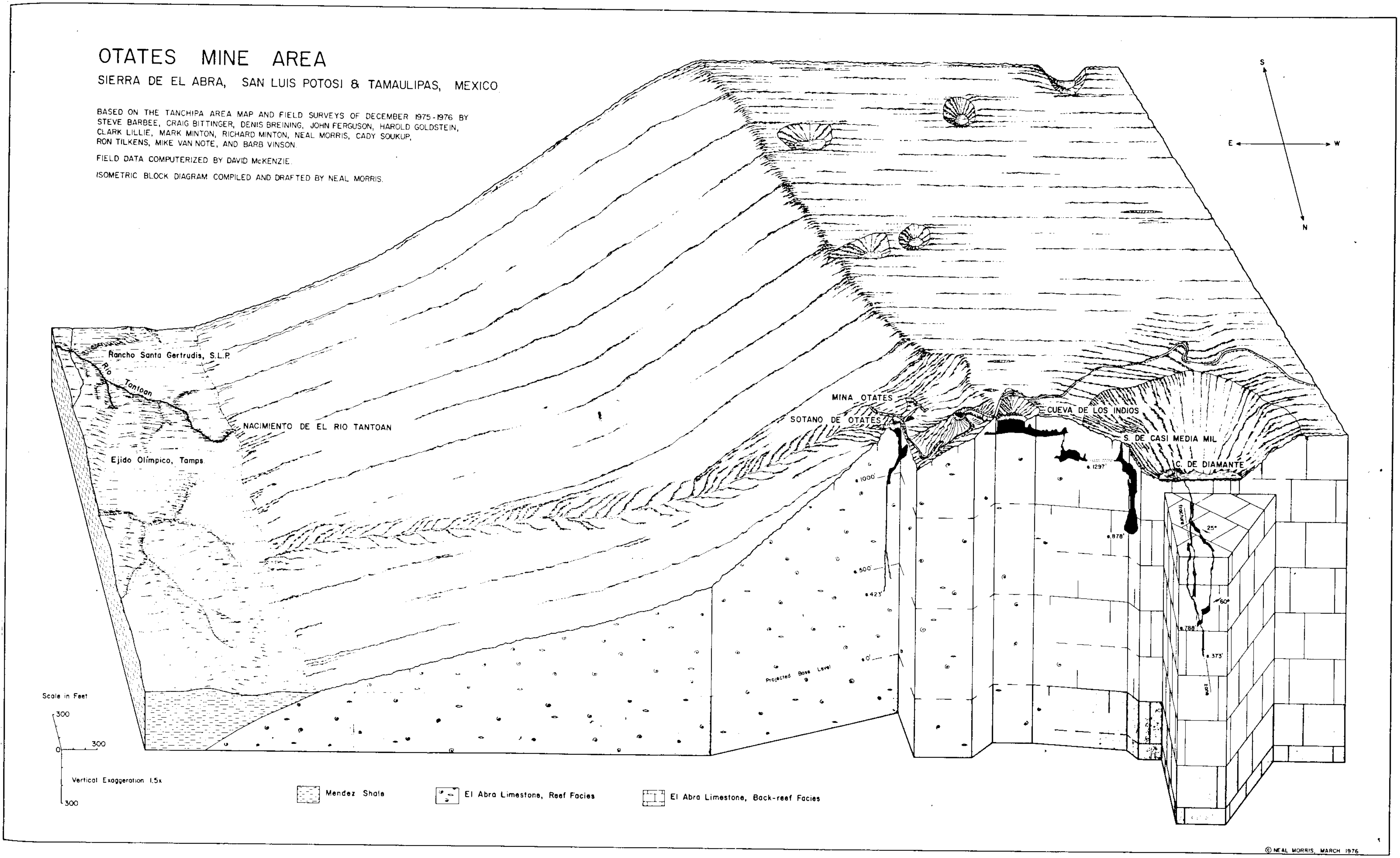
COMPASS & TAPE



Volume 5 Number 4 Spring 1988

COMPASS & TAPE

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Survey & Cartography Section - 1987/1988

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COVER: Otates Mine Area, Sierra de El Abra, Mexico. Created by Neil Morris, this impressive isometric diagram accompanied his article on the geology of the area (*AMCS Activities Letter* #4, May 1976). As with all Association for Mexican Cave Studies projects, the survey data for the El Abra was plotted with David McKenzie's ELLIPSE system running on the CDC 6600 at UT Austin. Later, with much human suffering, Cueva Diamante went over 2000 feet deep-- here it is about 850. Topographic mapping later showed that the range was higher than Morris' estimate. Tommy Shifflett, the 'Sole Survivor,' led a return visit in late 1987 which revealed no additional passage (*D.C. Speleograph*, May 1988). Today, the Mina Otates have expanded to several workings along the range, and the entrance to Sotano de Otates, with leads unpushed, has vanished under a pile of mine tailings! Yet Morris' diagram still says a lot about this complex and remote area, while serving as a reminder of the heyday of northern Mexico caving.

Editorial

Will We Map As We Survey?

The ethic appeared in the 1970s. Caving had begun to mean more than just finding and sampling new caves each weekend. There were frontiers to be pushed, patiently and systematically. There was a realization in the maturing caver community that little caves could be made into big caves through human force of will and mutual endeavor. Competition among groups, regions and nations had emerged. The 'Long and Deep Cave List' became standard fare in updates of new progress made, barriers broken. The Cave Project was seen as a community investment to be maintained through stewardship. Such sustained efforts, *cooperative* caving where the individual worked for group success, required some mechanism to reward 'team players.' And so there appeared an ethic: *Survey as You Explore.* Virgin passage was rationed. Caving had always been a gamble, and now the odds shifted to the long-term players. Patient cavers, the regulars who pushed the leads no one wanted, got their due. So they surveyed as they pushed, finding that with practice it could be done under even the most ghastly conditions. The somewhat bitter medicine was swallowed, the mild penance for our sin of first defilement paid.

And the survey notes? In many cases, they were turned into maps and reports; visible, tangible products of dedicated activity. We saw, for the first time, those interested in the science of caves able to draw broader understanding from these unprecedented stores of knowledge. But sometimes, along the way, the cavers forgot that survey notes are not a end product, but a small part of a process. Survey notes are fragments, shorthand reminders of what the survey team has experienced. They are simple interpretations which have the potential to be manufactured into a permanent community resource. But the pieces must first be reassembled. Survey notes are information for the surveyor, but they are not knowledge for the community. They remind the surveyor of what he has seen, but say little to anyone else.

The physicist Michael Polanyi, in *The Study of Man,* distinguishes between tacit and explicit knowledge. Tacit knowledge can never be properly expressed-- it is 'black art:' the surgeon's touch, the expert's hunch, the caver effortlessly navigating a familiar maze or levitating up a climb. Explicit knowledge, a map; a list; is put down, codified. You can look at it, read it, run it through your mind over and over. You can see the errors, fieldcheck, refine, test. You can begin to solve puzzles, to explain things, to see what was hidden there all the time. Explicit knowledge can be permanent, a time-capsule. Maps fade, but memory fades more. Explicit knowledge travels to others and imbues them with what you know, and how you have learned it.

There is a lot of tacit knowledge in caving. A tiny bit leaks into our folklore. You sense its presence around campfires, and occasionally you can be shown 'The Bypass' or hear a broken tale of how the miracle climb was done with no protection. But it fades, because it is refreshed only by doing. Cavers leave caving. They forget. And most of all, they cannot explain what they know. Have you ever asked someone about a complex cave that they have just visited? Half-phrases. Gestures. No. Yes. Stares off into a space which used to hold the answers. Let's See. How Can I Explain. Here, Let Me Draw You A Diagram. But the 'diagram' is deformed, revealing only confusion and inconsistencies which cannot be resolved now that the experience is over. So how are we to learn about caves, to 'see' them, unless tacit knowledge is promptly refined into maps and descriptions? How are cavers to carry on, to pursue the leads 'left for the next generation' if explicit knowledge is not produced which will communicate across time to this generation?

But what of secrecy, and conservation, and the individual's right (some would claim inalienable) to do Whatever-They-Damn-Well-Please in caves which they discover and explore? Some cavers reject the idea of community. They say they will not belong. But I suggest that often they do belong, even if, literally or figuratively, they pay no dues. No caver exists in a vacuum. They have learned, trained, been exposed to new experiences, found new caving areas, been steered away from old caving areas, supplied with companions. They have glimpsed role models and possibilities. Some accept awards, accolades, praise. Everyone takes; each should consider giving.

'Community' is also a relative term. There is no sin in making maps and writing descriptions which few will see. But this does not mean that explicit knowledge should not be created while the notes and experiences are still fresh. Times and attitudes change. Someday, the knowledge may need to be passed on. It is immeasurably safer to invest in the future rather than to condemn it.

And if you are interested only in the visceral, tacit pleasure of pushing caves? A caver once told me of exploring the caves of a previous generation who had left no trace a decade earlier. She anticipated, she told me with a smile, ignoring whispered questions in the years to come as the next generation discovered, and in their turn explored, the same caves. Recycling. But don't waste your time, and condemn your followers to waste their's, by pretending to survey.

Why have even the best-intentioned cavers had difficulty achieving their goals in producing what I am calling 'explicit knowledge' about the caves which they explore? Some of the problem lies in getting surveyors into situations, such as sketching, which they lack the experience to handle. There has been a discouraging amount of re-surveying which has had to be done. More to the point, the task of drawing, editing and updating maps inevitably becomes more and more complex as a cave project continues. Each survey trip may require the modification of large parts of the existing map. Meanwhile, the project participants want to see progress and some results from their work. Quite often, we use a line plot of the survey traverse as a manuscript map.

But it is important to recognize that a line plot is not a map. The survey traverse is a metric artifact of the way we orient ourselves underground. It gives us absolute position (within the limits of severe and poorly-understood error), general orientation and distance, and a crude notion of connectivity between passages and regions of the cave. But it gives us little sense of relative space; the sizes of passages, their shapes, what lies on their floors, where water flows. Most importantly, it does not show leads. Why? Because it is just data display. A data display becomes a map when a human gets involved and performs a *subjective* interpretation on the data. The human thinks, and the thought goes on the map. There is something here; it is represented by this symbol. A drop is here; they will need this amount of rope. This is a good lead; they will need to dig. As the Mapper interprets the cave, using notes, the traverse plot and memory, he or she creates through words and graphics an explicit document telling about the cave. The process is laborious, but the product communicates and explains, laying the foundation for future efforts.

Technology has the promise of reducing the labor of knowledge-creation in caving. Can we speed that critical process of reassembly, the combining of traverse and sketch? If a caver can quickly enter the results of surveying without tedious redrawing, then they will be encouraged to do so. We need to create tools which will reduce labor in maintaining collections of information, to allow rapid creation of documents. Functionality, not wizardry, is in order. We need to allow the caver to integrate cave maps, surface maps, geological information and written documents, both historical and created. The common denominator, the index to all this diverse knowledge, may be an extension of what we call a map today. Perhaps the 1990s will see the emergence of an achievable twin to the existing ethic: *Map What You Survey*

SOME COMMENTS FROM ACROSS THE POND

Bryan Ellis

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First may I congratulate the Survey and Cartography Section, and particularly its editor John Ganter, on their publication **"Compass and Tape"**. We have no such specialised journal on this side of the Atlantic which makes receipt of yours even more enjoyable.

Perhaps one of the things that has struck me is how parochial both British and American cave surveyors are, and how both of us are re-inventing what the other has already discovered! Mind you, I may have got it wrong because although nominally we both speak the same language it is amazing what differences there are even in the limited field of cave surveying. For example, what you call an azimuth we call a bearing, and what you refer to as a bearing hasn't been used over here since the days of sailing ships. If you asked a British surveyor what an azimuth was he would probably think that it was some form of alcoholic drink - but then that is the sort of person many of us are! I can only believe that the more contact there is between us the better for everyone.

I found Bill Mixon's article in the penultimate issue, "The Transit-Survey Myth", very interesting. It was good to see this mistaken concept finally (hopefully) put to rest. As in the U.S. it was believed by many over here that a theodolite (or transit as I believe you call it) traverse (series?) would 'automatically' be more accurate than one made with a compass, clinometer and tape. The early cave surveying works published in the United Kingdom (e.g. Butcher, 1950) certainly led one to believe this and it was not until the mid-sixties that surveyors began to see how wrong this was. This can be seen from a comparison of the survey accuracy gradings published by the Cave Research Group in 1950, and those published by the British Cave Research Association (successor to the C.R.G.) in 1973. In fact page 40 of my own book (Ellis, 1976) illustrates graphically the principal point made by Bill. I wonder if Bill is prepared to make available his computer program for generating random artificial survey data to save those of us less skilled in the art a lot of brain ache - assuming that it is written in something basic like BASIC. I would like to use it, or see it used, to prove non-statistically what the optimum survey leg (or should that be segment?) length is; for maximum accuracy the figure is very short, something like ten feet, but it would be nice to see it proved this way.

The 1987 Fall issue of **"C&T"** has just arrived; please may I take Fred Wefer gently to task on a small point? On page 42 he states, "But none of these [papers, including mine] come right out and say, 'If your error of closure is larger than X, then your loop probably contains a blunder.'" Near the bottom of page 17 of my book it states, "...if a result [i.e. a traverse misclosure] is obtained that differs very much either way from this graph [which Fred has said agrees with his figures] there are almost certainly mistakes [i.e. blunders] in the survey." I would contend that this was stating it pretty openly! Incidentally he may have confused matters in his bibliography by quoting the name of the printers (Bury Times Ltd) of my book - not that it really matters because it is now out of print; I have just submitted the manuscript of a replacement.

The note on Suunto maintenance in Volume 5, Number 1 also interested me and I took the liberty of forwarding a photocopy to Suunto. I have been in correspondence with them recently in connection with my new book and wanted to illustrate a point I had been making, namely the very unsatisfactory 'waterproofing' of the instruments. As a result of these letters I hope to submit a manuscript to "C&T" in the near future describing some recent developments with the Finnish compasses and clinometers.

In conclusion can I make a plug. One of the hats I wear is that of Sales Officer for the British Cave Research Association and a recent issue of our journal "Cave Science" was devoted entirely to cave surveying. It contains fourteen articles on various specialised subjects and most serious cave surveyors should find the majority of interest. Copies can be obtained through me at £3·60 each (including postage), or possibly could be ordered through Speleobooks in Schoharie. Unfortunately I can no longer accept dollar cheques but I can accept payment by VISAcard, just send me your card number and its expiry date.

