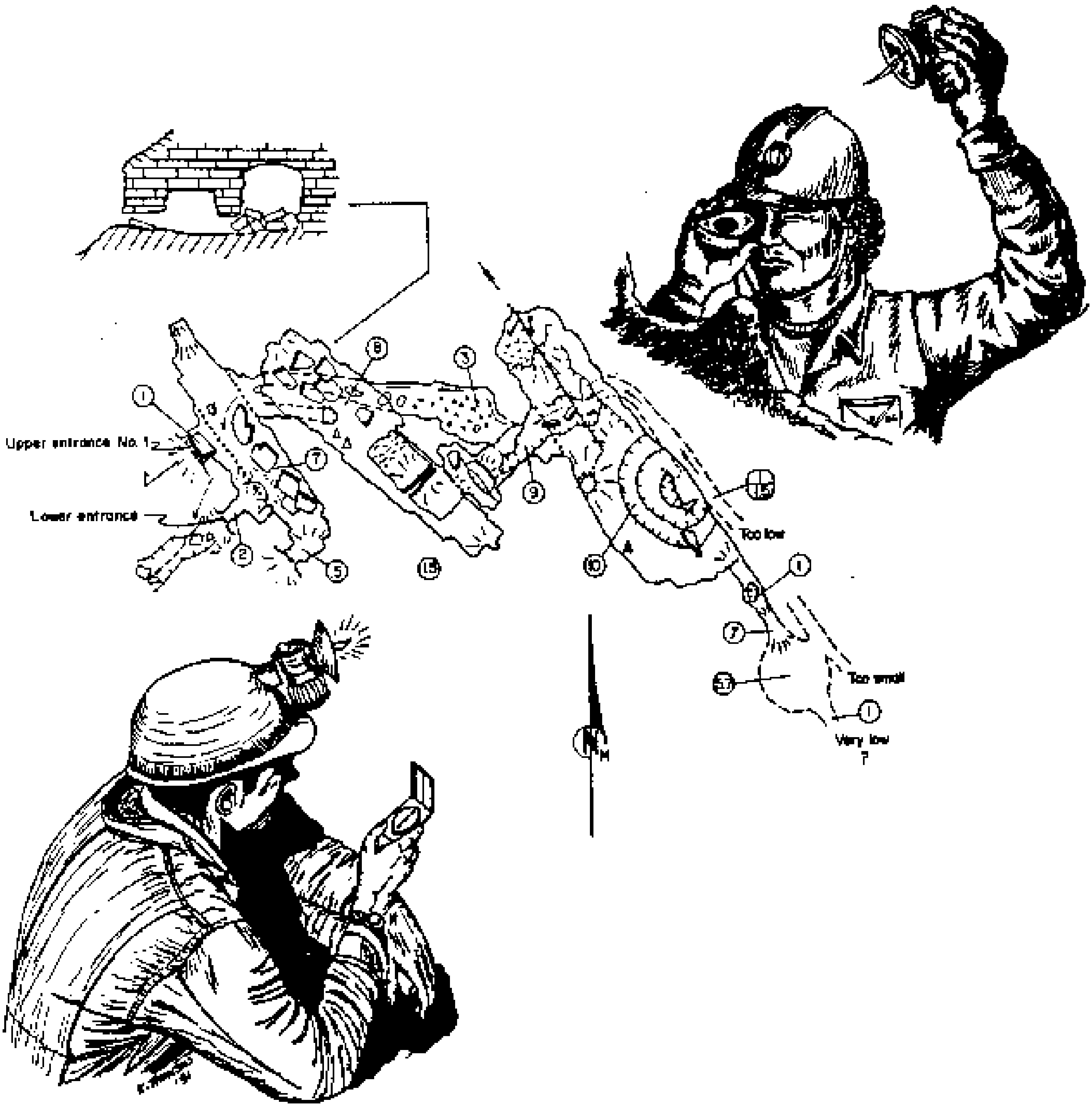
THE ART OF CAVE MAPPING



MISSOURI SPELEOLOGY

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THE ART OF CAVE MAPPING

1991

By

Kenneth C. Thomson [1] and Robert L. Taylor [2]

A guide to the art and science of cave mapping and cave map drafting. Basic methods of using the compass and tape for surveying are dealt with in detail. Included is an introduction to the more advanced techniques of plane table/alidade and stadia, surveying altimeter, electronic measuring devices, computer applications, advanced methods of cave locating, and geological observations as well as the techniques of map layout, drafting, and reproduction.

CONTENTS

1. Professor of Geology, Department of Geosciences, Southwest Missouri State University, Springfield, Missouri
2. Ph.D. Candidate, Department of Philosophy, University of Missouri-Columbia, Columbia, Missouri.

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Dr. Kenneth C. Thomson has been a member of the National Speleological Society since 1969 and has been mapping caves since then.

Ken is a charter member of the Ozarks Highlands Grotto of the N.S.S. and faculty sponsor of Heart of the Ozarks Grotto at Southwest Missouri State University. He is currently the President of the Missouri Speleological Survey, Inc., and a member of Ozarks Highlands Grotto.

Prior to coming to the Ozarks in 1968, Ken worked for the Utah Geological and Mineralogical Survey from 1959 to 1968 and was involved in mapping numerous uranium mines in southern Utah and about 100 metal mines in the Deep Creek Mountains on the Utah-Nevada border. He was also the Chief Illustrator and Geologic Research Associate for the Survey. Since coming to Missouri in 1968 to teach at Southwest Missouri State University, he has been personally involved in mapping at least 70 caves, including Smittle, Crystal, Ozark Underground Laboratory, and directed the mapping for several hundred more. During the past 20 years Dr. Thomson has conducted classes in cave mapping, teaching it to 335 students.

Ken Thomson was awarded the Lester B. Dill award of the Mississippi Valley-Ozark Region of the NSS in 1974, the J Harlen Bretz Award of the Missouri Speleological Survey, Inc. in 1978 and was made a Fellow of the NSS in 1979 in recognition of his contributions to the study of Speleology.

Ken's undergraduate degree is in mineralogy (1963) and he has a Doctor of Philosophy degree in mineralogy (1970), both from the University of Utah. He is currently a professor of Geology at Southwest Missouri State University where in addition to his geology courses, he teaches three courses in professional surveying. At present, Southwest Missouri State University has the only surveying program recognized by the State Land Surveying Board as a requirement for state license.

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Bob Taylor has been a member of the National Speleological Society since 1963 and has been mapping caves since 1969.

Organizationally, he is the founding chairperson of the Ozarks Highlands Grotto (MO) and the Green River Grotto (KY) and is a founding member of Heart of the Ozarks Grotto (MO, non-NSS) and the Association for Arkansas Cave Studies. He is presently a member of Chouteau Grotto (MO), Ozarks Highlands Grotto (MO); a director of the Missouri Speleological Survey, Inc., and a Joint Venturer with the Cave Research Foundation.

He has mapped or helped map over 200 caves, mostly in Missouri, but also in Arkansas and Kentucky. In Missouri, some of these mapping projects include: Welch Spring Cave, Jam Up Cave, Berry Cave, Smittle Cave and the Fry Creek Cave System. In Arkansas, some of the caves he surveyed are Ennis Cave, Joe Bright Cave and most of the Janus Pit System. He also is the East Passage cartographer for the CRF survey of Arkansas' Fitton Cave. In Kentucky, he initiated the current (beginning in 1977) mapping project in the Lost River System and helped map Whigpistle Cave and Hicks River Cave when he worked for Uplands Research Lab in Mammoth Cave National Park. He surveyed as a JV in Flint-Mammoth in the late 60s and early 70s. While involved in these mapping projects, Bob was able to teach many people the basic principles of cave mapping and several of these have gone on to map many caves themselves.

Bob was made a Fellow of the NSS in 1978 and received the Lester B. Dill award of the Mississippi Valley-Ozark Region of the NSS in 1985, in recognition for his cave mapping activities.

His undergraduate degrees are in geology (1987) and psychology (1975), and he has a masters in philosophy (1981). He is presently working on a Ph.D. in philosophy at the University of Missouri-Columbia, and is continuing to survey and explore caves.

FORWARD AND ACKNOWLEDGEMENTS

In the fall of 1980, the Board of Directors of the Missouri Speleological Survey, Inc. asked us to write an issue of Missouri Speleology on the techniques of Cave Surveying. This was to replace the issue done by Lang Brod in 1962 called "Cave Mapping. A Systematic Approach", Volume IV, Numbers 1-3, January to April, 1962. This had been reprinted in 1970 and was again going out of print. An Introduction to Cave Mapping was produced as Missouri Speleology, Vol. 21, Nos. 1-2, in 1981.

In the summer of 1985, the first edition of this work went out of print and we were asked to reprint it. We decided that the manuscript needed some revisions and improvement and we went about the preparation of a second edition. The second edition was printed also as Vol. 21, Nos. 1-2, but with a date of 1985.

With the second edition going out of print, and many new innovations in techniques, equipment, computers, etc., we felt it was time to totally revise the manuscript. After a year of revisions and additions, we felt that the manuscript was different enough to merit a different title, thus rather than calling this the third edition, we chose to call it The Art of Cave Mapping. We have used many of the illustrations from An Introduction to Cave Mapping, but we have added so many new topics that we have had to come up with many new ones. We have also used some of the material from the first two editions almost verbatum, but in general most of the book has been re-written.

The first edition was originally made possible with the help of many people and organizations. Jerry Vineyard read the original manuscript and made many valuable suggestions. Bonnie Curnock drew chapter heading illustrations and many of the text figures. These excellent sketches are used in this edition. In addition, Sherry Jott and Robert L. Taylor contributed additional valuable artwork and Kenneth C. Thomson added many sketches and drafted material. Thanks is extended to the Department of Geosciences at Southwest Missouri State University for the use of many departmental facilities to produce this edition.

The authors would like to express appreciation to Edda May Thomson, for her help and support during many long hours of typing, revising, and drafting on the manuscript and to Kathy Taylor for her long hours of help with the final editing of the manuscript for the third edition.

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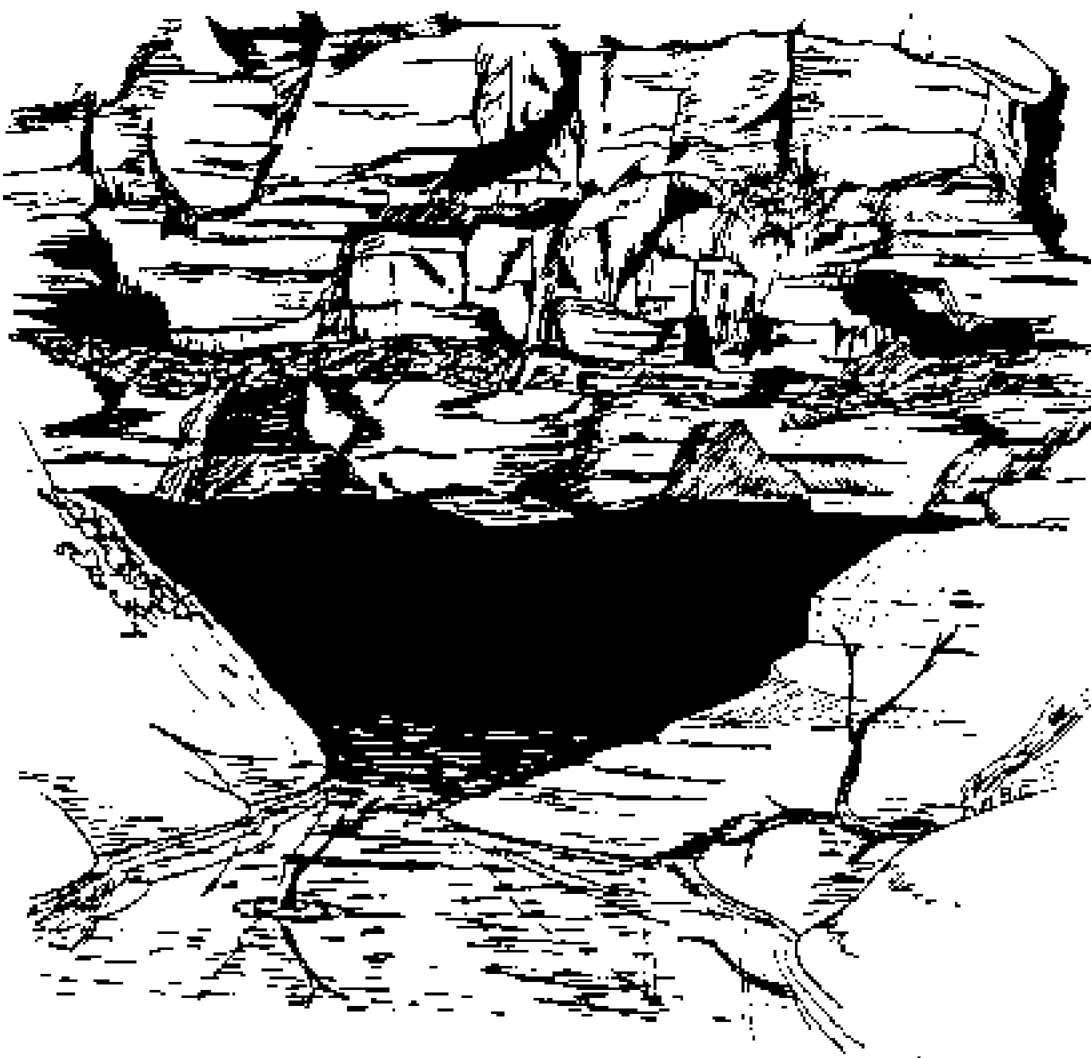


1

INTRODUCTION

The purpose of cave mapping is to provide a two-dimensional representation or map of a three-dimensional cave cavity, chamber, or passage. Because of the extreme irregularity often encountered in the shape of these "holes in the ground" or caves, this representation becomes much more difficult than mine mapping or other types of mapping.

A cave map is a two-dimensional graphic description of a cave and its features, shown by lines and symbols. All aspects of the cave are projected onto a horizonal plane which becomes the plan view of the cave. This basic plan view is generally inadequate by itself, so supplementary notes, sections, or block diagrams can be drawn to show the cave's vertical character and/or relationship to its surroundings. Supplementary views are selected when necessary to provide the clearest and most useful picture of the cave possible.

Cave maps have many uses: explorers use them to record explorations and to show leads and potential connections; geologists and hydrogeologists use them to study developmental controls; biologists find cave maps useful in recording the distribution and migration patterns of animal species through the cave; micro-climate researchers determine air movement and record temperature patterns on the maps; and, from the cave's layout, historians can use maps to identify specific caves which may have had name changes and historical significance.

Cave mapping is exciting, challenging, and can become a special interest of the avid caver. Some cave surveyors create maps so detailed and well drawn that they can almost be considered works of art. Some surveys in large cave systems become lifetime projects of several people, each contributing a portion of the survey as their share of the total cave map. Ongoing surveys in the Mammoth-Flint Ridge Cave System in Kentucky, Jewel and Wind Caves in South Dakota, Lechuguilla Cave in New Mexico, and in the Crevice and Moore Cave Systems in Missouri are examples of areas in which mapping by many individuals has been going on for a number of years. These caves extend for many miles. The Flint-Mammoth System has hundreds of miles surveyed so far and no one as yet can determine its final length. The large number of small and medium-sized caves that need to be mapped should not be ignored. One advantage of working in these smaller caves is that you actually have a reasonable chance of claiming that the cave map is actually a representation of the whole; whereas in a huge cave system, one can probably never be sure of mapping every last passage.

Cave mapping is not done under "ideal" conditions as might be found on the surface. The cave's natural state of total darkness, water passages, and tight crawlways present special problems to overcome as a cave survey progresses. The difficulty of providing adequate lighting makes it difficult to see passage details and to read surveying instruments. The muddy conditions, high humidity, and water in cave streams tend to make survey notes illegible and surveying instruments unreliable. Vertical shafts also require special expertise and equipment. The slow pace of cave surveying requires the surveyor to dress warmer than when just exploring in order to diminish the increased risk of hypothermia or exposure. Moreover, a great deal of patience is required of those helping the primary surveyor or surveyors. Through all of this, you must maintain the highest degree of precision and accuracy possible to be able to create an accurate and detailed map that will be useful to others.

To be of greatest value, cave maps must be an accurate representation of the cave. Only the use of proper surveying methods, techniques, and equipment can produce an accurate cave map. The exact position of all features in the cave should be located in space. Although in practice this absolute accuracy is impossible, it can be approached by a careful survey of a traverse through the cave using instruments of a high degree of precision and, using this traverse as a framework, sketching the details of the cave passage and rooms. This gives a reasonable representation of the cave. The traverse consists of a series of connected points which are precisely located by measuring their distances apart and the direction each point is from the preceding one. This traverse is normally made in a cave survey with a compass, clinometer, and surveying tape. The surveying tape gives the distance between the two points; the clinometer measures the declination or inclination from one station to the next; and the compass gives the direction from the first point to the second, and so on. This process is repeated until the whole cave is represented by a framework of lines connecting survey points. On this framework details are drawn to represent the cave walls and such features as pits and breakdown.

In this discussion of cave surveying, the means of obtaining the basic information for the traverse, the distance and direction of the points as well as their elevation differences are discussed in detail. This will give you, the beginning cave mapper, the necessary background to gather the database for the cave map framework. Once you have mastered the ability to create an accurate traverse, the next step, as mentioned above, is to add the details of the cave. In actual cave mapping, the framework and the details are mapped simultaneously.

To help you master the above skills it is advantageous to find and work with an experienced cave surveyor. This allows you the opportunity to become a member of a survey team, possibly starting in the least responsible position and working through the positions, learning the responsibilities of each member. This way you can get experience and an appreciation of all the skills required and an idea of the problems encountered in each position. The more often you get to go with the team, the more opportunities you get to improve your skills. Once this experience is gained, you might assemble a mapping team of your own and begin with a cave which is small, simple in plan, and easily accessible. It is probably best to select a cave that has been mapped previously by an experienced surveyor, so you can compare your beginning map with the existing map--a good way to check your accuracy and technique before attempting the survey of a previously unsurveyed cave.

2

MEASUREMENT SYSTEMS

One of the fundamental tasks of cave surveying is making measurements and subsequently making computations from them. The process involves a combination of human skill and the proper use of instruments. A knowledge of the various types of measurements that are taken, their units, and the conversions between different systems of measurements is very valuable.

TYPES OF MEASUREMENTS TAKEN IN CAVE SURVEYS

Three types of measurements are taken in the average cave survey:

1. Distance (linear) - horizontal, vertical, slope
2. Horizontal angles
3. Vertical and zenith angles

Figure 2-1 shows these types of measurements. Horizontal angle <DAC and distance (AC) are measured in a horizontal plane (a plane that is perpendicular to gravity) and vertical angle <BAC and distance (BC) are measured in the vertical plane (generally parallel to the direction of gravity). Slope distance (AB) is inclined to the horizontal plane. By using combinations of these measurements it is possible to compute relative positions in distance and direction between any two points.

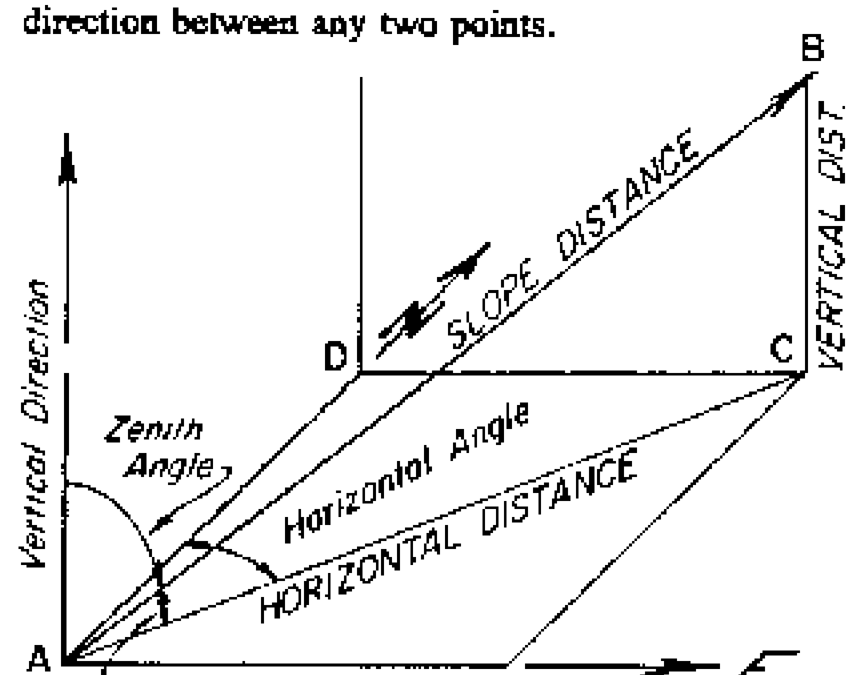


Figure 2-1. Types of measurement taken in a cave survey.

UNITS OF LINEAR MEASUREMENT

In the United States, the most common unit of linear or distance measurement is the **foot** (ft), which is of Anglo Saxon origin and is used universally in English-speaking countries. The meter (metre) originated in France and is used in most other countries of the world. On December 23, 1975, the provisions of the Metric Conversion Act of 1975 became law in the United States. This was passed to declare a national policy of coordinating the increasing use of the metric system in the United States and to establish a U. S. Metric Board to assist in the voluntary conversion to the new system. The meter is used by the National Geodetic Survey of the United States Department of Commerce as well as other federal agencies.

On all United States government land surveys, the unit of length is the Gunter's Chain, which is 66 feet long and divided into 100 links, each of which is 0.66 feet or 7.92 inches long. A chain is 1/80 of a mile long.

The relationships shown in table 2-1 exist in the English system of length measurement. Most surveyors use a decimal system of linear measurement based on the foot. Hence a foot is divided into 10ths, 100ths, and 1000ths of a foot. Rarely is the system used where a foot is divided into 12 inches and each inch is subdivided into halves, quarters, eighths, etc. Only in the building trade is this latter system popular.

Table 2-1. The relationship between units in the English system of measurements

1 foot = 12 inches
1 yard = 3 feet or 36 inches
1 mile = 5280 feet or 1760 yards
1 Gunter's chain = 100 links or 66 feet
1 Gunter's chain = 4 rods
1 rod = 16.5 feet
1 Engr's chain = 100 links or 100 feet

The international system of units known as the metric system was established in 1960 by the International Conference on Weights and Measures. Some of the most common terms and their relationships to each other are shown in table 2-2.

The meter was originally defined as 1/10,000,000 of the meridian distance from the equator to the north or south pole of the earth. Over the years several standards were used for the meter and and in 1960, the International Meter was defined as 1,650,763.73 wavelengths of the orange-red portion of the spectrum of light produced from krypton 86, a rare gas extracted from the atmosphere. Under this definition, the U. S. inch becomes equal to 41,929.483 wavelengths of krypton light. In 1983, the General Conference on Weigths and Measures (GCPM) defined the meter as the length a path of light travels in a vacuum in 1/299,792,458 second. At the present time the relationship between the English System of measurement and metric measurement is shown in table 2-3.

Table 2-2. The relationship between units in the metric system of measurements

1 meter	= 1,000,000 micrometers (μm)
1 meter	= 1,000 millimeters (mm)
1 meter	= 100 centimeters (cm)
1 meter	= 10 decimeters (dm)
1 kilometer (km)	= 1,000 meters

Table 2-3. The relationship between English system units and metric system units

1 yard	= 0.9144 meters (exactly)
1 foot	= 0.3048 meters
1 inch	= 25.4 millimeters or 2.54 centimeters

ANGULAR MEASUREMENT

An angle between two lines diverging from a point is given by the difference in the directions of the lines. The magnitude of any angle can be expressed in various units basically derived from the division of the circumference of a circle according to four commonly used systems:

Sexagesimal System. The circumference of a circle is divided into 360 equal parts; each part equals a degree (°). Each degree is subdivided into 60 equal parts called minutes ('). Each minute, likewise, is divided into 60 equal parts called seconds ("). This

Table 2-4. Angular measure conversion table. Multiply any value on the left by its equivalent listed below the headings in the table. For example, to convert degrees to grads, multiply the degrees by 1.1111.

	Degrees	Grads	Radians	Mils
Degrees	XXXX	1.1111	0.01745	17.77778
Grads	0.9	XXXX	0.01471	16
Radians	57.2957795	63.6619662	XXXX	1,018.5916
Mils	0.05625	0.06250	0.00098	XXXX

system is the most widely used system in the United States. For computations, the minutes and seconds are often converted to decimal degrees. This can be done by a simple proportion. Convert the seconds into decimal minutes by taking the seconds and divide by 60. This converts seconds to minutes. Add this on to the minutes and then take the resulting minutes and divide by 60 again. The result will then be decimal degrees. This is then added to the degrees to get decimal degrees. For example, to convert 32°15'30" to decimal degrees, take (30"/60") = 0.5'; add this to 15' to get 15.5'. Then (15.5/60) = .25833 degrees. This is then added to the 32° to get 32.25833°. Most calculators need to use decimal degrees to make calculations. To convert back, just reverse the process. In the above example, leave the 32°, take the .25833 X 50 = 15.5. Take the 15 as 15', then the .5 X 60 = 30".

Centesimal System. In this system a circle's circumference is divided into 400 equal parts called grads or grades. Each grad is divided into 100 centesimal minutes (100^c), and the centesimal minute is divided into 100 centesimal seconds (100^{cc}). An angle can be represented as 265.6572g, with the first two digits after the decimal point representing centesimal minutes and the second pair, centesimal seconds.

Radian System. In this system, one radian is defined as the angle at the center of a circle that is subtended by an arc having exactly the same length as the radius of the circle. There are 2π radians in a full circle. This is the official system for the plane angle in the metric system.

Military System. In this system, a full circle is divided into 6400 mils. Each mil can then be broken down by decimal divisions such as tenths, hundredths or thousandths, etc. of a mil. The system is used mainly in the military.

CONVERSION OF ANGULAR UNITS

It is useful at times to be able to convert from one system to another. Suppose that a cave survey has been done with a military Brunton Compass and all readings were taken in mils. If you are using the standard Sexagesimal System, you will have to convert mils to degrees, minutes, and seconds. In making conversions to the sexagesimal system, always convert to decimal degrees and then make the conversion. Table 2-4 will be useful in calculating the conversions. The result for degrees will be in decimal form. The Centesimal, Radian, and military system are already in decimal form.

SIGNIFICANT FIGURES

In recording any measurement, an indication of the accuracy of the measurement attained is the number of digits or significant figures that are recorded in the field notes. Brinker and Wolf (1989) define the number of significant figures in any value as "the positive (certain) digits plus one (only one) digit that is estimated." For example, if a 100-foot steel tape is used to measure a distance of 89.24 feet, the measurement would have four significant figures. The first three digits are certain and can be observed on the tape; the last is questionable because it was estimated.

Some rules on significant figures might be of value:

1. Significant figures are counted from left to right, beginning with the first nonzero digit; thus, in a decimal figure smaller than 1.0, all digits between the

decimal point and the first nonzero digit are not significant.

2. Zeros at the end of a decimal number are significant.

Some examples are:

259.075 has six significant figures
0.0004562 has four significant figures
22.00055 has seven significant figures
2.0 has two significant figures

It is very important that data measured in the cave be recorded with the proper number of significant figures. If a significant figure is dropped in recording a value, other values in the survey with more significant figures lose their value. On the other hand, recording too many significant figures gives a false accuracy and results in a waste of time recording and computing data with this false degree of accuracy. Try to record values consistently according to Brinker and Wolf's definition.

In computations of surveying data involving significant figures, it is important that the calculations be consistent with measured values. In adding or subtracting, the answer should be rounded off, retaining in it the digit found in the rightmost column with the least number of significant figures. For example:

```
392.342          36.302
 24.01    or      1.62
  2.156          52.3
343              90.2
761
```

In multiplication, round the more accurate numbers to one more significant figure than the least accurate number. The answer should be given to the same number of significant figures as are found in the least accurate factor. For example:

$$392.1 \times 863.3 = 338499.9300$$

This figure should be rounded to $338400 = 3.384 \times 10^5$. In division, the same rules apply as in multiplication.

ROUNDING OFF NUMBERS

It is obvious that when we consider significant figures it will be necessary to drop off some of the digits. In rounding off these digits, some will be large enough that they should change the digit to the left, others will not be that important. The following rules should be applied to rounding off figures:

1. When the digit to be dropped is lower than 5, the number is written without the digit. Thus, 63.563 becomes 63.56.

2. When the digit to be dropped is exactly 5, the nearest even number is used for the preceding digit. Thus, 65.375 becomes 65.38, and 65.365 becomes 65.36.

3. When the digit to be dropped is higher than 5, the number is written with the preceding digit increased by one. Thus, 56.378 becomes 56.38.

DIRECT AND INDIRECT MEASUREMENTS

Measurements may be made either directly or indirectly. A direct measurements of a line, for example, could be made by using a tape; a direct measurement of an angle, by using a theodolite and turning the angle. An indirect measurement of a quantity is obtained by determining its relationship to some other value which is either known or which can be measured directly. Generally, indirect measurements are the result of calculations of distance by standard trigonometric formulae. The indirect method of making measurements is very important in any surveying and thus a working knowledge of geometry and trigonometry is very important (see appendix II).

PROBLEMS

In the problems that follow, be sure to use the proper number of significant figures.

1. Convert the following lengths to meters:
a. 37.35 feet; b. 56 3/4 feet; c. 24 feet 6 3/4 inches; d. 32.5 yards; e. 2.56 miles.

2. Convert the following lengths to feet:
a. 32 kilometers; b. 654 meters; c. 2356.85

meters; d. 15.254 meters; e. 2.85 meters.

3. Convert the following lengths to miles:
a. 5264 feet; b. 1760 yards; c. 10,000 feet; d. 1330 feet; e. 660 feet.

4. Convert the following distances to feet and then meters:
a. 650 chains; b. 25 chains, 32 links; c. 25 chains, 62 links; d. 334.54 chains; e. 100 links.

5. Convert the following sexagesimal form (degrees, minutes, seconds) to the decimal form:
a. 35° 23' 56"; b. 235° 45' 35"; c. 10° 15' 59"; d. 330° 22' 34"; e. 182° 55' 39".

6. Convert the following decimal form degrees to the sexagesimal form (degrees, minutes, seconds):
a. 234.5677°; b. 23.33°; c. 198.912°; d. 333.55°; e. 89.6792°.

7. Convert the following from mills to sexagesimal form:
a. 2344 mils; b. 1566 mils; c. 656 mils; d. 3200 mils; e. 6400 mils.

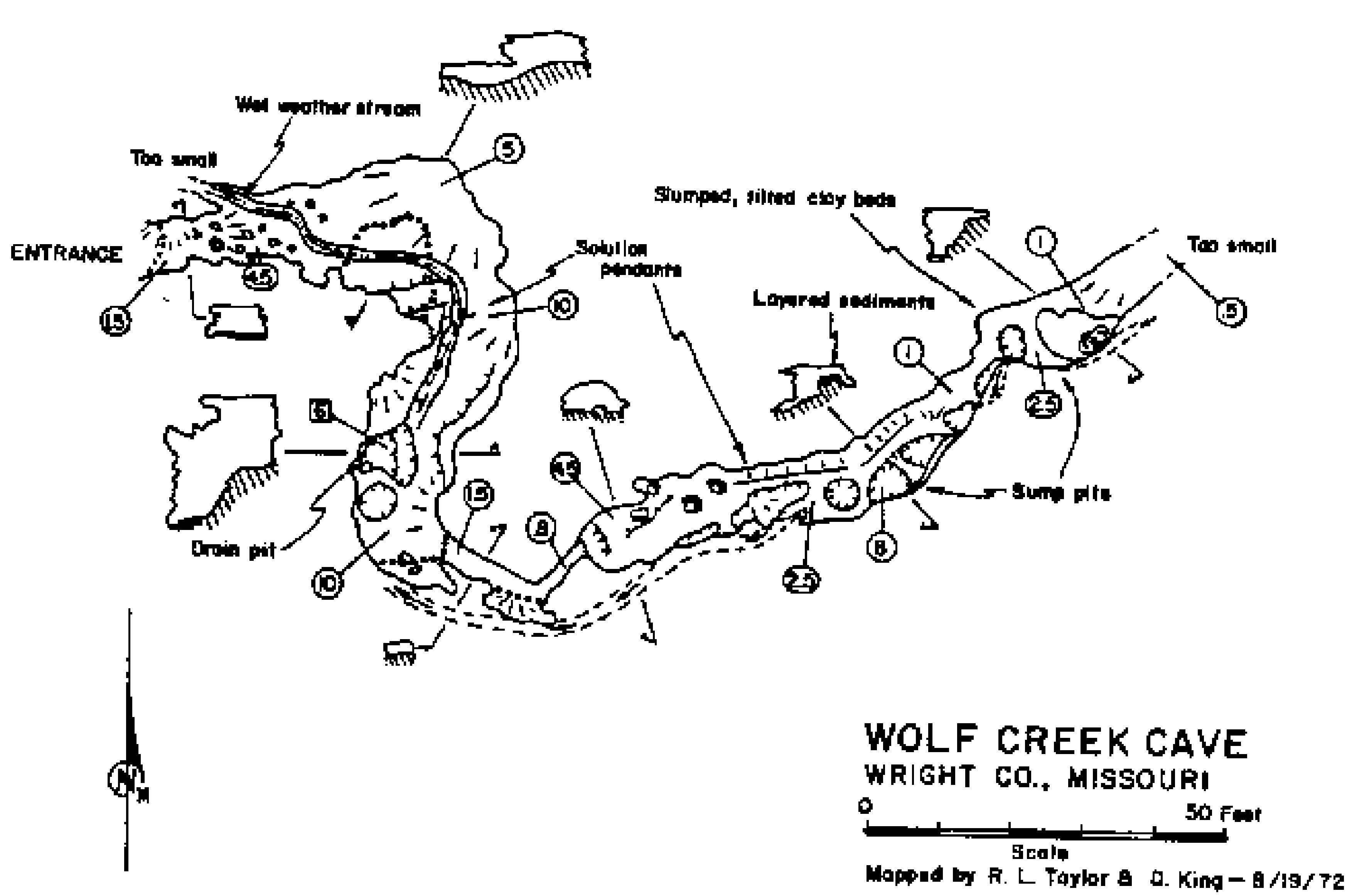
8. Convert the following decimal degrees to radians:
a. 45.55°; b. 67.667°; c. 185.55°; d. 275.26°; e. 335.3369°.

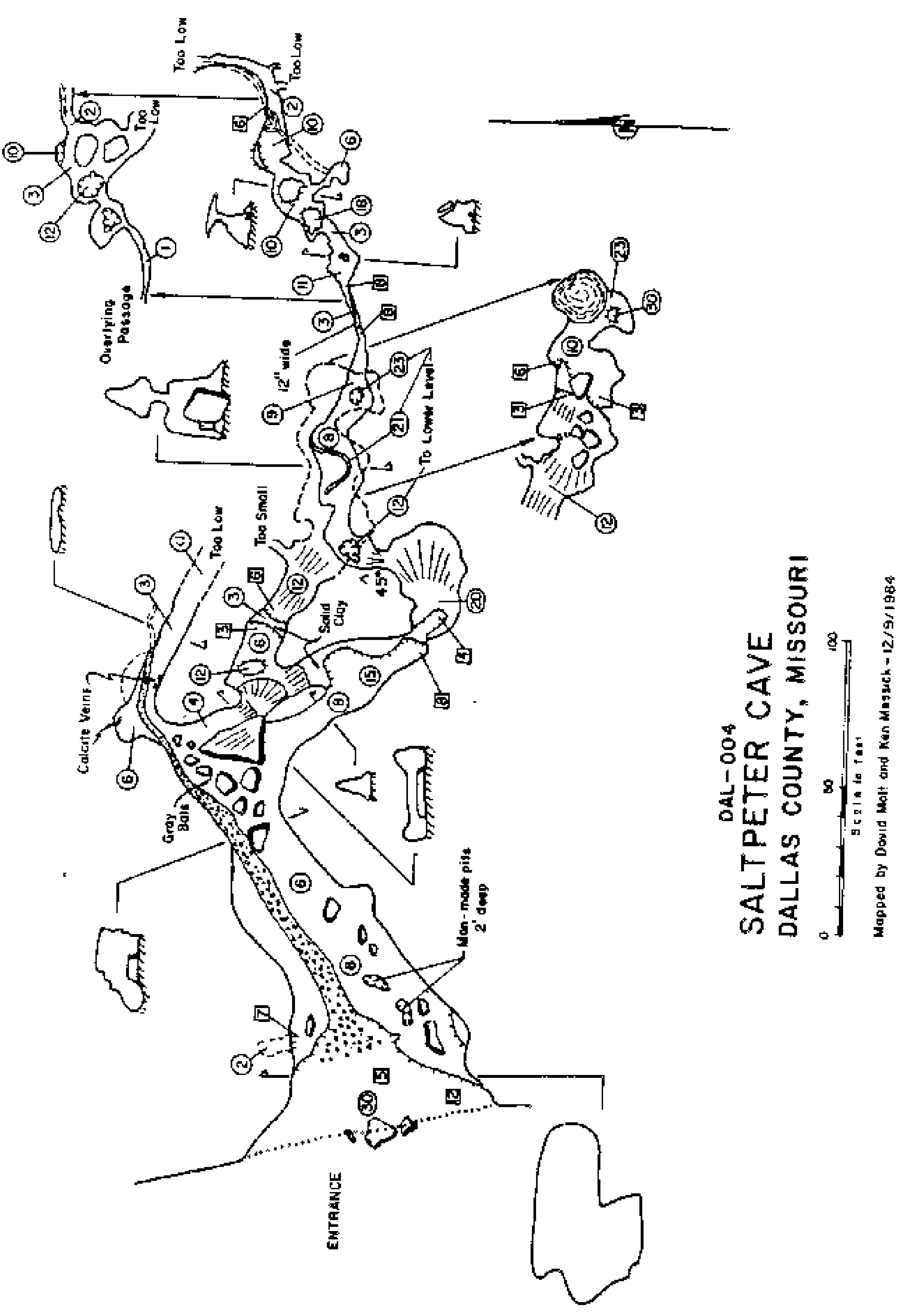
9. Convert the following radians to grads:
a. 0.25 rad; b. 3.56 rad; c. 5.52 rad; d. 6.28 rad; e. 1.25 rad.

10. Convert the following grads to degrees, minutes, and seconds:
a. 300 grads; b. 200 grads; c. 250 grads; d. 25 grads; e. 285 grads.

11. State the number of significant figures in the following set:
a. 0.0005624; b. 1.00002500; c. 0.0025; d. 657.24; e. 100.00256.

12. In the following numbers, round off to the nearest tenth.
a. 256.2456; b. 10.25; c. 135.23467; d. 65.6666; e. 100.333333.

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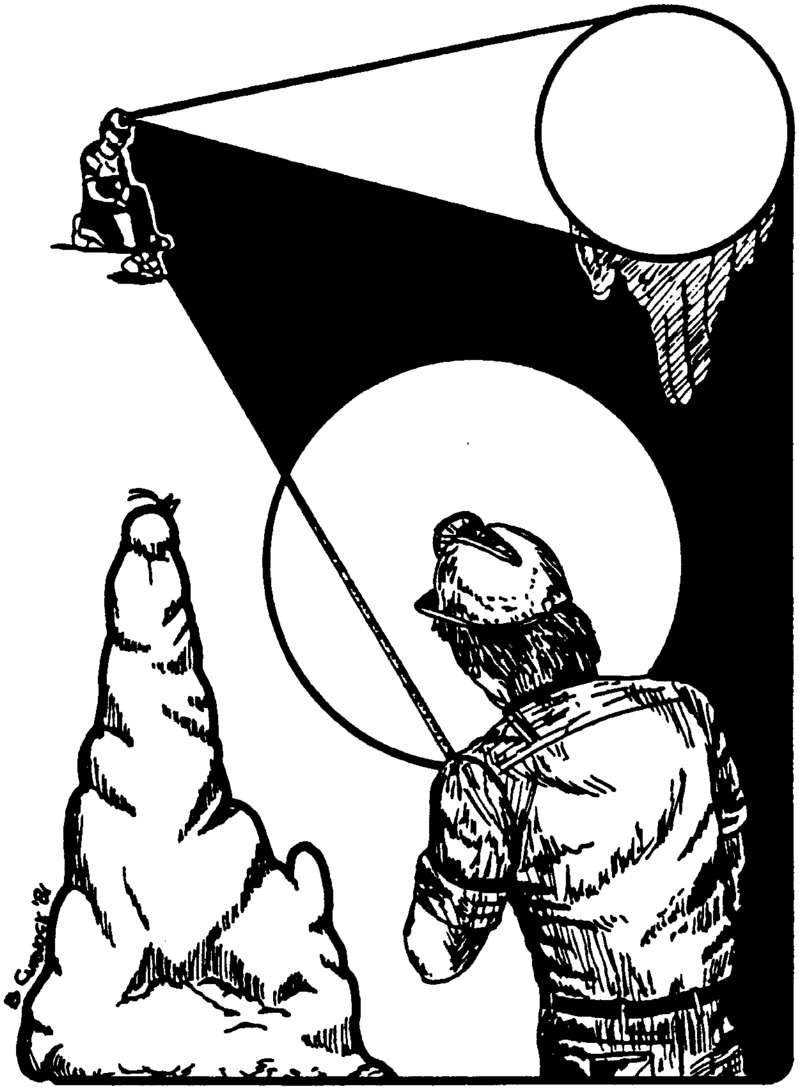


3

MEASUREMENT OF DISTANCE

The distance to an object in the cave or to the next survey point can be determined in a number of ways with varying degrees of accuracy. The choice of method depends on the nature of the survey, conditions under which mapping is conducted, and the experience of the surveyor. Cave surveyors often use more than one method in a cave survey.

ESTIMATION

Estimated distances are primarily used in cave surveys to relate nearby cave features to the survey line where precise measurements are not needed or easily obtained. Such things as short distances from the survey line to the walls, formations, and pits, as well as the height of passages, can be estimated. With this technique, you compare the height or length of objects of known size, such as an arm's length or the height of another caver, to the distance that needs to be determined. A technique that can be used is to imagine a five- or six-foot person stretched out in the direction that you wish to measure or the same person with his/her arms spread out, and then multiply that length by the number of bodies or armspans to the wall or cave feature to obtain the distance.

An effective technique of estimating greater distances (15 feet or more) from the tape is to walk about half the distance and then estimate the distance back to the tape. Doubling this would give the distance desired. Distances measured this way can be quite accurate because short distances are easier to estimate than long ones.

To effectively use estimation, you should become proficient at it. You should practice estimating distances and then measuring them for comparison. This will make it possible to estimate short distances with a reasonable degree of accuracy. Proficiency at estimation of distance can save a considerable amount of time in a survey and can maintain an acceptable degree of accuracy where precise measurements are not absolutely necessary.

An advantage of using estimation is that it will help preserve the cave floor from the excess damage that a direct measurement might cause. While this is often a desirable thing to do in many caves, it may be especially important in sensitive caves or in sensitive areas of a particular cave.

PACING

Pacing, a rapid and reasonably accurate means of measuring distance, is done by counting the steps taken in traversing from one point to the next and then multiplying the number of paces by the average distance per pace. Within the cave, pacing can be used for reconnaissance distance measurement and for positioning close objects on the accurately surveyed map framework. On the surface, one might use pacing to roughly measure distances between caves or from a cave entrance to some other object or feature.

The pace may be counted in one of two ways: either counting only the number of times the right foot hits the ground (stride) or counting every time either foot hits the ground (pace).

To determine the length of your pace, you should lay out a 100- or 200-foot taped course on a horizontal section of the ground or down a long hallway. Then pace the distance from one end to the other, counting either the number of steps/ paces taken or the stride. This number, divided into the distance, gives the average length of the pace or stride. For example, if you counted 80 steps or paces for a 200-foot course, the pace length is 200 feet divided by 80 paces, or 2.5 feet per pace. If you used stride, you might have 40 strides for the 200 feet, or 200 feet divided by 40 which is 5 feet per stride. Do not exaggerate your step, but use a normal stride when pacing. This will give you a pace that can be easily duplicated. You should check your pace periodically to make sure it remains the same, especially if you only use the method occasionally.

The length of the stride or pace varies with the land surface, becoming shorter going uphill and longer going downhill. It would be wise to set up a course which will duplicate the conditions that you might encounter while pacing, so that you can determine your pace for uphill and downhill. Pacing over rocky, brushy, or irregular ground requires patience and practice. In fact, if you plan to use pacing, should set up courses through such terrain to practice. You can pace through these conditions and correct the count to normal length as you proceed. When you encounter an obstacle, you might use a right-angle offset around the object and proceed making a right-angle offset back to the normal line when you have passed it. In some places you might be able to "estimate" the number of paces that there would be if you were able to continue on a straight line through the obstacle. You could then add this on and proceed with the traverse. You can do this by visually spotting where each pace would be if you were not diverted from a straight line course.

The greatest source of error from pacing results from miscounting, especially by dropping 10 or 100 in a large measurement. Loss of tally or forgetful repetition of the count also results in error. A device called a tally counter, a small odometer-like device which operates with a lever or button to count each pace can be used to keep track of the paces and help prevent error. A passometer which automatically keeps track of the number of paces you make or a pedometer, a device which tallies automatically each time it is jolted by a footfall, also can be used. These are especially helpful in measuring level terrain, but do not permit corrections for offsets and broken paces. Generally, for the normal pacing done in caves, these additional devices are not necessary.

A method which is similar to pacing involves the direct use of the size of body parts such as arm spans, body heights, etc., to measure distance. For example, a person's eye height can be used to measure some vertical distances. The length of a surveyor's arm or arm span can be used to measure passage widths, and in tight crawlways, the length of the caver's body might be used to determine the distance through the crawlway. You might want to record in a notebook and then memorize your eye height, body height, arm span, hand width, hand span, foot length, etc. While these methods may provide greater accuracy than estimates, they are not as precise as direct measurements.

SURVEY TAPES AND TAPING

The most precise means of measuring distance is with a survey tape. Several types of tape are available on the market.

Fabric Surveying Tapes

Fabric tapes made of fiberglass come in a variety of styles, lengths, and case types. These very flexible tapes are washable and do not kink or bend under normal working conditions. They are available with graduations in feet and tenths of feet, feet and inches, and in metric units. Fiberglass tapes also can be obtained in either open reel or closed reel models. When surveying muddy caves, closed reel survey tapes can get clogged with mud within the case so that the tape cannot be rewound into the case; whereas an open reel allows you to clean the collected mud from the tape and the case. Care must be taken when using fabric tapes. They can be broken if pulled too hard, especially if they have become cut on sharp rocks and weakened. Under normal use, a fabric tape can be used indefinitely. A general rule for all survey tapes is to not tread on them. Ignoring this rule can become expensive after awhile.

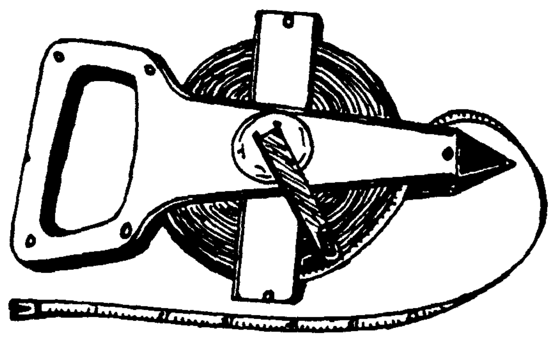


Figure 3-1. Fabric surveying tapes.

Steel Surveying Tapes

Steel surveying tapes or chains commonly have been used by surveyors seeking high precision in measuring distances. These tapes are 50 or 100 feet long and are normally marked in feet only, except at the ends. Here the last foot or an additional foot is divided into tenths of feet. Metric steel tapes also are available.

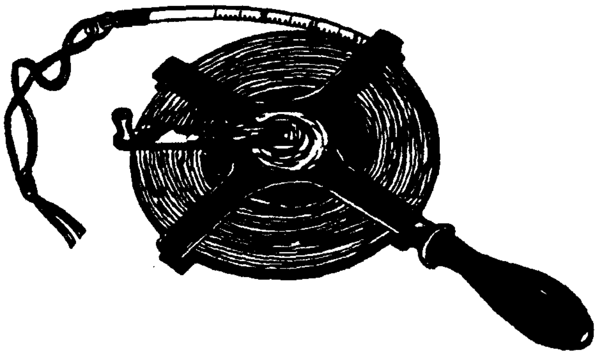


Figure 3-2. Steel surveying tapes.

Two types of steel surveying tapes are available: those that are on reels, either closed or open, and those that are thrown into loops and tied (figure 3-2). The tape that is on a reel is the easiest to use because it can be reeled out to the length needed. The unreeled or thrown tape has to be let out totally and, as the survey progresses, can be left unrolled and moved carefully from station to station to avoid kinking. A shorter steel tape can be rolled up and tied in two or three places and unrolled as needed or thrown from the loop. When the survey is complete, the tape should be wiped off, rolled up, and tied or put back on the reel. A steel tape can be very unmanageable even under good conditions, and if proper care is not taken, it will unravel rapidly into a tangled mess.

For cave-surveying jobs, the steel tape has many disadvantages:

1. The tape is stiff and is easily kinked and ruined by being doubled back on itself.

2. Most 50- or 100-foot tapes are dimensioned only on the first and last foot, rather than throughout their length. Therefore, it is necessary to hold one end on an even foot and read the additional proportion of a foot from the last or first foot. Many of the 50-foot tapes are dimensioned throughout their length.

3. Since cave surveying is generally in areas that

are wet or muddy, the tape generally will get wet and, unless properly cared for, will rust. Steel tapes require careful maintenance to prevent damage.

4. A steel tape can attract a compass needle, causing errors of directional measurement when the compass is held too closely to the tape.

The only advantages that might be found in a steel tape are its stability and the fact that systematic errors can be corrected to get the most precise distance measurement possible. The methods that can be used to obtain this precision can be found in any elementary surveying textbook and are beyond the scope of this discussion. Generally, this amount of precision is not appropriate for most cave surveys.

Hand Tape

A small hand tape, 8 to 10 feet long, can be used to supplement the longer survey tape. It is marked off in either inches and feet or feet and tenths of feet, or if you are working in metric, you can obtain a tape marked in meters and centimeters. The small tape is used to measure short distances to features in the cave relative to the survey framework.

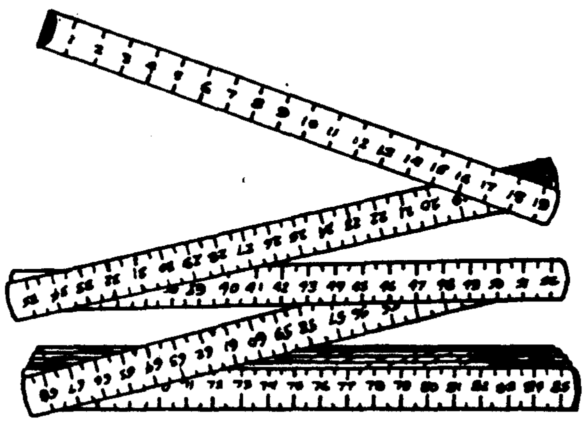


Figure 3-3. Folding rule.

Folding Rule

A folding level rod or an engineer's folding rule can be quite handy for measuring distances such as distances to the ceiling or floor from the survey station. These are 6 to 7 inches long when folded and can be extended 6 to 10 feet (figure 3-3).

Hip-chain Distance Measuring Unit

The hip-chain distance measurer (figure 3-4) is a device which uses a string connected to a metering device to measure distance. The device is attached at the surveyor's waist, and the end of the string is held at the back station. As the surveyor walks away from the point, the distance is registered on the meter in the device. The string is used only once; thus, there is no problem of mud collecting in the instrument. The counter can be reset, or the distance can be cumulative. The device can be obtained in English or metric units.

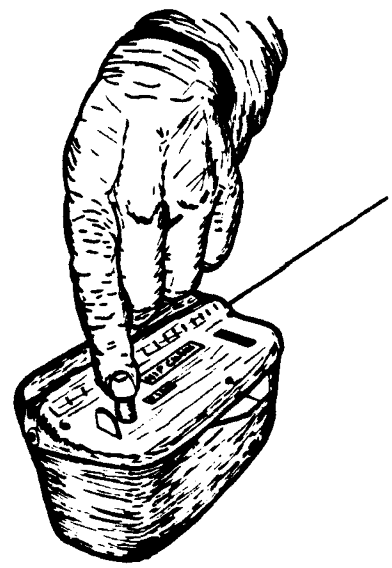


Figure 3-4. Hip chain.

Stringline or Ropechain

An inexpensive substitute for a fabric tape is a stringline or ropechain. This is a length of string or nylon cord which has been treated to be relatively waterproof and which can then be marked at intervals, such as every five feet, with tabs, knots or other means and used in the same manner as a fabric tape. The distances between the intervals can be estimated. If you use a stringline, your survey will be much less accurate than if you use a tape. A commercial ropechain is available which is graduated in either feet or meters and is made of 0.175-inch diameter fiberglass.

Taping Techniques

Whatever tape you use, you should employ certain basic techniques in order to produce the most accurate survey possible.

1. Make sure that the tape is straight and pulled taut at all times when measuring a distance. Do not stretch the tape around a corner or drape it over an object to measure a length.

2. Always place the zero end of the tape at the beginning station and run it along the cave passage to the next station.

3. After the direct measurement is taken, lay the tape face up on the cave floor. This makes it possible to use the tape as a reference line for sketching the details of the cave passage on the survey framework. Distances left and right to the passage walls or other cave features can be estimated or measured from any point along this tape reference line to provide an accurate picture of the cave and its shape. While this is a very accurate way for sketching details, some surveyors use only the stations as reference points and draw in rough estimations of the passage between points. In passages that have very little detail or where survey stations are very close to each other (ten feet or less), this method is adequate, but for very accurate maps with high resolution of detail of complex passages, the tape should be used as a reference line.

Broken tapes are sometimes used when nothing else is available. Generally, a tape will be broken within one or two feet of the zero mark due to heavy use on that end. In the event that this has occurred and you still wish to use the tape, you can begin the survey at the one- or two-foot mark and then proceed. Be sure to subtract that amount from each distance that you measure. This should probably be done at the completion of the day's survey so that you will make sure that all readings have been corrected by **subtracting** the error amount. As one well-known Missouri surveyor did, do not add one foot to the measured distance on the hypothesis that since the tape was a foot short, one should add a foot to the measurement to get the proper distance.

Broken tapes can be repaired by rejoining the broken end to the rest of the line by sewing or by using duct tape. As cuts in the tape occur, they can be repaired with a short bit of duct tape rather than letting the tape break completely.

INDIRECT DISTANCE MEASURING DEVICES

Several devices are available for measuring distance indirectly. These include rangefinders, transits or alidades and stadia rods, sonic tapes, and electronic distance measuring devices. These devices make use of sound or light in one way or another to determine the distance. They also have varying degrees of precision.

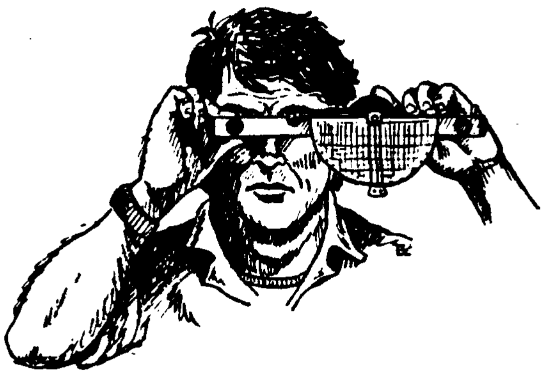


Figure 3-5. Split-image rangefinder.

Split-Image Rangefinder

This device works on the same principle that camera rangefinders employ. Two images of the object sighted upon are viewed through the eyepiece of the instrument. Adjustment of a dial brings the two light images together so they are viewed as a single image. The amount you rotate the dial is proportionate to the distance from the object to you. That distance is then shown on the dial. The reading scale of the instrument is logarithmic, and its accuracy decreases with an increase in the distance to be determined. The instrument is quite effective in the range from 20 feet to 100 feet, where it can be read with about 1 percent error.

Transit or Alidade and Stadia

Stadia methods require a surveying instrument such as a transit or an alidade, devices which consist in part of a telescope with two horizontal or stadia crosshairs in the eyepiece (figure 3-6). These crosshairs are placed in the telescope so that the image distance between them, as viewed on a board marked off in feet and tenths of feet (stadia board) horizontally 100 feet away, shows 1 foot between the stadia hairs. Thus, when the distance between the stadia hairs on the board at the station is measured and then multiplied by the stadia factor (100), the distance to the board is determined. For example, if the lower stadia hair crosses the board at 2.0 feet and the upper hair is at 2.80 feet, the difference is 0.8 feet, multiplied by the stadia factor (100), gives the distance to the board as 80 feet (see figure 3-6), If the stadia board is higher or lower than the surveying instrument, the telescope has to be tilted and a correction will need to be made to determine the horizontal distance. This method is fairly accurate and can be used in fairly precise surveys. The main problems with the technique are that the equipment is large and bulky, and providing adequate lighting for its use in caves is difficult. However, there are caves with rooms and passages large enough and light enough in color that they can be well-illuminated for the use of surveying instruments such as transits, alidades, theodolites, etc., to make a precise survey. The main passage in Smittle Cave in Missouri was surveyed using such equipment.

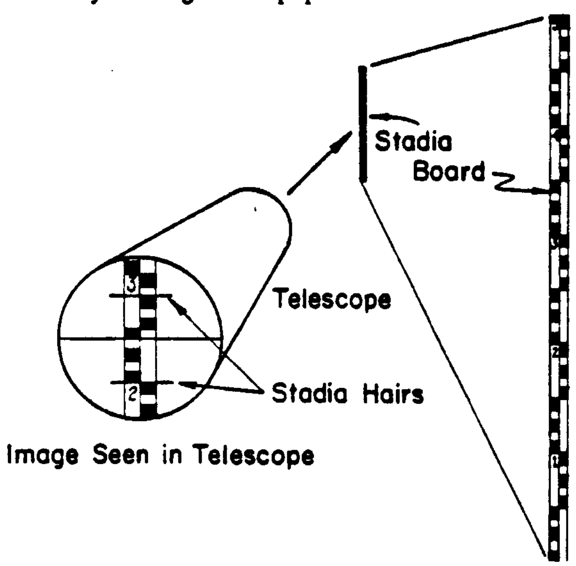


Figure 3-6. Stadia method for finding distances.

Electronic Distance Measurers

Two relatively inexpensive basic types of instruments to measure distance electronically are available. Distances from 1.4 to 60 feet can be measured with a device which emits a series of ultrasonic pulses that travel across the distance to be measured and are reflected back to the unit where the device processes the signal and computes and displays it on a digital screen. The instrument has the advantage of being a single unit, but the drawback of requiring a flat surface like a wall to reflect the signal. For longer distances, a second type of instrument is available in which a beam of infrared light is transmitted to a receiver which returns the signal to the original sending device for processing, computation, and display. A direct and unobstructed line of sight between the sending unit and the receiving unit is required for the device to be useable. Some units can measure distances up to 250 feet. Results are given in feet, inches, and quarter inches. With the push of a button, the same unit can be converted to provide metric results.

These instruments seem to work very well. Other than the problem of needing a flat surface in order to use the first instrument, the only difficulty is that wind can disturb the sound path of the instrument and affect the accuracy of the readings. However, most caves have little or no wind, so this would not generally be a problem in most cave surveys.

A more sophistocated electronic distance measuring instrument (EDMI), which uses an infrared beam and requires a retroprism as a target for reflecting the beam back to the unit is available for very accurate surveying. The instrument then processes the data and displays the results on a small digital screen can be used for measuring distances up to a mile with precision to one hundredth of a foot and is used mainly in conjunction with a theodolite or other surveying instrument which has to be mounted on a tripod. In general, the high cost and space required to utilize this type of EDMI makes it impractical to use in most cave surveys.

MEASURING DISTANCE IN THE CAVE

Most cave maps attempt to represent the three-dimensional character of the cave in a two-dimensional fashion; that is, they attempt to show passages that may ascend rapidly or make abrupt changes in elevation on a flat piece of paper. This necessity of drawing an overhead plan view makes it imperative that distances taken at ascending or descending angles be converted to their horizontal component, a distance that will be less than the distance read off of the survey tape. Basically, there are two ways to measure distance in a cave with a tape or other instrument: the level-line survey and the station-to-station survey.

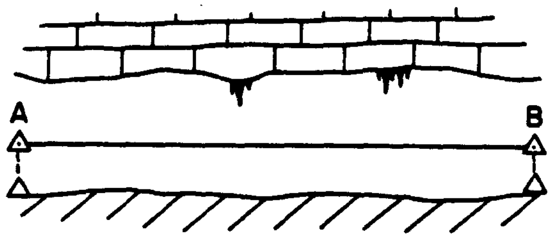


Figure 3-7. Use of the level-line survey for measuring distances in a horizontal cave passage.

In a **level-line survey**, the tape is held horizontally with its ends some distance directly above or below the survey stations (figure 3-7), thereby making one or two "floating" stations directly above or below the true stations. This measurement between the floating stations produces the true horizontal distance (THD) between the two real stations, since it ignores any difference in elevation between them. While the horizontality of the tape between the two floating stations is usually visually estimated, a hand level may be used in order to assure high accuracy when needed. This may be necessary because it is often difficult to visually determine a horizontal line in a passage that ascends or descends slightly (figure 3-8). In a level-line survey, it may also be necessary to use a plumb bob or similar device to ensure that the end of the tape is directly over the station (figure 3-9). The level-line survey has one disadvantage: the vertical differences of elevations are not carried through the survey, which results in loss of vertical control. However, cumulative elevation changes can be obtained by either estimating or actually measuring the vertical distance from the floating station to the actual second station and recording this data, for example, as +1.5 feet or -2.3 feet. A rough calculation of the relative elevation of each station in the survey can be made by adding and subtracting these distances.

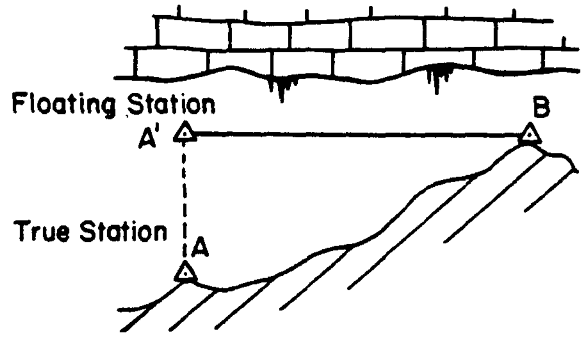


Figure 3-8. Use of level-line survey in a passage which has a gentle slope.

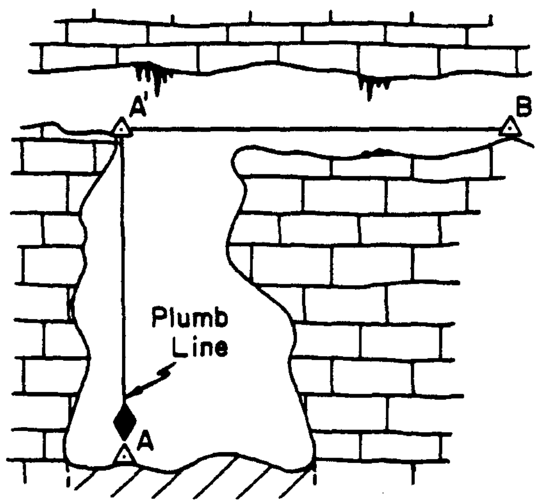


Figure 3-9. Use of the level-line survey showing the use of the plumb bob with the tape to determine passage length.

The advantage of this type of survey is that the tape can often be lifted clear of various floor obstructions, making for a longer survey shot than would ordinarily be possible. Thus, the level-line type of survey is generally faster, involves the making of fewer survey stations, and is easier than station-to-station method since the clinometer does not have to be used for all shots. However, a clinometer still has to be used for steep slopes, since a great number of short horizontal shots might have to be made to go up a long steep slope.

In the station-to-station survey (figure 3-10), both ends of the tape are held directly on the actual survey stations or at equal heights above them, and the vertical angle from one station to the next is directly measured. Keep in mind that the taped distance determined this way is not the true horizontal distance and must be corrected to the horizontal component either graphically or by multiplying the tape distance by the cosine of the vertical angle. In a station-to-station survey, be careful that the tape is held either directly on each station or that it is held directly above the two stations by the same amount. If one end is held higher in respect to the survey station beneath it, than the other, an error in either the horizontal distance, vertical relief, or both will occur. To be exact, you should prearrange with the person at the front end of the tape about how high the tape should be above the stations. Waist or belt height is generally convenient, especially if the surveyor and the front tape person have the same waist height; otherwise some other comparable point should be selected.

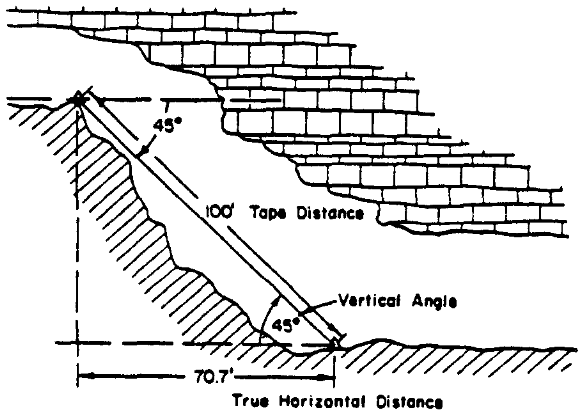


Figure 3-10. Station-to-station method for measuring distances.

An advantage of the station-to-station survey is that the changes of elevation are preserved in the survey by measuring the vertical angles (see chapter 5). Disadvantages are that it takes more time than the level-line survey and may require difficult contortions for the person attempting to read the compass and clinometer. Placing convenient stations is a virtue here--so be good to the front taper who selects the survey station locations. The authors generally recommend this second type of survey, as vertical control of survey shows elevation changes. Control of elevations may be useful for such other purposes as geological or speleogenetic studies later on.

