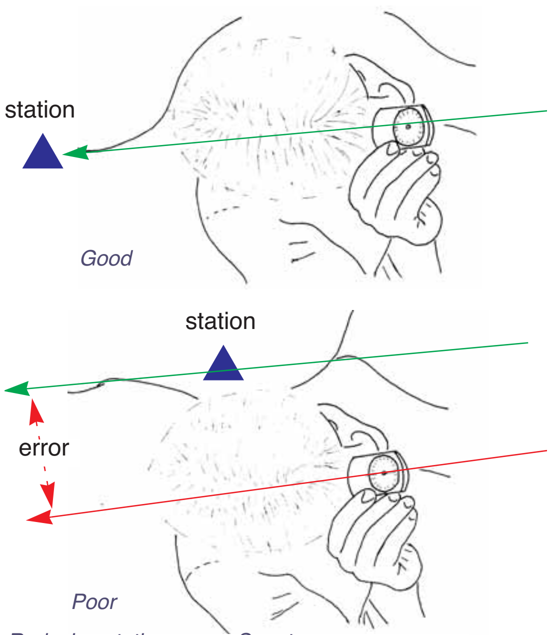


Reducing error on a steep sight

Compasses become increasingly difficult to read accurately as the angle of the sight leaves the horizontal. On high angle legs, improve accuracy by taking a vertical then a low angle sight rather than one high angle sight. On up sights droop the tape between the stations after you take the length and sight the compass to the tape. Most topofils do this automatically. Another possibility is to dangle the clinometer from its string as a plumbob at arm's length to line up the survey station with a spot on the wall at the same level as the surveyor. Sight the compass to the spot or the plumb line.

High angle compass error is mitigated by the fact that as the angle of the sight becomes steeper the possible displacement error from a rough compass reading decreases (a similar effect applies to low angle clinometer readings).

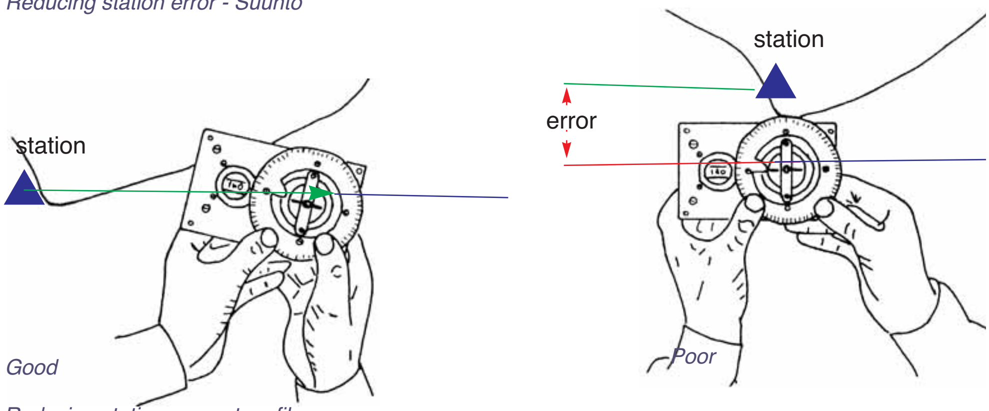
Station error



Reducing station error - Suunto

Avoid 'floating' stations such as sighting to the light of someone standing in mid-passage. The person holding the other end of the survey can never faithfully relocate them. When sighting it is often better to hold the instrument in line between the two stations rather than as close to the station as possible. This is especially relevant to Suuntos where the thickness of the surveyor's head can create a considerable station error. Topofils are more naturally held in line and their small size keeps the station error small when this is not possible.

The significance of the station error is especially great for short survey legs and diminishes with increasing leg length.



Reducing station error - topofil

Transcribing errors

Transcribing errors are common in cave surveying and once a reading is taken wrongly, it is difficult to identify as wrong and in need of checking. At least one survey program (Compass) attempts to find transcribing errors using statistical analysis of closed loops. Do not remember readings, note them down as the instrument reader calls them out. A roughly oriented sketch will help you pick up badly wrong compass readings. Have the note taker call back all readings including the sign of clinometer angle for confirmation. Short leg length aids communication. Do not mentally reverse readings while in the cave. Note the reading as given and indicate beside it whether it is a back or fore sight if it is different from the others. Direct entry into a PDA using Auriga reduces the problem. TopoScan will solve it.