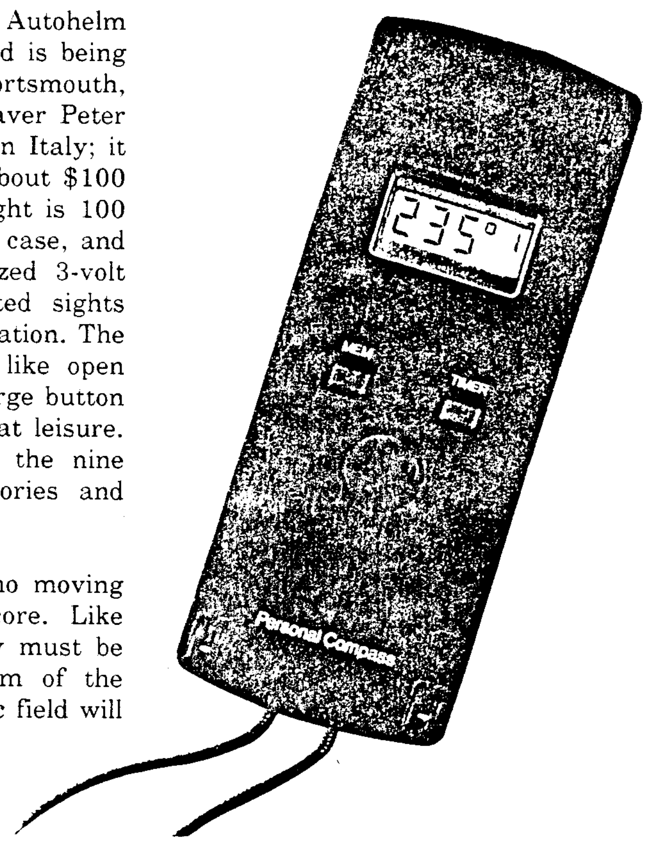
References:

- Butcher, A.L. (1950) "Cave Survey", Cave Research Group of G.B., Publication No. 3
- Ellis, B.M. (1976) "Surveying Caves", 88pp, British Cave Research Association (Bridgwater, U.K.)

The Autohelm Personal Compass

Information from Frank Reid

Popular Science magazine, April 1988, p. 94 has a small article about a new electronic digital compass called the Autohelm Personal Compass, which was developed in Germany and is being marketed by Nautech, Anchorage Park, Eastern Road, Portsmouth, Hants PO3 5TD, England. (Price not given). Austrian caver Peter Ludwig told me that he saw this device at a boat show in Italy; it costs $160 there but he believes that it should be only about $100 in the U.S. The dimensions are 150 x 59 x 10mm, weight is 100 grams, and the compass comes with a waterproof plastic case, and neck lanyard. The compass is powered by two coin-sized 3-volt lithium cells. There are two sets of tritium-illuminated sights molded into the plastic case, for left or right-handed operation. The front sight is a post, the rear sight is a "V" notch, like open gunsights. To operate, you aim at the target, push the large button on top to store the reading, and read the digital display at leisure. There are two other buttons on the top, for stepping the nine memories and activating the stopwatch feature (memories and timer are useful in boat navigation).



The Autohelm uses the fluxgate principle, with no moving parts. The sensor is a specially-wound toroidal magnetic core. Like a conventional compass, the electronic compass probably must be held level during operation. Otherwise, the vector sum of the horizontal and vertical components of the earth's magnetic field will produce an erroneous direction reading.

MORE ON CAVE SURVEY BLUNDERS

by

Fred L. Wefer

BACKGROUND

This paper continues the discussion on cave survey blunders begun in Wefer [1987], hereafter referred to as Paper-I. It is assumed that the reader is familiar with the material of Paper-I. Terminology and mathematical symbols introduced there are used here. For those readers who are not familiar with that paper, the next paragraph presents a brief summary of its contents. Words in all capital letters in the paragraph are section titles from Paper-I.

First a set of formal DEFINITIONS was presented for the terms used in cave surveying. The discussion continued with a brief section on THE IMPORTANCE OF LOOPS. The types of SURVEYING ERRORS were then discussed. This was followed by a detailed presentation on DETECTING THE PRESENCE OF A BLUNDER. It turned out to be possible to anticipate certain TYPES OF BLUNDERS which can occur in a cave survey. Forty-six types were identified and listed in this section. For each type of blunder the following information was presented: a label for easy reference, a one line description of the error, an example of the error, the size of the error in azimuth, dip, and/or distance, and the contribution to: the error of closure, the horizontal component of the error of closure, or the vertical component of the error of closure, as appropriate. The next two sections discussed the RELATIVE FREQUENCIES OF BLUNDERS and the RELATIVE SIZES OF BLUNDERS. The difficulty in FINDING THE BLUNDER was also touched upon. This was followed by a SUMMARY AND CONCLUSIONS and finally by the REFERENCES cited.

INTRODUCTION

This paper begins with a brief overview discussion of some TECHNIQUES FOR OBVIATING BLUNDERS. Then in separate sections each of the nine identified techniques is presented in detail. Following this is a SUMMARY OF TECHNIQUES in which the forty-six blunder types from Paper-I are listed along with the techniques which help to obviate them. This is followed by a SUMMARY AND CONCLUSIONS. APPENDIX-A presents the labels and one line descriptions of the forty-six blunders identified in Paper-I. APPENDIX-B presents a sketch of the history of some of the techniques for obviating blunders. APPENDIX-C presents a cave survey data form useful with the technique here called XFBS. The final section lists the REFERENCES cited.

TECHNIQUES FOR OBVIATING BLUNDERS

A future paper will discuss what to do if you think that your survey contains a blunder. Remember that the technique for detecting the presence of a blunder presented in Paper-I works only for traverses which are simple loops, and then only if the blunder is sufficiently large. So the best course of action is to obviate blunders, i.e., prevent them from occurring in your data in the first place. And that "first place" is at home before you even go to the cave.

In considering how to proceed, one might conclude that the best course of action would be to concentrate on the development of techniques for obviating blunders with two characteristics: those which result in large errors, and those which have a high frequency of occurrence. But as pointed out in Paper-I, almost nothing is known about the relative frequencies of occurrence of various types of blunders. Accordingly we will concentrate here on blunders which result in large errors, and not worry about the frequencies of occurrence of the individual blunder types.

It is important to remember, however, that the overall frequency of occurrence of blunders has been roughly measured at approximately 3% (see Paper-I), i.e., three percent of the measurements in a cave survey can be expected to contain blunders. Using the Butler Cave-Sinking Creek System in west-central Virginia as an example (Wefer [1986]), with more than 2600 stations in its survey, this frequency of occurrence would mean that there exist more than 70 blunders in the data!

At least nine strategies exist for obviating blunders, viz:

- Equipment Selection (ES)
- Equipment Modification (EM)
- Exercising Care (EC)
- Fore-/Back-Shots (FBS)
- Extended Fore-/Back-Shots (XFBS)
- Station Graphs (SG)
- Verify Inputs (VI)
- Range Checking (RC)
- Compare With Sketch (CS)

Each of these techniques is presented below along with a discussion of the blunder types which they help to obviate. The capital letters in parentheses following each bulleted item above are used in Table 1 to identify the techniques. A discussion of the history of the development of some of these techniques is deferred to Appendix-B of this paper.

The following presentation concerns only cave surveying with Brunton compasses. While not specifically stated, many of the techniques described apply also to surveys done with Suunto compasses and clinometers.

EQUIPMENT SELECTION (ES)

'Equipment selection' is listed because some blunder types can be obviated by your choice of equipment. For example, if the Brunton compass used is graduated in degrees, then blunder types Amx (Azimuth Blunders, Brunton compass graduated in mils) and Dmx (Dip Blunders, Brunton clinometer graduated in mils) are obviated. Of course, chosing a Brunton compass graduated in mils obviates blunder types Adx (Azimuth Blunders, Brunton compass graduated in degrees) and Ddx (Dip Blunders, Brunton clinometer graduated in degrees). So what's the difference?

In fact, choosing a compass graduated in degrees is a good idea. People seem to have a difficult time dealing with mils as an angular unit. It is not easy to look at the sketch and think, "Yeah, that right-hand turn was about 1600 mils." A similar statement concerning dip might be, "No, I don't think that shot is as steep as 800 mils. I had better check that reading to make sure it is correct." The only reason I can see for using military Brunton compasses is that they are sometimes very inexpensive. Modifying them can solve the azimuth problem, but may introduce new systematic errors.

Some people seem to do well with Bruntons graduated in quadrants (to indicate bearings instead of azimuths), and some do not. I suspect it is a matter of a difference in the way we think. I recommend that if you have a choice and have no strong preference, select a Brunton which is graduated to give you azimuth (0 to 360 deg.), not bearing. If nothing else, this obviates blunder types Ad6 and Ad7.

Choosing a tape graduated in either metric units or English units but not in both will obviate either blunder type df3 or dm3. Before purchasing a tape, take a good look at the numbers. Select one which makes it easy to distinguish sixes from nines. If the tape is graduated in both metric units and English units, make sure it is easy to tell which is which (for example metric in red, English in black). Your data entry person will appreciate it if the tape is not graduated in feet and inches. And one component of blunder type G5 will be obviated.

EQUIPMENT MODIFICATION (EM)

'Equipment modification' is listed because some blunder types can be obviated by slightly modifying your equipment. For example, take the glass out of your Brunton, paint over the percent grade scale with black paint, and replace the glass. This will obviate blunder type Dd2. You probably will never have the need to use the percent grade scale anyway.

Another modification to consider is setting the declination of your Brunton compass to zero, then fixing it there by a drop of epoxy or super glue on the adjustment screw. The necessary adjustment for magnetic declination is then made by the computer.

Finally, a curious type of equipment modification is caused by breakage. If the instrument is broken, either repair it or replace it before using it to survey again. This includes your tape. If it is broken, don't tie a knot at some convenient point, then blunder your way through the next survey, sometimes remembering to subtract the value at the knot, sometimes forgetting!

EXERCISING CARE (EC)

'Exercising care' means following applicable survey team procedures as detailed by many authors, e.g., Whittemore [1971a and 1971b], Freeman [1975], and Thomson and Taylor [1981]. While exercising care can be expected to help obviate all types of blunders, a few elements of special effort and importance will be mentioned here. Much of this special effort is expended by the book-person and the compass-person on the survey team.

Good habits on the part of the book-person can help obviate blunder types G2, G4, and G5. For example:

- Use the same format for all azimuth data, e.g.,

  degrees: 182.5, 067.0, 009.5, 000.5, ...
  in mils: 6350, 0200, 0050, ...

- Use the same format for all dip data, e.g.,

  degrees: -05.0, -13.5, +22.0, +03.5, ...
  in mils: -0240, +0260, -0050, +1250, ...

- Use the same format for all distance data, e.g.,

  in feet: 52.3, 10.5, 07.4, ...
  meters: 12.34, 29.76, 02.33, ...

The book-person should also check the numerical data against the sketch. For example, when the sketch indicates a right-hand turn, the azimuths should also. When the sketch indicates a climb up to the next station, the dip should be positive.

The compass-person on the survey team must attempt to obviate blunder types G1 and G3. If, while making the angular measurements, he or she sees more than one flame that could indicate the station, the extraneous one(s) should be identified and physically removed before the reading is made.

When re-surveying an area which has been previously surveyed, it is possible to confuse the new stations with the old stations. Using as many of the old stations as possible will help to obviate blunders of type G3. It will also make it easier to locate the problem should a blunder of some other type occur, since two sets of measurements of the same stations will then be available.

FORE-/BACK-SHOTS (FBS)

The Fore-/Back-Shot (FBS) technique (i.e., the making of both a fore-shot and a back-shot measurement of the azimuth and dip at each survey station with the same compass and clinometer) is time consuming, and management of the survey team is a little more complicated. But FBS is so effective in obviating blunders that it is rapidly becoming an accepted practice among cave surveyors. Experiments such as those documented by Hoke [1983] have helped to point out the seriousness of the blunder problem. The FBS technique (my name for it) also tends to reduce certain systematic errors, especially those caused by instrument problems. A brief discussion of the history of the development of this technique is presented in Appendix-B of this paper.

Using FBS, at any particular station the compass-person makes the azimuth and dip measurements to the next station (fore-shot) of the traverse, then turns around and makes the azimuth and dip measurements to the previous station (back-shot) of the traverse, using the same set of instruments. The book-person compares the two sets of readings for each segment. If they are different by more than say 1.Ø deg. (after taking into account that one is a fore-shot, the other a back-shot), then the readings for the segment are repeated until they agree to within the expected tolerance (here selected as 1.Ø deg.). Note that this may require that the compass-person occupy the previous station again. The fore-shot is made before the back-shot to prevent the compass-person from inadvertantly (or purposefully) cheating.

Figure 1 below shows the seventeen blunder types from Paper-I which result in errors in azimuth. The FBS technique helps to obviate all blunders with azimuth errors exceeding 1.Ø deg.,

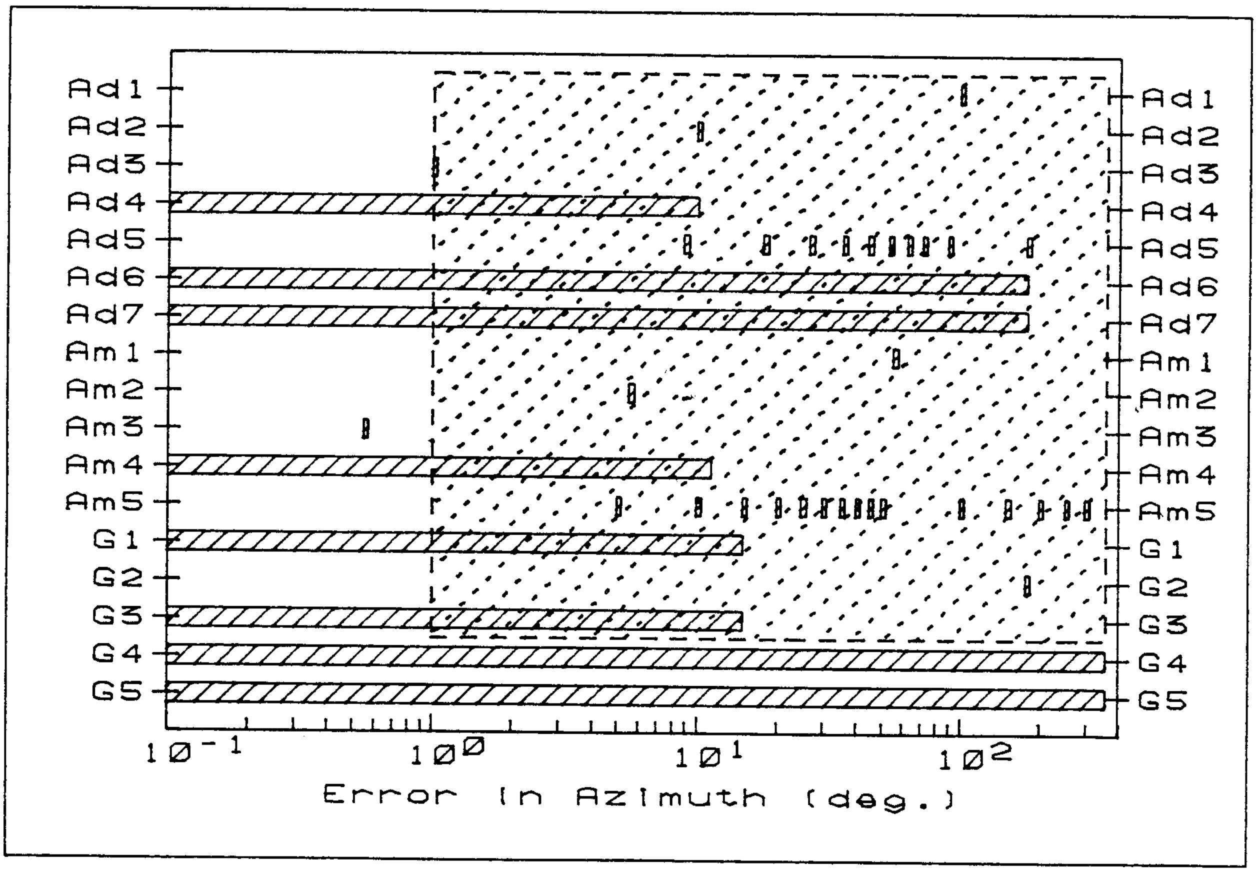


Figure 1. The azimuth errors are shown for each blunder type affecting the azimuth. Note the logarithmic scale in azimuth running from Ø.1 to 4ØØ deg. The ranges of the resulting errors are indicated by the hatched horizontal bands. Discrete errors are shown by short vertical bars at the error value. Azimuth errors within the stippled box are obviated by FBS and XFBS (XFBS is discussed below).

except blunder types G4 and G5. To emphasize the effectiveness of FBS, note that all azimuth blunder errors inside the stippled box are effectively eliminated. Note, however, that there are certain circumstances which will allow blunders larger than 1.0 deg. to go undetected, even with FBS. For example, if the compass-person reads the wrong end of the compass needle for a number of azimuth measurements, the fore- and back-shots will agree, but they will both be wrong. A similar case occurs when the percent grade scale is read for a series of dip measurements.