MISTAKES IN DISTANCE MEASUREMENT

The first step in preventing mistakes is to be aware of the most common mistakes and how they might occur. This knowledge will help the surveyor to be more careful. Some of the common mistakes made when measuring distance using a tape include:

1. Misreading the tape - There are many ways to make this mistake. The chief or note-taker needs to consider whether the distance readings make "sense" in relation to his/her sketch.

a. Misreading the tenths on the tape, such as reading 22.2 feet for a reading that should be 22.3 feet.

b. Misreading units on the tape, such as reading 33.5 for 38.5 feet.

c. If you have a combination metric-English tape, reading metric when you should read English or vice-versa.

d. Reading tenths of a foot as inches or vice-versa.

e. On tapes with no tenth numbers, reading the wrong way from a marked graduation, i.e., from the 16-foot mark 15.5 for 16.5 feet.

f. Transposition of digits such as reading a 45 for a 54 (Numbers are easily reversed or misunderstood when they are called out to be recorded. The zero digit and the decimal point are the most likely to cause mistakes).

g. Confusion of sixes and nines, such as recording a 26.9 for a 29.6.

h. If the tape is old and worn, mistaking one number for another, such as an 8 for a 3 (This confusion can be avoided by looking at the flanking graduations before calling off the distance.)

2. On very long horizontal-distance shots, failing to correctly count the number of full tape lengths - The best method of eliminating this mistake is to never exceed a tape length between survey stations. No distance measurement should exceed 100 feet or 30 meters. The tape length is then recorded for each

full tape distance even though the directions are all the same.

3. Mistaking the end mark - The end marks are differently arranged on different tapes. You should always check the tape to see where the end mark actually is before making measurements. Older tapes may actually have been made shorter because a foot or more of the tape may have been broken off. The tape can still be used, but it is necessary to be be aware that the tape is short. Make certain that you know what the end mark is.

4. Bent tapes - Any tape length pulled should not touch the sides, floor, or ceiling of the passage. The tape must be free and clear for the entire length. If it is draped over, around, or under an obstacle, the length of the taped distance will exceed the true distance that should be measured. This can be prevented by making sure that the tape is not touching anything for its entire length.

The best way to minimize the mistakes listed above is a system of checks. One way to do involves the following: as the surveyor or front taper extends the tape and reads the distance, he/she calls out the length. The chief then repeats the distance and this is then verified by the surveyor or lead taper. The chief then records the data in the field notes. A second method to ensure a correct distance measurement with a tape is to use a metric tape and an English tape either as a pair or use a tape that is marked in both English and metric scales. With this arrangement, record the measurement in both English and metric. If the metric distance multiplied by 3.281 equals the English measurement, you know that you have recorded the correct distance. If the two do not agree, the distance needs to be remeasured and checked again.

SUGGESTED FIELD EXERCISES

DETERMINING PACE

1. In this exercise, you will determine the length of your pace. To do this, obtain a 100-foot tape and stretch it out full length on level ground. A long hallway or parking lot would be a good place. Start at one end of the tape and walk in normal stride to the other end. Then turn around and return, counting your steps as you go. The total tally of steps divided into the distance paced (200 feet) gives the feet per pace. You should memorize this number. In pacing, be certain that you are always consistent in the method of pace. This can be done by counting every time a foot hits the ground (paces) or each time the right foot hits the ground (stride). Whatever you do, be consistent.

2. Find a road which is inclined at a fairly steep angle. Again, using the 100-foot tape, stretch it out full length up the hill. Using the same procedure as in number 1, count your paces uphill and divide into the 100 feet. This will give the pace length for that hill. Pace down the hill and do the same thing. You should find that the pace is shorter for the uphill segment and longer for the downhill segment than your normal pace. You might use this information to see how to adjust your pace for uphill or downhill conditions.

LEARNING TO ESTIMATE

1. In this exercise, you will learn to estimate distances. Find an area in which there are several objects such as trees, bushes, rocks, etc., in close proximity to you. Estimate the distance to each of these objects, then measure the distance with a tape and compare the results. A good way to do this is to use known length items such as arm span, a yardstick, body lengths, etc., for comparison. Everyone should know their arm span, eye height, body length, etc., to use for reference. Once you become proficient with horizontal distance estimates, you should practice estimating heights and again compare with the true heights as measured by a tape.

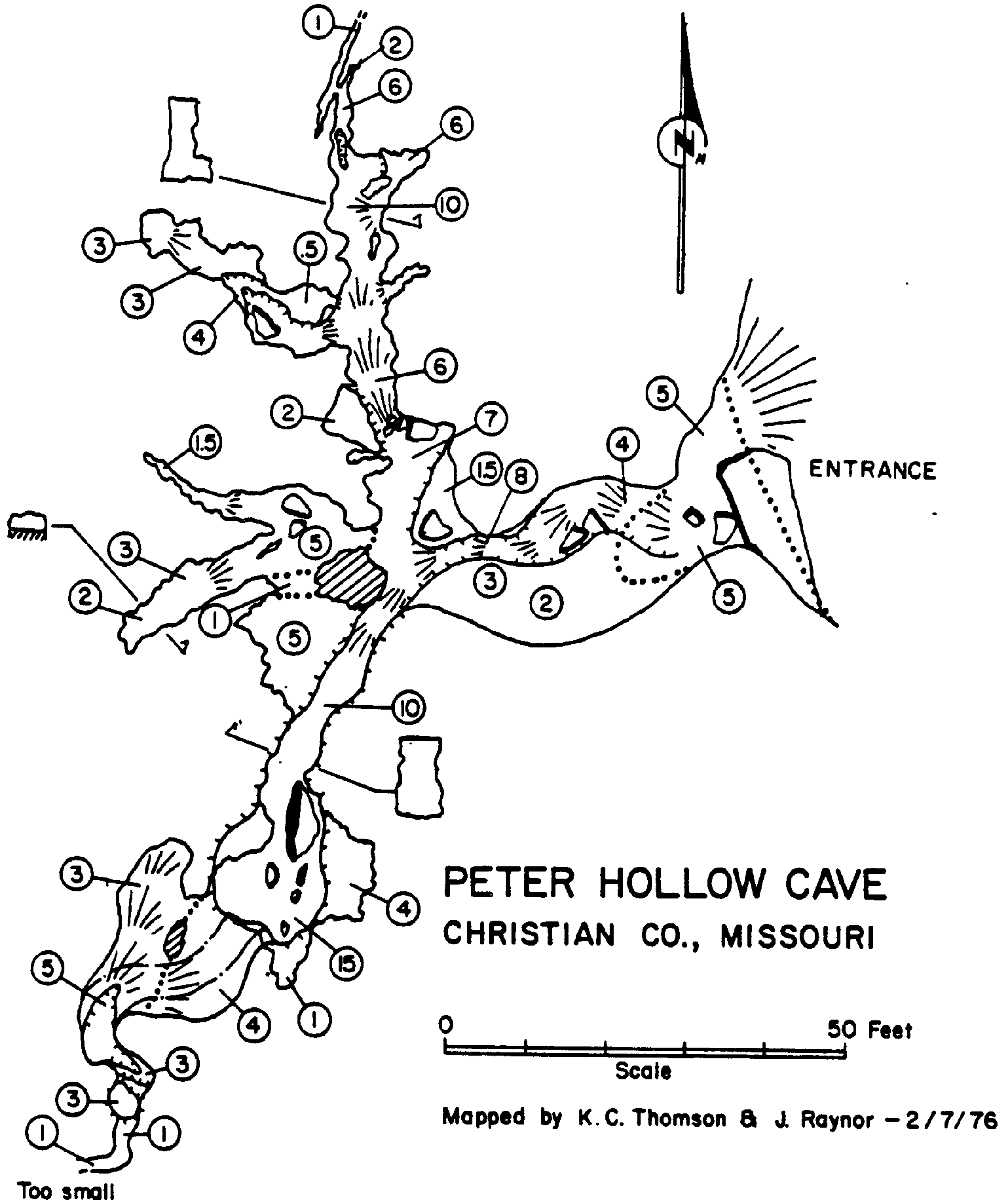
2. In this exercise you will determine the lengths of body parts of team members to use for comparison for distance estimating. Using a tape and a partner, measure your height, eye height, arm span, length of forearm, and hand span. Record the information in the following form and memorize:

Name:________________Age:_____Date:______

Pace length:_______Uphill:_____Downhill:_____

Height:______Eye height:_______Arm span:_____

Forearm length:_________Hand span:__________



ENTRANCE
PETER HOLLOW CAVE
CHRISTIAN CO., MISSOURI
0
50 Feet
Scale
Mapped by K.C. Thomson & J. Raynor - 2/7/76
Too small

4

MEASUREMENT OF DIRECTION

ANGLES, MERIDIANS, AND THE DIRECTION OF A LINE

The second necessary component used to locate survey stations in the cave is the direction from one station to the next. The direction of any line (as defined by two points such as two successive survey stations) is determined by the horizontal angular measurement between the line and some line of reference, known as a meridian. Three types of meridian are used in surveying: **true meridian, magnetic meridian, and assumed meridian.**

The **true meridian** is a line from the location of the survey to the north geographic pole. This meridian can be determined by astronomical means or through the use of a compass that has been set for true north using the magnetic declination. All surveys should be tied to the true meridian so that their relative positions in space are all correlative.

The **magnetic meridian** has its direction tied to the north magnetic pole, and all compass needles point in that direction. The magnetic north pole is not at the same location as the geographic north pole and hence will not usually be aligned with its meridian. In addition, unlike the geographic poles, the location of the magnetic poles constantly changes; therefore, the magnetic meridian also changes over time.

An **assumed meridian** is a reference line that is given an arbitrary direction in the survey.

Angles of direction can then be determined in reference to this line. An assumed meridian requires the use of an instrument such as a transit which can measure the horizontal angle from one line to another. A direction determined in this way is only relative to the assumed meridian and must be tied in space to the true north meridian to have any significance.

ANGLES AND ANGULAR MEASUREMENT

The angular measurement relative to either the true or magnetic meridian is read from a compass as either bearings or azimuths.

Bearings

A **bearing** is the acute angle (one less than a right angle or 90 degrees) that the direction line makes with the meridian; hence, bearings are measured from the north/south line and can never exceed 90 degrees. These angles are read to the east or west of the north/south line and are expressed as N.12° W., or S.10° E., etc. The exact north direction may be referred to as due north or as N. 0° 00' E. or N. 0° 00' W. Exact east is also referred to as due east or N. 90° 00' E. or S. 90° 00' E. South and west are referred to in a similar manner.

Back Bearings

A back bearing is the reciprocal of the bearing. As such the back bearing carries the bearing designation in reverse; that is, the cardinal point designations are reversed and the numerical value remains the same. Thus if the bearing is N. 23° E., the back bearing would be S. 23° W. or a bearing of S. 65° E. has a back bearing of N. 65° W., etc.

Azimuths

An **azimuth** is the angle between the direction line and the north meridian as measured in a clockwise direction from 0 to 360 degrees. Northeast bearings give azimuths from 0 to 90 degrees; southeast bearings from 90 to 180; southwest bearings from 180 to 270; and northwest bearings from 270 to 360 or 0. Figure 4-1 shows the relationship between bearings and azimuths.

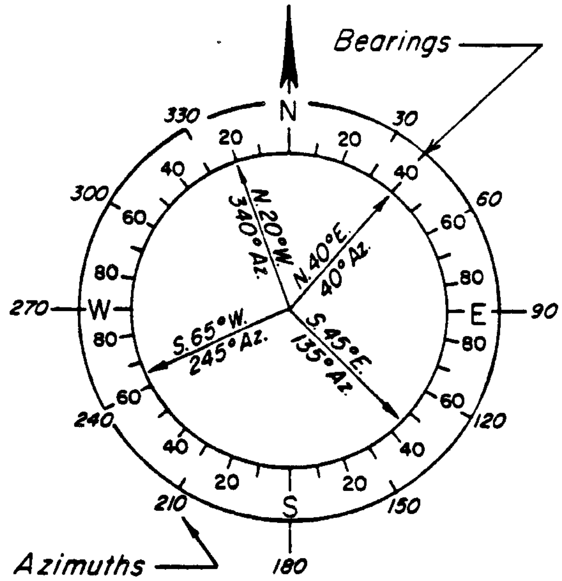


Figure 4-1. The relationship between bearings and azimuth.

Back Azimuth

A back azimuth is the direction of a line looking back to its origin from its terminus; that is, 180° from the initial azimuth direction. For example, if the azimuth is 125°, the back azimuth is 305° or if the azimuth is 285°, the back azimuth is 105° or 285°- 180°.

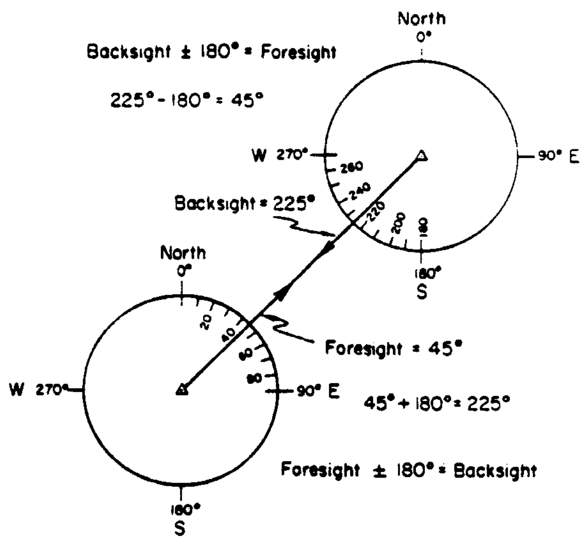


Figure 4-2. The relationship between foresight and backsight azimuths.

Value of Backsights (Back Azimuth or Back Bearing)

When the bearing or azimuth cannot be read in the forward direction, it may be possible to take a backsight from the target station to the source station (figure 4-2). Since the reading is a reverse reading, it will be 180 degrees from the original bearing or azimuth direction. This correction of 180 degrees can be applied to plot the proper azimuth or bearing. Backsights are also valuable as checks for the direction measurement. If you take both a foresight and a backsight, and they are 180 degrees apart, then your measurement is probably accurate. Any significant discrepancy should be checked. For most cave surveys, agreement within one-half or one degree is considered acceptable. The final answer should be derived from the average of the foresight and the backsight as corrected by 180 degrees. Backsights should be taken in all cave surveys to make certain that the measurements of direction are correct.

Azimuth to Bearing Conversions

Rules for converting azimuths to bearings depend on the quadrant in which the azimuth lies. In the northeast quadrant, the azimuth number is used as is with the addition of the N. and E. designations. For example, 76° Azimuth is a N. 76° E. bearing. In the southeast quadrant, the azimuth is subtracted from 180° and then given the appropriate designators of S. and E. For example, an azimuth of 135° becomes 180° - 135° = 45° or S. 45° E. In the southwest quadrant it is necessary to subtract 180° from the azimuth and then add the S. and W. designators. For example, azimuth 237° - 180° = 57° or S. 57° W. In the northeast quadrant the azimuth is subtracted from 360° and the designators N. and W. are added. For example, 335° is 360° - 335° = 25° or N. 25° W.

Bearing to Azimuth Conversions

Conversions of bearings to azimuths is done in the opposite way to azimuth to bearing conversions. In the northeast quadrant, the bearing angle is the azimuth. In other words, a bearing of N. 68° E. is 68° azimuth. In the southeast quadrant, the bearing angle is subtracted from 180° to give the azimuth. For example, S. 32° E. is 180° - 32° = 148° azimuth. In the southwest quadrant, the bearing angle is added to 180° to get the azimuth. If we have S. 65° W., this becomes 180° + 65° = 245° azimuth. In the northwest quadrant, the bearing angle is simply subtracted from 360° to get the azimuth. An example would be N. 35° W. which would be 360° - 35° = 325° azimuth.

MAGNETIC FIELD OF THE EARTH AND DECLINATION

The earth has a magnetic field that behaves as though its magnetism derives from a very short, very powerful bar magnet at the earth's center. The earth's rotational axis or the north-south; line does not coincide with the earth's magnetic field. Figure 4-3 is a simple graphic representation of the earth's magnetic field. Note that only at the "magnetic equator" are the field lines horizontal. As you move away from the equator the field lines dip into the earth at increasingly steep angles. A weight is placed on the south end to the compass needle in the northern hemisphere to counterbalance the magnetic dip to obtain only the horizontal component of the magnetic field. The compass needle will then point in the direction of the north magnetic pole. The angle between the direction of the true north meridian and the magnetic north meridian is the magnetic declination (figure 4-4). Declination is designated by both the angle and the direction. If the needle points west of true north, the declination is west, if east, the declination is east.

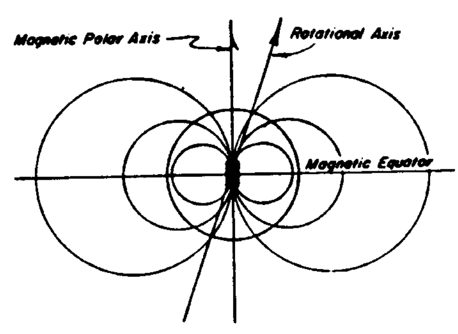


Figure 4-3. Diagrammatic representation of the earth's magnetic field.

MAGNETIC DECLINATION IN THE UNITED STATES

Declination varies with geographic location and changes over time. This variation must always

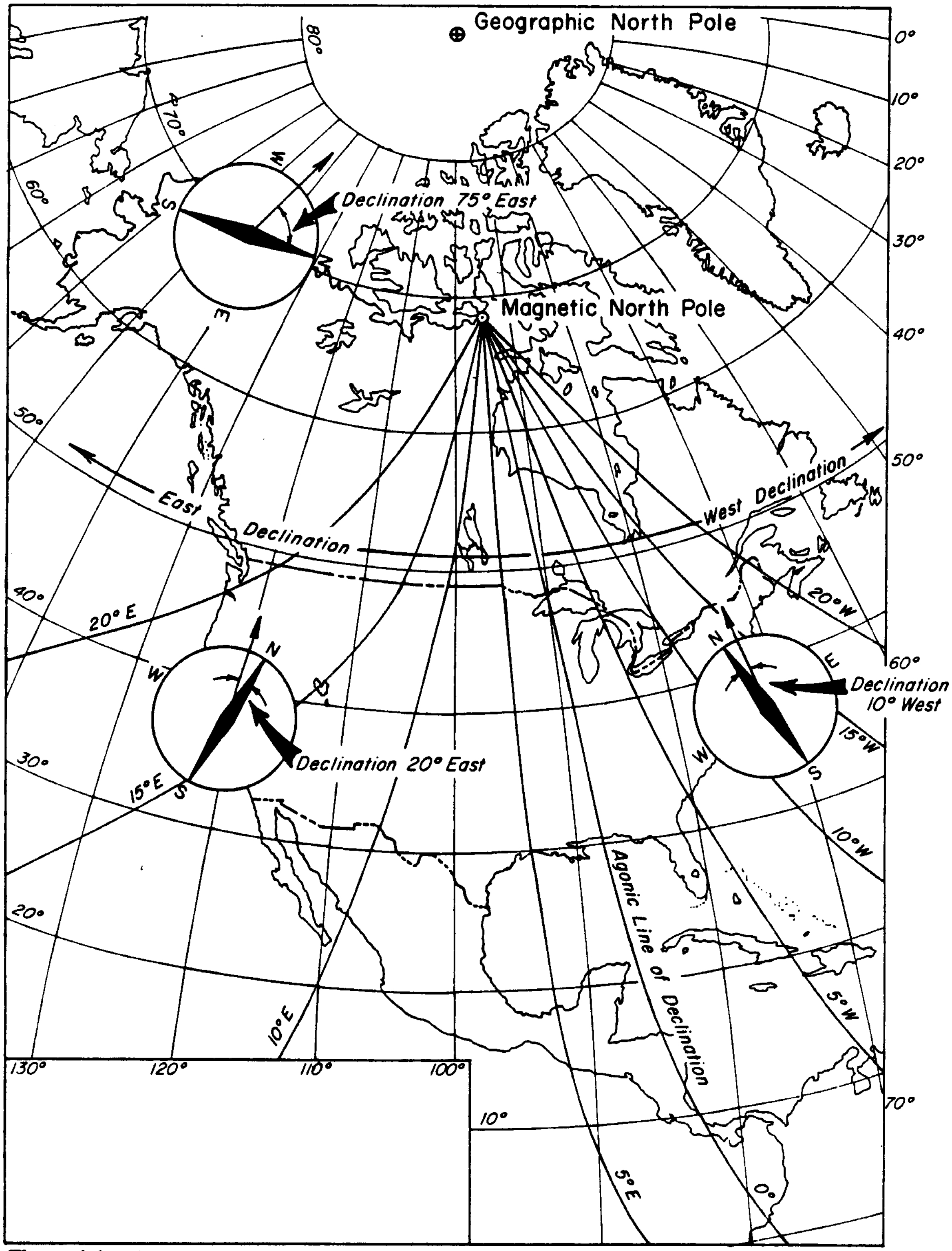


Figure 4-4. The relationship between true north pole, magnetic north pole, and magnetic declination.

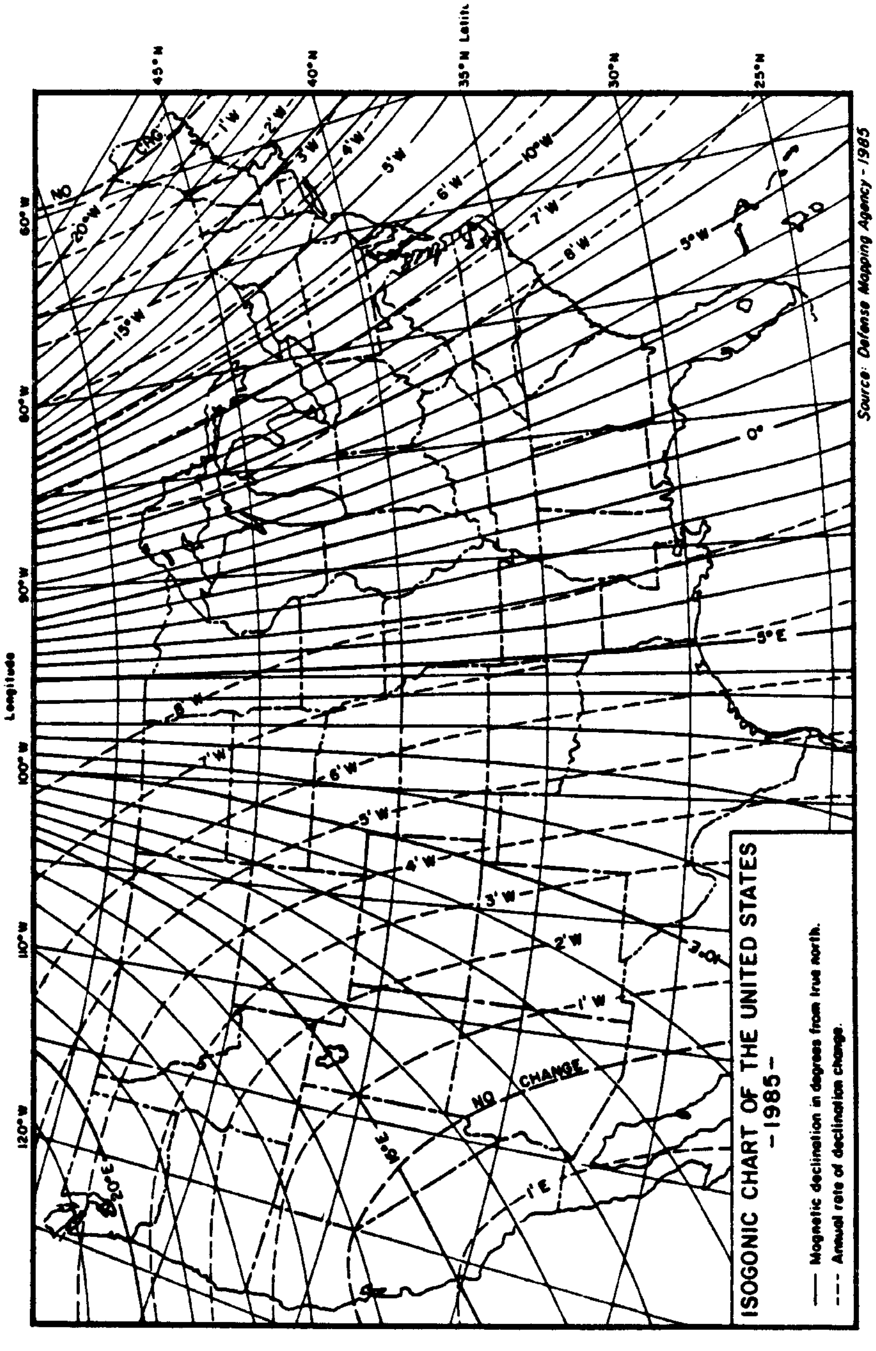


Figure 4-5. Isogonic Chart of the United States, 1985, taken from Defense Mapping Agency.

be considered when correcting a magnetic survey to a true north survey. Figure 4-5 is an isogonic map of the United States showing lines of equal declination (isogonic lines) for the date of the chart. The agonic line or line of 0 declination is also shown. The annual changes are also plotted so the declination for any area in the United States at the present time can be determined. The declination to the east or west must be added to or subtracted from magnetic north to get an accurate true north direction for any given area (see table 4-1).

The cave surveyor can obtain more accurate declination data than shown on the map by contacting the National Geophysical Data Center, NOAA, Cod E/GC4/FLI, 325 Broadway, Boulder, Colorado 80303 or by phoning (303)497-6124.

Table 4-1. Table for converting magnetic bearings to true north bearings.

For declinations of 0 to 90 degrees to the east:
- Northwest bearings from 0 to 90 degrees, subtract the declination angle.
- Northeast bearings from 0 to 90 degrees less the declination angle, add the declination angle.

For declinations of 0 to 90 degrees to the west:
- Northwest bearings from 0 to 90 degrees less the declination angle, add the declination angle.
- Northeast bearings from 0 to 90 degrees, subtract the declination angle.

For all bearings to the south, convert them to backsights and adjust as shown above.

CONVERSION OF MAGNETIC DIRECTIONS TO TRUE DIRECTIONS

It is important to be able to convert magnetic bearings and azimuths to true north bearings or azimuths. Always keep in mind that true directions never change. Magnetic directions are referenced to the local magnetic north, a direction that changes with time. When converting from magnetic declination at one time to a later magnetic declination, it is necessary to determine true direction. You can generally do this most easily by making a sketch to keep your positions straight (figure 4-6). Azimuth readings are generally simpler to convert than bearing readings.

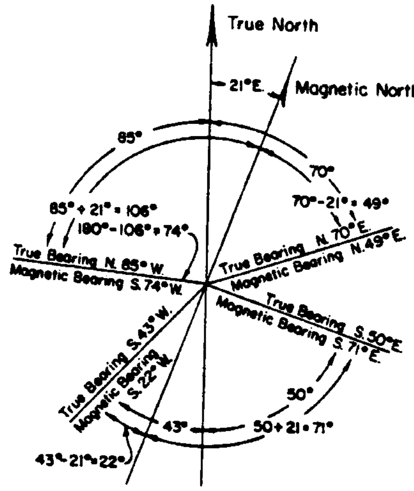


Figure 4-6. Relationship between true bearings and magnetic bearings.

If there is any doubt as to how to determine true north, then it is acceptable to indicate magnetic north on your maps. However, if magnetic north is used, then it must be noted on the final map or else the orientation of the map will be off by the difference between the magnetic meridian and the true meridian.

MAGNETIC DISTURBANCES

Local magnetic directions can be substantially in error as a result of fixed or variable disturbances in the local magnetic field. Fixed disturbances are called "magnetic anomalies". These can result from a number of causes such as a deposit of magnetic ore or an area of discarded automobile bodies in a buried landfill. These disturbances can be identified by always taking both foresight and backsight readings along the traverse. A discrepancy might indicate an anomaly (figure 4-7).

Significant magnetic disturbances of solar origin can also make the determination of magnetic directions unreliable or even impossible. Solar activity is monitored by the Space Environment Services Center of the National Oceanic and Atmospheric Administration, Boulder, Colorado. The level of activity in the last 24 hours and the forecast for the next 24 hours can be obtained by calling (303)497-3235 and listening to the recorded message. The information is also available on short wave radio station WWV at 18 minutes after each hour. The condition of the geomagnetic field will be described as "quiet", "unsettled", "active", "minor storm", "major storm", or "severe storm". A magnetic compass should only be used during times indicated as "quiet" or at worst, "unsettled" to get the best results.

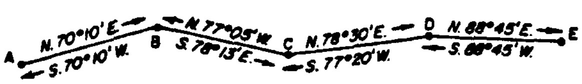


Figure 4-7. Traverse showing evidence of a magnetic anomaly in the middle two legs.

TURNED ANGLES

A cave can be surveyed from an assumed meridian by **"turning angles"** using a fairly sophisticated surveying instrument such as a transit. This can be done either by recording angles turned to the right or by recording deflection angles. In **turning angles to the right**, the meridian line is established as the line between the first two stations, such as stations 0 and 1 (figure 4-8). Then station 1 is occupied, a backsight to station 0 is taken by lining up the instrument, the angle is then turned to the right to station 2, and the turned angle is recorded. Then the process is repeated at station 2.

It is always necessary at some time to determine the true azimuth of the assumed meridian and then to convert all direction measurements from this meridian to true north azimuths or bearings.

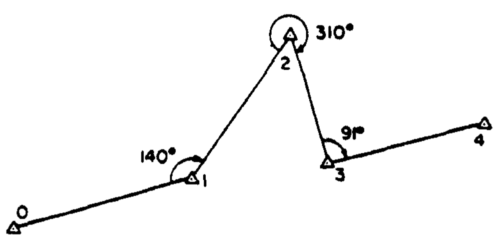


Figure 4-8. Surveying the cave traverse by turning angles to the right.

In using **deflection angles**, the instrument is again set up on station 1, and station 0 is backsighted. Then the instrument telescope is inverted so that the it is now facing a direction 180 degrees from station 0. The angle is turned to the right or left from the extension of line 0 to 1 (figure 4-9).

Both angles to the right and deflection angles are unaffected by magnetism from iron objects and ore bodies which might deflect a compass needle and give inaccurate readings.

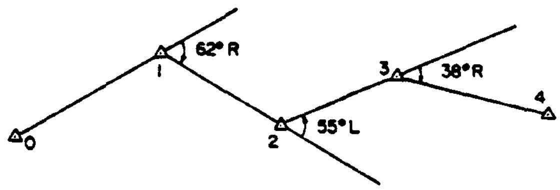


Figure 4-9. Surveying the cave traverse by using deflection angles.

When an error in either an angle to the right or a deflection angle is made, the error is carried through the remainder of the survey, multiplying its effect (figure 4-10).

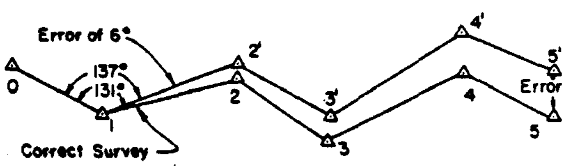


Figure 4-10. Traverse with turned angles showing how an error in one angle can be carried through the traverse.

DIRECTIONS FROM TURNED ANGLES

If interior angles, angles to the right, or even deflection angles are measured, it is necessary to convert to bearings or azimuths to calculate coordinates for survey points (Chapter 10). If a closed loop or traverse which closes on a second, surveyed control point, is used in the survey, then the loop or traverse can be adjusted for true angle direction and bearings or azimuths calculated. In survey loops it is important to remember that the sum of the interior angles in any closed geometric form is equal to (n-2) X 180, where n = the number of sides in the form. For example, a triangle with 3 sides, the sum of the interior angles would be (3-2) X 180 or 180°. In a triangle with the interior angles of 60°, 55°, and 65°, the sum equals 180°. If the interior angles do not match the total calculated, the descripancy can be distributed through the angles at each corner respectively. In the example quadrillateral (figure 4-11), the number of sides = 4, hence the sum of the interior angles has to be (4 - 2) X 180 or 360°

In the example (figure 4-11), the bearing from A to B was determined to be N. 45° 00' E. This then ties down the survey to a true north meridian. Then the interior angles must be converted to azimuths of the sides of the quadrillateral. This is done in the following manner:

Table 4-2. Interior angle traverse.

Side	Azimuth	Bearing
AB	45° 00'	N. 45° 00' E.
BA	225° 00'	
<B	70° 43'	
BC	295° 43'	N. 64° 18' W.
CB	115° 43'	
<C	120° 19'	
CD	236° 02'	S. 56° 02' W.
DC	56° 02'	
<D	64° 21'	
DA	120° 23'	S. 59° 37' E.
AD	301° 23'	
<A	104° 37'	
AB	406° 00'	
AB	45° 00'	N. 45° 00' E.

Checks with original azimuth.

These azimuths can then be used with the measured distances to compute coordinates for the four points in the simple traverse.

MEASUREMENT OF DIRECTION

The direction from one survey station to another is measured with either a compass, a transit, or some similar surveying instrument. The compass is the instrument used in nearly all cave surveys to measure direction relative to either the magnetic north or to the true north meridian. Since the compass needle always points to the magnetic north pole, directions can easily be measured relative to this direction. All surveying compasses have three essential features: a circle graduated in angular units, generally in degrees and parts of degrees; a magnetic needle; and a sighting device. Four compasses that are commonly used in cave surveying are the Brunton compass, the Suunto compass, the Sisteco compass, and the Silva compass.

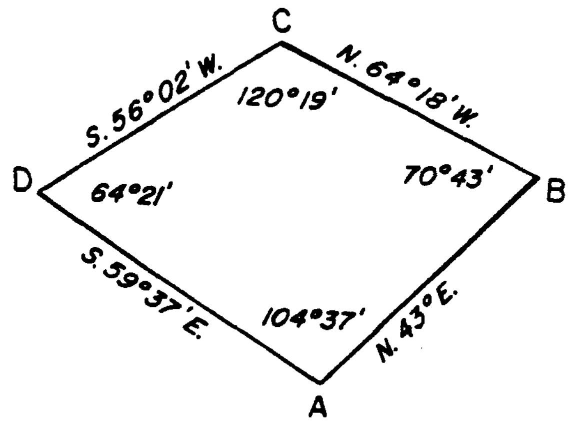


Figure 4-11. Example traverse using interior angles.

BRUNTON COMPASS

Brunton pocket transits or Brunton compasses have been standard equipment for geologists for many years. The Brunton compass and its component parts are shown in figure 4-12.

The compass is constructed of aluminum and brass so that the material in the compass itself will not affect the compass needle. This compass needle rests on a pivot needle which, when in use, allows a nearly frictionless motion of the needle. When the compass is closed, a damper, controlled by a lift pin, lifts the compass needle off of the pivot needle to prevent damage from sudden shock. In older models, this damper or lift pin also can be used in older models to slow down a rapidly oscillating compass so that a reading can be taken more quickly. Later models have induction dampening so that the needle "settles down" for a quick reading. The compass needle is carefully balanced for your latitude by a small wire coil wrapped around the compass needle. This coil is used to offset the vertical effects of the magnetic field lines that surround the earth which cause the needle to dip as it aligns with them. The compass needle is generally marked with one end white to designate the north-seeking end of the needle (also called the "north end of the needle"). This is generally opposite the wire coil on the needle in the northern hemisphere.

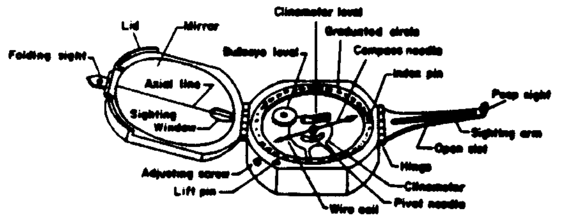


Figure 4-12. The Brunton compass.

Within the compass box are two level bubbles, a **bullseye bubble** and a **horizontal level clinometer bubble.** The bullseye bubble is used to level the compass so that the compass needle will swing freely and an accurate bearing or azimuth reading can be obtained The horizontal level bubble is a part of the **Brunton clinometer** which is used to measure vertical angles. In connection with this level are two scales and an arm with a vernier scale. These two scales contain an angular scale from 0 to 90 degrees and a percent grade scale from 0 to 100 percent. The vernier is used to read the angle of inclination.

The compass is equipped with a **sighting mirror** that has an **axial line** which can be lined up at an angle to the plane of the compass, and with a **sighting arm** that has a **peep sight** which also can be inclined and is used to sight the compass on the target. On the bottom of the compass is a lever for adjusting the clinometer.

An adjustable **graduated compass circle** is found around the outside of the compass. All azimuths and bearings are read from this circle, which can be rotated to adjust for magnetic declination with the aid of a screw on the side of the case. Because of this adjustment, you can directly read true north bearings and azimuths instead of having to calculate them later. The compass circle is also marked in a reversed manner, i. e., the east and west are transposed, with the east on the left side and west on the right side. The azimuth scale is read counterclockwise. This arrangement enables the compass to be pointed directly at the target and the compass needle to point at the exact azimuth or bearing (figure 4-13).

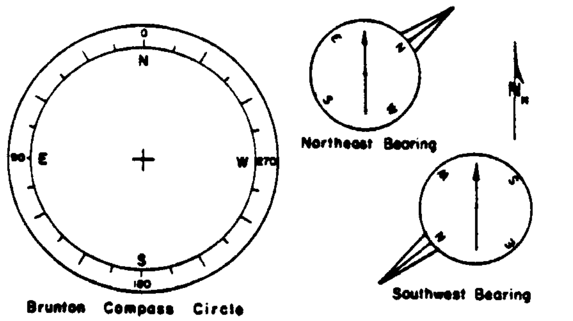


Figure 4-13. The Brunton compass circle showing direction measurement.

On the top of the closed compass are two important parts: the **table of natural sins**, which can be used in calculations if necessary; and, generally, the **compass serial number**. In most cave surveys where more than one compass is used, it is a good practice to indicate the serial number of the compass in case an inaccuracy due to compass error is discovered in a part of the survey.

The sides of the compass may or may not have two slots which are used to attach the compass to a non-magnetic tripod that is designed to be used with the compass.

Types of Brunton Compasses

Three types of Brunton are manufactured in the United States. All three types are used in the same way and differ only in the compass circle. The first, the **bearing** or **quadrant Brunton**, is divided into four quadrants: the northeast, northwest, southwest, and southeast. Each quadrant has a scale from 0 to 90 degrees from north to east, north to west, south to east, and south to west. On the scale, west is on the right side and east is on the left if you have north at the top (figure 4-14A). The second is the **azimuth Brunton,** which has the circle divided into 360 equal degrees in a counterclockwise direction (figure 4-14B). The third, less common than the other two, is the **military Brunton**, which has the compass circle divided into mils rather than degrees. There are 6400 mils in a full circle. This scale is also counterclockwise and is shown in figure 4-14C. The mil scale can be converted to degrees by multiplying the mil reading by 0.05625.

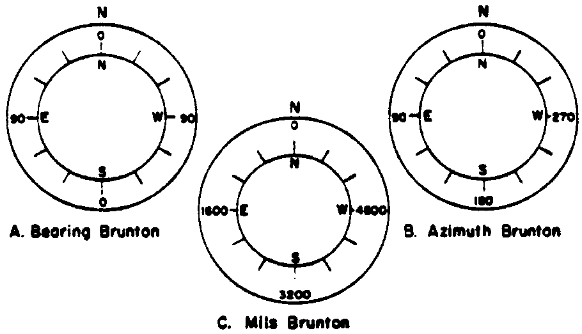


Figure 4-14. Types of Brunton compass circles.

Procedure for Taking a Bearing or Azimuth with a Brunton Compass

The Brunton compass is a direct-reading compass. That is, the reading obtained is the bearing or azimuth from the station you occupy to the target station. The north (white) end of the needle will give the bearing or azimuth reading directly. To obtain accurate compass readings, you must do four things simultaneously:

1. Level the compass.

2. Bring the next survey station into the exact center of the sights.

3. Wait until the needle comes to rest or is dampened.

4. Read the bearing or azimuth.

Waist-level Sighting

If the target station sighted is visible from the level of your waist or chest, the following procedure is used:

1. Open the compass. The lid hinge is near the sighting window. Set the lid at an angle of about 135 degrees with the compass, and turn the sighting arm out, also at an angle of near 135 degrees (this can be varied to suit the surveyor--figure 4-15).

2. Stand with the feet spread slightly in a comfortable position. Cradle the compass box in the palm of the left hand, held about waist height with the mirror and lid held closest to the body and the sighting arm aimed in the direction of the target station. Be sure the compass does not get too close to any iron objects, such as a belt buckle, which might deflect the needle.

3. Place your right hand beneath the left with the thumb over the lift pin so as to be able to easily depress the pin.

4. Place elbows and upper arms against the body for increased stability and proceed to center the bullseye level bubble.

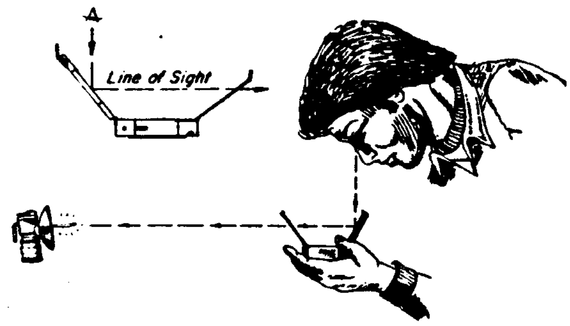


Figure 4-15. The Brunton compass as used in waist-level sighting.

5. Keeping the level bubble approximately centered, adjust the mirror up or down until the target station can be seen in the mirror with the sighting arm.

6. Keeping the compass level, rotate the whole compass about an imaginary vertical axis until the target station, the sighting arm, and the center line in the compass mirror are all aligned. In other words, the target station shows in the mirror along the center line with the sighting arm superimposed on it.

7. Read the bearing or azimuth from the north end of the needle. The needle should be almost at rest. If it is swinging, use the lift pin to slow it down carefully. Once the needle has come to rest or nearly so, do not depress the lift pin to read the azimuth or bearing, as this act will change the actual reading. Read the needle while it is in the free position, which will give the most accurate reading. The needle does not need to be completely at rest. The best practice is to retard the needle oscillations to about 5 or 6 degrees or less, then read the mean point of the swing. With some practice, the compass can be read to about 1/2 degree of precision.

8. After reading the bearing or azimuth, be sure that the line of sight is still in alignment and the compass is level.

9. Record the bearing or azimuth at once.

If the target station is very much below your elevation, the sighting arm of the compass can be inclined (as shown in figure 4-15) to facilitate the inclined shot. In that event, the mirror angle also will have to be changed. In using this method, the compass is reversed and the reading will actually be 180 degrees from the true direction. This should be corrected in your notes.

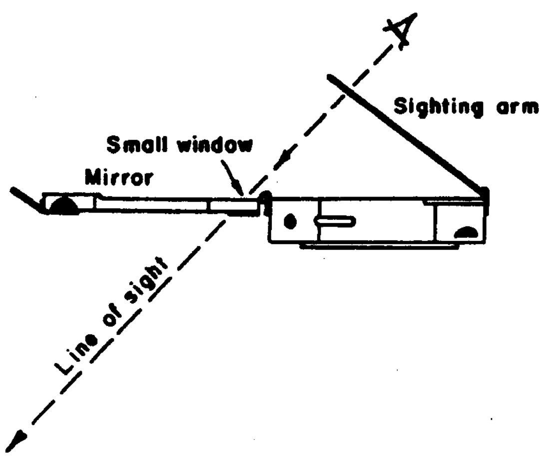


Figure 4-15. Brunton compass as used to sight down a steep slope.

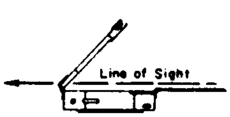


Figure 4-16. The Brunton compass used for eye-level sighting.

Eye-level Sighting

If the point being sighted is at eye level, or if you are in a position where it is impossible to use the compass in the normal way, you might use it in the reversed position:

1. Open the lid as before, but fold the sighting arm out, either horizontally or at a slight angle, and fold the lid and the mirror to a 45-degree angle to the compass box (figure 4-16).

2. Hold the compass in the left hand at eye level with the sighting arm pointing toward the right eye, but about a foot from the eye.

3. Level the compass by observing the bullseye level bubble in the mirror. This is the difficult part because in the mirror everything is reversed, and your mind will have to compensate for this. Once the compass is leveled, rotate it, keeping it leveled until the target station appears in the small sighting window of the lid.

4. Align the target station, the axial line in the window, and the sighting arm, keeping the compass level.

5. Read the bearing or azimuth in the mirror, double-checking for alignment. Keep in mind that since the compass is pointing backwards, the reading obtained from the white end of the needle will be the bearing or azimuth from the target station to the surveyor (a backsight). Therefore, you either must adjust the reading by adding or subtracting 180 degrees or must read the azimuth or bearing from the black or south end of the compass needle.

6. Record the reading.

With practice, both methods can give readings with a precision of about 1/2 degree. You must remember, however, that the compass must be properly leveled and aligned to attain this degree of accuracy.

The Shadow Method

The shadow method of determining bearings or azimuths is very similar to the first method of finding direction, as given above. The difference is that with the shadow method, instead of sighting through the mirror, you allow a single light at the target station to be the only light to sight on (figure 4-17). A tripod must be used to obtain the best results. The following procedure is used to determine direction with this method:

1. Set up the Brunton on the tripod and level the instrument using the bullseye level bubble.

2. Set the mirror at about a 90-degree angle to the compass box, and the sighting arm at an angle of about 90 degrees also.

3. Rotate the compass, keeping it horizontal until the shadow formed by the sighting arm aligns with the center line of the mirror. At this point, the compass is in proper alignment to take the bearing or azimuth.

4. Illuminate the instrument and take the reading.

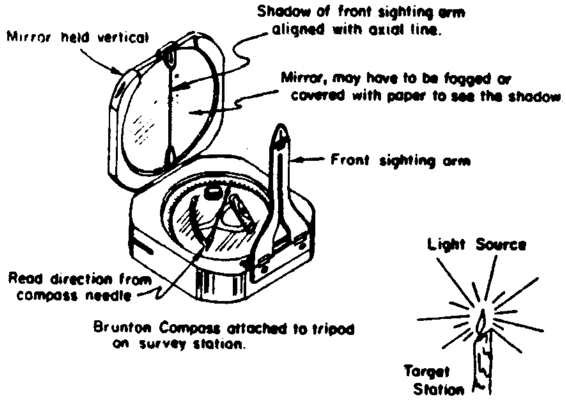


Figure 4-17. Use of the shadow method and a Brunton compass to determine direction.

It is very important that only one point light source be used at the target station; all other light sources should be out except the one used to cast the shadow. Other lights near the target station will cause multiple shadows on the mirror, and reading the wrong shadow will lead to an inaccurate survey shot. Once the shadow is lined up, leave the compass in that position, light up the compass scale, and take a reading. The main problem with this method is the extra time it takes to set up the tripod or to find a place to set it up. If this extra time is overcome or unimportant, the ease of reading the compass and the use of the tripod make the shadow method one of the most accurate surveying techniques for cave surveys.

SUUNTO-TYPE COMPASS

The Suunto-type compass consists of a metal or plastic case which encloses a plastic needle container and an optical lens. The needle container has a nonfreezing, nonboiling liquid which acts as a damper for the compass card. The magnetic needle is fixed to a circular compass card which rotates with the needle (figure 4-18). Suunto compasses are available in either quadrants or azimuths.

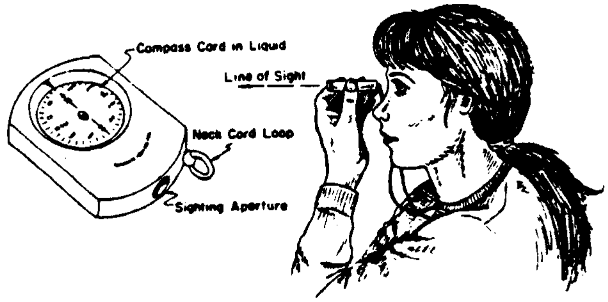


Figure 4-18. The Suunto-type compass, its component parts, and method of sighting.

The Sisteco compass is very similar to the Suunto compass and is used in the same way. One version of the Sisteco compass is actually two instruments in one as it combines both the Suunto-type compass and the Suunto-type clinometer into one unit. In addition, the Sisteco has larger lettering on the compass card for easier reading. It is reported to be accurate to 1/2 degree.

Procedure for Use of the Suunto-type compass

To use the Suunto compass, you should find a comfortable and steady position from which to take the compass reading. If you are not stable, the motion involved will make it difficult for you to get the reading. The compass should be on a vertical line with the station. That is, the compass should be directly over, under, or placed on the survey station (figure 4-19).

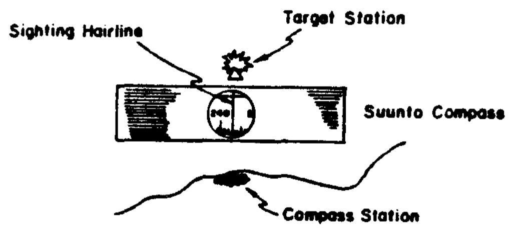


Figure 4-19. The compass held over survey stations to read azimuth of a line.

To take a reading with the Suunto compass, the manufacturer recommends that you keep both eyes open, hold the compass up to one eye, and look through the small view window at the rear end of the compass (figure 4-20). Through the window, you see a vertical hairline that is fixed in place in the compass. Beyond the fixed hairline is a compass card which is free to rotate around the central axis of the compass (figure 4-19). When using the Suunto, make sure that this compass card rotates freely. If the compass is held too far out of the horizontal plane, the compass card will stick and will give an incorrect reading. The angle is read below the hairline on the compass card. This two-eye-open method works fairly well when sighting distances over 100 feet. For sights of less than 100 feet, it is advisable to close one eye and look through and over the compass to take the azimuth with the open eye. The reason for closing one eye is that, in short shots, eye rivalry between the left and the right eye can cause angular error of up to 2.5 degrees which will not be compensated for in backsights. The error is also cumulative in a traverse and will result in a large positional error (Bartholomew, 1988).

To read the bearing or azimuth from the compass station to the target station, use the following steps:

1. Look through the small window of the compass with one eye (with the other eye closed) and line up the hairline in the compass with the light held at the target station (figure 4-20).

2. When the hairline and the target are lined up, focus your eye on the compass card and read the azimuth or bearing beneath the hairline.

With practice, readings can easily be made to 1/2 degree of accuracy on the Suunto compass.

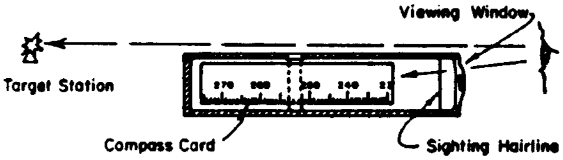


Figure 4-20. Taking an azimuth reading with a Suunto-Type Compass.

Illuminating the Suunto

In cave surveying, it is usually necessary to illuminate the Suunto compass to be able to take a reading. Suunto compasses which have a lighted azimuth with a battery operated light are available. Cavers have even modified the compass with a homemade light system (Market, 1987). A Cyalume chemical light which is nonmagnetic can be held against the top window of the Suunto to give illumination for sighting. If you have none of the above, you can illuminate the compass with your caving light. While sighting on a target station in a cave, the Suunto is usually held in one hand while the other hand holds a light to illuminate the compass card (figure 4-21). Be careful not to get this light too close to the compass, as the metal in the light may deflect the compass needle.

Figure 4-21. Using a lamp to illuminate the Suunto compass while taking an azimuth reading.

Problems with Using the Suunto Compass

The Suunto compass is a highly accurate and rugged instrument which is easy to use in cave surveying. However, poor handling can damage the instrument and affect the accuracy of the survey. Several problems have been reported by Suunto users:

1. Moisture causes fogging of the instrument. If the compass gets wet, the small view window will fog up

and make the azimuth difficult or impossible to read. You can try to wipe the window off or even use the flame of a carbide lamp held beneath the compass to heat the window to clear it. DO NOT hold the compass too close to the flame, as the plastic view window will crack. To keep moisture out of the Suunto compass, a bit of preventive maintenance should be undertaken when you first get the compass. Take the time to apply a thin line of clear sealant around the edges of both the small viewing window and the large compass-card window on the top. This procedure will help ensure that moisture stays out of the instrument.

2. Temperature-extreme problems. Even though the liquid in the compass is supposed to be unaffected by temperature, the compass should be kept from extreme climatic conditions since it is a precision instrument and quite expensive. The authors know of at least one Suunto that was damaged by below-freezing temperatures.

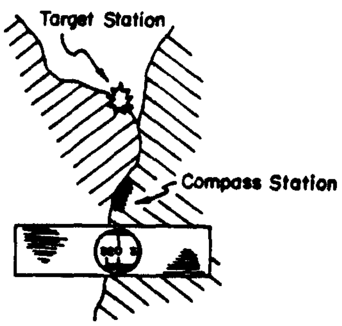


Figure 4-22. Alignment of Suunto compass and survey stations for an azimuth reading.

3. Sighting problems on normal survey stations. The best stations for the Suunto compass are those where the compass can be held directly above the survey point. Other, more difficult station placements can be dealt with by taking a backsight from a better station or by getting behind the survey station and aligning the Suunto with both the survey station and the target station to obtain the reading (figure 4-22). Many problems associated with taking accurate survey shots can be eliminated by taking care in choosing survey stations that are easy to take a reading from.

4. Target stations much above or below the survey station. The Suunto compass can be difficult to use

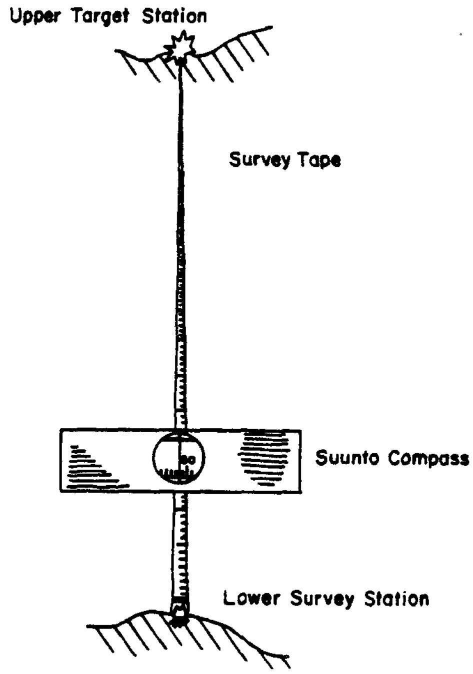


Figure 4-23. High-angle compass shot with the Suunto compass aligned with the survey tape.

accurately for target stations that are much above or below the level of the survey station. With practice, you can usually do a fairly accurate job of obtaining readings by projecting the cross hair up or down, but there are better ways to overcome this problem. One accurate method is to sight along the survey tape as it is stretched from the survey station to the target station (figure 4-23). Naturally, use caution when using a steel tape as it will deflect the compass readings. Another method is to modify the compass so that the target can be seen at the level of the compass. One method was designed by one of the authors (Taylor) in the early 1970s. Here, glass rods can be placed on the top and bottom of the compass, perpendicular to its main axis, so that no matter how high the target light is above the level of the compass, the light will be refracted through the rods. The glass rods should be cut in half lengthwise and then glued into place. The compass should be held as level as possible when taking readings from these rods; otherwise, the light from the target station could be refracted in a portion of the rod away from the center line of the compass. Lang Brod (1989) reported a very sophistocated modification that can be made with the help of a machinist and added to the Suunto. Some commercial Suunto models have a prism rather than a glass rod attached to the instrument, which probably is the best fix for the problem of high-angle shots, but which increases the cost of the compass and its repair.

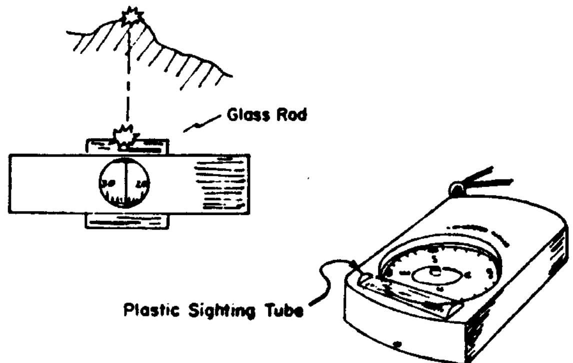


Figure 4-24. Taylor's modification of the Suunto compass for high angle compass shots.

5. **Carrying problems.** The Suunto compass is often carried with the attached cord around one's neck and the compass tucked into a shirt pocket or coverall pocket for convenience of use and transportation. To prevent damage to the top window in the compass, turn it inward toward the chest with the metal case facing outward.

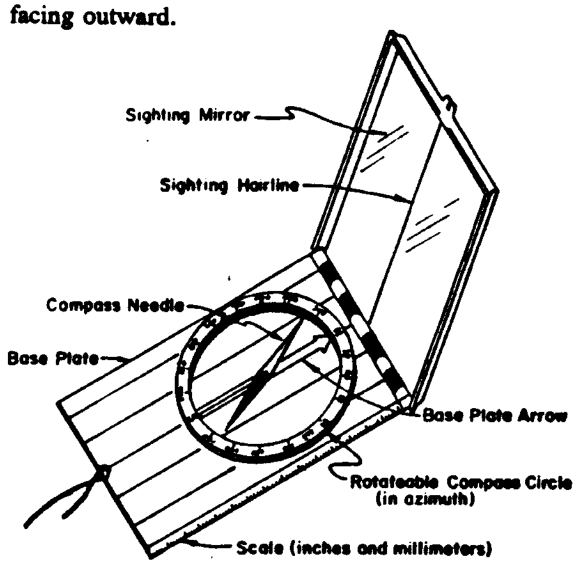


Figure 4-25. The Silva compass and its component parts.

SILVA COMPASS

The Silva compass consists of a plastic base plate 2 by 3 inches in size (figure 4-25) with scales provided in both inches and millimeters. An arrow is marked at the front of the base plate for indicating direction for the bearing or azimuth. Attached to this base plate is the compass, which consists of a short cylindrical chamber about 1 3/4 inches in diameter. This chamber is liquid filled and contains the compass needle. The liquid serves as a damper for the compass needle. The compass circle around the rim of the chamber is graduated in a 360-degree or azimuth scale in a clockwise direction. The chamber can be rotated to line up any azimuth with the compass needle. In the more expensive Ranger and Safari Silvas, a sighting mirror is attached for locating azimuths or bearings.

Procedure for Using the Silva Compass

The Silva compass is relatively simple to use. Since it is the type of compass commonly used by the Boy Scouts and other outdoor groups, you may find that it is quite familiar. The procedure for use is as follows:

Figure 4-26. Taking an azimuth with a Silva compass.

1. Lift the lid containing the mirror to about a 45-degree angle with the compass.

2. Hold the compass in the right hand near eye height and take a sight on the target station (figure

40-26). With the left hand, rotate the compass dial until the compass needle is centered in the orienting arrow etched in the glass.

3. Determine the bearing of the line at the index pointer.

4. It is necessary to do most of these movements by using the mirror to determine if the needle is centered in the orienting arrow.

Careful reading of the Silva compass can give azimuths with about 1 degree of accuracy. The compass is marked off in 2-degree increments.

MISTAKES IN DIRECTIONAL MEASUREMENTS

Like measurements of distance, there are always ways in which mistakes or blunders can occur in measuring directions. It is important that the cave surveyor understand the ways in which this can occur. The following mistakes can occur unless reasonable care is given to procedures of measuring direction:

1. Digit errors in reading the compass: 320° for 220°, 320° for 310° or even 321° for 325°.

2. Reading the wrong direction from a marked graduation: 246° for 234°.

3. Transposition errors such as 345° for 354°.

4. Reading the wrong meridian in bearings: N.-52°E. for N.52°W.

5. Reading the wrong direction in bearings: N.-23°E. for S.23°E.

The mistakes or blunders in direction measurement can be minimized in two ways. First, the surveyor using the compass should take the bearing or azimuth and relate the value to the chief. Before he/she records the value, he/she should repeat the value back to the surveyor who should check the reading and repeat it back. The chief then should records the value in the notes. Second, the surveyor should move to the next station and take a backsight on the previous station. This value should be 180 degrees from the foresight angle. Using a Brunton compass, you can read the black or south end of the compass needle and have the equivalent reading to the foresight for comparison. The procedure of calling and recording the value is used on the backsight data also. The foresight and backsights should agree within 1/2 degree. If they do not, a blunder is detected and the reading should be retaken.

FIELD EXERCISES

1. Practice taking a bearing or azimuth on an object about 100 feet away. Measure the direction three times and record the average reading. Then go to the target object and take three bearings or azimuths (backsights) to the initial position and also record this average. The readings of the two direction measurements should be exactly 180 degrees apart. This procedure will provide you with an opportunity to check the accuracy of your measurements. Do this at several targets to give yourself practice in taking bearings and azimuths. Try this with your caving gear on also, so that you can see if your equipment magnetically interferes with the compass direction.

2. In a parking lot or some other fairly level area, lay out a traverse by taking bearings or azimuths and measuring distances in a pattern that will form a loop which will connect back to the initial point. Carefully measure the distances to the nearest 1/10 foot and the horizontal angles to the nearest 1/2 degree. Plot these bearings or azimuths and distances on graph paper using an appropriate scale. The nearness of the final point to the initial point gives a check on the accuracy of the traverse. A well-run traverse will have the final point superimposed on the initial point.

STUDY PROBLEMS

1. The magnetic bearing of a line in 1864 was determined to be N.46°30'W., when the declination was found to be 3°30' E. In 1980, the magnetic bearing of the same line was found to be N.35°30'W. What was the magnetic declination in 1980?

2. The magnetic bearing of a line is S.23°30' W., and the declination is 23°W. What is the true bearing of the line?

3. The magnetic bearing of a line is N.25°W., and the declination is 6°W. What is the true bearing of the line?

4. The bearing from D to E is S. 60° 30' E. At E a left declination angle of 25° is turned. What is the bearing of EF?

5. The magnetic bearing of the line AB is N.46°-30'E. The true bearing of the line AB is N.32°30'E. What is the magnetic declination?

6. The bearing of the line AB is N.22°30'E. The bearing of line BC is N.52°30'E. What is the deflection angle at B in running a traverse from A to B to C? What would be the turned angle to the right from A to C?

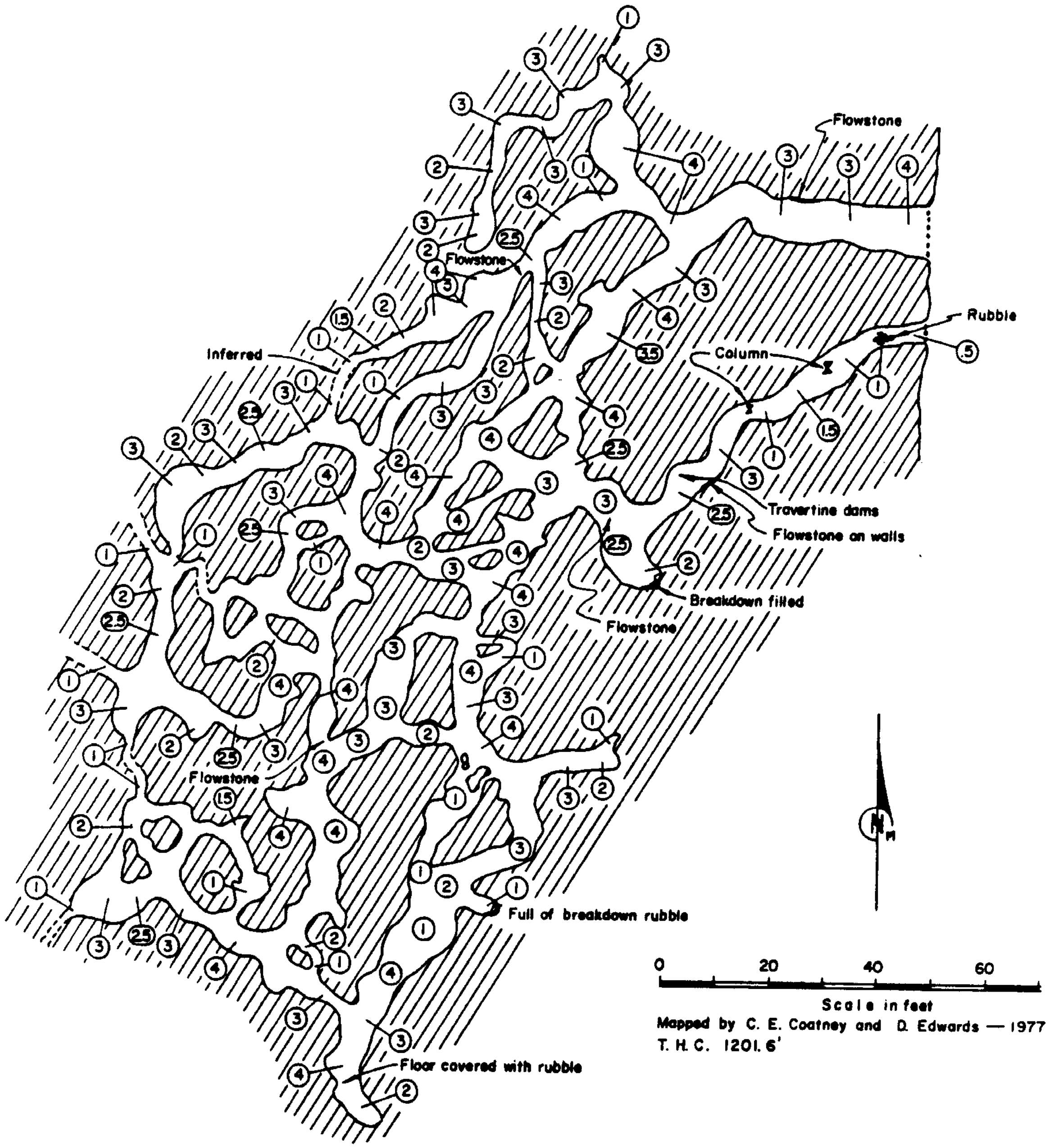
7. The azimuth of a line is 237° 30'. If the magnetic bearing of the same line is S.48°30'W., What is the magnetic Declination?

8. If the interior angles of a quadrillateral are: A = 120° 30', B = 78° 45', C = 55° 15', and D = 105° 30', and the azimuth of line AB is 30°. What are the azimuths of the remaining lines BC, CD, and DA?

