

Issue 25



# COMPASS POINTS

September 1999



*Figure 1: Bryan Ellis*

## **Bryan Ellis and Cave Surveying Underlying Instrument Error *versus* Blunders CSG Field Meet Report**

## COMPASS POINTS INFO

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## Editorial

I am sorry to report that your usual editor is suffering from a wrist injury, and was unable to produce this issue. As I was submitting three articles for publication, it seemed only fair that I undertook this task to help out. I can tell you – it was more work than I expected, so I apologise that it will arrive late. Fortunately, I am glad to report that Wookey is making good progress – I wish him a speedy recovery.

In this issue, we have a fascinating article on the contribution to cave surveying of the late Bryan Ellis.

The autumn field meet suffered from rain and hail, but despite the weather, some useful surveying was bagged.

Continuing the theme of instrument accuracy, we have three articles investigating errors in real data. It is difficult to give you any critical analysis of these articles, as I wrote them! Hopefully you will find them interesting. I am particularly hopeful that the last article will encourage further debate and analysis.

This is the December 1999 issue, but as I am writing this editorial already in January 2000, there seems little point in wishing you a Merry Xmas. However, on behalf of the CSG committee, I would like to wish you a very prosperous New Millennium.

*Ben Cooper*

# Snippets

## Drawing Board Give-Away

*Dave Irwin*

Dave has a freeby full size drawing board (approx 1.3m x 1m (parallel motion) to give away to any aspiring cave surveyor - 'buyer' collects. Will need a hatch back at least. Contact Dave on 01749 870369 or [dji@compuserve.com](mailto:dji@compuserve.com)

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## Software Updates

### WinKarst Version 7.0

*Garry Petrie <gp@europa.com>*

Finally, after several patches up to 6.4, WinKarst 7.0 is available. The software was completely reworked to better handle exceptions without crashing. The survey editor is enhanced and fully functional. As warned in the last release, WinKarst is now "shareware" with a 30-day trial period.

WinKarst runs on Windows '95, '98 and NT and it is recommended the computer has a display resolution of at least 800x600 and is set to display more than 256 colours. A fee of \$25 registers a license. Previously registered users can upgrade for free. The update includes an updated help file and online pdf manual suitable for printing. View the general description at

<http://www.europa.com/~gp/winkarst.html>

and download at

<http://www.europa.com/~gp/software/download.htm>

The major enhancements in Version 7.0 are

#### o File types

- Read and write comma delimited latitude/longitude files compatible with Waypoint+
- Export comma delimited table of survey data for import into MS Excel or Access.

#### o Processing

- Removed "split" survey problem, surveys can be disjoint.
- Calculate "best fit" strike and dip.
- Magnetic declination calculation through 2005.
- Corrected UTM grid rotation.

#### o Editor

- Support for "include" files.
- Shot spread sheet with moveable/resizable columns.
- Multi-line cut and paste between surveys.
- Tie-in station warning.
- Search for data in shot data
- Station orientated shot spreadsheet
- "Jump to" station tracing.
- New shot station predicting.

#### o Graphics

- Plot vertical passage distribution.
- Correct for strike and dip.
- Improved panning of selectable objects.
- Shots from a station as a plotable object.
- Measure distance between stations.
- UTM or Lat/Long grids on plot.
- 256 colours.

For previous users on 6.x, WinKarst 7.0 can be installed directly over an earlier version and it should assume your existing registration code. But in case all else fails, please write down your registration code by running the older version and accessing the Registration dialog from the Help pull down menu before installing the newer version.

### Detailed descriptions

#### o File types

- Read and write comma delimited latitude/longitude files compatible with Waypoint+

Waypoint+ can read and write track and waypoint data to/from comma delimited ASCII text files. When going from a GPS unit to WinKarst, Waypoints are converted into control points and tracks are converted to sequences of shots. In reverse, a cave's line plot is converted into a track, with waypoints at stations. The file format does not allow for elevation data, i.e. the plots are two dimensional.

- Export comma delimited table of survey data for import into MS Excel or Access.

Some fifty different data items are included in a comma delimited ASCII text table file. The table's data is sparse, i.e. not every cell contains data. Once the data is imported into a database program, it can easily be broken down into several smaller tables, e.g. caves, surveys, shots, etc. Where a data item would appear twice, one location is the unique keyed and the others are indexes.

For example the shots have to indexes into the stations that specify the name of the From and To stations.

#### o Processing

- Removed "split" survey problem, surveys can be disjoint.

All earlier versions of WinKarst processed survey data with the restriction that surveys were a connected set of shots. Unfortunately, people often surveyed in several sections of a cave during a "trip". WinKarst can now process surveys without breaking up trips into separate survey sequences.