Figure 2 below shows the fifteen blunder types from Paper-I which result in errors in dip. The FBS technique effectively obviates all blunders with dip errors exceeding 1.0 deg., except blunder types G4 and G5. To emphasize the effectiveness of FBS, note that all dip blunder errors inside the stippled box are obviated.

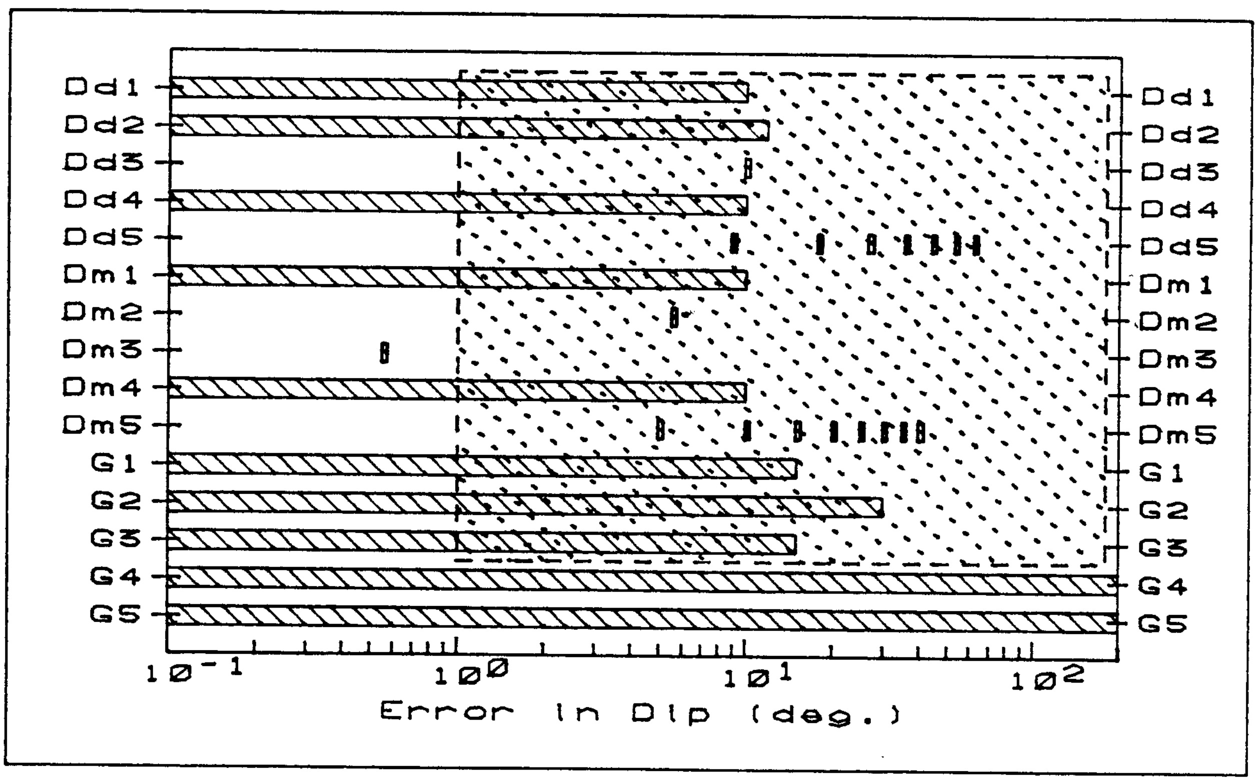


Figure 2. The dip errors are shown for each blunder type affecting the dip. Note the logarithmic scale in dip running from 0.1 to 200 deg. The ranges of the resulting errors are indicated by the hatched horizontal bands. Discrete errors are shown by short vertical bars at the error value. Dip errors within the stippled box are obviated by FBS and XFBS (XFBS is discussed below).

EXTENDED FORE-/BACK-SHOTS (XFBS)

The FBS technique is so effective in obviating azimuth and dip blunders that it seems natural to try to extend it to distance blunders. Using FBS the distances of the segments are not remeasured, i.e., they are measured only once. The reasons for this are several. First, the tape is an easy instrument to read. So distance blunders are percieved to be more infrequent than azimuth and dip blunders, even though more of the blunder types from Paper-I result in distance errors than in azimuth or dip errors. Second, the tape tends to get caught on rock projections, cave packs, etc., and might have to be reeled in and then out again if the ends of the tape are to be switched between measurements. Third, efficient survey team management might require two tapes and might result in an unacceptable increase in the time required to perform the survey.

The Extended Fore-/Back-Shot (XFBS) technique (XFBS includes the operations of FBS) solves these problems. Instead of selecting a survey tape which is graduated in metric units or English units but not both (as suggested above under Equipment Selection), use a tape graduated in both units and simply record both. While the tape is stretched between the stations, write the distance of the segment in both English units and metric units in the book.

The book-person then multiplies the metric measurement by 3.3 (3.281 if using a calculator) and compares the two values in much the same way he or she does for the azimuth and dip measurements in the FBS technique. If they do not agree to within about 0.6 feet, repeat the measurements until they do agree to within the selected tolerance. Using "3.3" and a tape not longer than 30 meters will detect all distance blunders larger than 0.6 feet.

Figure 3 below shows the twenty-three blunder types from Paper-I which result in errors in distance. The resulting errors are indicated in the same manner as in Figure 1. The XFBS technique effectively obviates all blunders with distance errors exceeding 0.6 feet, except blunder types G1, G3, G4 and G5. To emphasize the effectiveness of XFBS, note that all distance blunder errors inside the stippled box are eliminated. And since XFBS includes the operations of FBS, the blunder errors insides the stippled boxes in Figures 1 and 2 are also obviated.

Note that with XFBS, the tape has to be stretched between successive stations of the traverse only once, thus eliminating the chore of reeling the tape in and out twice for each segment. The difference between metric and English units makes it difficult for the tape-person to cheat. And compared with FBS there are no additional survey team management problems. Measuring the dis-

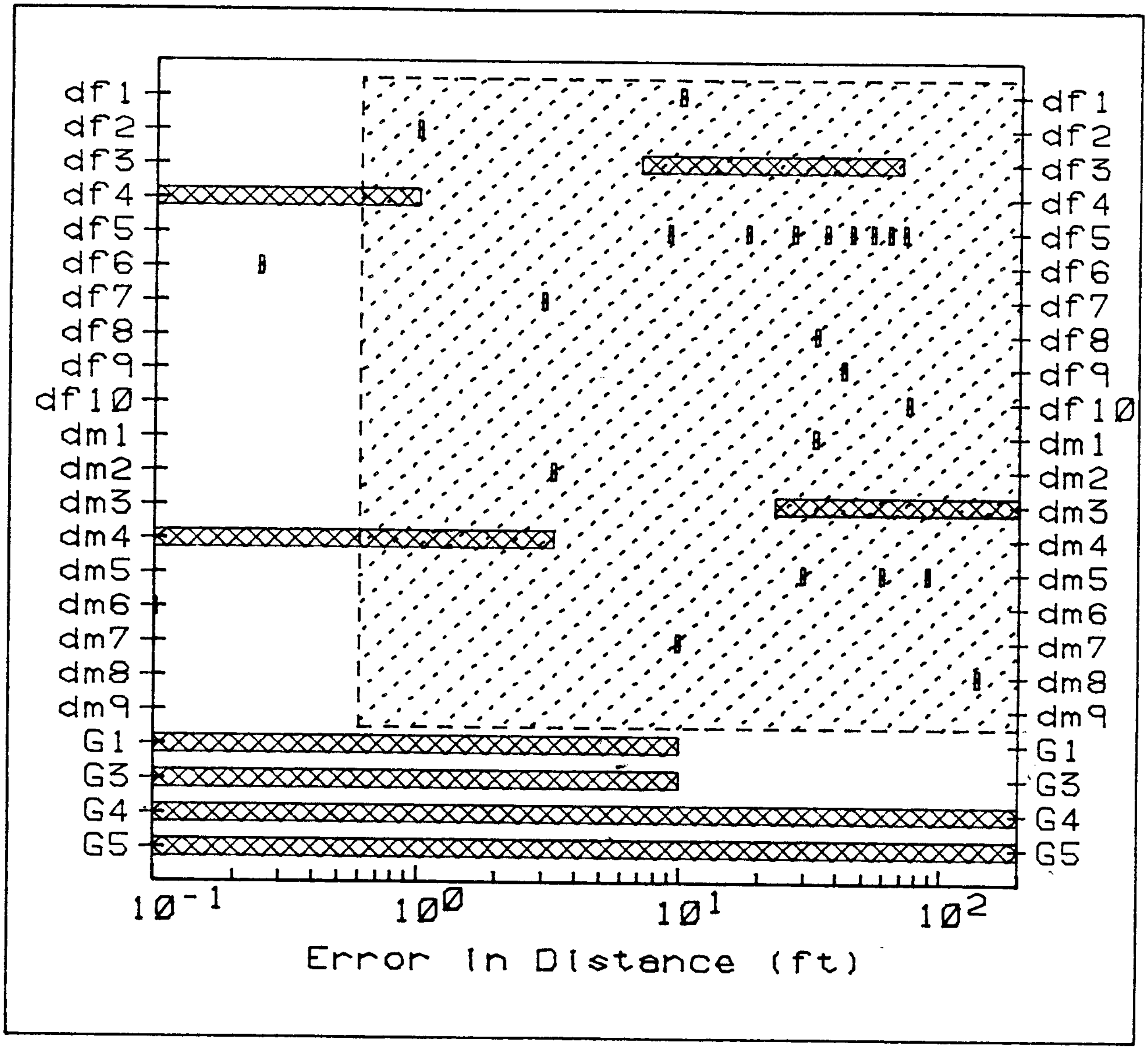


Figure 3. The distance errors are shown for each blunder type affecting the distance. Note the logarithmic scale in distance running from 0.1 to 200 feet. The ranges of the resulting errors are indicated by the crosshatched horizontal bands. Discrete errors are shown by short vertical bars at the error value. Errors within the stippled box are obviated by XFBS.

tance in two different directions (one in metric units and one in English units) would help obviate blunder types G1 and G3, but this is probably not be worth the additional hassle.

The XFBS technique (remember XFBS includes FBS):

- Obviates almost all azimuth blunder errors.
- Obviates the same azimuth blunder errors as FBS
- Obviates almost all dip blunder errors.
- Obviates the same dip blunder errors as FBS.
- Obviates almost all distance blunder errors.
- Creates no additional survey team management problems.
- Only slightly increases the survey time.

In Figures 1, 2 and 3 there is an area to the left of the stippled boxes which is not addressed by XFBS. These are angular errors smaller than 1.0 deg. and distance errors smaller than 0.6 feet. While blunders with errors in these ranges can certainly occur, they are so small that they are bound to be confused with, and to be nearly undistinguishable from, random errors and systematic errors (which typically fall into the same ranges). Because of this they are simply being ignored here.

STATION GRAPHS (SG)

Often the person who was the book-person on the survey crew is not the person who ends up interpreting the numbers in the book and typing the data into the computer. Sometimes one of the most difficult problems is figuring out the order of the stations in a series. This is often caused by a misguided desire to not waste paper (a renewable resource) in the survey book, with the result that a lot of time (a non-renewable resource) is wasted. Proper entry of the data into the book goes a long way towards alleviating this problem. Figure 4 below shows a way of entering XFBS numerical data so that the order of the stations is unambiguous.

Another technique for eliminating the difficulty in determining the order of the stations is to require from the book-person a 'station graph' of the survey. A station graph is a rough line plot of the traverse, designed to show the order of the stations. The exact (or even approximate) relative spatial locations of the stations are not important; only the order of the stations in the traverse is important. Figure 5 shows a station graph for the survey depicted in Figure 4. Note also that stations with valences of one or two (i.e., have one or two segments connected to them) are not very important here (see Wefer [1986] for a definition of the valence of a survey station). It is stations at intersections which cause the problems.