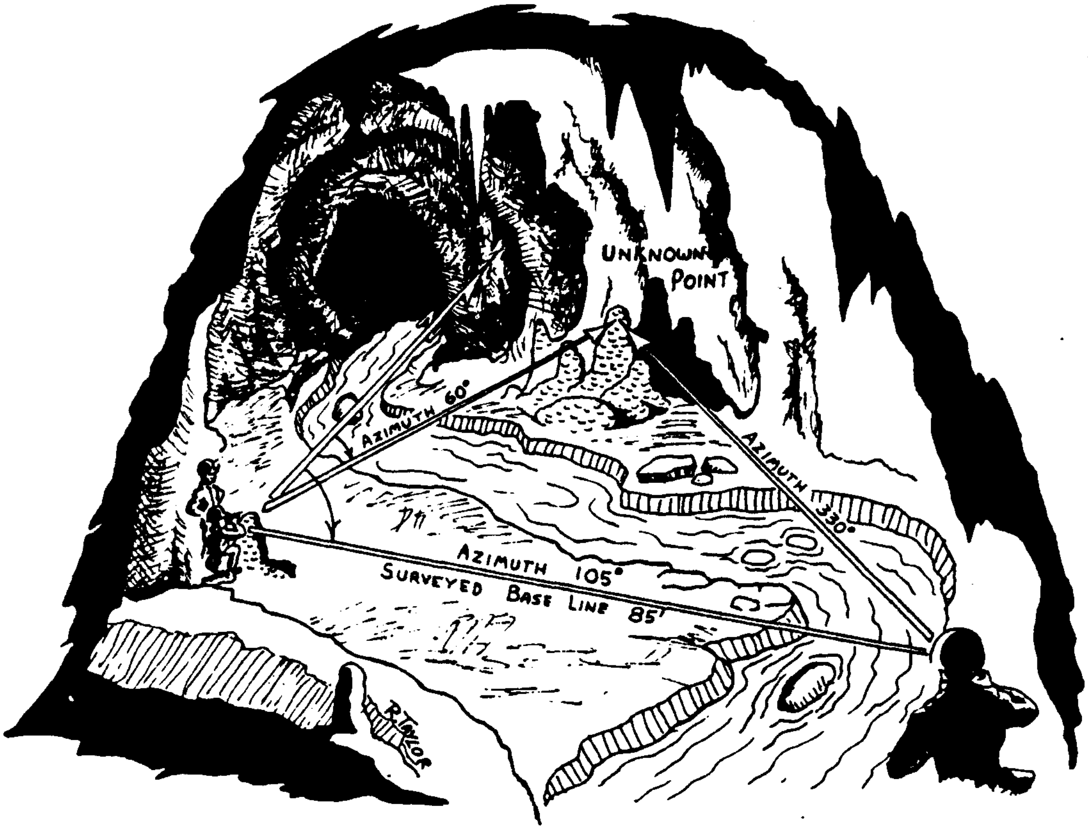
9. Convert the following azimuths and mils to bearings:

a. 237 degrees =
b. 145 degrees =
c. 95 degrees =
d. 215 degrees =
e. 172 degrees =
f. 289 degrees =
g. 310 degrees =
h. 65 degrees =
i. 25 degrees =
j. 187 degrees =
k. 1650 mils =
l. 2200 mils =
m. 3500 mils =
n. 600 mils =
o. 5200 mils =

10. Take the same readings and convert them to gons or grads and radians.



BARREN FORK MAZE CAVE
OZARK COUNTY, MISSOURI



5

DISTANCE DETERMINATION BY COMPUTATION

Many caves have areas or points that may be difficult or even impossible to get to such as beyond water barriers or on the far side of uncrossable pits. Although direct measurement of these distances is impossible, it is possible to determine them through indirect means. Using the location of known points and distances between them, it is possible to compute the position of the unknown points through triangulation or resection.

TRIANGULATION

Triangulation is a method of determining the location of unknown points by using a precisely surveyed base line of known location, length, and bearing or azimuth. From the two ends of a precisely surveyed base line, bearings or azimuths are taken to the unknown point or object. There are two ways in which the location can be determined, graphic or through computation.

GRAPHIC METHOD

The two bearings or azimuths that were taken from the ends of the base line are carefully plotted on the cave map from the ends of the known base line and lines extended along the two directions. The point at which these lines intersect on the map is the exact location of the point sought (illustration above). A third point can be picked at a specified distance from either end of the base line and on the base line and a bearing or azimuth taken from this point. Careful plotting of that line should also intersect the desired point on the map and therefore should confirm the exact location of the point (figure 5-1).

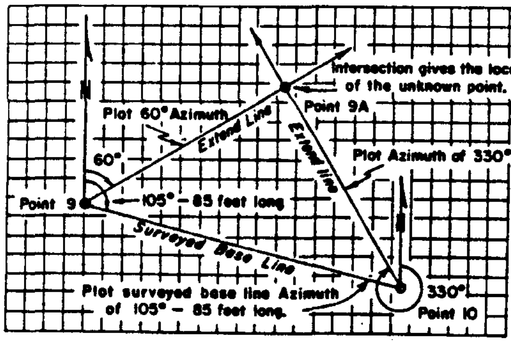


Figure 5-1. Graphic method for determining the location of inaccessable points in the cave.

COMPUTATIONAL METHOD

The lengths of the sides of the triangle created by the triangulation method discussed above can be calculated by using the law of sines. To be able to do this it is necessary to determine the interior angles of the triangle. The first two interior angles can be calculated by taking the difference in azimuth between the base line and the smaller of the two triangulation lines. The second can be determined by taking the back azimuth of the base line and determining the difference between it and the larger of the two triangulation azimuths. The third interior angle can be determined from the fact that the sum of the interior angles in a triangle is 180°. Hence $<3 = 180° - (<1 + <2)$. Then, using the law of sines:

$$a/\sin A = b/\sin B = c/\sin C$$

Rearranging the equations, we get the lengths of the two sides (figure 5-2).

$$\text{Length a} = (c \sin B)/\sin C$$

$$\text{Length b} = (c \sin A)/\sin C$$

The location of the point can then be plotted using coordinates or it can be plotted by using a compass and swinging two arcs of lengths of the two sides from each end of the base line. The location of the intersection of the two arcs is the location of point C.

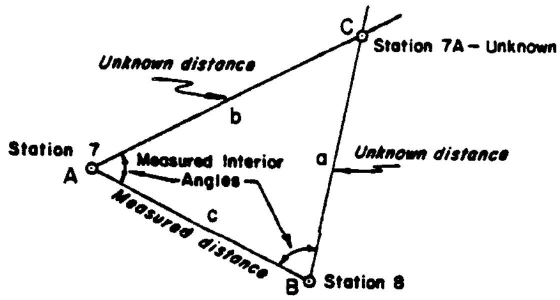


Figure 5-2. Location of an inaccessible point by using the lengths of the sides determined by the law of sines method.

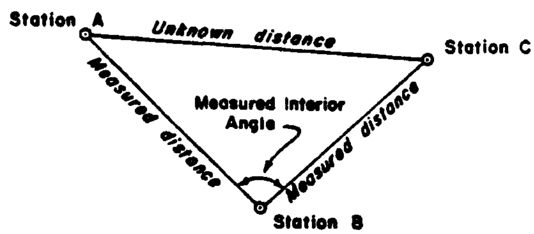


Figure 5-3. Determination of the length of a traverse leg using the law of cosines.

Another method of triangulation can be used to determine angles or sides if it is difficult or impossible to see the unknown point from one end of the base line, but the azimuth of the base line and the azimuth of one line to the unknown point along with the length of that line will allow the determination of the other two angles and the third side (figure 5-3). The law of cosines can be used to determine the additional values in the triangle:

$$a^2 = b^2 + c^2 - 2bc \cos A$$

$$b^2 = a^2 + c^2 - 2ac \cos B$$

$$c^2 = a^2 + b^2 - 2ab \cos C$$

Generally you can use either of the two laws to triangulate locations in a cave survey. The only requirement necessary is to have one or two known sides and two of the other five dimensions to obtain the remainder of the angles and distances. This can all be determined from one survey traverse. However, you will probably find that the easiest way to use the triangulation method is graphically by drawing the correct angles and plotting the distance to scale on graph paper (figure 5-4).

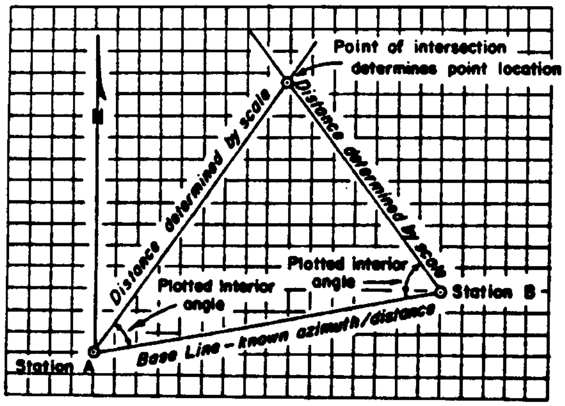


Figure 5-4. Triangulation location determined by plotting on graph paper.

APPLICATIONS OF TRIANGULATION TO CAVE SURVEYING

Triangulation can be used best in a large room or passageway in the cave. By running a traverse up the middle of a large passage (figure 5-5) or along the sides of the passage (figure 5-6), the exact location of the walls can be determined through the use of triangulation. Each leg of the traverse will serve as the base line and azimuths from each station to designated points on the walls will then serve as the triangulation shots. The location of the walls can then be either calculated or plotted.

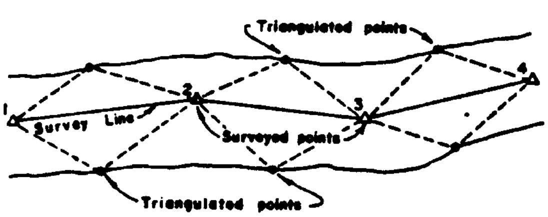


Figure 5-5. Use of a center line survey and triangulation to determine the location of passage walls.

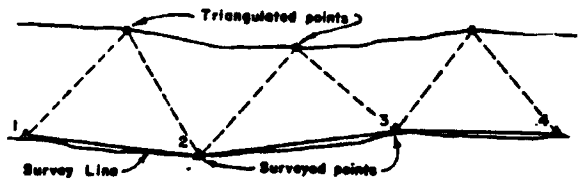


Figure 5-6. Use of triangulation and a passage wall traverse to determine the location of passage walls.

Triangulation can also be used to survey around a pit (figure 5-7) or over a pile of breakdown (figure 5-8).

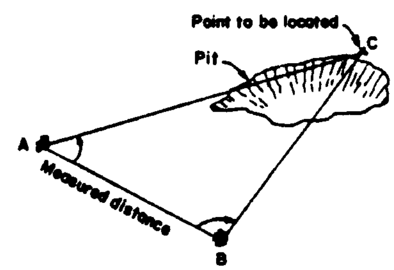


Figure 5-7. Use of triangulation for surveying across a pit.

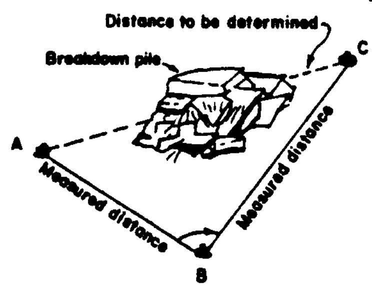


Figure 5-8. Use of triangulation for surveying around a pile of breakdown.

RESECTION

Location by resection is exactly the opposite of triangulation. If two points in the cave have been accurately plotted on the map, and thus their location is precisely known, your position can be accurately determined by taking a bearing or azimuth on each of the points, then plotting a backsight bearing from each of the points (backsight is the opposite end of the compass needle or 180 degrees from the foresight

-- see chapter 4); their point of intersection on the map is your location (figure 5-9).

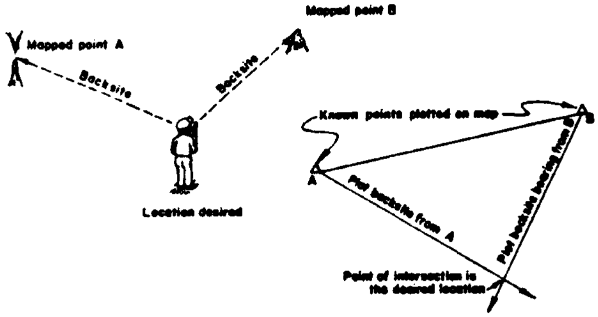


Figure 5-9. Use of resection to locate a point in a cave survey.

STUDY PROBLEMS

1. A base line of 100 feet was run between stations 26 and 27 in the Elephant Passage of Congo Cave. The base line azimuth is 135°. From station 26, an azimuth of 85° was shot to unknown point 26A. From station 27 a second azimuth was show to point 26A at 25°. Graphically determine the distance from 26 to 26A and from 27 to 26A.

2. In a survey of a large room in a Empire Cave, a line is run along one side of the room from station 10 to station 11, a distance of 87 feet. From station 10, an azimuth of 80° was taken to station 11. An azimuth of 350° was also taken to a large stalagmite on the far side of the room. From station 11, a second azimuth was taken on the large stalagmite. How far is the stalagmite from station 10 and from station 11?

3. Two legs of a cave survey were run carefully as follows: Station 6 to 7 is 87 feet at an azimuth of 165° and station 7 to 8 is 125 feet at 85°. What is the distance from station 6 directly to station 8?

4. On a map of Jones Cave, two points, station 6 and station 8 can be seen from station 7. Both stations are easy to see and identify. The azimuth from station 7 to station 6 is 20°and the azimuth from station 7 to station 8 is 105°. The distance between station 7 and station 8 is 120 feet and the azimuth from station 6 to station 8 is 160°. How far from station 6 and station 8 is station 7?

5. A traverse is run around the south side of a lake in Emerald Lake Cave using stations 10, 11, and 12. How far is it across the lake from station 10 to station 12? The traverse was run as station 10 to 11 is S. 65° E. bearing for 92 feet, and from 11 to 12 at N. 75° E. bearing for 132 feet.

6

VERTICAL ANGLES AND DISTANCES

Many caves throughout the world have great vertical relief: Reseau Jean-Bernard in France has more than 5000 feet; Reseau de la Pierre Saint-Martin in France and Spain has in excess of 4400 feet; France's Gouffre Berger has over 4000 feet; and, in the United States, a cave such as Ellisons in Alabama descends over 1000 feet; Great Expectations and Columbine Crawl Caves in Wyoming are over 1400 feet and 1550 feet deep, espectively, Lechuguilla Cave in New Mexico is 1565 feet deep, Bigfoot-Meatgrinder in California descends over 1200 feet; and Neffs Cave in Utah reaches down more than 1100 feet. These caves and many others have vertical drops and inclined passages which have to be measured in some manner to create maps that are accurate both in plan and profile. Even horizontal caves often have significant changes in elevation in passages that have to be accurately measured. Thus, along with measurements of distance and direction, the measurement of vertical angles and distances is one of the major components of an accurate survey.

VERTICAL DIRECTIONS AND ANGLES

A vertical line or the vertical direction is the direction or line from any point on the earth's surface that follows the direction of gravity at that point. So, if a weight is hung on a string and the string is suspended freely, the direction of the string is the vertical direction (figure 6-1). A vertical plane is any plane that contains a vertical line. There can be an unlimited number of vertical planes. In mapping, the **vertical distance** is the distance between two points that would follow a vertical line.

Vertical distances can be determined in several ways: by direct measurement along a vertical line, by using trigonometric calculations or by plotting the dimensions on graph paper. To calculate a vertical distance, it is necessary to determine a **vertical angle** or a **zenith angle**. The **vertical angle** is the angle measured within the vertical plane and is the difference in direction between any two intersecting lines in that plane. By convention, one of these lines, the reference line, is horizontal. Any angle measured above the horizontal line is a plus angle or angle of elevation, and any angle below the line is a minus angle or angle of depression. The **zenith angle** is also measured in a vertical plane, but uses the vertical line along the direction of the pull of gravity as the reference line. This direction is considered to be 0 degrees and is opposite in direction to the pull of gravity. The horizontal line then becomes either 90 or 270 degrees and the direction of gravity becomes 180 degrees. Plus angles are those from 0 to 90 or from 270 to 360, and minus angles are those from 90 to 270. Zenith angles are usually used in theodolites and in precision surveys.

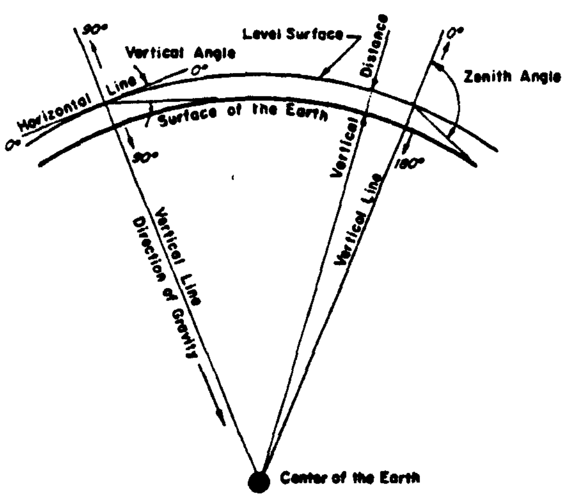


Figure 6-1. Definition of vertical direction and vertical plane.

Vertical angles can be measured in the same systems as horizontal angles as either degrees, minutes and seconds (DMS), grads (gons), mils, radians, or as percent grade. **Percent grade** is a simple ratio of amount of raise or drop to horizontal distance or run, expressed as a percentage. For example, in a 45-degree angle, the amount of raise is equal to the amount of run. This is 100 percent grade. For every 100 feet of horizontal distance covered, you get 100 feet of elevation difference. Percent grade can be calculated by:

$$\textit{Percent Grade} = \frac{\textit{Vertical Distance}}{\textit{Horizontal Distance}} \times 100$$

MEASUREMENT OF VERTICAL ANGLES

Several methods can be used to determine a vertical angle, ranging from imprecise guesswork or estimation to precise measurements with surveying instruments.

ESTIMATION OF VERTICAL ANGLES

Vertical angles can be estimated for quick approximations and other nonspecific needs. With some practice, the cave surveyor can estimate vertical angles to within plus or minus 5 degrees of the actual angle. This is important because parts of the survey line which have a vertical angle less than 5 degrees are reduced by such a small amount on the horizontal distance that the correction introduced by taking into account the vertical component is generally negligible. The measurement of vertical angles, however, should be taken when the angle is more than plus or minus 5 degrees or in all cases where precision is needed.

CLINOMETERS

Clinometers are instruments designed to measure vertical angles. Several commercially available types include the Abney, Brunton, Suunto or Sisteco, and electronic level. A simple usable clinometer can also be constructed from inexpensive materials. Vertical angles can also be measured using transits or theodolites.

Simple Clinometer

A simple clinometer can be made from a straight piece of wood, two nails, a protractor, and a weighted pointer. This can be constructed as shown in figure 6-2. In using a standard protractor on the side, it is necessary to use the following correction factor: 90 degrees minus the reading equals the vertical angle. This can be shown in the case of the two extremes of horizontal and vertical angles. First, with the clinometer held horizontally, the indicator reads 90 degrees. A corrected value involves the following calculation: 90 degrees minus 90 degrees equals 0 degrees or horizontal. Second, when the clinometer is held vertically, the indicator reads 0, but is corrected to 90 degrees, the expected figure.

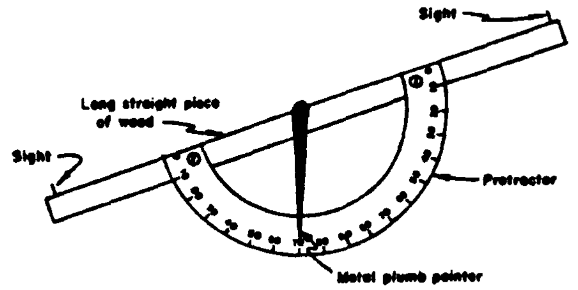


Figure 6-2. Homemade clinometer constructed from simple components.

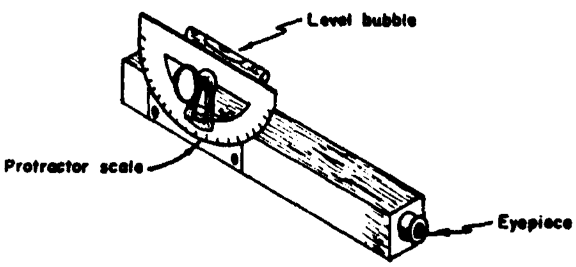


Figure 6-3. The Abney clinometer and its parts.

Abney Clinometer

The Abney clinometer is an instrument of relatively simple design consisting of a sighting device containing a narrow mirror set at a 45-degree angle (figure 6-3). This narrow mirror has an index line which also extends all the way across the field of view. Half of the view area is open for sighting. Attached to the side is a protractor-type scale with an attached level bubble. This level can be viewed through the mirror and leveled by moving the lever attached to the scale while simultaneously sighting the target object through the eyepiece--thus allowing the vertical angle to be read directly from the scale indicator.

Brunton Clinometer

The Brunton clinometer is a part of the Brunton compass and works in a manner very similar to the Abney clinometer. The Brunton clinometer consists of a sighting device made up of the peep-sight window in the compass lid, the compass box, sighting arm, and a horizontal level bubble connected to a movable control arm on the back of the compass (figure 6-4).

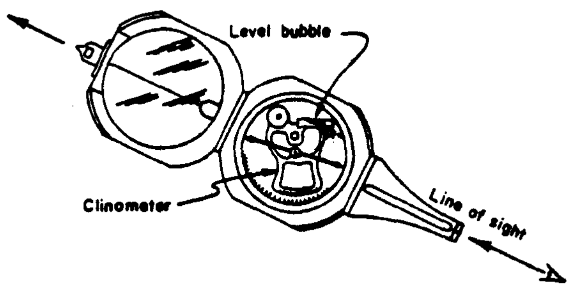


Figure 6-4. The Brunton compass, showing the parts that relate to the clinometer.

To determine vertical angles with the Brunton clinometer, use the following procedure:

1. Open the compass and incline the mirror to a 45-degree angle with the compass box, and extend the sighting arm on line with the compass.

2. Hold the instrument on the side with the horizontal level bubble at the top about 6 to 8 inches from the eye. Sight through the instrument from the sighting arm through the small sighting window to the target point (figure 6-5).

3. With the second finger on the right hand, move the clinometer control arm back and forth until the level bubble is leveled, and observe this in the mirror while maintaining the projected line of vision. This process is difficult at first because the image of the level bubble is a mirror image and, therefore, reversed..

4. Once the bubble is leveled, lower the instrument and read the vertical angle. The Brunton clinometer has two scales, the angular-scale reading from 0 to 90 degrees, and the percent grade scale reading from 0 to 100 percent-grade. The angular scale is the one

usually used, and the angles should always be recorded as plus (above the surveyor) or minus (below the surveyor). The clinometer is also equipped with a vernier which makes it possible to make the readings to the nearest 10 minutes.

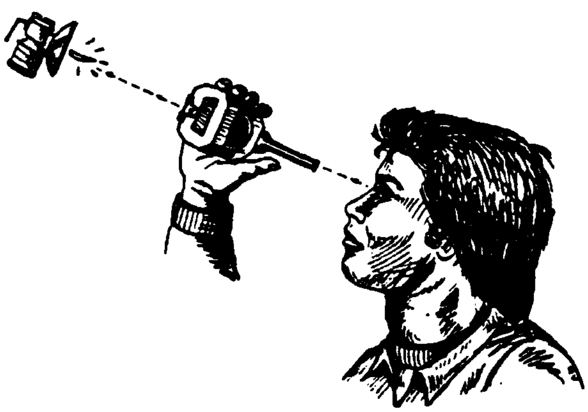


Figure 6-5. The Brunton compass used as a clinometer.

The Brunton clinometer can also be used on a tripod with the compass turned on its side. Here, the instrument has both the mirror and the sighting arm extended as shown in figure 6-5. The sighting procedure is as follows:

1. The instrument is tilted until you can sight through the sighting arm and the peep sight to the next survey station. When the instrument is aligned, lock it in place.

2. From the side, bring the level bubble to horizontal, then read the vertical angle or percent grade from the scale.

3. Record the angle carefully in the field notes.

Suunto or Sisteco Clinometers

The Suunto-type clinometer closely resembles the Suunto-type compass and operates on a similar premise. The instrument consists of an aluminum case which encloses a drum-shaped scale card with a point that is plumb-weighted (figure 6-6). This point keeps the drum in the same position relative to the earth at all times. The scale card is immersed in a fluid so as to dampen oscillations of the drum. Essentially, the clinometer case is rotated in the vertical plane around the card. The instrument contains a magnifying lens on one end designed to enlarge the angular scale. Because of the ease with which you can read the instrument, an accurate reading of the angle to within about 1/6 or 1/4 of a degree is possible, If you wish to obtain this kind of precision, you should either repeat the measurement at least 2 to 3 times and then take their average, or take backsights on each station. The clinometer scale card has two scales which measure the vertical angle both in degrees and percent grade, both of which are visible in the magnified window.

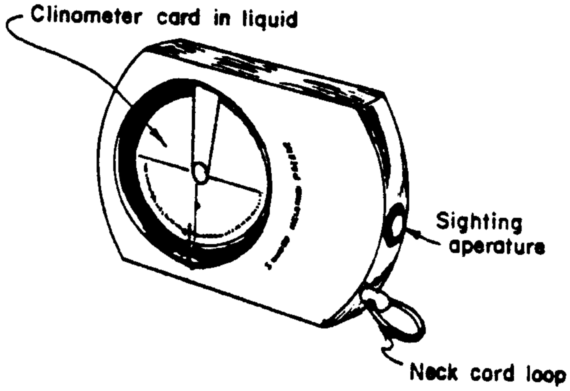


Figure 6-6. The Suunto-type clinometer.

To determine vertical angles with the Suunto-type clinometer, use the following procedure:

1. Hold the clinometer vertically in the right hand with the large window facing toward the left.

Figure 6-7. Use of the Suunto clinometer.

2. Keeping both eyes open, bring the clinometer to your right eye and rotate the instrument in a vertical arc until the horizontal index line, viewed through the lens, is aligned with the target station. By an optical illusion (parallax), the horizontal line appears to protrude from the instrument body and to project against the sighted point.

3. Read and record the reading either in degrees or percent grade.

Electronic Level/Clinometer

A new electronic-style carpenter's level is on the market. It is also a digital clinometer. The torpedo-shaped module is small enough to fit into a pocket. It can be used by itself or set into one of 3 different length rails (2, 4, or 6 feet long). The unit can be set to one of four different modes: pitch (rise over run); degree of slope (to the nearest tenth of a degree); percent of slope or grade; or actual level or plumb with a simulated bubble. Using the module by itself, the degree of slope can be determined easily by sighting along the top of the instrument with the mode set at degree of slope. The angle might have to be read by a second party.

DETERMINING VERTICAL AND HORIZONTAL DISTANCES FROM VERTICAL ANGLES AND SLOPE DISTANCES

Trigonometric Method

Through the use of basic trigonometry (Appendix II) and either tables or a calculator to determine the value of the sine and cosine of the vertical angles, vertical angles and slope distances can be used to determine the elevation difference and the corrected horizontal length of the survey line (figure 6-8). The following equations are used in the trigonometric method:

Hor. Dist. = Slope distance X cosine vertical angle

$$HD = S \cos A$$

Vert. Dist. = Slope distance X sine vertical angle

$$VD = S \sin A$$

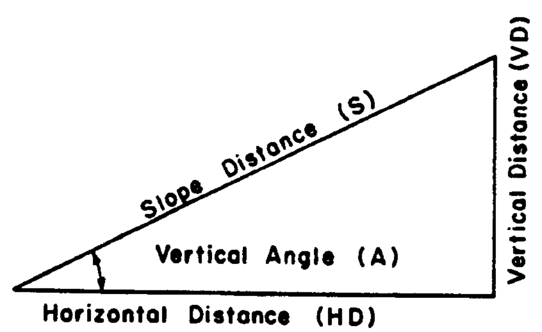


Figure 6-8. Relationship between slope distance, Horizontal distance, and vertical distance.

Graphic Method

Rather than using trigonometric tables or a calculator, it is also possible to use graph paper to plot the vertical angle and slope distance to scale (figure 6-9). The required dimension can then be scaled directly from the graph paper.

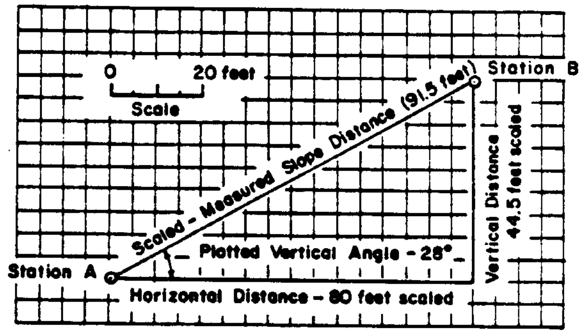


Figure 6-9. Graphic method of determining horizontal and vertical distances.

APPLICATIONS OF VERTICAL ANGLES AND VERTICAL DISTANCES

DETERMINATION OF PASSAGE HEIGHTS

Passage ceiling heights should always be indicated in some way on cave maps. These heights can be measured directly or indirectly or simply can be estimated.

Direct Methods

Direct methods are those in which the height of the passage is physically measured. A 10-foot hand tape can be used for passages up to that height.

For ceilings higher than this, an alternative method is needed. If the cave is easy to traverse, a telescoping fiberglass measuring rod can be used. These relatively light-weight rods can directly measure vertical distances up to 50 feet. Their only disadvantage is that they weigh up to 12 pounds and, collapsed, are 5 1/2 feet long, making them difficult to carry into many caves. Another method is to use helium-filled balloons. (The helium can be obtained from a local welding shop or from some scientific supply houses.) The balloon is attached to a long string and floated to the ceiling. The length of the string from the ceiling to the floor is then measured and, when combined with the size or length of the balloon, the distance to the ceiling is then determined directly. Wind currents and falling water can pose problems in using. Further, the weight of the string must be taken into account when determining the size of balloon or number of balloons needed. There is also the additional problem of possibly having the balloon burst when it touches the ceiling.

Indirect Methods

Indirect methods of determining heights involve the measurement of distances and vertical angles as shown in figure 6-10a, and then the use of triangulation and trigonometry to calculate ceiling heights. The easiest method to use is to find a point (point B) directly beneath the ceiling point you wish to measure. Determine a horizontal base-line distance to point A away from the initial point, and then measure a vertical angle to the ceiling location that is directly over point B. The ceiling location over point B can often be illuminated by a person at point B pointing the beam of a flashlight vertically upward from the point. The person located at point A can then sight the point on the ceiling and determine the vertical angle. The simple equation $h = b \text{ Tan } A$ will give the passage height.

If you cannot establish point B directly beneath the point on the ceiling for which you want to measure the height, then a slightly more complicated method can be used. With this method you begin by measuring a vertical angle to the point on the ceiling from a short distance back, then measure a horizontal base line still further back to a second floor station, and measure a second vertical angle to the ceiling point from this second floor station. The equation $h = b \text{ Sin } A \text{ Sin } B/\text{Sin } (B-A)$ gives the vertical distance (figure 6-10b).

The first two methods given require a horizontal survey leg, fairly uncommon in most cave surveys. Generally the traverse leg will slope, making an inclined base line for that leg. The passage height can still be determined indirectly using trigonometry. If the end point of the inclined base line is directly below the ceiling point, the equation in figure 6-10c can be used.

The equation becomes more complex if the end point of the base line is not directly beneath the ceiling point. In this case, the equations in figure 6-10d can be used. In addition, if you wish to compute the elevation difference between a ceiling point and the start of the survey leg, the last equation in figure 6-10d can be used.

A **graphic method** can also be used in all of the above cases. The information on vertical angles can be gathered in the cave. Then, through the use of graph paper, protractor, and scale, the passage heights can be determined.

In most cave surveys, ceiling heights are **estimated** throughout much of the survey because of the length of time it would take to directly measure every needed height, especially if the heights cannot easily be directly measured. To gain experience at estimating heights, you should practice estimating heights of everyday objects that can be directly measured. A good way to estimate heights (and, in fact, passage widths) is to compare an object such as a person of known height with the height to be determined. You can think of the height as being 2 or 3 times the height of the person, etc. With practice, you can gain enough experience to accurately estimate these distances.

Whatever method you use, direct, indirect, or estimated, depends on the accuracy needed and the ease of measurement. Most cave surveys involve a mix of all three, depending on the needs of the particular locations in the cave.

DETERMINATION OF ELEVATIONS

Elevations in the cave can be determined by three types of instruments: level tube, altimeter, and clinometer. The elevations determined are often used

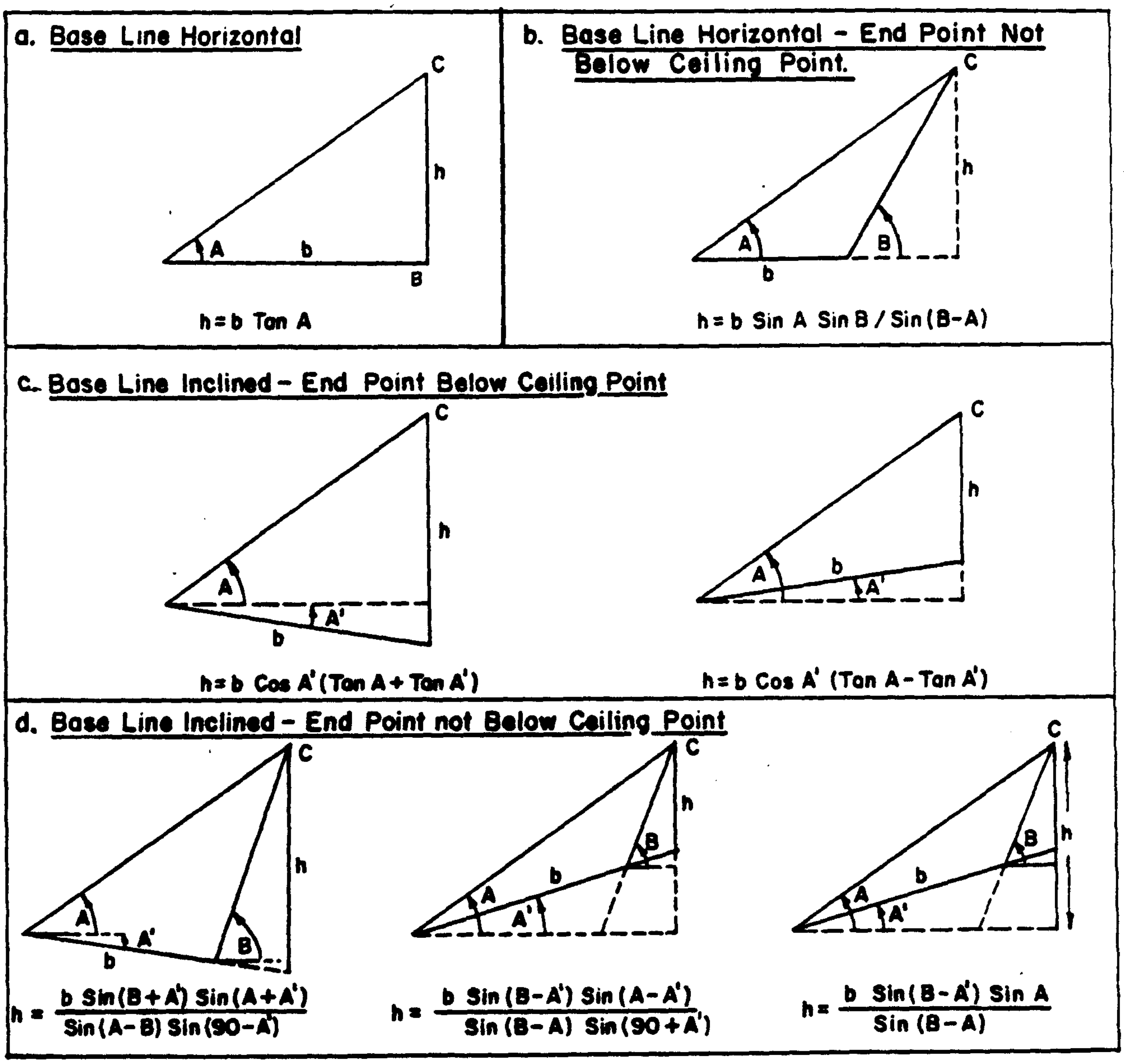


Figure 6-10. Use of vertical angles, measured distances, and trigonometry to determine elevation differences.

to prepare longitudinal profiles of the cave and to locate points in the cave relative to surface features.

Level Tube

The level tube is a very simple device consisting of a clear vinyl tube with an internal diameter of 1/4 inch and a length of about 50 feet, nearly filled with water and open at both ends. (Its use was described by Arthur Palmer in the *N.S.S. News* in April 1970.) One end of the tube is held upright at the initial survey station, and the other end is held in the same manner at the next station. This forms a U-shaped tube in which the water level in both ends will be the same, enabling the elevation difference to be measured directly at the desired station by measuring the amount of tube that extends above the level of the water in the tube.

The method is not practical for steep slopes, in low crawlways, or over breakdown piles. It is most effective in low gradient passages of walking height. To be most effective, the following precautions must be taken:

1. All bubbles should be out of the tube. By holding the two ends of the tube together, you can check to see if bubbles are present. The level of water in the two ends should be the same.

2. As you move the tube from place to place, you either have to plug the ends of the tube or hold your finger or thumb over the ends to prevent the loss of water. When you are ready to determine the level, remove your hand or thumb from the end of the tube so that air pressure will be equal at both ends. This will let the water level equalize in both ends of the tube. A valid measurement can only be made if both ends of the tube are open.

Surveying Altimeter

Elevations can also be determined through the use of a surveying altimeter (aneroid barometer). This is a device that measures elevation differences by changes in barometric pressure that occur with changes in altitude. Instruments are available that measure altitude in increments of 2 to 10 feet. An electronic altimeter is available which works on the same principle as other altimeters, but the data is presented in digital form. The instrument consists of a vacuum box which has a very sensitive side which moves in and out with changes in air pressure. A dial is used to adjust the instrument to show the elevation at a given location. The instrument can be continually calibrated and adjusted to nearby bench marks. Thus all elevations taken will thus be related to the elevations of known bench marks.

In running a survey with an altimeter, it is necessary to establish a base station. This can be a survey bench mark or any other place of known elevation, or it can be an artificially set elevation such as 100 feet or 1000 feet. You then set the altimeter for this elevation and then measure the elevations throughout the survey, recording them along with the time at which they were taken. Periodically, you should return to the base station and record the base reading. This is done because the instrument is based on changing air pressure and weather changes can effect changes in pressure. In fact, the altimeter should not be used if a weather change is predicted by the weather service or if the cave has strong air currents. Any differences in base-station readings should be distributed through the survey points based on a direct relationship between the change of elevation and the time. Table 6-1 shows how this can be done.

Surveying Clinometer

When using the surveying clinometer, you measure vertical angles between survey stations. Using this vertical angle along with the measured slope distance, you can calculate or graphically determine the elevation difference between the two stations, as previously discussed. To obtain the most precision, it is best to take a vertical reading (foresight) from the initial station and a vertical reading (backsight) from the secondary station and to record both. The readings should agree within 1 degree. If they do not, something is wrong with the measurements and you should take both over. Be sure to average the readings for the greatest accuracy unless you have a good reason to believe that the measurement in one direction is more accurate than the other. This can be due to difficulties in taking a reading from one of the stations. If this turns out to be the case, it is probably best to take several separate readings from the better station and then average those.

Table 6-1. Computation table for correcting altimeter readings to true elevations using data gathered from the base station.

Station	Time	Obs. Elevation	Elev. Correction	Corr. Elevation
Base Station	8:00	350	-	350
Station 1	8:30	800	-40	760
Station 2	9:00	650	-80	570
Station 3	9:30	1100	-120	980
Base Station	10:00	510	-160	350

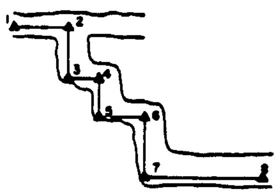
Evaluation of Methods

What factors determine whether one should use the level tube, the altimeter, or the clinometer in determining elevations within a cave? There are three types of elevation determinations in caves that influence the decision on the type of instrument to use: spot readings, continuous readings, and localized readings. With **spot readings**, the elevation of certain "spot" locations in the cave rather than a continuous series of locations are measured. The surveying altimeter is ideal for this sort of measurement since it does not need a series of connecting stations to tie to. The variation in atmospheric pressure with elevation provides this connection. With **continuous readings**, however, the elevation change from one station to the next has to be determined or else there is no way to find the actual elevation at any particular station. The clinometer is probably the best in a continuous reading, as it is lightweight, compact, and easily used. The level tube might be more accurate than the clinometer if carefully used, but its awkwardness and difficulty in using for high angles makes it less than ideal for most cave surveys. Sometimes a separate elevation survey can be run apart from the regular survey. If extreme precision is needed; the level tube may work best for this. However, with carefully taken foresights and backsights, the clinometer can approach the degree of accuracy of a level tube. The surveying altimeter would be of little use on a standard survey for each survey station since air pressure might change considerably over the course of the survey, and it would be inconvenient to run back to the base station after each reading on a new station. Too, the level of accuracy of a survey altimeter is not inherently as great as either of the other two methods. For **localized readings**, that is, those places in a generally level-line survey (Chapter 3) where actual vertical angles need to be read since the elevation between one station and the next is considerable, the clinometer also is best here due to its light weight, lack of bulk, and ease of use on high-angle shots. The level tube would be too awkward to carry only for an occasional reading in the survey and also works least well for high-angle readings. The surveying altimeter also suffers from its bulky nature when only an occasional reading is needed. It is also not precise enough in comparison with the clinometer.

SURVEYING IN VERTICAL PASSAGES

Many caves have vertical drops and near-vertical passages. Mapping of these passages require special techniques and methods to properly illustrate their character. Vertical angles, azimuths or bearings, and distances require special considerations in this type of situation.

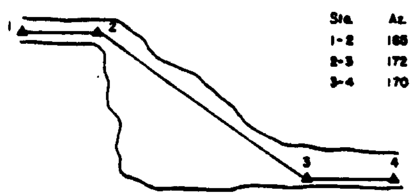
In general, survey stations should always be placed so that intervening obstacles will not interfere with the measurements of bearing or azimuth, vertical angle, and distance. So, in the case of pits, the best way to measure their drop is the direct way, that is, from the vertical or 90 degrees down. If possible, then, make the survey station at the top of the pit in a position directly over the drop so that the next survey shot will be to a point in the lower level directly below. The exact position of the lower point can be determined with a string line and plumb bob or simply a string with a weight tied to it. A small rock can also be dropped to determine the placement of the station in the lower passage. In practice, several rocks would need to be dropped for accuracy's sake. Taking an azimuth or bearing for this shot is not necessary because no horizontal distance has been covered. In the notes, put a dash where the bearing or azimuth is to be recorded. The vertical angle becomes 90 degrees, and the measured distance is the direct vertical distance between the two stations (fig. 6-11).



Sta.	Az.	Dist.	Vert.
1-2	182	50	0
2-3	-	28	90
3-4	168	30	0
4-5	-	30	90
5-6	170	40	0
6-7	-	50	90
7-8	173	100	0

note – there is no azimuth on vertical shots

Measuring vertical drops with a series vertical and horizontal shots.



Sta.	Az.	Dist.	Vert.
1-2	166	50	0
2-3	172	130	-40
3-4	170	50	0

Measuring vertical drops by total vertical angle, distance and azimuth of the line.

Figure 6-11. Vertical cave passages showing drops and methods of measuring them.

If the pit does not lend itself to a strictly vertical shot, then the exact vertical distance can be determined with a series of vertical drops and forward shots as in figure 6-11 or by measuring the total vertical angle, the azimuth or bearing, and the slope distance of the line. The vertical angle is measured with a clinometer and the distance is measured in the normal way with a tape. Calculations can then be made as for any type of survey leg. In practice, it can be more difficult to use a clinometer properly for high-angle shots than it can be for low-angle shots due to the awkwardness of getting one's body in a good position to read the instrument. This is especially the case when reading upward shots. Care should be taken in placing survey stations at these points so that undue contortions are not needed on the part of the surveyor.

The measurement of pit depths can sometimes be a problem if the depth of the pit exceeds the length of the tape or if you cannot see the bottom. To overcome these problems, either tie several tapes together or use a "non-stretching" wire. The end of either of these is weighted and lowered into the pit. When the bottom is reached, the wire or tape can be marked and the depth of the pit can be obtained by directly measuring the length of the wire or tape used.

Approximate pit depths can be calculated by carefully measuring the amount of time it takes an object (rock) dropped into the pit to impact the bottom of the pit and for the sound to return for you to hear (naturally, make sure that no one is at the bottom of the pit before determining the depth of the pit in this manner). One would not want to use this method if there are delicate speleothems or cave life near the place where the rock might land. The procedure for determining the depth of a pit with this technique is relatively simple. Drop a rock into the pit, being certain to time the fall in seconds. The weight of the rock is not important. From the total time you measure, standard equations can be applied to calculate the depth of the pit. The following equations are pertinent:

$$D_o = V_o T + (1/2)\, gT^2$$

Where: D_o = Depth of the pit
V_o = Initial velocity
g = Gravity (32 ft/sec^2)
T = Time in seconds

It is necessary to correct the distance for the time it takes the sound to return from the bottom of the pit. For practical purposes, the friction of the air on the rock can be ignored. The true depth then becomes:

$$D = D_o - S - F$$

Where: D_o = Depth of pit determined above.
S = Sound correction (Sound travels 1086 ft/sec)
F = Friction (negligible)

A simplified version of the equation is simply depth = time^2 (sec^2) X 16 ft/sec^2. To use an example, a rock was dropped into a pit. The time it took to hit the bottom and for the sound to return was 4 seconds. How deep is the pit?

Since depth = time $(sec)^2$ X 16 ft/sec^2

$$D = (4 \text{ secs})^2 \text{ X } 16 \text{ ft/sec}^2 = 256 \text{ feet}$$

The sound correction = 256/1086 = 0.24 sec.

Correction = $1/2\ gT^2$ = 1/2 X 32 ft/sec^2 X (0.24 sec) = 0.92 ft.

D = 256 - 0.92 = 255.08 feet deep for the pit

A graph can be made relating the depth of a pit to the time required for a rock to fall to the pit's bottom. By measuring the time and relating it to the curve on the graph, the depth can be read from the vertical part of the graph (Figure 6-12).

In sketching a pit, it is advisable to first sketch the top and then, if it has multiple levels, to draw each level separately as it is encountered. A composite of the separate levels can be drawn on the final map for the entire pit. If this is done, supplement it with a separate sketch of each level. Also, draw a profile in two different directions through the pit to get cross-section details. Figure 6-13 shows an example of a cave map of a predominantly vertical cave.

MISTAKES AND BLUNDERS IN MEASURING VERTICAL ANGLES

In measuring vertical angles with a clinometer, there are several ways in which mistakes or blunders can occur.

1. Reading a minus angle in place of a plus angle.

2. Reading percent grade instead of degrees or mils.

3. Making a digit error -- reading 15° for 25°.

4. Transposition errors -- 23° for 32°.

5. Reading the wrong way from the marked graduations -- 24° for 16°.

In taking a vertical angle, the index line must be lined up very carefully with the target station before reading the value. To minimize possible mistakes, the surveyor should measure the vertical angle and call it out to the chief or data recorder, who in turn reads it back. This number is then verified by the surveyor, who then reads it back to the chief. The chief then records the angle. To further minimize mistakes, it is wise to take both foresight and backsight vertical angles. These are then compared and if there is more than a half degree descrepancy, they should be remeasured. Multiple readings can also be taken from one station if the other station is difficult to read from.

PROBLEMS IN MEASURING VERTICAL ANGLES AND ELEVATIONS

1. A slope in Slimy Hollow Cave was determined to have a 40 percent grade. What is the elevation difference between two points 130 feet apart?

2. The slope distance measured in Tom's Cave was 75.6 feet and the vertical angle was +15°. What is the horizontal distance and the elevation difference?

3. In the large breakdown room of Herman Cave, the height of the highest point in a ceiling dome was to be determined. To do this, a point on the floor directly below the high point was found from water dripping out of the ceiling dome. A line was run for about 100 feet from the floor point to a survey point. From this point a vertical angle was determined to the high point and found to be + 47°. A second vertical angle was taken to the floor point and found to be -10°. What is the elevation difference between the floor point and the ceiling point?

4. During the survey of a cave passage with a great deal of vertical relief, the slope distance was measured from station 27 to station 28 and found to be 96.2 feet. The vertical angle is +30°. What is the elevation difference between station 27 and station 28?

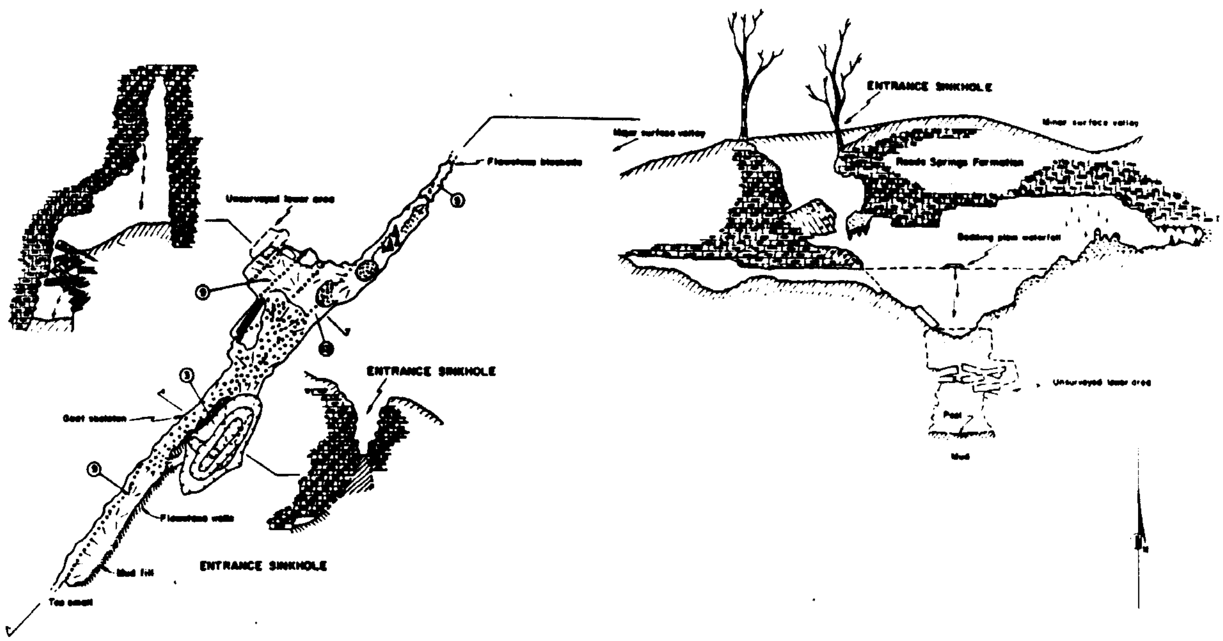
5. A rock was dropped into a pit and the time it took for the rock to hit the bottom of the pit and the sound to return was 9 seconds. How deep is the pit?

6. In Hogup Cave there is a large room which needs to have the height determined. Below the high point is a wide deep pool so that it is impossible to locate a point directly below the ceiling point. At a point some unknown distance from the pool, a point is marked and a vertical angle taken to the ceiling point (45°). Sixty feet further out in a direct line from the ceiling point, a second vertical angle is taken (35°).

How high is the ceiling point above the pool if both vertical angles are in a line directly away from the ceiling point?

7. In Quincy Cave, there is a very high, narrow passage. In this passage the floor inclines at +15°. At survey station 37 the ceiling gets very high and a point on the ceiling can be easily located using a flashlight. From station 36, a vertical angle of 50° measured to the ceiling point. The distance between 36 and 36 is 135 feet. What is the height of the ceiling point above station 37?

8. A rock was tossed into a pit taking care that it would free fall to the floor of the pit. It took 5 seconds for the rock to hit the floor and the sound to return. How deep is the pit?



HAIRL CHAPMAN'S PIT

STONE COUNTY, MISSOURI

0 50 100 Feet

Scale

Mapped by R. L. Taylor, M. Warshauer & S. Warshauer — 1/20/74

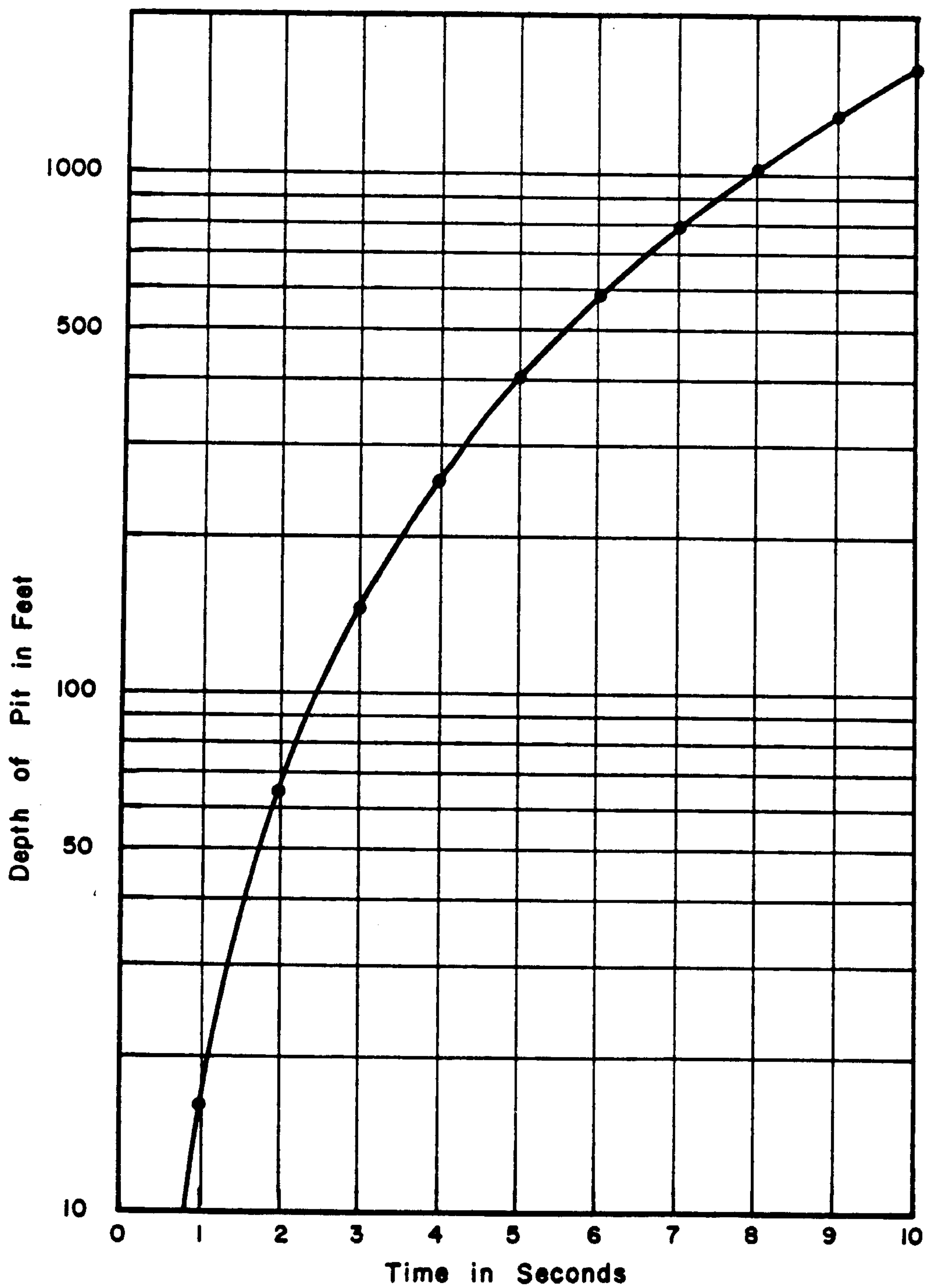


Figure 6-12. Plot of pit depth versus time of fall of rock.

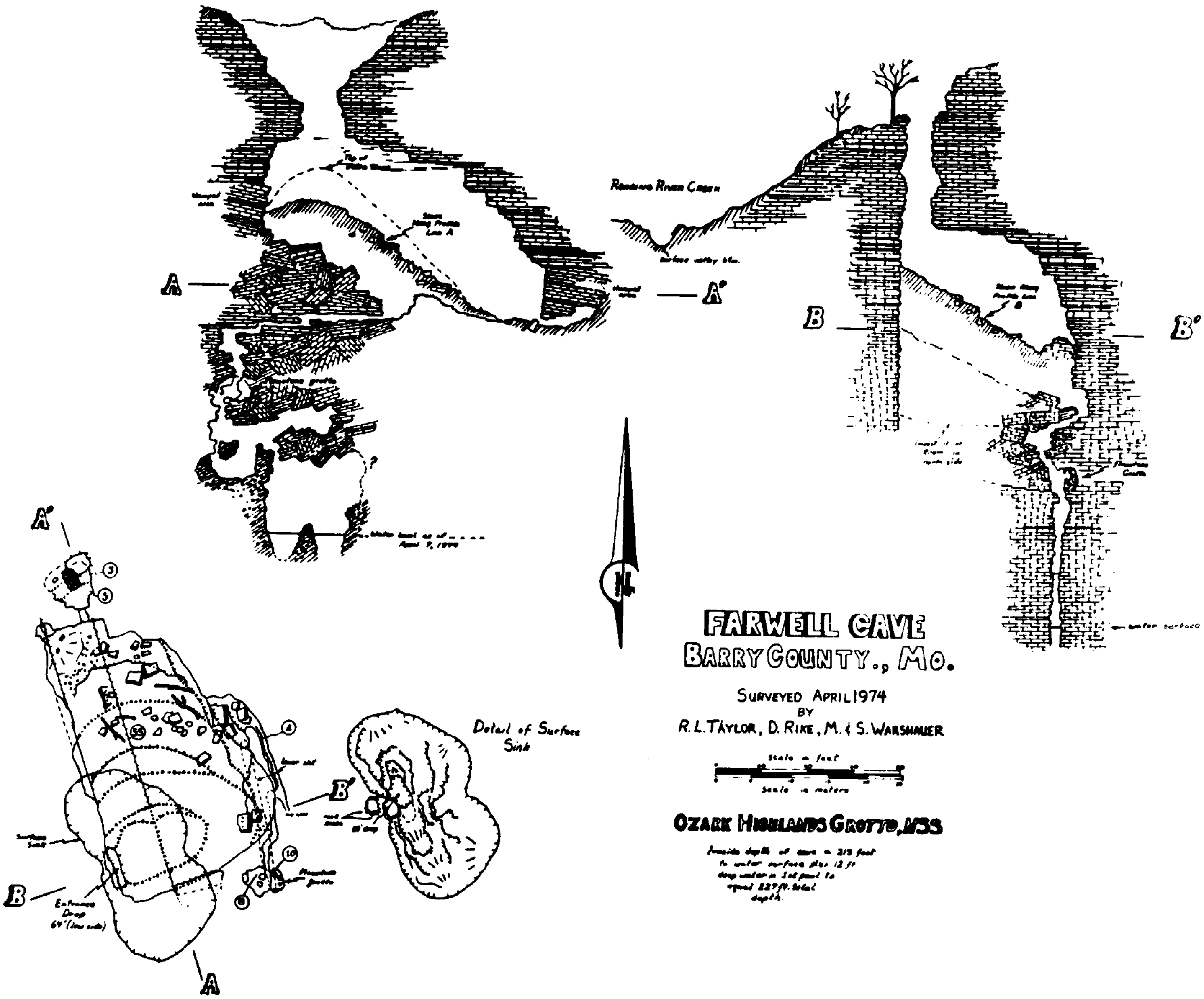


Figure 6-13. Example of a predominantly vertical cave and how it is mapped.

7

MAPPING THE CAVE

THE SURVEY TEAM AND ITS EQUIPMENT

The survey team usually consists of 2 to 4 individuals trained to carry out certain specific responsibilities to make the cave survey both efficient and accurate. The composition of the team is determined by the number of people available, the type and size of cave to be mapped, the mapping instruments to be used, and the purpose of the cave survey. For mapping large caves, four people constitute the ideal mapping or survey team: the chief (bookman, sketchman), instrument person (compassman), and two tapers. In smaller caves and for less efficient, but not necessarily less accurate mapping of larger caves, some of the responsibilities can be combined, and a two-member survey team formed: the chief-surveyor, who sketches, takes compass readings, and holds the back end of the tape; and the lead tape, who may also take backsights.

MAPPING PERSONNEL

Chief

The chief, often the most experienced member of the team, is usually the author of the cave map. The chief is in charge of the survey and decides which passages to map, and in which sequence, the measurements to be taken, the instruments to be used, and the scale of the map. He or she must be familiar with the various types of survey equipment, and their limitations and advantages, as well as the procedures and symbolism used. The accuracy of the cave map is highly dependent on the skill of the chief. Some important things to consider concerning the chief's duties are:

1. **The sketch.** Careful work on the original or in-cave sketch reduces the amount of interpretation necessary later and can save a return trip for the

purpose of clarification. In the sketch, secondary features of the cave should be accurately located. The chief should anticipate any problems and solve them while the mapping is in progress.

2. **The survey.** The chief can aid the instrument person by noting any apparent errors in the bearings. This should be done by plotting the bearings and distances on the sketch and checking to see if they agree with the turns and distances of the actual cave passage.

In a two-person survey crew, the chief sketches the cave and also takes over the duties of the instrument person and the rear tape.

Instrument Person

It is the instrument person's responsibility to see that the chief has all the numerical data necessary to create an accurate sketch of the cave. Bearings or azimuth readings should be taken carefully. Backsights should be taken on every station to verify bearings and azimuths. This ensures greater accuracy and exposes any mistakes made in the compass reading. After taking the compass and clinometer readings, passage heights, and widths should be determined, as well as any other necessary numerical data.

Prior to starting the survey, the instrument person should do a self-inspection in order to see if any item of clothing or equipment that he has will magnetically interfere with the compass. Some items to check include: belt or pack buckles, metal in eyeglasses, carbide or electric head light and an ammo can (containing photo gear).

Tapers

The job of measuring the distance between two stations has to be performed by two persons. A four-person survey crew has a front or lead taper and a rear or back taper. The rear taper makes certain that the zero end of the tape is held precisely over or on the survey station and does not deviate from that position. The front taper, an experienced cave surveyor, establishes all survey stations. These stations should be placed in such a manner that an accurate compass reading can be taken from the station. Each station must be seen from the preceding station and placed in a suitable place to establish the next station at an appropriate distance and location down the passage. The front taper should also establish stations in appropriate places such as passage junctions to provide for proper side shots.

SURVEYING PROTOCOL

In an efficient surveying team, each person knows his/her responsibility and does it efficiently. The only problem is knowing when a task is complete so that the survey may move one. Paul Hill (1985) posed the following questions regarding surveying protocol:

"(1) How do you know when the person on the other end of the tape is ready for you?

(2) How do you know that the book person got the reading written down, and got it written down right?

(3) How do you know that the shot is complete and that you can begin to move on to the next?"

The answer to good surveying protocol is proper preparation, communication and coordination between the chief and the other members of the surveying team. Hill pointed out a series of steps that might be taken to coordinate one survey reading. These steps are paraphrased here:

Step 1: Synchronize - Establish that the other member of the team is ready to perform the requested step.

Step 2. Transmit - Take the reading and transmit it to the recorder of the information.

Step 3. Acknowledge - Receive a reply and acknowledge either positively or negatively to verify that the recorder received it correctly.

Proper communication can take care of the three steps as illustrated by the following conversation between the chief and the front taper:

Rear Taper: "On station!"

Chief: "Chain!"

The tape is pulled tight, the distance is measured and the data passed to the chief.

> *Front Taper: "Chain, Sixty-five-point-seven."*
>
> *Chief: "Six-five-dot-seven."*
>
> *Front Taper: "Check."*

This same communication should continue through all facets of the cave survey. This helps to eliminate mistakes and blunders.

COMFORT AND THE CAVE SURVEYOR

One major prerequisite for accurate cave surveying is the comfort of the survey team. The surveyor who is cold, wet, hungry, or tired, is the surveyor who makes mistakes. Proper clothing and equipment will help to make the survey both more efficient and more comfortable.

The surveyor should always have a hard hat with some type of head lamp attached. This frees up the hands for drawing and running surveying instruments. It is necessary to have a light which will illuminate the cave well enough for you to see the details to be mapped and yet be portable enough to be easily carried through the cave. Lights available for use in cave surveying are the same as used as cave exploration lights, the two most common are the carbide lamp and the electric cap lamp. These provide sufficient light for surveying. Other useful lights available include: coleman lanterns, and even a portable light mounted on a clipboard. Be careful with any light source when taking azimuths or bearings so that the metal in the lamp does not affect the compass needle. In addition, two back up light sources should be available. A flashlight is often quite handy for lighting up a survey point while someone else reads the compass or the tape. This flashlight is usually placed directly on or in line with the station so that the instrument person can sight on the point of light rather than some hard-to-see station.

Be sure to dress in clothing that can be shed or opened up when moving rapidly to prevent overheating, and closed up when you are traveling slowly to prevent getting too cold. Drill pants and jacket over woolen underwear will often be quite comfortable. Coveralls have the advantage of being easily opened up in the front to allow air in to cool you down. Avoid becoming overheated early, as this will cause your body to lose heat. A serious loss of heat will lead to hypothermia or exposure. When in doubt about the inside temperature of a cave, always bring along an additional garment to wear such as a sweater. Gloves are also an essential item of clothing. They serve two purposes: first to protect the hands from cuts and abrasions and second, to keep the hands clean so that the surveyor can keep his/her notes and surveying equipment clean and in working order. Boots or shoes constitute another very important part of the cave surveyor's equipment. It is important to have footwear that will not slip in the mud. It is very difficult to read a bearing or an azimuth next station if your feet are slowly sliding out from under you.

If you are going to be extensively immersed in water during the cave survey, you should seriously consider investing in a wetsuit to protect your body against hypothermia. The investment may save your life and at least might enable you to do a lot more surveying without becoming chilled early on and having to leave.

Prevent hunger pangs and replenish your energy levels during the survey trip by including some high-energy carbohydrate foods in your cave pack. Caver's gorp, a mixture of high-carbohydrate foods such as chocolate, nuts, fruits, candy, etc., carried in a water-tight container can help maintain body heat and provide energy. Longer mapping trips should include such items as canned meat and fruits which can be eaten to replenish both moisture and energy to the system. These should be compact and all containers should be removed from the cave.

