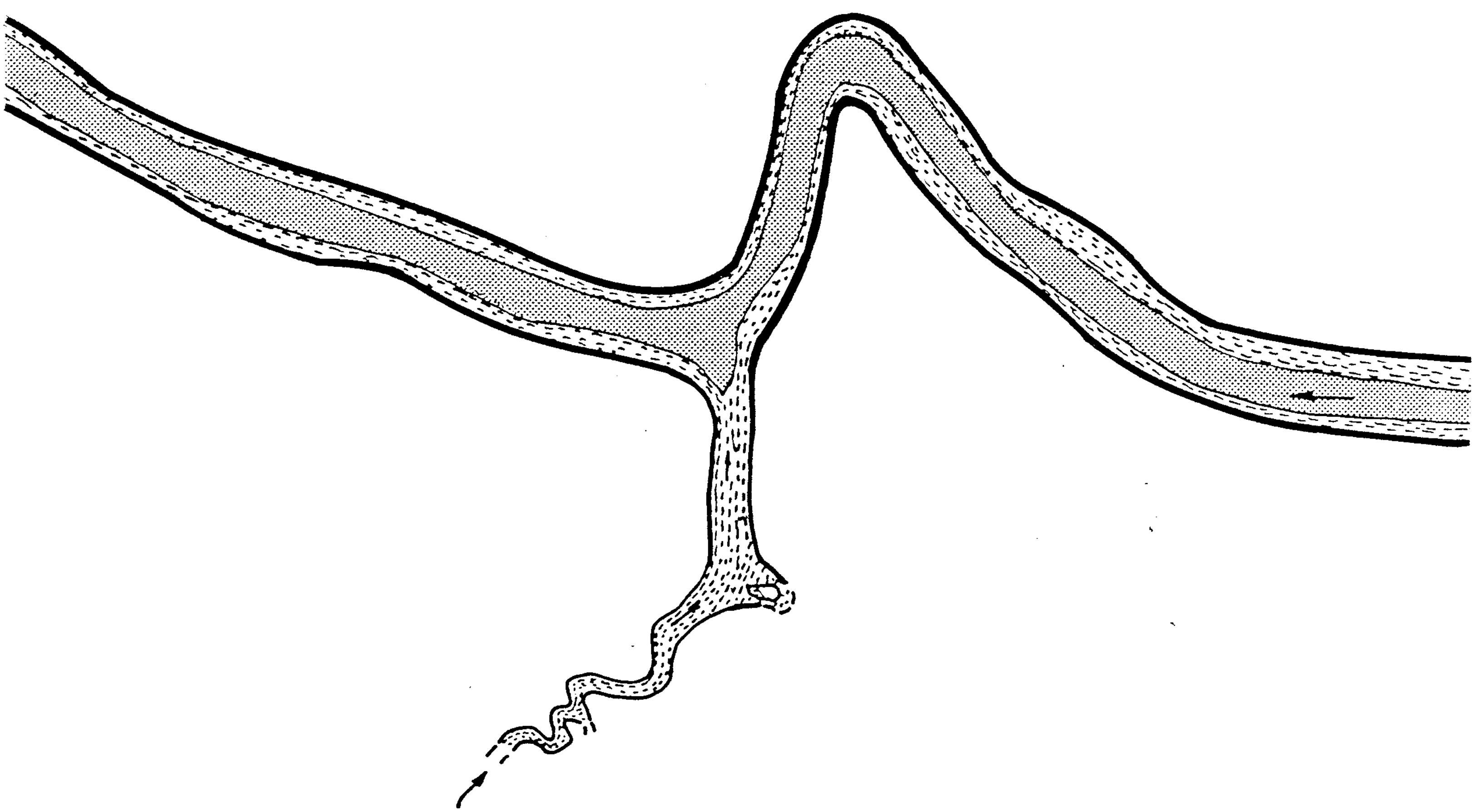
COMPASS & TAPE



Volume 5 Number 2

Fall 1987

COMPASS & TAPE

Volume 5 Number 2 Fall 1987

COMPASS & TAPE is the quarterly newsletter of the Survey & Cartography Section of the National Speleological Society, Cave Ave., Huntsville, Alabama 35810, U.S.A. The cost is $4.00 per year for 4 issues. Please make checks payable to Survey & Cartography Section. Include your NSS number for Section membership. Foreign members and subscribers are **welcome!** Rates are US$4.00 per year for surface mail: inquire for air rates. We regret that payment must be in US$, and checks drawn on U.S. banks. The volume runs from the annual NSS Convention: those paying later will receive all back issues. Expiration dates are printed on mailing labels. Volumes 1, 2, 3 and 4 are available for $5.00 each.

Dues, Subscriptions, Articles,
Maps, Letters, Address Changes,
Comments, Tips, Photos:

John Ganter
Editor, Compass & Tape
Department of Geography, 302 Walker Bldg.
The Pennsylvania State University
University Park, PA 16802 USA
H: 814-237-7841 O: 814-865-6421
BITNET: GL0 @ PSUVM

Submissions: Short items may be in any form. Articles: Disks are preferred. Send 5 1/4-inch DOS Double or High-density, with ASCII, Word, Wordstar or Word-Perfect Files. Modem service is not available. Hard Copy: Should be in black ink, fixed pitch; typewriter or daisy-wheel preferred. Dot-matrix must be large and highly legible. Illustrations: Are strongly encouraged! Camera-ready copy is appreciated and should be designed for reduction. Contact the Editor if you have any questions or special requirements.

COVERS: Section of Dickenson Cave, Todd Co., Kentucky. Scale is about 50 feet per inch.

CONTENTS

On Cave Survey Blunders by Fred L. Wefer 23
Testing the Ultimeter by John Ganter 44

Text Processing Courtesy of the Department of Geography,
College of Earth & Mineral Sciences, The Pennsylvania State University.

ON CAVE SURVEY BLUNDERS

by

Fred L. Wefer

INTRODUCTION

This paper presents some information on cave surveying in general and on cave survey blunders in particular. First a set of formal DEFINITIONS is presented for the terms used in cave surveying. The discussion continues with a brief section on THE IMPORTANCE OF LOOPS. SURVEYING ERRORS are then discussed, followed by a detailed presentation on DETECTING THE PRESENCE OF A BLUNDER. It turns out to be possible to anticipate the TYPES OF BLUNDERS which can occur in a cave survey. Forty-six types have been identified and are listed in this section. The following two sections discuss the RELATIVE FREQUENCIES OF BLUNDERS and the RELATIVE SIZES OF BLUNDERS. The difficulty in FINDING THE BLUNDER is touched upon next. This is followed by a SUMMARY AND CONCLUSIONS and finally by the REFERENCES cited.

DEFINITIONS

Local training and practices in cave surveying result in slightly different terminology being used in discussing surveying activities. In addition, references such as Hosley [1971] and Ellis [1976] which do present more or less formal definitions, do not always agree on those definitions. Most of the general literature on caving practices and techniques do not even deal with cave surveying. Table 1, for example, lists some major references available to the beginning caver. It is surprising to see how little information on surveying is available in these popular works. And this has been true in every decade. One author devotes more space to how to remove a corpse from a cave than to how to survey a cave!

There are five notable exceptions to the comments listed above, viz: Hosley [1971], Freeman [1975], Ellis [1976], Thomson and Taylor [1981], and Ganter [1985]. But these are more specialized works not as readily available or as appealing to the beginner.

Table 1. Popular works on caving practices and techniques are listed. Also shown are: the level of the presentation of cave surveying methods, the number of pages devoted to the subject, whether definitions of surveying terms are included, and whether sources of surveying errors are discussed.

Reference	Level of the Presentation	No of Pages	Definitions of Terms	Sources of Error
Cullingford [1953]	Basic	27	No	No
Longsworth [1959]	None	Ø	No	No
Pinney [1962]	Very Basic	2	No	No
Storey [1965]	Very Basic	8	A Few	No
Cullingford [1969]	None	Ø	No	No
Lovelock [1969]	None	1	No	No
Slaven [1971]	Very Basic	3	No	No
McClurg [1973]	Very Basic	8	No	No
Anderson [1974]	None	Ø	No	No
Halliday [1974]	None	Ø	No	No
Ford and Cullingford [1976]	Very Basic	1Ø	No	No
Lovelock [1981]	None	1	No	No
Larson and Larson [1982]	None	Ø	No	No
Hassemer [1982]	None	Ø	No	No
Lyon [1983]	Very Basic	3	A Few	No
Judson [1984]	Very Basic	6	No	No
McClurg [1986]	None	Ø	No	No

In an effort to ensure that the reader knows the basic terms used by this author, a set of more or less formal definitions is presented below. These have been taken, with some slight modifications, from Brinker and Taylor [1957] which is a textbook on the fundamentals of surveying, and from Wefer [1971].