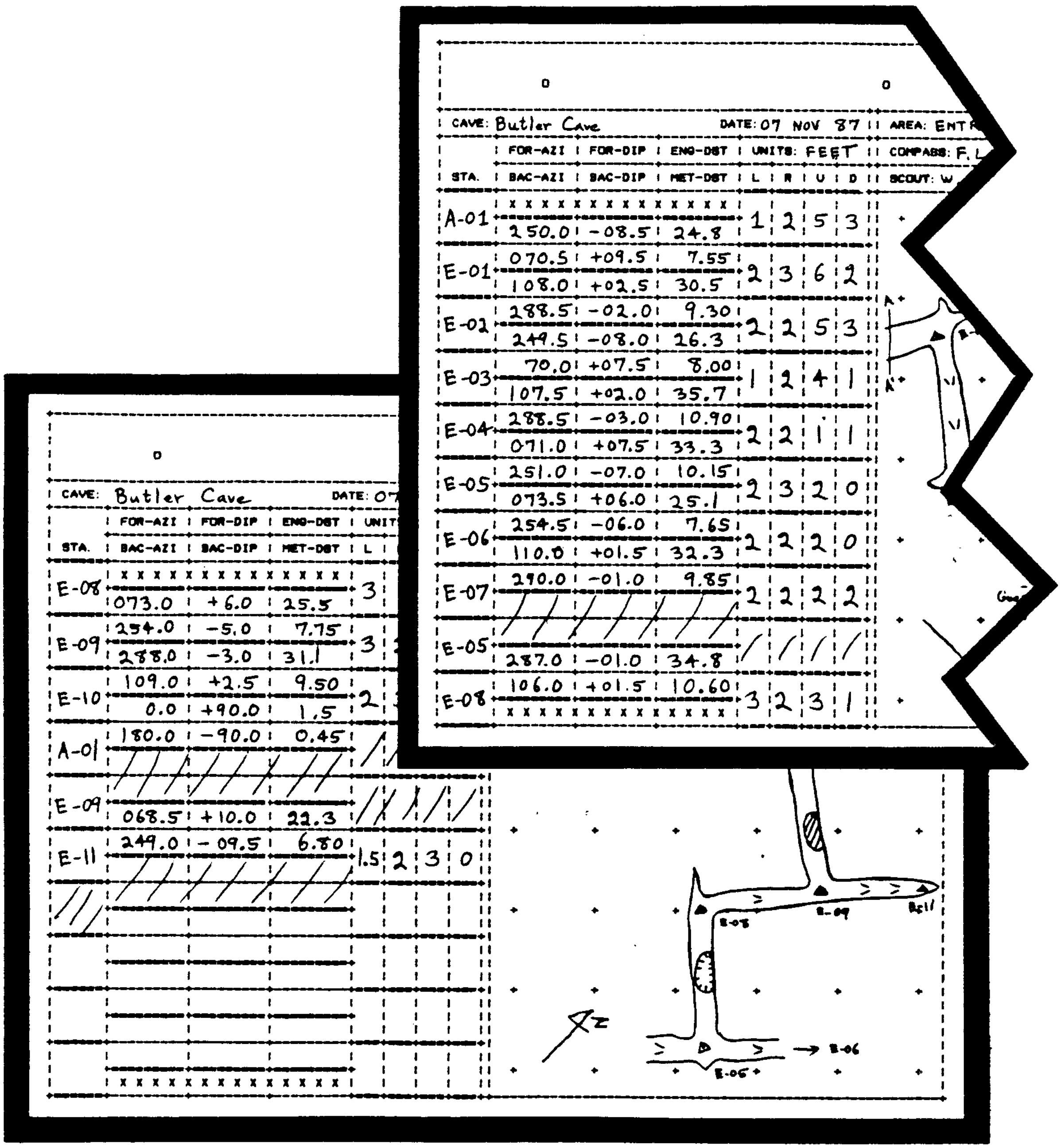


Figure 4. XFBS data entered in the cave survey book so that the order of the stations is unambiguous.

Armed with a station graph, the person typing the traverse data into the computer should be able to figure out the correct order of the stations, even if the book-person has been less than clear in entering the data into the book.

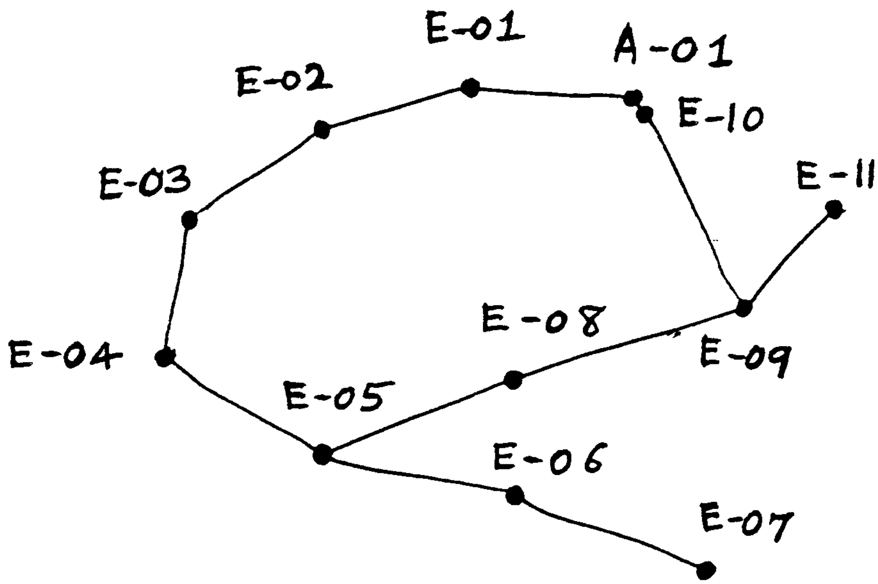


Figure 5. Sample station graph for the traverses in Figures 4, showing the order of the stations in the series.

VERIFY INPUTS (VI)

After the data has been entered into the file which will be read by the computer program during processing, get a listing of the file and compare it against the book. This is a boring step but can save you a lot of effort later on if blunders are caught at this stage of the processing.

A good practice is to line up the decimal points in the columns for azimuth, dip, and distance, and to always provide the same number of digits after the decimal point (e.g., if you use two decimal places like 10.26, then enter 10.20 not 10.2). It is amazing how much more easily errors can be detected in a neat input file. For example, compare the two version of the same data in Figure 6 below.

```
+-----------------------------------------------+
|   A-01     100.05      -4.5    13.5    A-02   |
|   A-02       10.0    -300.0     22.7   A-03   |
|    A-3     180. 5   +25.5    36.9     A-04   |
|   A-04       375.5    -10.0    51.3    A-05   |
|   A-05      223.10      -7.5    41.1   A-06   |
|  1A-06      224.5     -7.0    47.41   A-07   |
+-----------------------------------------------+

+-----------------------------------------------+
|   A-01      100.05     -4.5    13.5    A-02   |
|   A-02       10.0   -300.0    22.7    A-03   |
|   A-3       180. 5   +25.5    36.9    A-04   |
|   A-04      375.5    -10.0    51.3    A-05   |
|   A-05      223.10     -7.5   41.1    A-06   |
|  1A-06      224.5      -7.0   47.41   A-07   |
+-----------------------------------------------+
```

Figure 6. Two versions of the same data file, one neatly done with all decimal points lined up, one not so neatly done. Errors are more easily spotted in the neat version. There are at least six possible errors in the above series.

A blunder I discovered in one of my surveys resulted from mispla-cing the variable in the FORTRAN "F" format field. The azimuth was 355.0, but was placed in the field as shown in Figure 7, so it was read by the computer as 5.0 . Because the resulting azi-muth error was only 10.0 deg. and the series was not a loop, the error was discovered only by accident. If the decimal points had been lined up, the error would have been avoided or made obvious. The point here is neatness counts!

```
| |     |                         |       |       |       |  |     |
| |STA. |  LOCATION DESCRIPTION   |AZIMUTH|  DIP  | DIST. |  |STA.|
I1| A4  |          6A4            | F7.0  | F7.0  | F7.0  |I2| A4 |
| |     |                         |       |       |       |  |     |
| |A-37| UNDER THE FORMATION   35|5.0    |-3.0   | 22.7  |  |A-38|
| |A-38|                         |32.0   |   2.0 |  13.8 |  |A-39|
| |A-39|                         | 135.5 |12.0   | 42.1  |  |A-40|
| |     |                         |       |       |       |  |     |
```

Figure 7. The layout of the input fields in the author's cave survey computer program. The symbol "|" is used here to indicate the field boundaries. These symbols do not, of course, appear in the actual input files. The azimuth between stations A-37 and A-38 was read as 5.0 deg. instead of the cor-rect value of 355.0 deg.

RANGE CHECKING (RC)

Some typographical errors can be caught simply by having the processing computer program perform range checking on the input data. If you are surveying in degrees and feet & tenths, have the program check that the azimuth is in the range 0.0 through 360.0, that the dip is in the range -90.0 through +90.0, and that the distance is in the range 0.1 through 100.0 .

If you are surveying in mils, have the program check that the azimuth is in the range 0.0 through 6400.0, and that the dip is in the range -1600.0 through +1600 .

If any input variable is out of range, print an error message to the screen identifying the segment, its two stations, and the value which is out of range. If your program generates printed output, print the error message there also.

The use of a context sensitive editor program to generate the input data files used by the processing computer program will also help eliminate these errors. But if you then use a generic text editor to make changes and/or corrections to these files, additional errors may be introduced. Range checking by the processing computer program will help catch these new errors.

COMPARE WITH SKETCH (CS)

After the input data is successfully processed, the X, Y, and Z coordinates of the stations of the series will be available. Plot the plan view of the traverse line and compare it with the sketch in the survey book. When the sketched passage bends to the right, does the traverse line bend to the right also? Look at the Z-coordinates of the stations. If the sketched passage shows a climb up a slope, do the Z-coordinates increase as they should? Are the results of the computations in general agreement with the survey book sketch? If not, find out what the problem is and fix it!

SUMMARY OF TECHNIQUES FOR OBVIATING BLUNDERS

Table 1 below shows the forty-six blunder types from Paper-I and the techniques which help to obviate them. Obviously not all techniques are applicable to all survey situations. It is up to the survey leader(s) to decide which techniques to use, based on criteria such as: the importance of the series being surveyed, the relative cost effectiveness of the technique, the knowledge and skills of the team members, environmental conditions in the passages being surveyed, the cost of doing a resurvey if a blunder is detected, etc.

BLUNDER TYPE	COMPONENT	OBVIATING TECHNIQUE								
		ES	EM	EC	FBS	XFBS	SG	VI	RC	CS
Ad1	AZI			X	X	X		X	X	X
Ad2	AZI			X	X	X		X		
Ad3	AZI			X	X	X		X		
Ad4	AZI			X	X	X				
Ad5	AZI			X	X	X		X	X	X
Ad6	AZI	Z		X	X	X				X
Ad7	AZI	Z		X	X	X				X
Am1	AZI	Y		X	X	X		X	X	X
Am2	AZI	Y		X	X	X		X		
Am3	AZI	Y		X	X	X		X		
Am4	AZI	Y		X	X	X				
Am5	AZI	Y		X	X	X		X	X	X
BLUNDER TYPE	COMPONENT	ES	EM	EC	FBS	XFBS	SG	VI	RC	CS
		OBVIATING TECHNIQUE								

Table 1. For each blunder type from Paper-I, the affected component is indicated and also the techniques which help to obviate the blunder. The 'Ys' in the 'ES' column correspond to the equipment selection of a Brunton Compass graduated in deg. The alternative of a Brunton compass graduated in mils would move the 'Ys' to the Adx and Ddx blocks. The 'Zs' in the 'ES' column correspond to the equipmemt selection of a Brunton compass graduated to give azimuths instead of bearings. The COMPONENTS listed in the table are: AZI = azimuth, DIP = dip, and dis = distance. A key to OBVIATING TECHNIQUEs appears below each section of Table 1.

KEY TO OBVIATING TECHNIQUES:

ES = Equipment Selection
EM = Equipment Modification
EC = Exercising Care
FBS = Fore-/Back-Shots
XFBS = Extended Fore-/Back-Shots
SG = Station Graphs
VI = Verify Inputs
RC = Range Checking
CS = Compare with Sketch

BLUNDER TYPE	COMPONENT	OBVIATING TECHNIQUE								
		ES	EM	EC	FBS	XFBS	SG	VI	RC	CS
Dd1	DIP			X	X	X		X		X
Dd2	DIP		X	X	X	X				
Dd3	DIP			X	X	X		X		
Dd4	DIP			X	X	X				
Dd5	DIP			X	X	X		X		X
Dm1	DIP	Y		X	X	X		X		X
Dm2	DIP	Y		X	X	X		X		
Dm3	DIP	Y		X	X	X		X		
Dm4	DIP	Y		X	X	X				
Dm5	DIP	Y		X	X	X		X	X	X
df1	dis			X		X		X		X
df2	dis			X		X		X		
df3	dis	X		X		X				X
df4	dis			X		X				
df5	dis			X		X		X	X	
df6	dis			X		X				
df7	dis			X		X				
df8	dis			X		X				X
df9	dis			X		X				X
df1Ø	dis			X		X				X
dm1	dis			X		X		X	X	X
dm2	dis			X		X		X		
dm3	dis	X		X		X			X	X
dm4	dis			X		X				
dm5	dis			X		X		X		X
dm6	dis			X		X				
dm7	dis			X		X				X
dm8	dis			X		X				X
dm9	dis			X		X				X
BLUNDER TYPE	COMPONENT	ES	EM	EC	FBS	XFBS	SG	VI	RC	CS
		OBVIATING TECHNIQUE								

Table 1 (continued).

KEY TO OBVIATING TECHNIQUES:

ES = Equipment Selection
EM = Equipment Modification
EC = Exercising Care
FBS = Fore-/Back-Shots
XFBS = Extended Fore-/Back-Shots

SG = Station Graphs
VI = Verify Inputs
RC = Range Checking
CS = Compare with Sketch

BLUNDER TYPE	COMPONENT	OBVIATING TECHNIQUE								
		ES	EM	EC	FBS	XFBS	SG	VI	RC	CS
G1	AZI			X	X	X				
G1	DIP			X	X	X				
G2	AZI			X	X	X		X		X
G2	DIP			X	X	X		X		X
G3	AZI			X	X	X				
G3	DIP			X	X	X				
G3	dis			X						
G4	AZI			X			X	X	X	X
G4	DIP			X			X	X	X	X
G4	dis			X			X	X	X	X
G5	AZI			X				X	X	X
G5	DIP			X				X	X	X
G5	dis			X				X	X	X
BLUNDER TYPE	COMPONENT	ES	EM	EC	FBS	XFBS	SG	VI	RC	CS
		OBVIATING TECHNIQUE								

Table 1 (continued).

KEY TO OBVIATING TECHNIQUES:

ES = Equipment Selection
EM = Equipment Modification
EC = Exercising Care
FBS = Fore-/Back-Shots
XFBS = Extended Fore-/Back-Shots

SG = Station Graphs
VI = Verify Inputs
RC = Range Checking
CS = Compare with Sketch

SUMMARY AND CONCLUSIONS

Nine techniques for obviating blunders have been discussed in detail. The expected results have been summarized in Table 1 above. Applying these techniques will go a long way in eliminating blunders from our cave surveys. As the appreciation of the existence and importance of cave survey blunders increases among the cave surveying community, these techniques will likely gain in acceptance. Some surveyors already use FBS (see Appendix-B). For them the extension to XFBS should be an easy one. Appendix-C presents a cave survey data form which is designed for XFBS data.