The survey trip should always be planned around the weakest individual in the group. A tired surveyor is an inaccurate surveyor as well as a candidate for an accident. Do not overextend yourself or your team.

SURVEYING EQUIPMENT AND SUPPLIES FOR TAKING NOTES

The equipment used for cave surveying

depends upon the length of the cave, the purpose for which the map is being made, the availability of equipment, and the time allotted to conduct the survey. The most important items for cave surveying are the compass, clinometer and tape previously discussed in Chapters 3, 4, and 6. Other supplies and tools that are needed include a scale, protractor, pencil, eraser, and notebook. It is best to combine as many of these materials as possible to make a compact assortment.

Scales

A scale is similar to a ruler with specific divisions used to represent units of distance on the map. The units may be in centimeters and millimeters or in 10ths, 20ths, 40ths, or 50ths of an inch. Most available scales are 12 inches long, a length that is unwieldy for cave mapping. This type is excellent when working at home plotting up the cave map, but it is better to find a small plastic 6-inch scale for use in the cave. Handy scales marked with 10-20, 20-40, and 10-50 units per inch can be obtained from various sources such as Forestry Suppliers, Inc, the C-Thru Company and others.

Protractors

A simple, cheap protractor can be obtained from the nearest variety store. These are not accurate, but they are good enough for a rough sketch in the cave. The more precise protractors, available in half and full circles, can be used to plot the survey data for the rough draft. Dual purpose protractor/-scales are also available--a combination that can be very useful in saving plotting time in the cave. These can be obtained from the same sources described above.

Pencils

A good pencil is indispensable for recording data on the survey. If you have only one pencil and break the lead and cannot sharpen it, the survey ends. The common wooden pencil works well, but be sure to bring more than one and have a knife to keep them sharp. Your pencil shouldn't be longer than 3 or 4 inches since longer ones break easily. An eversharp pencil is particularly effective because it is inexpensive and easily kept sharp. Other possibilities include an engineer's drafting pencil or the 0.5 to 0.3 mm drafting pencils. These can also be easily kept sharp. Be sure to have plenty of HB or 2B lead available in the pencil. The pencils should also have erasers or erasers should be available, so that mistakes can be easily corrected. Do not use felt-tip, ballpoint, or rapidograph pens because they clog or run on the paper and smear. Always bring one or more backup pencils. Survey trips have been aborted after the cavers have traveled hours in a cave to reach the end of a survey and found that the pencil had been lost or forgotten.

Notebooks

The information obtained during a cave survey should be recorded. Several types of notebook or media are useful for this purpose. The type you choose depends on your personal preference and the type of cave (wet, dry, etc.) you plan to survey.

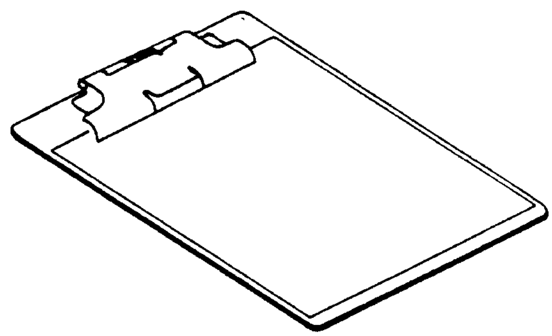


Figure 7-1. Clipboard used for cave surveying.

A clipboard with 8 1/2 x 11-inch graph paper can be quite useful in surveying larger and more complex passages, but can become cumbersome in crawlways and small caves (figure 7-1). Various types of paper or mylar (plastic) can be used on the clipboard, but because it may get wet, a protective cover should be used. A sheet of plastic or a plastic bag large enough to contain the entire clipboard or a clipboard with a cover that folds book-like over the graph paper can be used. If one needs to have both hands free in order to climb around in the cave, a clipboard of this size can be quite awkward. Sometimes this problem can be overcome by carrying it between one's outer shirt and T-shirt.

A folder-type book about 6 x 9 inches in size can be purchased wherever office supplies are sold. The lined pad can be removed and a graph paper pad can be trimmed to 6 X 9 inches and placed inside. This type of book has a cover and a place in which to keep the protractor scale and a pencil to make a nice compact package for surveying caves (figure 7-2).

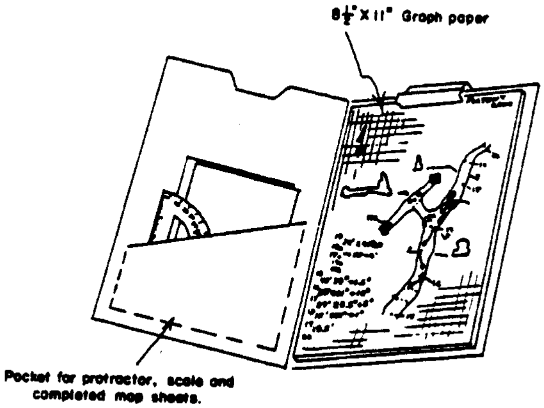


Figure 7-2. Folder-type notebook.

The standard field book (figure 7-3) is an excellent media for taking notes, especially the inexpensive student paper-bound version. The size of these notebooks is from 4 x 6 inches to 6 x 9 inches and they are available with a variety of graph paper pages. The ideal choice is level paper, since the paper has a square grid on one side and lined paper with columns on the other (figure 7-3). These are available in permanently bound versions or loose-leaf styles in which paper can be added or taken out as needed. These are available with plastic covers for better durability in the cave.

Another type of survey notebook that is often used by cave surveyors is the small shirt pocket-sized loose leaf notebook (figure 7-4). These are small enough so that they can be conveniently carried in either the shirt pocket or cave pack. They are especially useful in the survey of larger passages with little complexity or detail and in small passages. Be sure to skip a page between each page of notes so that if the notebook gets wet, the survey notes will remain legible. Similar to this type of notebook in size are those that can sometimes be bought from caving suppliers. The latter have the convenience of being waterproofed and already marked: on the left side is a page for recording survey data and on the right is a page of graph paper for the sketch.

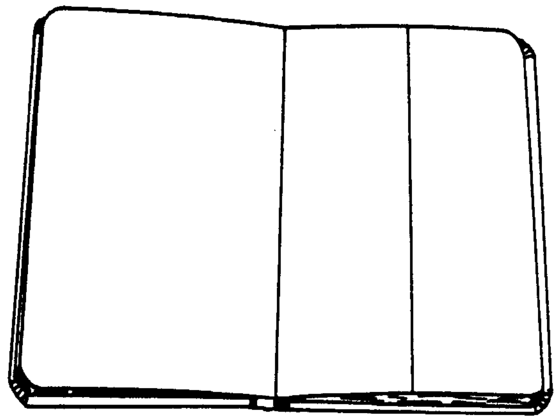


Figure 7-3. Standard field notebook used for cave surveying.

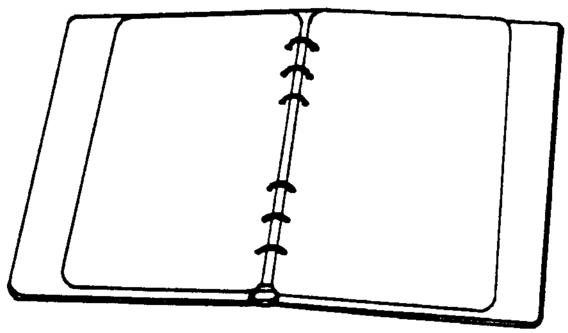


Figure 7-4. Small pocket looseleaf survey book.

Whichever notebook you choose, be sure that the paper is durable and can get wet without falling apart, and that it is lined, preferably as graph paper, with horizontal and vertical lines. Also be sure that the notebook interior receives a minimum of soiling while you traverse the cave. The adage "keep your powder dry" is aptly modified for cave surveying by saying, "keep your notes dry."

Pack

A small side pack, essential for carrying the above equipment, can also be used to carry extra food and water. This side pack should be easy to carry, light in weight, and highly durable since it will probably be dragged along the cave floor as much as it is carried by the cave surveyor.

Other

In addition to the other surveying equipment, a rangefinder, hand level, and an altimeter can be quite helpful if available, and if cave conditions permit their use. However, these are not necessary as basic surveying equipment.

CAVE MAPPING PROCEDURES

TRAVERSING

A **traverse survey** is one of the most commonly used methods for determining the relative positions of a number of points. Basically a traverse consists of repeated compass readings and distance measurements. By starting at some selected beginning point, measuring a distance and laying out a direction, the location of a second point is determined. From this second point a new distance and azimuth or bearing is obtained to determine the location of a third point. This procedure is repeated from point to point throughout the cave. The resulting framework is called a **traverse.**

Types of Traverse

There are two basic types of traverse: closed and open. A **closed traverse** can close in one of two ways: (1) the survey lines either return to the starting point of the survey forming a closed polygon, i.e., a survey loop (figure 7-5); or (2) the line finishes upon another survey station either within that survey traverse or established by a separate survey that has positional accuracy equal to or greater than the initial survey station (figure 7-6). Closed traverses provide a check on the accuracy of the measured angles and distances in the traverse.

An **open traverse** consists of a series of survey lines created by azimuths or bearings and distances that are connected to one another, but do not return to the starting point of the survey or close on a previously determined survey station (figure 7-7). Open surveys provide no means of checking for errors or mistakes except for repeating the reading or taking backsights. Unfortunately, most cave surveys are open traverse surveys.

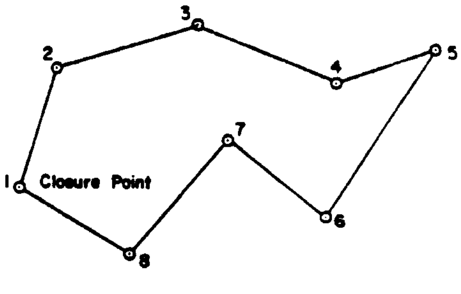


Figure 7-5. Closed traverse loop.

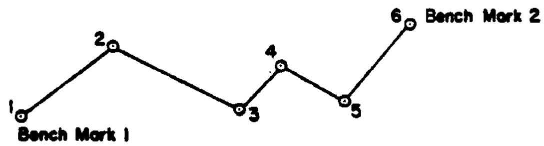


Figure 7-6. Traverse loop that closes on a known survey point. Both benchmarks 1 and 2 have been located.

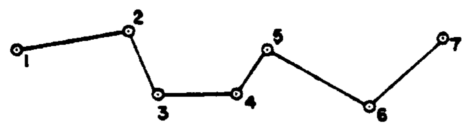


Figure 7-7. Open survey traverse.

Traversing in the Cave

The traverse in the cave is created by measuring distances and directions to relate survey points in space as described in chapters 3 and 4. There are several ways in which a traverse can be created:

1. **Traversing by Compass Bearing.** The Brunton compass was designed for use as a traversing instrument. Bearings are read directly on the compass as sights are taken along the lines (courses) of the

traverse. Distances are measured and backsight bearings are taken as checks.

2. Traversing by Azimuth. The Suunto or Sisteco compass and some Bruntons are designed to read direction as azimuth. These azimuths are also read directly from the compass as sights are taken along the lines or courses of the traverse. Again, distances are measured between stations in the traverse and backsight azimuths are taken as a check.

3. Traversing by turning angles with a transit or theodolite. A transit or a theodolite is not designed to directly traverse by azimuth or bearing, but is used for turning angles between traverse lines. This can be done in one of three ways: interior angles (figure 7-8A), deflection angles (figure 7-8B) or angles to the right (figure 7-8C). These angles are generally tied to one leg of the traverse or a known meridian to establish the exact location of each station in the traverse. Since transits and theodolites are bulky and require a lot of care, this method is not usually used in cave surveying.

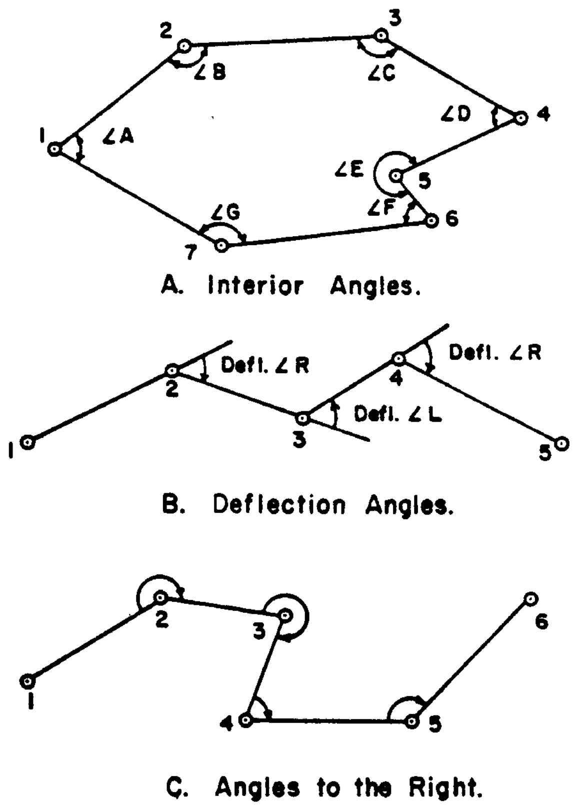


Figure 7-8. Methods of turning angles using a transit or theodolite.

SURVEY STATIONS

The basic components of the survey framework are the survey stations. These are the points in space to which the directions and distances in the survey are tied. Improper numbering and bad placement of survey stations can lead to confusion and inaccuracy in the survey.

Survey stations should be placed so that you can easily and accurately take the bearings or azimuths between them. To ensure accuracy, you should consider several basic factors:

1. Type of compass used to conduct the survey. A good station for one compass may not work for another. For example, in using a Suunto compass, you have to be able to sight through the compass by holding it up to your eye. If the survey station is located where this is not possible, an accurate reading cannot be taken from that station with a Suunto compass. A reading with a Brunton compass, however, may or may not be easily taken from that same station, and what may be an easy station site for a Suunto may, in turn, be difficult for a Brunton.

2. Location of the survey station. The direct line of sight from one survey station to the next should be free of obstructions. The survey line should not be bent around or caught beneath rocks or ledges. The person at the front end of the tape should always make sure that the person at the back end of the tape can see the new survey station from the last survey station before proceeding. Otherwise, time will be wasted in choosing a new survey station, or the survey will be inaccurate. Spacing of survey stations is normally dependent only on the tape length and the ability to view one station from the next. Placing one station instead of two or three can be valuable both in terms of time and accuracy, since taking more tape and compass readings increases the chances of survey error. However, short survey shots may be necessary in order to place a survey point at all passage junctions as tie points for side passage surveys. In general, it is best to place survey stations at or near the center of the cave passage. This leads to a more correct measurement of the actual length of the cave. Measurements or lines taken from one side diagonally to the other and then back again throughout the cave will give the wall locations accurately, but will give a greater-than-true length of the cave. A true cave length would have to be calculated from the data, or an attempt would have to be made to measure it directly from the drawn map--processes that are both unwieldy and inaccurate.

3. **Comfort of the surveyor.** Survey stations should be placed at sites where the surveyor can be relatively comfortable when measuring directions. If he/she is uncomfortable, the likelihood of errors increases. Survey stations that force the surveyor to lie on his/her stomach in the water or to hang over a pit to take a bearing should be avoided (except in water crawls and over pits...).

Marking Survey Stations

During the cave survey, stations should be marked in some recognizable manner. Survey stations may be set up and marked either permanently or temporarily. Permanent survey stations should be used only if future studies or surveys are to be made. These stations should never deface the cave in any way and should be placed only at locations where they are absolutely necessary.

There are several ways in which survey stations can be marked permanently. The point can be painted carefully on a rock or wall in an unobtrusive place. It may also be placed with nail, piton, rock bolt, expansive bolt, or some other fastener. This permanent mark should be labelled with red or orange fluorescent flagging and identified with the survey station number unless such labeling would increase the likelihood of someone disturbing the station. A method of permanently marking survey stations that has recently been recommended is to drill a small hole about 1/2 inch deep into the rock with a small star bit. This mark is unobtrusive, but can be positively identified later if you properly identify the survey station in your field notes. These survey stations can be marked temporarily with a candle or reflective flagging which makes the station show up well. The tape can even be written on to designate the station number.

Temporary survey stations are marked for use by the surveyor as the survey progresses, but generally cannot be recovered at a later date. In fact, once the survey is complete, these should be removed. Stations may be marked with a carbide dot created by turning the carbide flame on the lamp up, and then applying the flame to the site. These marks should be kept small and non-objectionable. Some examples of temporary survey stations may be small rocks carefully marked, fluorescent orange or red flagging tied to a rock or wall outcrop, etc. Some surveyors carry a handful of popsicle sticks along with them which have been pointed and marked with fluorescent tape or flagging. They may even be painted with fluorescent paint. These can be stuck in the mud at the survey point and then recovered when the survey is complete. Another survey station marker might be made by piling rocks into a small cairn at the survey site. Still another non-permanent method of station numbering that has been used successfully is a lumber crayon. This is excellent for marking on rocks in the cave. Circles can be drawn and numbers marked. This is quite easy to see and given some time, it flakes off and eventually will disappear from the cave. In all cases, place the temporary marker so that it can be easily removed or obliterated and the cave returned to its natural state.

Sometimes it may be unnecessary to mark on the cave at all during a survey. This may be accomplished by having the front taper choose an obvious point (protrubance, discoloration of the rock, etc.) and then simply point it out to the rear taper and instrument person when they arrive at the station. Naturally, one has to be careful that the identification is carefully made or serious errors in accuracy can result.

Numbering Survey Stations

Every survey station needs to be identified in some manner. There are many methods that have been used in cave surveys. Some examples of these systems are given below to aid you in designing your numbering system. It is not the purpose of this discussion to recommend any particular system or means of station numbering, but to let you choose a system which meets your needs.

In small or simple caves, stations can be identified by a number such as 0, 1, 2, 3, etc., or alphabetically as A, B, C, D, etc. In more complicated caves, a combination of the two can be used to designate side passages or complex sections. The A section or B section of the cave survey, for example, might have stations numbered A-1, A-2, A-3, etc. or B-1, B-2, B-3, etc. A further extension of this method could combine different letters and even add lower case letters, for example, CF-3, AB-5c, etc. Generally, lower case letters such as c are used for recording radiating shots from the main survey line. These radiating lines can be one or two shot readings in places where detail is needed (such as in a large room) and the length values are not to be recorded in the total survey length. With this method one can also either proceed alphabetically (A, B, C, ..., AA, AB) or use a passage name to provide the letters (main line = ML-1, Ditty Loop = DL-2).

Another workable system for station numbering was presented in the *Arkansas Caver*, Vol. 5, 1967, by David Taylor. In this numbering system, all stations are numbered consecutively as one proceeds into the cave beginning with 0 and progressing 1, 2, 3, etc., until the first passage to the right is encountered. At this point, the survey continues into the right-hand passage. All subsequent passages are numbered and surveyed to the right as they are encountered going in and coming out of the cave. The station number that succeeds the number in any passage junction will be the same in all passages that extend from that junction. For example, the junction might have three passages leading off. If the junction number is 10, then the first point in the first side passage is numbered 11, then succeeding numbers would be 12, 13, etc. You would then return to the junction and proceed to survey the next passage to the right and its first survey number would also be 11, and succeeding numbers 12, 13, 14, etc. A line is drawn below each change in side passage in the notes to indicate easily what has transpired. In the above example, a line would be drawn below each station number 11. The passages are then numbered in order in a counterclockwise pattern until the cave has been mapped. If you don't want to survey a small side passage when a large borehole looms ahead and you want to stay in the large passage, the system is easily modified. Simply mark the junction station and label this in the notes, then proceed to number the stations consecutively down the passage. A gap can be left in the data list and a series of stations can be placed in that gap later. This will still fit into the numbering system. Figure 7-9 shows a cave map with the stations numbered using this system.

Mike Warshauer, in the *Underground Leader*, Vol. 7, No. 3, 1977 described a method used by members of Central Ohio Grotto as follows:

"A four digit number is used for each station. There are enough in supply to furnish all but the longest, longest cave with station designations. Simply the first two digits run from 00 to 99, and indicate the series. One need no longer hang up the tape at the 'Z' survey. The second two numbers, running from 00 to 99, indicate the station. A typical example in a large cave would be 3015. That's the 15th station in the '30' series.

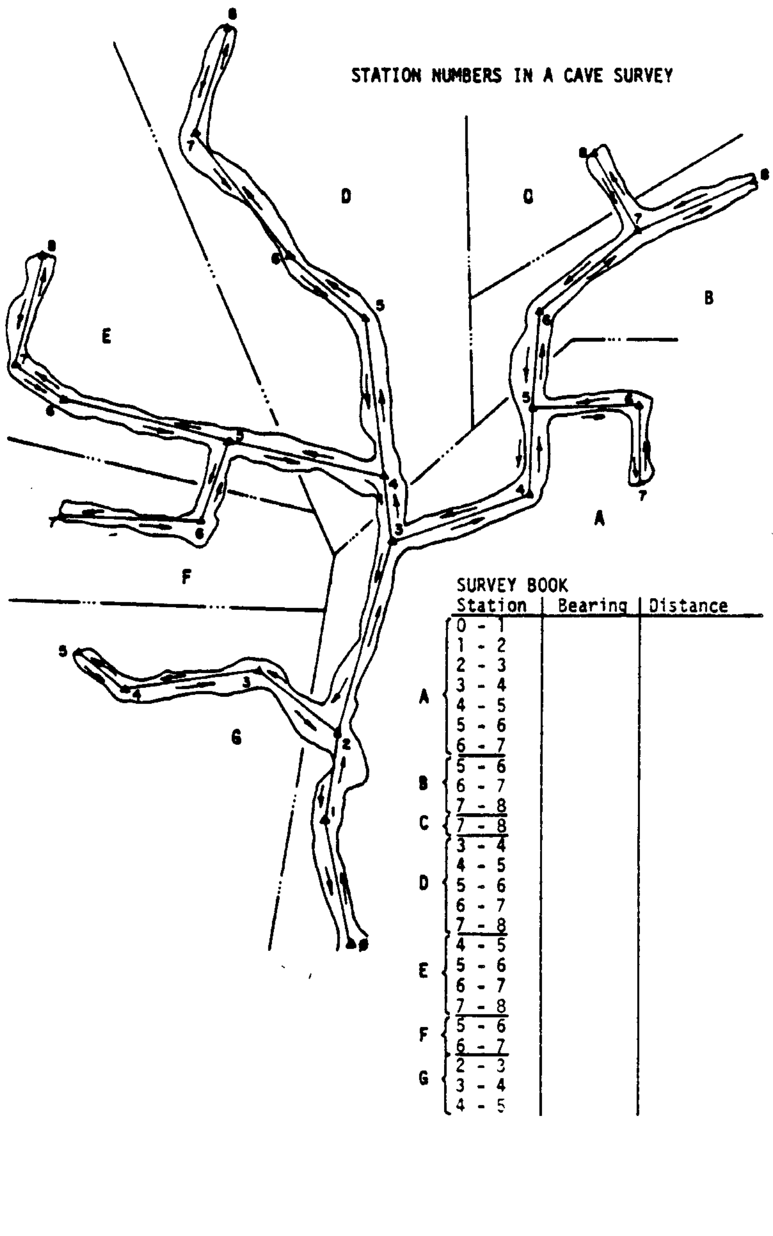
"For consistency, the original station in each series should always be thought of as 00. Obviously, when mapping down a side passage starting at 3014, station 3100 equals 3015. The first true station in the branch will be 3101. And so on, through 3102, 3103... Likewise, when 'closing' (or attempting to close) a loop, the last station of the series equals the oncoming closure station and should be so noted."

There are many other ways that are used to number cave surveys, but a choice from the above examples will probably work in most cave survey situations.

It is important that the survey numbering not be confusing, especially when the map isn't immediately plotted. If you're not careful, when you go to plot the map after weeks or months have passed, you may not remember how one particular notation was used. A method of numbering survey stations should be decided on before beginning the survey and then used consistently. Any departure from that notation method should be clearly noted on the survey sheet.

NOTE TAKING

The success of any cave survey depends of the accuracy and completeness of the survey notes. While cave surveying is a science, note taking is as much an art as it is a science. Field notes are the most important single aspect of cave surveying.



SURVEY BOOK

	Station	Bearing	Distance
A	0 - 1		
	1 - 2		
	2 - 3		
	3 - 4		
	4 - 5		
	5 - 6		
	6 - 7		
B	5 - 6		
	6 - 7		
	7 - 8		
C	7 - 8		
D	3 - 4		
	4 - 5		
	5 - 6		
	6 - 7		
	7 - 8		
E	4 - 5		
	5 - 6		
	6 - 7		
	7 - 8		
F	5 - 6		
	6 - 7		
G	2 - 3		
	3 - 4		
	4 - 5		

Figure 7-9. Cave map showing the Taylor (1967) method of station numbering.

Without the notes, there is no survey. The field notes constitute the written record of the mapping process. They contain all pertinent information necessary to make the final cave map including a record of all measurements, their location, as well as sketches and descriptions of mapped areas and features. The field notes are generally made by the chief of the survey team, who should be alert to spot obvious errors in compass readings and any other problems. As the chief records information in the notes, it is wise to make the following hypothetical assumptions about anyone who might read the notes later including himself/herself: (1) they have poor eyesight, (2) they are not clairvoyant, and (3) they will try to blame all mistakes on the field notes. To overcome this assumed situation, it is necessary that the notes are: (1) neat and legible, (2) complete and self explanatory, and (3) honest and generally self checking.

Field notes should be complete in and of themselves. Many cave surveyors feel that the field notes, reinforced by their memories, are sufficiently comprehensive to be used for the immediate purpose of making a cave map. Experience shows this supposition not to be true. The field notes should be complete enough to stand by themselves without clarification by the surveyor. If this is not done, the following will result: (1) lost time trying to decipher the notes, (2) probably a return visit to the cave to clarify the notes (this might be quite difficult if the section of cave being mapped is 4 hours into the cave), (3) erroneous information may be placed on the map, and (4) a general mistrust of the surveyor's mapping ability.

Since good field notes are so essential, there are some basic requirements that should be considered:

1. Neatness:
   a. Keep your pencil relatively sharp.
   b. Make liberal use of enlarged details. Avoid crowding sketches or descriptions. Remember, paper is cheap, time is expensive.
   c. Keep your lettering parallel with or at right angles to the feature it refers to.
   d. Look at the lay or direction of the cave passage and orient the map sheet so that it is parallel to the major run of the passage. This will enable the surveyor to record more of the cave on each sheet. Having to change sheets more often than necessary wastes time and leads to a greater likelihood of difficulties in accurately matching up the sketches from one sheet to the next when one is drawing up the final map.
   e. Keep your notes clean. Wear gloves while traversing the cave and take them off to map. It is wise to carry a small towel in your cave pack to wipe your hands on. Muddy maps are very difficult to decipher.

2. Legibility:
   a. Do all lettering carefully and be sure it is all legible.
   b. Use proper symbols and abbreviations to keep your notes compact.

3. Clarity:
   a. Always start a new project on a new page. Even on a continued survey of a large cave. Personnel and equipment change.
   b. Use of note forms can be quite handy in organizing field notes, especially for the numerical data gathered.
   c. On all decimal numbers less than 1, place a 0 before the decimal mark...0.51 rather than .51.
   d. Show a north arrow on all pages.
   e. Station number systems should be either explained or be self evident or self explanatory.

4. Completeness:
   a. Show all pertinent measurements. In some cases lengths of traverse shots can be indicated directly on the sketches. Be sure to indicate passage heights and drop-off depths on the sketches.
   b. Record complete data. Be sure to indicate full names of all individuals involved in the mapping process, the name of the cave, the passage surveyed, and the date of the survey. If one is surveying a complex cave or several caves, the lack of information on individual map sheets can be confusing. Also, if more than one compass is being used, indicate the kind of compass used and

its serial number and the type of tape along with any pertinent information about the tape (such as broken at aa certain length, etc.). Any other special equipment should be noted.

c. Review your notes before leaving the cave to be sure they are complete.

d. If you are in doubt about recording any data, record it. Do not leave anything to be assumed. If you leave anything out deliberately, state that you did so.

5. Self Explanatory:

a. Make maximum use of explanatory notes.

b. Place a title at the beginning of the work stating what you are doing.

6. Honesty:

a. Record exactly what was measured in the field as you did it, not later from memory.

b. Any measurements made by someone else should be so noted in the field notes.

c. Record notes with the degree of precision that was actually determined in the field, i.e., record 6.3, not 6.30 if you read a measurement to the nearest tenth.

d. Record actual measurements, not what they are supposed to be.

Take pride in your field notes. The cave survey stands or falls on the completeness, neatness, legibility, and honesty of the field notes.

Sta.	Dist.	Bearing or Azimuth	Vert. Angle	R	L	C	D
		F / B	F / B				
		F / B	F / B				
		F / B	F / B				
		F / B	F / B				
		F / B	F / B				

Figure 7-10. Format for recording survey data.

Content of Field Notes

The basic data that must be recorded in any cave survey prior to the actual mapping includes: the name of the cave and its location, the type of survey, the make and type of compass and clinometer, as well as their serial numbers if more than one set of instruments will be used on the survey, the type of tape being used and any special considerations such as "the tape is short by a foot" etc., the magnetic declination setting, the date of the survey, and the full names of the team members correctly spelled and their responsibilities. If you are surveying a large cave, you should indicate which section of the cave you are surveying.

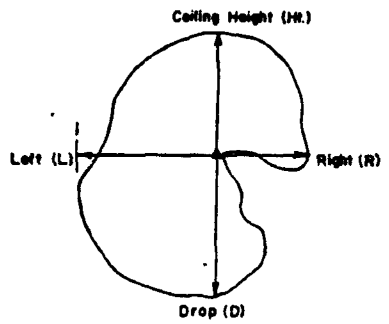


Figure 7-11. Diagrammatic cross section of cave showing the meaning of left (L), right (R), ceiling (Ht), and drop (D).

Next, the chief needs to record the basic cave survey data. It is generally a good idea to make a form in the notebook on which to record this information (figure 7-10). On the form, the station (STA) should be recorded in the direction of the survey, i.e., 0-1, 1-2, etc. Under the distance (DIST), the actual tape reading uncorrected for slope, should be recorded. Under bearing or azimuth (BEAR, AZI), the exact reading should be recorded. Backsights should also be indicated (BS). Under the vertical angle (VERT), the exact angle and a plus (+) if the angle is uphill and a minus (-) if it is downhill should be indicated. Show both front vertical angle and back vertical angle (BS VERT). Under the headings right (R) and left (L), ceiling (Ht) and floor (D), the distance to the right and left of the survey station, and to the ceiling or floor from the survey station (figure 7-11) should be included. The ceiling and floor data are helpful in two ways--for

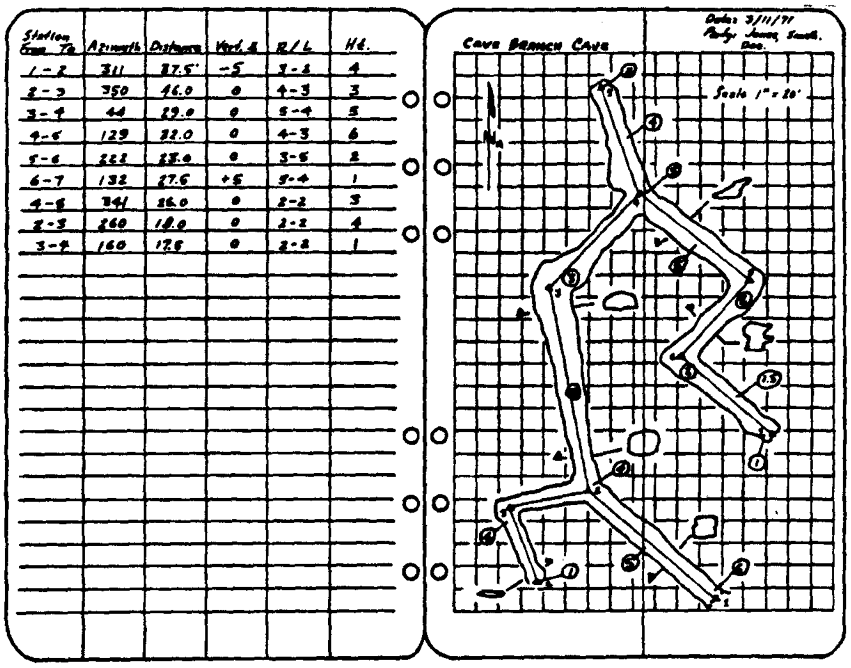


Figure 7-12. Method of recording survey data on field notebook sheets using the notebook format.

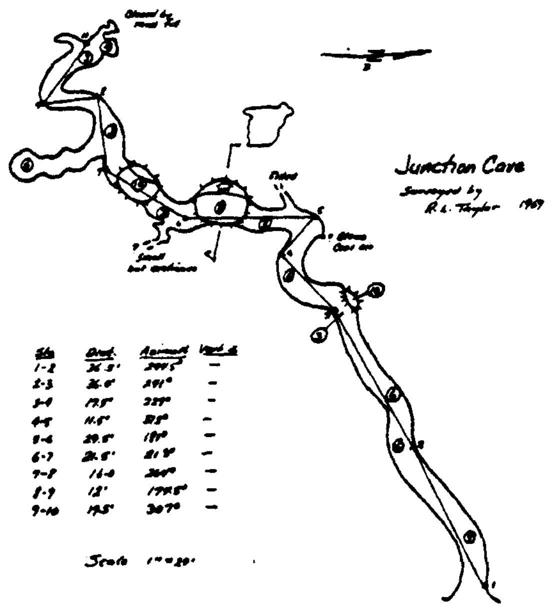


Figure 7-13. Method of recording survey data directly on the survey sheet with the sketch map.

drawing longitudinal and transverse profiles, and for identifying the vertical relationships of cave passages (which can be valuable in studies of cave development).

Sketch Map

An integral and very important part of the record-keeping process in cave surveying is the sketch map. This is a free-hand drawing of the plan of the cave passage around the surveyed map framework as plotted from the information recorded. It is not pictorial, but diagrammatic. The detail of the sketch depends on the scale of the map and the detail that the surveyor wishes to preserve. In the record this sketch might be drawn on the page opposite the survey sheet (figure 7-12) or the data sheet might be located on a part of the sketch map (figure 7-13). The two sheets go together. To make a good sketch map, you must do the following basic things:

1. Determine the scale of the map. This depends on how much detail you wish to preserve. Small caves are usually mapped at scales of 1 inch equals 10 feet (1:120) or 20 feet (1:240). In larger caves, scales such as 1 inch equals 40 feet (1:480), 50 feet (1:-600), or 100 feet (1:1200) can be used. Many times larger caves are mapped at scales where greater detail can be preserved (for example, 1 inch equals 20 feet) but then are drawn on the final map at a smaller scale, such as 1 inch equals 100 feet. Selected areas on the final map which exhibit a lot of detail may be drawn in an expanded form (for example 1 inch equals 10 feet). Be sure that the scale is recorded on the sketch.

2. Decide where north is to be on the map page. When working on graph paper, there are only two choices: to the top or to the right side of the page. Choose the direction based on the lay of the cave, if possible. You want to get as much of the cave on the page as possible, so put north so that the longest direction of the cave will fit on the page. Put a north arrow on each map sheet.

3. Determine where on the page the initial point in the cave is to be. Again, determine this from the way the cave is oriented. This also a way of getting as much on paper as possible. However, keep in mind that paper is cheap, time is expensive. Take as much paper along as you feel might be necessary. As the survey proceeds, if the passage runs off the edge of the paper, begin on the next sheet with the last survey station and continue on with the survey. Sometimes, however, if you are about to run out of sketch paper or only one small survey shot is left to finish the cave or side passage, the subsequent sketching can be relocated on the same sheet, depending upon the amount of free space available. If this is done, the stations need to be clearly marked on the sketch so the segments will fit together easily.

4. Plot the framework for the survey by beginning at the initial point drawn in step 3 and plotting the direction of the survey line, then scale the distance for that leg of the survey. Be sure to label the station numbers on the sketch map for future reference.

5. Sketch the cave passage on the framework carefully.

Plotting the Cave Map Traverse on the Field Sheet

The first step in making the field map of the cave is to plot the surveyed framework points onto the field sheet. This is mainly done by plotting azimuth or bearings and distance (polar coordinates) onto the field sheet while surveying the cave and drawing the sketch map.

To use this method, first determine an initial point on the paper to start plotting the survey points. This can simply be an intersection of the horizontal and vertical lines on graph paper, placed so that the cave map being drawn will fit onto the survey sheet.

A protractor can be used in one of the following ways to plot the azimuth or bearings:

1. Line the 0 and 180 degree marks of the protractor with a vertical line on the graph paper or north/south line of the paper (figure 7-14), and the 90° and 270° marks on the protractor with the horizontal or east/-west line on the graph paper (assuming a full circle protractor). Read the angle on the protractor and make a dot on its edge. Remove the protractor and draw a ray or line from the initial point through the dot. Then use the scale to measure the distance along the line, and mark the second point or station. Lastly, erase the segment of line drawn that extends

beyond the dot.

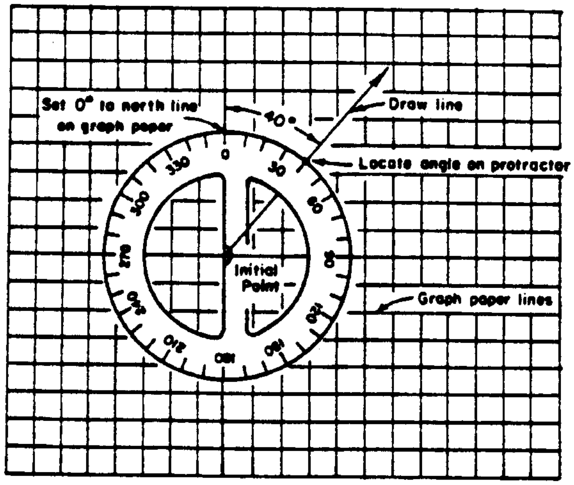


Figure 7-14. Use of the protractor to determine location of points and directions on a map. Method 1.

2. In the second method, place the protractor base point at the initial point. Rotate the protractor until you read the bearing angle from the vertical line. Then draw a line along the protractor base and plot the distance (figure 7-15).

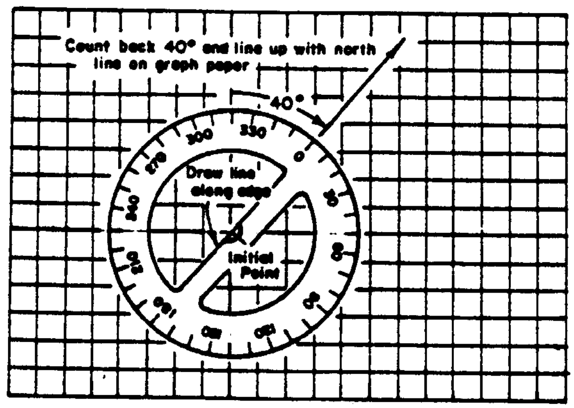


Figure 7-15. Use of the protractor to determine the location of points and distances on a map. Method 2.

A combined (half circle) protractor-scale is available which is compact and easy to use. To use this device, place the scale on the map so that the edge with the protractor center passes through the initial point. Hold the point on the scale edge and pivot the scale until any north/south coordinate line on the paper coincides with the center of the protractor and with the desired bearing or azimuth reading (figure 7-16). The scale edge should then be properly oriented for the desired bearing and can be used as a straight edge to draw the desired course. Sometimes it is easier to measure from the horizontal or east/west lines. If this is the case, use the complement of the angle (90 degrees-bearing angle). For example, if the bearing is N.38 E., measure it from the east/west line by measuring 52 degrees counterclockwise from the line (figure 7-17).

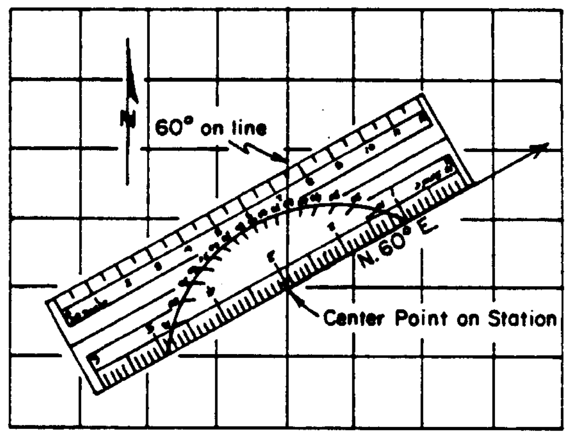


Figure 7-16. Use of the protractor-scale, method 1.

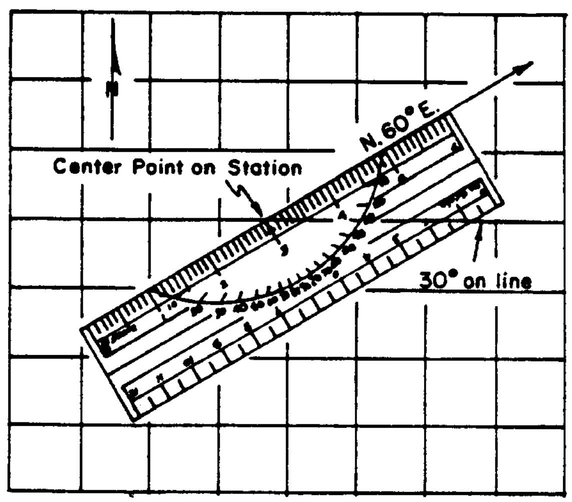


Figure 7-17. Use of the protractor-scale, method 2.

The sketch of the passage section can then be drawn around the traverse line.

Sketching the Passage Details

Oftentimes, the sketch is simply "eyeballed" from various positions along the laid-out survey line.

This may be good enough for non-complex or small passages, but it will not suffice in all cases. It may be necessary sometimes for the survey team to set up survey shots radiating out from the main line of the survey in order to draw in detail and/or determine the dimensions of a passage or room. Too, the chief may carry a separate compass with him/her so that at complex areas of the cave a compass shot can be taken to some cave feature from some point on the main line. Then, the chief can either estimate the distance to that feature or, further along the main line, take a second shot to that same feature, and then graphically triangulate to it. This use of a second compass is also good for sighting along joints. It also frees up the instrument person from having to take time out from his/her main job of accurately providing instrument data for the main passage framework.

For the greatest degree of control over the passage detail, the sketch of the cave should be made by walking along the stretched out survey tape and sketching the passage details every 5 or 10 feet, depending upon the complexity of the passage. Draw the walls and the floor first. The location of passage walls should drawn to scale at a certain datum level. A horizontal slice taken at the floor will be different in most cases than a slice taken about 3 feet above the floor. A good standard to follow is to map at waist level. It is also a wise move to dimension things along the way such as the exact size of a large breakdown block or the actual distance to a drop-off. This can be labeled right on the sketch map.

After the cave walls are on the sketch, begin to put the details of the cave survey on the sketch. Include ledges, speleothems, ceiling channels, and other features as well as the passage dimensions such as ceiling heights, pit depths, etc. Be sure to use standard cave symbols and be sure to place these features accurately on the map. In many cases you can speed up your sketching by using proportions of the distances that have been surveyed such as half or one-third the distance from one wall to the other (for example, if the edge of a breakdown block is half the distance to the previously drawn wall, it is easy to simply draw it in in relation to the wall without having to do any more measurements). If the recommended symbols are not followed entirely or you use special symbols, be sure to include an explanation of the symbols used on the final map. Depending upon your artistic abilities, the standard symbols can be individualized to look like the particular piece of breakdown, the particular speleothem, etc. This enhancement of the symbols will add to the map's utility and to its aesthetic character.

Be absolutely certain that all the sketching you do is clear and legible. It should be done neatly enough that it could be turned over to an illustrator and completed. However, it is generally best to have the same person sketch and draw up the rough draft of the final map, since he or she may be the only one who can interpret accurately a certain squiggle on the sketch.

In making a sketch map, experience is the best teacher. If you're a beginner at making a sketch map of a cave on the survey framework, you won't be as good as the experienced surveyor. Practice should make you improve in your style and accuracy. When the map is complete, if you can use it to locate cavern features or find your way through the cave, then the map is good. It is important to realize that your skill will improve and that nearly all maps can be made better.

Cross Sections

A cross section is a slice cut vertically through and perpendicular to the long direction of a passage. Cross sections can help show in detail the cave passage shape and are used to clarify the map representation. If a cave were a simple cylindrical passage, then only the passage height and width would be necessary for a complete understanding of the cave shape, but the modification of cave passages by various processes, such as stream erosion, can produce some rather complicated cross sections which cannot be adequately shown by a map view alone.

Many features important to a study of the origin of a cave, such as joint-controlled passages, ceiling channels, passages with shelves, meander notches, and bedding-plane controlled passages, can be shown better in cross sections than in map views. In areas of geologic structure, the nature of dipping strata and joints can be shown diagrammatically (figure 7-18).

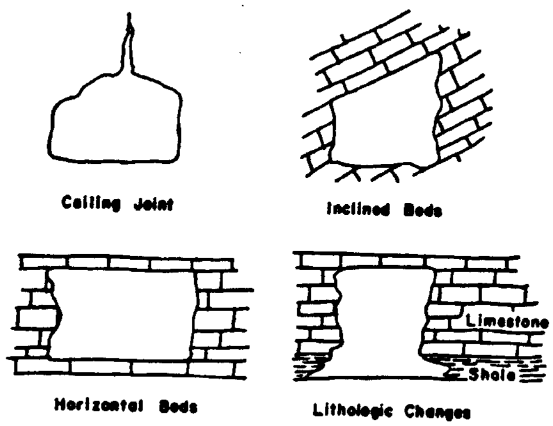


Figure 7-18. Cave cross sections showing how structure and stratigraphy can be shown diagrammatically.

Cross sections are best sketched while the cave mapping is in progress. Well-meaning surveyors who intend to return to the cave later to add cross sections often never do and thus are left with a much less useful map.

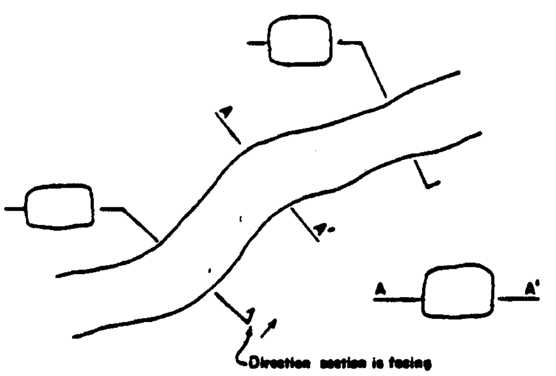


Figure 7-19. Symbols used to show the location of cross sections.

The cross section can be drawn by standing back from the site and sketching what you can see at that site. The best way to draw the section is to begin by estimating or measuring the passage height and width. Then, by using that information, draw a box bounded by those dimensions and, lastly draw the cross section by visual estimate within that box. Many times, for the sake of showing details, the cross section may be a larger scale than the plan view of the map. This different scale should be indicated on the map in the title block. When drawing the cross section on the sketch map, indicate where the top of the section is, and put the location of the section on the map with a line, as shown in figure 7-19. Indicate the direction of view with arrows or letters.

The number of cross sections made for a map is dependent on the complexity of the cave (figure 7-20). Use enough sections to clarify the shape, size, and lay of the cave passages. A good rule of thumb is to add a cross section where the cave geometry changes distinctly or where some particular features need clarification.

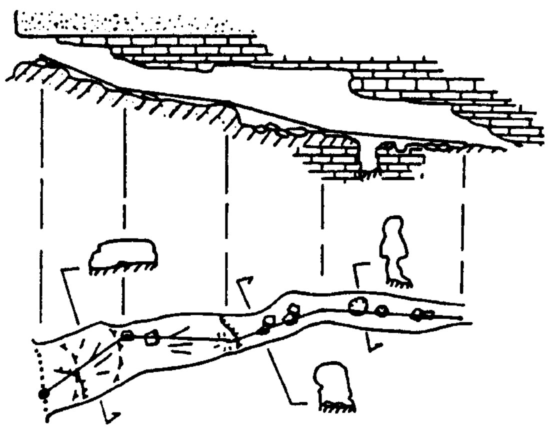


Figure 7-20. How cross sections and longitudinal sections are shown and plotted on the map.

Longitudinal Sections or Profiles

A longitudinal section or profile is very useful in showing the relationship of the cave to the ground surface and to the geologic structure (figure 7-20) as well as showing the vertical relationship of in-cave features and passages.

The longitudinal profile can only be created where adequate survey data exists. This requires taking vertical angles throughout the cave and taking accurate ceiling heights and floor elevations in relation to the survey line. Good longitudinal sections can only be made where proper planning has provided the information. In addition to the data collected to construct the longitudinal section, some parts, if not all of the longitudinal section can be sketched while in the cave. This adds to the accuracy of the section.

If one wishes to show the vertical relationship of the longitudinal section to the surface and no topographic map is available for the cave area, it will be necessary to survey a traverse along the surface (starting at the cave entrance) following the trend of the cave. Be sure to carefully measure vertical angles so that elevations can be determined. This can then be plotted later on the graph paper along with the longitudinal section.

Cave Map Symbols

A really effective cave map is one in which the viewer can picture the cave as the surveyor saw it (to make this illustration really successful, the map should be viewed in the warm glow of a carbide lamp...). In constructing such a map, it is necessary to portray the features found during the survey as clearly and accurately as possible. As mentioned previously, the symbols that represent these features can be individualized to look quite similar to the cave features they represent and should be drawn to scale.

Cave map symbols have been devised by cave mappers throughout the world. In some cases the symbols differ, but in most cases the symbols are the same or are similar. The National Speleological Society published its list of symbols in the *N.S.S. Bulletin*, Vol. 41, No. 3, April 1979. The Missouri Speleological Survey, Inc., published a list of symbols in 1960 and then updated it in 1979. Other organizations such as the Association for Mexican Cave Studies, the Cave Research Foundation, and the British Cave Research Association have published lists of symbols. The list of symbols in Appendix I is an attempt to combine as much as possible the cave map symbols used throughout the world. When more than one symbol is commonly used to represent the same thing, all of the symbols will be shown.

CAVE MAPPING PROCEDURE

A rigid sequence of rules to follow in mapping a cave cannot be established because of the complexity of most caves and their mapping problems. A sequence of procedures which has worked in a number of caves can be suggested, but this is idealized and deviations to suit the situation should be worked out as a matter of individual preference. Nevertheless, the basic rules should be followed for the sake of surveying accuracy and conservation of time.

Before Starting the Survey

1. Except in very large caves, thoroughly explore the cave to determine its extent, rough orientation, and potential problems that might be encountered while mapping. An obstacle such as a water crawl for example, can be an obstable to the members of a survey team if they haven't prepared for it. A rough sketch map is handy as a guide to plan the survey.

2. Plan the mapping procedure, its approximate duration, sequence of mapping and the map scale. Also pick your mapping team and determine each individual's responsibility. Use these people wisely and effectively and bring only necessary persons. Too many people lead to inefficiency.

3. Do not divide your energies by attempting to photograph the cave while you survey unless you only have this one opportunity to visit the cave. It is better to have a separate trip to the cave or have another team in the cave to accomplish these other projects such as photography.

4. Make certain you have all the proper equipment for the survey: compass, tape, pencil (plus a back-up), notebook, protractor/scale, and eraser.

5. Dress appropriately for the cave and remember that you will cool down during the relatively slow survey. Bring high-energy food along to keep up your energy level and improve team morale.

The Survey

1. The chief should indicate in the notes the name of the cave, location, date, scale of the map, north arrow, the kind and serial number of the compass that is used, the type of tape and any problems with it (short a foot, etc.), and the full names of all members of the surveying team and each person's responsibility. Include the declination setting for the compass if used.

2. Start the survey from the entrance drip line, or from the back of the cave and mark the initial survey point with fluorescent flagging (in a non-permanent manner), with a pile of rocks, or just choose some easily identifiable feature that can be relocated if necessary. Label and mark the initial station point on the paper.

3. The front or lead taper should then proceed into the cave or along the cave passage with the lead end of the tape (leaving the tape's zero point at the first station) to pick out the second survey station. This station should be picked so that the initial station is in a straight line with it and can easily be seen from it, and that a third station likewise can be easily made on the next leg of the survey. Be careful to place the station in an appropriate and easily accessible place. Keep in mind how the compass is used, that it must be on or above the survey station.

4. Next, the tape is pulled tight from the non-zero end so that the distance between the two stations is determined to the nearest 1/10 of a foot or to the nearest centimeter. Make certain the tape is straight and not draped over formations or around corners. The distance is then called out to the chief who should repeat it and record it in the notes after verification. (The chief should always call the distance back to the front taper for a double check.)

5. The tape is then laid on the floor (unless the distance is very short) and used as a reference for sketching the details of the passage. Make certain that the face side of the tape is up and readable.

6. The instrument person occupies the initial station and takes a bearing or azimuth on the lead tape who holds a carbide light, flashlight, or other light source on the survey station. This reading should be taken to the nearest 1/2 degree. A backsight should also be taken to ensure accuracy in this reading. Then, the compass readings, similar to the distance, is called out to the chief, who again repeats the reading back to the instrument person for verification and then records both the frontsight and the backsight in the notes.

7. The instrument person then determines the vertical angle between the two stations. The reading should be taken either directly from source station to the target station or from a point above the source station to a point at an equal height above the target station for a true vertical reading. The instrument person and front taper should pre-determine how to make this reading. The instrument person then calls the reading to the chief, who repeats it for confirmation before recording it.

8. The chief plots the azimuth or bearing on graph paper in the notebook and scales the distance (see above for the use of the protractor to plot the azimuth or bearing), labelling the two ends of the line as stations 0 and 1. this is drawn in reference to the grid lines of the notebook paper because the north direction should be parallel to one set of these lines. North is usually chosen on the page so that the long axis of the cave is drawn on the long axis of the notebook. This allows more of the cave to be drawn on the paper before changing map sheets.

9. The chief sketches in the passage walls by measuring distances left and right as well as passage heights from the survey tape as it lies on the floor. These measurements can be determined either by estimating or directly measuring with the hand tape wherever necessary or where the passage widths change. Generally, all passage features should be sketched by referring them to a standard level through the cave. A convenient level to use is the approximate waist level of the chief.

10. Once the cave walls have been drawn, the chief begins sketching in the detailed cave features on the paper, placing them in the correct position by distance estimate and actual measurements. These features are represented by map symbols and drawn as near to the scaled size and shape as possible, so as to present a diagrammatic/pictorial view of the cave passage. Cross sections are added as necessary to clarify the map. Make certain that passage heights, depths, drop-off distances, etc., are added to the map as the mapping progresses. Too many dimensions are far better than not enough as they may help clear up any confusion as the final map is being drawn. If a feature cannot be drawn on the map with a symbol, make notes to clarify the feature, or draw a sketch of it.

11. When the chief reaches station 1, the procedure starts over again. The tape is drawn up and brought

forward so that the rear tape holds the zero end of the tape on the new station and the front tape proceeds to station 2.

12. After the survey data for this new survey shot have been determined, called back, and checked the chief plots them in the notes and checks to be certain that the angle turned from station 0-1 to station 1-2 is relatively correct by comparing the sketched angles with the actual cave passage. This is a good way to catch surveying errors and prevent later drafting problems. Remember to take backsights on all shots.

13. If the chief finds it necessary and valuable, a longitudinal section can be sketched as the survey proceeds. This is the best time to do this, as the passage details can be observed and sketched simultaneously on the map and section.

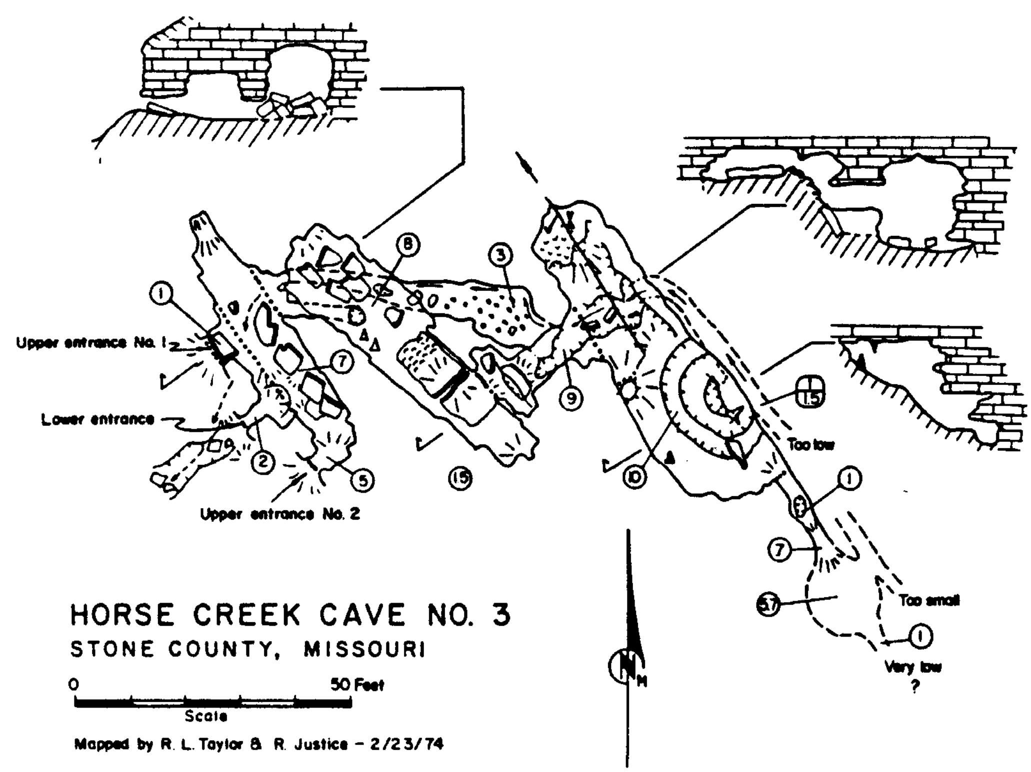
14. If the survey has not been completed by the time the survey crew has to leave the cave, the final survey station of the day should be marked in such a manner that, upon return to the cave, the station can be recovered and mapping continued. Make certain that this mark cannot be removed by floods or animals and that it is easy to find later (see station numbers and markers earlier in this chapter). Oftentimes, it is best to choose some prominent feature to make your final survey station on so that if something does happen to your mark, the station can be easily relocated.

15. In the case of an incomplete survey, if possible, the original mapping crew should be the one to complete the survey. This will enable the same chief to sketch all the cave details to be consistent. Subsequent additions to the cave map should be through this chief's direction.

16. Before leaving the cave, recheck the map to see if it is understandable. It is far easier to correct or clarify the problems while the cave is available than later when you are home and have forgotten many of the details.

Back at Home

At home after completion of the day's work, draft up or lay out the completed map as a rough draft of the cave. Do this as soon as possible after returning from the cave. Naturally, before commiting a large sheet of paper and your time to a rough draft, you should have a fairly good idea of where the cave goes. If not, the cave may run a different direction at some point than you are prepared for and the plotted passage may run off of the sheet.



8

PROBLEMS IN SURVEYING HORIZONTAL CAVE PASSAGES

Horizontal cave passages come in many sizes, shapes, and types, each with its own particular problems for the surveyor that need to be taken into account in order to create accurate and useful maps of various types of cave passages. Some of these problems include those encountered when surveying large rooms or trunk passages, choosing survey stations, taking accurate bearings or azimuths and staying relatively comfortable while surveying.

TRUNK PASSAGES

Surveying in large trunk passages may not seem to be a problem, but their very size can pose several difficulties. Passages may be so large that one side cannot be seen from the other or large piles of breakdown may obscure parts of the passage. Lakes and rivers may occupy parts of the passage floor making access to portions of the passage difficult or even impossible. Ceilings may be very high and difficult to measure.

Survey Stations should be selected so as to set up a framework from which an accurate cave map may be created. In a large passage, the survey framework can be established as a zig-zag pattern from one wall to the other and then back again in order to place the exact location of the cave walls (fig. 8-1). Another method, known as a center-line survey, is the placing of survey stations down the center of the passage. Each of the survey stations can become a control point from which side shots can be taken to directly measure some cave feature or from which triangulation may be done to locate some feature. Triangulation requires two carefully located survey stations, but from these many sites may be located. The authors recommend the second of these techniques, the center-line survey, so as to preserve in the survey the true length of the cave. As survey stations are placed in the trunk passage, remember to place them so that side passage surveys may be readily tied to them and the cave survey framework.

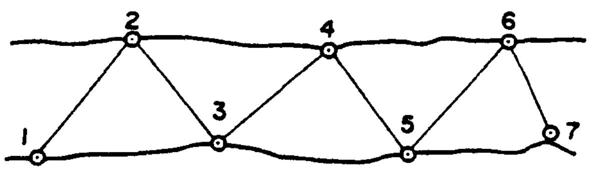


Figure 8-1. Surveying large trunk passage by traversing from side to side.

Trunk Passages may have high ceilings, the heights of which should ideally be determined by direct measurement rather than estimation, this may be achieved by using helium filled balloons, or by the used of vertical angles and trigonometry, and two established survey stations. It is very difficult to estimate high passage heights beyond 25 or 30 feet with any degree of accuracy.

The location and extent of bodies of water should be accurately determined by using direct measurement or triangulation. Water depths should be measured wherever possible. It may be necessary to use a weighted line in order to measure some deep pools. Water will often pose access problems as some areas in the passage may be on the other side of deep or swift water bodies where it is impossible to measure them directly. Here triangulation may be the only method for locating cave details.

Breakdown piles should be carefully surveyed and the boulders represented diagrammatically. Heights of the passage over the breakdown should be determined and the total extent of the break-down pile measured.

Large trunk passages can also be quite complex, for example, several cave levels can intersect at one area in the passage making the surveying and sketching more difficult than is found with single-level passages. It is important to treat these complex areas as you would any problem, step by step. Sketch small areas one at a time and then put the total picture together later. If there are several levels, treat each one separately and put in as much detail as possible. Be sure as you map each level that you tie them together with the main trunk survey line.

It is tempting in large trunk passage surveys to map rapidly and not put in much detail because it is easy to traverse. This is a big mistake. Detail in trunk passages is as important as it is in any cave passage. Side passages may be missed during too-rapid and careless mapping and the cave map loses some of its value because of lack of sketch detail. It is far easier to eliminate superfluous data later than it is to try to construct a map from inadequate data.

NARROW CANYON PASSAGES

Narrow canyon passages can create some interesting problems. Except for the necessity of placing survey stations on walls, the locating of stations is not a problem, but the large number of stations can be. Narrow canyon passages often meander just enough that every leg of the traverse is short making it necessary to shoot and plot many survey stations. Increasing the number of survey shots increases the number of possible errors in the instrument readings, so take extra care in placing and reading from the survey stations. In some places it can be nearly impossible to occupy the survey station. In this case, you may use only the backsight, since, hopefully, one of the stations will be easier to sight from than the other. In addition to the horizontal meanders, there may be overhead meanders and underlying passage loops. These additions make mapping quite complicated and difficult. If meanders are larger at the bottom of the canyon, then the best place to run the survey is probably at the bottom--but always remember the overhead detail. It might even be necessary in some cases to survey the upper part of the canyon separately and tie it to the lower part through interconnecting survey stations to show the detail. In some caves, the bottom of the canyon may be too narrow to walk in so one may have to do all of the surveying from a higher level in it. In canyons like this, be careful not to drop anything into the canyon bottom where it cannot be recovered. All surveying equipment should be attached in some way to a member of the survey party so that it won't get lost.

WIDE-LOW PASSAGES

In surveying very wide and low passages there are two major problems--reading the instruments and sketching the passageway. In surveying this type of passage, you have to use surveying methods which can be done lying down. Taking bearings in this type of passage is not too difficult when using most compasses. The Suunto lends itself quite well to this type of survey. The Brunton and Silva Compasses can be read in reverse, using the mirror. The major problem may be sketching. This can be done either right after leaving the wide-low passage if is short, or it can be done in place. This is where the type of survey book and your experience can make the survey a success. It is often quite difficult to estimate passage widths in wide-low areas. In areas where the sides of the passage may be mud-filled, it may be difficult or impossible to determine where the passage wall actually is. Special symbols are used to indicate some of these areas (See appendix I). Some areas may have to be mapped using triangulation and estimation because they are too low to actually enter and explore, let alone survey. With good lights you can see back into these areas in order to estimate their extent and to sketch their character. In areas of wide-low passages that you can explore and survey, it pays to check all the surrounding areas for evidence of low leads that should be mapped, since they can be easily missed.

NARROW-LOW PASSAGES

These passages often create the greatest difficulty in reading the survey instruments and making the sketch because of the confinement of the surveyor. It may be very difficult to illuminate the compass and still see ahead. However, in some cases, the confinement of the passage will let the reflected light of the headlamp of the surveyor light up the area so that the compass can be read without direct illumination. There is also the problem of seeing the target station or of placing a light on the target station so that one can shoot to it. Because of the tight nature of the passage, the front taper may not be able to turn around to place a light on the target. It may be possible to attach the tape to the front taper's foot and use that for the target. If the instrument readings can be obtained this way, the next step is to sketch the passage. This may also be difficult. A possible strategy to use in this situation is to have the chief remain outside of the tight passage to record and plot the information given by the surveyor and the front taper and then, crawl into the passage so that the detail can be sketched onto the survey framework.

BREAKDOWN PILES

Here the main difficulty is in illustrating the breakdown. If at all possible, try to portray the breakdown on the cave map in a diagrammatic, but relatively accurate manner. Attempt to illustrate many of the large boulders as close to scale and shape as possible. Remember that the goal of a good mapper is to make it possible to recognize all areas of the cave by using the map as a guide.