Surveying -- The science or art of making the measurements necessary to determine the relative positions of points above, on, or beneath the surface of the earth, or to establish such points.

Station -- One of the points whose position relative to other such points is being determined by the surveying. The measurements necessary to determine the relative positions are usually, but not always, made at the survey stations.

Segment -- A straight line connecting adjacent successive stations of a survey.

Shot -- A term having multiple meanings, but generally referring either to one or more of the measurements required to define a segment, or to the segment itself.

Meridian -- An established horizontal reference line used in measuring the direction of another line. Two meridians are in common use, the "true meridian" and the "magnetic meridian".

True Meridian -- The great circle projected on the earth's surface, which passes through the observer's position and the north and south geographic poles. The true meridian is sometimes called the "geographic meridian".

Magnetic Meridian -- The great circle projected on the earth's surface, which passes through the observer's position and the north and south magnetic poles.

Azimuth -- The direction of the horizontal component of a segment indicated by the clockwise angle between the horizontal component and the meridian. In cave surveying the angle is always measured from the north.

Bearing -- The direction of the horizontal component of a segment indicated by the acute angle between the horizontal component and the meridian. The angle is measured either from the north or south, toward either the east or west, as may be necessary to give a reading less than 90.0 deg.

Compass -- A surveying instrument utilizing a magnetized iron needle (or a magnetized disk) on a pivot. A graduated circle and sights allow the measurement of the angle between the horizontal component of a segment and the magnetic meridian.

Dip -- The angle between the segment and the projection of the segment onto the horizontal plane passing through the station where the measurement is being made. If the segment is above the horizontal plane the dip is positive in sign, while if it is below the horizontal plane the dip is negative in sign.

Inclination -- A synonym for "dip".

Vertical Angle -- Another synonym for "dip".

Clinometer -- A surveying instrument utilizing a bubble level mounted on an axle at the center of a graduated arc. Sights mounted with the graduated arc allow the measurement of the dip of a segment.

Distance -- The straight line distance between successive survey stations, i.e., the length of the segment.

Tape -- A surveying instrument for measuring the distances of segments.

Traverse -- A set of distances, azimuths (or bearings), and dips connecting successive stations of a survey. The word "traverse" refers primarily to the measurements of the segments, i.e., the azimuths, the dips, and the distances.

Series -- A set of segments which form a continuous path through cave passages, hence the set of segments represented by a traverse. The word "series" refers primarily to the segments themselves.

Traverse Line -- A synonym for "series".

String -- Another synonym for "series".

Branch -- Still another synonym for "series".

Open Traverse -- A series which begins at a given point in space and terminates at a different and unknown point in space.

Closed Traverse -- A series which begins at a given point in space and terminates at either the beginning point or some other known point in space.

Loop -- A synonym for "closed traverse".

Simple Loop -- A closed traverse in which the first station and the terminal station are the same point in space.

Compound Loop -- A closed traverse in which the relative positions of the first and terminal stations of the loop are known, but are not the same point in space. It is called compound because another traverse must exist in determining the relative positions of the first and terminal stations, otherwise their relative positions could not be known.

Multiple Loop -- A closed traverse in which there are more than two distinct traverse lines from any given station to any other station in the loop.

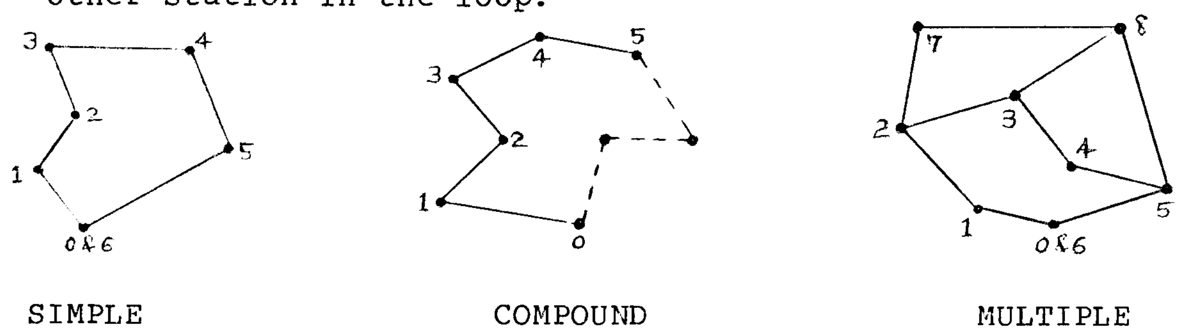


Figure 1. Examples of a simple loop, a compound loop, and a multiple loop.

THE IMPORTANCE OF LOOPS

After reading the previous section, the reader knows pretty clearly what a loop is. But why are loops important? The reason is that with an open traverse, since the location of the terminal station is unknown, no information exists in the traverse on the accuracy with which the location of the terminal station has been determined.

With a closed traverse or loop, the location of the terminal station is known. Hence we have only to compare the position of the terminal station (computed from the closed traverse) with its already known position to know the accuracy of the determination.

Strictly speaking, we can check only the accuracy of the determination of the location of the terminal station. This is not particularly useful since we already know its location, even without the survey. After all, that is what makes it a loop. What is useful is the inference that, if the determination of the location of the terminal station is precise, then so are the determinations of the locations of the other stations of the series. That this inference is not necessarily true is one of the little ironies of cave surveying.

A number of techniques exist for adjusting the traverse so that the location of the terminal station computed from the adjusted traverse, coincides with the known location of the terminal station (Schmidt and Schelleng [1970], Wefer [1971], etc.) The inference here is that if the adjusted location of the terminal station is improved by the adjustment process, then the adjusted locations of the other stations of the series are also improved. That this inference is not necessarily true is one of the big ironies of cave surveying.

SURVEYING ERRORS

Errors in measurements are of three types: systematic errors, random errors, and blunders. While different authors may use different names for these, there is general agreement as to their definitions. Each of these is defined and discussed next.

Systematic Errors

Systematic errors are measurement errors which conform to known mathematical and/or physical laws. An example is a compass with its pivot not at the center of the graduated circle. Azimuths read from such a compass will be in error by:

$$e[A] = e[A,max] \sin (F+G)$$

The definitions of the quantities in this equation are not important here. What is important is that the resulting error is predictable and measurable, hence correctable. For a discussion of such errors, see Brod [1971]. If they are not corrected (as is the usual case) such errors will, of course, contribute to the total error at each station of the traverse.

Random Errors

Random errors conform to the laws of probability. They tend to be small, to be of random magnitude, and to be of random sign. An example is the error introduced by rounding azimuth readings to the nearest degree. There is no absolute way to compute random errors or to eliminate them. The understanding and decreasing of random errors in a traverse are the subjects of numerous papers, e.g., Schwinge [1962], Schmidt and Schelleng [1970], Wefer [1971, 1974a, and 1974b], Irwin and Stenner [1975], Kaye [1981a and 1981b], and Thrun [1981].

Blunders

Errors which are blunders have the following properties: they do not conform to physical or mathematical laws, they are not necessarily small, and they occur infrequently enough that they are not accurately described by the laws of probability. An example is transposing the digits in an azimuth (recording 275 deg. when the correct azimuth is 257 deg.). With the important exceptions of Freeman [1975], Hawes [1977], and Hoke [1983], not a lot seems to have been written about this type of error.

Every traverse contains random errors and unknown and/or uncorrected systematic errors. Not every traverse contains blunders. The remainder of this paper deals with blunders, their detection, and their characteristics.

DETECTING THE PRESENCE OF A BLUNDER

The combination of properties of blunders listed above makes them difficult to deal with. First you have to detect the presence of a blunder. Once you know (or suspect) that a blunder exists in a particular loop, you then have to decide what to do about it.

The key to detecting the presence of a blunder is knowing what to expect in the way of accuracy from the survey crew. Failure to meet the expected accuracy is a good indication of the presence of errors including blunders, provided the expected accuracy is appropriately chosen.