In retrospect, the efforts at developing ever more sophisticated loop closure algorithms might be viewed differently. Such algorithms can not correctly account for blunders in the survey. And once the blunders are removed, maybe it doesn't matter very much which algorithm is used to distribute the remaining errors.

Again this work needs to be extended to blunder types peculiar to Suunto type compasses and clinometers. As in Paper-I, this work is left to someone with lots of experience with these types of instruments. I expect that XFBS will be as devastating to those blunders as it is to the ones discussed herein.

The next (and last) paper in the series addresses the question, "I think I have a blunder in my survey; now what do I do?"

APPENDIX-A

This appendix lists the labels and one line descriptions of the forty-six blunder types identified in Paper-I. More complete information on these blunders was presented in Paper-I.

Azimuth/Bearing Blunders (Brunton compass graduated in degrees)

Ad1 -- Digit error (hundreds)
Ad2 -- Digit error (tens)
Ad3 -- Digit error (units)
Ad4 -- Reading the wrong way from a marked graduation
Ad5 -- Transposition errors in azimuth
Ad6 -- Reading the wrong meridian for a bearing
Ad7 -- Reading the wrong direction for a bearing

Azimuth Blunders (Brunton compass graduated in mils)

Am1 -- Digit error (thousands)
Am2 -- Digit error (hundreds)
Am3 -- Digit error (tens)
Am4 -- Reading the wrong way from a marked graduation
Am5 -- Transposition errors in azimuth

Dip Blunders (Brunton clinometer graduated in degrees)

Dd1 -- Reading the wrong sign
Dd2 -- Reading the percent grade scale instead of the angle scale
Dd3 -- Digit error (tens)
Dd4 -- Reading the wrong way from a marked graduation
Dd5 -- Transposition errors in dip

Dip Blunders (Brunton clinometer graduated in mils)

Dm1 -- Reading the wrong sign
Dm2 -- Digit error (hundreds)
Dm3 -- Digit error (tens)
Dm4 -- Reading the wrong way from a marked graduation
Dm5 -- Transposition errors in dip

Distance Blunders (Tape graduated in feet)

df1 -- Digit error (tens)
df2 -- Digit error (units)
df3 -- Reading metric side instead of English side of tape
df4 -- Reading the wrong way from a marked graduation
df5 -- Transposition errors in distance
df6 -- Confusing sixes and nines (inches)
df7 -- Confusing sixes and nines (units)
df8 -- Confusing sixes and nines (tens and units)
df9 -- Confusing sixes and nines (tens and units)
df1Ø - Confusing sixes and nines (tens and units)

Distance Blunders (Tape graduated in meters)

dm1 -- Digit error (tens)
dm2 -- Digit error (units)
dm3 -- Reading English side instead of metric side of tape
dm4 -- Reading the wrong way from a marked graduation
dm5 -- Transposition errors in distance
dm6 -- Confusing sixes and nines (centimeters)
dm7 -- Confusing sixes and nines (units)
dm8 -- Confusing sixes and nines (tens and units)
dm9 -- Confusing sixes and nines (tens and units)

Generic Blunders

G1 -- Sighting on the wrong flame
G2 -- Backshot errors
G3 -- Measuring from the wrong station
G4 -- Data interpretation errors
G5 -- Data entry errors

APPENDIX-B

This appendix presents a brief history of the development of FBS. I first heard of the beginnings of FBS around 1977. By the way, FBS is my name for it. I have not heard it named anything before. Since this makes talking about it difficult, I named it myself.

I was living in Boston at the time and was on my way to Kentucky for a Cave Research Foundation (CRF) expedition. It was a very long drive, so I went with a group of other CRF Joint Venturers (JVs) from the Boston area. Of course, most of the conversation was about caves, cave surveying, the Flint-Mammoth System, etc. The story I heard went something like this.

> A team of JVs was sent into Flint Ridge to survey a long loop. When the traverse was run on the computer, the loop didn't close very well. So at the next expedition, another team of JVs was sent in to resurvey the same loop. Because CRF surveyors mark every station, the second team was required to use the same survey stations as the first team. But when the second traverse was run on the computer, the second loop didn't close well either.
>
> So at the next expedition still another team was sent in to resurvey the same loop. They too were required to use the same survey stations as the first team. But when the third traverse was run on the computer, the third loop didn't close well.
>
> After several more surveys, the CRF people began to compare the several measurements for each segment of the loop. To their surprise they discovered that about one shot in twenty contained a blunder!

As a result of this, CRF began requiring fore- and back-shots in azimuth at each station. CRF did not require back-shots in dip because at that time CRF surveyors did not measure the dip unless it was obvious that it exceeded about four degrees (cosine dip = 0.998, i.e., distance error less than 0.1 feet with a 50 ft tape). When the dip exceeded four degrees, other techniques were used.

The technique as established by CRF is detailed by Freeman [1975], so it was not new in 1977. My previous CRF expedition was before I moved to San Diego in 1973. I do not remember making both fore- and back-shots on the surveys we did at that expedition, so the survey events described above must have happened (if they happened at all) between 1973 and 1975. Perhaps someone from CRF will provide more accurate historical data on this topic.

Looking at other references, Bridgemon [1970] in the NSS NEWS shows what he calls "Kunath's AMCS survey form". It is clear from this form that only one measurement is expected of the azimuth, dip, and distance for each segment. Lindsley [1970] in the same issue does not mention FBS in his 'mapping procedure' section.

Whittemore [1971b] makes no mention of FBS, and the cave survey data forms shown make no provision for back-shots in azimuth or dip.

Hosley [1971] mentions FBS as follows: "There is a practice used in civil surveying which should be kept in mind even though it is used rarely, if ever, in cave surveying. The method may be useful to increase accuracy where sightings are particularly difficult because of the cave structure. At each traverse station (sic) the azimuth or bearing measurement is taken in the forward direction to the next station, and in the reverese direction to the previous station. The average of the two readings obtained for each traverse line (sic) will be more precise than a single measurement would be. Double tapings of distance measurements are similarly obtained in civil practice where tapes are employed. In addition to the increase in accuracy by averaging the two measurements, the method of double readings serves as a useful check in an open traverse where mistakes may otherwise go undetected."

Knutson [1973] makes no mention of FBS.

Irwin and Stenner [1975] mention FBS as follows: "The forward and backsight (sic) technique is by far the best method to use, providing that time and patience is available, as this has the advantage of zeroing the clinometer at each station, as well as checking the compass reading and tape measurements, and so reducing the chances of gross errors (sic) occurring." By "gross errors" they mean blunders. There is no discussion of the actual checking of the "compass reading and tape measurements".

Ellis [1976] makes no mention of FBS.

Thrun [1981] mentions FBS as follows: "Data set 1, part of the Trout Cave survey, was done by seven different instrument readers. They used Suuntos and took both foresights (sic) and backsights (sic) on every shot, which means that each angle was measured twice and that blunders were detected at once."

Thomson and Taylor [1981] mention FBS as follows: "6. The surveyor 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 read to the nearest 1/2 degree. If possible, a backsight (sic) should be taken to ensure accuracy in this reading. Then, the compass reading, similar to the distance, reading is called out to the chief, who again repeats the reading back to the surveyor and records it in the notes." Curiously, the cave survey form shown in their Figure 7-3 makes no provision for recording the back-shot. Further on in a discussion of "ERRORS OF DISTANCE AND DIRECTION" they state, "Great care must be taken in determining azimuth or bearing. Do not let one casual reading determine the location (sic). At least two readings and possibly a backsight (sic) should be made to insure (sic) accuracy of direction."

Ganter [1985] makes no mention of FBS.

Swicegood [1986] stresses the use of FBS for detecting and eliminating blunders during the surveying process. She describes the technique in detail and gives the following description of how a three-person team can use FBS efficiently: "1) Point sets a station in the forward direction, and the instrument reader takes readings to the forward station. 2) The instrument reader moves up to the forward station, while the sketcher stays at the rear station prepared to hold a light on the station for backsight (sic). 3) The instrument reader takes the tape from point and secures it (stands on it, wraps it around an arm, wraps it around a rock, sits on it-- whatever it takes), then pivots and reads the backsight (sic) while point is moving to the next station. It is important for the reader to be able to ignore the tape while doing this-- a short tether may be helpful in keeping the end of the tape out of the way, yet instantly in hand. 4) The sketcher works up to the station where the instrument reader is, as the instrument reader pivots and reads the forward station which point has now set. 5) The instrument reader moves up to join point, while the sketcher remains at the rear station."

This is all a little confusing since authors seem to alternate between mentioning FBS and not mentioning it. In an effort to make it a little clearer, Figure B-1 below shows the references as a function of time. Authors who mention FBS are listed above the time scale, those who don't are listed below. Hosley [1971] appears to have made the first mention of FBS in the caving literature; however, my search has not been exhaustive.

The point here is that since authors of books and papers on cave surveying techniques have been inconsistent in mentioning (let alone describing in detail) the FBS technique, it should not be surprising that its acceptance has been slow.

```
                                             Wefer [This Paper]
                                                      |
                                    Swicegood [1986]  |
                                                  |   |
                                 Thrun [1981]     |   |
                                            |     |   |
               Thomson and Taylor [1981]    |     |   |
                                       |    |     |   |
           Irwin and Stenner [1975]    |    |     |   |
                            |          |    |     |   |
         Freeman [1975]     |          |    |     |   |
                      \     |          |    |     |   |
    Hosley [1971]      \    |          |   /      |   |
                \       \   |          |  /       |   |
SOME MENTION     \       \  |          | /        |   |
                  \       \ |          |/         |   |
+-+-+-|-+-+-+-+-|-+-+-+-+-|-+-+-+-+-|-+-+-+-+-|-+-+-+-+-|-+-+-+-+
      |         |         |         |         |         |
    1965.0    1970.0    1975.0    1980.0    1985.0    1990.0
      |         |         |         |         |         |
+-+-+-|-+-+-+-+-|-+-+-+-+-|-+-+-+-+-|-+-+-+-+-|-+-+-+-+-|-+-+-+-+
               /|  \   \     \                 |
NO MENTION    / |   \   \     \                |
             /  |    \   \     \               |
 Lindsley [1970] |    \   \     \              |
                 |     \   \     \             |
      Bridgemon [1970]  \   \     \            |
           Whittemore [1971b]  \     \         |
                    Knutson [1973]    \        |
                              Ellis [1976]     |
                                     Ganter [1985]
```

Figure B-1. Works on cave surveying are listed in chronological order. Authors who mention FBS are listed above the time scale, those who do not are listed below.

APPENDIX-C

Because the XFBS technique requires that additional data be recorded in the survey book, a new cave survey data form is required. Figure C-1 below shows the form being used by the author for surveys employing the XFBS technique. It has been reduced to 0.65 of the original size. If you enlarge it by 1.54 it will come out filling an 8.5 by 11.0 sheet of paper.

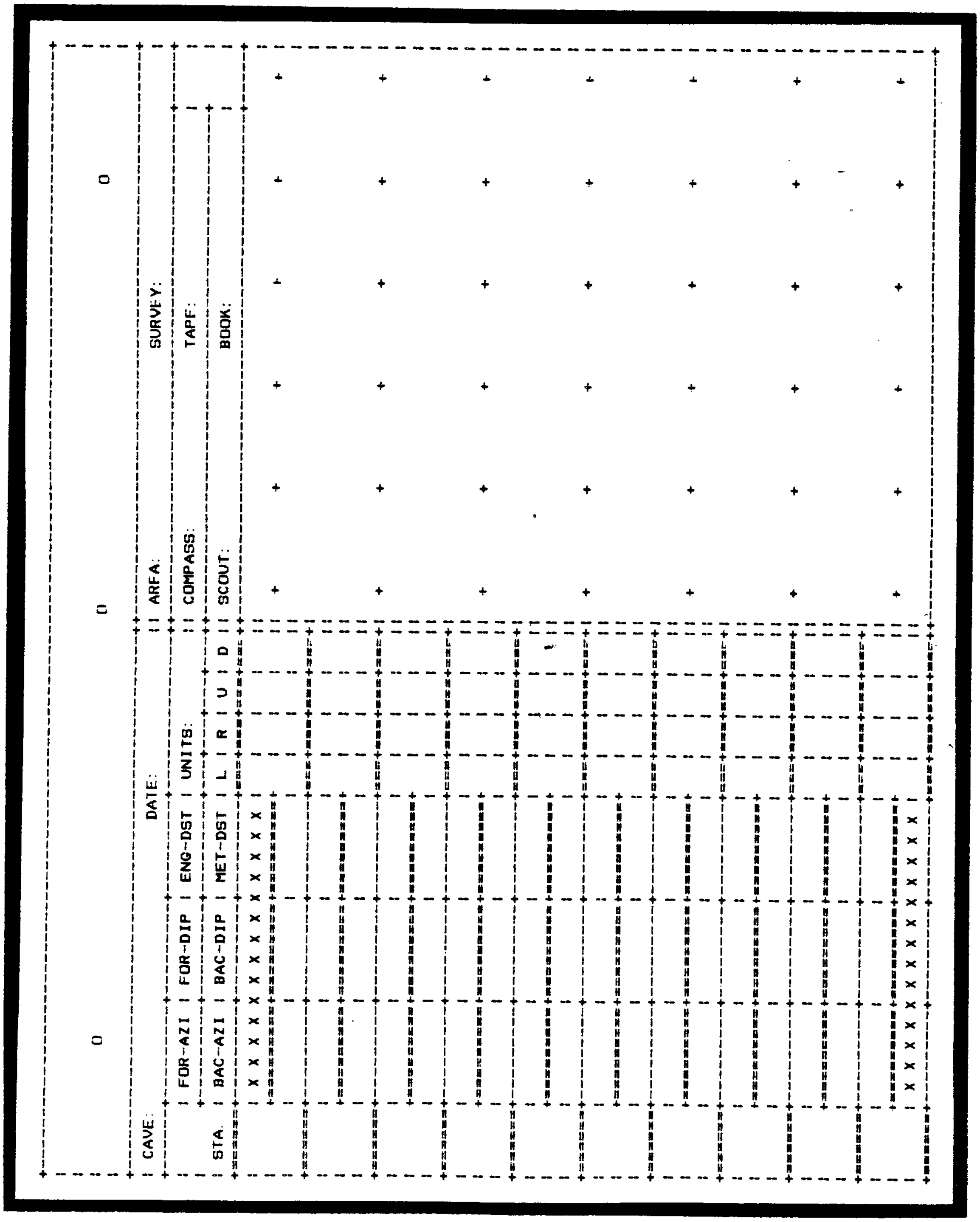


Figure C-1. Cave survey data form for XFBS surveys.

REFERENCES

Bridgemon, R. [1970], "Cave Surveying Issue", NSS NEWS, Vol. 28, No. 4, pp. 41-42, April 1970.