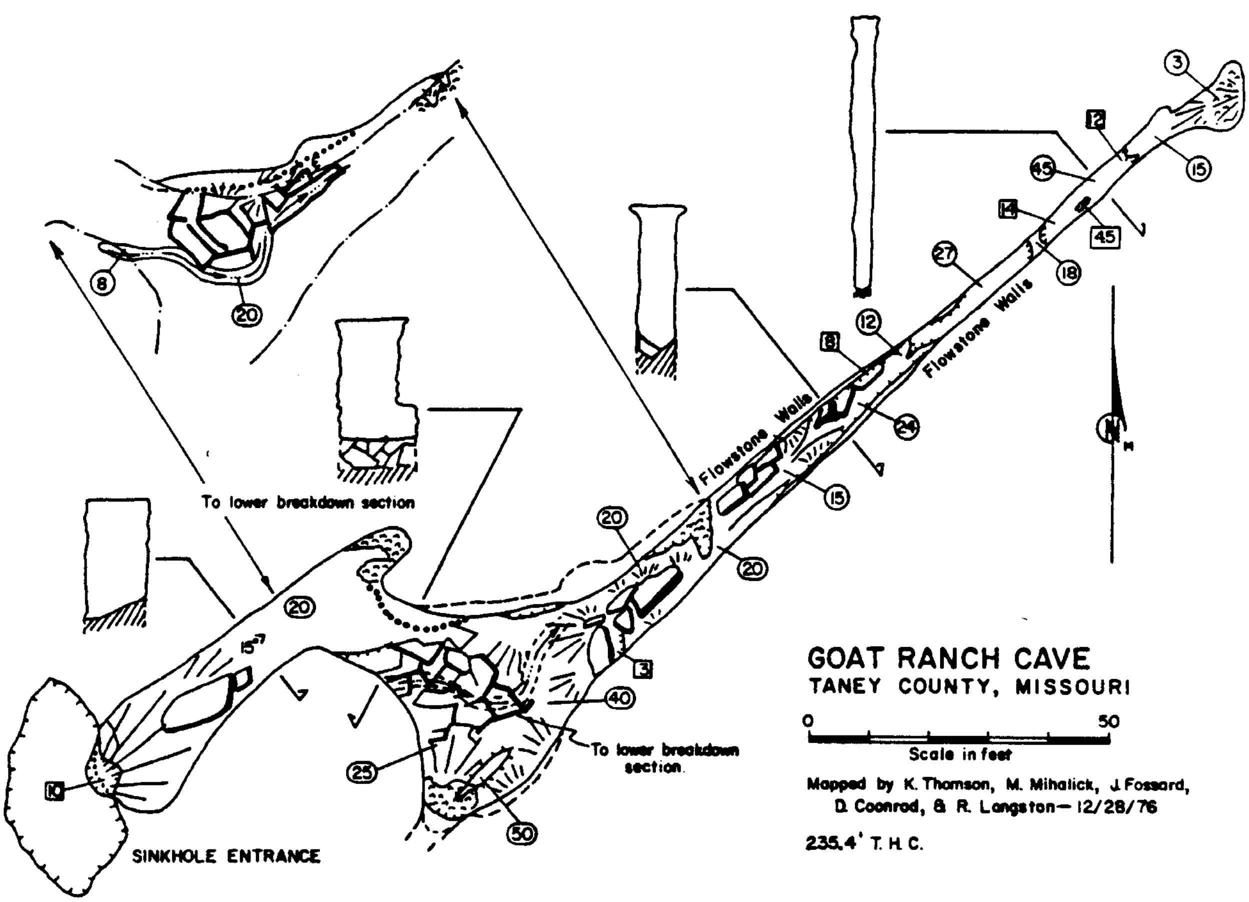
WATER-FILLED PASSAGES

There are two types of water-filled passages: totally water-filled and partially water-filled. Totally water-filled passages should be indicated as such on the map (see chapter 15). Skillful cave divers might be able to extend the cave survey, but your survey will necessarily stop at that point. In partially water-filled passages, you can continue the survey if you keep some points in mind. First, surveying in water can lead to hypothermia, so dress warmly and, if possible, use a wet suit. The survey can even be carried out when necessary by taking bearings or azimuths on the reflection of the light of the target station on the water, if necessary. In some passages where there is deep water, it is best to survey along one side of the passage or the other where the shallowest part of the water is; otherwise it can become very difficult to take bearings or azimuths while trying to swim at the same time. Frosted plastic sheets (mylar) probably should be used for note taking in the water area as they will not be ruined when wet. A 2B pencil will also work quite well on the sheets and generally won't rub off even when immersed.

MUDDY PASSAGES

Very muddy passages create special difficulties, especially with equipment. A muddy survey tape presents two problems: it is difficult to reel in, and the numbers may be covered with mud when you try to read distances. A solution to the first problem is to never roll up the tape when surveying. However, this solution can lead to the second problem with the tape becoming even more covered with mud. The tape can be cleaned a bit by holding it between the thumb and forefinger to rub off some of the mud as it is rolled up. It is best to have the lead taper clean the tape off so that the instrument person and the chief can keep their hands as clean as possible. Also, if water is available, wash the tape off now and then to make readings easier.

In mud-filled passages it is impossible to keep clean. Wear gloves to keep your hands clean if you have to sketch or handle surveying instruments. Make sure that the kind you wear can be easily removed and replaced. If not, your hands will get dirty just taking the gloves off and putting them on, and the purpose of the gloves will be partially defeated. A cloth carried on the inside of your coveralls can also be used to wipe your hands. Mud can ruin surveying instruments, so never handle them with muddy hands. Probably the worst problem is getting your notes muddy and obscuring drawings and notes. Messy notes are difficult or impossible to plot and create a clear cave image. Watch out for muddy shirt or jacket sleeves as they can transfer mud to one part of the sketch while you are working on other areas.



9

ERRORS IN CAVE SURVEYING

In a survey, measurements are never exact and no matter how careful the surveyor is, errors will always arise. It is important that the cave surveyor understand the different kinds of errors, as well as their sources and expected magnitudes under various conditions. Then he/she can choose instruments and methods that will minimize these errors.

Understanding the magnitude of the errors in their measurements is important so that these may be corrected, new measurements taken, or errors accounted for in calculations. Formulae and computer programs have been designed to distribute errors after the measurents have been made and corrections applied to the raw data.

TYPES AND SOURCES OF ERRORS

Measurement errors come from three major sources:

1. **Natural Errors** - these can be caused by variation in wind, temperature, humidity, refraction, gravity, and magnetic declination. In the cave environment, most of these can be minimal since temperature and humidity are constant, leaving only variations in gravity, refraction and magnetic declination to give this type of error.

2. **Instrumental Errors** - These result from imperfections in the construction of instruments and from the movement of individual instrument parts. Such things as sticking compass needles and imperfect scales fit into this category. Some of these errors can be eliminated by careful surveying techniques.

3. **Personal Errors** - These come mainly from personal limitations of sight and touch. These include the small errors caused by sighting one side

of a target light rather than its center in a compass sight. Many of these errors can be eliminated by careful and consistent techniques.

ERRORS IN MEASUREMENTS

A true error in a measurement is the difference between the measured value for a quantity and its true value. Mathematically the true error e_i of a measured value x_i is:

$$e_i = x_i - x^t \quad \text{where } x^t \text{ is the true value of the measurement.}$$

Brinker and Wolf (1989) state unconditionally that (1) no measurement is exact, (2) every measurement contains errors, (3) the true value of a measurement is never known and (4) the exact error present is always unknown.

The amount of error can be estimated by comparing the measured value with another measured value done by using a more accurate instrument. Here the estimate v_i of the true error e can be computed from $v_i = x - x'$ where x' is the second measurements. Again, the estimate will depend on how close x' is to x^t.

Errors in surveying measurements can be classified into three types: (1) blunders or mistakes, (2) systematic errors, and (3) random errors.

BLUNDERS OR MISTAKES

Blunders are generally caused by a misunderstanding of the problem, fatigue, haste, carelessness, or poor judgement. A blunder can be either positive or negative and can have any magnitude. Its occurrence is totally unpredictable. Careful surveying techniques and systematic checking of all work and even resurveying some segments can eliminate most blunders. Wefer (1987, 1988) wrote an extensive treatise on blunders, where they can occur and how they might be obviated. Small mistakes are very difficult to detect and should be treated in the same way as errors are (see below).

SYSTEMATIC AND RANDOM ERRORS

There are two types of errors - systematic and random. The systematic errors, known as cumulative errors, are those which conform to mathematical and physical laws. These are mainly caused by some maladjustment of the surveying instruments and personal bias or inclination of the surveyor as well as the natural environment. The amount of error may be constant or variable depending on the conditions. Most of these can be computed and their effect eliminated by applying corrections. An example is a surveying tape that is either too long or too short. This gives an error that will occur in every measurement and which can be easily eliminated mathematically from each measurement. Another example is a defective compass. This can be determined by comparing it with another instrument. This is known as calibrating the instrument.

Random or accidental errors are those that remain after systematic errors and mistakes or blunders have been eliminated. These errors are beyond the control of the surveyor and obey the laws of probability. They occur in all surveying no matter how precise. Through statistical analysis these may be estimated and eliminated to some degree although there is no absolute way to compute or remove them. For a more extensive treatment of random errors, the reader is referred to Brinker and Wolf (1989), Moffat and Bouchard (1988) or any other recent surveying textbook.

In all cave surveys, the members of the surveying team should always make an effort to minimize errors and mistakes by using good consistent surveying practices. Mistakes can only be corrected if they are recognized. There are two ways to do this: (1) make several measurements of the same quantity and compare the results, and (2) make a common sense estimate of the quantity and compare with the measured value.

PRECISION AND ACCURACY

Several definitions need to be introduced here. A **discrepancy** is the difference between two measured values of the same quantity. A small discrepancy indicates that there are no mistakes and that the random errors are small. Systematic errors may still be present. **Precision** is the consistency or repeatability of a series of measurements of the same quantity. Small discrepancy values will indicate a high degree of precision. Generally this is dependent on the equipment being used. **Accuracy** is the nearness of the measured value to the true value. Precision and accuracy should not be confused. An example of precision with poor accuracy is to measure a distance 10 times with a tape that is 1 foot short. The ten measurements may be very close which would be considered to be very precise, but the distance is still a foot short which is not an accurate measure of the distance. Hence a survey can be very precise without being accurate. Generally accuracy of measurement depends on three major factors: (1) scale division size, (2) reliability of the equipment being used, and (3) human limitations in interpolation closer than about one tenth of a scale division. As better equipment is developed, measurements will more closely approach the true value.

ACCURACY OF CAVE SURVEYS

While it is impossible to tell exactly how accurate a map is, the user of a cave map should have an idea of accuracy gained from a knowledge of the method used to survey the cave. Each method requires specific surveying instruments, each of which has its own degree of accuracy.

SKETCH MAPS

A sketch map give a sketch of the cave layout. Distances and directions are estimated and few or no measurements are taken. The details are drawn mainly from memory. The map is made either while visiting the cave or shortly after the visit to make a report. A sketch map is valuable for planning the eventual, more careful survey of the cave as well as for visually describing the cave layout. Accuracy of this type of map is low.

COMPASS-PACE MAPS

A compass-pace map is made by measuring the general trend of the cave passages with a compass and then measuring the distances by pacing. The surveyor's pace should be known (see Chapter 3). This method can be used in short caves and for adding some details in larger caves. A variation of the method is to use body lengths in crawlway passages. Compass-pace maps are more accurate than sketch maps, but not as accurate as a compass-tape survey.

COMPASS-TAPE MAPS

This is the most widely used surveying method for caves. Its accuracy is dependent on the compass, the tape and the surveyors. Careful attention to surveying methods can make the method quite accurate.

PLANE TABLE/ALIDADE-STADIA MAPS

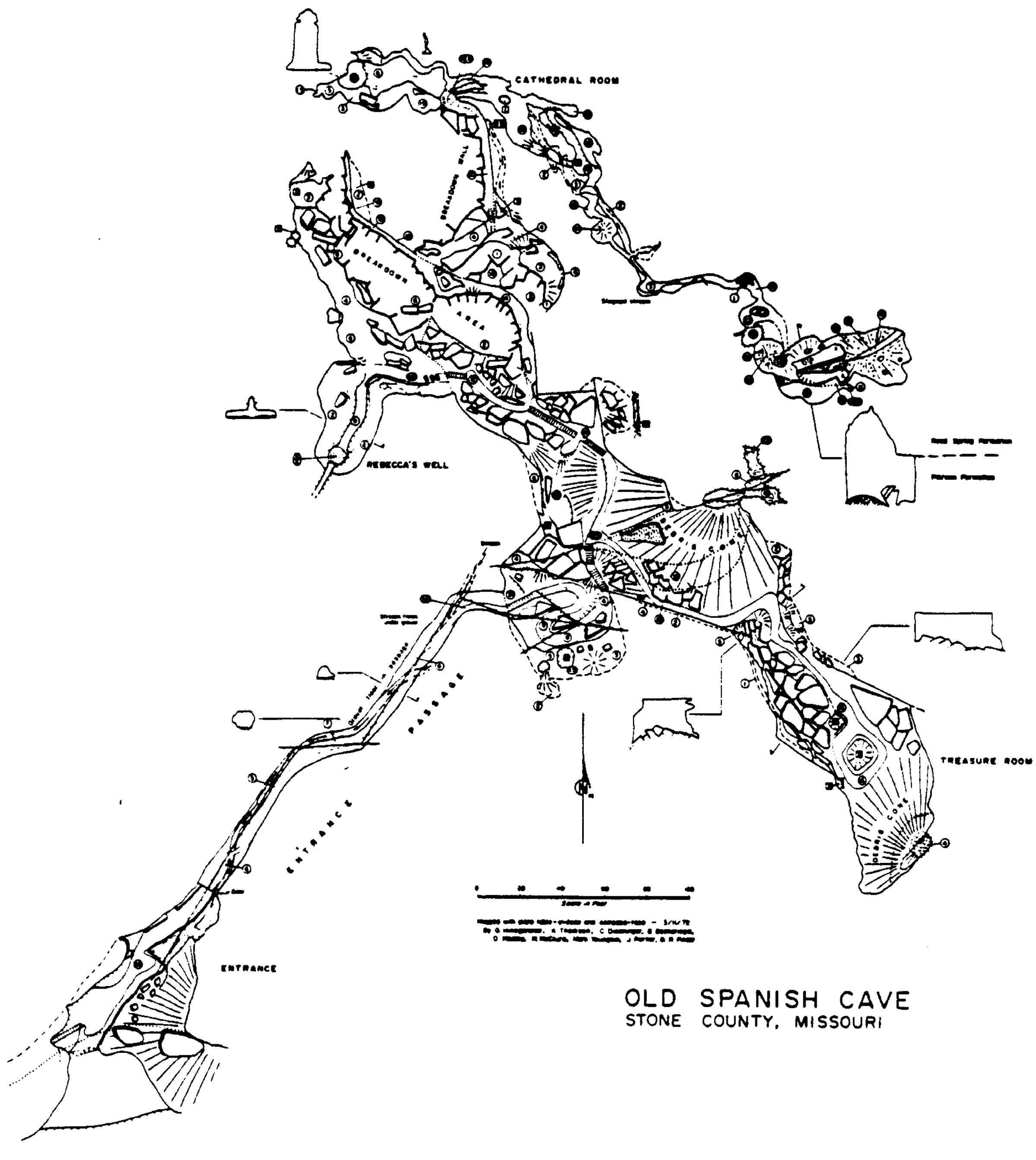
A moveable transit called an alidade is used on a portable drafting table (plane table), and a map is drawn on a sheet of paper that is attached to the plane table board. The plane table is oriented in space with a compass, and the directions are transferred directly to the table with the alidade. Distances are measured using a stadia board. The method is quite accurate. A thorough discussion of the method is found in Chapter 12. Use of this method is generally restricted to surface surveys and very large cave passages.

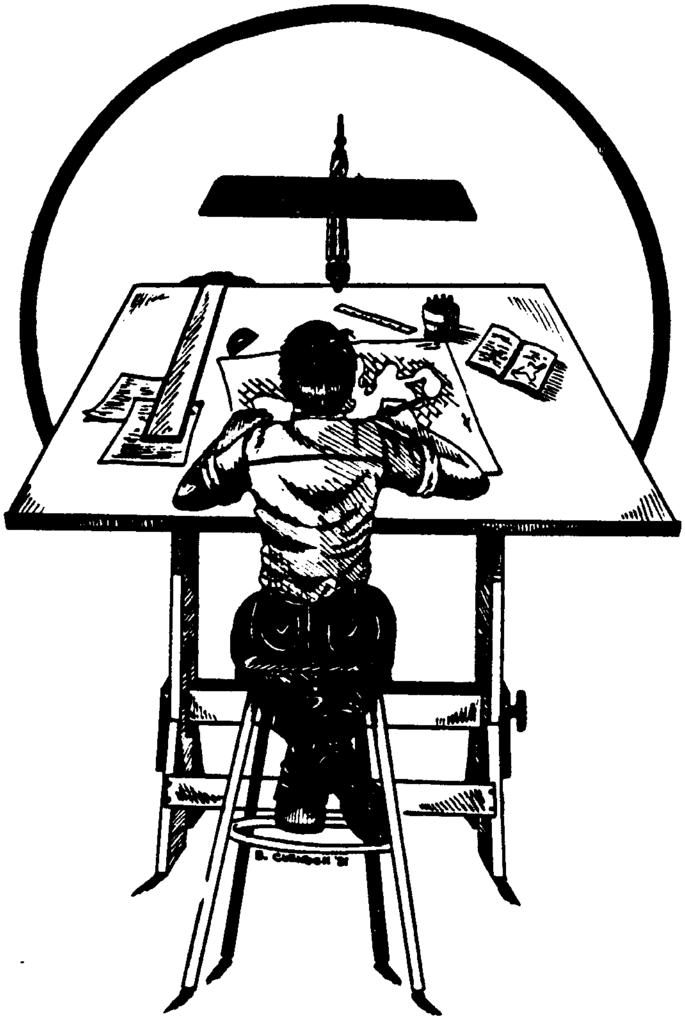
TRANSIT-STADIA MAPS

The transit provides a great deal of accuracy in measuring horizontal and vertical angles without having to rely on an external orientation. Each direction measurement is related to the previous line of sight, and the compass readings can be used to orient the entire map later. Distances are determined through the use of the stadia board (Chapter 3). The accuracy is very high, but the equipment is very bulky and difficult to use in the cave environment. A discussion of this method can be found in Chapter 12 with the Plane Table/Stadia and the Transit/Theodolite discussion.

TRANSIT-TAPE OR THEODOLITE-EDM MAPS

These, the most exacting and accurate of the surveying methods, are independent of external orientation. The distances are measured with a very accurate steel tape or electronic distance measuring device. While the accuracy is excellent, the equipment is too bulky and expensive for much use in caves. See chapter 12 for a discussion of transit and theodolite methods.


CATHEDRAL ROOM
BREAKDOWN
AREA
REBECCA'S WELL
ENTRANCE PASSAGE
TREASURE ROOM
ENTRANCE
OLD SPANISH CAVE
STONE COUNTY, MISSOURI



10

DRAWING THE CAVE MAP

The basic survey data of direction and distance, along with the sketch map incorporating them and the details of the cave passages, are worthless unless compiled and neatly presented as a final cave map.

The numerical data of passage direction and length, as well as passage heights and widths, drop off depths, etc., and the sketch map made while surveying the cave, make possible the drawing of the first (rough) draft of the cave map. The team chief should draw up the first draft since he/she did the original in-cave sketch and can probably do the most accurate presentation of the data. Since the first draft of the cave map is done carefully in pencil, corrections and changes can be easily made to get a correct final picture of the cave prior to making a clean, inked version. A rough draft, if properly made, will make the final draft of the map in ink a simple tracing process.

DRAFTING EQUIPMENT

Several items of equipment are necessary to draw up the first draft of the cave map and the final inked copy. These include all or some subset of the following:

1. Drafting Surface
2. T-Square
3. Scales
4. Triangles
5. Curves
6. Templates
7. Protractor
8. Pencils
9. Erasers
10. Erasing shield
11. Pens
12. Drafting Set
13. Lettering Set
14. Proportional Dividers
15. Scissors
16. Cutting knives

DRAFTING SURFACES

Several types of drafting surfaces are available to support the cave map as it is being drawn. Any drafting surface must be smooth, free from scratches or dents and large enough to hold the map. Drafting or drawing boards are available from any drawing supply store in sizes up to 36 X 42 inches. These can be used for most small cave maps and are easily stored away where they can be protected from dents and scratches. If the cave map is larger, it is necessary to have a larger drawing surface. Tables, such as the kitchen table have been used, but the problem of nicks and splits in the table make it difficult to work on a cave map effectively. If you plan to work on larger cave maps and want an effective drawing surface, you should consider a drawing table. These can be purchased from drawing supply companies or they can be constructed at home by the cave surveyor. A very effective drawing table can be made from either a smooth door (preferably solid rather than hollow core) or a 3/4 inch piece of plywood large enough (4 foot X 8 foot) to make a good surface. A support framework can be built from 2" X 4" stock. The drawing surface of the plywood or door can be improved by covering it with a vinyl drafting surface which can be obtained from a drawing supply store.

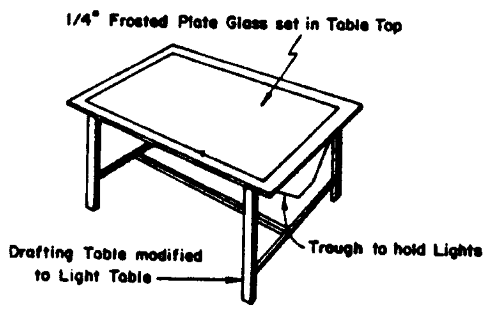


Figure 10-1. Homemade light table created from small drafting table.

A light table (glass top table with a light source) is very helpful for tracing maps. Commercial models are available in several surface sizes up to 36" X 48". A light table can be built from a small drafting table by cutting a 2 foot by 3 foot opening in the surface. Small slats can be nailed inside the opening to support a 36" X 24" piece of 1/4 inch double strength frosted glass. A fluorescent light fixture is then mounted below the glass to provide the light source (figure 10-1).

T-SQUARES AND RELATED DEVICES

The basic instrument for keeping alignment in drawings is the T-Square (figure 10-2). This is a T-shaped instrument with an arm from 24 to 36 inches long. The short side of the instrument is held against the left edge of the drawing surface keeping the arm in horizontal alignment (for left handed persons this is held on the right edge of the drawing board). Thus horizontal lines can be drawn by moving the T-square up and down using the left hand. Vertical lines can be drawn by using triangles held against the T-square. The T-square should never be used in a vertical manner by placing the T part of the square against the top of the drafting surface because there is no guaranty that the surface is square.

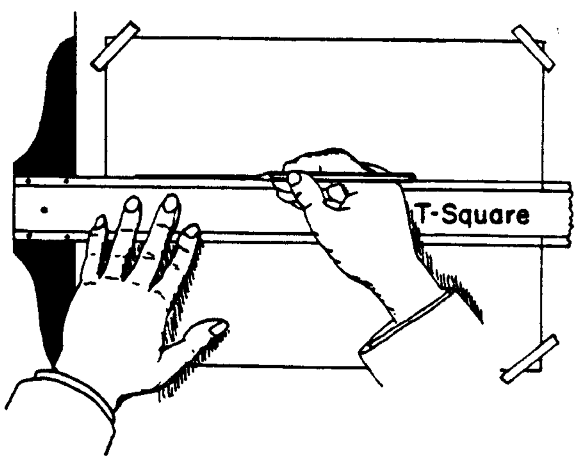


Figure 10-2. The T-square and its use.

A related device is the parallel arm board. Here a straight edge is connected to the drawing surface by means of cables on both sides of the board. These cables keep the parallel arm in a perfectly parallel alignment from the bottom to the top of the board. Again horizontal lines are easily drawn and vertical lines are drawn using triangles held against the straight edge.

A drafting machine attached to the drawing surface is the most versatile of the related devices. The drafting machine comes in two styles: Elbow-

Type or Track-Type. Both styles provide a method of drawing both horizontal lines and vertical lines on the drawing surface. In addition, the drafting machine can be set to any angle and locked into position and lines drawn at the preset angle. The drafting machine can save considerable time in plotting and drafting cave maps.

SCALES

A scale is used to measure distances on the map in proportion to the actual distance in the cave. The most commonly used scale for drawing cave maps is the Engineer's Scale. This 12 1/2 inch long triangular bar is marked of in 10, 20, 30, 40, 50, and 60 units per inch, with two scales to a side (figure 10-3). Similar scales are available in metric divisions. The scale can be used in two different ways: first, it can be used directly to scale the distances on the drawing; and second, a set of dividers can be used with the scale by extending them to the desired length and then transferring that length to the map (figure 10-4). The second method is the most accurate.

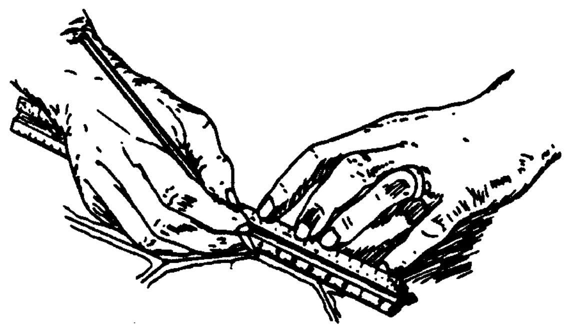


Figure 10-3. Use of the scale to determine distance on a map.

TRIANGLES

Triangles greatly facilitate drawing procedures. In connection with T-Squares or Parallel Bars, they can be used to draw vertical lines. They are useful for drawing all types of straight lines on the map from leaders to section lines. Two types are generally available: 30-60 degree and 45-degree (figure 10-5). These two types make it possible to draw lines singly at 0, 30, 45, 60 and 90 degree angles. Used together they can provide additional angles of 15 and 75 degrees. It is wise to have triangles of assorted sizes available.

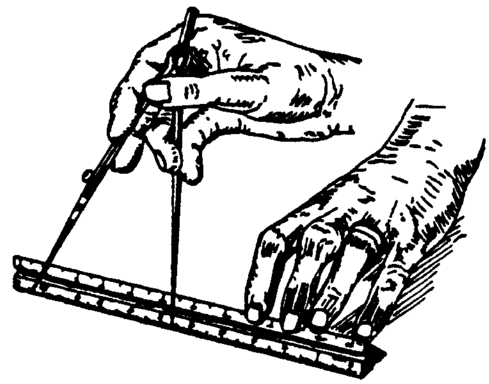


Figure 10-4. Use of scale and dividers to determine distances on a map.

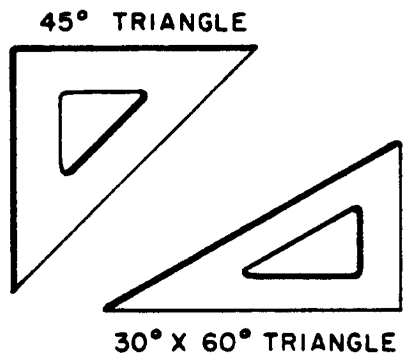


Figure 10-5. Types of triangle used in cave map drafting.

Figure 10-6. Use of curve in drawing maps.

CURVES

French curves (figure 10-6) are useful in drawing smooth curved lines on the map. These can also be used to connect several known points on a map with a smooth curve. Several shapes and sizes should be available for drawing smooth curved lines on the cave map.

TEMPLATES

A template is a plastic sheet that has been stamped or molded with standard symbols or common configurations which makes it possible to precisely draw the shapes. Common templates include circles, ellipses, squares, and triangles. The circle and ellipse templates can be used for passage heights. Triangle and square templates can be used respectively for survey stations and drop off depths.

PROTRACTORS

A protractor (figure 10-7) is a circular or semicircular plastic sheet which divides a circle into degree graduations relative to a center. They are used to lay off angles in the cave survey. Both full circle and half circle drafting protractors are available. These are more accurate than the ones used in the cave survey and can be used to plot the framework on which the map is drafted.

Protractors are available for measuring in either mils or gons (grads), if measurements are done using these systems of measurement.

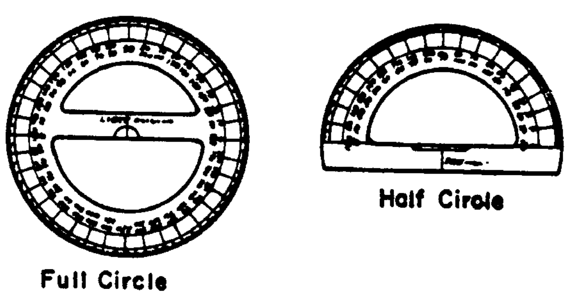


Figure 10-7. Protractors used for cave map drawing.

PENCILS

Pencils are drawing tools made of a holding material such as wood which encloses a lead, made from finely powdered graphite mixed with clay. The more clay, the harder the pencil lead. Hardness of pencil leads is graded from 9H (hardest) through HB (medium) to 6B (softest). Hard leads mark into the paper and their marks are difficult to erase. These work quite well for field pencils where the lead might smear. The softer pencils are best to use on pencil drafts since the marks can be erased fairly easily. For the best results when using softer lead keep the point sharp. Various types of pencil sharpeners are available to keep the pencil points sharp. The points can also be kept sharp using a pencil pointer with an abrasive surface (figure 10-8) or by using emery-board nail files which are cheap and very good for the purpose. Several types of mechanical pencils are available which hold leads of various hardnesses. A recent innovation is the pencil which holds leads of 0.3, 0.5, and 0.7 mm diameter. A soft lead is best used in these pencils because of the thin diameter of the lead.

Figure 10-8. Use of sandpaper block to sharpen pencil for drafting maps.

ERASERS

Soft erasers are the best kind to use for correcting and making changes in all drawings. The hard erasers have an abrasive in them that can spoil the surface of the drawing media, a surface made to take ink without spreading. An electric eraser with the pink pearl eraser can even take out ink lines with a little care (figure 10-9). An erasing shield is indispensable when using an electric eraser so that only the area needed to be removed is erased. A draftsman's dusting brush is also quite valuable for removing the eraser shavings from the drawing surface.

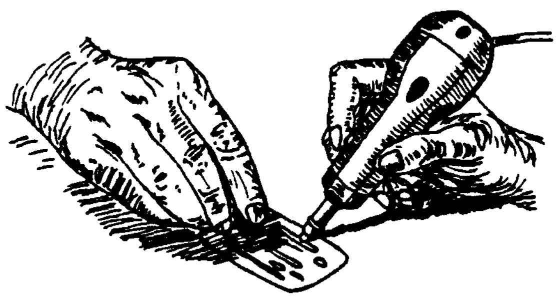


Figure 10-9. The electric eraser and its use with the erasing shield.

PENS

Several types of pen are available for use with india ink. Pens have been designed for specific purposes such as lettering, drawing fine lines, drawing border lines, etc.

Ruling Pens

A ruling pen (figure 10-10) is designed for inking straight lines and non-circular curves. These come in several styles, but all of them have two metal blades attached at one end with an adjustable screw to vary the distance between the blades. A drop of ink is placed between the blades and the width of the line drawn can be adjusted by varying the distance between the blades. Care must be taken to place only about 3/16 to 1/4 inch of ink between the blades. Too much ink will cause a blob at the beginning of the line or the ink will drip out of the pen. A ruling pen is always used in connection with a guiding edge such as a T-square or triangle. The pen should be held carefully in the finger tips as shown in figure 10-11. It should then be held against the straight edge with the blades parallel to it, the screw being on the outside and the pen inclined slightly to the right and always kept in a plane passing through the line and perpendicular to the paper. Deviations from this method will produce lines which are ragged on one side or the ink may even run under the straight edge making a blot. Be sure to use a light touch. Pushing the pen too tightly against the straight edge will produce lines that are thinner than the one needed.

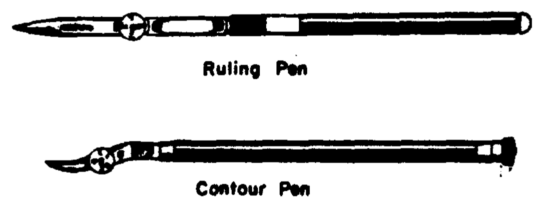


Figure 10-10. The ruling pen.

A long line drawn with a line pen should be done with a whole-arm movement. This will produce a consistent line. Short lines can be drawn with finger movements only. Always stop the line short of the end and finish with finger movements. Don't overshoot the line. If you do, you will have to erase it.

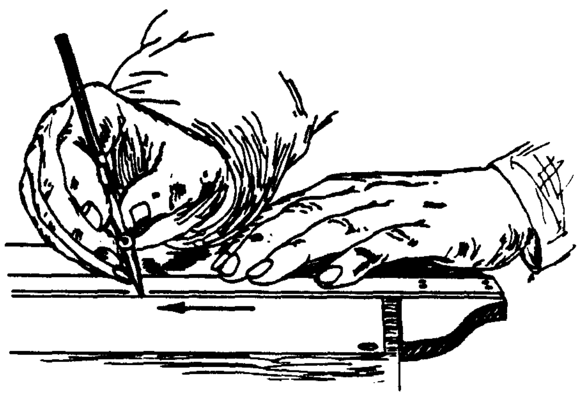


Figure 10-11. Use of the ruling pen to make lines.

If the ink refuses to flow through the points, pinch them together or try the pen on your finger. Make sure that the ink is flowing by trying it on a piece of scratch paper identical to the type you are drafting on, then proceed to draw the inked line.

Used appropriately the ruling pen will produce the best and most consistent straight line possible.

Several special types of ruling pen are available for use in special purposes. The contour pen is similar to the ruling pen except that the pen point is attached to a swiveling handle so that the pen can be used freehand to draw smooth curved lines (figure 10-10). The **border pen** has broader blades to hold more ink for drawing long straight lines. Generally this pen is used for thicker lines also. The **railroad or road pen** consists of two ruling pens attached to a common handle. These can be either fixed or attached to a swivel handle similar to the contour pen. This pen is used to make two lines that are parallel. In a map, this pen is used for drawing roads.

Lettering Pens

There are many types of lettering pens available. Pen Points are available in many styles and sizes to fit in a pen point staff. A crow quill pen is commonly used for drawing very fine lines and details on a map as well as for very small lettering. Larger pen points such as Gillotts, Ball Points, and Esterbrooks can be used for free hand lettering of relatively fine and medium letters. Larger lettering can be done with speedballs and other tank-type pens which have reservoirs of ink for wider lines. Specialty pens have also be used such as the Burch-Payzant and the Leroy which come in a variety of sizes. The Leroy pen is the predecessor to the modern reservoir or rapidograph pen and can be used in a pen staff or in a scriber for mechanical lettering. In all cases the draftsman should practice with the pen and develop his/her lettering skills.

Figure 10-12. The reservoir pen.

Reservoir Pens

The rapidograph or reservoir pen (figure 10-12) has become so successful that many copies of it (reservoir pens, rapidograph, and stadler pen) are currently on the market. Basically these types of pens have various sized tubular pen points (similar to the Leroy Pen) with a needle through the tube which both keeps the ink flowing and regulates the amount of ink that is delivered to the paper. In choosing a reservoir pen, it is best to choose the ones with all metal tips rather than the ones made of plastic. These all metal tips are designed to be used in a mechanical lettering scriber and hence the pen is more versatile.

Many people prefer this type of pen because the line widths are fixed and the pen is suitable for freehand and mechanical lettering and line work. The pen does require an occasional filling and a minimum of skill to use. To use this pen in the best manner, the pen should be used perpendicular to the paper.

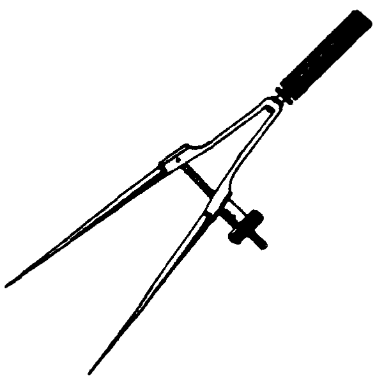


Figure 10-13. Dividers used for measuring distance on drawings.

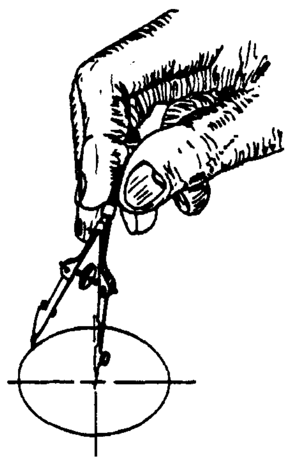


Figure 10-14. The compass and its use.

DRAWING INSTRUMENTS

Drawing instruments are either sold in sets housed in a velvet lined case or can be purchased individually. A set of drawing instruments includes one or more ruling pens, a compass, dividers, bow pencil, bow pen, bow dividers, and various auxiliary parts. Some sets include a large bow compass rather than the standard large compass. The dividers can be used to carefully transfer accurate distance measurements and for setting off a series of equal distances (figure 10-13). The compasses are used for drawing circles on the map (figure 10-14) and the ruling pens are used as discussed above. A good set of drawing instruments can be quite valuable in creating a good cave map.

LETTERING SET

Various lettering sets, manufactured under several names are available. One of the most commonly used is the K & E Leroy set (figure 10-15). The full set comes in a standard san serif style with lettering templates ranging in size from 80 (0.08 inches high) to 500 (0.5 inches high). The lettering can be italicized by inclining the scriber. Many different lettering guides are available which can be used for unusual lettering situations. Symbol templates are also available.

Lettering templates that are similar to stencils are available for use with rapidograph pens. Lettering can be done by tracing the template.

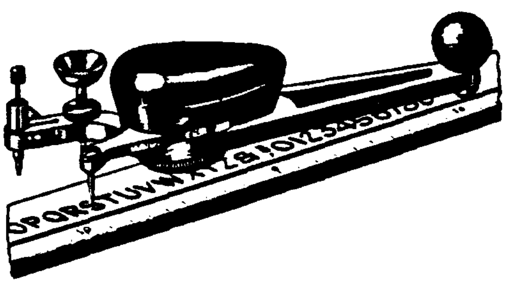


Figure 10-15. Leroy scriber used to ink lettering on maps.

PROPORTIONAL DIVIDERS

For enlarging or reducing a drawing, proportional dividers (figure 10-16), are convenient. The dividers can also be used for dividing distances into a number of equal parts or for obtaining a reduction of a distance.

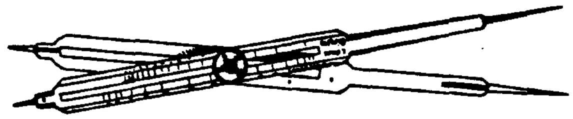


Figure 10-16. Proportional dividers.

SCISSORS AND KNIVES

Scissors should be available for cutting drawing media. The best scissors are those which have a long cutting edge and are designed for cutting paper. They should be kept sharp and able to make a clean cut in the media.

An exacto knife blade or a razor blade is an important addition to the drawing equipment. The blade can be used for cutting adhesive aids to be discussed below and for scraping ink from the drawing to correct a minor error. Extra, sharp blades should be kept available.

DRAWING SUPPLIES

DRAWING INK

The ink used in drawing the final cave map must give a solid black line. If the ink is watered down, the line will appear gray and will not reproduce well if one wishes to make copies of the map. Drawing ink is composed mainly of carbon in colloidal suspension, and gum. The fine particles of carbon give the deep, black luster to the ink and the gum or shellac makes it waterproof and quick to dry. Keep the ink bottle closed when not used as the ink will thicken due to evaporation. You can thin the ink with a few drops of a solution of aqua ammonia to one part of distilled water. It is wise to use a good grade of india ink such as koh-i-noor or Pelikan. Both of these are opaque and will hold true black on reproduction. A special ink is manufactured for use on mylar and other plastics which contains acid in the ink to make it adhere to the plastic better. However, it is corrosive to drawing instruments and they must be cleaned immediately after use.

DRAWING MEDIA

The drawing media used should be selected carefully to get the best possible results. The following qualities must be considered when choosing a drawing material, of either paper or plastic products.

1. **Dimensional Stability:** This is the ability of the paper to withstand changes in humidity and temperature without shrinking or expanding. This quality is particularly important in two situations: first, when the map must maintain absolute scale, and, second, when the drawing must fit or "register" with another drawing or overlay.

2. **Ink adherence:** This is the ability of the surface to "hold on to" the ink. Some surfaces are so porous that the ink sinks in and is held by the fiber when it dries. Other surfaces are so dense that the ink simply dries on the surface and may easily be chipped or rubbed off.

3. **Translucence:** This is the ability of the material to transmit light and image, which is important whenever you trace any map or drawing. Tracing is used in map making for compiling information and final drafting of the cave map from the rough layout. Tracing is used so much that translucence may be more important than other qualities mentioned here.

4. **Erasing Quality:** This is the amenability to making corrections or changes. This is most important for rough draft work where repeated changes are made. The material obviously must be tough.

5. **Strength:** Some drawings must withstand repeated rolling and unrolling as they require frequent revision. This happens when working on a large cave map where many additions and changes must frequently be made.

Many materials are available for cave map drawing. These can be divided into two major categories: Paper products and plastic materials. Of these materials, only those suitable for making cave maps will be discussed.

1. **Bond Paper:** This is good for making paste-up maps and small drawings which can be reproduced by photography or photocopying.

2. **Vellum:** This is the best paper for drawing. It reproduces well by diazo or photography, and has an excellent surface for drawing. It comes in varying transparencies and weights. A non-reproducing grid overprint can be obtained on vellum which can be quite useful for lettering and layouts.

3. **Mylar:** This is dimensionally stable, takes ink well, and cannot be torn. Its few disadvantages include the fact that ink will spread on it, so a smaller pen size should be used to compensate for the problem. Also, the mylar tends to wear out drawing instruments.

Most cave maps are drawn on either vellum or mylar because of the great flexibility in making reproductions of those materials.

DRAWING TAPE

Drawing tape is a paper tape with an adhesive that is used to fasten the map sheet to the drawing surface. Generally a piece of tape is used at each corner of the map sheet. If the sheet is large, it might be necessary to put additional pieces of tape on the centers of the sides (figure 10-17). The tape should hold the drawing media firmly in place on the surface, but should be relatively easy to remove without damaging the surface of the drawing media. The best way to remove the tape is to pull it back slowly toward the edge of the paper. Tape specifically designed for holding drawings is available from drawing supply stores. Masking tape can also be used if it is rubbed on a pair of pants a couple of times to take some of the stickiness out and thus protect the surface of the drawing media.

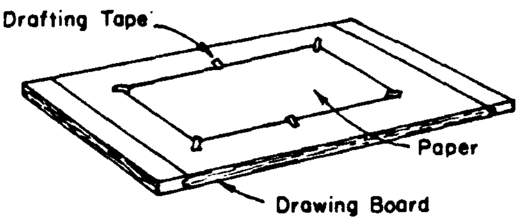


Figure 10-17. Taping the drawing to the drawing surface.

ADHESIVE AIDS

Adhesive aids include any material that can be placed on the drawing such as lettering or patterns to enhance the drawing. Sheets of lettering are available from several companies. Two types have been used. The first consists of lettering that is on a plastic film with an adhesive backing. The lettering can be cut out, joined into words and then the entire word can be transferred to the drawing and placed where needed. The second type is a transfer lettering that each letter is placed in the location it is needed and burnished into place directly. The second type is most commonly used and comes in a variety of type styles and sizes. Sheets of patterns printed on film are also available. These can be used on maps to fill in specific areas such as gravels, sands, limestone bedrock, etc. The film is placed over the area that it is to cover and while still on the base film, it is cut using the exacto knife described above. The area is then peeled from the backing sheet and placed carefully on the drawing in the appropriate location. When it is located exactly where needed, the pattern is burnished onto the drawing for permanent use. Catalogs of patterns ranging from screens (regular dot patterns of varying densities) to lines of various thickness and spacing, and also various other patterns are available under the names zip-a-tone or craft tint, etc. These can be very time saving and can make a cave map look much more professional. Figure 10-18 shows some of the available patterns.

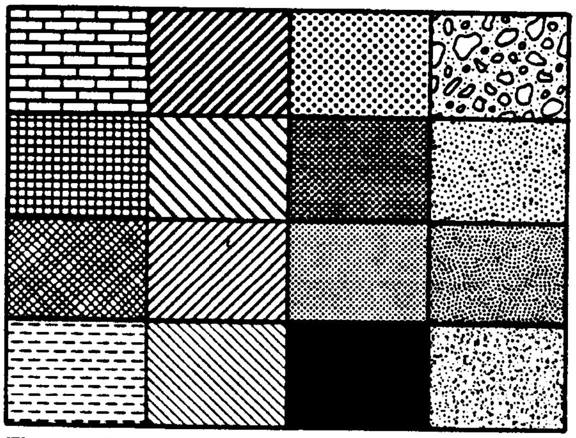


Figure 10-18. Examples of adhesive patterns that can be applied directly to maps.

THE ROUGH DRAFT OF THE CAVE MAP

The rough draft of the cave map is done in pencil so that changes or additions can easily be made to the map or mistakes can be corrected. This rough draft includes all of the details and the lettering in freehand so that a final inked copy of the map can be made with a minimum of effort.

METHODS OF PLOTTING CAVE MAP TRAVERSES

The first step in making a first draft of the cave map is to accurately plot the surveyed framework points onto a piece of paper. There are two commonly used methods to plot these points, 1. The angle and distance or polar coordinate method, and, 2. the rectangular coordinate method.

Polar Coordinate Method:

The angle and distance or polar coordinate method of plotting cave data is more commonly than is used than is the rectangular coordinate method. It is a more carefully done version of the in-cave method used for plotting the survey data in the notebook.

To use this method, first determine an initial point on the paper to start plotting the survey points. This can simply be an intersection of the horizontal and vertical lines on graph paper, placed so that the cave map being drafted will fit onto the graph paper.

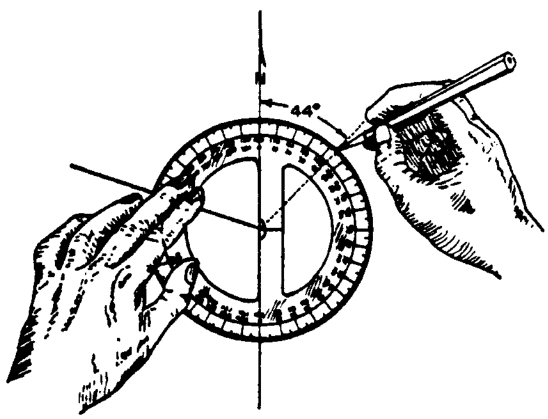


Figure 10-19. Use of full circle protractor to plot lines on the map.

A protractor or drafting machine is used to plot the azimuth or bearing. Various types of protractors can be used. Perhaps the most accurate and convenient type is a **full-circle protractor**; one that shows the full 360° of azimuth. With this type of protractor, one can align both the 0° and 180° line on the protractor with the north/south line on the graph paper and the 90° and 270° line on the protractor with the east/west line on the graph paper. By carefully aligning the protractor with both the north/south and east/west, the plotted survey line should be quite accurate. This double alignment is often more accurate than just aligning the protractor with the north/south line of the paper since it gives a check on the accuracy of the placement of the protractor on the paper. A full-circle protractor is also convenient since the azimuth can be plotted directly on the paper just by reading the appropriate direction from the protractor (figure 10-19). A **half-circle protractor** by contrast only shows the azimuth from 0° to 180° and has a straight-edge (which often has a scale for measuring lengths) along that direction (figure 10-20). To plot directions from 180° to 360° with this type of protractor requires some simple math. For example, to plot an angle of 256.5°, one has to rotate the protractor around the station point that one is plotting from on the graph paper so that the 0° is facing south (the 180° position) and the 180° is facing north (the 360° position). This, in effect, covers the missing half of the full-circle and enables one to plot those directions. Only simple math is required at this point: subtract 180° from the 256.5° (the surveyed azimuth) and the result will be 76.5°. So, to plot 256.5° on the paper, one moves clockwise on the protractor and makes a mark at 76.5° on the protractor. One then uses the scale to mark the distance of the survey shot on the paper. The plotting of bearings requires other simple manipulations of the protractors.

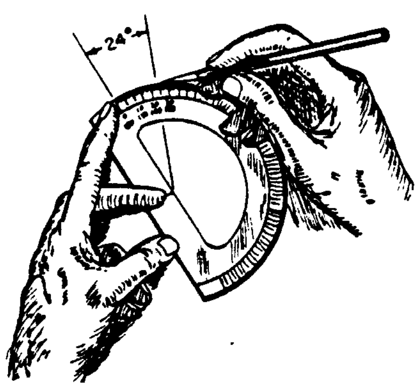


Figure 10-20. Use of the half circle protractor to plot cave data.

Once the leg of the survey traverse from station 1 to station 2 is plotted, the protractor is moved to station 2 on the paper and the bearing or azimuth is laid off in a manner similar to the first leg. The distance is then scaled off and station 3 marked and labeled. The protractor is again moved up and the next bearing or azimuth laid off to plot the third leg of the survey and so on through the remainder of the traverse.

Closer control on the plotting of the first draft of the cave map can be obtained by using a **drafting machine** to measure the azimuth or bearing angles. Once an angle has been set on the machine, the straight edge arm can be moved to the initial point and the bearing line drawn, measured to scale.

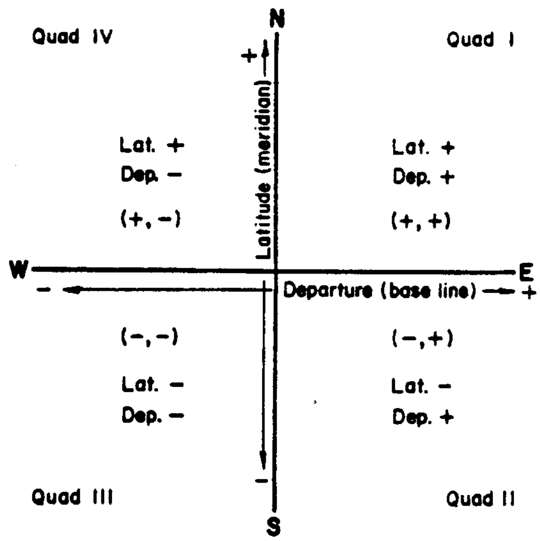


Figure 10-21. Latitude and departure base and meridian lines.

Rectangular Coordinate Method:

Rectangular coordinates can also be used to plot survey points on the map. A base line and a meridian line are set up for each cave, and all points are calculated so they can be plotted as coordinates on this base and meridian system. Using this system with the appropriate scale, you can plot all the survey points by the distance to the right or left (east or west) of the meridian line (departure) and by the distance above and below the base or departure line (latitude). Each survey station then will be identified by two numbers: first, the distance to the north (positive) or south (negative) of the base line and, second, the distance to the east (positive) or west (negative) of the meridian line (figure 10-21). In cave surveying this coordinate system is expanded into three dimensions, with the actual bearing, distance, and vertical angle describing a three-dimensional line that must be plotted on two-dimensional paper (figure 10-22). These translate into latitude, departure, and elevation.

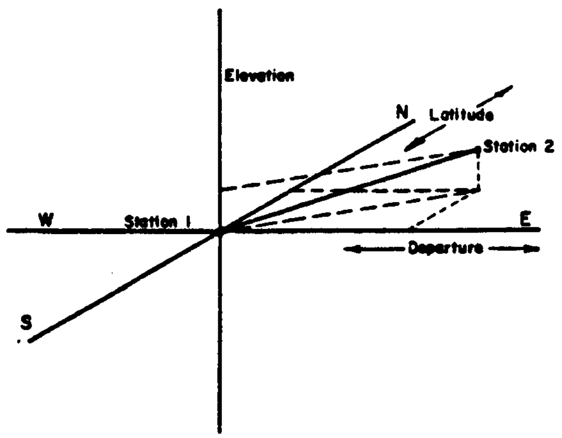


Figure 10-22. Position of survey points and survey lines in three dimensions as related to the initial point.

The advantage of this method over the polar coordinate method is the elimination of plotting errors that creep into the system of plotting by angle and distance. With the rectangular coordinate method, each point is located on the map by its coordinates and is not dependent on the accuracy of the previous point's position. A second advantage to this method is that laying out the cave on the drafting paper becomes easier because you know exactly where all the points are going to lie without having to plot the entire framework first. The calculated coordinates locate all the points, and the limits of the cave map can be easily identified from these coordinates. Thus you won't have most of the map plotted and find a section extending off the graph paper. This situation usually necessitates starting over on a new sheet of paper or grafting an extra sheet onto that section of the main sheet to cover the extension.

To use the rectangular coordinate method, the raw survey data of bearings or azimuth, distance, and vertical angle must be converted into north/south, east/west, and vertical components. The procedure is as follows:

Step 1. Calculate the true horizontal and vertical distance (figure 10-23):

True hor. dist. = surveyed dist. X cosine of the vertical angle. HD = MD X Cos A

True vert. dist. = surveyed dist. X sine of the vertical angle. VD = MD X Sin A

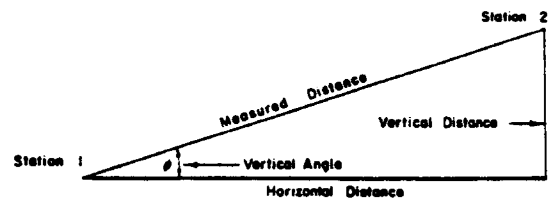


Figure 10-23. Calculation of true horizontal and vertical distances from survey data.

Step 2. Using the corrected true horizontal distance, calculate the north/south component (latitude) and the east/west component (departure) (figure 10-24):

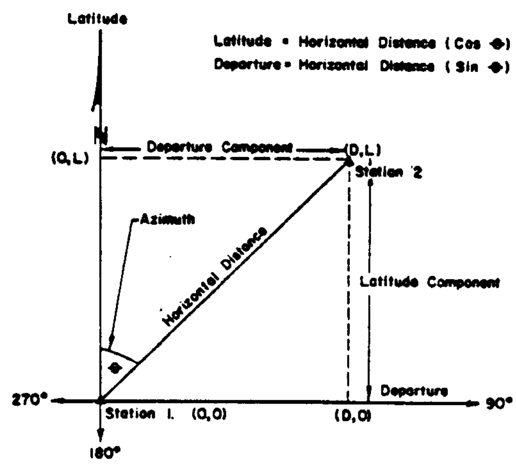


Figure 10-24. Calculation of latitude and departure.

Lat. = true hor. dist. X cosine azimuth or bearing.

Lat = HD X Cos 0

Dep. = true hor. dist. X sine azimuth or bearing.
Dep = HD X Sin 0

In calculating these coordinates, both azimuth and bearings can be used. When using bearings, it is important to apply the correct algebraic sign to the coordinates. Figure 10-25 shows the signs to use. When using azimuth, there are two approaches. In using trigonometry tables, it is probably easiest to convert the azimuth to bearings and then assign the algebraic signs as in figure 10-25. In each quadrant, the conversion to bearings is as follows:

Quadrant	Azimuth to Bearing
I	Bearing = Azimuth
II	180 - Azimuth = Bearing
III	Azimuth - 180 = Bearing
IV	360 - Azimuth = Bearing

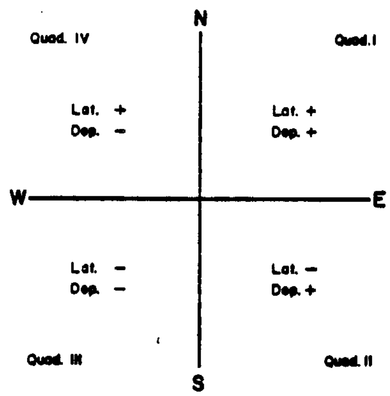


Figure 10-25. Algebraic signs of departure and latitude quadrants.

When using commercial hand calculators which give trigonometric functions, it is not necessary to reduce the azimuth. The calculator will give the trigonometric function with the appropriate sign.

From these calculations, the coordinates of the second point will have been determined relative to the initial point or point of origin, as well as the elevation difference between them. The next calculation will be from the second to the third point and will be relative to the second point. This is awkward and difficult to keep plotting each point based on a changing origin point for the base and meridian. This difficulty is overcome if you simply maintain an algebraic sum of all the latitudes and departures, which can then be plotted relative to the original point. These simply become the coordinates of the survey points.

When calculating latitude and departure, it is wise to use a printed form to tabulate the data as shown in figure 10-26. The survey data in figure 10-26 are plotted as figure 10-27.

The use of latitude and departure in surveying lends itself readily to computer reduction of data. Programs have been written taking the raw survey data, converting it to latitude, departure, cumulative latitude, cumulative departure, and station elevation, and then adjusting the survey from magnetic north to true north. A discussion of computer applications to cave surveying can be found in Chapter 11. A computer plotter can even be used to draw the survey lines on a sheet of paper.

Closures

Two types of traverses can be made in surveying a cave: an open traverse consisting of the survey points and lines extending through the cave and ending at the back of the cave; and a closed traverse, which returns to some point along the survey, thus closing a loop in the traverse. A total closure occurs when the traverse returns to the point of origin, that is, the first survey point or station. Closures can be used to check the accuracy of a cave survey. The closer the initial point and the final point in the loop coincide when plotting the survey framework, the more precise the survey. An error in the survey loop is most easily revealed and corrected after latitude and departure calculations have been made.

In a completely closed traverse, the original and the final coordinates should be identical. However, there is usually a certain degree of error in the survey due to slight mistakes in the azimuths or bearings and distance measurements as taken in the cave. Calculation errors can also be detected by the closure method. The degree of error of a survey is

Latitude - Departure Worksheet

Station From	To	Azimuth	Measured Distance	Vertical Angle	Horizontal Distance	Vertical Distance	Departure	Latitude	Cumulative Departure	Cumulative Latitude	Elevation
0	1	30	35.2	4.9	35.1	3.0	17.5	30.4	17.5	30.4	3.0
1	2	75.8	61.1	9.4	60.3	10.0	58.5	14.8	76.0	46.2	13.0
2	3	127.0	49.6	4.6	49.4	4.0	39.5	-29.7	115.5	15.5	17.0
3	4	169.6	41.3	29.0	36.1	20.0	6.5	-35.5	122.0	-20.0	37.0
4	5	226.4	46.0	-40.8	34.8	-30.0	-25.2	-24.0	96.8	-44.0	7.0
5	6	306.2	46.2	-12.5	45.1	-10.0	-36.8	26.0	60.0	-18.0	-3.0
6	7	258.7	38.2	12.1	37.4	8.0	-36.2	9.2	23.8	-27.2	5.0
7	0	318.8	36.5	-7.9	36.2	-5.0	-23.8	27.2	0.0	0.0	0.0

Figure 10-26. Tabulated data from the calculations for latitude and departure.

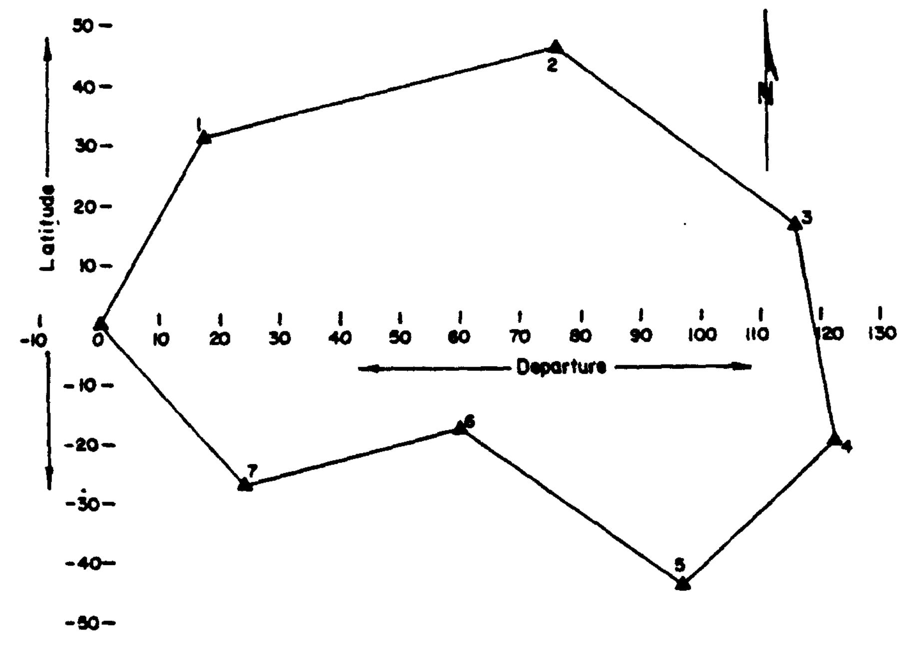


Figure 10-27. Plotted data derived from latitude and departure calculations.

calculated by taking the difference between the original and final coordinates of the starting survey point. The total error for this closed traverse becomes the square root of the sum of the squares of the errors:

$$\text{Total error} = \quad (\text{lat. diff})^2 + (\text{dep. diff})^2$$

The accuracy of the survey is the ratio of the total error to the total length of the survey. For example, if the total error is 1.25 feet and the total survey length is 3739 feet, then the accuracy is 1.25:3739 or 1:2992.

To overcome survey errors and close the loop in the survey plot so the map can be plotted accurately, it may be necessary to adjust the survey data so that the final point and the initial point are identical. This can be done by using either the compass rule or the transit rule:

Compass Rule: *Here, apply the corrections in proportion to the length of the legs of the traverse. Do this by using the equation, Correction = CS/L, where the correction is for latitude and/or departure, C = total error in sum of latitudes or departures with sign changes, S = length of the particular leg of the traverse, and L = total length of the survey. This rule changes the latitudes and departures so that both bearings and distances of each leg of the traverse are adjusted.*

Transit Rule: *Here, apply the corrections to the latitudes and departures in proportion to their respective lengths, using the equation, Correction = CS/L, where correction = correction to latitude or departures, C = total error in sum of latitudes or departures with sign changes, L = sum of latitude or departures without regard to sign, and S = length of particular latitude or departure. Here the correction changes the lengths of each leg of the traverse slightly but does not change the bearing.*

Since most surveys in caves do not have the accuracy of a transit for turning angles, it is probably best to use the compass rule to adjust the latitude and departures to close the loop. Computer programs have been devised to perform the above function on the cave survey data. Note that the use of the compass rule method for example, assumes that the error found in the survey is distributed evenly between all stations in the framework, whereas the source of much of the error might lie in certain places where the reading of the compass was unusually difficult. One should therefore attempt to generate accurate compass and distance readings as much as possible before using this method to correct the plot of the map. See chapters 2 and 3 for the proper use of surveying instruments and surveying methods.

DRAWING THE MAP VIEW

Once the cave survey framework is plotted, the details of the map can be added. The first step is to draw in the passage walls (figure 10-28 left). If the sketch map was drawn to scale in the cave, the in-cave sketch sheet can be laid under the framework on the map sheet and traced. Align the surveyed line on the sketch with the plotted line on the rough draft framework and trace the details from the sketch. In most cases the sketch has to be adjusted to fit the precisely plotted survey line. The details of the survey are shown in figure 10-28 right. In this sketch, place all of the details in their exact place. Use all of the proper symbols and draw the cave map exactly like you plan to have it in ink, only in pencil. This makes the final ink drawing much easier to do.

CROSS SECTIONS

Cross sections should be carefully plotted on the map in the preliminary or first draft copy. These are redrawn to the correct scale and positioned in the proper place on the map. An easy way to do this is to draw a box using the passage width and the passage height for the dimensions. Then draw the cross section to scale within the box. Be sure to place the cross section in such a manner that the down direction on the cross section is also down on the map. Also make certain that you place the cross section at a location that will not get in the way of the lettering that will be placed on the map. A line of section should be drawn at the location of the cross section and the direction that the section faces should be noted with either an arrow point opposite the section view or by the use of letters in the proper order to indicate direction (figure 10-29). Do not draw the line of section through the cave part of the map, stop the line just before the cave wall.

LONGITUDINAL SECTIONS

Several types of longitudinal section can be plotted. The type you choose will determine the method of projection of the survey data. There are three kinds of sections: the true vertical section, the projected vertical profile, and the transverse section (figure 10-30). The **true section** is plotted along the actual survey line drawn through the cave. Only the parts of the cave that are crossed by the line are to be shown (figure 10-30A). In the **projected section**, the same section as in the true section is shown, but any deviations of the passage from the section survey line are projected into the line of section so that a good perspective of the passage in one direction can be viewed (figure 10-30B). In a **transverse section**, the length of the survey traverses are plotted with the station elevations and passage heights to form a profile which runs the length of the cave. This section shows only the relationship of the floor and ceiling to the horizontal plane (figure 10-30C).

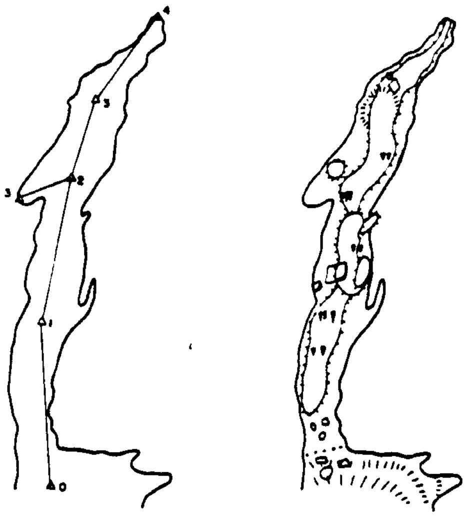


Figure 10-28. Plotted cave map framework with passage outline (left) and added details (right).

To plot a longitudinal profile, it is necessary to align the graph paper on which the profile is to be drawn with the line of section (figure 10-31A). From the framework of survey points, lines extend from the stations perpendicular to the line of section on the graph paper. Where the lines cross the graph paper, plot the exact elevations of the floor and ceiling heights of the passage. Then connect all the appropriate points to make the longitudinal section (figure 10-31B).

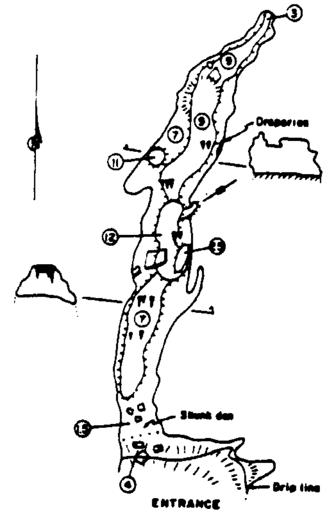


Figure 10-29. Cave map with added cross sections.