In order to compare the actual accuracy of the survey with the expected accuracy, two things are required: a well defined measure of accuracy and a record of values of this measure of accuracy actually attained by survey crews. Wefer [1971, 1974a, and 1974b] has demonstrated the usefulness of the "ratio of error" for such a measure of accuracy.

$$R = C / P \quad (1)$$

where: R = the ratio of error (dimensionless),

C = error of closure of the loop (ft), and

P = perimeter of the loop (ft).

The usefulness of the ratio of error is that if the traverse is adjusted to produce zero error of closure using the Compass Rule (see Wefer [1971]), then the resulting changes in the traverse are predictably limited (see Wefer [1974a and 1974b]).

The author has computer processed more than a hundred cave surveys during the last twenty years. Among these were 50 simple loops with the following characteristics: all were Brunton compass and tape surveys in which both azimuths (or bearings) and dips were measured; most were done with hand-held Bruntons (but a couple were accomplished with tripod mounted Bruntons); most were done in the Butler Cave-Sinking Creek System (but some were made in Arizona, Mexico, and the Dominican Republic); no corrections were made for systematic errors; and all loops are thought to be free of blunders.

Figure 2 below shows the ratios of error plotted versus the perimeters of the loops for this set of simple loops. A number of interesting features are apparent in this scatter diagram. Note that 78% of the loops have ratios of error less than 0.02, and that the 11 loops with R greater than 0.02 are all short, with perimeters less than 350 feet. Note also that all points fall below the line described by

$$R = 0.75 * P^{-0.5} \quad (2)$$

What is desired here is a simple criterion for the existence of a blunder in the traverse. Equation 2 fulfills this requirement, but it may be too restrictive since some of the points lie very close to the line. A better choice is probably

$$R = P^{-0.5} \quad (3)$$

Remember that the perimeter "P" is here measured in feet. If the survey is conducted in meters, one would use the metric equivalent of Equation (3), viz:

$$R = 0.55 * Q^{-0.5} \quad (3a)$$

where here "Q" is the perimeter of the loop measured in meters.

The reader should note that the use of different surveying instruments and techniques can be expected to yield somewhat different results.

We note in passing that ratios of error below 0.02 are consistent with the general findings of Ellis [1976]. Note also that the errors depicted in Figure 2 are approximately three times those predicted by Irwin and Stenner [1975] for similar instruments and practices. But then the actual measurements presented by Irwin and Stenner were also on the order of two to three times their predictions, albeit they only presented data for 10 loops, and only in tabular form.

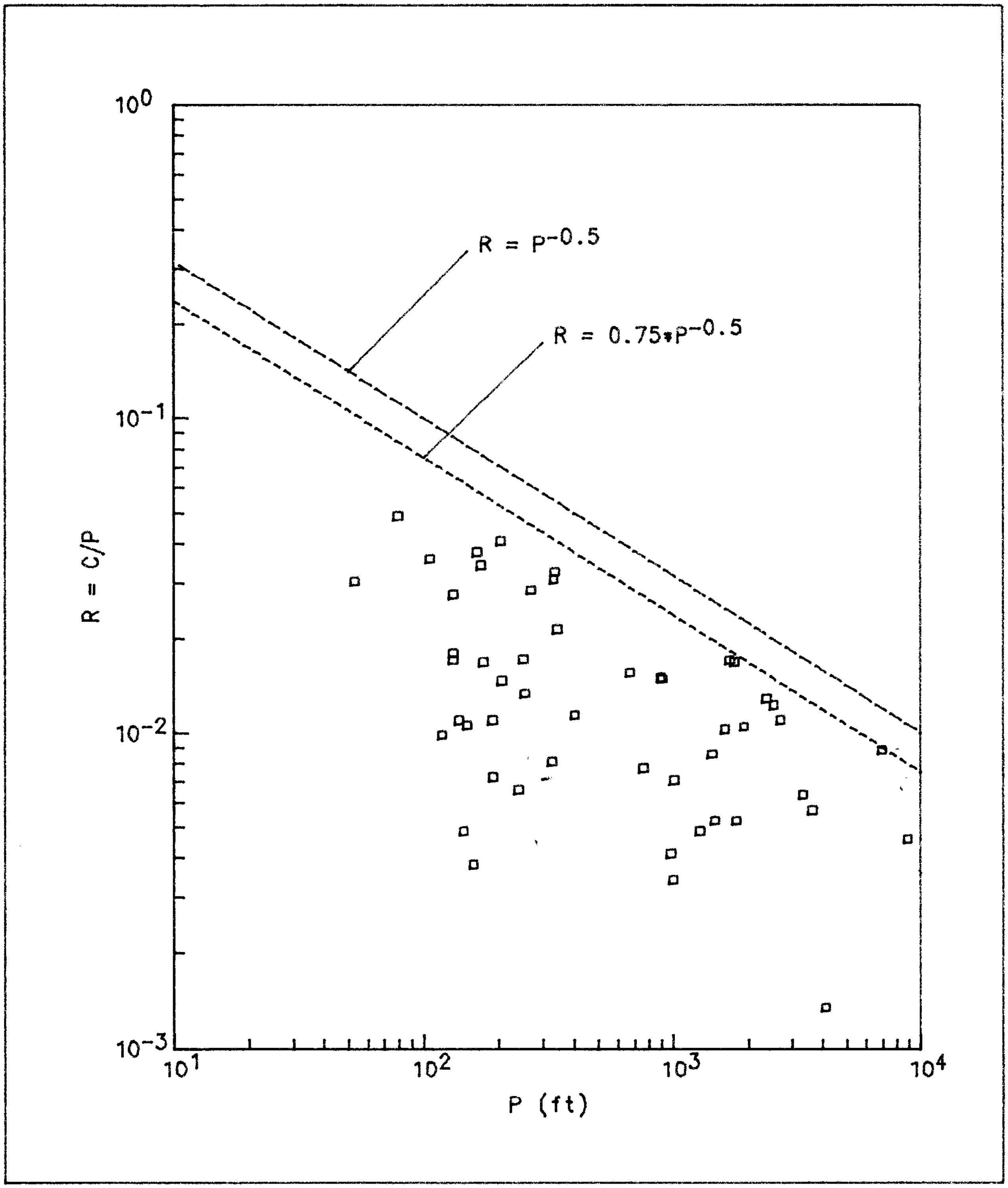


Figure 2. The ratio of error (R) plotted versus the perimeter of the loop (P) for 50 Brunton compass and tape surveys of simple loops. Any survey which falls above the upper dashed line is suspected of containing one or more blunders.

TYPES OF BLUNDERS

We now have a simple method of detecting the presence of a blunder, if it is large enough. But we still do not know what the error is. We continue the discussion now by considering the possibilities. The following list of blunders was compiled from: Freeman [1975], Kaye [1981a], Hawes [1977], and the experiences of the author. But most of the blunders listed below are the result of looking at the instrument and asking the question, "How could I possibly screw up the measurement?"

Seven categories of blunders are listed:

- Azimuth/Bearing Blunders (Brunton compass graduated in deg.)
- Azimuth Blunders (Brunton compass graduated in mils)
- Dip Blunders (Brunton clinometer graduated in degrees)
- Dip Blunders (Brunton clinometer graduated in mils)
- Distance Blunders (Tape graduated in feet)
- Distance Blunders (Tape graduated in meters)
- Generic Blunders.

Each listed blunder has the following data presented for it:

A label for later reference.
A one line description of the error.
An example of the error.
The size of the error in azimuth, dip, or distance.
The contribution to C, Ch, or Cz as appropriate.

where: C = total error of closure,

Ch = horizontal component of C, and

Cz = vertical component of C.

The contributions to Ch and Cz listed below are approximations which rely on the assumption that D(i) < 15 deg, which is true for most surveys. Elementary trigonometry then yields:

$$\Delta Ch = d(i)*SQRT\ (\ 2.0*(1.0 - \cos e[A]))\qquad (4)$$

ΔCz = d(i)*sin e[D] (5)

ΔC = e[d] (6)

where: ΔCh = contribution to Ch,

e[A] = error in azimuth,

ΔCz = contribution to Cz,

e[D] = error in dip,

ΔC = contribution to C, and

e[d] = error in distance.

Some additional symbols used above are:

A(i) = azimuth for segment i,

B(i) = bearing for segment i,

D(i) = dip for segment i, and

d(i) = distance for segment i.