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

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.

Knutson, S. [1973], "Cave Mapping - Get Out & Do It!", Speleo Digest 1973, pp. 263-266.

Lindsley, P. [1970], "The Shadow Method For Cave Surveys", NSS NEWS, Vol. 28, No. 4, pp. 42-44, April 1970.

Swicegood, R. [1986], "Backsights for Fun and Profit", Compass and Tape, Volume 4, Number 1, pp. 6-7, Summer 1986.

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

Wefer, F.L. [1986], "Characteristics of the Butler Cave-Sinking Creek System", BCCS Newsletter, Volume 12, pp. 36-42, 1986.

Wefer, F.L. [1987], "On Cave Survey Blunders", Compass and Tape, Volume 5, Number 2, pp. 23-43, Fall 1987.

Whittemore, R.E. [1971a], "Brunton Reading Made Easy", Speleo Digest 1971, pp. 281-287.

Whittemore, R.E. [1971b], "Note Taking Made Difficult", Speleo Digest 1971, pp. 292-295.

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STILL MORE ON CAVE SURVEY BLUNDERS

by

Fred L. Wefer

BACKGROUND

This paper continues the discussion on cave survey blunders begun in Wefer [1987 and 1988], hereafter referred to as Paper-I and Paper-II, respectively. It is assumed that the reader is familiar with the material of these papers. Terminology and mathematical symbols introduced there are used here. For those readers who are not familiar with these papers, the next two paragraphs present brief summaries of their contents. Words in all capital letters in the paragraphs are section titles from Paper-I and Paper-II.

Paper-I began with a set of formal DEFINITIONS for the terms used in cave surveying. The discussion continued with a brief section on THE IMPORTANCE OF LOOPS. The types of SURVEYING ERRORS were then discussed. This was followed by a detailed presentation on DETECTING THE PRESENCE OF A BLUNDER. It turned out to be possible to anticipate certain TYPES OF BLUNDERS which can occur in a cave survey. Forty-six types were identified and listed in this section. For each type of blunder the following information was presented: a label for easy reference, a one line description of the error, an example of the error, the size of the error in azimuth, dip, and/or distance, and the contribution to: the error of closure, the horizontal component of the error of closure, or the vertical component of the error of closure, as appropriate. The next two sections discussed the RELATIVE FREQUENCIES OF BLUNDERS and the RELATIVE SIZES OF BLUNDERS. The difficulty in FINDING THE BLUNDER was also touched upon. This was followed by a SUMMARY AND CONCLUSIONS and finally by the REFERENCES cited.

Paper-II began with a brief overview discussion of some TECHNIQUES FOR OBVIATING BLUNDERS. Then in separate sections, each of the nine identified techniques was presented in detail. These techniques were: EQUIPMENT SELECTION, EQUIPMENT MODIFICATION, EXERCISING CARE, FORE-/BACK-SHOTS, EXTENDED FORE-/BACK-SHOTS, STATION GRAPHS, VERIFYING INPUTS, RANGE CHECKING, and COMPARING WITH SKETCH. Following this was a SUMMARY OF TECHNIQUES in which the forty-six blunder types were listed along with the techniques which help to obviate them. This was followed by a SUMMARY AND CONCLUSIONS. APPENDIX-A listed the labels and one line descriptions of the forty-six blunder types identified in Paper-I. APPENDIX-B presented a sketch of the history of some of the techniques. APPENDIX-C presented a cave survey data form useful with the technique here called XFBS. The final section listed the REFERENCES cited.

INTRODUCTION

This paper addresses the question, "I think I have a blunder in my survey; now what do I do?" Before answering this question, let's explore what asking the question implies.

Asking the question implies that there is some reason for thinking that a blunder is present in the data. If the series is not a loop, then there is no sure way of knowing that a blunder is present. The skills and the dedication of the survey team may be in doubt, and the conditions under which the survey was performed may have been worse than usual. But these are grounds only for suspicion.

If you already know the location of some point in the new traverse, you can compare that already-known location with the location from the new survey. From this you may be able to detect the presence of a blunder. But recognize that in this circumstance you really have a loop. The already-known location may originate from: another survey of cave passages (the same passages or different ones), from a surface survey, from locating entrances on a topographic map, from radio location techniques, etc. But you still have a loop.

The key to detecting the presence of a blunder is having two independent sets of coordinates for the same survey station. When these coordinates disagree by more than a certain amount, then the presence of a blunder (or possibly some other type of error) is indicated. The caveat is required here because if two surveys are involved, systematic errors in the instruments used for one survey can cause serious disagreements between computed positions of survey stations even when no blunders are present.

For simple loops, the computer program used to reduce the cave survey data should compute: the perimeter of the loop (P), the error of closure (C), and the ratio of error (R). See Appendix-A for a presentation of the computation of these and other parameters of the series. If the ratio of error is greater than the inverse of the square root of the perimeter, then the loop probably contains a blunder (see Paper-I for a more complete discussion of this technique). It is important to note that while

$$R > 1.0 \;/\; SQRT\,[\,P\,] \qquad (1)$$

indicates the presence of a blunder in the loop,

$$R < 1.0 \;/\; SQRT\,[\,P\,] \qquad (2)$$

does not guarantee that the loop is blunder-free. In the following discussion it is assumed that asking the question "I think I have a blunder in my survey; now what do I do?" implies that we are talking about a simple loop and that Equation (1) holds.

THE OPTIONS

What one does when one thinks there is a blunder in a loop depends on many factors, for example:

- o The importance of the specific loop in the cave
  - Location of the loop in the cave
  - Perimeter of the loop
  - Side passages off of the loop
- o The importance of the cave
  - Size of the cave
  - Location of the cave
  - Depth of the cave
  - Anticipated special uses of the cave or the cave map
  - Special resources of the cave
- o The cost of another survey
  - Cost of travel in time and money
  - Difficulty of getting to the cave
  - Difficulty of getting to the loop in the cave
  - Motivational factors

Each individual circumstance must be evaluated to determine the appropriate course of action. While meaningful generalizations are difficult to make, there seem to be at least four broad options to be considered. These are listed below and are discussed in the following sections.

- o Do Nothing
- o Resurvey The Entire Loop
- o Resurvey A Portion Of The Loop
- o Find And Correct The Blunder

DO NOTHING

It may seem strange to say, but in some circumstances the best course of action is to 'do nothing'. For example, suppose the loop is a short one, is of no particular importance, and is in an obscure portion of a cave system located thousands of miles from home. Practically speaking, there may be nothing you can do, except chalk it up to experience and try to do better in the future. So close the loop using the Compass Rule (see Wefer [1971]) if it is necessary in order for you to complete the map, make a note of the problem in the expedition report (or on the map itself), and get on with your life!

RESURVEY THE ENTIRE LOOP

At the other end of the spectrum from 'do nothing' is 'resurvey the entire loop'. There are obviously circumstances in which this should be done. For example, suppose the loop is an important one with many side passages branching from it, is the key loop in a cave system which is close to home, and is an easy loop to get to in the cave. Then go back and resurvey the entire loop. Use as many of the old stations as possible. Try to find the blunder. If it is not one of the forty-six types listed in Paper-I, write a paper on your blunder for Compass & Tape.

RESURVEY A PORTION OF THE LOOP

Resurveying a portion of the loop is a compromise between the extremes of 'do nothing' and 'resurvey the entire loop'. In fact it is possible to construct the survey to take advantage of this technique. An example will help explain.

In 1977 the Butler Cave Conservation Society, Inc. (BCCS) was faced with resurveying the downstream Trunk Channel in The Butler Cave-Sinking Creek System. The downstream Trunk Channel is a single passage more than 8000 feet long. It is the sole link between the several miles of passages in the downstream sections of the cave system and the rest of the cave. The BCCS wanted the survey to be as accurate and blunder-free as possible, but they also didn't want to make a career of surveying this passage. The resulting effort has been described by Wefer [1978].

The initial resurvey involved two teams. One team began at a survey station near the Moon Room ($ T-18 at the beginning of the downstream Trunk Channel) and surveyed to a base station in the

Pool Room ($ E-Ø1 at the other end of the passage). (Note: In the BCCS, "$" has become a more or less standard abbreviation for "survey station", but is normally only used preceeding a station label. Hence "$ T-18" means "survey station T-18".)

The other team went to the Pool Room, set $ E-Ø1, and began surveying back towards $ T-18. Each team marked about every 12th station with: a carbide dot, a station label, and a piece of flagging tape. After the two teams met, both continued to survey in the direction they had begun. They also made sure to include in their own series the stations flagged by the other team.

As a result of this procedure the BCCS ended up with a loop 886Ø feet long which could be decomposed into 6 smaller loops. The idea was to run the whole series as a loop. If it closed to within say R < Ø.ØØ5, then they would accept the results. If R exceeded this value, then each of the small loops would be run to try to determine which stretch of passage contained the problem. It turned out that 3 of the 6 loops needed to be resurveyed. But only about 12 shots were involved in each, since a one-way survey was sufficient. The new survey was simply combined with one of the two previous one-way surveys to form the new loop series. When the process was complete the ratio of error for the combined loop turned out to be only Ø.ØØ46.

This procedure can be viewed as an intermediate step between single measurements of each azimuth, dip, and distance, and XFBS (see Paper-II). Obviously if instead of flagging every 12th station they had flagged each and every station, then they would have been using a technique equivalent to XFBS. Another way of looking at XFBS is that it turns every series into a loop. While the common practice in XFBS is to average the fore- and backshots and enter only the average into the computer, one could enter both and run each series as a loop (see Appendix-B for a discussion of this). The point here is that it is possible to anticipate problems and to structure the survey to aid in isolating the problems.

FIND AND CORRECT THE BLUNDER

Some general techniques for finding blunders in loops have been presented, notably by Bassham [1979]. These techniques are necessarily based on the assumption that there are no other errors in the survey. Let's proceed with this assumption and discuss the effects of the blunders. We will return to the question of errors and how one tells which kind of blunder one is dealing with.

In the discussions which follow it is assumed that the computer program you used to reduce the cave survey data has computed the following parameters of the series in which you think there exists a blunder:

P = perimeter of the loop (ft),
Cx = x-component (east) of the error of closure (ft),
Cy = y-component (north) of the error of closure (ft),
Ch = horizontal component of the error of closure (ft),
Cz = z-component (up) of the error of closure (ft),
C = error of closure (ft),
Rh = horizontal ratio of error (dimensionless),
Rz = vertical ratio of error (dimensionless),
R = ratio of error (dimensionless),
Af = fore-shot azimuth of the error of closure (deg.),
Ab = back-shot azimuth of the error of closure (deg.),
Df = fore-shot dip of the error of closure (deg.),
Db = back-shot dip of the error of closure (deg.),
NAf = azimuth of the clockwise normal to Af (deg.),
NAb = azimuth of the clockwise normal to Ab (deg),
NDf = dip of the more downward normal to Df (deg.), and
NDb = dip of the more upward normal to Db (deg).

Appendix-A presents definitions of these parameters, details on how they are computed, and shows the coordinate system used. It is also assumed that you have available a plan view of the unadjusted series showing: each survey station, each segment, the error of closure, and the perpendicular bisector of the error of closure. These last two should be plotted using a different line style than the actual segments, and should extend across the entire plan view as shown on the left-hand side of Figure 1. It may also be necessary to consult a profile view drawn in the vertical plane through the first and last stations of the loop. Such a plot is shown on the right-hand side of Figure 1.

The possible blunder situations include at least the following six, each of which is discussed below.

- Missing One Segment
- Back-Shot Blunder
- Blunder In Azimuth Of One Segment
- Blunder In Dip Of One Segment
- Blunder In Distance Of One Segment
- Combination And Multiple Blunders

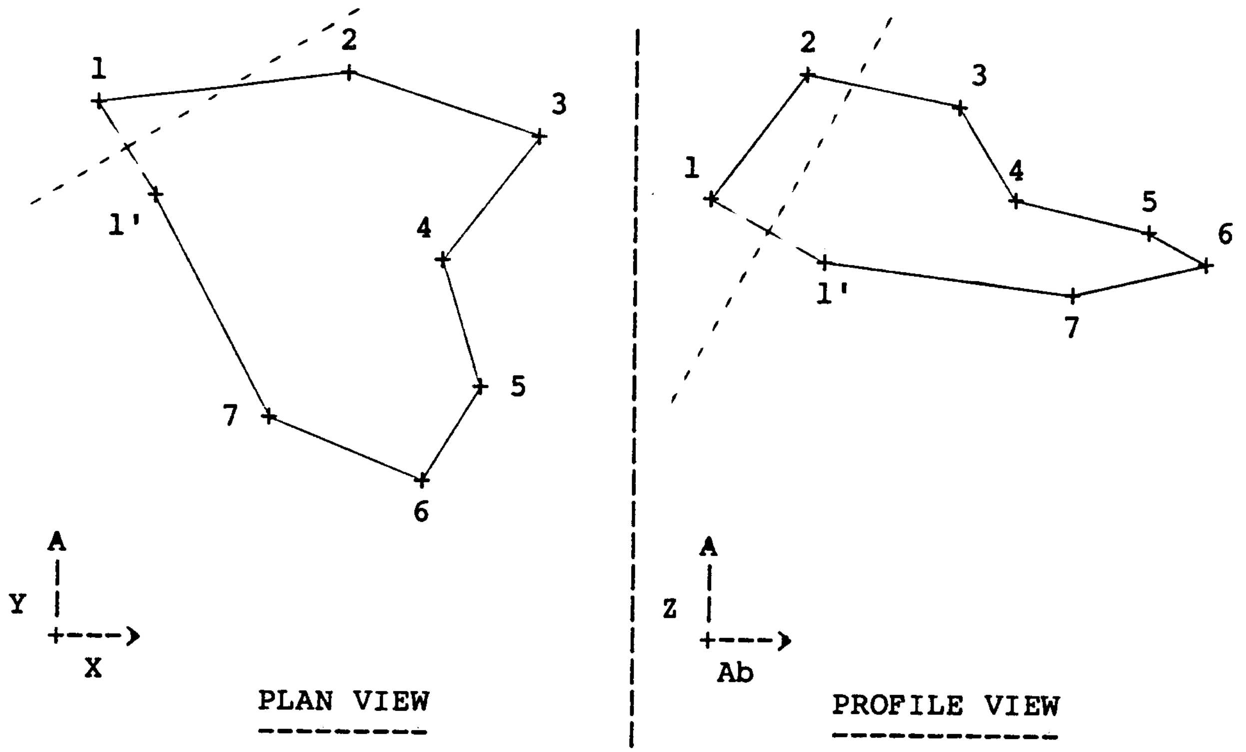

Figure 1. Plan and profile views of a loop containing a blunder. The solid lines are segments of the series. The dashed line is the error of closure. The dotted line is the perpendicular bisector of the error of closure. Survey stations are shown by plus signs. Note that $ 1 and $ 1' are the same point in the cave. The profile view is constructed in the vertical plane through the error of closure.

