CAVE SURVEYING

Jim Nieland

Introduction

Cave maps are used by everyone interested in caves; explorers use them to record their exploration, show areas likely to lead to more passage, and to find their way through caves. Geologists and hydrologists use maps to determine how caves formed, and to identify water flow patterns. Microclimate researchers use maps extensively to determine air movement and to record temperature patterns. Biologists use cave maps to plot the distribution of animal species. For the historian a cave map acts like a fingerprint to identify long lost caves or ones whose names have been changed. Cave mapping is the first step in the study of a cave, and the one which can be of the most benefit to the greatest number of researchers. Interestingly enough, most caves are not mapped by scientists but by cavers who survey to record their exploration, or for the pleasure of it. There certainly is a special satisfaction in knowing your visit to a cave will be of lasting value.

Surveying is an activity which can be enjoyed by any interested caver, and which does not require years of study to master. Each of you, even if you have never mapped a cave before, are encouraged to give it a try. I'm sure many of you know someone who would welcome your help on a surveying trip. This is an excellent way to get started and to gain a feel for what cave mapping is all about. The intent of this article is to explain some of the basic concepts and procedures used in mapping a cave, and to show you how to draw a cave map once the survey is completed.

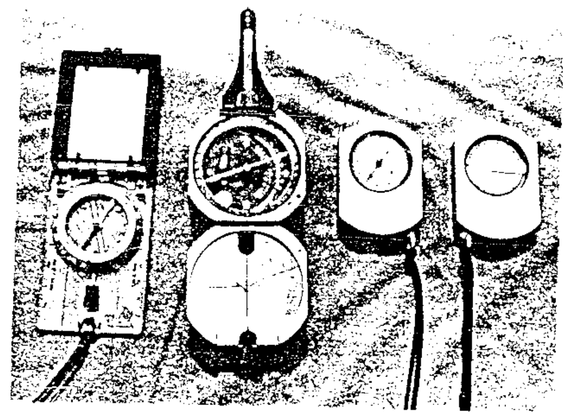


Figure 1. Commonly used cave surveying instruments. From left to right: Silva Ranger compass, Brunton compass, Suunto compass, and Suunto clinometer.

Equipment

The equipment used for cave mapping is simple and rather inexpensive. A compass is needed to determine passage direction, a clinometer to determine slope, and a tape to measure distances. A notebook is used to record all measurements and a running sketch of the cave.

Choosing a compass for surveying can be difficult since there are many choices available. See figure 1. The old standby is the Brunton pocket transit; a sturdy compass in a metal case with a built-in clinometer. Suunto makes both compasses and clinometers in metal housings. These instruments are very accurate but are difficult to read in a cave under conditions of poor lighting. The Suunto compass also has a tendency to give erroneous readings when sighting is attempted up or down steep slopes. The Silva Ranger is a less expensive compass, is suitable for mapping, and has a setting for declination. The Silva is accurate to within ±2°; enough accuracy for most surveys.

There are several scales commonly found on compasses. See figure 2. The azimuth scale runs from 0 to 360 degrees, with 0 degrees being north, 90 degrees being east, etc. The next most common scale is the quadrant. The compass card for this scale is broken into 90 degree quadrants which are read starting at 0 degrees north or 0 degrees south (see illustration). This scale causes confusion even with surveyors who have used it for years, and is a source of many directional errors. The least common scale is in mils and may be found in some old style military Bruntons. A mil is a unit of angle measurement used for military fire and is equal to 1/6400 the circumference of a circle.

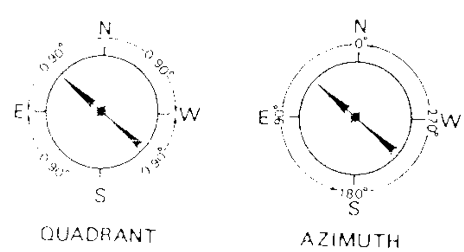


Figure 2. The two most commonly found compass scales are the quadrant and azimuth. The azimuth scale is the easiest to use and usually causes the fewest reading errors

A clinometer is used to measure slope angles. This measurement is necessary for correction of slope distances when plotting the plan view of the cave. Three common clinometers are frequently used for cave surveying; these are the built-in Brunton clinometer, the Suunto, and the Abney. A simple homemade clinometer can also be built using a protractor and a weighted string. Surprisingly, the protractor-clinometer is nearly as accurate as many expensive instruments.