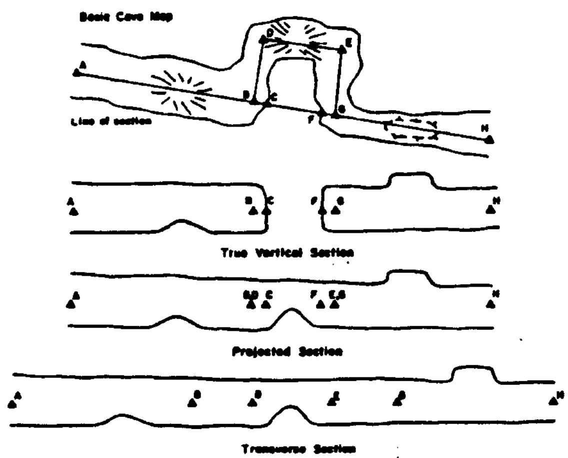
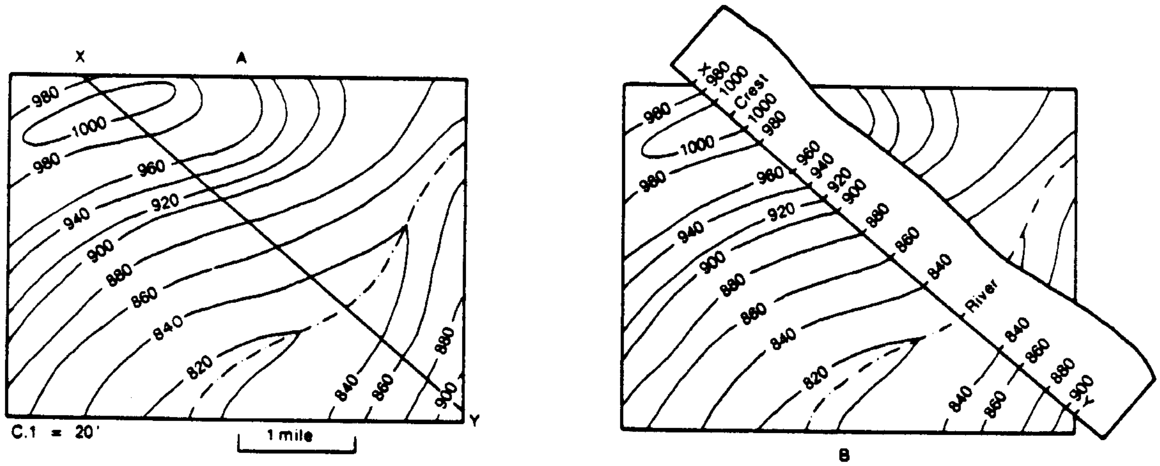
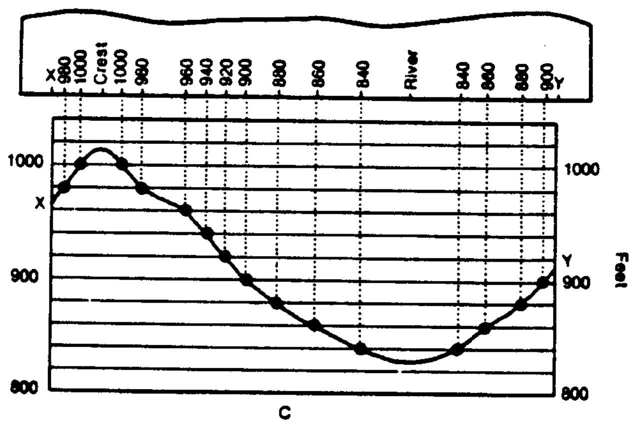


Figure 10-30. Longitudinal sections are plotted in three basic ways: A. true vertical section, B. projected section, and C. transverse section.

Plotting the topographic profile in conjunction with the section is also valuable if the topographic data is available. To do this, the exact location of the entrance and its elevation must be determined on a topographic map as well as the exact location of the longitudinal section line. To plot the topographic profile, again lay the graph paper along the line of section. Extend lines perpendicular to the line of



1. Place a strip of paper along a selected profile line.
2. Mark on the paper the exact place where each contour line, hill crest, and valley crosses the profile line. Label each mark with its elevation.



3. Place the paper strip above a calibrated vertical grid and project each marked topographic feature downward to its proper elevation.
4. Connect all points on the grid with a smooth line which is consistent with topographic trends. The result is a silhouette of the topography along the profile line.

Figure 10-31. Procedure for plotting a topographic profile.

section from each contour line to the graph paper, and plot the elevation of each contour line (figure 10-31). Join the points in a smooth curve to form the topographic profile. Because the topographic map and the cave map differ in scale, the topographic profile must be enlarged in order to match the map scale.

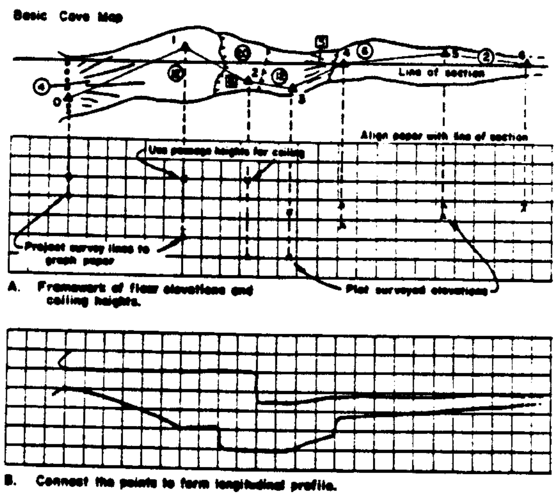


Figure 10-32. Procedure for plotting a longitudinal section.

The profile can also be made from a surface traverse that has been made over the cave. If the proper vertical angles were determined, the elevations of all the surface points can be determined and a profile created and plotted on the graph paper along with the longitudinal section of the cave.

All longitudinal profiles should be carefully plotted on the map in such a manner that down on the profile is parallel to the bottom of the map.

LETTERING

The lettering layout is one of the most important parts of the rough draft. The lettering should be placed in pencil on the first draft to properly label all the features. The title, scale, north arrow, notes, passage heights, and all the numbers for proper descriptions should then be added at the appropriate places on the map. Be sure to place all lettering so that it can be read from the bottom or right side of the map. Be sure to use the proper symbols for the dimensions and place lines (leaders) from the site of the measurement to the number.

SYMBOLS

If the survey were properly done, the features will be shown on the field sheets with the proper symbol and these can then be transferred to the rough draft of the cave map. The proper cave map symbols are shown in Appendix I.

When the rough draft is completed, it should diagrammatically portray the cave as accurately as possible. It should be possible to easily recognize where you are in the cave by using the map. The standard symbols are designed so that they can be individualized to look as much like the cave feature as possible. For example rock or breakdown symbols should be dimensionally drawn to look as much as possible like the rocks they represent, and slope symbols should be oriented in the position of the slopes they represent.

METHODS OF ENLARGING OR REDUCING MAPS

As cave maps are drawn, it may be necessary for any number of reasons to change the scale. The scale used to map the cave may not have been large enough to show the details of a particular section of the cave, or it may have been too large for the whole map to fit onto a single sheet. In these cases the map must either be enlarged or reduced to a more appropriate scale. This can be done in any one of several ways.

MECHANICAL METHODS

Proportional Dividers

Cave map frameworks can be enlarged or reduced using proportional dividers (figure 10-16). These can be set so that the length measured at one end is either enlarged or reduced at the other by a specific amount. It is a very slow and tedious process which is best used for changing the scale of line segments such as the legs of the survey framework.

Enlargement by Squares

To use this method, first, take the original drawing and superimpose a grid system over it. Secondly, transfer the drawing freehand square by square, to a second grid system which is either larger or smaller by the desired factor. For example, if you desire to enlarge a map to double its present size, use graph paper that is 10 X 10 squares per inch to lay over the drawing, and then transfer the drawing to graph paper that is 5 X 5 squares per inch. The process is slow, but it is generally regarded as a good method because of its accuracy.

Pantograph

A pantograph is a mechanical device consisting of four bars, which for any setting must form a parallelogram and have the pivot, tracing point, and marking point in a straight line (fig. 10-33). Any arrangement of the four arms that fits this requirement will work in true proportions. The pivot point must be clamped down and then the tracing point can be tracing point can be traced around the outline of the map. The drawing point will then draw the enlarged or reduced image of the map.

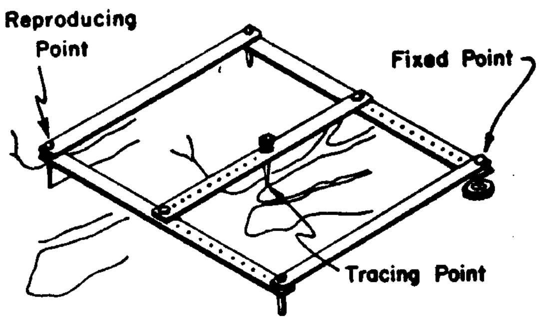


Figure 10-33. Use of the pantograph to enlarge or reduce a map.

OPTICAL-SKETCH METHODS

Enlargement with Overhead Projector

A transparency can be made of the drawing or map that needs to be enlarged using a "thermofax" machine. This transparency is placed on an overhead projector where the image is projected onto a piece of paper to be traced. This method is only good for enlarging drawings, especially where the size must be 5 to 10 times larger than the original.

Kail Projector

The Kail Projector is a unique light table equipped with an intense light source, two front surfaced mirrors, and an intermediate lens. With this device, the original drawing is placed face down in the side with the intense light source. From this, the image is transmitted to the first mirror, through the lens to the second mirror, and then up to the surface on which the image is projected. There it is traced and the enlargement or reduction is completed. The size of the image can be increased or decreased as much as 4.5 times by adjusting the mirror and lens arrangement.

PHOTOGRAPHIC-TYPE METHODS

Photography

There are two photographic methods that can be used. First, a 35 mm slide copy can be made of your original (be sure that the camera is perpendicular to the map). The slide can be put into a slide projector and the image projected onto a piece of drafting paper where it can be traced. This method is good for enlarging only. Secondly, a process camera such as found in a print shop, can be used. With this method, a photographic negative can be made at the scale desired and then either enlarged or reduced. This can directly be made into a photographic print or a transparency.

Copy Machine

Some office copy machines (Xerox, IBM, Sharp, Sarin, etc.) have fixed and variable reducing and enlarging capabilities that can be used to change the map scale to something more manageable. With maps larger than the machine's copy surface, it is possible to copy parts of the map on several sheets and paste them together for a second stage of copying. By using several reductions of the same copy, it is possible to change the map size by 60, 75, 95, 100, 120, or 150 percent and increments in between.

PREPARATION OF THE FINAL CAVE MAP

The final inked cave map is the end result of the cave survey. It is only as good as the data on which it is based, and should be the result of a carefully and precisely drawn rough draft of the cave map. It is impossible to draw an attractive map directly from notes and sketches. This final map is also dependent on the quality and type of materials used as well as the skill of the illustrator. You should use good quality vellum or mylar and good ink to create the final professional quality map.

MAP SETUP

The first thing to do is to lay out the rough draft of the map on the drafting table or board. Align it with the T-square with north at the top of the map if at all possible. Most lettering should align with the bottom of the board or table. Once aligned, tape the corners down using drafting or masking tape. Sometimes the rough draft is in several sheets, and this is the point at which they are carefully assembled to show the complete map. This can be done by carefully taping the pieces into place on the drafting table.

The next step is to lay the drafting material for the final draft over the rough draft. Cut it large enough to enclose the entire map area, with some allowance for border areas. Then center the vellum or mylar sheet carefully over the rough draft and tape it down securely. On larger sheets of drafting paper, it may be necessary to tape down the middle of the sides as well as the corners to hold the paper in place. You are now ready to begin drafting the map.

ORDER OF DRAFTING

The map can be drafted in the most efficient manner if the following order of inking is followed:

1. All lettering, including title block, numbers, notes, etc.
2. North arrow and scale
3. Passage outline
4. Internal details and lines
5. Lines of sections
6. Cross and longitudinal sections

Note that lettering is in the first place above, because, for the following reasons, it takes precedence in all maps. First, lettering is the most time-consuming part of drafting a map and if done first, the inking of the remainder of the map seems to be easier. Next, if the lettering is done first, any mistakes are easily corrected without having to redraft the cave map outlines or details. Lastly, the map legibility is increased if the map lines (passage outlines, section lines, etc.) are broken around the lettering. Following the remaining order of drawing is not as critical as doing the lettering first.

LETTERING

The styles, sizes, alignment, and positioning of lettering help make the map understandable by conveying all notes, all dimensions and all descriptive information on the map.

Methods of lettering:

Lettering can be done by printing directly on the map, or by printing on a secondary medium and then placing this on the map.

Direct lettering includes several techniques. **Hand lettering**, the easiest method, is generally not recommended for final-drafted maps unless you are exceptionally skilled and consistent in your lettering. Hand lettering, however, can be used to locate and position on the rough draft all lettering that is to be placed on the map in the final draft.

Perforated templates are available which help make lettering consistent in the final draft. These come in several sizes and are relatively easy to use with a rapidograph or a similar type of pen.

Lettering can be done using the **Leroy lettering set** (figure 10-15). With this set, templates and scribers are used together to create the letters. The templates can produce both vertical and italic lettering ranging from 0.080 inches to 0.5 inches high. The template is placed against the T-square or a triangle where it can be slid back and forth to position the lettering correctly. The scriber is then placed with the tail in the long groove or track, and guide pin in the desired letter, and the ink point on the paper. The letter is then traced with the point, and the ink point puts the letter on the paper. You should practice with a set to get a feeling for the proper spacing of the letters both horizontally and vertically.

Lettering can be placed on the map by using **transfer lettering**, which comes in many styles and sizes and is manufactured by several companies. Alphabets with several copies of each letter adhere to a clear plastic sheet. Letters from the sheet are placed in the proper position and then transferred by being rubbed onto the map with a burnisher. Once the letters have been transferred, it is wise to protect them with a plastic spray called workable fixative. A second type of lettering is available which is permanently printed on a plastic material. This is then cut out and the lettering assembled and transferred intact to the point where it is to be placed. Here it is burnished down and held in place. The adhesive often used for this is wax so the map should never be subjected to heat.

Lettering can be typeset by a printer or a computer with a word processing program and a laserprinter. The typeset words and phrases are then cut out and placed on the map with some type of adhesive. The lettering looks attractive, but it must be realized that maps prepared with typeset lettering should be photographed or xeroxed for reproduction.

The method of lettering used depends on you. Your skill, the cost, and the permanence desired are all factors to consider. If you use the indirect methods of lettering, you should carefully consider the method of reproduction. In the diazo process, for example, a hot light is used to produce the copies; and wax adhesives will melt from this heat, making the lettering move or fall off. The most permanent lettering on the original will always be some method of direct lettering, such as using lettering sets or hand printing.

Sizes of Lettering:

The size of lettering you use on the final map should be determined very carefully. Lettering that is too small can be uninformative and hard to read, especially when the map is reduced for publication. Lettering that is too large may inform but can also distract from the feature that it is meant to describe. When picking a lettering size, visualize the map in its final size and make sure that the lettering you use will reduce and still be readable.

Lettering sizes are measured in two ways: points and actual letter height. Printers measure in points. One point equals 1/72 inch and is measured from the bottom of one line of print to the bottom of the next and, therefore, includes both the lettering and the line spacing. Leroy lettering is measured in actual lettering height and is described in thousandths of an inch. thus a 100 leroy template is 100/1000 of an inch or 1/10 of an inch high.

A change in lettering size is used to denote a change in importance of the feature being lettered. Most of the lettering should be done with an initial capital and lower case letters in a manner similar to book titles. If you want to draw attention to some feature, you can either use all capital letters or two sizes of capital letters.

Styles of Lettering:

There are two basic styles of lettering: **serif or Roman style** (shown as text lettering) and **sans serif** (figure 10-34). Many typefaces can be found in typesetter catalogs, but all of these are simply vertical or italic (slanted) modifications of the above two lettering styles. Most lettering on the cave map will be san serif, while the lettering in the title may be a fancy Roman style. The choice of lettering is up to you, but you should choose simple, descriptive and attractive lettering.

SANSERIF LETTERING

sanserif lettering 0123456789

ITALIC LETTERING

italic lettering 0123456789

Figure 10-34. Styles of lettering used for drawings and figures.

Positioning of the Lettering:

Most of the lettering on a map should parallel the title of the map and the bottom of the map. Anything that is labelled out of the horizontal position must be done with a good reason. Major passages and areas in the cave are sometimes labelled out of the horizontal with the lettering paralleling the feature. Generally, this lettering follows a straight line; sometimes it flows along the feature. This should be along a smooth curve and the lettering should be carefully and evenly placed.

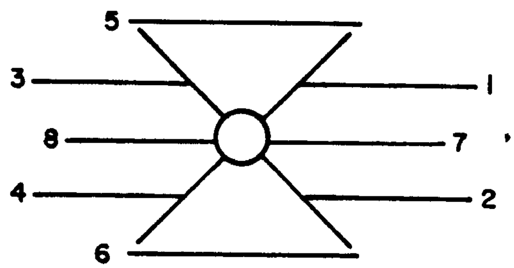


Figure 10-35. Position preference in lettering placement.

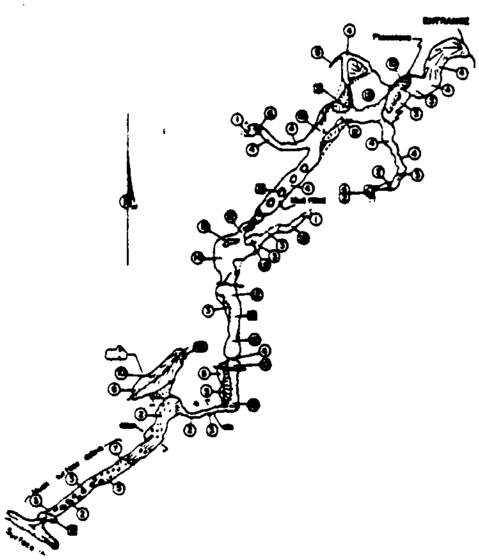


Figure 10-36. Use of leader lines for identifying figures.

In placing lettering around a point or feature, there is generally a standard procedure or order of preference that should be followed (figure 10-35). All lettering should be placed as close to the location of the point as possible. In lettering passage heights, place them so the number is at the exact spot of the height they represent. If this is not possible, place the number outside the passage with a leader line showing the exact location of the point (figure 10-36). This same rule applies for drop offs, pit depths, and any other dimensional lettering. In all lettering, make sure not to letter over lines and not to draw lines through lettering. Always break lines around lettering and let the lettering take precedence. Lettering should be placed in such a way that it can always be read from the bottom or right side of the page. Never letter anything upside down.

LINES AND LINE WEIGHTS

Lines can be drawn on maps in a number of ways and with a number of thicknesses. These thicknesses should be chosen with care to highlight the map in the best way possible. Line weight plays a major role in the interpretation of the drawing by others. Lines, other symbols and their arrangement depict the view desired by the illustrator. The heavier the line, the greater the importance attributed to that feature. Figure 10-37 shows the thicknesses of lines produced with the use of radiograph or reservoir pens. It is best that the final copy of the map have lines that are not less than 0.015 inches or approximately the size of the 00 pen in the rapidograph set. To be distinctly different, the size must be a factor of 2 larger, so the passage outline should be a 0 or 1 pen.

If a map is to be reduced, the weight of the lines might be increased. If the final map is to be 8 1/2 X 11 inches in final size and the present map is 17 X 22 inches, the size of the original will be reduced by 50 percent. Consequently, the line weights must be thick enough to show easily. Experience, however, shows that the line size need not be increased to twice the size. In fact, the outline can generally be made with a number 2 Leroy pen and the details with an 0, and the map can then be reduced as much as 60 percent and still be readable.

A visual hierarchy should be established on the cave map to make it easier to read and also to make it aesthetically pleasing and informative. To do this the elements of the map should be prioritized into the following manner from thickest lines to finest:

1. Main Passage Outline.
2. Secondary Passage Outlines.
3. Floor topography or features.
4. Floor sediments.
5. Ancillary Information

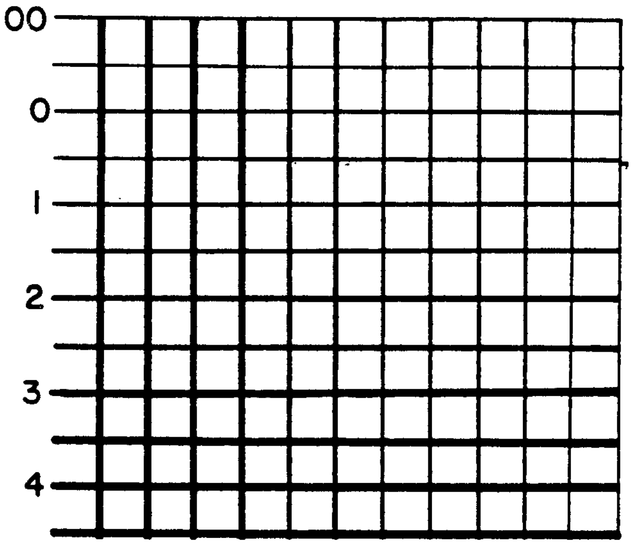


Figure 10-37. Line thicknesses of pens used in drawings.

MAP LAYOUT

The layout of the cave map on the paper is the easiest part. Center the paper over the rough draft with north at the top of the map. The actual pattern of the cave will then determine the center of balance of the map sheet. Once this is determined, the remaining items such as north arrow, scale, and title block can be placed on the map in a way that balances the map artistically.

While it may bear no relation to the accuracy of the map, an artistically arranged and neatly drafted map reflects credit on the craftsmanship of the author and can be easier and more pleasant to work with.

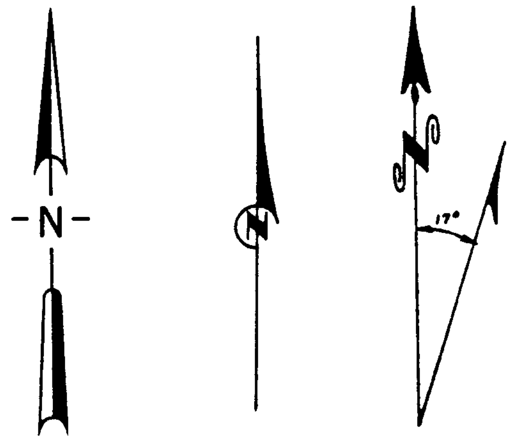


Figure 10-38. North arrows commonly used on maps.

NORTH ARROWS

A north arrow should always be shown and is placed in a position of true orientation to the map. It is a subordinate but essential part of the map, and as such it should be distinctive, but should not be so dramatic or large that it dominates the map. Styles of north arrows vary and the style used depends on the individual's choice. Figure 10-38 shows several styles. When true north is shown, the arrow should have a full barb; when magnetic north is shown, use a half barb. The best method is to show both the true north and magnetic north with the amount of declination written out.

SCALES

All cave maps must have a scale to show size and distance relationships of passageways and features. Two types of scale are generally used on maps: stated scales and graphic scales. A stated scale is a ratio such as 1 inch equals 20 feet or 1:240, etc. This is easy to use as the figure is usually dimensionless, and a unit on the map will represent so many of the same units on the ground (i.e., 1 inch on the map may equal 240 inches on the ground, if the scale is 1:240). However, a major problem will develop if you photographically enlarge or reduce the map, because this scale will no longer be correct. A graphic scale is simply a line on the map which represents the true length on the ground and is sometimes known as a bar scale or rake scale. These scales consist of measured lines which are divided into segments, each of which is designated as a specific distance on the map. If possible, the scale should be divided into at least four small divisions with one large division. The type of scale is indicated as scale in feet or scale in miles, etc. When making cross sections and longitudinal sections in which a vertical scale is used that is different than the map scale, this should be marked on the section and the units labelled on the scale. Because many cave maps are used internationally, it is wise to put a double scale on the map for both the English and metric systems. These should be labelled as such.

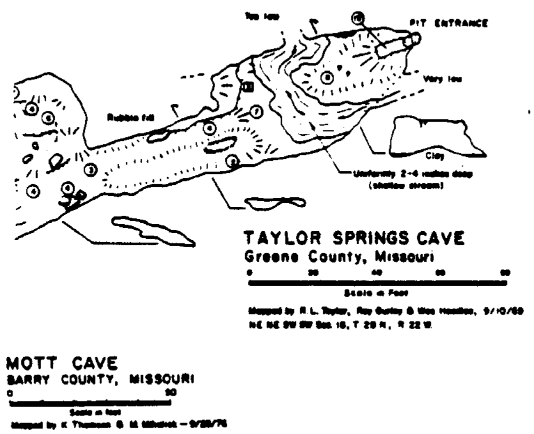


Figure 10-39. Title box styles.

TITLE BOX

The title box on a map contains the name of the cave and the pertinent information concerning the mapping of the cave. The title should be the largest and most bold lettering on the map. Below the name of the cave should be information regarding the location of the cave. To preserve the confidence of the exact location, the county and state names are normally the only information placed here. Below this is the line of credits which indicates the author of the map and other members of the survey team along with the date the mapping was done. Information about the total cave length both in English and metric lengths, the method or grade of mapping, and the illustrator should be included in the title box. Sometimes the scale is also included. An example of a title box is shown in figure 10-39.

SCRIBING OF CAVE MAPS

The difference between drawing and scribing is in the former we add some material such as ink, graphite, or paint to a base sheet. In the latter we remove some.

Negative scribing is generally done on a stable plastic base material such as mylar on which a photographically opaque coating has been placed. Into this coating, lines, patterns, and symbols are cut with special gravers. This allows light to pass through and thus in effect creates a negative of the cave map.

Negative scribing has some advantages over map drafting. Lines are more even and consistent than those drawn in ink. In addition, some people feel that it is easier to scribe lines than learn to be consistent with ink drawing. It saves photographing the map to a specific size because scribing is done at the final scale. It is easily possible to work in more detail at a reduced size. Revisions are easier to make. The portions that need to be corrected are simply re-coated and re-scribed. Some disadvantages of scribing are that all work is done in negative and the illustrator must think in reverse. Because of this, mistakes are not easy to detect. In addition, lettering is not easily done.

Generally negative scribing of maps is done where the map is to be reproduced in large quantities. Most cave maps are copied in terms of two or three copies at a time. For more information on scribing techniques, the reader is referred to any good cartography book such as Erwin Raisz (1962), *Principles of Cartography*, Arthur H. Robinson (1984), *Elements of Cartography* or any other cartography book.

REPRODUCTION OF CAVE MAPS

Because there may be a variety of reasons for mapping a cave, such as biological studies, geologic studies, and exploration, more than one copy of any cave map may be needed. Also it would be very unpleasant if you lost your only copy of a map that required months to map. You would either have to redraft the map or if you also lost your notes you would have to remap the cave. Therefore always make more than one copy of a map. There are three ways by which a cave map can be duplicated efficiently: diazo, xerox or office copier, and the photography/offset method.

DIAZO PRINT REPRODUCTION

The diazo process consists of passing a strong light through the original map onto a light sensitive paper. This light exposes the background and allows the paper under the map lines to remain unexposed and still light sensitive. This light sensitive paper is then developed, and the unexposed portions of the paper either become black or blue, depending on the paper type used. This gives a fairly good copy of the cave map. The exposure and developing process are all done in the same machine at the same time.

The original tracings or prints must be on a translucent or transparent base material such as vellum, mylar, or linen to reproduce using the diazo process, since it is dependent on light passing through the paper. Large map sheets can be easily duplicated this way.

Copies can also be made on a translucent paper (sepia) or on a film base (mylar), both of which can be used as a duplicate original.

The copies made using the diazo process are very sharp and clean, but they tend to fade with age. However, copies made on mylar are as close to permanent as possible to make using this process.

The diazo process is an excellent method to use when only a few copies (10 to 20) are needed. The size of the copy is limited only by the size of the machine width, as any length can be run through it.

In using this method, however, you must be careful that any lettering or patterns used are heat resistant. Those that are not will probably come off in the machine. You should also be aware that the copies made on a diazo machine will be slightly distorted because they are copied around a drum. The copy will be slightly larger than the original in the lengthwise direction.

OFFICE COPY MACHINES

These operate with a process similar to a camera process by which copies are made electrostatically or by other similar means from the original.

The original material can be any clean, sharp copy. Since no light needs to pass through the original, paste-ups and opaque paper can be used. Lettering can be typeset and glued or taped onto the original. The original material must fit the size of the machine or it must be copied in pieces. Generally, these copiers will cover from 8 1/2 X 11 to as large as 11 X 17. Maps as large as 24 X 30 can be duplicated on special copy machines.

Xerox and several other office copiers will print on nearly any kind of paper, including vellum, bond, and offset masters. Copies printed on good quality bond paper made on Xerox will be excellent if the machine is clean and well cared for; otherwise, the copies will either be light or have a background which detracts from an otherwise clean copy.

PHOTOGRAPHIC/OFFSET PRINTING

This process is used to produce numerous copies of a cave map, often for publication. Copies made by this process are usually printed on good quality bond paper and will be fairly opaque. Copies can be run on almost any type of paper desired, including vellum for special purposes.

In this method, the original must first be photographically reduced to fit the size of the offset press to be used. The original can be any type of material, opaque or translucent. To use this method, a negative is made with a process camera. This negative is then touched up (to eliminate errors or defects), mounted in a mask, and exposed to a light-sensitive chemical on a metal plate. The plate is then run on the printing press, making possible the printing of thousands of copies of the map.

This is the best way to reproduce a map. The copies will be as good as the original or even better, and they will be permanent. As many copies as desired can be made for a reasonable cost.

11

COMPUTER APPLICATIONS TO CAVE MAPPING

Computers and calculators are readily adaptable to the routine survey calculations necessary for plotting cave maps. Calculators have become increasingly more sophisticated and many can even be considered to be small computers due to their programmability. Since computers are becoming more and more accessible with greater capabilities; it has become common for cave surveyors to take advantage of this technology to reduce cave survey data and even in some cases to produce the entire cave map with a computer and plotter.

CALCULATORS

The calculator used to be a bulky device, only useful for simple calculations, but in the last few years with the advent of more powerful chips and circuit miniaturization, calculators have become increasingly sophisticated. Many calculators have functions such as the ability to perform some statistical analysis of data, the ability to store constants or other numbers and the ability to change from degrees to radians to grads. These calculators simplify computations of the large amounts of data gathered during a cave survey. In addition, calculators are continuing to decrease in cost and are easier to use.

The scientific calculator has taken the place of both the trigonometry tables and log tables that were necessary in calculations of survey data in the past. A good scientific calculator can be used to compute the rectangular coordinates of any point from its polar coordinates using simple trigonometry. Some calculators even have conversion keys available to convert directly from polar to rectangular or from rectangular to polar coordinates.

Programmable calculators are basically small computers which can be programmed to take basic surveying data and manipulate it for specific purposes. For example, a program can be made which will take azimuths, distances and vertical angles and compute latitude and departure changes between stations and rectangular coordinates for all survey stations in a traverse. It can also make adjustments to close a survey loop when the unmanipulated data doesn't yield such a result. In addition, the calculator can be used to calculate the distances between points not in succession in the survey. Many programmable calculators are available such as Casio, Hewlett-Packard, and Texas Instruments. The Hewlett-Packard HP-41CV or CX and the HP-48SX have available surveying pacs with.programs which directly perform many surveying computations useful to cave surveyors. In addition, the HP-48SX can store data for up to 1200 survey points and can be interfaced with a computer so that the stored data can be downloaded directly into the computer.

The main value of a calculator is the fact that it can speed up computations and yield an accuracy equal to the maximum allowed by the data. The cost of calculators is not prohibitive. The non-programmable types, such as those available from Casio and Radio Shack, cost under $20 and are easy to find. Naturally, the programmable calculators are more expensive, but their usefulness makes them worth the additional cost. To get the best results be sure to verify that the calculator will convert degrees, minutes and seconds to decimal degrees and will reconvert back to degrees, minutes and seconds without rounding to the nearest minute when using angles in excess of 100 degrees.

COMPUTERS

Computers with a great deal of power and features are now readily available to the average cave surveyor for a relatively low cost. Surveying programs of varying degrees of usefulness and complexity are also available for nearly all of the most popular microcomputer systems. Some of these personal computers include the Apple II, the Apple Macintosh, IBM, and Commodore Amiga.

Computers can be used in the following ways for cave surveying and data reduction:

1. Simple programs are available to reduce survey data to Cartesian coordinates.

2. More advanced programs can reduce the survey data to Cartesian coordinates, and then adjust that data in order to plot it out on a plotter.

3. Spreadsheets such as EXCEL, LOTUS 1,2,3, and QUATTRO-PRO can process survey data.

4. Computer Assisted Drafting (CAD) Systems allow the surveyor to draw the cave details on the adjusted framework.

5. Commercially available surveying programs can take survey data, compile it, adjust it, and plot the traverse and either use a self-contained CAD system to draw the maps, or combine with another CAD system such as AutoCAD to do the drawing.

Table 11-1. Types of data collected in the field, the intermediate computations, and the final cumulative results needed when considering any computer program.

1. Input Data:
   - Station identification
   - Azimuth or bearing
   - Distance
   - Vertical or zenith angle
   - Elevation of base station
   - Magnetic declination
   - Passage dimensions
   - Turned angles
2. Intermediate Results:
   - Corrected azimuth or bearing
   - Corrected horizontal distance
   - Corrected vertical distance
   - Latitude
   - Departure
3. Cumulative Results:
   - Cumulative elevation
   - Cumulative latitude
   - Cumulative departure
   - Total survey length

Simple Computer Programs:

Computer programs for cave surveying have been written by many individuals to perform the relatively simple task of taking the raw survey data and computing a final traverse that can be easily plotted. This type of program replaces the much more error prone method of plotting the final map with protractor and scale. To be able to do this, it is necessary that any surveying program utilize the raw field data, manipulate it to an intermediate result, then evaluate it and convert it to cumulative information. A set of very simple surveying programs are given in the 8th edition of *Elementary Surveying* by Brinker and Wolf (1989) in IBM BASIC which can be easily entered into a computer and used for cave surveying. The compiled data resulting from the programs can be printed out on a printer for a hard copy of the data. This set includes the following programs:

1. Program to solve for unknown parts of oblique triangles.
2. Program to compute latitudes, departures and areas of closed traverses from azimuths or bearings, vertical angles, and distances.
3. Program to calculate horizontal and vertical distances from stadia shots.
4. Program to calculate astronomical azimuth by the hour angle method.
5. Program to compute astronomical azimuth by the sun's altitude.

Another source of BASIC programs for surveying is a book called *Solving Problems in Surveying* by Bannister and Baker (1989). This book includes listings of programs for the following which can be used in cave surveying:

1. Trigonometric leveling
2. Tape corrections for accurate distance measurement.
3. Stadia tacheometry.
4. Closed loop traverse corrected by Bowditch's method.
5. Area inside of traverse.
6. Resection.
7. Subroutine to check angles.

A source of BASIC programs which can be run on Apple II computers is available in a book by by Milne (1984), *BASIC Programs for Land Surveying*. Twenty two programs are listed, but only the following have applications cave surveying:

1. Triangle solutions.
2. 2-D intersection solutions.
3. 2-D resection solutions.
4. Traverse surveys.
5. Coordinate transformation.
6. Error analysis.
7. Adjustment of observations.
8. Braced quadrilateral solution.

The book also contains conversion statements so that the programs in it can easily be converted to other computers.

Other early programs written to reduce surveying data to a more usable form have been published in various journals. Some examples of early programs are the ones by Allen R. Lawrence (1969), Norman Frater (1969), C. A. Plantz and V. A. Schmidt (1970), Fred L. Wefer (1971), T. Rea (1973), John M. Rutherford and Robert M. Amundson (1974)

A program designed by John Northrip of the Physical Sciences Department at Southwest Missouri State University in 1971 was run on the university's mainframe computer. This program would process raw survey data of station, magnetic azimuth, vertical angle and distance, reduce it to latitude and departure and then finish with the adjusted coordinates of each point corrected to true north. The computer program could also plot the coordinates; the only limit we had at the time was the size of the plotter available.

A BASIC program by Joel Laws of Southeast Missouri Grotto worked quite well on some of the earlier personal computers was provided to the authors in 1980. One of the authors of this manual, Taylor, has written a surveying program in Applesoft BASIC for the Apple II in 1985 and has converted and modified it in 1990 for the Commodore Amiga. This program provides the basic latitude and departure calculations. A modified version is planned that will incorporate many more features.

Advanced Surveying Programs

By the late 1980s, computers became less expensive, more user friendly, and new and better programs started to appear. Cave surveyors, recognizing the potential, started writing more complex application programs.

Steve Peerman (1986) designed the Cave Mapping System (CMS) Version 4.3 program to be run on an Apple IIe (with an Extended Memory 80 column card) or an Apple IIc computer. The program is written in Apple Pascal Version 2.1 and must have 128K of memory space. This program has three general types of routines: Data entry, data modification, and data display. The data entry feature allows all of the survey data gathered in the cave to be entered into the program. This includes the survey leg number, the stations from and to, the distance, azimuth, elevation, and passage characteristics such as distance to left wall, right wall, floor, and ceiling. In the modifications routine, the raw data is converted to cartesian coordinates, surveyed loops can be closed, and other corrections can be made to the data. In the third routine, the data can be displayed as line maps, data summaries, rose charts showing shot direction distributions, and distances between stations. The author of the program indicates that it is very "user-friendly" and self-explanatory.

The SMAPS Cave Survey Management System Version 4.1 designed by Doug Dotson (1988) is also specifically designed for cave surveying data reduction and management on IBM PC/XT/AT or compatable machines with 640K RAM and a hard disk recommended. This program has provisions for entry of all the data that CMS has, plus it has provisions for entering both front sights as well as back sights of both horizontal angles and vertical angles. It also includes the instrument height, the target height, depth gauge reading and a provision for those using a thread measuring device such as TopoFil. The program can then make corrections for declination, change in initial coordinates, as well as computing the position of each point by cartesian coordinates. In addition, this program has a graphic option which can be used for manipulating the data and for preparing maps with borders, title blocks, depth scale, horizontal scale, tick marks, and the absolute location of a station relative to a datum. Many other features are present which can enable the cave mapper to create a more accurate cave map. This program can be used with an interface program called SMAPCAD written by Jim Nepstad (1987) to read in the coordinates produced by SMAPS and rearrange them into another file which AutoCAD, a computer assisted drafting program, could use to automatically create a drawing of the survey stations, the traverse lines running between them, and the survey station names.

Spreadsheet Programs

Probably one of the most basic and popular kinds of software programs available for use on the personal computer is the electronic spreadsheet. The original spreadsheet, designed in 1979 by Dan Bricklin, a student at Harvard Business School, was a major breakthrough for surveying computations. It made the computer's numerical processing capabilities available to people who had no desire to learn computer programming and who, in many cases, had no computer experience. Many spreadsheet programs are presently readily available and some are relatively inexpensive. Some of the products on the market today include: VISICALC, LOTUS 1-2-3, EXCEL, QUATTRO-PRO, and many others.

Spreadsheets share a common form and command structures. Displayed on the monitor screen, they consist of a surface divided into horizontal rows and vertical columns very much like the ruled pad of columns and rows used by accountants for keeping track of expenses, etc., and by professional surveyors for keeping track of surveying data for performing traverse calculations. Each data value such as azimuth and distance would have an address (cell) on the spreadsheet defined by the column number and row number. Some of the columns could be designated as survey leg, azimuth, distance, vertical angle, station, latitude, departure, etc. Modern day spreadsheets can contain considerable amounts of data. The original VISICALC Program contained 63 columns and 254 rows for a total of 16,002 cells. The table below lists the capacity of some of the modern spreadsheet programs. When viewing the monitor, only a small part of the spreadsheet can be viewed at one time, but the sheet can be scrolled easily from right to left and bottom to top. In fact, any part of the spreadsheet can be viewed directly by employing a "go to cell" command.

The value of the spreadsheet to the cave surveyor is that having entered the numeric data in various cell locations, mathematical calculations can be performed on that data. For example, if in cell location C5 we have the adjusted azimuth of a traverse course, and in D5 we have the slope distance for that course and in E5 we have the vertical angle, the spreadsheet program will allow us to take these data and calculate the value of the unadjusted latitude, departure and elevation and place in cell locations F5, G5, and H5 respectively. The power of the spreadsheet can be seen from the fact that it can be told to perform the same calculations for all the data within the specified column positions and thus compute the latitude, departure, and elevation for all legs of the traverse.

Table 2. Comparison of the data item capacity of modern programs.

Name of Spreadsheet Program	Total Cells
VISICALC	16,002
LOTUS 1-2-3	524,288
EXCEL	4,194,304
QUATTRO-PRO	2,097,152

In picking a spreadsheet program for surveying, it is important to consider the following:

1. That the program will perform all the mathematical and trigonometric functions needed for computing the data desired.

2. That the degree of precision or number of significant figures to which a number can be calculated is appropriate.

3. That the program will recalculate (that is, if a value is changed in the data, the program will recompute the remaining values that were dependent on the one changed).

4. That the screen and the print-out must be able to be formatted.

5. That the program has a good, easy to read instruction manual and/or tutorial or help screen available.

While the electronic spreadsheet is relatively inexpensive, it is a very flexible and powerful item of software that can be of great use to the cave surveyor.

Computer Assisted Drafting (CAD) Systems

A number of Computer Assisted Drafting (CAD) systems are currently available on the market. AutoCAD is probably the best known system. Others that can be obtained include: SURVCADD, PRODESIGN II, CADDVANDTAGE PLUS 4.2, GENERIC CAD, and a program produced by the U. S. Geological Survey called GSMAP/GSDRAW. CAD systems are primarily drafting systems. Many of the surveying programs have provisions to transfer the final compiled data to a CAD system for final drafting.

A thorough knowledge of the use of a CAD system will show how it might be applied to cave mapping. The cave map itself can be drawn in final form using one of these systems. Probably one of the best features of a CAD System is the ability to correct errors and change drawings easily and then print out the newly revised drawing without having to completely redraw the map.

Scanners

A handheld page scanner can be used to scan field notes and transfer the image into a CAD program where it can be joined with data transferred from a mapping program. The image from the scanned pages can then be enlarged, reduced, rotated or even stretched to fit the survey framework. Portions of the image can then be traced using CAD commands to add to the cave map.

Professional Surveying Programs

There are many commercial surveying software packages available on the market. These include the following: CEDRA SYSTEM, INTERGRAPH SYSTEM, D.C.A. Engineering Software, Westcom Software, MAPTECH by AutoCAD,

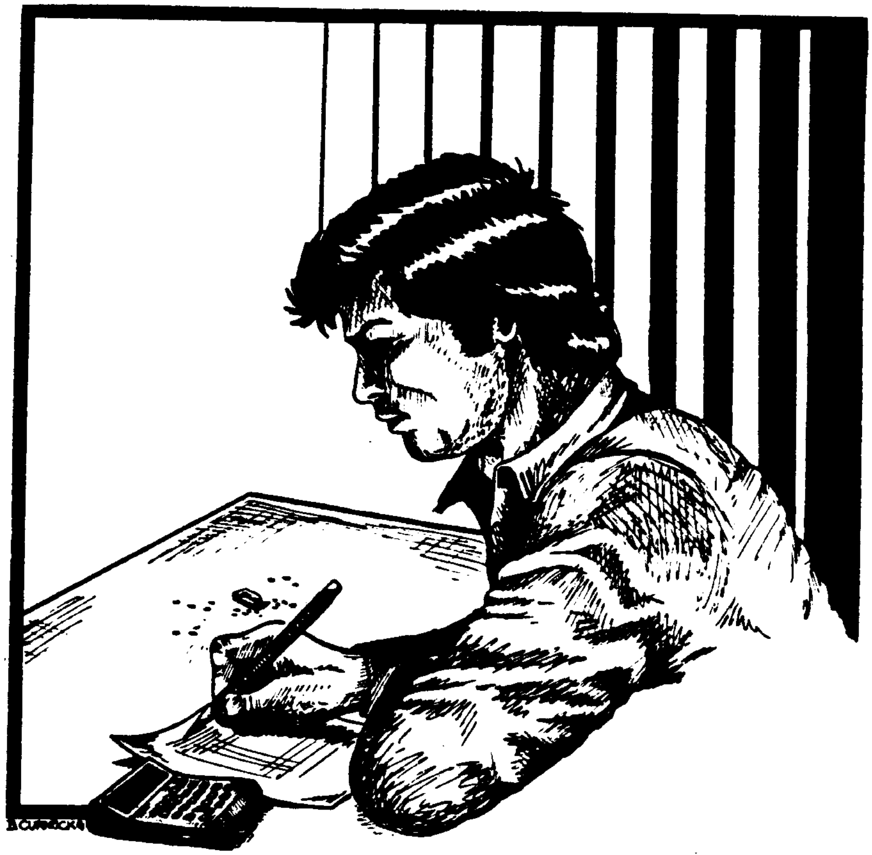
Simplicity Systems, MTI Survey Software, Tech-Mac Survey Systems, Lietz Software System, Benchmark Professional Survey System, Surv-A-Soft, Quicksurf, and Wildsoft.

Professional surveying software packages are designed to accept all types of raw survey data from compass bearings or azimuths, vertical angles or zeniths and distances to turned angles to the right or deflection angles with backsights and frontsights. The survey data is entered into the computer as the program prompts you with such things as the identification of the instrument station or occupied station, previous station, and next station; elevation of the station, height of instrument, horizontal circle for backsight, horizontal circle for frontsight, vertical or zenith angle and distance. Provision is made for entering azimuths or bearings. This original data is then locked in a file which cannot be altered. In professional surveying this can become part of a legal document showing what was observed during a survey of an area. The data file can be copied and the copy can be changed or adjusted, and coordinates computed as part of the program. From the coordinates, all the survey points can be plotted, either on the monitor screen or on a plotter and thus the framework for the survey can be laid out. These programs also feature some other valuable parts, including a coordinate geometry feature which allows the calculation of areas, volumes, distances and directions between any two points in the survey. Other features of the program which are possibly applicable to cave surveying include an automatic contouring feature which is valuable if you have enough controlled survey points. In addition there are some on-line graphics which can be used to allow some drafting and plotting of maps. Many of the programs require specific surveying equipment as well as data collectors (which are basically small computers) designed to store all the survey data in the field. These data collectors can be interfaced directly into the computer system to download the field data directly, thus saving time and decreasing the likelihood of an error occurring during data entry.

The main drawback to these commercial programs for cave surveyors is their high cost. For most cave applications, this degree of sophistication is not necessary.

Three Dimensional Computer Representation of Caves

One of the interesting possibilities of computer applications to cave surveying is the generation of a three dimensional representation of the cave. If enough data are available in terms of height, width and length of the cave passage, it is possible to portray the cave in three dimensions using a CAD system like AutoCAD. The advantage of this is that the view direction of the cave can be readily changed and so that it may be viewed from the north, south, east, west, top, bottom, and obliquely from any place in between. An excellent treatment of the subject can be found by Fred L. Wefer in his discussions entitled "The Computerization of the Cave Map", and a series of three articles on Stage 4 Cave Maps in the 1989 and 1990 issues of Compass and Tape.



12

ADVANCED SURVEYING TECHNIQUES

Once you have mastered the basic techniques of compass and tape surveying and can map a cave completely using these tools, you might consider using some of the more accurate and/or advanced techniques. Most of these have special applications, and not all of them have application to just any cave. In all cases, special instrumentation is needed and careful techniques are required. Some of the methods include plane table/alidade and stadia, transit or theodolite, and laser/light and camera.

PLANE TABLE/ALIDADE AND STADIA METHODS

The alidade and plane table are surveying instruments which have been used by geologists and topographers for years. Through the use of the stadia board and the alidade (surveying instrument), distances can be determined and a map can be created directly while the cave or area is being surveyed. This method has been used for mapping topography, geology, and for other detailed types of surveys which call for a direct plot of data on a map. It can also be used to make a highly accurate large scale map.

In cave surveying there are some marked disadvantages in the use of the plane table and alidade. These include:

1. The plane table, alidade, and incidental equipment are usually cumbersome and difficult to move through the cave.

2. The alidade can easily become maladjusted.

3. The applicability of the method is limited to open areas both on the surface and underground.

Even with the disadvantages, in easily accessible large cave rooms, a plane table and alidade can be very useful in accurately portraying cave details. The authors have successfully used the method to survey large rooms in two caves in southwest Missouri.

EQUIPMENT AND SUPPLIES

Basic equipment for this method consists of a plane table, alidade, and stadia board. In addition, you need to have an engineer's scale, a pencil, a large sheet of paper for the plane table board with a waterproof cover, a scratch pad, and a calculator.

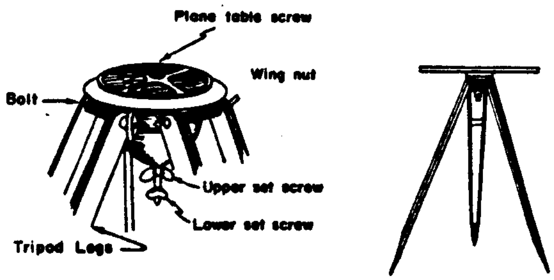


Figure 12-1. The plane table and its components.

Plane Table

Plane tables consist of two parts: the drawing board and a tripod. Drawing boards range in size from 15 x 15 inches to 22 X 30 inches. A map sheet is fastened to the drawing board and the map is drawn directly on this sheet as the survey is made. A waterproof cover should be included for cave surveys to protect the map from water dripping from the ceiling. The drawing board has a special plate attached to the bottom which allows it to be joined to the tripod. The tripod can have either fixed or adjustable legs and usually has a special head, called a Johnson Head, which allows the plane table when attached to the tripod to swivel and rotate so that it can be leveled and oriented to north (figure 12-1).

Alidade

The alidade is a portable transit-type instrument used for determining distance and direction. Several types of telescopic alidades are on the market, all based on the primary principle of measuring distance by stadia interval and the proper plotting of their respective directions and distance by using the fiducial edge of the instrument and a scale. The most suitable type of alidade for use in cave surveying is naturally the smallest and most portable model.

Most alidades have a specially graduated vertical arc called the Beaman Arc attached to the side of the telescope at the horizontal axis. This mechanical device is used to determine differences in elevations and corrections for slope in distances (figure 12-2).

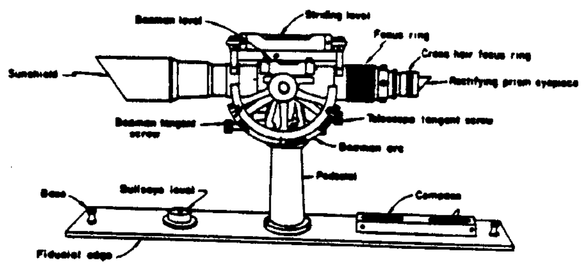


Figure 12-2. The alidade and its component parts.

Since the alidade is a precision surveying instrument, it should be handled with care both during transportation and while in actual use.

Stadia Rods

There are many types of stadia rod, most of which are divided into foot and tenths of foot units. These markings should be readily recognizable (figure 12-3). The primary requisites for stadia rods include:

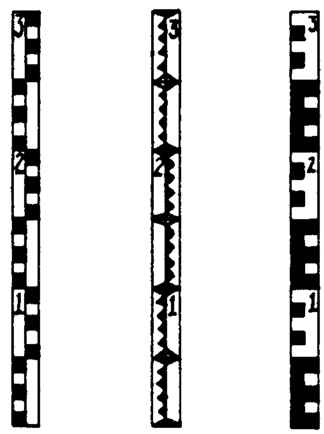


Figure 12-3. Stadia rod types.

1. Legibility - the numbers must be read through a telescope from a distance.

2. Sufficient length (10 to 14 feet) to accommodate long observations. For cave surveying it is necessary to have a stadia rod that is from 4 to 6 feet long.

3. A design, material, and construction which will permit relatively easy transportation.

USE OF STADIA TO DETERMINE DISTANCE AND ELEVATION

Through the use of a stadia board or rod (see chapter 3, figure 3-6), and a sighting instrument with cross hairs and stadia hairs (alidade), it is possible to determine fairly accurately the distance and elevation difference between sighting instrument and the stadia rod.

Distance Measurement

An alidade (or transit) is designed so that the upper and lower horizontal cross hairs (stadia hairs) on the telescope intercept a one-foot interval on a stadia rod at a distance of 100 feet. This distance between the upper and lower stadia hairs is designated the stadia or rod intercept (R). The laws of perspective state that the dimensions of the intercept vary proportionally as the distance between the instrument and the rod is increased or decreased from this constant 100 feet. From this we have a direct means to determine any field distance by using the equation:

Distance = amount of rod intercept (feet) X 100

Distance = 100 R

This is true only for the actual or slope distance between the rod and the alidade, and only if the rod is perpendicular to the line of sight. This distance must be adjusted to obtain the horizontal distance, which can be calculated by using the following equation (if the stadia rod is held in a vertical position):

Hor. Distance = (1 - sin a) X 100 R

H. D. = 100(1 - sin A)R   A = slope angle

Elevation Measurements

The difference in elevation between the alidade site or station and the target point can be determined by creating a line of sight that is parallel to the ground surface between the two points. This can be done by measuring the height of the instrument (HI) and then sighting the stadia rod at the same height above the ground. The height of the instrument can be determined by using a tape measure or the stadia rod and measuring the distance from the ground to the center of the horizontal telescope axis.

The equation then for the difference in elevation between the two points would be:

Vert. Distance = slope dist. X sine vert. angle

Because of the geometry of the inclined shot on a vertical stadia board, the equation becomes:

Vert. Distance = 100 X R (1/2 Sin 2A)

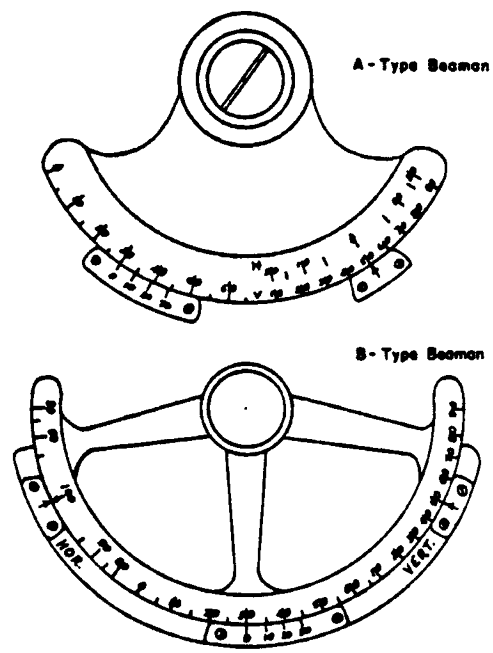


Figure 12-4. The Beaman arc and its variations.

Beaman Arc

The Beaman or Stadia Arc is a special

accessory on the alidade which simplifies the calculations of elevations and horizontal distances. By using this device, the trigonometry calculations discussed above are eliminated. The Beaman Arc is a specially designed graduated vertical arc attached to the common or regular vertical arc or the alidade (figure 12-4). It is laid off in two scales, one marked H for horizontal, the other V for vertical. The arc design can be one of two types, both based on the same principle and both read by the same operation. In the A type, the H and V scales are concentric and the coincident zero point of each scale is 0 and 50 respectively. The other or B type has the H and V scales on the same arc, but the scales are at the opposite ends of the arc. On the B type H scale, the coincident zero point of each scale is 100 on the H and 50 on the V.

The method used to determine the vertical difference in elevation is to sight in the stadia rod with the lower stadia hair set at an even number on the rod while the center cross hair is near the HI as determined above. Determine the stadia interval by observing the distance on the rod from the lower stadia hair to the upper. Then set the center cross hair to the HI and read the Beaman V index. To determine the elevation difference use the following equation:

Elev. Diff. = R X (V - 50) - Rod + HI

The procedure used to determine the vertical difference in elevation is:

1. Read the V scale on the Beaman arc.

2. The V index reading, minus 50 (algebraically), and multiplied by the stadia intercept, will give the difference in elevation between the center of the instrument and the point on the rod intercepted by the center cross hair.

3. The elevation difference, minus (algebraically) the middle cross hair reading and plus the HI or height of the instrument will give the actual vertical distance between the ground point of the instrument and the bottom of the stadia rod at the station.

Two examples of this method are:

Case 1. Stadia intercept = 3.4 feet
Height of instrument = 3.5 feet
Center cross hair on rod = 4.5 feet
V reading is 25

Elev. Diff. = [R X (V - 50)] - Rod + HI

Elev. Diff. = [3.5 X (25 - 50)] - 4.5 + 3.5 = -84 feet
or 84 feet below the instrument.

Case 2. Stadia intercept = 4.0 feet
Height of instrument = 3.5 feet
Center cross hair on rod = 3.8 feet
V reading is 67

Elev. Diff. = [4.0 X (67 - 50)] - 3.8 + 3.5 = 67.7 feet or 67.7 feet above the instrument.

To determine the horizontal distance, determine the type of Beaman arc and then read the H index and use the appropriate equation for the specific type.

A-Type Beaman - this gives the correction factor as a percentage of the slope distance. All that is necessary to determine the horizontal distance is to take the stadia intercept X 100 times the percentage from the Beaman Arc.

Hor. Dist. = R X 100 X H%

B-Type Beaman - this gives the correction factor as a value that must be subtracted from the slope distance. To do this take the H value from the Beaman and multiply it times the stadia intercept times 100. This should then be subtracted from the slope distance to get the horizontal distance:

Hor. Dist. = (R X 100) - (R X 100 X H%)

The procedure used to determine the horizontal distance is:

1. The H or Horizontal value and V or Vertical index are on the same scale and can be read at the same time.

2. The stadia intercept multiplied by 100 gives the stadia or slope distance.

3. The slope distance is then corrected to the horizontal distance as described above.

Some examples of both types of Beaman are:

A type: Rod intercept = 9.2 feet
Slope distance = 9.2 X 100 = 920 feet
Hor. Beaman = 95 or 95 percent
Horizontal dist. = 95% of 920 feet = 875 feet

B type: Rod intercept = 9.2 feet
Slope distance = 920 feet from above
Hor. Beaman = 5 or 5 percent
Horizontal dist. = 920 - (920 X 0.05) or 920 - 45 = 875 feet.

PROCEDURE FOR MAKING A PLANE TABLE SURVEY

The ideal plane table survey party consists of three people: a rod handler, surveyor, and calculator. The party can get along with just the rod handler and the surveyor, but this makes the process slower. The party should have the following items of equipment:

1. Plane table with waterproof cover.
2. Paper for plane table board and tape to hold it in place.
3. Johnson Head tripod.
4. Calculator
5. Pencils and eraser
6. Engineer's scale
7. Field Notebook for the rod handler
8. Field Notebook for the surveyor
9. Scratch pad for calculations

In conducting the survey, the rod handler will pick the sites for points in the field or in the cave and set up the rod on them. If you are making a topographic map and you are the rod handler, then you must pick points which will afford critical and important topographic locations. You must then make notes concerning what each station is so that later you can help plot the details on the map. Likewise, in the cave you should pick points that are significant to the cave map. You should also make sketches of what you see to aid in the construction of the cave map. Stations in the field notes should be numbered in the same sequence as the stations at the plane table.

As the surveyor, you must plot all of the points and draw the map as the data comes in. Basically, you have the following responsibilities:

1. Set up the tripod with the legs firmly set in the ground at the point that will be the initial survey point with the tripod head as close to level as possible.

2. Place the plane table on the tripod and screw it onto the tripod head.

3. Be sure that both wing nuts on the tripod are tightened snug, but not too tight.

4. Take the alidade out of its case and set it on top of the plane table board near the center.

5. Loosen both the upper and lower wing nuts of the tripod set screws on the tripod head (figure 12-5). Using the "bull's eye level" on the alidade, level the plane table board as shown in figure 12-5 and tighten the upper wing nut.

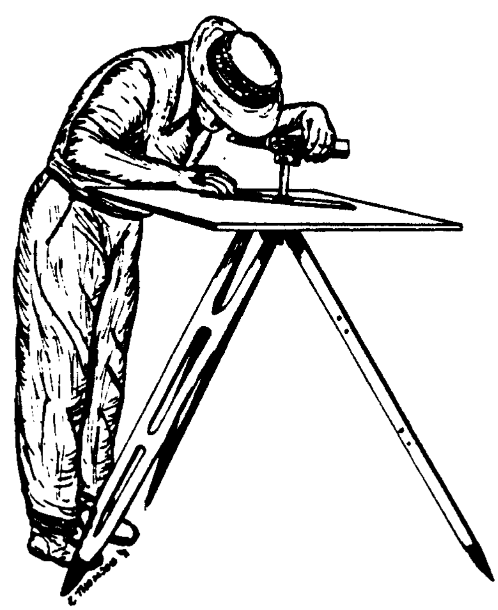


Figure 12-5. The plane table and how to set it up.

6. Put a sheet of paper on the board and fasten it

down securely. Place the alidade parallel to one side of the plane table board and rotate the board until the compass needle on the alidade is pointing to magnetic north. Tighten the lower wing nut and then check the compass and draw a north arrow along the fiducial edge of the alidade. This should be marked as magnetic north. The board is now properly oriented in space.

7. Plot the initial point. For the initial point, locate it on the paper in such a position that most of the map can be placed on the one sheet. If you are on a secondary point, the plane table should be set up and the previous initial point sighted to locate the new point.

8. Determine the scale to be used on the map and distinctly label it on the map. This scale is dependent on the detail to be used and the size of the area to be mapped.

9. Determine the elevation of the instrument station. If you do not know this elevation, you will have to determine it from a known point or survey it in with a level or a transit. If this is not possibly, you could just set the elevation of the initial point as 1000 (to eliminate negative elevations) and make a relative topographic survey. This is done quite often in cave mapping. If you know the elevation of the station, determine the height of instrument by measuring the distance from the ground to the center of the alidade (HI).

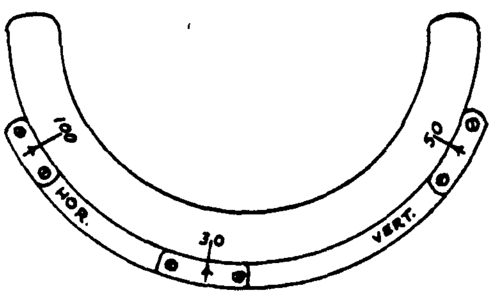


Figure 12-6. The Beaman arc set at 50 and 100 to level.

10. Make sure the alidade is level on the plane table. Set the telescope to horizontal by using the striding level. Using a reading glass, set the Beaman V index at exactly 50 by means of the vernier tangent screw (figure 12-6). Using the tangent screw on the side opposite the Beaman arc, level the Beaman so that the level bubble is centered in the vial. If the alidade is self leveling, this step is not necessary. The instrument is now ready for surveying.

11. Loosen the telescope and point the alidade at the stadia rod keeping the fiducial edge of the alidade immediately next to the instrument station on the map. Sight the rod, check the fiducial edge and station point on the board, then recheck the rod sighting.

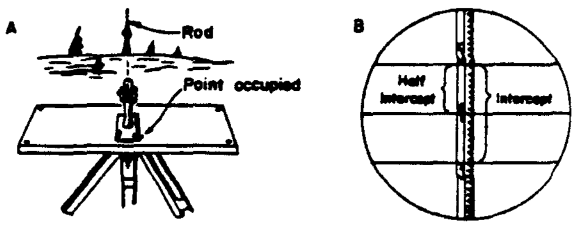


Figure 12-7. (A) Aligning the alidade on the rod by sighting over the telescope. (B) Appearance of the rod in the telescope.

12. When the alidade is aligned with the rod so that the vertical hair in the field of view is lined up with the center of the stadia rod, draw a line along the beveled edge or fiducial edge of the alidade. Draw the line lightly so that it can be erased later. Caution, do not draw the line completely through the instrument station. Because of the many lines that will be drawn, the station area will become too cluttered.

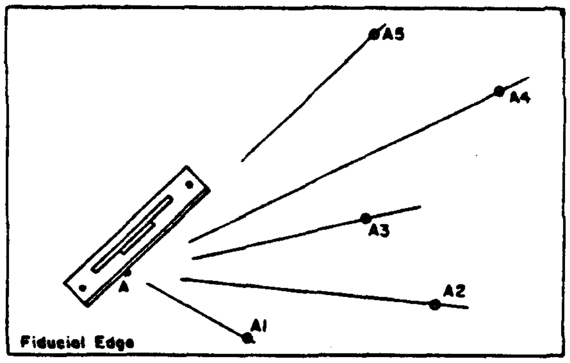


Figure 12-8. Drawing rays along the fiducial edge of the alidade to the survey stations.

13. Determine the stadia intercept for each station by

using stadia. A view through the alidade telescope may look something like the drawing in figure 12-7. To use the stadia, sight approximately on an even whole number on the lower stadia cross hair (any whole foot mark will do). In figure 12-7 this value is 3.0. Tighten the axis clamp on the telescope using the tangent screw, set the bottom cross hair exactly on an even whole number on the rod. Determine the distance from the lower cross hair to the upper cross hair as you see it on the stadia rod. It is best to count the feet and tenths and then estimate the hundredths up to the top stadia hair. Counting will help to prevent errors caused by subtracting readings of the lower stadia hairs from the upper. Be careful to have the cross hairs in focus and double check your readings.

14. After clamping the horizontal axis of the telescope securely, use the tangent screw to adjust the "V" scale reading on the Beaman arc. The "V" scale number nearest to the Beaman index is moved exactly to the index mark by adjusting the tangent screw. Read the "V" on the Beaman arc and record it in your notes. This index number should be somewhere between 0 and 90 (figure 12-9). At the same time read H on the Beaman and also record it in your notes.

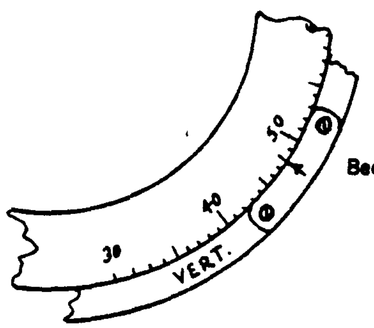


Figure 12-9. Adjusted Beaman showing how the "V" should be read after adjustment.

15. The V index reading minus 50 gives the V factor. Record in the notes. V will be positive if the rod station is higher than the instrument station and negative if lower. This factor, multiplied by the stadia interval or intercept, will give the difference in elevation between the center of the instrument and the point on the rod intercepted by the middle cross hair. Record this value. This quantity, minus (algebraically) the middle cross hair readings and plus the HI will give the actual vertical distance between the ground point of the instrument and the bottom of the stadia rod. Record this data both in the field notes and on the map sheet.

16. Read the value of the horizontal cross hair on the rod (figure 12-10) and record. At this point you can signal the rod person to move to the next rod station.