We want presently to compare the sizes of the contributions to the error of closure from each type of blunder. To do this they must all be expressed in the same "units". Most of the contributions to the errors in C, Ch, and Cz are easily expressed in terms of d(i). Where necessary, in order to express a contribution in terms of d(i), it has been assumed that d(i) is in the range:

$$10 \text{ ft} < d(i) < 100 \text{ ft} \quad (7)$$

With this assumption, for example, an error of e[d] can be represented as a contribution to C of:

$$(e[d]*d(i)/100 \text{ ft}) < C < (e[d]*d(i)/10 \text{ ft}) \quad (8)$$

We proceed now to the list of blunders in each of the seven categories mentioned above.

Azimuth/Bearing Blunders (Brunton compass graduated in degrees)

Ad1 -- Digit error (hundreds)
312.0 instead of 212.0 deg.
Azimuth error: e[A] = 100.0 deg.
Contribution to Ch: ΔCh = 1.53*d(i)

Ad2 -- Digit error (tens)
202.0 instead of 212.0 deg.
Azimuth error: e[A]= 10.0 deg.
Contribution to Ch: ΔCh = 0.17*d(i)

Ad3 -- Digit error (units)
102.0 instead of 101.0 deg.
Azimuth error: e[A] = 1.0 deg.
Contribution to Ch: ΔCh = 0.017*d(i)

Ad4 -- Reading the wrong way from a marked graduation
158.5 instead of 161.5 deg.
Azimuth error: e[A] < 10.0 deg.
Contribution to Ch: ΔCh < 0.17*d(i)

Ad5 -- Transposition errors in azimuth
274.0 deg. instead of 247.0 deg.
Azimuth error: e[A] = 9*N deg., where N = 1, 2, 3, 4, 5, 6, 7, 8, 10, or 20
Contribution to Ch: ΔCh = M*d(i) , where M = 0.16, 0.31, 0.47, 0.62, 0.77, 0.91, 1.0, 1.2, 1.4, or 2.0

Ad6 -- Reading the wrong meridian for a bearing
S 15.5 E instead of N 15.5 E
Azimuth error: e[A] = 180.0-2.0*B(i)
Contribution to Ch: ΔCh < or = 2.0*d(i)

Ad7 -- Reading the wrong direction for a bearing
N 15.5 W instead of N 15.5 E
Azimuth error: e[A] = 2.0*B(i)
Contribution to Ch: ΔCh < or = 2.0*d(i)

Azimuth Blunders (Brunton compass graduated in mils)

Am1 -- Digit error (thousands)
2220 instead of 1220 mils
Azimuth error: e[A] = 1000 mils = 56.3 deg
Contribution to Ch: ΔCh = 0.94*d(i)

Am2 -- Digit error (hundreds)
1220 instead of 1120 mils
Azimuth error: e[A] = 100 mils = 5.6 deg.
Contribution to Ch: ΔCh = 0.10*d(i)

Am3 -- Digit error (tens)
1230 instead of 1120 mils
Azimuth error: e[A] = 10 mils = 0.56 deg.
Contribution to Ch: ΔCh = 0.010*d(i)

Am4 -- Reading the wrong way from a marked graduation
1280 instead of 1320 mils
Azimuth error: e[A] < 200 mils = 11.3 deg.
Contribution to Ch: ΔCh < 0.20*d(i)

Am5 -- Transposition errors in azimuth
4300 mils instead of 3400 mils, or
4310 mils instead of 4130 mils
Azimuth error: e[A] = 90*N mils, where N = 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 20, 30, 40, 50, or 60
Contribution to Ch: ΔCh = M*d(i) , where M = 0.088, 0.18, 0.26, 0.35, 0.44, 0.52, 0.61, 0.69, 0.77, 0.86, 1.55, 1.94, 1.96, 1.61, or 0.94

Dip Blunders (Brunton clinometer graduated in degrees)

Dd1 -- Reading the wrong sign
-5.0 instead of +5.0 deg.
Dip error: e[D] = 2.0*D(i) < 10.0 deg.
Contribution to Cz: ΔCz < 0.17*d(i)

Dd2 -- Reading the percent grade scale instead of the angle scale
Both scales are present on a Brunton's clinometer
Dip error: e[D] = (D(i)-100*tan D(i))
Contribution to Cz: ΔCz = 0.26*d(i)

Dd3 -- Digit error (tens)
18.5 instead of 28.5 deg.
Dip error: e[D] = 10.0 deg.
Contribution to Cz: ΔCz = 0.17*d(i)

Dd4 -- Reading the wrong way from a marked graduation
8.5 instead of 11.5 deg.
Dip error: e[D] < 10.0 deg.
Contribution to Cz: ΔCz < 0.17*d(i)

Dd5 -- Transposition errors in dip
81.0 deg. instead of 18.0 deg.
Dip error: e[D] = 9*N deg., where N = 1, 2, 3, 4, 5, 6, or 7
Contribution to Cz: ΔCz = M*d(i), where M = 0.16, 0.31, 0.45, 0.59, 0.71, 0.81, or 0.89

Dip Blunders (Brunton clinometer graduated in mils)

Dm1 -- Reading the wrong sign
- -100 instead of +100 mils
- Dip error: e[D] = 2.0*D(i) < 178 mils (10 deg.)
- Contribution to Cz: ΔCz < 0.17*d(i)

Dm2 -- Digit error (hundreds)
- 340 instead of 240 mils
- Dip error: e[D] = 100 mils (5.6 deg.)
- Contribution to Cz: ΔCz = 0.10*d(i)

Dm3 -- Digit error (tens)
- 250 instead of 240 mils
- Dip error: e[D] = 10 mils (0.6 deg.)
- Contribution to Cz: ΔCz = 0.010*d(i)

Dm4 -- Reading the wrong way from a marked graduation
- 8.5 instead of 11.5 deg.
- Dip error: e[D] < 10.0 deg.
- Contribution to Cz: ΔCz < 0.17*d(i)

Dm5 -- Transposition errors in dip
- 120 mils instead of 210 mils
- Dip error: e[D] = 90*N mils, where N = 1, 2, 3, 4, 5, 6, 7 or 8
- Contribution to Cz: ΔCz = M*d(i), where M = 0.088, 0.18, 0.26, 0.35, 0.43, 0.51, 0.58, or 0.65

Distance Blunders (Tape graduated in feet)

df1 -- Digit error (tens)
- 34 ft instead of 24 ft
- Distance error: e[d] = 10 ft
- Contribution to C: 0.1*d(i) < ΔC < 1.0*d(i)

df2 -- Digit error (units)
- 34 ft instead of 35 ft
- Distance error: e[d] = 1 ft
- Contribution to C: 0.01*d(i) < ΔC < 0.1*d(i)

df3 -- Reading metric side instead of English side of tape
- 12.3 ft (actually meters) instead of 40.5 ft
- Distance error: e[d] = 0.70*d(i)
- Contribution to C: ΔC = 0.70*d(i)

df4 -- Reading the wrong way from a marked graduation
- 41 ft 4 in instead of 40 ft 8 in
- Distance error: e[d] < 1 ft
- Contribution to C: ΔC < 0.1*d(i)

df5 -- Transposition errors in distance
45 ft instead of 54 ft
Distance error: e[d] = 9*N ft, where N = 1, 2, 3, 4, 5, 6, 7, or 8
Contribution to C: $0.09*d(i) < \Delta C < 7.2*d(i)$

df6 -- Confusing sixes and nines (inches)
40 ft 6 in instead of 40 ft 9 in
Distance error: e[d] = 0.25 ft
Contribution to C: $0.0025*d(i) < \Delta C < 0.025*d(i)$

df7 -- Confusing sixes and nines (units)
6 ft instead of 9 ft
Distance error: e[d] = 3.0 ft
Contribution to C: $0.030*d(i) < \Delta C < 0.30*d(i)$

df8 -- Confusing sixes and nines (tens and units)
66 ft instead of 99 ft
Distance error: e[d] = 33.0 ft
Contribution to C: $0.33*d(i) < \Delta C < 3.3*d(i)$

df9 -- Confusing sixes and nines (tens and units)
61 ft instead of 19 ft
Distance error: e[d] = 42.0 ft
Contribution to C: $0.42*d(i) < \Delta C < 4.2*d(i)$

df10 - Confusing sixes and nines (tens and units)
91 ft instead of 16 ft
Distance error: e[d] = 75 ft
Contribution to C: $0.75*d(i) < \Delta C < 7.5*d(i)$