A tape is used to measure distances. The most versatile is made of fiberglass. See figure 3. Steel tapes have a tendency to kink and break, which in the absence of a repair kit has called a halt to many a mapping trip. Tapes come in three standard lengths, 50, 100, and 200 feet. For most caves a 100 foot tape is best. Fiberglass tapes can be purchased loose or in reels. Generally a reel is a good idea. It eliminates having to carry a coil of tape when the full length is not being used. This can be a big help when moving through restricted passages.

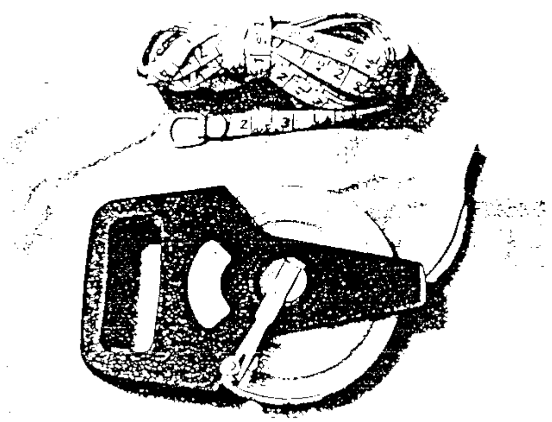


Figure 3. The most versatile tapes are made of fiberglass and can be purchased loose or in a reel. These tapes are very rugged and nearly impossible to break. Following a mapping trip they should be hosed off then allowed to dry before storage.

To record your data you will need a notebook. For dry caves almost any pocket sized notebook will work. In wet caves a waterproof one will be necessary. "Write-in-the-rain" notebooks are available at most surveying and drafting supply stores. These notebooks are filled with paper which will not crumble when wet and remain easy to write on. All waterproof paper, however, is difficult to erase when wet. It is better to cross out the unwanted data and re-enter the correct data on the next line. Also available for the notebooks are heavy plastic covers which provide excellent protection.

The Survey Team

Mapping a cave is difficult to do alone; you will need some help. Two to five and sometimes more people can be used to make up a survey team. Usually a team of three works best, however. In a small cave, or one with restricted passages, too large a team gets in the way and makes work difficult.