- Calculate "best fit" strike and dip.

WinKarst employees linear regression to determine the "best fit" plane that models a cave's distribution of stations and passages. From the equation of the plane, the strike and dip are determined. Alternately, the plane can be used to "level" the cave, presenting the plot as seen along the bedding plane. The method can help visualise where the cave is near its geologic limits.

- Magnetic declination calculation through 2005.

While not a Y2K issue, the previous version of WinKarst could only calculate magnetic declinations through the year 2000. With the release of the next 5 year epoch parameters of the IGRF (International Geomagnetic Reference Field), calculations are available through 2005.

- Corrected UTM grid rotation.

When a single cave is plotted on the computer screen or on paper, there is no question which direction north is: straight up in the view. But a problem occurs when more than one cave is plotted, based on geographic coordinates and the type of map projection. WinKarst defaults to the UTM map projection, but unfortunately the UTM grid seldom points to true North. WinKarst now corrects for the grid's rotation, which is essential for determining if two near by caves have a chance of connecting underground.

## o Editor

- Support for "include" files.

The previous version of WinKarst would flatten or smash a cave survey made up of several included files into a single file when saved. While this was not a limitation for single, small caves, it made the data management of large systems or caves difficult. The program now tracks which file each survey or cave comes from and re-writes to those files when saving the data.

- Shot spreadsheet with moveable/resizable columns.

The shot spreadsheet is now easier to use because the entire editor can adjust to a larger size. Now more shots and columns can be displayed on a page. The ordering of the data columns is totally user selectable. Each of the data fields has two units of measurements.

- Multi-line cut and paste between surveys.

The editor now has a buffer to save deleted shots. The deleted shots can be restored to the source survey with an undo button, or moved to another survey with a paste button. The user can also move or delete a series of shots.

- Tie-in station warning.

Anytime a station's name is edited, the new name is compared to stations within the survey and in the rest of the cave. If the new name is already in the survey or does not exist in the cave, there is no warning. Otherwise, the user is warned the station should be regarded as a tie-in station.

- Search for data in shot data

Within the shot spreadsheet, WinKarst can search for any station name, number or word in a comment field. When found, the focus of the spreadsheet automatically jumps to the cell with the data. There is a repeat find button for subsequent searches for the same data.

- Station orientated shot spread sheet

In addition to the traditional survey orientated shot spreadsheet, the program has a station orientated spreadsheet. The shots in this view are the ones that contain the station has either the From or To station. If the user changes the common station's name in one of the cells, then all occurrences of the station name are changed.

- "Jump to" station tracing.

In both the survey and station orientated shot spreadsheets, when the shift and enter keys are press when focused on a station name, the program will jump to the next survey or station. The user can then trace a shot sequence in the station spreadsheet or view tie-in surveys in the survey spreadsheet.

- New shot station predicting.

Whenever a new shot is created, the FROM station is automatically brought forward from the previous shot's TO station and the new shot's TO station name is predicted to be the next in a sequence based on the last character of the FROM station name. The spreadsheet's focus remains on the TO station, so pressing the ENTER key accepts the predicted name, BACKSPACE to correct the name.

## o Graphics

- Plot vertical passage distribution.

WinKarst can now display how the cave's passages are distributed vertically in the cave. The program divides the

cave's vertical extent into 256 slices and the passage in each slice is totalled. The totals are then displayed in an histogram. The peaks in the histogram are automatically identified, labelled and coloured. The new colouring scheme is used for subsequent colour by depth plots.

- Correct for strike and dip.

The program can now calculate the best fit plane for the distribution of stations and cave passages through linear regression. From the plane, the cave's strike and dip are calculated. The values can be used to "level" the plot to the bedding plane of a geologically confined cave to determine where the cave is approaching the limits.

- Improved panning of selectable objects.

When an object, e.g. survey, loop, station, is labelled and the user clicks near the label, WinKarst selects that object for focus. If the object extends beyond the field of view, the view automatically pans and scales to include the new object. The object's colour is inherited from the previous object.

- Shots from a station has a plotable object.

All plotable objects in WinKarst are collections of shots. An new object has been created, the shots that tie into a particular station. When the Shots of a Station are coloured and labelled, the user can click through the stations of a survey to verify data entry.

- Measure distance between stations.

A "scale" cursor, available on the toolbar, can now be used to measure distances between stations. The stations need not be in the same cave to be measured, just displayed in the field of view.

- UTM or Lat/Long grids on plot.

To aid in the registration of cave plots on USGS topographical maps or other published maps, WinKarst can now calculate and display a UTM or Latitude/Longitude grid on the plot. The later is spaced on two minuted steps and in both cases the grid lines are labelled.