Magnetic errors

Keep anything electrical or magnetic well away from compasses. Be especially careful of holding a hand torch and anything with a magnetic switch too close when lighting the compass dial. The bigger the piece of steel the worse the problem.

Rope lengths

Do not measure pitch length by using a 'known' rope length. The rope will almost certainly have shrunk since it was last measured and knots, rebelays, deviations and non-vertical hangs upset the calculation further. At worst, measure the rope length after derigging provided it was rigged as a freehang.

Training

Be sure all surveyors and assistants know what they are doing, have practised using the instruments and understand the surveying style required.

Computing

Even in the most remote location it is possible to process raw survey data and have it back as an on-screen plot within a few hours of exiting the cave.

It is easiest to calculate data on a purpose designed program such as Compass, Survex or Walls. Most cave survey reduction software can be downloaded for free. Most have been written to solve a specific cave surveying problem, then improved. Download a few, try them out and see that one suits your needs. Whatever software you use, proof read the data you enter as soon as possible in order to pick up any errors in both the data itself and its organisation.

If you're forced to a more basic level by the lack of a computer, calculate X, Y, Z, D data on any calculator that has trigonometric functions by using four simple formulae:

p	= d cos c	p=plan distance
ΔX	= p sin b	c=compass
ΔY	= p cos b	d=distance
ΔZ	= d sin c	b=bearing
D	= sum of p	ΔX=change in X
		ΔY= change in Y
		ΔZ = change in Z

Table 10:3 **Nada Cave coordinates**

Station	X	Y	Z	D
N2701	0.0	0.0	0.0	0.0
2	5.0	1.8	-2.0	5.3
3	5.0	1.8	-11.8	5.3
4	8.1	-3.5	-10.2	11.5
5	9.8	-0.4	-13.3	15.1
6	11.3	-0.2	-13.0	16.6
7	12.6	-2.6	-16.6	19.4
8	16.9	-2.6	-15.0	23.7
9	16.9	-2.6	-27.0	23.7
10	19.5	5.1	-26.0	31.9

Traverse length = 57.5 m

Carefully list the results, then make a cumulative list made of these relative coordinates (ie. relative to the previous point) to give coordinates relative to the starting point.

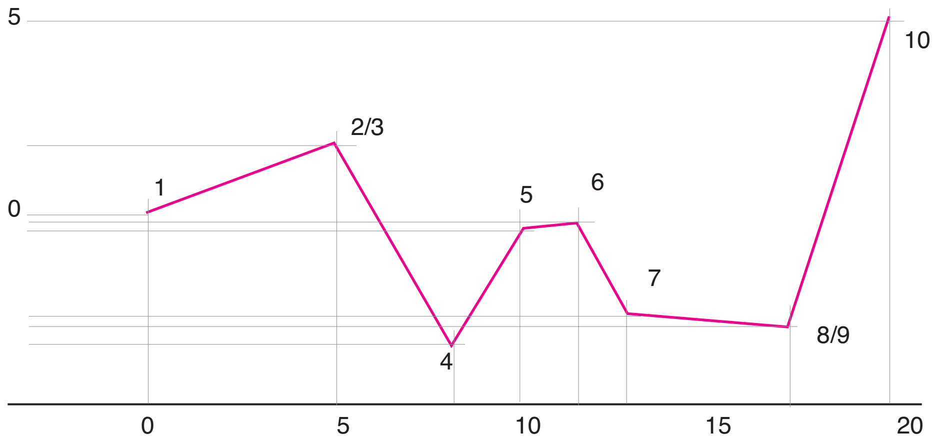
Hand plot the X Y Z D data you've calculated in the field as a plan and projected or developed section at a suitable scale (usually 1:1000) so that it can be used in further exploration of the cave. Once you get the data home you can reprocess it using a more sophisticated program on a bigger computer to get special features such as loop closures and 3-D graphics.

Plotting the survey

Before drawing up settle on a scale that either matches that of other caves in the area or allows the cave to fill the page you are drawing it on. How much hand drawing you have to do depends on the software that you choose. Chances are, you'll have a line plot perhaps with left and right (or up and down points), marked to match your sketch too.