Distance Blunders (Tape graduated in meters)

dm1 -- Digit error (tens)
12 m instead of 22 m
Distance error: e[d] = 10 m (32.8 ft)
Contribution to C: $0.33*d(i) < \Delta C < 3.3*d(i)$

dm2 -- Digit error (units)
12 m instead of 13 m
Distance error: e[d] = 1 m (3.28 ft)
Contribution to C: $0.033*d(i) < \Delta C < 0.33*d(i)$

dm3 -- Reading English side instead of metric side of tape
35.0 m (actually ft) instead of 10.67 m
Distance error: e[d] = 2.3*d(i)
Contribution to C: $\Delta C = 2.3*d(i)$

dm4 -- Reading the wrong way from a marked graduation
  11 m 4Ø cm instead of 1Ø m 6Ø cm
  Distance error: e[d] < 1 m (3.3 ft)
  Contribution to C: ΔC < Ø.33*d(i)

dm5 -- Transposition errors in distance
  12 m instead of 21 m
  Distance error: e[d] = 9*N m, where N = 1, 2, or 3
    Assumes a 1ØØ ft tape (d(i) < 3Ø m)
  Contribution to C: Ø.3Ø*d(i) < ΔC < 8.9*d(i)

dm6 -- Confusing sixes and nines (centimeters)
  11.36 m instead of 11.39 m
  Distance error: e[d] = Ø.Ø3 m (Ø.Ø98 ft)
  Contribution to C: Ø.ØØØ98*d(i) < ΔC < Ø.ØØ98*d(i)

dm7 -- Confusing sixes and nines (units)
  6 m instead of 9 m
  Distance error: e[d] = 3 m (9.8 ft)
  Contribution to C: Ø.Ø98*d(i) < ΔC < Ø.98*d(i)

dm8 -- Confusing sixes and nines (tens and units)
  61 m instead of 19 m
  Distance error: e[d] = 42 m (137.8 ft)
  Contribution to C: 1.4*d(i) < ΔC < 14.Ø*d(i)

dm9 -- Confusing sixes and nines (tens and units)
  91 m instead of 16 m
  Distance error: e[d] = 75 m (246.1 ft)
  Contribution to C: 2.5*d(i) < ΔC < 25.Ø*d(i)

Generic Blunders
- - - - - - - - -

G1 -- Sighting on the wrong flame
  Sometimes more than one lamp is near the station
  Azimuth error: e[A] < 15 deg.
  Dip error: e[D] < 15 deg.
    Error sizes depend on size and shape of passage
  G1a - Contribution to Ch: ΔCh < Ø.26*d(i)
  G1b - Contribution to Cz: ΔCz < Ø.26*d(i)

G2 -- Backshot errors
  Reading the wrong end of the compass needle, failure to
    tell book man it is a backshot, failure to place
    backshot indication in book
  Azimuth error: e[A] = 18Ø deg.
  Dip error: e[D] = 2.Ø*D(i) < 3Ø deg.
  G2a - Contribution to C: ΔC = 2.Ø*d(i)
  G2b - Contribution to Cz: ΔCz < Ø.5*d(i)

G3 -- Measuring from the wrong station
On a resurvey, an old station may be mistakenly used when the team advances
Azimuth error: e[A] < 15 deg.
Dip error: e[D] < 15 deg.
Distance error: e[d] < 10 ft
Error sizes depend on size and shape of passage
G3a - Contribution to Ch: $\Delta Ch < 0.26*d(i)$
G3b - Contribution to Cz: $\Delta Cz < 0.26*d(i)$
G3c - Contribution to C: $\Delta C < 1.00*d(i)$

G4 -- Data interpretation errors
Difficulty in reading the numbers in the book
Error is impossible to predict
Contribution to C: ΔC = almost anything

G5 -- Data entry error
Typographical error in the input data
Error is impossible to predict
Contribution to C: ΔC = almost anything

While this list of 46 blunders is certainly long, it is probably not exhaustive. For example, I have not listed blunders peculiar to Suunto compasses and clinometers, for the simple reasons that I do not have them, nor do I have enough experience using them to do so. Considering the large number of types of blunders and the horrible conditions under which some caves are surveyed, one might well marvel that any traverse is free of blunders.

RELATIVE FREQUENCIES OF BLUNDERS

Very little is known about the relative frequencies of occurrence of these blunders. By definition they occur infrequently enough that they are not accurately described by the laws of probability. The results presented by Hoke (1983) for experiments performed on the surface indicated 25 blunders out of a total of 468 segments measured. Since there were two measurements per segment (in the experiment only azimuths and dips were measured) and any measurement may contain a blunder, his results indicate a blunder rate of somewhat less than 0.027 (i.e., 2.7%).

Some blunder types may never occur in your surveys. For example, if the tape you use is graduated in meters and centimeters and is not also graduated in feet and tenths on the other side, then blunder dm3 will never occur. But this just means that for you the relative frequency is 0.000.

In my own experience the most frequent blunders are those having to do with backshots, i.e., when the azimuth and/or dip are measured from the next station back to the previous station. The blunder is a failure to note the backshot in the survey book, or incorrectly reversing the angular measurements in the cave, or reversing one angle but not the other, or noting the backshot in the book and also reversing the angular measurements, or ...

RELATIVE SIZES OF BLUNDERS

Figure 3 below graphically shows the sizes of the 46 types of blunders described above. In this figure contributions to the total error of closure are indicated by crosshatched bars, contributions to the horizontal component of the error of closure are indicated by hatched bars, and contributions to the vertical component of the error of closure are indicated by bars with no hatching.

It will be noted that some types of blunders result in small errors only, e.g., an Am2 or a df4 blunder will seldom cause a problem in closing the loop. On the other hand a single df5 can ruin your whole day.

There is a set of blunders which have the property that the resulting error of closure is localized in Figure 3 and also large enough that there is a chance of finding it in the survey data. The error needs to be large because random errors tend to mask blunders which result in only small contributions to the error of closure. This set includes: Ad1, Am1, Dd2, Dd3, df3, and dm3.

FINDING THE BLUNDER

Figure 3 shows some surprising things. For example, the largest azimuth related blunder produces a contribution to Ch of only 2.0*d(i). This sounds like a lot, but consider this. If there are 100 segments in the loop, and if all the other errors average to zero, then the resulting error of closure will be < 2%. If the average distance measurement is 20 feet, then the perimeter of the loop is 2,000 feet, and our rule of thumb Equation (3) does not indicate the existence of the blunder.

Let's look at another example, this time of a small blunder, say Ad2. Suppose the Azimuth is recorded as 202.0 deg. instead of the correct value of 212.0 deg. The contribution to the error of