MISSING ONE SEGMENT

Suppose there is one segment missing from the series. Then in the absence of any other errors, the error of closure will be identical to the missing segment. Look through the survey data for a segment with an azimuth of Af, a dip of Df, and a distance of C. Check the station graph (see Paper-II). Perhaps you have just not included this segment in the data on the computer.

BACK-SHOT BLUNDER

Suppose there is a back-shot blunder. This could be a shot which was a back-shot, but was not indicated as such to the computer. It could also be a shot which was not a back-shot, but which was indicated as a back-shot to the computer. Then in the absence of any other errors, the segment in error will be parallel to the error of closure but opposite in direction and half as long. Look for a segment with an azimuth of Ab, a dip of Db, and a distance of Ø.5*C.

A list of segments with nearly the azimuth Ab should be made. The list should be organized in order of increasing values of the magnitude of the difference between Ø.5*C and the distance d(k).

BLUNDER IN AZIMUTH OF ONE SEGMENT

If the blunder is in azimuth, the effect will be seen only in the horizontal component of the error of closure (Ch). Bassham [1979] has described the effects of this blunder. In the absence of any other errors, and if the error is not too large, the segment in error will be nearly parallel to the normal of the error of closure. It will, therefore, have an azimuth near to NAf or NAb. The larger the blunder, the more the azimuth of the segment in error will differ from NAf or NAb.

A list of segments with nearly these azimuths should be made. If the kth segment is the one in error, then the magnitude of the error will be given by:

$$e[A(k)] = 2.0 * \mathrm{ARCSIN}\ [\ Ch\ /\ d(k)\ ] \qquad (3)$$

where: e[A(k)] = required error in azimuth for segment k to be the one containing the blunder. The list should be organized in order of increasing values of e[A(k)]. A plan view of the series (see Figure 1) is very helpful in understanding the problem. Search through the data and try to figure out which segment is in error. If you decide to resurvey only a portion of the loop, concentrate your efforts on the segments at the start of the list.

BLUNDER IN DIP OF ONE SEGMENT

If the blunder is in dip, the effect will be seen mainly in the vertical component of the error of closure (Cz). If the error is not too large, there will be only a slight effect on the horizontal component of the error of closure. Bassham [1979] has described the effects of this blunder. In the absence of any other errors, and if the error is not too large, the segment in error will be nearly parallel to a line which is in the vertical plane through the error of closure and nearly normal to the error of closure. It will, therefore, have a dip near to NDf or NDb.

A list of segments with nearly these dips should be made. If the kth segment is the one in error, then the magnitude of the error will be given by:

e[D(k)] = 2.0 * ARCSIN [C / d(k)] (4)

where: e[D(k)] = required error in dip for segment k to be the one containing the blunder. The list should be organized in order of increasing values of e[D(k)]. A profile view of the series in the vertical plane containing the error of closure (see Figure 1) is very helpful in understanding the problem.

Search through the data and try to figure out which segment is in error. If you decide to resurvey only a portion of the loop, concentrate your efforts on the segments at the start of the list. In the absence of any other errors, the segment containing the blunder will lie in the same vertical plane as the error of closure. Look especially at segments with azimuths near to Af and Ab. Note that since the dip blunder will also cause a small misclosure in the horizontal plane, correcting the dip blunder should also decrease the horizontal error of closure.

BLUNDER IN DISTANCE OF ONE SEGMENT

If the blunder is in distance, the effect will be seen in both the horizontal and vertical components of the error of closure. Bassham [1979] has described the effects of this blunder. In the absence of any other errors, and if the error is not too large, the segment in error will be nearly parallel to the error of closure. It will therefore have an azimuth near to Af or Ab and a dip near to Df or Dd. A list of segments with nearly these azimuths and dips should be made. If the kth segment is the one in error, then the magnitude of the error will be given by:

e[d(k)] = C (5)

where: e[d(k)] = required error in distance for segment k to be the one containing the blunder. The list should be organized in the order of increasing differences between e[d(k)] and C. A plan view of the series and a profile view in the vertical plane containing the error of closure are very helpful in understanding the problem (see Figure 1). Look through the data and try to find segments which might fit the distance blunder types listed in Paper-I. Correcting the distance blunder should decrease both the horizontal and vertical components of the error of closure.

COMBINATION AND MULTIPLE BLUNDERS

If there are two or more blunders of the same or different types in the series, then it is almost impossible to untangle them and correct the data. You might luck out and find them, but it would be mostly luck. The number of possible combinations is very large and makes the problem intractable.

DETERMINING THE CAUSE

It has been assumed that Equation (1) holds for the loop being considered. The next question is "Which of the above five blunders is it likely to be?" To answer this question we return to the fifty Brunton compass and tape surveys of simple loops used in Paper-I to determine Equation (1).

Figure 2 below shows the horizontal components of the ratios of error plotted versus the perimeters of the loops for this set of fifty loops. Assuming that these loops contain no blunders, we see that a reasonable condition for the existence of a blunder affecting the horizontal ratio of error is:

$$Rh > 0.66 / SQRT [P] \tag{6}$$

Figure 3 below shows the vertical components of the ratios of error plotted versus the perimeters of the loops for the same set of fifty loops. Assuming that these loops contain no blunders, we see that a reasonable condition for the existence of a blunder affecting the vertical ratio of error is:

$$| Rz | > 0.75 / SQRT [P] \tag{7}$$

The absolute magnitude is used here because while Rh is always positive in sign (see Appendix-A), Rz may be either positive or negative. We are not here interested in the sign of the error.

Table 1 below shows the possible causes of the misclosure in various situations. Possible causes which depend on the presence of vertical or near-vertical segments in the series are indicated by a "(V)" in the table. Possible causes which depend on horizontal or near-horizontal segments in the series are indicated by an "(H)" in the table. It is assumed that Equation (1) holds for all cases being considered.

Determine from the values of C, Ch, and Cz which of the three cases holds for the loop. Then follow the suggestions given above for finding the blunders listed with that case in Table 1.

CASE	POSSIBLE BLUNDER CAUSES
Rh > 0.66/SQRT[P] $\lvert Rz \rvert$ < 0.75/SQRT[P]	Blunder In Azimuth Of One Segment (H) Back-Shot Blunder (H) Blunder In Distance Of One Segment (H) Missing One Segment
Rh < 0.66/SQRT[P] $\lvert Rz \rvert$ > 0.75/SQRT[P]	Blunder In Dip Of One Segment (V) Back-Shot Blunder (V) Blunder In Distance Of One Segment (V) Missing One Segment
Rh > 0.66/SQRT[P] $\lvert Rz \rvert$ > 0.75/SQRT[P]	Back-Shot Blunder Blunder In Distance Of One Segment Missing One Segment

Table 1. Components of the ratio of error and related possible blunder causes.

EFFECTS OF OTHER ERRORS

It has been assumed that there exists only one blunder in the loop. But if the blunder rate is as high as was discussed in Paper-I (i.e., 0.03), then in a loop of 100 stations there will be three blunders. In this situation the above techniques will not work. If the loop is short enough that only one blunder exists (33 stations), then you may just want to resurvey the loop. It is expected, however, that use of the techniques for obviating blunders discussed in Paper-II will reduce the blunder rate enough so that the assumption of only one blunder per loop is realistic.

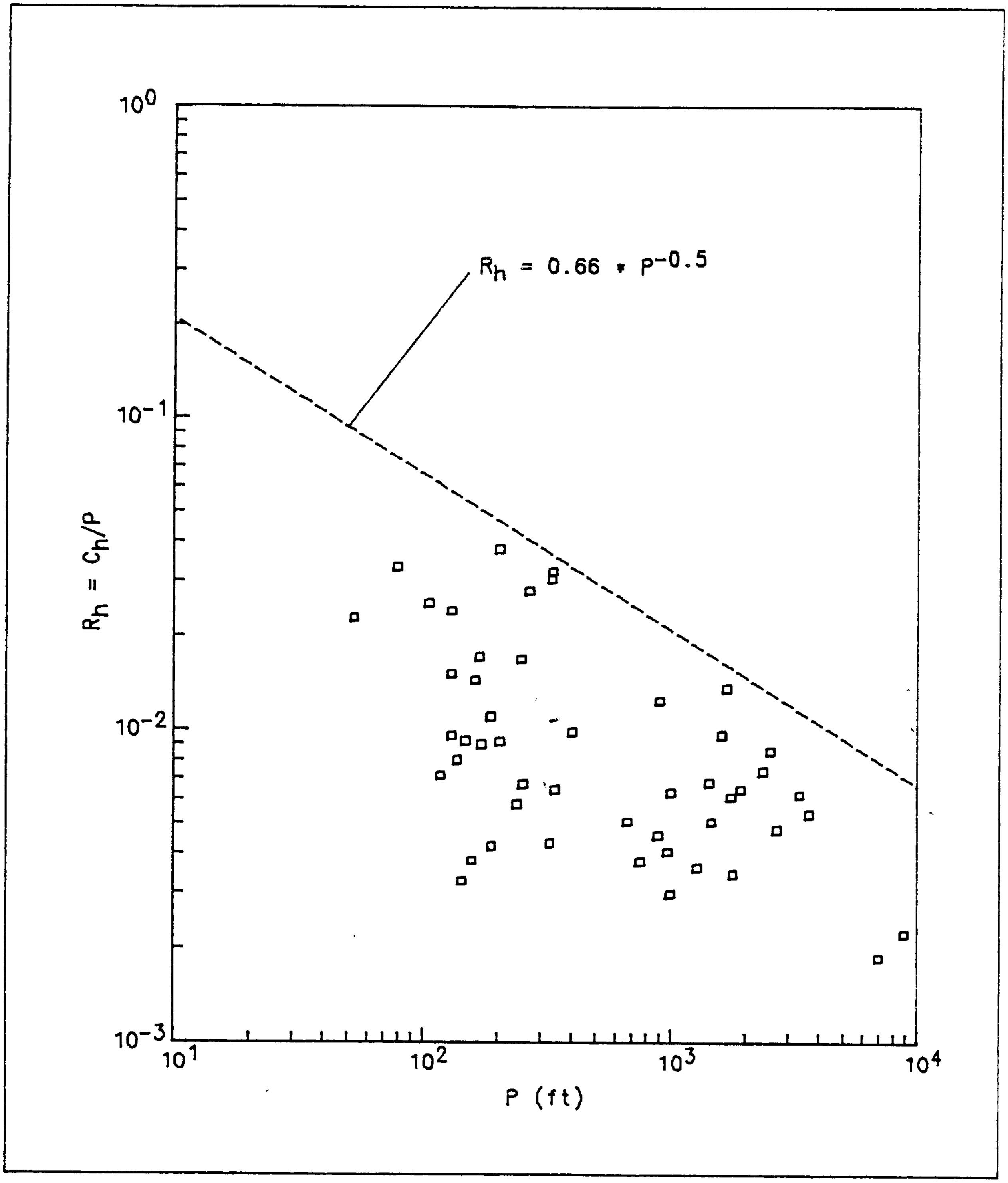

Figure 2. The horizontal components of the ratios of error of fifty blunder-free Brunton compass and tape surveys of simple loops.

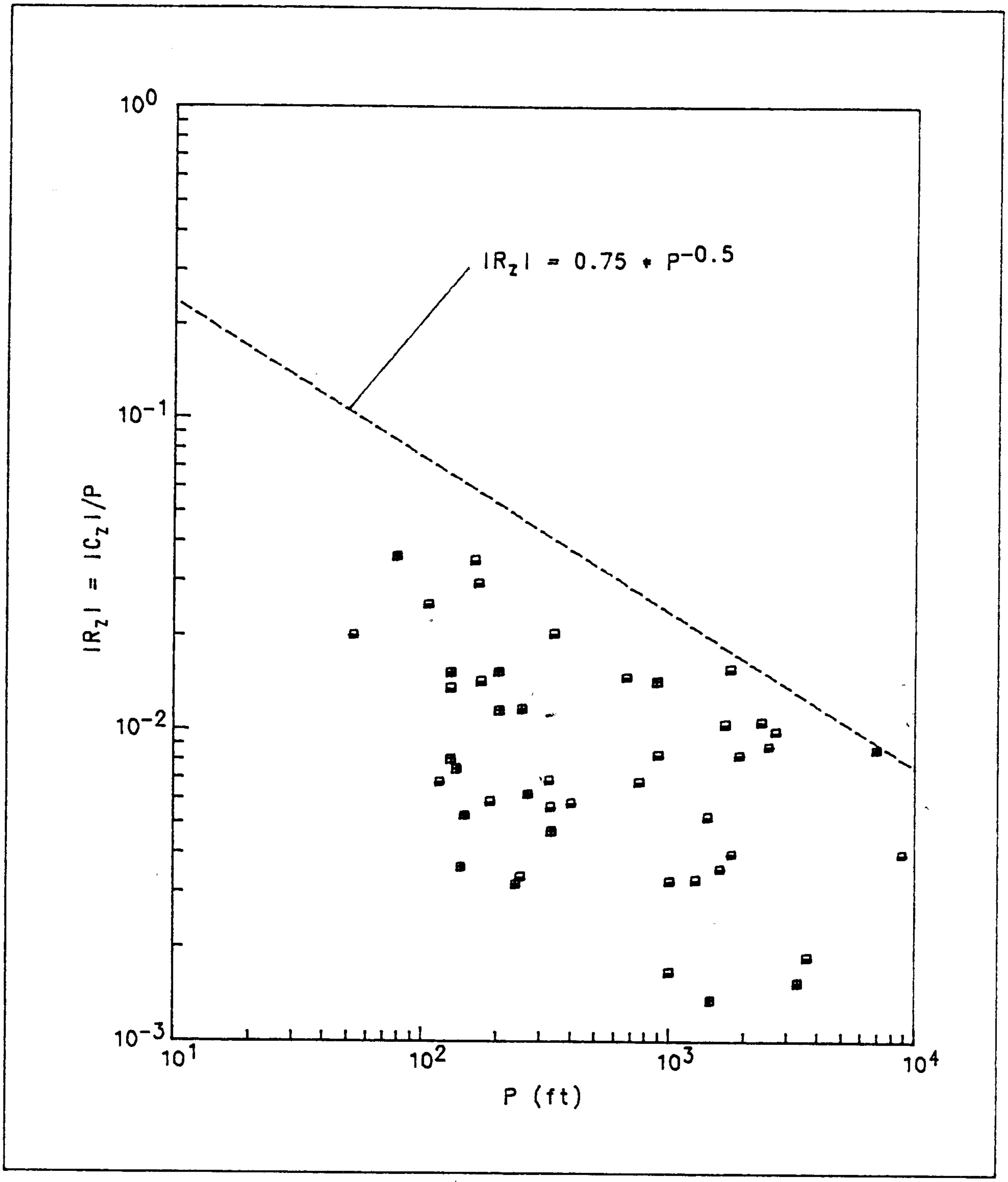

Figure 3. The absolute magnitudes of the vertical components of the ratios of error of fifty blunder-free Brunton compass and tape surveys of simple loops.