For hand plotting, choose a zero point that allows the cave to fit on the page and draw scales along the margins. Graph paper is better than trying to scale off distances with a ruler.

Traverse line



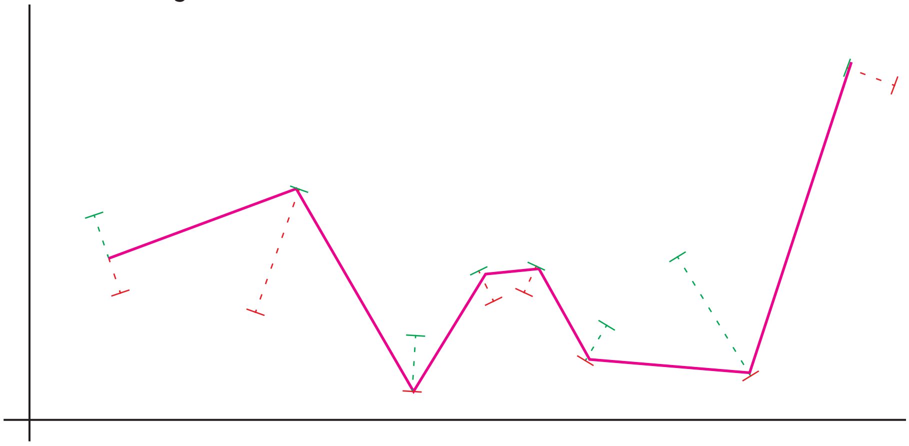
Plot the X (east) ordinate across the page against the Y (north) ordinate up the page.

Label each point with its station number and join the dots to produce the traverse.

Unless the cave is relatively straight it is easiest to plot a few stations at a time, join the dots, then plot a few more so as not to become lost in a page of dots.

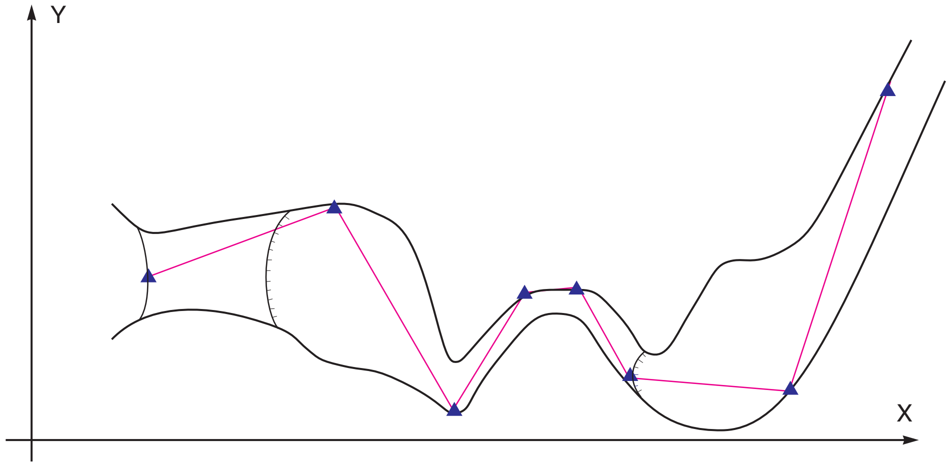
Mark left and right

Lightly mark left and right estimates from each station.



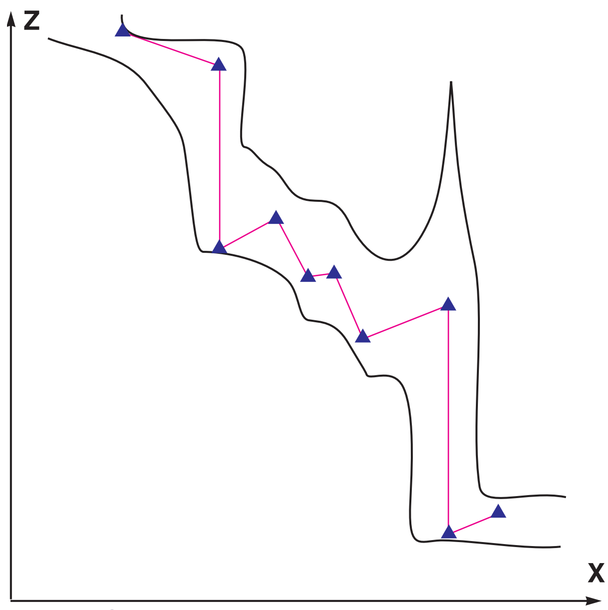
Sketch

Copy the sketch taken in the cave so that it fits the traverse, then fill in the details.