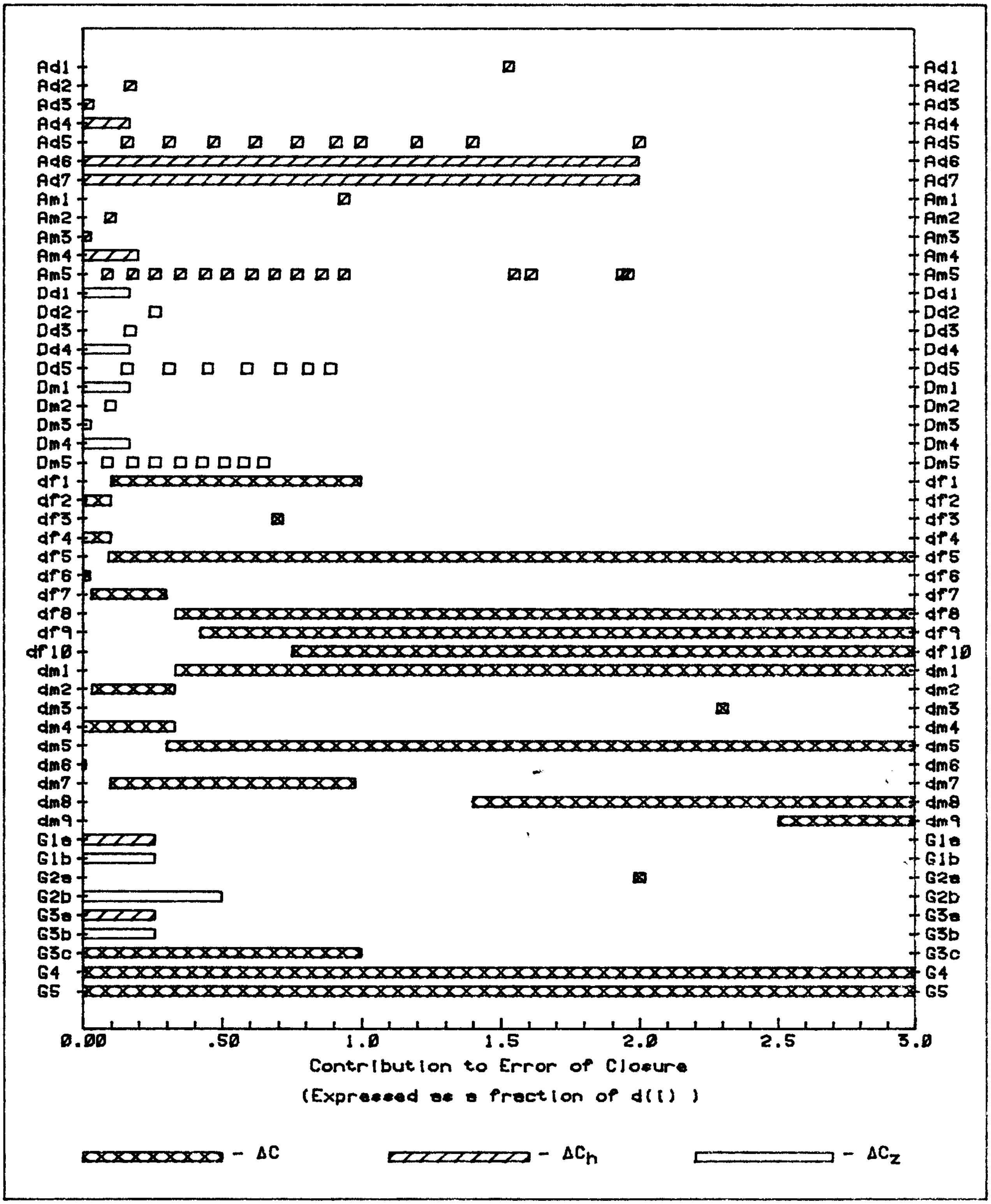


Figure 3. The contributions to the error of closure for the 46 types of blunders listed above are shown by the horizontal bars. All contributions are shown in terms of the distance measurement of the segment at which the blunder occurs.

closure is approximately Ø.2*d(i). Assuming for simplicity that all distance measurements are the same and that there are N segments in the loop, then P=N*d(i) and the ratio of error is simply R = Ø.2/N . Only ten shots will reduce the error to 2%. If the distances are all 2Ø feet, as we assumed above, then the rule of thumb ratio of error is 7.1%, so the existence of the blunder will never be noticed!

SUMMARY AND CONCLUSIONS

So what has been accomplished? Well, we have a set of consistent (I hope) definitions on which to base future work. The importance of loops and the types of surveying errors have been discussed. While these two topics are not new, they are here discussed in light of the definitions given above.

The detection of blunders in cave surveys has been discussed before. Schwinge [1962] first addressed this topis (sort of), Irwin and Stenner [1975] took it a step further (kind of), and Ellis [1976] incorporated some of Irwin and Stenner's results into his book. But none of these come right out and say, "If your error of closure is larger than X, then your loop probably contains a blunder."

Listing the possible types of blunders is tedious; however, some useful insight has, I believe, been gained by doing so. Future work is needed here in adding to the list the blunder types peculiar to Suunto compasses and clinometers. Perhaps some reader with lots of experience with these instruments would be so kind as to provide this information in a paper in this journal.

Other useful topics would be the consideration of current methods of surveying which tend to minimize the occurrence of blunders, and the development of new methods of eliminating each blunder type. Other topics for a future paper are some hints on how to find and correct the blunder when Equation (3) indicates that the loop contains a blunder. This author plans to address these topics in a future paper.

You may expect to see additional uses of the data of the fifty loops shown in Figure 2. It is possible to learn a lot about surveying by "looking in the horse's mouth".

Continues....

REFERENCES

Anderson, J. [1974], CAVE EXPLORING, 126 pages, Association Press, New York, NY.

Brinker, R.C. and Taylor, W.C. [1957], ELEMENTARY SURVEYING, 550 pages, International Textbook Company, Scranton, PA.

Brod, L. [1971], "An Analysis of Instrument Errors", Speleo Digest 1971, pp. 302-305.

Cullingford, C. [1953], BRITISH CAVING, 592 pages, Routledge & Kegan Paul, London, U.K.

Cullingford, C. [1969], MANUAL OF CAVING TECHNIQUES, 416 pages, Routledge & Kegan Paul, London, U.K.

Ellis, B. [1976], SURVEYING CAVES, a British Cave Research Association book, 88 pages, Bury Times Limited, Bridgewater, U.K.

Ford, T.D. and Cullingford, C.H.D. [1976], THE SCIENCE OF SPELEOLOGY, 593 pages, Academic Press, London, U.K.

Freeman, J.P. [1975], CRF PERSONNEL MANUAL, Central Kentucky Karst Area, 109 pages, Cave Research Foundation, Columbus, OH.

Ganter, J.H. [1985], "A Systematic Guide To Making Your First Cave Map", privately printed, Bedford, PA.

Halliday, W.R. [1974], AMERICAN CAVES AND CAVING, 348 pages, Harper & Row, Publishers, New York, NY.

Hassemer, J. [1982], CAVING BASICS, National Speleological Society, Huntsville, AL.

Hawes, W.S. [1977], "Surveying Errors and Multiple Loop Closure", submitted to the NSS Bulletin but, I think never published.

Hoke, R. [1983], "Some Factors Affecting Survey Accuracy", Computer Applications Section Newsletter, No. 12, pp. 7-13, 1983.

Hosley, R.J. [1971], CAVE SURVEYING AND MAPPING, 136 Pages, Crown Press, Indianapolis, IN.

Irwin, D.J. and Stenner, R.D. [1975], "Accuracy and Closure of Traverses in Cave Surveying", Transactions of the British Cave Research Association, Vol. 2, No. 4, pp. 151-165, December 1975.

Judson, D. [1984], CAVING PRACTICE AND EQUIPMENT, 238 pages, David & Charles, London, U.K.

Kaye, T.A. [1981a], "Analysis of the Propagation of Error in Cave Surveys", Proceedings of the Eighth International Congress of Speleology, Volumes I & II, pp. 800-801, 18-24 July 1981.

Kaye, T.A. [1981b], "Loop Closure Analysis", Speleo Digest 1981, pp. 262-263.

Larson, L. and Larson, P. [1982], CAVING, The Sierra Club Guide to Spelunking, 311 pages, Sierra Club Books, San Francisco, CA.

Longsworth, P. [1959], EXPLORING CAVES, 174 pages, Thomas Y. Crowell Company, New York, NY.

Lovelock, J. [1969], CAVING, 144 pages, B.T. Batsford, London, U.K.

Lovelock, J. [1981], A CAVING MANUAL, 144 pages, B.T. Batsford, London, U.K.

Lyon, B. [1983], VENTURING UNDERGROUND, The New Speleo's Guide, 160 pages, EP Publishing Limited, Wakefield, U.K.

McClurg, D.R. [1973], THE AMATEUR'S GUIDE TO CAVES & CAVING, 191 pages, Stackpole Books, Harrisburg, PA.

McClurg, D.R. [1986], ADVENTURE OF CAVING, A Practical Guide for Advanced and Beginning Cavers, 332 pages, D&J Press, Carlsbad, NM.

Pinney, R. [1962], THE COMPLETE BOOK OF CAVE EXPLORATION, 256 pages, Coward-McCann, Inc., New York, NY.

Schwinge, H.T. [1962], "The Accuracy of Cave Surveys", NSS Bulletin, Vol. 24, Part 1, pp. 40-47, January 1962.

Schmidt, V.A. and Schelleng, J.H. [1970], "The Application of the Method of Least Squares to the Closing of Multiply-Connected Loops in Cave or Geological Surveys", NSS Bulletin, Vol. 32, No. 3, pp. 51-58, July 1970.

Slaven, J. [1971], THE SPELEO-GUIDE, 92 pages, privately printed by the author.

Storey, J.W. [1965], AMERICAN CAVING ILLUSTRATED, 302 pages, privately printed, Atlanta, GA.