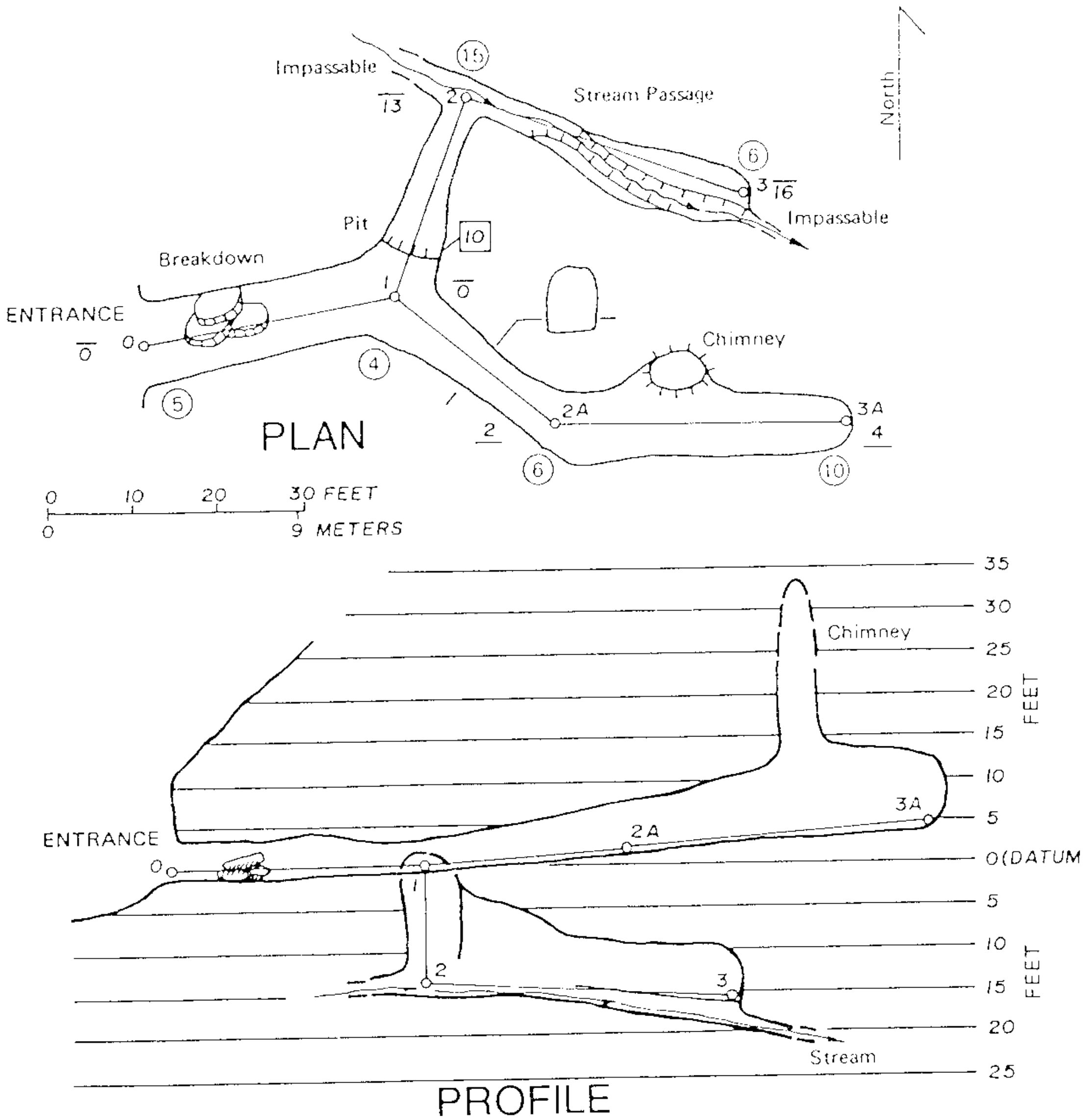
With a team of three, one person establishes stations and pulls the tape ahead, down the passage. A second person (rear chainman) reads the tape, and also takes compass and clinometer readings. The notetaker stays to the rear to record all readings and to sketch the passage outline, profile, and cross sections. In selecting a notetaker be sure that person will also be the one responsible for drawing the map since he will be better able to detect errors if any should occur.

Additional people can be used to read the tape, to measure passage heights, or to measure passage widths. It is sometimes helpful to have a person stand at a station so it is not lost as the rear chainman moves forward. Extra help can also be used to check side leads to see if they will require surveying or just sketching.

Surveying

The process of surveying is rather simple but care must be taken to assure accuracy. The normal process requires the lead tapeman to proceed as far down the passage as possible while remaining at the center of the passage and within sight of the compass man. Exceptions occur when there are side passages or other features which must be accurately positioned on the map. In this event it is wise to establish stations at those points. Once the lead tapeman has selected a station he holds the zero mark of the tape directly above the point while the rear chainman pulls all the slack out of the tape and reads the distance. Next the lead tapeman holds a light over the station for the compass man to sight on. The light should be held at a known height so clinometer readings can all be taken from the same elevation, otherwise an error may result if the cave's depth is being determined.

The notetaker follows the compass and tapeman and records all data. Since the notetaker is responsible for recording data he will be the team leader. He will tell the team which points he needs azimuths and measurements to in order to draw the map. The



STA	AZ.	DIST.	VERT	HT.	WD.
0	80°	30'	0°	5	10
1	20°	25'	-30°	4	12
2	110°	36'	-5°	15	4
3	—	—	—	6	7
1-2A	130°	24'	+5°	4	12
2A	90°	35'	+3°	6	8
3A	—	—	—	10	6

BAT CAVE — ALL AZ TO TRUE N
BRUNTON COMPASS AND TAPE SURVEY, DECL CORRECTION 21° EAST
7/18/77 BY P. SLADE, J. SMITH, AND D. BROWN

Figure 4. A typical page out of a survey notebook showing station numbers, azimuth, distance, vertical angle, ceiling height, and passage width.

notetaker should repeat all readings called out by the rear chainman as a double check for accuracy.