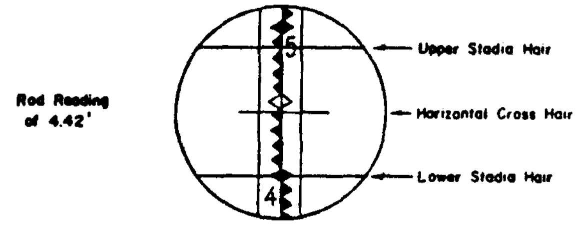


Figure 12-10. Location of the horizontal cross hair on the rod.

17. Determine the true horizontal distance. If the H reading is in the range of from 80 to 100, this becomes a direct percentage and you use this on the stadia distance determined above. This becomes the true horizontal distance which should be recorded.

18. Using an engineer's scale, plot the points and their elevations through the use of the stadia information and a scale. The line along the edge of the alidade when the edge is on the initial point and the cross hairs are on the rod, is a true bearing from the instrument to the rod. A line can therefore be drawn along this edge or bearing, and a distance scaled on the paper indicating the distance to the rod. Corrected readings must always be used for both the elevations and distances.

19. If a topographic map is to be made, contours can be drawn in the field and observed detail can be incorporated into the map.

20. If underground surveying is to be done, the passage widths as well as other passage details should be drawn on the map. It is easier to do this in the cave, than to try to remember the details later. That is

another reason for good complete notes at all times.

KEEPING NOTES

All field notes should be kept in a good quality field notebook. The following headings should be used in the field notebook: Station, Stadia Intercept, Slope Distance, Horizontal Beaman, Vertical Beaman, Height of Instrument, Survey Rod, Elevation Difference, and Corrected Horizontal Distance. In addition, the rod handler should be keeping notes which have the same station numbers and a description of each point.

In making computations, keep the figures either on the plane table paper in numbered squares which correspond to the station numbers or on scratch paper again with numbers corresponding to the station numbers.

TRANSIT OR THEODOLITE SURVEYS

A transit is an instrument which is used to determine vertical and horizontal angles (figure 12-11). In combination with a stadia board or a 100 foot steel tape, distances can also be determined. Basically, the transit consists of a telescope containing a vertical cross hair and three horizontal cross hairs (two stadia hairs and the center cross hair).

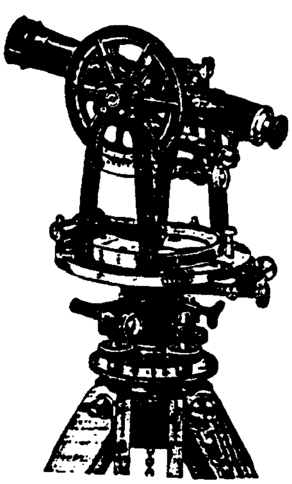


Figure 12-11. The surveying transit.

This telescope is mounted on both a horizontal and a vertical axis, each with a circular protractor. In addition, many transits have a compass in the base to be used for orientation. A theodolite is similar, but generally does not have a compass (figure 12-12). The vertical and horizontal angles can be read through a microscope arrangement which magnifies the scales on the horizontal and vertical protractors. The theodolite is generally much more accurate than the transit. In many cases an electronic distance measuring device can be attached to the theodolite to determine distances electronically.

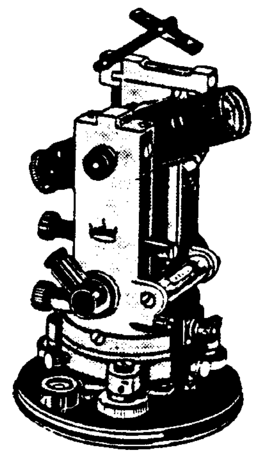


Figure 12-12. The surveying theodolite.

The transit can be used to measure exact horizontal angles relative to some arbitrarily chosen orientation. There are two ways in which this is generally done:

1. **Angle to the right method.** The angle between the two stations is turned to the right by taking a backsight on the previous station, setting the horizontal circle to 0, then turning the angle to the right to the next succeeding station and reading the angle turned. This angle is then recorded in the field notes. To make the method more accurate, the current angle reading is clamped in and the telescope turned back to the original station, centered on the station and unclamped and the angle turned to the right again. Now the angle should be twice the size of the correct value. This can be done several times and should be done with the telescope normal and inverted an equal number of times. The total angle divided by the number of times it was measured,

gives the angle which can be determined to less than 10 seconds of arc.

2. **Deflection angle method.** Here again, the horizontal circle is set to 0 and the previous station is sighted with the telescope. The telescope is inverted, the line is then prolonged and the deflection angle to the next station, either to the left or right is measured. Again, this number can be multiplied to get a more probable answer. Again the angle can be determined to less than 10 seconds of arc.

The vertical angle can also be determined precisely by sighting on the target station with the telescope and reading the angle on the vertical protractor scale. This angle can also be multiplied for greater accuracy. Be sure that when you measure the vertical angles, that you measure parallel to the ground surface. This can be done by determining the HI (height of instrument) and then placing the horizontal cross hair at that same height on the rod or at the next station.

Horizontal distances can be determined with a transit using either a 100 foot steel surveying tape or a stadia rod in the same manner as described above in the section on Plane Table/Alidade and Stadia. The total station electronic distance measuring unit contains a theodolite which can be used to turn both horizontal and vertical angles and can digitally display them on an electronic screen. In addition, an electronic distance measuring unit is included to determine distance very accurately.

There are some advantages to using a transit. The information obtained with the transit is basically the same as that obtained using compass and tape—the direction, vertical angle, and distance. However, there are several orders of improvement of precision with the transit. Direction as determined with the transit is found without the problems of magnetic anomalies or declination variations as is the case with compass surveying.

There are also some disadvantages. First, the equipment is very expensive and delicate. Mud, water, and a transit are not very compatible. Second, the equipment is very bulky and heavy, and must be set on a tripod. Unless you are surveying in large trunk passages, the transit is impossible to use. Third, the instrument is very sensitive and takes time to set up, level, and precisely take the direction and other measurements. It can take up to 10 times as long to get a transit direction as it does to get the same information with a compass. Fourth, an error in one direction measurement will be carried though the entire survey because of the dependence of each direction on the previous direction. However, by multiplying angles, almost any error of direction can be picked up and corrected.

The transit is a very accurate method of survey, but its use in cave surveying is very limited because of the physical nature of most caves. The transit often is used on a surface survey to connect cave entrances together or to tie the cave entrance to a bench mark or section corner for a precise location.

CROSS SECTIONS OR PROFILES BY LASER/LIGHT AND PHOTOGRAPHY TECHNIQUES

Profiles can be exactly portrayed using a 35 mm camera and a columnated light source. A discussion reprinted in the June 1981 issue of the N.S.S. News under Safety and Techniques states:

"Using a flashlight (or headlamp) secured to a tripod in such a way as to enable it to be rotated in the vertical plane at right angles to the center line of the cave, a strip of high intensity light is projected on the cave wall. This light is then photographed with a camera on a tripod using a wide-angle lens, wide open, on ASA 400 film.

"With the shutter open, the flashlight is rotated 10 to 20 times for periods varying from 90 to 150 seconds, depending on the type of cross section encountered.

"In order to have a comparative scale available for subsequent measuring and plotting of each profile, a one-meter staff having a (cat's eye) reflector at each end is fitted horizontally to the tripod and photographed by flash on the same negative."

In an article written in the Wild Reporter #21, May 1983 (Newsletter of Wild-Heerbrugg, Ltd.), Reprinted in Compass and Tape, Vol. 2, No.

2, P. Waldhausl discusses the use of a laser in place of the light discussed above and having the camera mounted on a theodolite. In this discussion, a Wild T16 theodolite had been fitted with a GLO laser eyepiece. Since the laser beam goes through the optics of the theodolite, the shots taken with the instrument are visible. At the location where the profile is to be taken, a pentaprism is set up which can be rotated with a motor. This pentaprism is designed to be perpendicular to the laser beam. As the prism rotates, the laser produces a thin band of light on the wall surface of the cave. This is then photographed with the 35 mm camera attached to the theodolite telescope with its film plane parallel to the profile. The time exposures are made on high-speed color diapositive film (Kodachrome 400 ASA/27 DIN) similar to the system designed above, with exposure times ranging from 5 seconds to 60 seconds depending on the distance from the profile, size of the profile and reflectivity of the wall surface. A photoflash can then be used to show the adjacent area of cave wall and to show a scale bar. Greater accuracy of the profile can be obtained with a more sophisticated camera system. The author described a case where over 500 profiles were measured in the Koppenbruller Cave in Austria using this method.

Wild Heerbrugg has an automatic laser level which can simplify the above system. An automatic laser level is designed with a horizontally rotating prism which sends a laser beam in a horizontal circle so that levels can be directly obtained by using a rod with a detector that identifies the location of the beam on the rod. The Wild level has a provision to hinge back the top, add an optional adapter and the laser then generates a vertical plane (figure 12-13). This can then be photographed as described above to portray the profile.

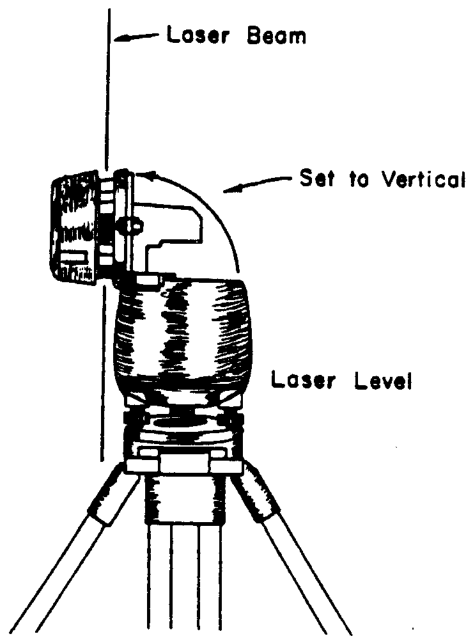
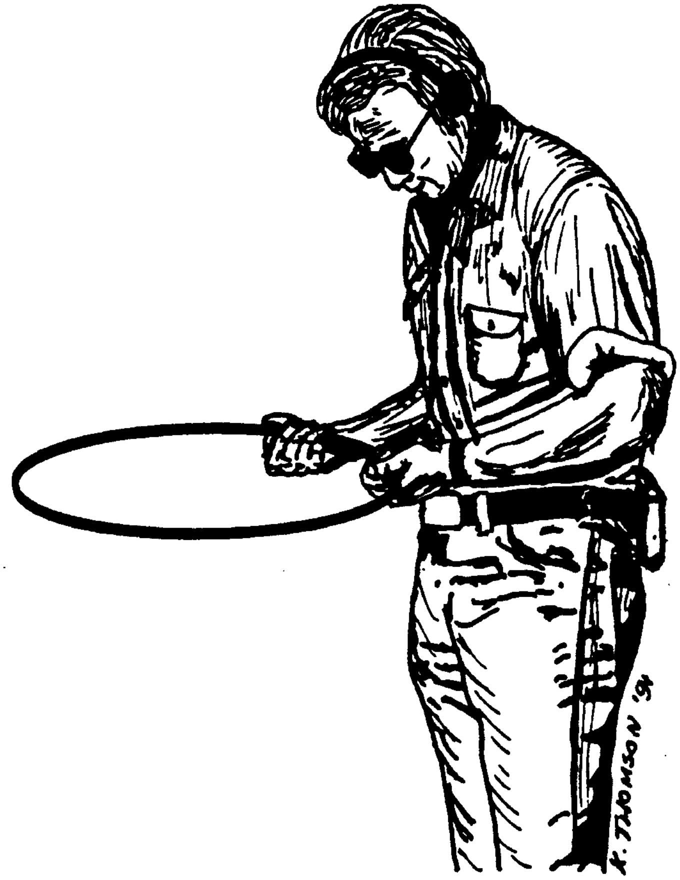


Figure 12-13. Laser level set up to create cross sections for the cave map.

Figure 12-14. Profiles as generated by the use of laser level.



13

CAVE SURVEYING BY MAGNETIC INDUCTION

In complex caves with interconnecting passages, conventional cave surveying methods can be used to provide an accurate cave map. This accuracy is possible due to the opportunity of controlling systematic and random errors by surveying loop closures which provide a check on the accuracy of the survey. However, in cave surveys in long narrow passages ending in sections that are too tight, sumped or blocked off in some other way, surveying accuracy is not certain because these traverses cannot be checked by loop closures. In this case, the exact location of the passage with regards to the entrance and surface features becomes doubtful. In cases where it is critical to know precisely where a cave passage is running, such as consideration of alternative cave entrances or the possibilities of connecting two caves or two sections of the cave with a tunnel, it is necessary to rely on some type of a control mechanism that can help to reduce the probability of errors in the traverse. It is in this situation that a geophysical technique known as magnetic induction surveying can become quite useful. In 1981, one of the authors was able to successfully check the accuracy of a cave survey in Arkansas in which a new entrance was to be created. A standard cave survey was run and then magnetic induction surveying techniques were used to verify the surface location of a passage in the cave. Later drilling and excavation proved the effectiveness of the technique.

Magnetic Induction Surveying techniques have been used in various forms for many years. It was first demonstrated in the United States and Canada in the late 1920s to early 1930s (Eve and Keys, 1929). Through the years a number of people and organizations employed various modifications of the technique for locating cave passages from the surface (Charlton, 1966; many British, American, and Australian Groups described by Glover, 1976; Caving Information Series --Number 18 by Bill Mixon) and even the federal government employed the technique for finding trapped miners in deep mines (U.S. Bureau of Mines Report of Investigations 8745, 1977; and other reports and contract reports). The methods were refined and further described by Reid (1984), and Bell (1988). With the advent of smaller scale electronic components, the equipment involved has become scaled down and easier to use. This makes the system and the technique more available to the cave surveyor and in fact, most individuals build their own system for a reasonable cost.

PRINCIPLES OF MAGNETIC INDUCTION SURVEYING

To describe the principles of magnetic induction surveying we must begin by examining the magnetic field surrounding a simple bar magnet. This can be easily done by taking a bar magnet and placing a sheet of paper over it an then sprinkling iron filings over the magnet. The filings will line up along the magnetic field lines giving a pattern similar to the one shown in figure (13-1). This pattern can be defined mathematically, but a few main characteristics should be noted: (1) All the lines of force describe ellipses that close with the exception of that line of force that goes through the long direction of the magnet. This latter is a curve of infinite curvature. (2) There are three places where the field lines are parallel: directly perpendicular to the bar magnet on each side and straight through the middle of the long direction of the magnet. (3) In all other places, the lines effectively point toward the magnet or away from the magnet. If we had a strong bar magnet held vertically in a cave, these lines of force would emerge at the surface of the ground and if we could locate the one that is vertical, we have the point directly over the bar magnet in the cave. Once we have located the point directly over the cave or the bar magnet, we can then measure the vertical or zenith angle made by any other line of force emerging at the surface at a given distance from the point directly over the bar magnet and from this calculate the depth of the bar magnet below the surface.

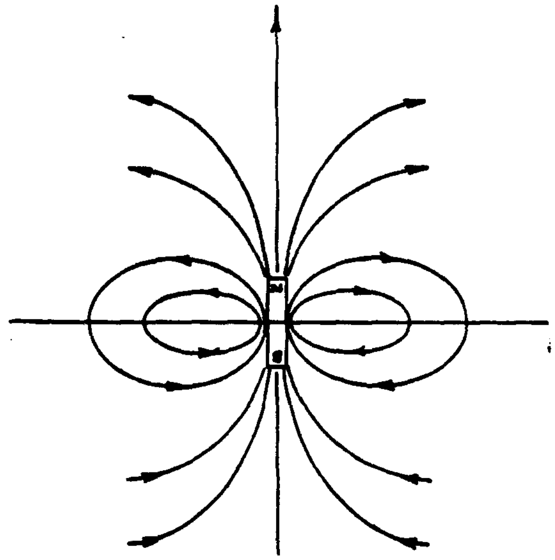


Figure 13-1. Flow lines around a bar magnet.

It is known that electricity flowing through a flát coil of wire will give essentially the same magnetic flow lines as a bar magnet. If we replace the bar magnet in the cave with a flat circular coil of wire mounted horizontally, we should have the same lines of force flowing through the rock from the coil (figure 13-2). Since the strength of the magnetic field is determined by the current flowing, the area of the coil and the number of turns of wire in the coil we can actually vary the strength of the magnetic field by changing these conditions.

Detection of the Magnetic Field

The direction of weak, static magnetic fields other than that of the earth itself are difficult to detect and measure. An oscillating magnetic field will induce a voltage in a coil of wire that is placed so that the lines of force pass through the coil. Here the amount of voltage induced depends on the coil area, number of turns of wire in the coil and the frequency of oscillation of the magnetic field. This coil becomes a detector for the magnetic field. This detector is designed so that it is thin, flat, and circular. The direction of the force field can be determined by turning the detector coil until its plane is parallel with the magnetic lines of force. When this occurs, no lines of force can pass through the coil and no current will be detected (figure 13-3). The point directly over the coil in the cave can be determined by finding the point where the coil held in a vertical plane and rotated will have no current flow. The slope or dip of the magnetic flow lines can also be detected by holding the coil in a horizontal position and then rotating it about a horizontal axis perpendicular to the flow lines. The dip at which the voltage is not detected is the dip of the flow lines.

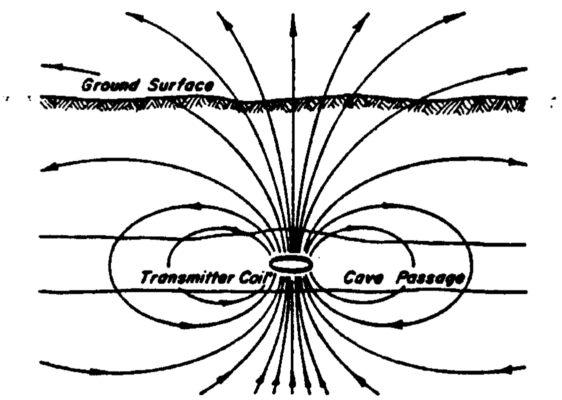


Figure 13-2. Flow lines around an electromagnet placed in a cave and method of determination of ground zero and depth of transmitter coil.

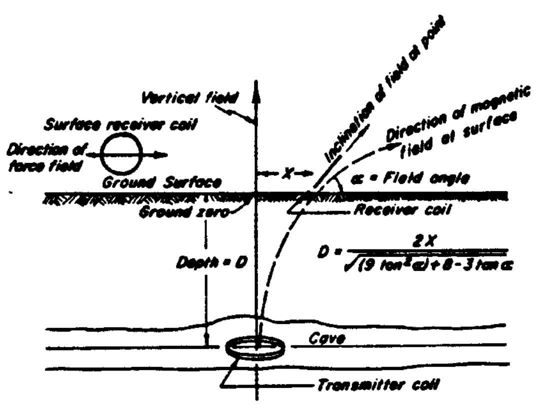


Figure 13-3. Principle of depth determination using magnetic induction.

It is important that the strength of the magnetic field induced by the underground coil be sufficient that it can be detected on the surface. In induced magnetic fields, the field strength along the direction of the transmitter coil axis decreases as the distance from the coil is increased. Because of this, the field strength or signal power at the receiver is an inverse function of the sixth power of the distance between coils.

MAGNETIC INDUCTION EQUIPMENT

Equipment used for the above procedure must be light weight, portable and easy to use in the cave and in the field. A complete system consists of a transmitter coil and its electronics and a receiver coil and its electronics. The transmitter is basically an audio oscillator driving an amplifier which drives a coil. In addition, a device is added to cause the circuit to pulse rather than give a steady signal. The receiver is a simple resonant coil connected to an audio amplifier. It is important to use crystal earphones to prevent the feedback that will occur in magnetic earphones. Circuitry diagrams for both the transmitter and the receiver are available from many published sources such as: Charlton, 1966; Mixon, 1969; 1973; Reid, 1984; and Bell, 1988.

FIELD PROCEDURES

The Transmitter

The transmitter should be quite rugged and waterproof as it is the portion of the system that must be transported underground to the exact location of the point to be determined. Once the transmitter is at the location desired, it must be placed in a perfectly horizontal plane. This can be accomplished if the transmitter has either a bullseye level bubble or two spirit level bubbles at right angles to each other mounted in alignment with the coil. The transmitter is then turned on. Some transmitters are capable of voice communication with the surface, which can be quite useful in running the survey.

The Receiver

The receiver should be a rigid coil that is also flat, light and portable. It should be capable of being suspended vertically so that it can be rotated about a vertical axis or held so that rotation about a horizontal axis is possible. The receiver should also be fitted with a protractor/plumb bob unit to measure the dip angle of the magnetic field. The receiver amplifier should provide a signal strong enough to drive earphones so that the operator can detect a null signal.

Interferences with the System

Power lines are probably the major source of interference, even in isolated areas. Thunder storms can also be a problem. In addition, magnetic field lines will follow fence lines, pipe lines and other linear metal objects. The operator should be aware of these interferences and realize that readings taken near any of these features could be erroneous. Some system designs minimize the interferences.

Procedure to Find Surface Location of Cave Point

Transmitter:

1. Prior to entering the cave, check the equipment to make certain that it is functioning. The best test is to simply hold the two aerial loops in a vertical position. Then move the two loops apart until the signal is lost. This will also give an idea of the maximum depth that the equipment can be used.

2. Agree on the time at which transmission will be made unless the unit has voice transmission capability. For example, 15 minute transmissions could be made every half hour.

3. The transmitter is moved into the cave, placed at the station, carefully leveled, and transmission started at the pre-decided time.

Receiver:

On the surface there are two methods in which the surface location of the cave point "ground zero" can be determined:

Method 1

1. The receiver coil is held in a vertical plane, the signal is detected and then the coil is rotated until a null in the signal is obtained. This will give an azimuth that will pass through the center of the magnetic field or "ground zero".

2. The operator walks a hundred or so feet perpendicular to that azimuth and repeats the operation. Again an azimuth is determined. The two azimuths are plotted on a map. The intersection of the two azimuths is the location of "ground zero". A third repetition will create a triangle of error in which the "ground zero" point should lie (figure 13-4).

3. This point can then be checked by taking the receiver coil to the site and rotating it in a vertical position through 360 degrees. The signal should be null in all directions directly over the transmitter.

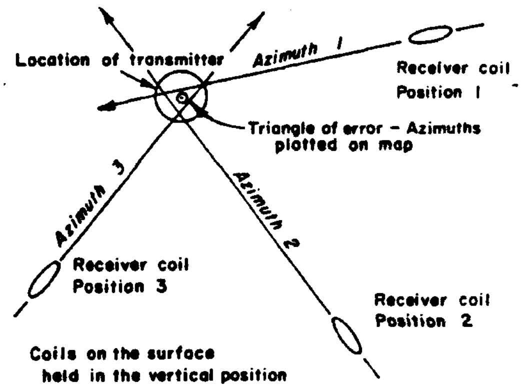


Figure 13-4. Location of ground zero - method 1.

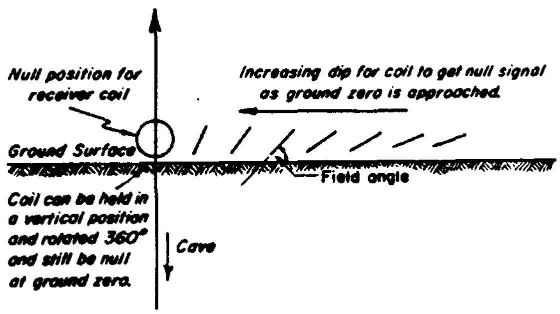


Figure 13-5. Location of ground zero - method 2.

Method 2

1. The first part of method 1 is repeated and the azimuth determined.

2. The direction along the line to the location of "ground zero" is verified by holding the coil with a

horizontal axis perpendicular to the azimuth direction.
3. The coil is rotated about this horizontal angle until a null is obtained. The direction of dip of the coil is the direction toward "ground zero" (figure 13-5).

4. The angle of dip can be determined using a protractor and plumb bob.

5. The operator then moves in the direction of dip and makes several more measurements of this dip, the steeper the dip, the closer you are to "ground zero".

6. Once the coil is directly over the cave station, it can be held vertical and rotated about the vertical axis to verify the location of "ground zero".

Determination of Depth of Point

The depth to the cave transmitter can be determined using the receiver. Away from "ground zero" the magnetic field will dip towards the transmitter. This angle of dip can be determined as discussed in Number 3 in Method 2 above. At all points on a circle at a specific radius from "ground zero" the dip value should be uniform, thus to measure the angle of dip for calculation of depth, two or three measurements should be made at the same distance but in different directions from "ground zero" and the data averaged. Using the angle of dip and the distance from "ground zero", the depth can be calculated by using the equation:

$$Depth = \frac{L(3+\sqrt{(9+8\tan^2\alpha)})}{4\tan\alpha}$$

Where: L = distance from "ground zero"
α = zenith angle of dip of receiver coil

There is a short cut method for determining the depth to the transmitter using special case dip angles. To do this, move away from ground zero until the angle of dip of the receiver becomes one of two special cases. Then the depth can be determined by measuring the distance away from ground zero and using the following simple computations:

1. Special Case α = 45°00', Depth = 1.78 L
2. Special Case α = 71°34', Depth = L

Depth can also be determined using graphical methods. The most common one used is Mixon's method (1966). A family of curves of plotting field angle of inclination against depth for equal distances from "ground zero" is shown as figure 13-5. To determine the depth, simply determine the distance from "ground zero" (L or X) and the angle of the field from either the horizontal (dip) or vertical (zenith). Mixon's chart was derived from the equation:

$$Tan\theta = \frac{3LD}{(2D^2-L^2)}$$

Where: L = distance from "ground zero"
Θ = zenith angle of dip of receiver coil

SOURCES OF ERROR

The most likely error to occur would be the failure to set the transmitter loop in a precisely horizontal position. This should always be done because a slight slope here will move the location of ground zero on the surface.

A second source of error would occur in terrain of high relief. If the receiver is on a horizontal plane with the transmitter loop, a null will occur because the field at this level is vertical just like over the top of the transmitter.

A third source of error is the presence of metallic conductors such as power lines, pipe lines, buried telephone wires, fences, etc. These can cause distortion of the magnetic field and cause some very serious errors.

ACCURACY

With good equipment and careful surveying, accuracy has been quoted at better than 3% for location and 10% for depth. Thus at depths up to 300 feet, ground zero should be located within 3 to 6 feet and depth within about 16 feet.

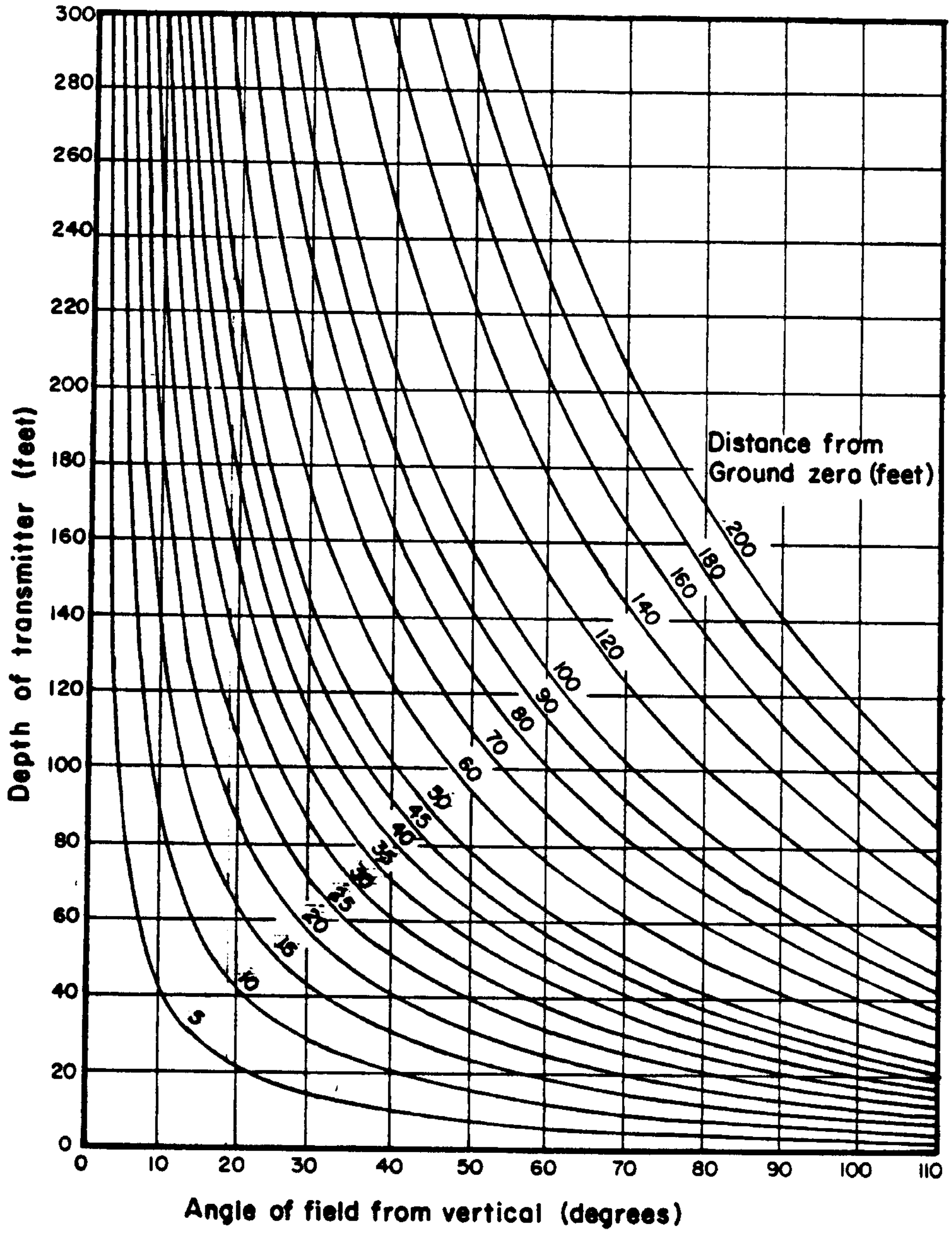


Figure 13-6. Mixon's curves for depth determination.

14

CAVE LOCATING AND ORIENTATION

The exact location of a cave as well as the exact orientation of the cave passages is very important to any cave surveying project. Many location methods are available which vary broadly in accuracy. The cave location can be determined by observation on topographic maps or aerial photos, if they are available. The accuracy of these locations depend on the ability of the surveyor to interpret the aerial photos and transfer the information to topographic maps or to be able to read the topographic map satisfactorily. If maps or aerial photographs are not available, the methods discussed in this chapter can be useful. Astronomic observations can be done by carefully using a compass or by using a transit or theodolite. Loran and GPS methods require special receivers to determine locations.

ASTRONOMIC OBSERVATIONS

Astronomic observations consist of measuring positions of the sun or certain stars for the purpose of determining the direction of the true meridian or for the determination of the location of a point by longitude and latitude. When the true meridian is established, the true azimuth of any line can then be obtained by using a compass or a transit/-theodolite.

The usual procedures used by surveyors to determine the direction of the true north meridian involve the following steps:

1. A transit or theodolite is set up and leveled at one end of a line whose azimuth is to be determined.

2. The horizontal and vertical circles are read when pointing at a celestial body.

3. The precise time of pointing is recorded.

4. A horizontal angle is measured from the celestial body to a point on the other end of the line.

The calculations used to determine the azimuth of the celestial body involves the determination of the precise location of the celestial body at the time of the observation from an ephemeris (almanac of heavenly body positions), the computation of the celestial body's azimuth based on observed and ephemeris data and the calculation of the line's azimuth by applying the measured horizontal angle to the computed azimuth of the body.

The celestial bodies normally used for the determination of azimuth are the sun and polaris (north star). Polaris observations generally provide a higher-order accuracy than those using the sun.

EPHEMERIDES

A current ephemeris is essential to using astronomical observations for the determination of true meridian. These are published by many agencies, governmental and private. The following is a list of ephemeris sources:

1. The Leitz Celestial Observation Handbook and Ephemeris, published by Elgin, Knowles, and Senne, Inc., P.O. Box 3371, Fayetteville, Arkansas, 72702 or from the Leitz Company, 9111 Barton, Box 2934, Overland Park, Kansas 66201.

2. The Apparent Place of Polaris and Apparent Sidereal Time, available from the U. S. Dept. of Commerce, National Geodetic Information Center, Rockville, Maryland 20852.

3. The Nautical Almanac, published by the U. S. Naval Observatory, available from the U. S. Government Printing Office, Washington, D. C., 20402.

THE CELESTIAL SPHERE

In using astronomical observations it is important to be able to visualize the relationship between the earth, the heavenly body, and the standard meridians and parallels for location. To be able to visualize this, we need to define and illustrate some terms (figure 14-1). Everything is related to the celestial sphere.

For a better visualization of the position and movement of the sun, stars, and celestial coordinate circles, they are projected onto a sphere of infinite radius surrounding the earth. This sphere is assumed to rotate in such a way as to conform to all the various motions of the earth as it rotates about its axis and revolves around the sun.

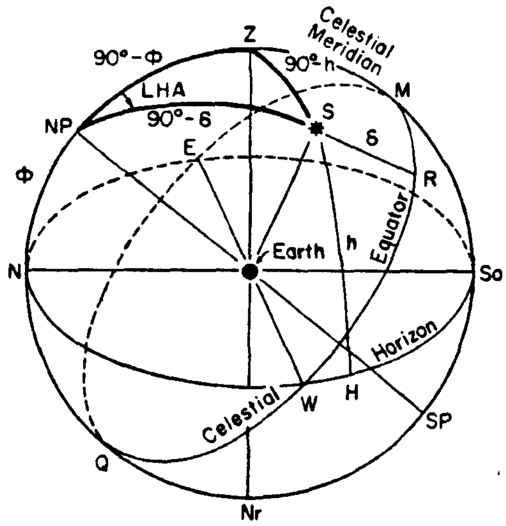


Figure 14-1. The celestial sphere.

Definitions of Features on the Celestial Sphere

North Celestial Pole (NP) - The point at which the earth's rotational axis extended from the north geographic pole, intersects the celestial sphere.

Zenith (Z) - This is the point directly above the observer's head. It is located where a plumb line projected above the horizon meets with the celestial sphere.

Celestial Equator - This is the great circle on the celestial sphere that is perpendicular to the axis of rotation of the earth. It corresponds to the earth's equator enlarged in diameter.

Hour Circle - Any great circle on the celestial sphere which passes through the north and south celestial poles. Hour circles are perpendicular to the plane of the celestial equator. They correspond to meridians (longitudinal lines) and are used to measure hour angles.

Prime Meridian - In celestial observations, this refers to the reference line that is used to measure longitude; zero degrees longitude. It passes through the Royal Naval Observatory in Greenwich, England, hence it is known as the Greenwich Meridian.

Longitude (λ) - The angle measured at the poles east and west from the Prime Meridian to another meridian. Longitude varies from 0 to 180 degrees east or west.

Horizon - A great circle on the celestial sphere whose plane is perpendicular to the direction of the plumb line. The horizon is determined by spirit level.

Celestial Meridian - This is the hour circle containing the zenith and is also defined as the vertical circle that passes through the Celestial poles. The intersection of the celestial meridian plane with the horizon determines the direction of true north. This is the astronomic line used in surveying.

Diurnal Circle - This is the complete path of travel of the sun or a star in its apparent daily orbit about the earth.

Upper Culmination - This is the body's position when it is exactly on the upper branch of the celestial meridian. This is also referred to as the **Upper Transit.**

Hour Angle - This is the angle between the celestial meridian plane and the hour circle passing through a celestial body. It is measured by the angle at the pole between the meridian and hour circle, or by the arc of the equator intercepted by those circles. Hour angles are measured westward (in the direction of apparent travel of the sun or star) from the upper branch of the meridian of reference.

Greenwich Hour Angle (GHA) - This is the angle, measured westward, from the upper branch of the meridian of Greenwich to the meridian over which the body is located at that moment.

Local hour angle (LHA) - This is similar to GHA except it is measured from the observer's meridian. It is also designated as "t" angle when measured 0° to 360°. The Greenwich hour angle is a special case of LHA as measured from the Greenwich Meridian.

Declination - The declination of a heavenly body is the angular distance measured along the hour circle between the body and the equator; it is plus when the body is north of the equator and minus when south of it. Declination is usually denoted by sigma (δ) in formulas and is represented by SR in the diagram.

Altitude - This is the angular distance of a body measured along a vertical circle above the horizon. **h or HS** in the diagram. It is measured with the vertical arc of a transit, theodolite, or sextant and usually denoted in formulas by **h**.

Co-altitude or Zenith Distance - This is designated by arc ZS in the diagram and equals 90 degrees minus the altitude.

Astronomical or PZS Triangle - The spherical triangle whose vertices are the pole (NP), zenith (Z), and astronomical body (S). Because of the body's apparent movement through its diurnal circle, the three angles in this triangle are constantly changing.

Azimuth of the heavenly body - The arc of the horizon clockwise from either the north or south point to the vertical circle through the body. An azimuth from north is represented by the angle Z of the PZS triangle.

Latitude of the Observer - This is the angular distance, measured along the meridian, from the equator to the observer's position. In the diagram it is the arc MZ or it is also the angular distance from the pole to the horizon, or arc N-NP. Latitude is measured north or south of the equator and is designated **φ**.

Vernal Equinox - This is the point of intersection of the celestial equator and the hour circle through the sun at the instant it reaches zero declination (about March 21 each year). For any calendar year it is a fixed point on the celestial sphere (the astronomer's zero-zero point of coordinates in the sky) and moves with the celestial sphere just as the stars do. In the diagram it is designated as V.

Right Ascension - This is the angular distance VS measured eastward from the hour circle through the vernal equinox to the hour circle of a celestial body. Right ascension frequently replaces Greenwich Hour Angle as a means of specifying the position of a star with respect to the earth.

TIME

Computations of azimuth and longitude/latitude are dependent on accurate time values. Likewise the ephemeris values are also time dependent, hence it is necessary to know the exact time of the astronomical observation and how to convert to an international standard time.

Four kinds of time are used in making and computing an astronomical observation.

Sidereal Time: Sidereal time is dependent on the rate of rotation of the celestial sphere. Stars rotate around the celestial pole at sidereal time rate. When using a star for location or azimuth, it is necessary to use sidereal time. A sidereal day is the interval of time between two successive upper culminations of the vernal equinox over the same meridian. At any location for any instant, it is equal to the local hour angle of the vernal equinox. Sidereal time is the equivalent of solar time with a gain of 3 minutes and 56 seconds per day.

Solar Time:

There are two types of solar time, apparent (sundial) time and mean solar time.

Apparent Solar Time: An apparent solar day is the interval of time between two successive lower culminations of the sun. Apparent solar time is sun time and the length of a day varies somewhat because the rate of travel of the sun is not constant. Since the earth revolves about the sun once a year, there is one fewer day of solar time in a year than sidereal time. Thus the length of a sidereal day is shorter than a solar day by approximately 56 seconds.

Mean Solar or Civil Time: This time is related to a fictitious sun, called the "mean" sun, which is assumed to move at a uniform rate. It is the basis for watch time and the 24 hour day. This system also includes civil time and universal time which are useful to surveying.

Equation of Time: The equation of time is the difference between mean solar and apparent solar time. Its value changes continually as the apparent sun gets ahead of and then falls behind the mean sun. Values for each day of the year are given in the ephemeris. Local apparent time is found by subtracting the equation of time from local civil time.

Standard and Universal Time: Standard time is the mean time at meridians 15 degrees or 1 hour apart, measured eastward and westward from Greenwich. Eastern standard time (EST) at the 75th meridian differs from Greenwich civil time (GCT) by 5 hours (earlier). Daylight savings time in any zone is equal to standard time in the zone to the east. Sun and star positions tabulated in ephemerides are given in Greenwich Civil Time (GCT), which is also called Universal Time (UT). Observation times are usually recorded in the standard times of an observer's location and must therefore be converted to GCT. Conversion is based on the longitude of the standard meridian for the same time zone.

TIMING OBSERVATIONS

Accurate signals of Universal time are generated each minute by the National Bureau of Standards at station WWV in Ft. Collins, Colorado at frequencies: 2.5, 5, 10, and 15 MHz. This can be received on a short wave radio or special radios available from Radio Shack or other electronic stores. You can also receive the time signal by calling (303) 499-7111 on the telephone. You can use this time signal to set your digital watch or other time device to the exact Coordinated Universal Time (UTC), or to check how close your watch is by noting the number of seconds fast or slow from the time signal. You can then record the precise time of your celestial observation.

Computation of Greenwich Civil Time from Standard or Daylight Time:

Since all data is in the ephemeris tables at Greenwich Civil Time, the observations at any place on the earth should be changed to the equivalent Greenwich Civil Time to get the correct information for determining azimuth or latitude and longitude. The following procedure can be used to make the conversion:

1. Determine the exact time at the time of observation and write it down in the notes.

2. Check your watch against the time signal service and determine the possible watch error.

3. If you are using A.M. time, go to the next step, if you are in the P.M., you will need to add 12 hours to the time to get a 24 hour time value (24 hour clock).

4. Add the hour difference for the time zone you are dealing with. Each hour away from Greenwich Civil Time Zone is 15 degrees of longitude. Hence the following table should help to determine the hour difference.

5. If you exceed 24 hours of time, you go to the next day in Greenwich Civil Time.

Table 14-1. Longitudes of Standard Meridians in the United States and Time Differences from Greenwich.

Standard Time Zone	Longitude of Std. Meridian	Correction in Hours to add to obtain GCT Std. Time	Daylt Time
Eastern (EST)	75	5	4
Central (CST)	90	6	5
Mountain (MST)	105	7	6
Pacific (PST)	120	8	7

Example of Determining Time:

Determine the GCT of an observation made at 8:55 A.M., CST.

Solution:

8:55 A.M. CST
+6 hours
14:55 GCT

Determine the GCT of an observation made at 9:30 P.M. MST.

Solution:

9:30 P.M. MST
+12 hours for 24 hour clock
21:30 hours MST
+ 7 hours time difference
28:30 GCT (since it is beyond 24 hours,
-24 subtract the 24 hours)
4:30 GCT (on the following day)

SUN OBSERVATIONS FOR AZIMUTH

There are two methods used for determining the azimuth of the sun: the altitude method and the hour angle method. The difference between these is that the altitude method requires accurate measurement of the vertical angle and an approximate time while the hour angle method requires very accurate time, but no vertical angle. For determination of azimuth of the sun in cave surveying, the hour angle method is the most practical because digital watches have made accurate time determinations very easy.

To use the hour angle method, it is important to measure precisely the azimuth of the sun using a compass, or to measure a horizontal angle from the first traverse line in the cave to the sun. The first method only requires a compass, but the second method requires a transit or theodolite. Knowing the accurate time of the observation and the observer's position (longitude and latitude), you can compute the sun's azimuth.

Using a compass mounted on a tripod and the shadow method, the magnetic azimuth of the sun can be determined and the exact time noted. The latitude and longitude of the cave can also be determined carefully from the U. S. Geological Survey topographic map of the cave area. These values and information obtained from the ephemeris are applied to the following equation:

$$AZ = \tan^{-1} [-\sin LHA/(\cos \phi \tan \delta - \sin \phi \cos LHA)]$$

LHA = Local Hour Angle
δ = Declination of the sun from the Ephemeris
ϕ = Latitude of the observer
AZ = Azimuth of the sun. This azimuth must be adjusted from 0° to 360° by algebraically adding a correction from the table 14-2.

Table 14-2. Azimuth correction factors.

When LHA is 0° to 180°:
If Az is positive, the correction is 180°

If Az is negative, the correction is 360°

When LHA is 180° to 360°:
If Az is positive, the correction is 0°
If Az is negative, the correction is 180°

Declination of the sun is tabulated in the ephemeris for 0 hours UT1 of each day (Greenwich). The declination at the UT1 time of observation can be calculated by linear interpolation by using the following equation:

$$\text{Decl} = \text{Decl } 0^h + (\text{Decl. } 24^h - \text{Decl. } 0^h)(\text{UT1}/24)$$

Decl. 0^h = Declination at 0 hour for the Greenwich date of observation. Decl. 24^h = Declination at 0 hour for the next Greenwich day.

Note: a negative declination indicates that the sun is south of the equator and must be used as a negative value in the above azimuth equation as well as in the declination equation.

Local Hour Angle (LHA) at the UT1 time of observation is essential to the computation of azimuth. This is defined as the angle, measured westward at the north celestial pole, from the observer's meridian to the hour angle through the sun. This is calculated using the equation:

$$\text{LHA} = \text{GHA} - W\lambda \quad \text{(west longitude)}$$

$$\text{LHA} = \text{GHA} + E\lambda \quad \text{(east longitude)}$$

LHA should not exceed 360°. If it does, subtract 360° from it.

The Greenwich Hour Angle (GHA) for the sun can be found in the Ephemeris listed for 0^h UT1 of each day (Greenwich Date). Interpolation of GHA for the time of observation should be done. The GHA of the sun increases 360° each 24 hour day because of the earth's rotation. Interpolation of GHA can be done using the following equation:

$$\text{GHA} = \text{GHA } 0^h + (\text{GHA } 24^h - \text{GHA } 0^h + 360)(\text{UT1}/24)$$

GHA 0^h = GHA from ephemeris at 0 hours on the Greenwich date of observation.

GHA 24^h = GHA from ephemeris at 0 hours on the next day.

FIELD PROCEDURE

Using the Brunton compass and the shadow method, take an azimuth on the sun (preferably with the compass declination set to 0 degrees). Note the exact time and read carefully the azimuth. Record both of these values. Using a U. S. Geological Survey topographic quadrangle, determine the exact longitude and latitude of your location and record with the time and azimuth. This should be done several times. Then calculate the azimuth by using the formula discussed above.

Example Problem

Joe Caver is surveying Deep Hole Cave at location longitude 93°17'30", latitude 37°20'10". From the entrance to the cave he determines the magnetic azimuth of the sun using the shadow method and finds it to be 264°30' at exactly 1:35 P.M. C.D.T. on August 22, 1990 (Figure 14-2). Determine the true azimuth of the sun and then the magnetic declination at the cave site.

Solution:

Step 1. Determine UTC

	1:35	P.M. CDT Aug. 22, 1990
+	<u>12:00</u>	for 24 hour clock
	13:35	
+	<u>5:00</u>	hours to correct to GCT (time diff.)
	18:35	GCT or UTC

Step 2. Calculate the GHA of the sun.

From the ephemeris: 319°15'18.1" 0 hr. Aug. 22
320°14'26.0" 0 hr. Aug. 23

$$\text{GHA} = \text{GHA } 0^h + (\text{GHA } 24^h - \text{GHA } 0^h + 360)(\text{UT1}/24 \text{ hr})$$

$$\text{GHA} = 319°15'18.1" + (320°14'26.0" - 319°15'18.1" + 360)(18.58/24 \text{ h})$$

$$\text{GHA} = 238°46'05.26"$$

Step 3. LHA = GHA - Wλ
238°46'05.26" - 93°17'30

LHA = 145°28'35.2"

Step 4. Declination = Decl. 0^h + (Decl.24^h - Decl. 0^h)(UT1/24)

From the ephemeris: Decl. = -18°01'58.9" 0 hr., Aug. 22.

Decl. = -18°01'58.9" 0 hr., Aug. 22.

Decl. = -18°01'58.9"+(-18°01'58.9"+ 18°01'-58.9")
(18.58/24)

Decl. = -18°01'58.9"

Step 5. Calculate the azimuth using the equation given above.

$AZ = \tan^{-1}[-\text{Sin LHA}/(\text{Cos } \phi \text{ Tan } \Delta - \text{Sin } \phi \text{ Cos LHA})$

Where: LHA = 145°28'35.2"
ϕ = 37°20'10"
δ = 18°01'58.9"

AZ = -89°54'18.9"; by using the table above,
= 270°05'01.47

Step 6. Take the true azimuth and subtract for the compass reading.

270°05'01.47"	True azimuth of the Sun
264°30'	Magnetic azimuth taken with the compass.
5°35'01.47"	This then is the magnetic declination.

Step 7. Set the declination on the compass to 5°35' and all the remaining traverse legs through the cave will be mapped on true bearings.

SUMMARY

An astronomical observation is quite simple to make at the start of a cave survey. All the information that needs to be gathered consists of:

1. Exact time of the observation.
2. Azimuth of the sun using the shadow method and a Brunton compass.
3. Longitude and latitude of survey stations.

The calculations can all be done at home after the survey is complete and the traverse can be adjusted to the true north meridian.

DETERMINATION OF LOCATION BY LONGITUDE AND LATITUDE USING SOLAR OBSERVATIONS

Latitude

The determination of latitude using the sun requires very careful measurements of vertical angles using either a transit or a theodolite. The lens must be covered or shielded so that you don't look directly at the sun through the telescope.

To determine the latitude, it is necessary to measure the altitude of the sun at the instant the sun reaches the highest point in its path. To do this the transit is set up at the station shortly before noon and carefully leveled. The sun is then carefully followed as its altitude increases to a maximum, at which position it is on the meridian. At this point the vertical angle and time is recorded. The observed vertical angle is then corrected for refraction using the equation:

$$C_r = 16.38\, b/(460 + f)\text{Tan } V$$

and parallax using the equation:

$$C_p = 0.147 \text{ Cos } V$$

where: b = barometric pressure
f = Temperature °F
V = Observed altitude of the sun

Refraction correction is always negative and parallax is always positive.

From the ephemeris the instant of apparent noon can be determined. The latitude can then be calculated from the equation:

$$\phi = 90° - h + \delta$$

where: h = altitude of the sun corrected for index error, refraction, parallax and semidiameter

δ = declination taken from the ephemeris for the observation time. If the declination is southerly, a negative sign must be used in the computation.

Example

On November 13, 1990, a transit was set up before noon at the entrance of a cave of unknown latitude and carefully leveled. The vertical angle to the center of the sun at its maximum altitude was measured as 35°44'37" at 12:05 P.M. C.S.T. Temperature and pressure were 68° and 29.1 in. Hg., respectively. Compute the latitude of the point.

Solution:

1. True altitude:
   - Observed altitude 35°44'37"
   - Refraction correction:- 1°15'16"
   - Parallax correction: + 0°07'09"
   - Sun's true altitude: 34°36'31"

Refraction and parallax calculated using the equations listed above.

2. UT of Observation:
   - Observed Time: 12:05 P.M., C.S.T.
   - \+ 6 Hrs. Corr. to Greenwich
   - Observation Time 18:05 GCT

3. Sun's declination from the ephemeris:
   - November 13: -17°50'05.8"
   - November 14: -18°06'02.7"
   - Difference: 0°15'56.9"

Using the time 18.08/24 X 0°15'56.9" = 0°12'01.0"

Then the declination is corrected by straight line interpolation to be -18°02'06.8".

4. Latitude then becomes:

$$\text{Latitude} = \phi = 90° - h + \delta$$

$$\phi = 90° - 34°36'31" - 18°02'06.8"$$

$$\phi = 37°21'23"$$

Longitude

Longitude can be determined by measuring the precise time at which the sun's center reaches culmination (crosses the true meridian). The time can then be used to calculate GHA. Since the local hour angle equals zero when the sun is on the meridian, longitude is equal to GHA. Because of this the longitude can be determined using the same set up and the same time as the latitude.

Example

Using the same information as for the example in the latitude discussion, find the longitude of the cave entrance.

Solution:

1. Determine the UT of observation:
   - CST of observation: 12:05:00
   - Corr. to Greenwich: +6
   - UT Nov. 13, 1990: 18:05:00

2. Determine the GHA of the sun using the ephemeris:

GHA at 0^h on November 13 = 183°56'59.2"
GHA at 0^h on November 14 = 183°54'53.0"
Since the value on Nov. 14 is smaller than on the 13th, add 360 degrees to the value:

183°54'53.0" (+360) - 183°56'59.2" = 359°57'5-3.8"
Thus the change for 24 hours = 359°57'53.8"

Increase for 18 hours, 05 minutes and 00 seconds =

(18.08333/24) X 359°57'53.8" = 271°13'25"

GHA of sun at observation:

183°56'59.2" + 271°13'25" = 95°10'24"
(Note, whenever a measurement exceeds 360 degrees, subtract 360 from the value.)

3. When the sun is due south, longitude = GHA
Hence: Longitude = 95°10'24".

Exact time is the most important piece of data to be recorded here. The method can produce longitudes accurate to within about ±30 seconds, but an error of 4 seconds can cause approximately a 1 minute error in the longitude.

LORAN LOCATING

A method of determining the geographic coordinates of a cave's entrance based on radio transmissions is the loran navigation system. Loran (an acronym for **lo** ng-**ra** nge **n** avigation) is based on radio-transmission travel times. Loran employs pairs of radio-transmitting stations, called master (M) and slave (S) stations, located some distance apart. Each pair of stations transmit readily identifiable, synchronized radio pulses. These pulses are received by a special radio receiver whose location is to be determined. This radio receiver can be portable or mounted in a car or airplane. The receiver measures the time interval between the two pulses and this is then used to determine the location of the receiver.

When the M and S stations simultaneously transmit signals, a radio located at a point midway between the two will receive both transmissions at the same time. If a receiver moves closer to M, it will receive that signal sooner than it will receive the signal from S. This same timing difference occurs at many other points which, when plotted, fall on a hyperbolic curve (CD). Sets of these curves, based on expected time differences between the reception of M and S signals are plotted on specially constructed loran charts. Each individual curve on the chart represents locations at which the signals from the designated pair of stations are received at a specified time interval.

To use the chart, the operator first tunes to a given pair of stations. The time reading thus obtained indicates that the receiver is located somewhere along the curve that represents that interval. The operator then tunes to a second set of stations and determines the time interval for that set. Again the curve for that set is located. The intersection of the two curves represents the location of the receiver. Modern equipment eliminates the need for tuning to two separate sets of transmitters, finding the appropriate curves on the chart and then finding the intersection of the curves. This operation is all done electronically in the system and the location data indicated on the instrument screen in longitude/latitude. Each instrument measures signals from the loran chain locally and converts the information to display the position in either time differences (TD's) or in latitude/longitude (LAT/LON). In addition, as the position of the receiver is changed (if mounted in a car or airplane), the rate of change of position is used to compute the speed and course to destination.

The accuracy of the technique is dependent on the atmospheric conditions that exist at any particular time. The conditions are generally better at night than in the day. The location of the transmitter pairs relative to the observer also influence the reception. The effective range and level of accuracy of the system depends upon the particular frequency used and the vintage of the equipment.

Loran can be used to locate cave entrances within 50 to 100 feet by longitude and latitude. The method has excellent potential because the cost of the equipment is becoming more affordable with some units costing less than $1000.

GLOBAL POSITIONING SYSTEMS (GPS)

The global positioning system (GPS) is a state-of-the-art system for determining very precise locations of points on the surface of the earth. With new computer technology, it is becoming available to surveyors and potentially to cave surveyors.

Global positioning systems are based on observations of signals transmitted from satellites. These signals are picked up at ground stations by computerized receivers. GPS satellites have been placed in near-circular orbits about 20,200 kilometers above the earth. The initial operational plan called for 18 satellites in six separate orbital planes with three satellites spaced evenly in each orbit. These orbits are inclined at an angle of 60° to the equatorial plane. At this time it appears that there will be 4 satellites in each orbit for a total of 24. The system is designed to have each satellite travel around the earth twice every sidereal day and be visible to the observer for approximately 10 hours each day. Using this configuration, there should be from four to six satellites visible at any time in any given location on the earth. By 1991 there were eleven GPS satellites in orbit, but some of these are prototypes that are scheduled to be replaced.

The satellites continuously broadcast signals on two L-band carrier frequencies: 1. L1 (1575.42 MHz) and 2. L2 (1227.60 MHz), which contain coded information, such as predicted satellite ephemeris, satellite identification, and clock information. The L1 carrier is modified by a precision (P) code known as the precise positioning service (PPS) code, and a course acquisition (C/A) code known as the standard positioning service (SPS) code. The C/A or SPS code is intended for general use and is capable of providing single point accuracy at the 100- to 300-m level. The P or PPS code is capable of providing point-precision accuracies to the 5- to 10-m level, but will be reserved for the military and selected governmental use when the system is fully operational. The codes permit ground receivers to lock onto the broadcast signal and to receive the exact transmission time of each modulation-frequency pulse. The received signals may then be used to determine either the absolute position of the receiver or its position relative to another receiver on a point of known position.

Until very recently, GPS receiving equipment was very expensive, generally in the price range of $25,000 to $80,000. These were very sophisticated and very accurate units designed for precise location on bench marks, etc. These "carrier-phase" instruments can be accurate to within centimeters. During the late 1980's, code-phase, point-positioning GPS receivers became available for use in "rough" locating of surface points. These have been used successfully for locating oil/gas wells, mapping remote trails and tree stands, navigation, exploration, etc. Code-phase receivers determine position from measurements of the 300 meterC/A code "measurement wave" generated by each GPS satellite. If three satellites are visible, a single code-phase receiver can determine the latitude and longitude of a point within a range of 50 to 100 feet accuracy in just a few minutes. With four or more satellites visible, latitude, longitude, and even elevation can be determined in a very short time.

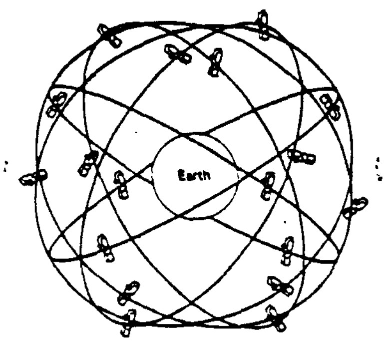


Figure 14-2. Proposed constellation of GPS satellites.

These new code-phase receivers are even becoming more affordable since they are now getting into the under $4,000 price range. Prices will continue to decrease as electronics continue to improve. These systems are small and very portable and can give locations in a very short time. The application to precise determination of the location of cave entrances is obvious.

15

SURVEYING IN WATER FILLED PASSAGES

Surveying in many caves comes to an end because the passage is water filled and most cave surveyors cannot breathe very well under water. Beyond this point is a totally unknown section of cave. The water filled section of passage may be short with large air-filled passage beyond or the passage may be sumped for a long distance before the roof level raises, if it ever does. It is at this point that the surveyor quits or finds a way to continue. Sometimes diving equipment is used to penetrate the sumped portion; sometimes the sump is free-dived if it is thought to be short; and sometimes the surveyor waits until a drought lowers the water level enough for him to continue. The first one of these options can be very dangerous and only experienced and trained cave divers should attempt to dive sumps. The second option is very dangerous and not recommended at all. The third option is probably the safest, but one may never experience a drought long enough (hopefully) to lower many sumps. Most surveying through and beyond a sump should be accomplished by an experienced team of cave divers using the proper underwater equipment such as an air supply, wet suit, etc.

Surveying in water filled passages presents very special problems in addition to the normal ones encountered in most cave surveying and in open water diving. You are limited in time to the amount of air you have in your tanks and deep diving may even present problems with nitrogen narcosis or the bends. In addition, traversing water filled passages generally stirs up silt, drastically cutting down visibility. You are also limited to following passages that are large enough to allow passage of you and your air tanks. Surveying under these conditions requires special considerations and equipment.

Cave surveying underwater, like all caving, should never be done alone. Always take a second experienced cave diver with you. As with normal cave mapping, at least two divers are necessary to map a cave efficiently.

UNDERWATER SURVEYING EQUIPMENT

Surveying equipment used in underwater cave mapping is generally specially designed or modified for that use because of the conditions that are found in water filled passages. This equipment must be easy to read and be able to function while totally immersed in water. Special required equipment includes compass, clinometer, tape, notebook and pencil.

Compass

The surveying compass must be water tight and easily read under the reduced light conditions of water filled passages. The Suunto diver's compass attached to the wrist is an effective compass for use for these conditions. Be sure you check your diving equipment with the compass to determine the potential for magnetic errors as such could cause the compass needle to deflect leading to positional errors.

Clinometer

The clinometer, like the compass, must also be water tight and easily read under the reduced light that can be used in the submerged passages. Any sealed clinometer can be used here. Probably the Suunto clinometer is the best and easiest to use under the circumstances.

Tape

The ordinary fiberglass surveying tape is very difficult to use under water. A better device is a nylon stringline which has been marked at 5 or 10 foot intervals or if you are measuring in metric, 2 or 5 meter intervals. The markings should be large and bold enough to be seen under the reduced lighting conditions. Color coding is generally quite useful in this regard. In addition, the markings should indicate the direction back to the entrance since it is very easy to get disoriented under water. Commercial stringlines for measuring in waterfilled passages are available under the name "rope chain". These are yellow for easy visibility and made of fiberglass coated with clear PVC to prevent abrasion of the numbers. They are marked off in feet except for the first and last foot which are divided into tenths. Ropechains are also available in meters.

Notebook and Pencil

The notebook for underwater surveying cannot contain anything that the water could destroy. Generally notes are written on frosted mylar sheets on a waterproof clipboard. The mylar sheets should have a grid imprinted to make it easier to plot the directions determined during the survey. Don Rimbach, a Missouri caver who has done extensive underwater mapping uses sheets of plexiglass which have been sandblasted to create a frosted surface and on which a grid had been scribed. This forms a permanent material rigid enough to draw on. A normal graphite pencil is used to inscribe notes on the plexiglass. When a section is completed, the notes are touched up and the plate is then xeroxed to form a paper copy of the information. The plexiglass can then be cleaned off and reused. Several sheets of plexiglass can be kept together in a manner similar to any notebook and then used for a survey. Several sizes could be made that could be used for any type of project or condition.

Whether you are using the mylar sheets or the plexiglass sheets, you should use a graphite pencil which will mark on either material. To prevent losing the pencil, it should be attached to the clipboard or the plexiglass sheets with a cord.

Notes should be recorded in the same manner as any other survey, including station numbers, distance, azimuth, and vertical angle. Be sure to include a north arrow and scale.

UNDERWATER SURVEYING PROCEDURES

Many of the procedures in underwater surveying are the same as for air filled passages. However, there are some circumstances that should be carefully considered to make sure the survey is accurate.

1. Since visibility is cut down, measured distances

will be shorter because the surveyor has to be able to see each succeeding station from the previous one.

2. Foresights and backsights should always be taken to minimize errors.

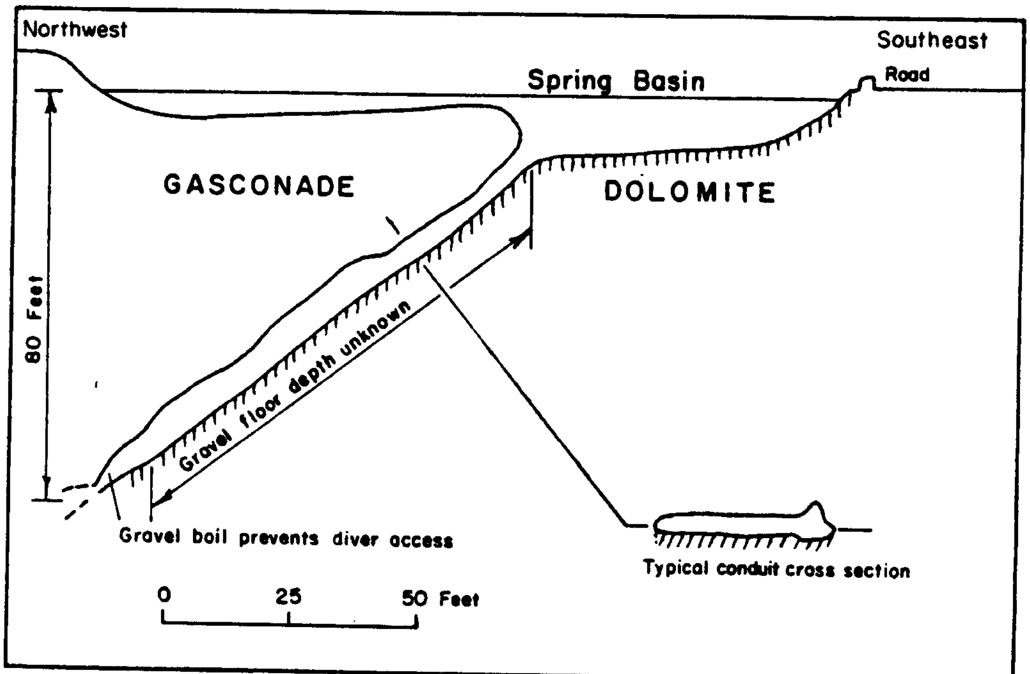
3. The distance has to be carefully determined, generally by counting the markers.

4. Determination of passage heights and other measurements can be very difficult because of the reduced visibility.

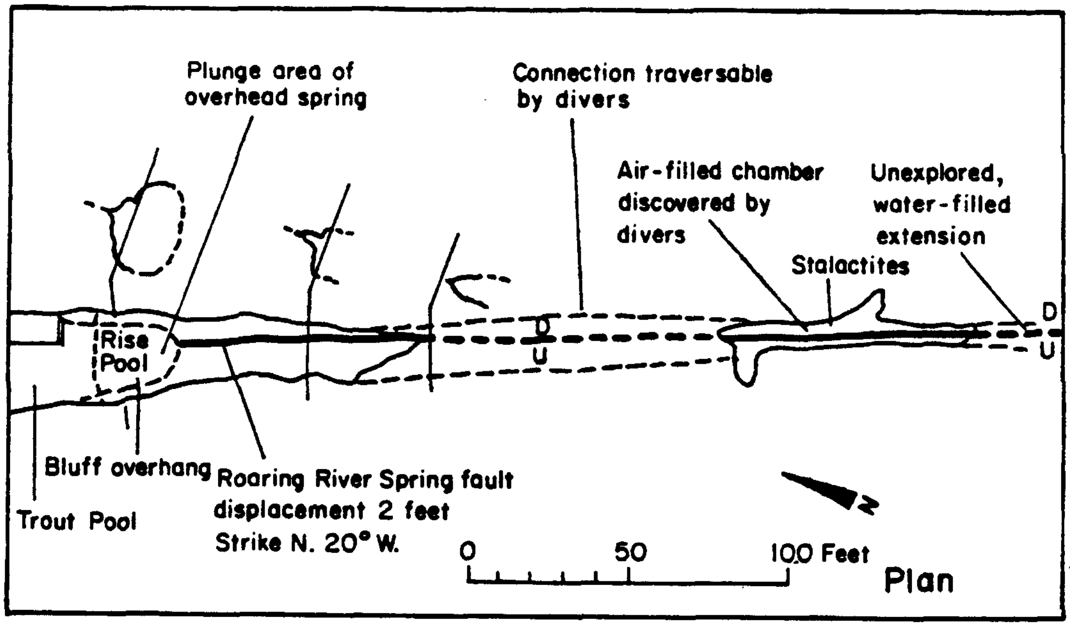
5. Cross sections should be made, but will be difficult to do because of the low visibility.