Thomson, K.C. and Taylor, R.L. [1981], "An Introduction to Cave Mapping", Missouri Speleology, Vol. 21, Numbers 1-2, January 1981.

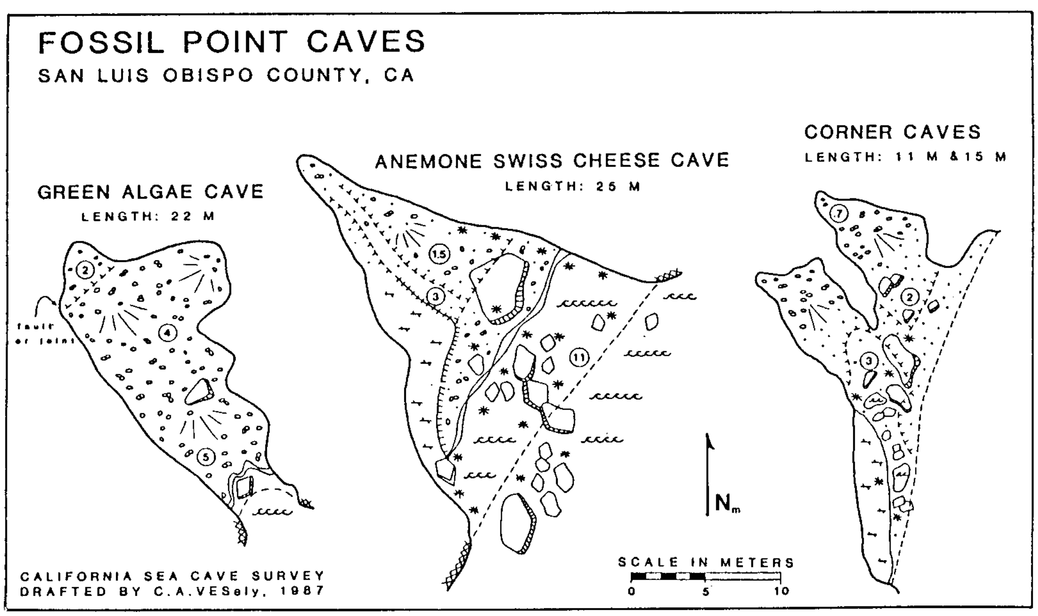
Thrun, R. [1981], "A Comparison of Expected Survey Errors With Closure Adjustments", Proceedings of the Eighth International Congress of Speleology, Volumes I & II, pp. 648-649, 18-24 July 1981.

Wefer, F.L. [1971], "The Cave Survey Computer Program", Speleo Digest 1971, pp. 307-313.

Wefer, F.L. [1974a], "On The Compass Rule", Speleo Digest 1974, pp. 243-246.

Wefer, F.L. [1974b], "More On The Compass Rule", Speleo Digest 1974, pp. 246-248.

//*/*/*



(from the CAlifornia Caver, Special Sea Caves Issue, 37:2, presumably somewhereabouts the middle of 1987)

Testing the Ultimeter

by John Ganter
State College, Pennsylvania

The idea is attractive. Go far into caves, down drops, through crawls, then pull from one's pack a small device and determine your depth. Unfortunately, it doesn't work. Altimeters cannot be relied on to replace standard cave surveys, verify depths or even to obtain rough estimates for reconnaissance.

The problem of course lies in the nature of the barometric pressure which barometers measure. Simply, there is less weight of air as one rises in elevation and this weight decreases in a predictable manner. So you stick a feet or meters scale on the barometer and you have an altimeter. Over short distances and time periods, under open sky, altimeters work pretty well. But as air density changes from heating and cooling, and air masses pass with global circulation, all sorts of complications arise. The traditional solution has been to repeat readings at a fixed point. You make a reading at, say a benchmark, go to an unknown point, then return. The benchmark will have moved, according to the barometer. Distribute this movement over elapsed time, and the resulting relationship serves as a correction factor.

Past Uses of Altimeters in Caving

Cavers have used altimeters for surface locating, but in most cases have not used them underground. During the early 1970s, extensive fieldwork was done on and around the El Abra range of Mexico in studying the blind characin fishes found in caves there. Topo map coverage was non-existent at the time, and the terrain and vegetation were formidable obstacles. Surveying altimeters, large clocklike devices costing around $1000, and with scales readable to a couple feet were used to obtain elevations of cave entrances and springs. Through careful calibration and correction, accuracies of under one meter were claimed (1).

Around the same time, cavers working in the tight, muddy and vertical confines of the Virginia cave known as ***Better Forgotten*** were using a more portable and rugged altimeter to obtain depth estimates (2). Through the 70s, altimeters were tried by many but abandoned because of unpredictable and conflicting results. Clearly, the intricacies of caves (particularly constrictions) were creating turbulence and pressure differentials in any air movement, whether chimney effect in multi-entrance caves or "breathing" in single entrance caves. This complex micrometeorology is an interesting field of study (3), but causes nothing but trouble for the altimeter user.

Findings in Cueva Ensueno

Recently, the effect of a constriction on barometers was clearly shown during studies of air quality in a cave being evaluated for commercial development (4). ***Cueva Ensueno*** (Bayaney, Puerto Rico) is a linear one-entrance cave with walking passage reducing in size to a crawl for a few feet, then opening into a room. Joe Troester found that air pressure was consistently higher beyond the constriction (Figure 1; note that higher pressure appears as lower elevation; also, that all the readings were made within a few minutes). Up-and-down relations to the compass and tape survey traverse are preserved but both magnitude and proportion are inconsistent. Discrepancy between the two increases steadily and in this case appears to be a arithmetic curve with distance. Carbon dioxide concentration was also found to increase beyond the constriction, and oxygen decreased slightly (5). The altimeter used in this case was an American-Paulin, one of the expensive clock-types. It was carried into Ensueno with great care and misgiving. As part of this study it was teamed with an Ultimeter electronic altimeter-barometer (6). In addition to the cave work the instruments were carried around to various geological observation points on the surface.

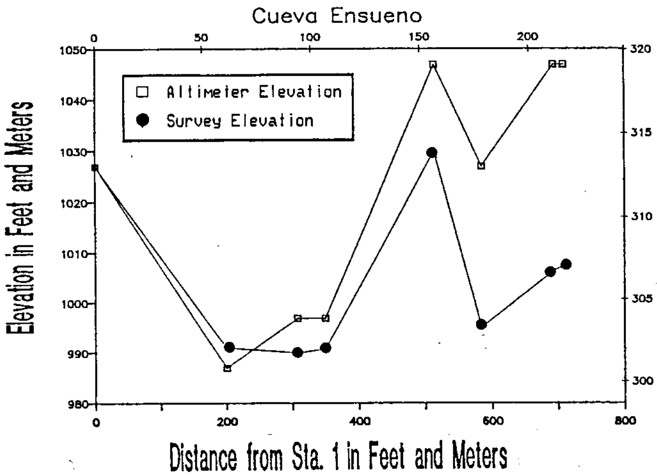


Fig. 1 : Barometric Pressure in Cueva Ensueno (from Troester, 1987)

Fig. 2 : Joe Troester reads the American-Paulin and Ultimeter at a benchmark above Blue Hole, sinkpoint of the Rio Camuy. (J. Ganter photo)

This is typically what geologists use altimeters for; quick, relative elevation measurements, with frequent returns to the nearest benchmark (Figure 2). The Ultimeter was not useful; its precision of +/- 10 feet simply didn't register the small changes that the American-Paulin did in this relatively low-relief area.

The Ultimeter

The Ultimeter is reminiscent of the traditional Texas Instruments calculator in size and shape (Figure 3). It weighs about the same, runs off either 3 or 6 AAA batteries or an AC adapter, and has a foil membrane keypad and LCD display. It costs about $180 retail, and is manufactured by Peet Bros. Co. Inc., PO Box 2007, Ocean, NJ 07712.

The device measures absolute barometric pressure to the nearest .01 inch or 1 mm of mercury, and converts this to both sea level pressure and elevation.

Figure 3

Two temperature sensors are supported. One, recessed into the outside of the case is used to compensate the barometer. The other remote sensor is on the end of a 10-foot cable, which plugs into the case. The remote range is -80 to +350-degrees F; the built-in sensor is less since the electronics are more delicate. A 60 hour timer is also included. On all functions except the last, output units can be either English or metric, and precision either full units or tenths. The Ultimeter tracks minimum and maximum values, and audible alarms can be set for any chosen points.