- 256 colors.

In all colour modes, 256 colours are now available. This requires the user's computer to be in a video mode with more than 256 colours available, e.g. "true" colour mode.

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## Compass

*Larry Fish <lfish@nyx.net>*

I would like to announce a new release of the cave survey software package COMPASS. There are many major new features and lots of minor improvements.

1. AUTOCAD DXF EXPORT. The Viewer now has the ability export DXF files compatible with AutoCad versions 12, 13 and 14. The files can include passage wall models, station labels and surveys as separate layers. You even have control over each the layer's colors.

2. HIGHSPEED FLYTHROUGHS. CaveX the DirectX cave viewer has many improvements. There are new pan, zoom and rotate buttons and the ability to finely control their increments. CaveX also has the ability to fly around and through the cave image using simple mouse movements. I am currently getting solid modelling speeds of 20 frames per second and 2 million polygons per second on 20 mile long caves, with Gouraud

shading and limestone photo texturing. This give you the ability to do game-like "flying" in and around the cave.

3. AUTOMATIC LIMESTONE TEXTURING. CaveX also has a one step texturing procedure that simplifies the process of creating smooth-textured passage walls. It also has a built-in limestone texture that gives a rock-like appearance to the passages.

4. SAVING MOVIES AND SLIDESHOWS. The Viewer now has the ability to save movie files to disk. This allows you to create movies and slide shows of various caves and save them for later viewing or showing. There is also much more extensive support for editing the movie frames.

5. MORE REALTIME FEATURES. The Viewer also has several new features that allow better control of the "real-time" "flythrough" of the cave. This is all done with simple mouse movements. The program also now supports "live" tracking of the 3D Compass to give even smoother and more realistic rotations.

6 COMPILER IMPROVEMENTS. The Compiler can now save a set of default settings. This means that you can set the Compiler to run with a specific set of value each time it runs, without manually setting the options. Also, the Compiler now allows you to print the list of errors that appears in the error log.

7. MINOR IMPROVEMENTS. There are many other minor improvements and bug fixes. Also, there is information on the web page about running COMPASS under linux.

## How To Get COMPASS

COMPASS is a shareware product. You can try it out free. If you like it and want to use it, you must register. If you don't like it, then don't use it and pay nothing.

The registration cost is \$25.00 for the DOS version and \$25 for the Windows version. Combined registration is \$38.

Registration for the data base program is \$15 for previously registered individual COMPASS users. For new registrations the database program is \$20 for private individuals. For institutions, business, and government agencies, the database registration is \$50. Special group rates, and support programs are available.

COMPASS is available free of charge for evaluation purposes. Copies are available through the COMPASS World Wide Web page at: <http://members.iex.net/~lfish/compass.html>

The Web Page also has full color screen images of some of the most important features. It also has connections to other cave related WWW pages including links to the USGS DEM files. The whole COMPASS package has hundreds of features and a full description of the software is beyond the scope of this document. However, the COMPASS Web Page also has a complete and detailed description of all the features and options.

You can also get an evaluation copy of the software directly from me for \$10.00 to cover materials and handling. If you are a registered user you can get an updated version directly from me for only \$5.00. My mailing address is:

Larry Fish  
123 E. Arkansas  
Denver CO 80210

Please specify DOS and/or Windows and disk size. If you like the software, please register. You will receive notification of updates and other special offers.

## More Information

If you don't have access to the World Wide Web, send an e-mail request to: [lfish@nyx.net](mailto:lfish@nyx.net) and I will send you an information packet.

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# Assessment of Aggregated Survey Error

Ben Cooper [ben.cooper@sbs.siemens.co.uk](mailto:ben.cooper@sbs.siemens.co.uk)

In my article in CP24, reference [1], I stated that the error of one of my surveys was  $\pm 2m$  over a traverse length of 201m. This was not justified, and the purpose of the current article is to explain how this error was derived.

The portion of cave survey of interest in reference [1] was not a closed loop, and the stated error was derived purely theoretically. However, it was compared to loop closure errors from the same expedition (reference [2]), and found to be consistent. In this article, I will not use that particular cave portion, but instead use another cave portion from the same expedition that is a closed loop. This is so that I can compare the calculated error directly with the closed loop error. This is precisely what Larry Fish has done in reference [3]. My focus here, however, is to discuss the technique of deriving the calculated error.

Since writing the article, I have noticed that the CSG web site also contains information on calculating errors, which may be of interest (reference [4]).