The notetaker must record certain data in order for the map to be drawn. See figure 4. Measured data includes the azimuth between stations, slope, and the distance. At each station the height and width of the passage are recorded. Height and width estimates can be used when distances are under

STATION FROM-TO	AZ	DIST	VERT	HT	WD
0 – 1	80°	30'	0	5	10
1 – 2	20°	25'	-30°	4	12

Method 1

STA.	AZ.	DIST.	VERT.	HT.	WD.
0				5	10
	80°	30'	0		
1				4	12
	20°	25'	-30°		

Method 2

STA.	AZ.	DIST.	VERT.	HT.	WIDTH	
					LEFT	RIGHT
0	80°	30'	0	5	5	5
1	20°	25'	-30°	4	6	6

Method 3

Three methods of recording survey data. Many more variations are possible but these are the ones most commonly used. The format you choose is mostly a matter of personal preference and is not important as long as all the necessary information is recorded and you can understand it later.

twenty feet; over twenty feet accuracy drops off rapidly and more measurements should be taken. If the traverse line does not follow the center of the passage it will be necessary to record the distances to the right and left wall. When the survey notebook is opened there are two pages showing; the left hand page is used for all measured data. The right hand page is used for sketching.

Two different sketches of the cave passages must be made. First is the plan view; this is an outline of the cave as viewed from above. It is important to show and number all survey stations on the plan sketch along with any special features such as streams, pits, pools, breakdown, or speleothems. The second sketch is a profile view as seen from the side. This sketch shows the cave as if it were cut in two vertically; slope of the floor and any irregularities of passage height are drawn. Station numbers must be shown in the profile, though less other detail is needed since it is already shown on the plan sketch.

At each survey station it may also be desirable to draw a cross section of the passage. If passage shape is fairly uniform it may only be necessary to draw an occasional representative cross section. Between stations passage heights may change and should be noted on the plan sketch. Special features between stations can be located by noting their distance from the last station.

When a large room is encountered its outline can be surveyed by setting a station near its center then measuring the distance and azimuth to different points along the walls. The wall shape can then be sketched between measured points and an accurate plan drawn. This same method can also be used to locate important features within a large room.

The speed at which a survey team can move depends on many factors, including the team's experience, difficulty of the cave, and the length of sights which can be made between stations, to name just a few. It is to the team's advantage to take the longest sights possible. This will speed up the survey and also tend to increase its accuracy.

Another way to increase accuracy and reduce the possibility of erroneous readings is backsighting. To do this both the compass man and the lead tape man take sightings on each other. The two azimuths are compared and if they do not agree they are shot over. In the event that no agreement can be reached an average is decided upon and recorded in the notebook. This method greatly reduces the chance for errors and also helps give an indication of magnetic anomalies near the survey stations.

Local magnetic anomalies may at times deflect the compass needle from north and result in erroneous readings. In most solution caves this is not much of a problem; however, in lava tubes it is always present to some degree.

Deflections of up to 20 degrees have been reported from some lava caves. Needle deflection can also be caused by pipes, railings, carbide lamp reflectors, electrical wiring, and even knives, watches, and belt buckles. In lava caves it is best to stay near the center of the passage, away from walls or any large pieces of breakdown, to help reduce the possibility of unwanted magnetic attraction. If an unwanted magnetic attraction is suspected a quick check can be made. Hold the compass firmly in hand, keep it pointing in the same direction, and move it slowly toward the suspected anomaly. If the needle shows additional deflection move away from the object before making a sighting, or move on to the next station and take a back sight.