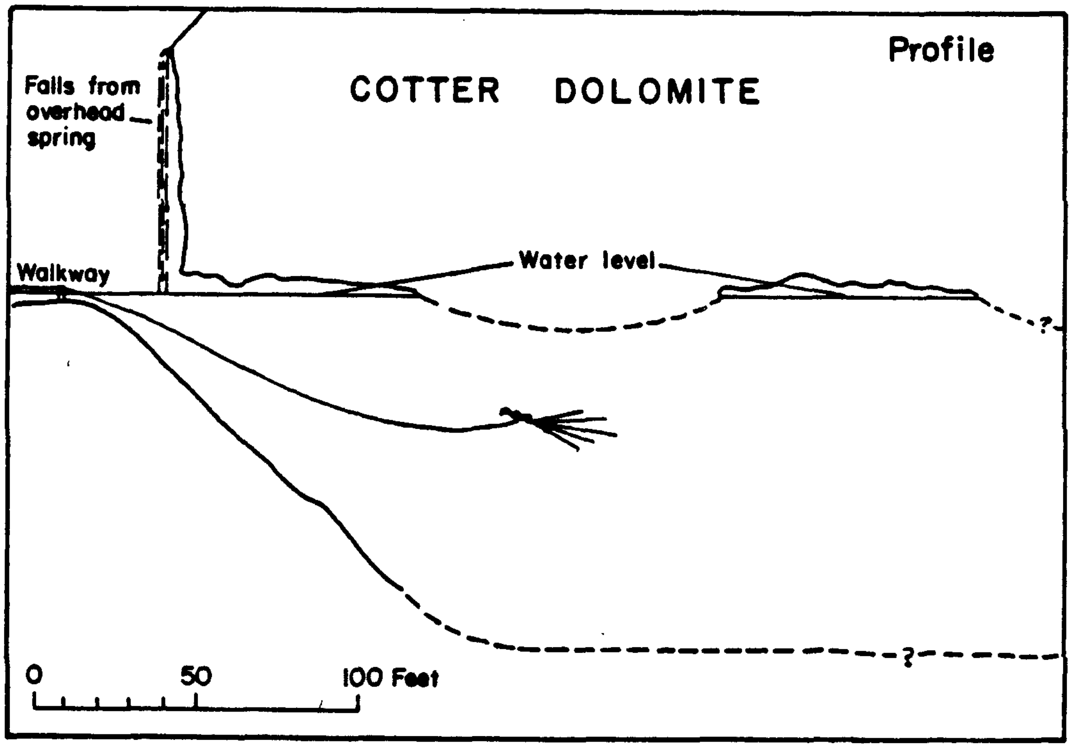
UNDERWATER SAFETY

Probably the most important consideration in underwater cave surveying is that of safety. It cannot be overly stressed that cave diving is very dangerous and should not be undertaken by amateurs. Surveying connected with cave diving should be done slowly, deliberately and safely. Contact the National Speleological Society Cave Diving Section for information and training in safe cave diving.



BENNETT SPRING





Taken from Springs of Missouri

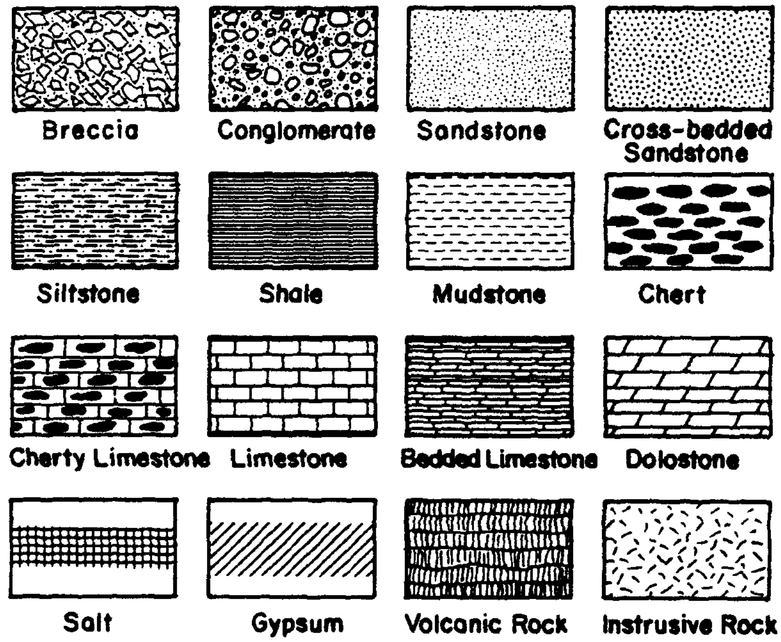


Figure 16-1. Symbols used to designate rock types on cave cross sections.

the cave. The answers can help determine the cave's history and reason for its geologic location.

ATTITUDE OF THE ROCK UNITS

The attitude of the rock units (the way the rocks lie) should be determined if possible. Attitude is portrayed by determining strike and dip. The definition of strike is the direction of the intersection of a horizontal plane with the rock unit. Dip is the maximum angle of slope of the same rock unit. Strike is always perpendicular to dip. The strike of a rock unit can be determined in several ways:

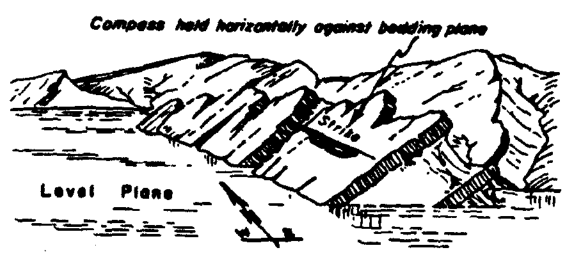


Figure 16-2. Determination of strike using a Brunton compass.

1. If you have a Brunton compass, lay the compass with the straight side against the rock bedding plane and level it using the bullseye level bubble (figure 16-2). This makes the Brunton compass represent a horizontal plane. The line of intersection of a horizontal plane with the rock unit is where the edge of the compass and the rock bed come in contact. The direction of this intersection can be read directly from the compass. Strike is always measured from north, for example N.22°E. Dip is then measured by laying the edge of the compass on the bed and using the clinometer to measure the slope (figure 16-3). This is designated by writing the angle and the direction, i.e., 32° NW.

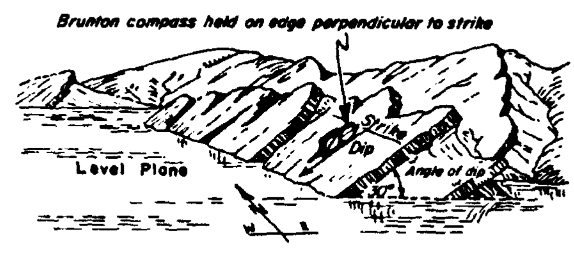


Figure 16-3. Determination of dip using a Brunton compass.

2. With any compass, find a bed that can be traced from one side of the passage to the other. Then find

where a horizontal plane will intersect the bed on the opposite wall. This can be done by putting one's head against the bedding plane on the wall that you are next to and using a clinometer set at zero, sight across the passage until the cross hair intersects the bed. Note this location and then use the compass to sight from your eye to the point on the opposite wall where the cross hair intersected the bed (figure 16-4). This then gives the direction of the strike. The dip can be measured by holding the clinometer out and sighting along the bedding plane down the dip direction (figure 16-5). This can then be recorded in the notes and plotted in the true direction, using the proper symbol as shown in figure 16-6.

Strike and dip information is important in determining the structural setting for the cave.

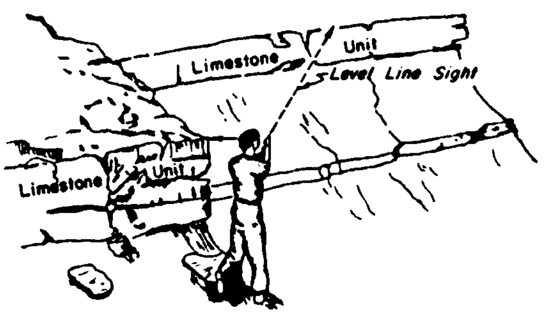


Figure 16-4. Sighting to determine strike direction.

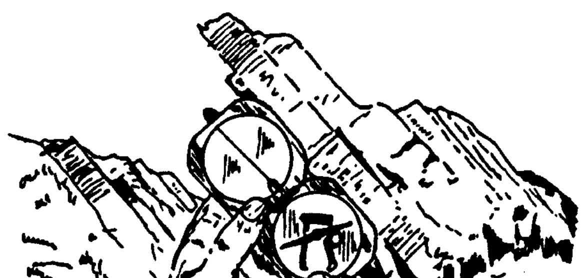


Figure 16-5. Sighting method of determining dip.

JOINTS (FRACTURES) AND FAULTS

The location of joints (fractures) in the rock is an important key to the development of the cave. Many cave passages are influenced to some degree by joints. All major joints or fractures that are observed in the cave should be mapped and shown with the appropriate symbol (figure 16-6). The relative size of the mapped joints should also be recorded where possible.

Faults are fractures in the rock along which movement has occurred. Generally faults can be identified by the presence of slikensides (polished surfaces with striations or lines parallel to the direction of movement), breccia zones (areas of broken or crushed rock), and other evidence such as offset rock units. The position, character, and relative offset of the fault and associated phenomena should be indicated on the map with the proper symbols (figure 16-6). Faults, like joints, are features which can control the development of the cave.

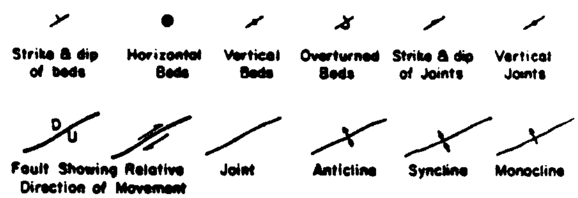


Figure 16-6. Symbols used for mapping rock structure.

DIKES, VEINS AND OTHER FEATURES

Dikes are tabular bodies of igneous rock which can often be found cutting through rocks. Veins are bodies of mineralization such as calcite or ore minerals which follow fractures in the rock. These are often encountered in caves. Both of these features should be mapped when encountered as they may give further information needed to determine the genesis of the cave.

Unconformities or gaps in the rock record, can be seen in some cases, especially where the rock units on both sides of the unconformity have different dips. These should be shown where found and are probably best indicated on cross or longitudinal sections.

IGNEOUS ROCKS

In some areas the caves that are mapped are lava tube caves which are situated entirely in lava flows. In general, the methods of mapping these caves are the same as those for mapping in sedimentary rocks. However, magnetic anomalies often present a problem in igneous rock units. This problem can escape detection if you map without taking backsights on all bearings or azimuths. It can also vary throughout the cave so that a simple correction to the entire map cannot be made as can be done when the deflection is constant. The best method for checking on this problem is to take both foresights and backsights on all bearings or azimuths. If these agree, then there is no magnetic anomaly and the cave can be surveyed normally. If they don't agree, there is the possibility of an anomaly and steps should be taken to survey the cave directions by turning angles using a transit or theodolite if you want your map to be accurate.

CAVE SEDIMENTS

Materials found on the cave floor such as sand, gravel, and clay, can also give clues to the genesis of the cave. The distribution and nature of these sediments can be quite important and can be shown using the appropriate map symbol (figure 16-7).

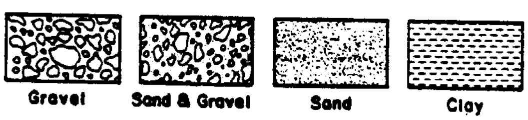


Figure 16-7. Symbols used for cave sediments.

GEOLOGIC MAPS

For any cave mapping project, it is a good idea to check a geologic map of the area if it is available to determine the host rock. Geologic maps of entire states are usually available at appropriate state agencies, for example, the Department of Natural Resources, Division of Geology and Land Survey in Missouri. Sometimes geologic maps are available at the quadrangle level from the same sources.

Faults shown on the geologic map in the vicinity of the cave might also be found in the cave. Be aware that a dipping fault plane will project into the cave at a different location than shown on a detailed geologic map. It will be displaced horizontally in the direction of dip.

Caves provide an opportunity to view the geology of the area in more detail than is often the case on the surface because oftentimes, rock features on the surface are obscured by vegetation or soil.

16

GEOLOGY AND CAVE SURVEYING

Most cave surveyors are not geologists. However, even amateurs can make simple observations such as bedding thickness, type of limestone, attitude or dip of beds, the presence and direction of fractures or joints, occurrence and possible movement of faults and the presence of special features such as dikes, veins, irregular beds, or unusual rock formations. Even the type of cave sediment should be recorded as the cave is surveyed.

HOST ROCK

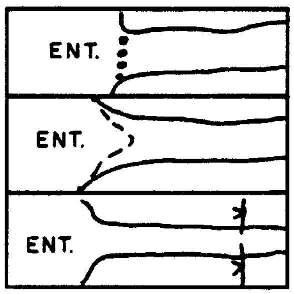
As you enter the cave, you should record on the map what the host rock formation is if you know it. The formation name is a name that geologists give the rock unit of a specific age and lithology. If you don't know it, determine what the general rock type is. Is it a limestone, dolomite, or something else? Describe what the rock looks like and include the thickness of the beds and the texture of the rock. You should also observe the partings between rock beds. This might give additional information about how the cave developed. Additional rock types present such as chert in the limestone or layers of sandstone and shale enclosed in the limestone or dolomite should all be recorded. All rock types can be shown on cross sections by using the appropriate rock symbols (figure 16-1). Some other geologic questions to ask would include: Does the cave change from one rock unit or type to another? Is there a rock unit which limits the vertical extent of

APPENDIX I.

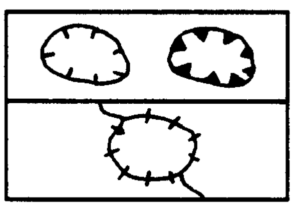
CAVE MAP SYMBOLS

An effective cave map is one in which its viewer can understand in some detail what the cave is like. Thus, each symbol used on the map should look much like the feature which it represents. In 1960, the Missouri Speleological Survey formally adopted a set of symbols which is still being used in the state of Missouri and in 1976, the National Speleological Survey published a slightly different list of symbols. The following list is a combination of the lists from the Missouri Speleological Survey, the National Speleological Society, the British Caving Association, and others. All variations of the symbols are shown that may be of use to the surveyor. Special symbols can be created by the surveyor as needed, but these should be explained on the final map sheet.

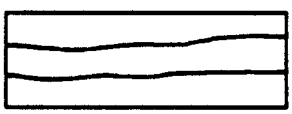
CAVE PASSAGES



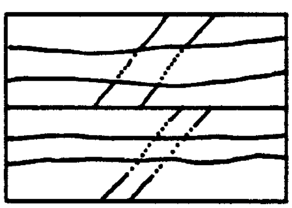
Cave entrance showing dripline. The entrance should be labelled and the dripline should be configured as closely as possible to the actual alignment. The MSS uses a dotted line and the NSS uses a dashed line. The British delineates the limit of penetration of daylight under most favorable conditions.



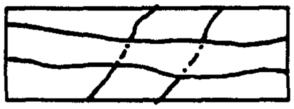
Vertical cave entrance showing depth. The MSS uses either a sinkhole symbol or a symbol with black triangles. The NSS uses a pattern with tick marks all the way through the line. In all cases, show the depth.



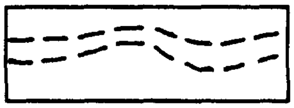
Surveyed cave passage. The line width varies with the scale, but is always greater than widths for passage details.



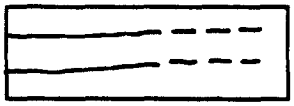
Underlying cave passage. Dotted lines indicate lower level only where the levels are superimposed. Letters "U" and "L" may be added. British symbols have the lower passage dotted at the intersection and slightly outside of the superimposed area.



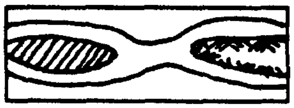
Overlying cave passage. Dotted-dashed lines indicate upper level only where the levels are superimposed.



Unsurveyed cave passage. This symbol applies also where the passage wall is obscurred by fill or the ceiling height is so low that the passage wall cannot be determined.

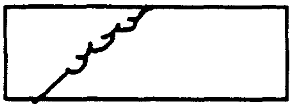


Unexplored cave passage. This symbol should be used where the unexplored cave passage can be seen to continue.

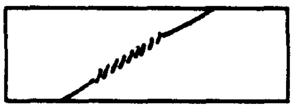


Bedrock or solid areas between cave passages. The solid areas are rock pillars. The MSS uses a cross hatch pattern and the NSS uses a two directional hatching to indicate the solid rock area.

Bedrock walls in cave passage. This is the same symbol as that used for the cave passage. It is shown here again for completeness.



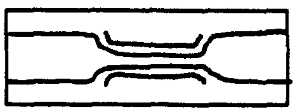
Flowstone covered cave walls. This should be used in areas where the bedrock is obscurred by secondary mineralization.



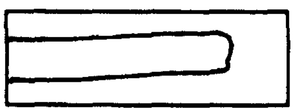
Sediment cave walls. This symbol indicates areas in which the passage is totally filled with sediment along the side of the passage.

Cave wall in breakdown. The symbol indicates areas in which the side of the passage is totally in breakdown. The blocks of breakdown should be drawn to scale if possible.

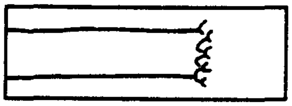
Indeterminate cave wall. This symbol indicates areas in which the passage height is so low that the edge cannot be seen. The symbol is the same as shown above as an unsurveyed passage.



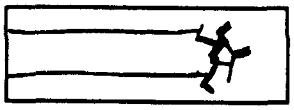
Artificially enlarged cave passage. This is generally found in a commercial or developed cave in which someone has blasted and mined the cave to enlarge the passage.



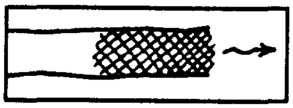
Cave passage terminates in solid rock. Use this symbol when you can actually see that the passage ends in solid rock.



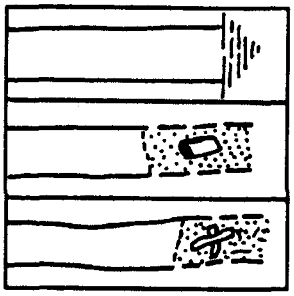
Cave passage terminates in flowstone. Passage is totally blocked by flowstone.



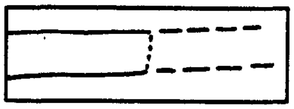
Cave passage terminates in breakdown. Continued passage is stopped by breakdown. Draw the breakdown blocks to scale if possible.



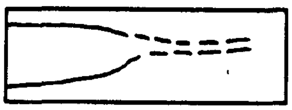
Cave passage terminates in a siphon. The cave cannot be mapped further because water fills the passage to the ceiling.



Cave passage terminates in sediment or other detritus. The cave passage is totally choked by cave mud or other sediment. MSS symbol only indicates mud fill. NSS symbols designate other types of fill such as detrital and vegetal debris. Two varieties of the NSS representation are shown.



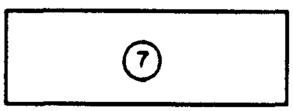
Cave passage continues, but low. This is generally used where the passage may be too low to enter by the cave surveyor. Someone else may be able to continue the survey beyond this point later.



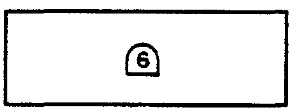
Cave passage continues, but narrow. This is generally used where the passage may be too narrow for the surveyor to continue. Someone else may be able to continue the survey beyond this point later.

DIMENSIONS

All dimensions should be in the same units. Consistently use either metric or English systems throughout the entire map. Also, use either feet and tenths of feet or feet and inches on any one map.

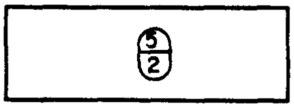


Ceiling height. This is the distance measured from the apparent cave floor to the ceiling. The British use a ^ over the dimension number.



Ceiling height over water. This is the distance measured from the water surface to the ceiling.

Water depth. This is measured from the water surface to the apparent cave floor. The British use a "v" under the dimension to indicate water depth.

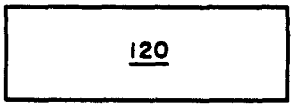


Height of air space over depth of water. This is related to the water surface and measured both from the water surface to the ceiling and to the apparent cave floor.

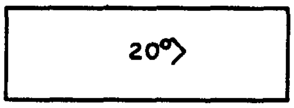
Ceiling height over traversable breakdown. This is the average distance from the breakdown blocks to the ceiling.

Vertical difference in floor elevation. Use this symbol in combination with the symbol for ledge, waterfall, or pit. The British simply indicate a line and put a negative number on the drop side of the line or a plus number on the upper side of the line.

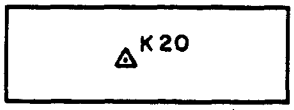
Depth of cave floor below primary cave entrance. If more than one entrance, designate the primary entrance.



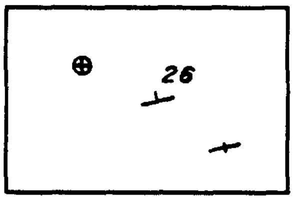
Elevation of cave floor above primary cave entrance. If more than one entrance, designate the primary entrance.



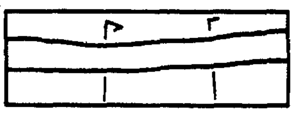
Degree and direction of floor slope. In the symbol, the arrow or point indicates the downslope direction.



Marked or fixed survey station. These are permanent stations which can be recovered within the cave.



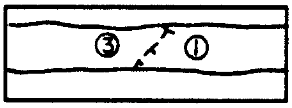
Strike and dip of beds. The symbols are designed to indicate the attitude of the rock units within the cave. The number indicates the degree of slope of the beds perpendicular to the elongated line. The circle with the plus indicates horizontal beds and the line with the small cross indicates vertical beds.



Line of cross section. The exact location of the cross section is shown by the line. The direction of view is indicated by the arrow or point on the end of the section line. Some cross sections indicate this by using numbers or letters.

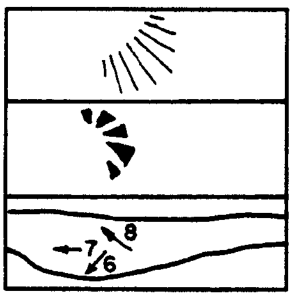
Water and air temperatures. These are given in either degrees celsius (°C) or degrees fahrenheit (°F). This should be indicated unless stated in the explanation or legend.

Direction of air flow. This should be shown by a double pointed arrow.

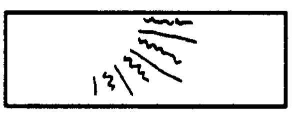


Change in ceiling height. Hachure in the line symbol points to the lower side of the ceiling.

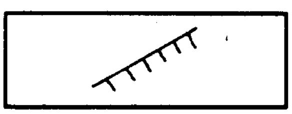
PASSAGE FEATURES



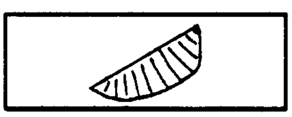
Slope, arcuate. Convex side downslope, non-arcuate slopes have a single line at the top of the slope. MSS uses straight lines for the slope and NSS uses long black triangles to show the slopes. The British indicate slopes with an arrow along with the angular dimension.



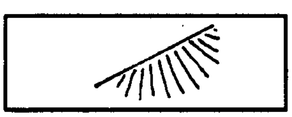
Steeply dipping flowstone.



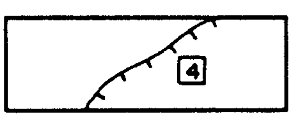
Slope, non-arcuate.



Slip off slope. (Towards the Passage Wall). Use this symbol for such features as sumps, tops of long uniform slopes, or for earth slides. The straight line indicates the top of the slope.

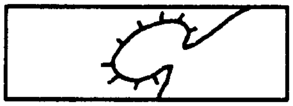


Semi-dome. Slope is away from the passage wall.



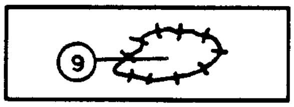
Ledge or pit rim with depth. Use the symbol for vertical change in floor elevation. Hachures and dimension symbol are on the lower side. This is the same symbol as listed above under vertical difference in floor elevation.

Dome in the ceiling (with height shown). The height is measured from the floor to the ceiling. The British illustrate this with a circle surrounded by dots.

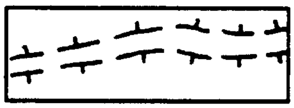


Dome in bedrock. This is generally shown outside of the passage lines.

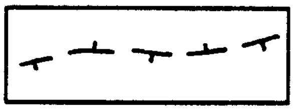
Pit, sink, or well (with depth shown). Depth measured from the floor of the pit to the level of the floor of the cave. The British use a circle with dots lining the inside for this symbol.



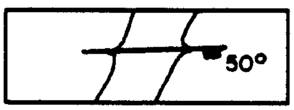
Domepit (with vertical dimensions shown). The distance here is measured from the floor to the ceiling. This feature must extend both below the cave floor and above the cave ceiling.



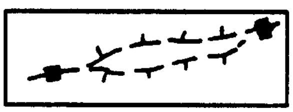
Ceiling channel (large). Hachure marks point away from the channel.



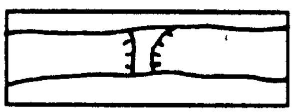
Ceiling channel (narrow). Hachure marks point away from the channel.



Joint in the ceiling. Dip of the joint is indicated on the side of the joint symbol.

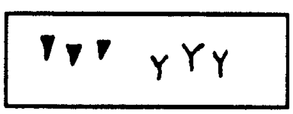


Enlarged joint in the ceiling. This is basically the same as an elongated dome, with joint orientation shown.

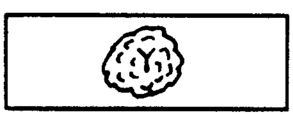


Rock span or natural bridge. Draw this symbol to scale as much as possible.

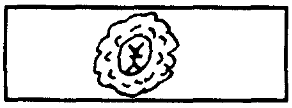
SECONDARY MINERALIZATION



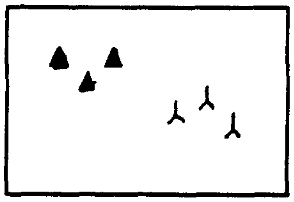
Stalactite. Symbol size can be used to indicate relative size of the formation. Use notations when the stalactites are profuse. MSS symbol is a simple black triangle with the point in the direction of gravity. NSS symbol is a "Y" likewise oriented.



Large stalactite. NSS symbol outline to show the size of the area that connects with the ceiling.

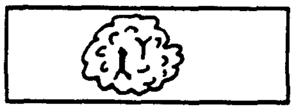


Stalactite over stalagmite. NSS symbol shows the size of connection to the ceiling and the diameter of the base of the stalagmite. This is not a column.

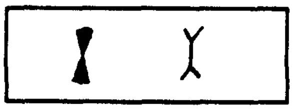


Stalagmite. Symbol size can be used to indicate relative size of the formation. Both MSS and NSS symbols are inverted versions of the stalactite symbol.

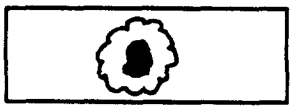
Large stalagmite. Outline shows the relative size of the base. NSS symbol of inverted "Y" shows the peak.



Large stalagmite with stalactites. The outline shows the relative size of the base. The NSS symbol indicates both the stalagmites and stalactites.

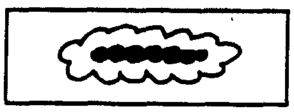


Small column. NSS and MSS symbols are matched stalactite and stalagmite symbols.

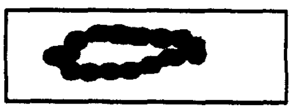


Large column, smaller ceiling juncture. Cross section of the column at the floor is denoted by the outline of the column symbol. Interior area indicates junction with the ceiling as compared to the juncture with the floor.

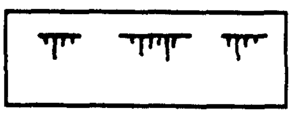
Large column, larger ceiling juncture. Outline of column symbols denotes approximate cross section of the column at the ceiling juncture. Interior area indicates that juncture with the floor as compared with the juncture with the ceiling.



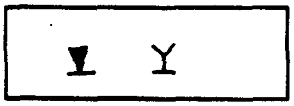
Compound column with smaller ceiling juncture. The outline of column symbols denotes the approximate average cross section of the column. Interior area indicates juncture with the ceiling as compared with juncture with the floor.



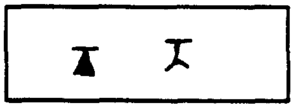
Compound column with larger ceiling juncture. The outline of the column symbols denotes approximate cross section of the column. Interior area indicates juncture with the floor as compared with juncture on the ceiling.



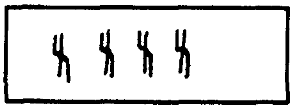
Soda straws.



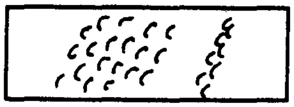
Stalactiflat. The MSS symbol is the same as the stalactite symbol with a base line added. The NSS symbol likewise is the same as the stalactite with a base line added.



Stalagmiflat. The MSS and NSS symbols are the same as the stalagmite symbols with a base line added.

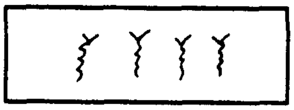


Helictites.



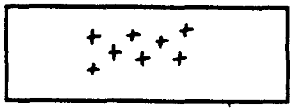
Flowstone covered floor.

Shield.



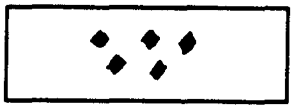
Draperies

Cave coral.

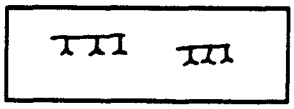


Crystallizations. This symbol has also been used for helictites, anthodites, gypsum, spathites, etc.

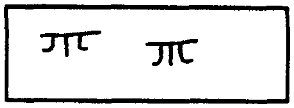
Boxwork.



Areas of spar.



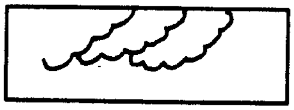
Anthodites.



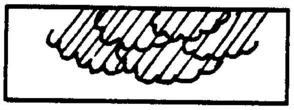
Oulopholites.

Moon milk.

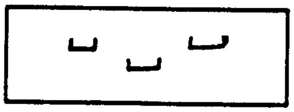
Flowstone. Convex side of the symbol is downslope.



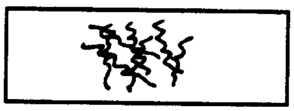
Rimstone dams (gours). Convex side of the symbol is downstream.



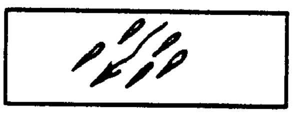
Rimstone pools.



Splash cups or drill holes.



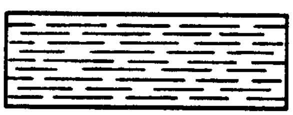
Anastomoses areas.



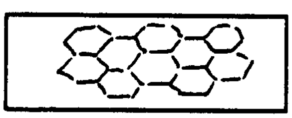
Scallops. Specify form and direction.

Flowstone covered breakdown blocks.

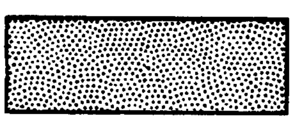
CAVE SEDIMENT AND OTHER FLOOR MATERIALS



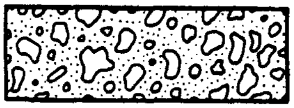
Clay or silt floors.



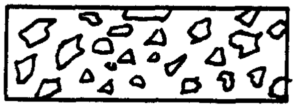
Mudcracks.



Sand.



Gravel. This symbol represents any larger sized floor fragments.

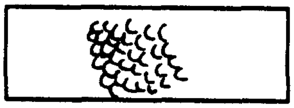


Angular rock fragments.

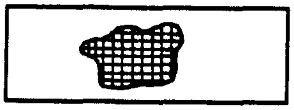
Rubble.

Breakdown. Symbols should be drawn to scale as much as possible.

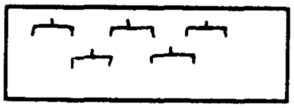
Chert.



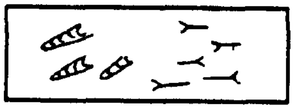
Flowstone floor.



Bedrock floor surrounded by sediment or water.

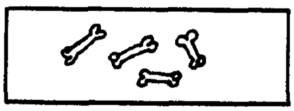


Bedrock floor (NSS symbol).

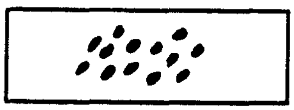


Fallen speleothems. Can be drawn diagrammatically or using the "Y" symbol of the NSS.

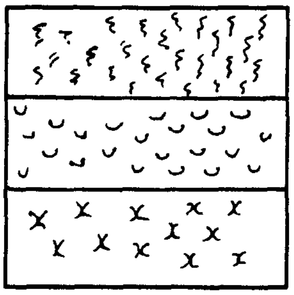
Invertebrate remains.



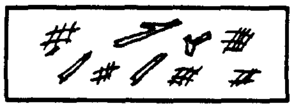
Vertebrate remains.



Large feces. This is an NSS symbol which could be used to show areas of bear or raccoon dropings.

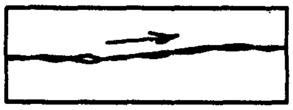


Guano. The MSS, NSS, and British symbols are shown in order from top to bottom.

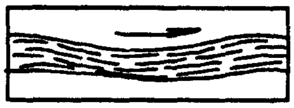


Vegetal debris.

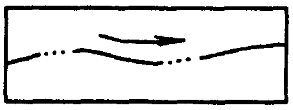
HYDROLOGICAL SYMBOLS



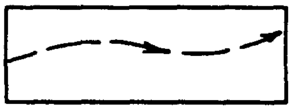
Small stream. Arrows indicate direction of flow.



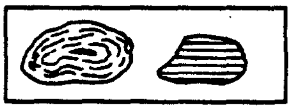
Large stream. Arrows indicate direction of flow.



Intermittent stream. Arrows indicate direction of flow.

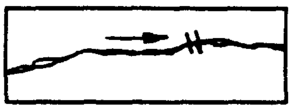


Conjectural stream. Projected location of the cave stream.



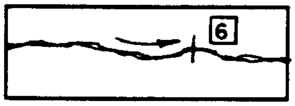
Pool. MSS and NSS symbols are similar. The British use a parallel line pattern for their symbol.

Intermittent pool.

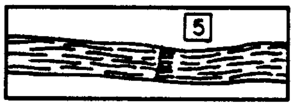


Small rapids.

Large rapids.

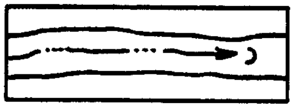


Small waterfall showing height.

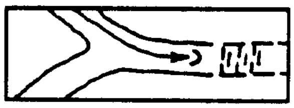


Large waterfall showing height.

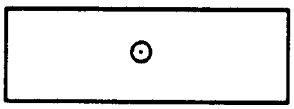
Perennial or seasonal resurgence.



Diffuse sinking stream.

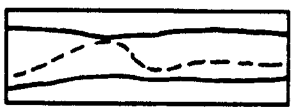


Sinking stream.

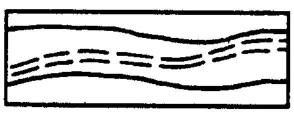


Well pipe or casing.

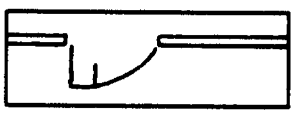
SYMBOLS FOR MAN-MADE FEATURES



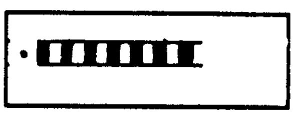
Trail. Dashes in this symbol should be much shorter than the symbol used for an unsurveyed passage.



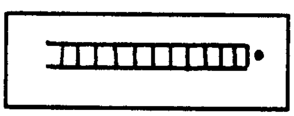
Paved trail.



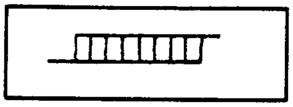
Gate.



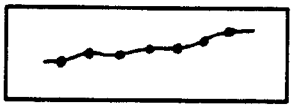
Stairs. Dot indicates the top end in MSS symbols. Open part of the NSS symbol indicates the lower end.



Ladder. Dot on the MSS symbol indicates the top of the ladder. Open part of the NSS symbol shows the lower end.

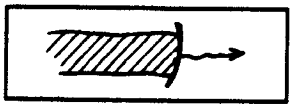


Boardwalk.

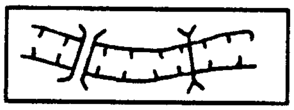


Guardrail.

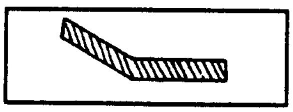
Saltpetre vats.



Dam. Lake Symbol indicates the upstream lake.

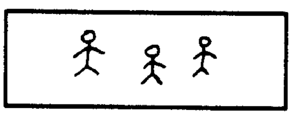


Bridge. Small bridge is on the right, large bridge on the left.

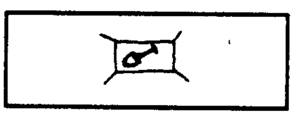


Artificial wall.

Pavement.

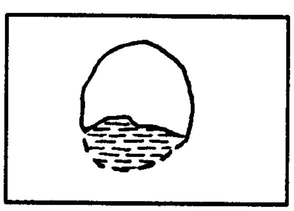


Pictograph or petroglyph

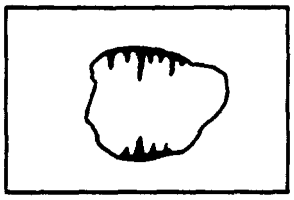


Archaeological excavation.

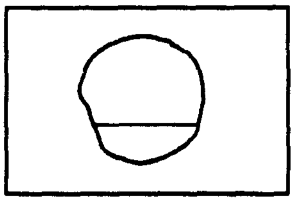
CROSS SECTIONS



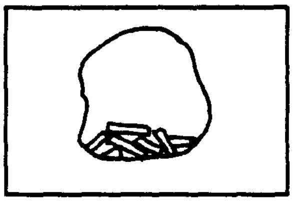
Cross section showing cave fill. Cross sections are drawn to scale. Dashed line shows area obscurred by fill. Use appropriate symbols for the type of fill.



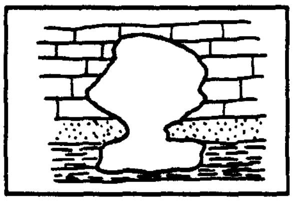
Cross section showing speleothems. Speleothems are drawn to approximate scale.



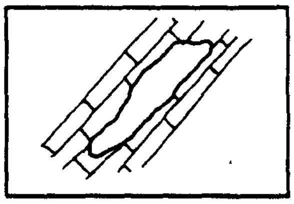
Cross section showing water. Water surface drawn with a straight edge.



Cross section showing breakdown. Symbol size and shape indicates the nature of and type of breakdown.



Cross section showing lithologic control. Use appropriate geologic symbols for various rock types.



Cross section showing structural control.

APPENDIX II.

TRIGONOMETRY FOR CAVE SURVEYORS

The solution to many kinds of surveying problems involves the use of triangles, particularly right triangles. Problems that can be solved through the use of triangles include passage heights, widths of streams and distances between various points.

The basic properties of triangles allows the development of some basic and useful relationships between their sides and angles. These relationships are important to the mathematical study called trigonometry (literally "triangle measurement"). Trigonometry makes it possible to compute the relationships between the lengths of the sides and the sizes of the angles of a triangle. It is the only link between straight-line measurements and angular measurements and because of this, it has innumerable uses and is essential in all surveying computations.

RIGHT TRIANGLES

Trigonometry is based on the relationships between the angle and sides of right triangles. Every right triangle has two acute angles, such as A and B in figure II-1. If we consider each of these angles separately, we can name the sides of the triangle with respect to the angle considered. For example, if we consider angle A, side CA is the side adjacent to angle A, the side CB is the side opposite angle A and the third side is the hypotenuse side. The same system can also be used for angle B.

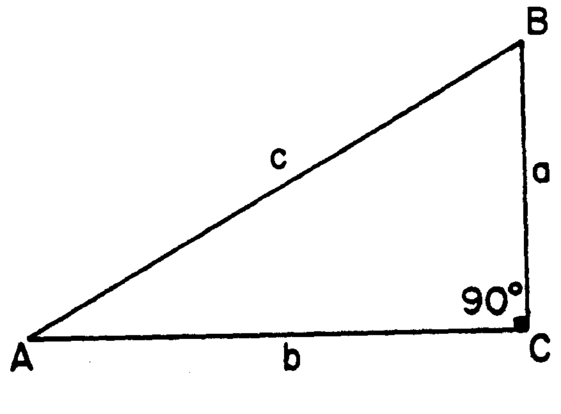


Figure II-1. Nomenclature of sides with respect to each acute angle in a right triangle.

TRIGONOMETRIC FUNCTIONS

From geometry we know that if we have two right triangles and that the acute angle of one is equal to an acute angle of the other, they are similar and their sides are proportional. From this it follows that if we take the ratio of any one side divided by any other, the ratio will remain the same no matter how long the sides are. There are basically six proportions or ratios that can be derived from the right triangle:

opp./hyp. adj./hyp. opp./adj.

adj./opp. hyp./adj. hyp./opp.

The values of these will change only if the acute angle changes.

Each of these ratios therefore has a certain value for any given angle; and for angles between 0 and 90 degrees, once the value of any one of these ratios is known, the size of the angle is known, and vice versa.

Since these ratios are dependent on the size of the acute angle, they are called trigonometric functions of that angle. Table II-1 lists the names of these functions.

Table II-1. Nomenclature of trigonometric functions.

Ratios in triangle	Definition of function	Name of function
a/c	opposite/hyp.	sine
b/c	adjacent/hyp.	cosine
a/b	opposite/adjacent	tangent
b/a	adjacent/opposite	cotangent
c/b	hyp./adjacent	secant
c/a	hyp./opposite	cosecant

Note that cosecant = 1/sine, secant = 1/cosine and cotangent = 1/tangent.

Because of this only the first three functions are necessary.

It is also important to note that from geometry the second acute angle is equal to 90 degrees minus the first. In figure II-1, B = 90° - A, B is the complement of A. Every function of an angle is therefore equal to the cofunction of its complement. For example:

sin A = cos B   sin B = cos A

tan A = cot B   tan B = cot A

sec A = csc B   sec B = csc A

VALUES OF TRIGONOMETRIC FUNCTIONS

Tables are available which give the values of sines, cosines and tangents for any angle. In addition, most scientific calculators are designed to give the values of trigonometric functions.

ALGEBRAIC SIGN OF THE TRIGONOMETRIC FUNCTIONS

If we take the cartesian coordinates of the functions and relate them to the compass directions, we get the signs of the functions as indicated in figure II-2.

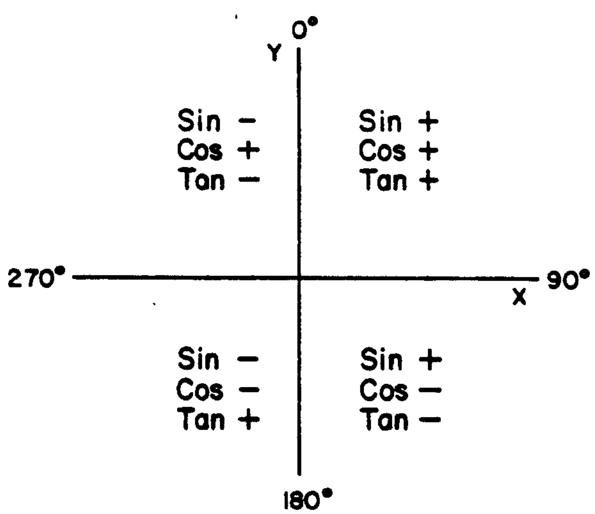


Figure II-2. Algebraic signs of the trigonometric functions.

INVERSE TRIGONOMETRIC FUNCTIONS

In some trigonometric problems, the value of the trigonometric function is known, but the angle is unknown. The process of finding the angle is the inverse or opposite process of computing a trig. function. These are then called inverse trigonometric functions. Using an electronic calculator, it is easily possible to determine the angle by using the inverse function of the calculator. This is shown as the INV key. Nomenclature for these functions are:

Arcsin x means "an angle whose sin is equal to x."

Arccos x means "an angle whose cos is equal to x."

Arctan X means "an angle whose tan is equal to x."

These are also represented by $\sin^{-1}$, $\cos^{-1}$, and $\tan^{-1}$.

SOLUTION OF RIGHT TRIANGLES

As previously discussed, the definition of the trigonometric functions was first given in terms of a right-angle triangle and then extended to arbitrary angles with the help of a unit circle. Some additional relationships from geometry should be noted here:

1. Pythagoras theorem: $c^2 = a^2 + b^2$

2. Each of the angles with its vertex on the hypotenuse of the triangle is the complement of the other: $\alpha + \beta = 90°$.

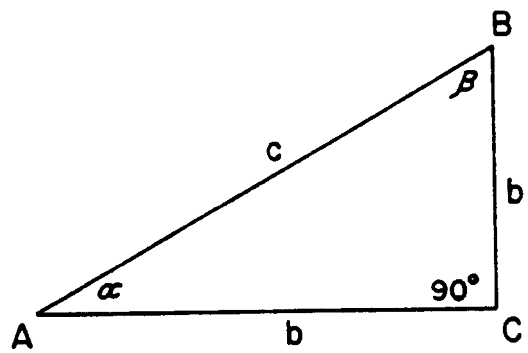


Figure II-3. Right-angled triangle.

Using figure II-3, the following solutions may be stated:

I. Given the hypotenuse c and one adjacent angle α:

1. $\beta = 90° - \alpha$

2. $\text{Sin } \alpha = a/c \quad a = c \text{ Sin } \alpha$

3. $b = c \text{ Cos } \alpha$

II. Given the hypotenuse c and one other side (a):

1. $\text{Sin } \alpha = a/c, \ \beta = 90° - \alpha$

2. $b = \sqrt{(c^2 - a^2)}$

3. Using the calculated angle α;
$\text{Cot } \alpha = b/a$
$b = a \text{ Cot } \alpha$ or $b = c \text{ Cos } \alpha$

III. Given an angle and the side opposite to it - α and a:

1. $\beta = 90° - \alpha$

2. $\text{Cot } \alpha = b/a, \ b = a \text{ Cot } \alpha$

3. $c = a/\text{Sin } \alpha$

IV. Given the two sides a and b and the right angle:

1. $\text{Tan } \alpha = a/b$

2. $\beta = 90° - \alpha$

3. $c = \sqrt{(a^2 + b^2)}$

TRIGONOMETRIC FUNCTIONS IN THE GENERAL TRIANGLE

In many surveying cases it is impossible to use a right triangle to calculate side lengths or angles. Because of this, equations have been derived for the general triangle, figure II-4.

Sine Rule:

The sine rule states that in a plane triangle the ratio of any two sides is equal to the ratio of the sines of the opposite angles.

$$a/\text{Sin } \alpha = b/\text{Sin } \beta = c/\text{Sin } \gamma$$

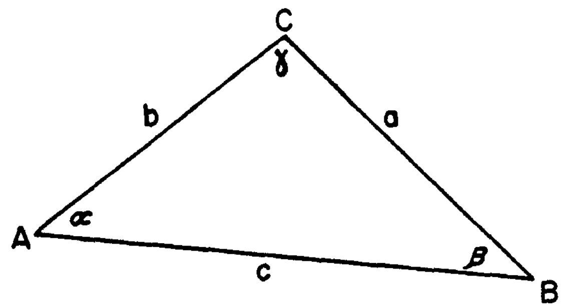


Figure II-4. The general triangle.

—Cosine Rule:

In a plane triangle the square of one side is equal to the sum of the squares of the other two sides minus twice the product of these two sides and the cosine of the angle between them.

$$a^2 = b^2 + c^2 - 2bc \text{ Cos } \alpha$$

$$b^2 = a^2 + c^2 - 2ac \text{ Cos } \beta$$

$$c^2 = a^2 + b^2 - 2ab \text{ Cos } \gamma$$

$$\text{Cos } \alpha = (b^2 + c^2 - a^2)/2bc$$

$$\text{Cos } \beta = (c^2 + a^2 - c^2)/2ca$$

$$\text{Cos } \gamma = (a^2 + b^2 - c^2)/2ab$$

FOUR MAIN CASES FOR THE SOLUTION OF A TRIANGLE

I. SAA Case: Given a side and two angles in the triangle. (Law of Sines)

1. Since the sum of the internal angles of a triangle is 180°

$$\gamma = 180° - (\alpha + \beta)$$

2. $a = \text{Sin } \alpha \ (b/\text{Sin } \beta)$
$= \text{Sin } \alpha \ (c/\text{Sin } \gamma)$

3. $b = \sin\beta\ (a/\sin\alpha)$
   $= \sin\beta\ (c/\sin\gamma)$

4. $c = \sin\gamma\ (a/\sin\alpha)$
   $= \sin\gamma\ (b/\sin\beta)$

II. SSA Case: Given two sides and an angle opposite one of them. (Law of Sines)

1. $\sin\alpha = (a \sin\beta)/b$
   $= (a \sin\gamma)/c$

2. $\sin\beta = (b \sin\alpha)/a$
   $= (b \sin\gamma)/c$

3. $\sin\gamma = (c \sin\alpha)/a$
   $= (c \sin\beta)/b$

4. Once any additional angle is determined, then

   $\gamma = 180° - (\alpha + \beta)$, etc.

III. SAS Case: Given two sides and included angle. (Law of Cosines)

1. $a = \sqrt{(b^2 + c^2 - 2bc \cos\alpha)}$

2. $b = \sqrt{(a^2 + c^2 - 2ac \cos\beta)}$

3. $c = \sqrt{(a^2 + b^2 - 2ab \cos\gamma)}$

IV. SSS Case: Given all three sides of the triangle. (Law of Cosines)

1. $\cos\alpha = (b^2 + c^2 - a^2)/2bc$

2. $\cos\beta = (a^2 + c^2 - b^2)/2ac$

3. $\cos\gamma = (a^2 + b^2 - c^2)/2ab$

There are many other trigonometric relationships that can be found in standard trigonometry text books that might be used for cave surveying. It is a good idea that the cave surveyor take a course in trigonometry or at least expend some effort studying it.

PRACTICE PROBLEMS IN TRIGONOMETRY

1. The angle of elevation of the sun is 52° at the time a television tower casts a shadow 356 feet long on level ground. Find the height of the tower.

2. From the top of a vertical cliff 200 feet high, the angle of depression to a boat is 23°. How far is the boat from the foot of the cliff?

3. A flagpole is atop a building. From a point on the ground 1000 feet from the building, the angles of elevation to the top and bottom of the flagpole are 33° and 30° respectively. How tall is the flagpole?

4. A surveyor wants to determine the width of a river. He sights a point B on the opposite side of the river from point C. He then measures off 400 feet from C to A such that C is a right angle. He then determines that angle A is 56°. How wide is the river?

5. A ship's captain, desiring to travel due south, discovers that, due to an improperly functioning compass, he has gone 22.6 miles in a direction that is 4° east of south. How far from his course (to the east) is he?

6. A ship leaves a port and travels due west. At a certain point it turns 30° north of west and travels an additional 42.0 miles to a point 63.0 miles from the port. How far from the port is the point where the ship turned?

7. A person measures a triangular piece of land and reports that one side is 58.4 feet long and another side is 21.1 feet long. The angle opposite the shorter side is 24°. Could this information be correct?

ANSWERS TO TEXT PROBLEMS

CHAPTER 2

1. a. 11.38 m; b. 17.30 m; c. 7.49 m; d. 29.72 m; e. 4119.92 m.
2. a. 104,986.88 ft.; b. 2145.67 ft.; c. 7732.45 ft.; d. 50.05 ft.; e. 9.35 ft.
3. a. 0.997 mi.; b. 1 mi.; c. 1.89 mi.; d. 0.25 mi.; e. 0.125 mi.
4. a. 42,900 ft. or 13,075.92 m; b. 1671.12 ft. or 509.36 m; c. 1690.92 ft. or 515.39 m; d. 22,079.64 ft. or 6729.87 m; e. 66 ft. or 20.12 m.
5. a. 35.3988°; b. 235.7597°; c. 10.2664°; d. 330.3761°; e. 182.9275°
6. a. 234° 34' 03.72"; b. 23° 19' 48"; c. 198° 54' 43.2"; d. 333° 33' 00"; e. 89° 40' 45.12"
7. a. 131° 51' 00"; b. 88° 05' 15"; c. 36° 54' 00"; d. 180° 00' 00"; e. 360° 00' 00"
8. a. 0.7948 rad; b. 1.1808 rad; c. 3.2378 rad; d. 4.8033 rad; e. 5.8516 rad
9. a. 15.9155 grad; b. 226.6366 grad; c. 351.4141 grad; d. 399.7871 grad; e. 79.5775 grad
10. a. 270° 00' 00"; b. 180° 00' 00"; c. 225° 00' 00"; d. 22° 30' 00"; e. 256° 30' 00"
11. a. 4; b. 9; c. 2; d. 5; e. 8
12. a. 256.2; b. 10.2; c. 135.2; d. 65.7; e. 100.3

CHAPTER 4

1. 7° 30' W.
2. S. 0° 30' W.
3. N. 31° W.
4. S. 35° 30' E.
5. 14° W.
6. 30° R deflection; 210° turned angle
7. 8° 30' E.
8.

AB = 30°	or	AB = 30°
BA = 210°		BA = 210°
<B = -78° 45'		<B = 78° 45'
BC = 131° 15'		BC = 288° 45'
CB = 311° 15'		CB = 108° 45'
<C = -55° 15'		<C = 55° 15'
CD = 256° 00'		CD = 164° 00'
DC = 76° 00'		DC = 344° 00'
<D = -105° 30'		<D = 105° 30'
DA = 330° 30'		DA = 89° 30'
AD = 150° 30'		AD = 269° 30'
<A = -120° 30'		<A = 120° 30'
AB = 30° 30'		AB = 30° 00'

9. a. 237° = S. 57° W.; b. 145° = S. 35° E.; c. 95° = S. 85° E.; d. 215° = S. 35° W.; e. 172° = S. 8° E.; f. 289° = N. 71° W.; g. 310° = N. 50° W.; h. 65° = N. 65° E.; i. 25° = N. 25° E.; j. 187° = S. 7° W.; k. 1650 mils = S. 87° 11' 15" E.; l. 2200 mils = S. 56° 15' E.; m. 3500 mils = S. 16° 52' 30" W.; n. 600 mils = N. 33° 45' E.; o. 5200 mils = N. 67° 30' W.

10. a. 237° = 263.331 grads = 3.874 rads; b. 145° = 161.110 grads = 2.370 rads; c. 95° = 105.555 grads = 1.553 rads; d. 215° = 238.887 grads = 3.514 rads; e. 172° = 191.109 grads = 2.811 rads; f. 289° = 321.108 grads = 4.723 rads; g. 310° = 344.441 grads = 5.067 rads; h. 65° = 72.223 grads = 1.062 rads; i. 25° = 27.778 grads = 1.062 rads; j. 187° = 207.776 grads = 3.056 rads; k. 92° 48' 45" = 103.124 grads = 1.517 rads; l. 123° 45' 00" = 137.497 grads = 2.023 rads; m. 196° 52' 30" = 218.748 grads = 3.218 rads; n. 33° 45' 00" = 37.500 grads = 0.552 rads; o. 292° 30' 00" = 324.997 grads = 4.78 rads.

CHAPTER 5.

1. 26 to 26A = 111 feet; 27 to 26A = 88.5 feet.
2. 10 to stalagmite = 73.00; 11 to stalagmite = 113.57 feet
3. 6 to 8 = 164.22 feet.
4. 6 to 7 = 98.67; 7 to 8 = 77.43 feet
5. 10 to 12 = 210.94 feet

CHAPTER 6.

1. 52 feet
2. horizontal distance = 73.0; elevation difference = 19.6 feet
3. 122.63 feet
4. 48.1 feet
5. 1273.2 feet
6. 140.18 feet
7. 120.46 feet
8. 397.83 feet

APPENDIX II.

1. 455.66 feet tall
2. 471.17 feet out
3. 72.06 feet
4. 593.02 feet
5. 1.58 miles
6. 23.02 miles
7. no

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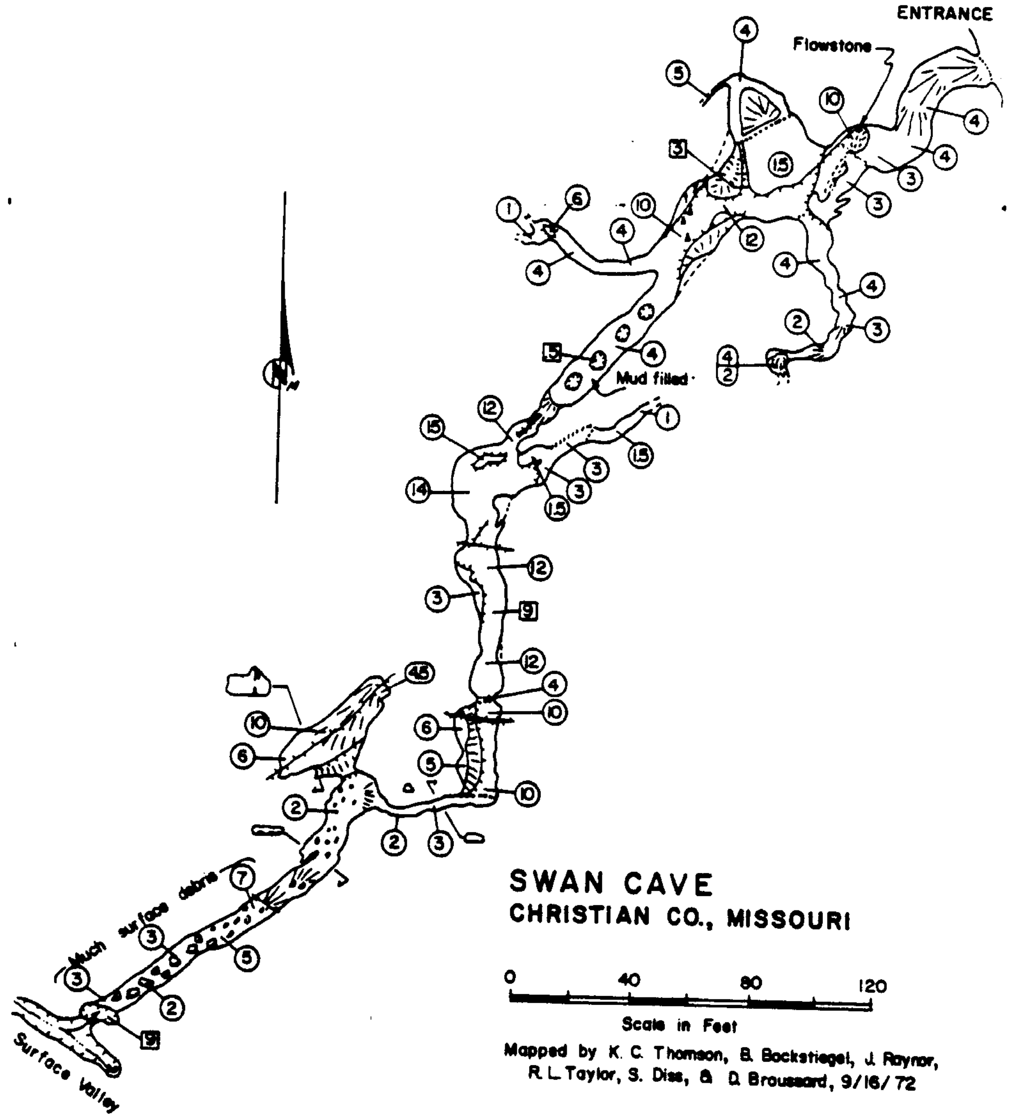
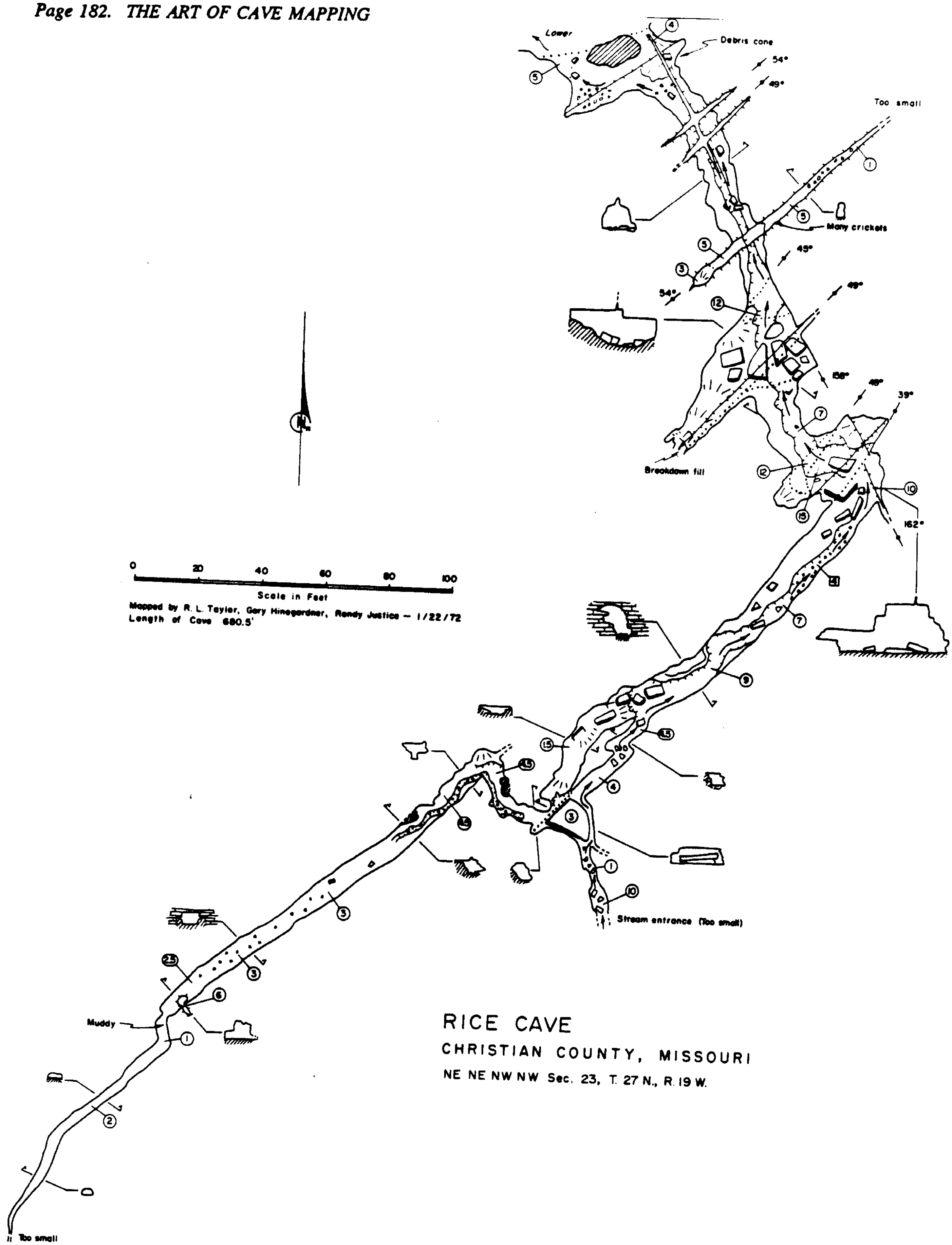


INDEX


Lower
Debris cone
Too small
Many crickets
Breakdown fill
Stream entrance (Too small)
Muddy
Too small
0 20 40 60 80 100
Scale in Feet
Mapped by R. L. Taylor, Gary Hinegardner, Randy Justice – 1/22/72
Length of Cave 680.5'
RICE CAVE
CHRISTIAN COUNTY, MISSOURI
NE NE NW NW Sec. 23, T. 27 N., R. 19 W.

MISSOURI SPELEOLOGICAL SURVEY, INC.

The Missouri Speleological Survey, Inc., is a non-profit organization of groups and individuals in the state of Missouri who are engaged in study and research in speleology. The Survey actively promotes cave conservation as a means of insuring the continued availability of caves in their natural state. To implement these aims and purposes, the survey publishes a quarterly journal, current cave catalogs, cave maps, and a monthly publication designed to keep cooperators informed on the progress of current research.

The Survey was incorporated as a not-for-profit organization under the laws of Missouri and is administered by a Board of Directors, selected by affiliate organizations and members, and a President, Vice President, Treasurer, and Secretary, selected by the Board. The directors meet three times a year to formulate the policies of the Survey which are then acted on by the officers and appointed committees.

The Survey is supported by Missouri chapters of the National Speleological Society, local caving clubs, other agencies, and individuals who are interested in supporting cave research. Funds for the operation of the Survey come primarily from the sale of publications, from grants and gifts, and from membership and affiliation fees.

The Missouri Department of Natural Resources, Division of Geology and Land Survey, and the National Speleological Society have supported the Survey since its inception. The Division of Geology and Land Survey provides a permanent repository and reproduction service for cave maps and maintains a cooperative cave file. The Society provided grants and technical assistance in the early years of the Survey. During recent years the Survey has worked with the National Park Service, United States Forest Service, the Missouri Department of Conservation, the Nature Conservancy, the United States Army Corps of Engineers, planning commissions, and other state, local and federal agencies and organizations as well as with individuals and land owners.

The Missouri Speleological Survey is primarily a service organization, and in this capacity it provides numerous services for its affiliates, members, and cooperators that would be difficult for local organizations, agencies, or individuals to provide. The Survey's status as an independent research organization allows much more effective interaction with other organizations than would normally be possible on a local scale.

The Missouri Speleological Survey does not presume to be a national cave research organization. It was conceived and operated primarily for the study of the caves and related features of Missouri. It is designed to be compatible with other state and national groups having similar aims, purposes, and standards.

CONSERVE MISSOURI'S CAVES