Draw sections (elevations, profiles) in the same manner as the plan but use different coordinates, depending on the nature of the cave and the effect you desire.

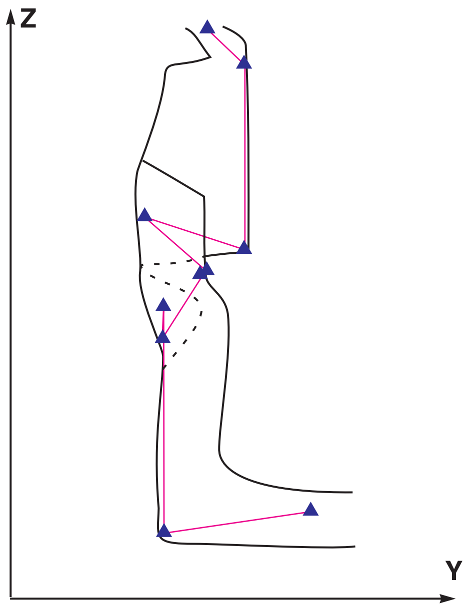
Projected sections compress any part of the cave that does not run parallel to the projection plane and make a vertical cave appear much steeper and shorter than it really is.



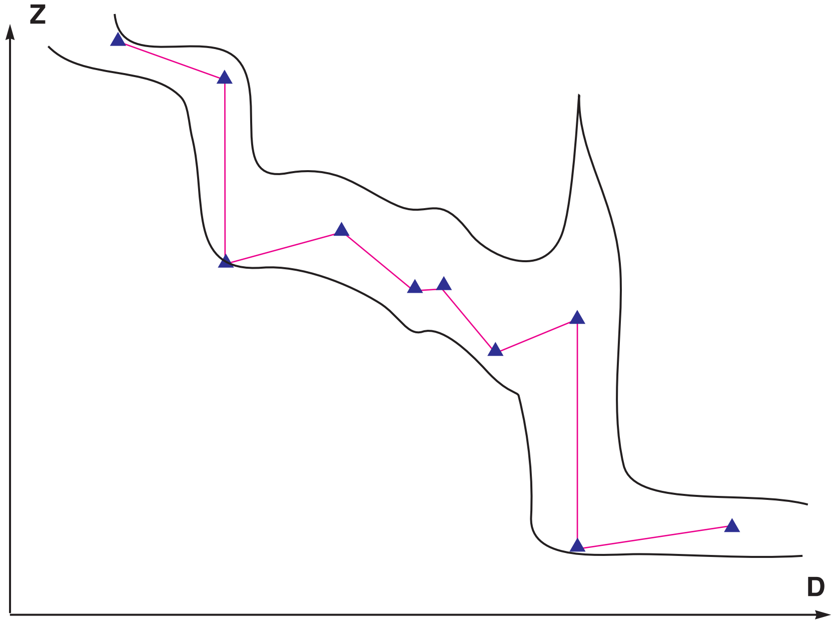
Projected Section, East-West plane

Plot X ordinates across the page against Z down the page and add the walls with the aid of LRUD data and the plan.

Plot Y ordinates across the page against Z down the page.



Projected Section, North-South plane



Projected Section, East-West plane

Plot D across the page against Z down the page to give a right trending plot, that may indeed be what the cave does. Often however caves zig-zag beneath themselves and by referring to the plan you may wish to fold the developed section back on itself when the cave makes a major change in direction. Once you plot the traverse, draw the floor and roof on as before.

‘3D’ view

VRML representation of Nada Cave

Provided you supply LRUD data along with the traverse data, some survey reduction programs can plot a 3D representation of your cave in seconds for on-screen viewing using VRML. Unfortunately, this usually doesn’t translate very well to printed images. Such images usually work better for big, complex systems by making the relationships between the various passages more evident. Small caves tend to look blocky and stylized, while long, straight caves show most of the cave ’too far away’ to be especially useful.