Marking of survey stations is coming under a new ethic. In the past it was felt that survey stations were of some permanent value and needed to be marked and preserved forever. Most surveyors now find that permanent markers are not necessary, they mar the cave, and can cause confusion if subsequent surveys are made. Most modern surveyors find that tying their survey into prominent natural features gives them permanent reference points which are just as good as big orange stakes driven into the floor. Temporary, removable station markers are frequently used and include such things as heel marks in dirt

Angle	Sine	Cosine
1°	.0175	.9998
2°	.0349	.9994
3°	.0523	.9986
4°	.0698	.9976
5°	.0872	.9962
6°	.1045	.9945
7°	.1219	.9925
8°	.1392	.9903
9°	.1564	.9877
10°	.1736	.9848
11°	.1908	.9816
12°	.2079	.9781
13°	.2250	.9744
14°	.2419	.9703
15°	.2588	.9659
16°	.2756	.9613
17°	.2924	.9563
18°	.3090	.9511
19°	.3256	.9455
20°	.3420	.9397
21°	.3584	.9336
22°	.3746	.9272
23°	.3907	.9205
24°	.4067	.9135
25°	.4226	.9063
26°	.4384	.8988
27°	.4540	.8910
28°	.4695	.8829
29°	.4848	.8746
30°	.5000	.8660

Angle	Sine	Cosine
31°	.5150	.8572
32°	.5299	.8480
33°	.5446	.8387
34°	.5592	.8290
35°	.5736	.8192
36°	.5878	.8090
37°	.6018	.7986
38°	.6157	.7880
39°	.6293	.7771
40°	.6428	.7660
41°	.6561	.7547
42°	.6691	.7431
43°	.6820	.7314
44°	.6947	.7193
45°	.7071	.7071
46°	.7193	.6947
47°	.7314	.6820
48°	.7431	.6691
49°	.7547	.6561
50°	.7660	.6428
51°	.7771	.6293
52°	.7880	.6157
53°	.7986	.6018
54°	.8090	.5878
55°	.8192	.5736
56°	.8290	.5592
57°	.8387	.5446
58°	.8480	.5299
59°	.8572	.5150
60°	.8660	.5000

Angle	Sine	Cosine
61°	.8746	.4848
62°	.8829	.4695
63°	.8910	.4540
64°	.8988	.4384
65°	.9063	.4226
66°	.9135	.4067
67°	.9205	.3907
68°	.9272	.3746
69°	.9336	.3584
70°	.9397	.3420
71°	.9455	.3256
72°	.9511	.3090
73°	.9563	.2924
74°	.9613	.2756
75°	.9659	.2588
76°	.9703	.2419
77°	.9744	.2250
78°	.9781	.2079
79°	.9816	.1908
80°	.9848	.1736
81°	.9877	.1564
82°	.9903	.1392
83°	.9925	.1219
84°	.9945	.1045
85°	.9962	.0872
86°	.9976	.0698
87°	.9986	.0523
88°	.9994	.0349
89°	.9998	.0175
90°	1.0000	.0000

Figure 5. Trigonometric functions of angles between 1 and 90 degrees. The vertical rise or fall between stations is determined by multiplying the sine of the vertical angle times the slope distance. The corrected horizontal distance is determined by multiplying the cosine of the vertical angle times the slope distance.

floors, pieces of plastic flagging ribbon, several small stacked rocks, or even pieces of Scotchlite tape. Study plots have been marked using small aluminum tags anchored by concrete nails driven into cracks. These are removable and cause little damage if discreetly placed.

Drawing The Map

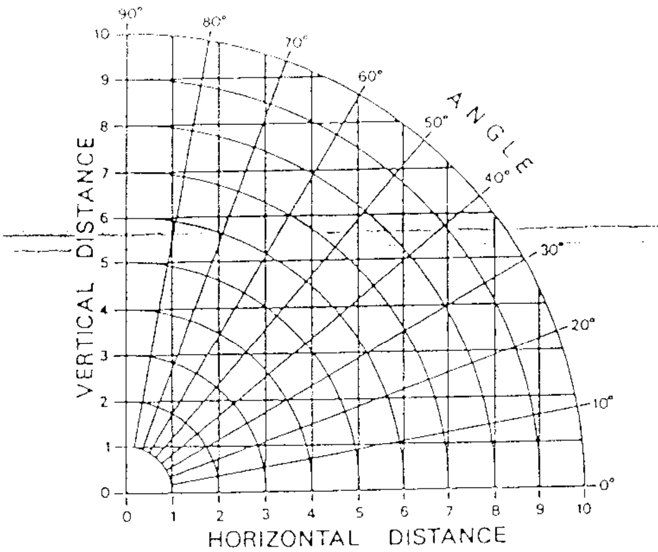
Drawing of the map will take as long or longer than it took to survey the cave. In any event, it is important to pay special attention to detail so none of the care taken during surveying will be lost while plotting the survey data.