If there are no other sources of error, then the determination using the above techniques would be an easy one. But there are always other sources of error (see Paper-I), hence each component of the error of closure will be non-zero even when no blunders are present. This complicates the situation. For example, it is possible that correcting a dip blunder will make the horizontal misclosure worse, rather then better. Other errors will also change the values of diagnostic parameters like Af, Df, etc. This makes the job of finding and correcting the error much more difficult, and in some cases impossible.

A good computer program which: performs the necessary computations, makes the comparisons of Equations (1), (6), and (7), computes the diagnostic parameters, and prepares the lists discussed above, helps tremendously. If your computer program does not currently perform these operations, you should think about adding these functions into your code.

SUMMARY AND CONCLUSIONS

The options one has when one thinks there is a blunder in a simple loop have been discussed. The option which received the most attention here was 'find and correct the blunder'. Five possible blunder situations in which one may be able to find and correct the blunder were discussed. By augmenting your computer program to aid in the process, it may be possible to correct some blunders without having to resurvey. Even if it is not possible to correct the blunder, the techniques discussed above can help the resurvey team concentrate their efforts in areas of the loop where the blunder most likely exists.

This paper completes my series of papers on cave survey blunders. It is my hope that readers have found the topics and techniques which have been discussed both interesting and useful. If I have stimulated some thought, some discussions, some new ideas, and even some arguments, then I have more than satisfied my goals in writing these papers.

APPENDIX-A

This appendix presents the basic computational techniques and definition of parameters used in the above discussions. The mathematical development is from Wefer [1971].

COORDINATE SYSTEM AND BASIC DATA

In cave survey data reduction a series is defined by the set of azimuths, dips, and distances of the segments of the series, and by the set of station labels for the stations of the series. These are used below in mathematical expressions, hence we begin by introducing symbols for these quantities. Let

A(i) = azimuth of the ith segment of the series (deg.),

D(i) = dip of the ith segment of the series (deg.),

d(i) = distance of the ith segment of the series (ft),

N = number of segments in the series, and

L(j) = label of the jth station of the series. Note that L(Ø) is the label of the initial station of the series. For historical reasons the labels are commonly restricted to four alphanumeric characters.

The coordinate system used in cave survey data reduction problems is shown in Figure A-1. It is a right-handed Cartesian coordinate system with the +X axis pointing eastward, the +Y axis pointing northward, and the +Z axis pointing upward.

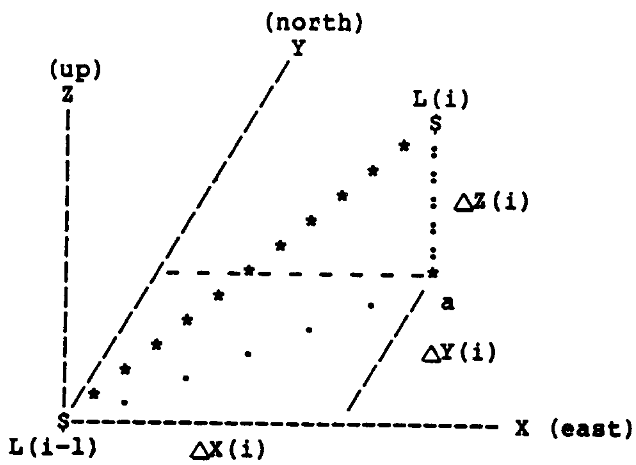

Figure A-1 Coordinate system used in the mathematical development of cave survey data reduction. The following symbols are used in the figure: "$" = survey station, "$ * * $" = segment between two survey stations, "$ . . *" = projection of the segment onto the XY-plane, and "a" = point where the perpendicular from station L(i) intersects the XY-plane.

The distance d(i) is simply the straight line separation of the stations L(i) and L(i-1). If a vertical line is constructed through point L(i), it intersects the XY-plane at a point labelled "a" in Figure A-1. The azimuth A(i) is the angle measured in the XY-plane clockwise from the north direction to the line [L(i-1),a]. The dip D(i) is the angle measured in the vertical plane upward from the XY-plane to the line [L(i-1), L(i)].

COMPONENTS OF THE SEGMENTS

The first step in computing the Cartesian coordinates of the survey stations is to compute the components of each segment defined as follows:

$$\Delta H(i) = d(i) * \mathrm{COS}(\ D(i)\ ) \tag{A-1}$$

$$\Delta X(i) = \Delta H(i) * \mathrm{SIN}(\ A(i)\ ) \tag{A-2}$$

$$\Delta Y(i) = \Delta H(i) * \mathrm{COS}(\ A(i)\ ) \tag{A-3}$$

$$\Delta Z(i) = d(i) * \mathrm{SIN}(\ D(i)\ ) \tag{A-4}$$

where: $\Delta H(i)$ = horizontal component of the ith segment,
$\Delta X(i)$ = east component of the ith segment,
$\Delta Y(i)$ = north component of the ith segment, and
$\Delta Z(i)$ = up component of the ith segment.

Note that $\Delta X(i)$ is sometimes referred to as the "departure", $\Delta Y(i)$ is sometimes referred to as the "latitude", and $\Delta Z(i)$ is often referred to as the "vertical". This author prefers the terms "east", "north", and "up" because these are the positive directions of the components and are easy to remember.

COORDINATES OF THE STATIONS

Once the X, Y, and Z components of the segments are known, the Cartesian coordinates of the survey stations are easily computed via:

$$X(0) = \text{known} \tag{A-5}$$

$$X(k) = X(0) + \mathrm{SUM}_{i=1}^{k} [\ \Delta X(i)\ ] \tag{A-6}$$

where: $X(k)$ = X-coordinate of station $L(k)$. Similar equations obtain for $Y(k)$ and $Z(k)$.

MEASURES OF ACCURACY

A number of parameters are required in determining the accuracy of the survey, viz:

$$P = \sum_{i=1}^{N} [\, d(i) \,] \tag{A-7}$$

$$Cx = X(N) - X(0) = \sum_{i=1}^{N} [\, \Delta X(i) \,] \tag{A-8}$$

$$Cy = Y(N) - Y(0) = \sum_{i=1}^{N} [\, \Delta Y(i) \,] \tag{A-9}$$

$$Cz = Z(N) - Z(0) = \sum_{i=1}^{N} [\, \Delta Z(i) \,] \tag{A-10}$$

$$Ch = \mathrm{SQRT}\,[\, Cx^2 + Cy^2 \,] \tag{A-11}$$

$$C = \mathrm{SQRT}\,[\, Ch^2 + Cz^2 \,] = \mathrm{SQRT}\,[\, Cx^2 + Cy^2 + Cz^2 \,] \tag{A-12}$$

$$Rh = Ch/P \tag{A-13}$$

$$Rz = Cz/P \tag{A-14}$$

$$R = C/P = \mathrm{SQRT}\,[\, Rh^2 + Rz^2 \,] \tag{A-15}$$

where: P = perimeter of the loop (ft),
Cx = X-component (east) of the error of closure (ft),
Cy = Y-component (north) of the error of closure (ft),
Ch = horizontal component of the error of closure (ft),
Cz = Z-component (up) of the error of closure (ft),
C = error of closure (ft),
Rh = horizontal ratio of error (dimensionless),
Rz = vertical ratio of error (dimensionless), and
R = ratio of error (dimensionless),

DIAGNOSTIC PARAMETERS

If the survey does not meet the accuracy criteria, then the presence of a blunder is indicated. Some additional disgnostic parameters should be computed to aid in finding the blunder.

$$Ab = 90.0 - \mathrm{ARCTAN}\,[\,Cy/Cx\,] \tag{A-16}$$

$$Db = \mathrm{ARCTAN}\,[\,Cz/Ch\,] \tag{A-17}$$

$$Af = Ab + 180.0 \tag{A-18}$$

$$Df = -\,Db \tag{A-19}$$

$$NAf = Af + 90.0 \tag{A-20}$$

$$NAb = Ab + 90.0 \tag{A-21}$$

$$NDf = Df - 90.0 \tag{A-22}$$

$$NDb = Db + 90.0 \tag{A-23}$$

where: Ab = back-shot azimuth of the error of closure (deg.),
Db = back-shot dip of the error of closure (deg.),
Af = fore-shot azimuth of the error of closure (deg.),
Df = fore-shot dip of the error of closure (deg.),
NAf = azimuth of the clockwise normal to Af (deg.),
NAb = azimuth of the clockwise normal to Ab (deg),
NDf = dip of the more downward normal to Df (deg.), and
NDb = dip of the more upward normal to Db (deg).

The fore-shot azimuth (Af), the fore-shot dip (Df), and a distance equal to the error of closure (C) are the parameters which represent the shot from the position of the last station of the series (as computed from the survey data) back to the position of the initial station of the series. If a segment with these parameters were added to the series, then a zero error of closure would result for the loop.

APPENDIX-B

In the section above titled RESURVEY A PORTION OF THE LOOP, it was mentioned that, while the common practice in XFBS is to average the fore- and back-shots and enter only the average into the computer, one could enter both and run each series as a loop. One might well ask, "Would this result in better locations for the stations of the series?" The answer is, "I don't know." It is certainly a topic for further research. There are at least two possible approaches to answering the question: to perform an analytical comparison, and to perform numerical experiments.

Mixon [1987] has used the latter approach to study the accuracy of theodolite surveys compared with compass and tape surveys. Wefer [1974a and 1974b] has used the former approach to show that when the Compass Rule is used to adjust a loop, the resulting changes to azimuths, dips, and distances are mathematically limited. In fact, these limits have something to tell us about the tolerances which should be adopted for the agreement of the fore- and back-shots in XFBS. The limits derived by Wefer for the Compass Rule are:

$$| dA(i) | < 57.3 * R * SEC [D(i)]$$

$$| dD(i) | < 114.6 * R * SEC [D(i)] \qquad \text{(B-1)}$$

$$| dd(i) | < R * d(i)$$

where: dA(i) = adjustment to the azimuth of the ith segment (deg.),
dD(i) = adjustment to the dip of the ith segment (deg.), and
dd(i) = adjustment to the distance of the ith segment (ft).

The necessary but not sufficient condition for there to be no blunders in the loop is given by Equation (2), viz:

$$R < 1.0 / SQRT [P] \qquad \text{(B-2)}$$

where: P = perimeter of the loop (ft) and unity carries the peculiar units of square root of feet.

Substituting Equation (B-2) into Equations (B-1), and making the assumption that the dips in the loop do not exceed about 15 deg., we get:

$$| dA(i) | < 60 / SQRT [P]$$

$$| dD(i) | < 120 / SQRT [P] \qquad \text{(B-3)}$$

$$| dd(i) | < d(i) / SQRT [P]$$

Ideally we would like the above changes to be no greater than half the tolerances used in the XFBS survey. The "half" occurs because, for example, if the tolerance on the azimuths is 1.0

deg., then presumably each azimuth could be off by 0.5 deg. (if the average azimuth is correct). Suppose we use the tolerances suggested in Paper-II, viz:

$$t[A] = 1.0 \text{ deg.}$$
$$t[D] = 1.0 \text{ deg.} \qquad \text{(B-4)}$$
$$t[d] = 0.6 \text{ ft.}$$

where: t[A] = tolerance in XFBS azimuth (deg.),
t[D] = tolerance in XFBS dip (deg.), and
t[d] = tolerance in XFBS distance (ft).

Then the Compass Rule adjustment in azimuth will always be smaller than half the XFBS tolerance when the perimeter exceeds 14,400 feet. The Compass Rule adjustment in dip will always be smaller than half the XFBS dip tolerance when the perimeter exceeds 57,600 feet. The Compass Rule adjustment in distance will always be smaller than half the XFBS distance tolerance when the perimeter exceeds 1,111 ft. For shorter loops, the Compass Rule can generate changes in the measured quantities larger than the tolerances used in XFBS.

I suppose this means that for shorter loops the tolerances could be relaxed somewhat, since the Compass Rule changes can exceed those given in Equation (B-4). But the main function of the XFBS tolerances is to limit the area of undetected blunders in Figures 1, 2, and 3 of Paper-II. Limiting the Compass Rule changes is a secondary consideration.

This analysis tells us that we may encounter a loop in which we detect no blunders, but in which the Compass Rule adjustments exceed the XFBS tolerances. One cannot but have the nagging feeling that Equations (1), (6), and (7) are not strict enough, i.e., that some of the fifty loops used to define them actually do contain blunders. If this is found to be the case, it would simply mean a parameter change in your computer program. You are, of course, free to adopt stricter standards than the above equations indicate.

REFERENCES

Bassham, E. [1979], "Traverse Blunders And Their Detection", NSS Bulletin, Vol. 41, Number 1, pp. 23-26, January 1979.

Mixon, W. [1987], "The Transit-Survey Myth", Compass & Tape, Volume 5, Number 1, pp. 3-4, Summer 1987.

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.

Wefer, F.L. [1978], "What The ---- Are We Doing", BCCS Newsletter, Vol. 4, pp. 27-30, 1978.

Wefer, F.L. [1987], "On Cave Survey Blunders", Compass and Tape, Volume 5, Number 2, pp. 23-43, Fall 1987.

Wefer, F.L. [1988], "More On Cave Survey Blunders", Compass and Tape, Volume 5, Number 4, Spring 1988.

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Brunton Compasses, Etc.

Bob Salika sends information on two companies which offer a selection of outdoor and military equipment, including all sorts of compasses and map cases. (US Calvalry, 1361 N. Dixie Blvd, Radcliff KY 40160; Brigade Quartermasters, 1025 Cobb International Blvd, Kennesaw GA 30144) Each company offers a Brunton M2 compass for $150 and $120, respectively, but US Calvalry gives a Mil-Spec number. Each is said to have a plastic body. Is this the 'New Brunton,' and is it any good?

Computer-Aided Cave Cartography Workshop

There will be a workshop/demonstration of various applications for plotting survey data and drafting cave maps on Monday morning of the NSS Convention. This will include a demonstration of the SMAPS/AutoCAD system in use at Wind Cave National Park. If you would like to demonstrate your own work, contact Jim Nepstad (Wind Cave National Park, Hot Springs, SD 57747) so that he can arrange for the necessary hardware to be on hand.

Going Once, Going Twice...

As noted last year at this time, a new editor will be needed to take *Compass & Tape* into the next 5 years. In order to maintain the publication, the new editor will probably have to actively search for, solicit and encourage writers. Readers seem to want a mixture of both basic skills instruction and advanced topics; there is a limited supply of good articles throughout this spectrum. Access to word processing and printing resources is required. If interested, please contact the staff immediately at 814-356-3553.