On a small scale (10 stations), Nada Cave on the following page looks too stylised but you could use it to provide the basis for a hand drawn map. However on a larger scale—the 3D of Dead Dog Cave has 700 stations —with hidden lines removed, the plot gives a better idea of what the cave is like than a conventional map. By plotting the same data twice, at viewing angles a few degrees apart, you can generate stereo pairs of the cave.

Ozto Ocotal/J2, Mexico. Photo: Enrique Ogando

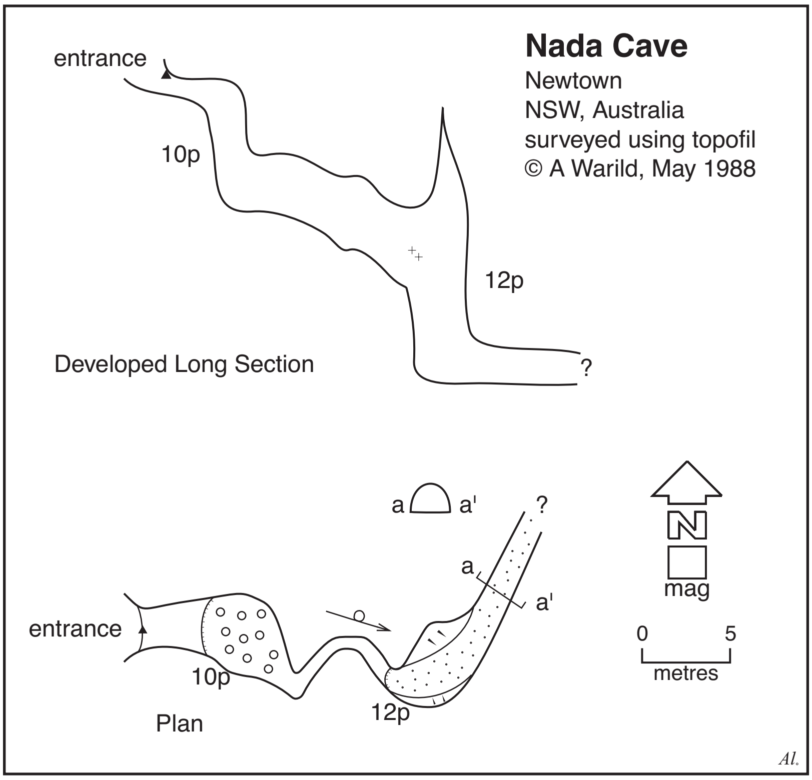
The final product

A line plot on screen or graph paper is all you need in the field. Once the map reaches this stage you can superimpose the line plot over the sketch and trace and adjust it for the final presentation.

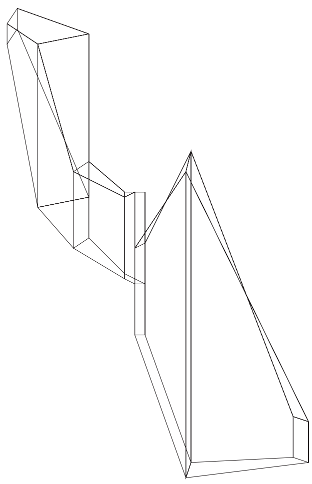
The ultimate product of a cave survey should be a high quality map that is rich in information and self explanatory. It should be accompanied by a tackle description or equipment list as well as a cave description if the cave is complex or the information cannot be clearly shown otherwise.

The map can be a projected section and plan if it is of a system and interpassage relationships need to be shown. A developed long section gives a better representation as to what the cave is really like. It straightens out the cave by showing the true length and inclination for each leg of the survey. However interpassage relationships are difficult to depict as developed sections only show true displacement between any two consecutive points. A developed section needs an accompanying plan to show the actual horizontal extent of the cave.