There are two basic drawings to be made; plan and profile views. A plan view will show the outline of the cave as seen from above, and a profile will show the cave as seen from the side. It is beneficial to have both the plan and profile drawn on the same map sheet so they can be compared by the map user.

In order to draw the plan view of the cave it is necessary to correct all slope distances so they represent true horizontal distances when plotted on a flat piece of paper. This is easily done by multiplying the slope distance times the cosine of the slope angle. See figure 5. The rise or fall between stations can be determined by multiplying the slope distance times the sine of the slope angle. These corrections are most conveniently placed on a separate piece of paper along with the copied survey station notes. Rarely there may be room to place the corrections directly in the notebook. See figure 6.

You will need some equipment for plotting the survey. Grid paper, ten lines per inch, is the best for drawing. You will also need a protractor, calibrated to half a degree, a hard pencil, and an engineers scale. A drafting machine can be used instead of a protractor for plotting directions, and may result in more accuracy. Masking tape is used to firmly hold the grid paper down on a flat working surface, such as a table or desk top.

Before plotting can be started it is necessary to decide on a map scale. The scale should be a compromise between the detail which you would like to show and the size of map to which you are limited. No map should be drawn which covers an area much



SPELEOMETRIC CHART. The speleometric chart can be used to determine the horizontal and vertical correction without the use of trigonometric tables, a slide rule, or calculator.

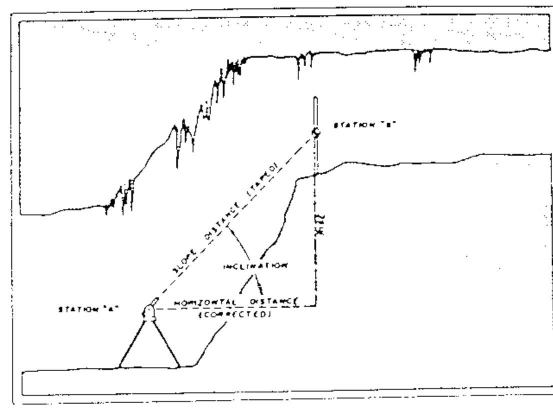
To use the chart locate the surveyed distance then follow the arc (curved line) until it intersects the vertical angle measured between survey stations. From this intersection read the chart vertically below for the horizontal distance, or horizontally to the left for the vertical distance (rise or fall).

STA.	AZ.	SLOPE DIST.	HORIZ. DIST.	VERT. ANGLE	VERT. CHANGE	STA. ELEV.	HEIGHT	WIDTH
0	80°	30'	30'	0	0	0	5	10
1	20°	25'	21.6'	-30°	-12.5'	0	4	12
2	110°	36'	35.9'	-5°	-3.1'	-12.5'	15	4
3	——	——	——	——	——	-15.6	6	7
1-2A	130°	24'	23.8'	+5°	+2.1'	0	4	12
2A	90°	35'	35'	+3°	+1.8'	+ 2.1	6	8
3A	——	——	——	——	——	+3.9	10	6

Figure 6. Corrected survey data.

Before the map can be accurately plotted it is necessary to correct the survey data. Above is a convenient form for copying survey notes, and showing corrected horizontal distances, change in elevation between stations, and station elevations.

larger than 36 by 50 inches. Sizes larger than this are difficult to handle and hard to reproduce. For publication purposes maps over 16 by 30 inches become increasingly difficult to faithfully reproduce during printing. If your cave is of a known length, calculate the distance it will cover on a map at different scales, say at 20' = 1", 50' = 1", and 100' = 1". In this way you can decide upon a scale which will allow you to stay within the size map sheet you prefer. After this is done you are ready to start plotting.