The Ultimeter was fairly easy to set up and use, with a reasonably clear instruction manual. I was not impressed with the temperature functions from the start. Having used other devices with thermistors, I expected either very fast response with wild variations (useful for detecting drafts around doors and windows), or fairly fast response with stability and accuracy (useful as a fever thermometer or water samples). The Ultimeter tended towards the latter, but was inaccurate. Frustrated by attempts to get it to register properly, and assuming that it was simply miscalibrated, I froze the remote sensor into a block of ice. Lo and behold, this registered EXACTLY 32.0 degrees F, and did not waver. In attempts to obtain a oral temperature, the reading never got closer than one degree and was inconsistent. I did not try other core temperature access points. Because of its agonizingly slow response time and inaccuracy, the Ultimeter is not useful as an electronic thermometer except for meteorology.

Taking the Ultimeter High and Deep

I decided for dubious reasons to take an Ultimeter on a trip to an area of high elevation where there were deep and relatively simple shafts. Perhaps it would be useful for verification of compass and tape cave surveys, and surface scouting.

The testing was rather limited. Small details tended to interfere at critical measuring points like the tops and bottoms of the pits; details like rigging, surveying, sketching, swimming, photography, remembering to put ropes back on rope pads, rockfall, getting tackle bags over lips, etc.

The first experiment involved a half-mile hike from basecamp (BC) and descent of the Cave A entrance (Figure 4), denoted as `E'. Elevation from the altimeter is on the vertical axis, day in 6 hour increments is on the horizontal. The line indicates the traverse, and cirles indicate Ultimeter readings. Squares connected by dashed lines are the depths according to compass and tape survey (7). `B' is the base of the entrance and `DS' is the furthest downstream point. The Ultimeter was off by about 100 feet over a very short time time period on the "open air" entrance drop. Also, it failed to register the gradual drop in the downstream cave passage (DS). Near noon on Day 12, `E' was higher; the weather had changed slightly and the barometric pressure had dropped.

The second experiment involved two 1.5-mile hikes from BC and descents of Cave F over two days (Figure 5). The cave entrance (E) is essentially horizontal, and slopes rapidly to the lip (L); below this the shaft is the size of a train tunnel and in darkness (8). Given these conditions, I expected air movement to be more complex than the relatively open Cave A. Actually, this may not be the case since sunlight causes rapid heating of Cave A entrance walls as high noon approaches. Again, the Ultimeter was wrong and also inconsistent due to pressure changes.

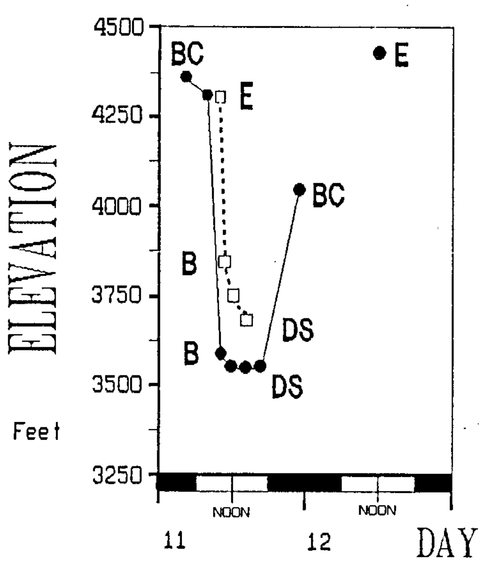


Fig. 4 : Cave 'A' Ultimeter Traverse

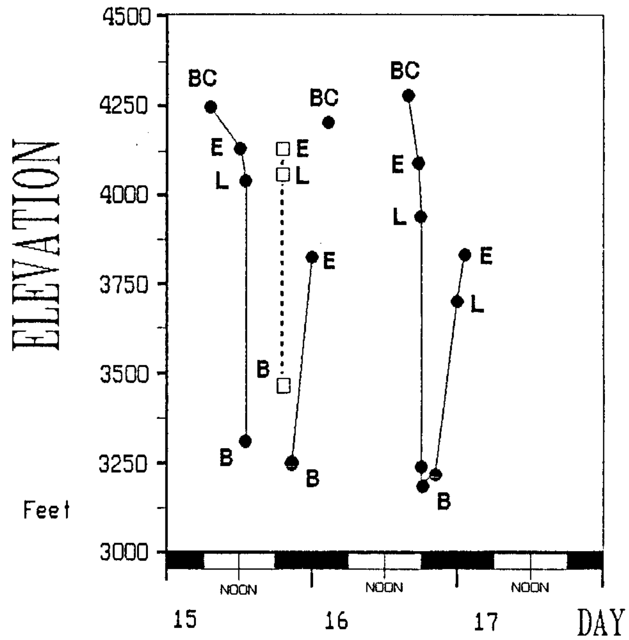


Fig. 5 : Cave 'F' Ultimeter Traverse

Conclusions

Shortly after the second experiment the Ultimeter joined me in an unexpected swim, and refused to function until resuscitated by its manufacturers. I didn't miss it, having already concluded that altimeters have no place in cave mapping or reconnaissance. The meteorology of caves is a fascinating area of research and it is quite possible that with enough compensations one might be able to determine depth in caves with some degree of accuracy. But the problem is so complex as to be insurmountable to the cave surveyor. As for the Ultimeter, its slow and inaccurate thermometer functions make it unusable for anything but a portable weather station.

FOR SALE Ultimeter Altimeter/Barometer. Hardly used, swims some. Best Offer. Contact the Author.

NOTES

1. Robert W. Mitchell, William H. Russell and William R. Elliott. (1977) ***Mexican Eyeless Characin Fishes, Genus Astyanax: Environment, Distribution and Evolution.*** Special Pubs. of the Texas Tech University Museum, No. 12, 89 pages. (Available from the Association for Mexican Cave Studies)

2. Fred L. Wefer and Ike Nicholson (1982) "Exploration and Mapping of the Sinking Creek System." ***NSS Bulletin*** (Burnsville Cove Symposium), 44:3, pp. 48-63.

3. For a complete listing of cave meteorology papers in the ***NSS Bulletin*** , see Ira D. Sasowsky (1986) ***Cumulative Index to the NSS Bulletin, Volumes 1 through 45, and Occasional Papers 1 through 4.*** NSS, 200 pgs. (Available from the NSS Bookstore). In the mainstream literature, see De Freitas, et al. (1982) "Cave Climate: Assessment of Airflow and Ventilation." ***Journal of Climatology*** , 2, PP. 383-397. (This contains an interesting isometric diagram of Glowworm Cave, Australia, where the study was conducted.)

4. Jeanne and Russell Gurnee (1987) "Exploration and Study of Ensueno Cave." Paper given in the International Exploration Session, 1987 NSS Convention Program, Saulte Ste. Marie, Mich. p. 31.

5. Letter from Joe Troester (Mayaguez, PR) to J. Ganter, 20 April 1987.

6. The Ultimeter was announced in ***Compass & Tape*** , 3:2, Fall 1985, p. 54.

7. The Cave A entrance was measured in 6 shots, only one of which was vertical. The longest was wired at 283 feet, with an inclination of 72-degrees. Inclination error of 1-degree on this shot alone would cause a vertical error of 5 feet. However all steep readings were made with a Brunton instrument which had been calibrated against a bubble level, and this survey is considered fairly accurate.

8. Because of small ledges and a slight leaning, this traverse was done in 6 shots, the longest wired at 374 feet, inclination 85-degrees. As in Cave A, all readings were made with a Brunton and the traverse is considered accurate.

Survey & Cartography Section of the
National Speleological Society

John Ganter
Department of Geography
302 Walker Building
The Pennsylvania State University
University Park, PA 16802 USA

Non-Profit Org.
U.S. Postage
PAID
State College, Pa.
Permit No. 138

Forwarding Postage Guaranteed.
Address Correction Requested.

Look, Harold, an Atlas of Caves!

Is caving in danger of being taken seriously ? There it is in the Nov. 28 ***Science News,*** that 16-page (never more, never less) weekly capsule summary of goings-on in the world of science, in the ***Science News Books*** list, right under the newest on unification theory... ***The Underground Atlas: A Gazetteer of the World's Cave Regions.*** Hurrah for John Middleton and Tony Waltham, they've made the big time! Now millions can send $16.95 plus $1.00 post to Science News Books, 1719 N Street, NW, Washington, DC 20036 for their copy.