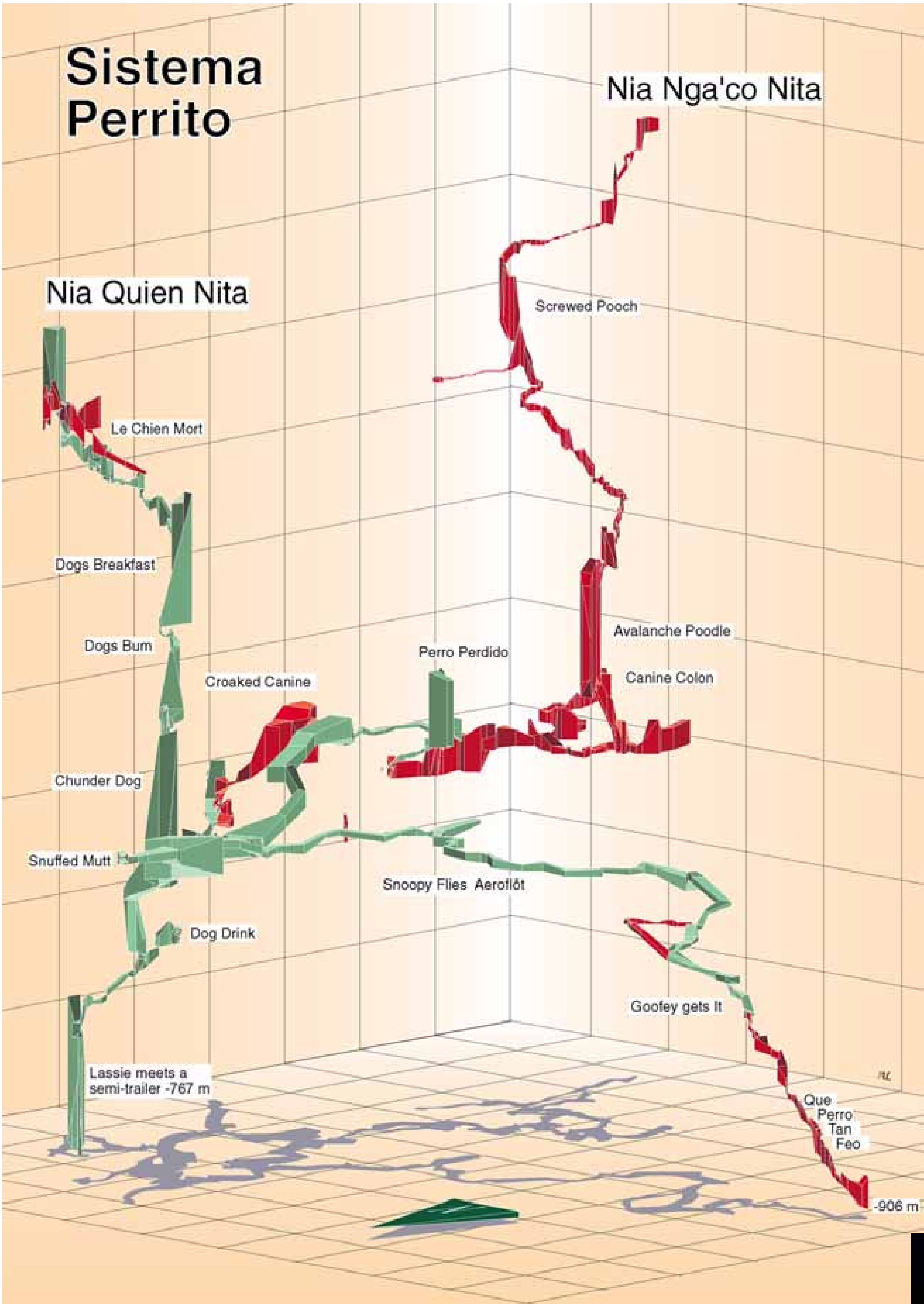
The final scale of the drawing depends on the extent of the cave and the sheet of paper it must fit on for publication. Preferably the scale should be some simple multiple such as 1:200, 1:500, 1:1000 and be represented as a bar scale so that the map may be reduced or enlarged without losing it. Information such as cave name, surveyors, north arrow, date, survey instruments used (survey grades such as M5.4 may be meaningless in another country) and scale can be placed for balance or shown as an information block.



Finished product – traditional



3D skeleton



3D representation of Dead Dog Cave