When the slope of a passage varies more than a few degrees it becomes necessary to shorten the survey distances before drawing the map. To do this measure the angle of inclination of the passage. The true horizontal distance is then calculated using trigonometric functions or a speleometric chart.

When calculating station elevation it is customary to use the entrance as the datum level. Station elevations are then shown as + (above entrance) or - (below entrance) e.g. +3.9 = 3.9 feet above the entrance. On the map the elevation is rounded to the nearest whole foot (4) and shown as 4.

The first step in plotting is to determine which direction the cave runs. You must be careful to start plotting so the survey stays on the paper and does not immediately run off the edge. By quickly looking through the notes you will be able to determine the

NOTEBOOK ABBREVIATIONS:

STA. *Station number. Stations should be numbered consecutively starting at station '0'. Letter suffixes can be used to denote branching survey lines following side passages, etc.*

AZ. *Azimuth between survey stations.*

DIST. *Distance between survey stations.*

VERT. *Vertical angle (inclination) between survey stations.*

HT. *Passage height at survey station.*

WD. *Passage width at survey station. If the station is in the center of the passage, half of the width will be on either side. A more accurate method is to record the distance from the station to the left and right hand walls.*

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general direction, north, east, southwest, etc. At the starting point make a pencil dot then orient the protractor over it making sure that north (0 degrees) is toward the top of the paper. Use the grid lines to precisely orient the protractor to north. As soon as the protractor has been lined up make a small pencil mark along the outer to correspond with the compass azimuth taken for that station. Remove the protractor then line up the engineers scale between the starting dot and the mark made along the edge of the protractor. Mark off the corrected distance between the starting point and the first station. Make a dot at the station and a light line between the points; be sure to place station numbers at the appropriate points. This process if repeated for each station of the traverse.

After all the traverse lines have been drawn the passage outlines can be drawn in. If the traverse line follows the center of the passage the widths are split equally and a mark placed on either side of the survey station. If distances right and left of the station have been recorded they must be scaled off and marked accordingly. Once this step has been completed, refer back to the sketch of the passage outline. Using the sketch and traverse line as a guide, carefully sketch in the walls between stations. Once the passage outline has been completed the remaining detail can be added, such as drops, ledges, breakdown, streams, pools, notations, ceiling heights, etc.

There are two types of passage profiles which can be drawn. First the cave can be drawn showing the profile along the traverse line; using this method the true distances and slopes are used and the cave plotted out on a single vertical plane. For simple caves the method works well but is not good for complex caves which have passages on several different levels. For more complex caves it is better to draw a profile which projects the precise station locations much as a side view does in a mechanical drawing. Station elevations must be determined by adding or subtracting the rise or fall between stations as determined from the corrected survey data.

In profiles some cave surveyors exaggerate the vertical scale to show greater slope while keeping the horizontal the same as found on the plan view. This exaggeration can be used to accentuate slope in gently sloping caves. Care, however, must be taken to not misrepresent the cave by showing a feature which does not exist. For the most part it is best not to exaggerate the vertical scale.

The cave map should contain some standard data to identify it such as the name of the cave and the state and county it is located in. The name of the surveyors, date of the survey, and the type of survey should be located below the cave name. The map scale should be of the bar type, so if the map is reduced the scale will be reduced proportionately.

The final cave map is a tracing made from the pencil copy and drawn using India ink. At the time the tracing is made the final map can be drawn to

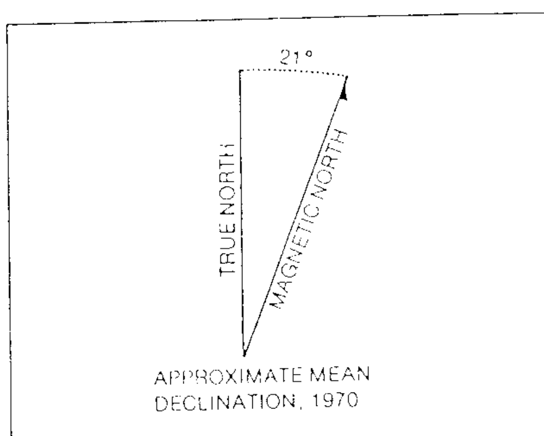
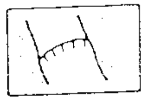


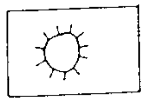
Figure 7. Magnetic declination varies depending upon geographical location. The declination for an area can be determined from U.S.G.S. quadrangle maps. In this illustration magnetic north is 21° east of true north.

CAVE MAP SYMBOLS. Shown here are a few of the more commonly used cave map symbols. For a more complete listing see CIS No. 16, "Proposed Standard Map Symbols" by James Hedges.

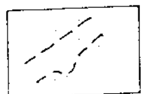
Drop, Hatchers point down slope



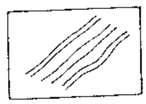
Dome or Chimney



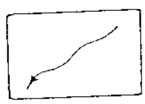
Unsurveyed Passage



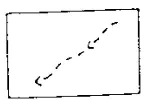
Large Stream



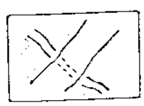
Small Stream



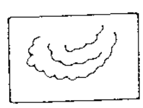
Intermittent Stream



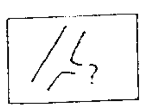
Large Passage Overlying Small Passage



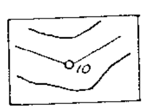
Flowstone



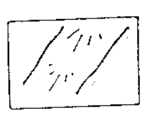
Unexplored Side Passage



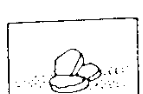
Survey Lines and Station Numbers



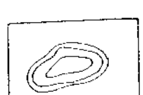
Sloping Passage, Lines are Splayed Down Slope



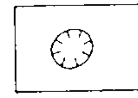
Large Breakdown



Pool

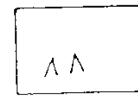


Pit or Sinkhole

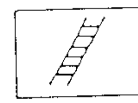


Prominent Stalactites

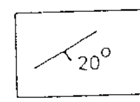
Prominent Stalagmite



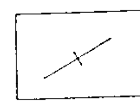
Ladder



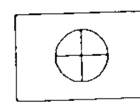
Dip and Strike of Bedrock. Long Axis is Along Strike, Short Axis Points Down Dip. Angle of Dip is Shown.



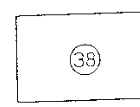
Vertical Beds, Long Axis is Along Strike of Beds.



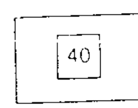
Horizontal Beds



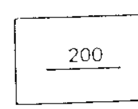
Ceiling Height



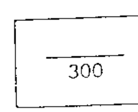
Depth of Pit or Drop



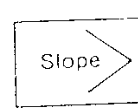
Height Above Entrance



Distance Below Entrance



General Slope of Cave (Used for Lava Caves)



compensate for local magnetic declination. Depending upon where the cave is located there will be a discrepancy between magnetic and true north. This magnetic declination is shown on all U.S.G.S. quadrangle maps (figure 7). True north will be either to the east or west of magnetic north except for a narrow zone in the east central United States where both magnetic and true north correspond. Magnetic declination can be handled in three ways. First, many compasses have a setting by which the compass card can be rotated so all readings are automatically to true north (Brunton and Silva Ranger). Secondly, all readings can be taken to magnetic north and a note placed on the map indicating that no correction has been made. This leaves the correction up to the map user. The third way is to draw the map to magnetic north, then rotate the tracing to compensate for the declination. The important thing to remember is to label which north is being shown, true or magnetic.

There are several excellent texts for the advanced surveyor listed in the references at the end of this paper. The drafting of maps for publication is an art in itself and is dealt with in another CIS article; "Drafting of Cave Maps". "Drafting of Cave Maps" should be used in conjunction with this paper. As you become more skilled you will find many ways to speed up your surveys and make them more accurate. There is no "right" way to survey a cave but rather many different approaches and a wide variety of equipment to try.

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The Caving Information Series of the National Speleological Society

Editors: Jim & Libby Nieland