## Theory

A closed loop in a survey traverse is analysed by converting the measurements into three-dimensional grid co-ordinates (X,Y,Z), each leg of the traverse giving the incremental values (dx,dy,dz) for that leg. The position of the final station at the end of the traverse is then simply the vector sum of the incremental values. For the purposes of analysis, the starting station is taken to be the

co-ordinate origin with a co-ordinates value of (0,0,0). If the traverse is a loop, then the vector sum of all the legs should be zero. Any value different to zero indicates an error, and the magnitude of the difference is called the loop closure error.

The maths to convert the survey data is simple geometry using the following formula, where Tape is L, Compass Bearing is  $\beta$ , and Clino inclination is  $\tau$

Horizontal distance,  $H = L \cdot \cos(\tau)$

Change in Easting,  $dE = H \cdot \sin(\beta) = L \cdot \cos(\tau) \cdot \sin(\beta)$

Change in Northing,  $dY = H \cdot \cos(\beta) = L \cdot \cos(\tau) \cdot \cos(\beta)$

Change in Altitude,  $dV = L \cdot \sin(\tau)$

The base compass error is taken from reference [5], as  $1.2^\circ$ . However from experience, I would propose that the error of a bearing increases with angle of inclination, so I have added an additional error proportional to the angle of dip. My gut-feel is that a dip of  $60^\circ$  should add about  $2^\circ$  to the uncertainty in the compass reading, which equates to an additional 3% error.

The inclinometer seems more accurate than the compass, in the sense that repeat measurements tend to give a more consistent reading. This makes sense in that the clinometer is not affected by external effects in the same way as a compass. Experience has taught me that very steep upward inclines tend to be harder to measure than shallow inclines, so I have added an error

proportional to the incline. Downward inclines tend to be easier than upward inclines (it is easier to look down than up), but I have not bothered to reduce the error for downward inclines. My gut-feel is that a dip of 60° should add about 1.5° to the uncertainty in the inclinometer reading, which equates to an additional 2% error.

The tape measure is generally held onto the station with an accuracy of about 1cm at each end. No one ever seems to know how tight to stretch the tape, so an additional error is introduced in proportion to the length of the tape. (One tape I once used was supposed to be held with a tension of 2Kg, but most don't specify). I have guessed an amount of 5cm over 10m, which equates to an additional error of 0.5%.

Thus, the measurement errors can be expressed by the following formula:

$$\sigma_{\beta} = 1.2^{\circ} + 0.03 \iota$$

$$\sigma_{\iota} = 0.5^{\circ} + 0.02 \iota$$

$$\sigma_E^2 = \sigma_L^2 \cdot (\cos(\iota) \cdot \sin(\beta))^2 + \sigma_{\iota}^2 \cdot (L \cdot \sin(\iota) \cdot \sin(\beta))^2 + \sigma_{\beta}^2 \cdot (L \cdot \cos(\iota) \cdot \cos(\beta))^2$$

$$\sigma_V^2 = \sigma_L^2 \cdot (\cos(\iota) \cdot \cos(\beta))^2 + \sigma_{\iota}^2 \cdot (L \cdot \sin(\iota) \cdot \cos(\beta))^2 + \sigma_{\beta}^2 \cdot (L \cdot \cos(\iota) \cdot \sin(\beta))^2$$

$$\sigma_V^2 = \sigma_L^2 \cdot (\sin(\iota))^2 + \sigma_{\iota}^2 \cdot (L \cdot \cos(\iota))^2$$

$$\sigma_L = 0.02 + 0.005 L \text{ (m)}$$

The combined error from our measured values propagates according to the combination of errors formula (references [6] and [7]),

$$\sigma_E = \sigma_L^2 \cdot (\delta/\delta L(E))^2 + \sigma_{\iota}^2 \cdot (\delta/\delta \iota(E))^2 + \sigma_{\beta}^2 \cdot (\delta/\delta \beta(E))^2$$

where  $E = F(L, \beta, \iota)$

This gives an error in co-ordinates for each survey station. To get the error over the whole loop, the error must be summed over all stations in the loop, once again using the combination of errors formula. In this case, it reduces to the simple sum of the squares:

$$\text{Overall } \sigma_E^2 = \sum (\sigma_{E_i}^2)$$

and similar for Y and Z.

Table 1 is an extract from my spreadsheet, showing the errors I have calculated for actual survey data.

Notice the various sizes of the error for tape, clino and compass ( $\sigma_L$ ,  $\sigma_{\iota}$  and  $\sigma_{\beta}$ ) for different values of bearing, inclination and tape, and how these have resulted in smaller or larger values of the easting and northing error. Notice also, that for the plumbed line, I have set the bearing to 45°, so that any horizontal error is shared between the easting and northing equally.

The calculated error for the entire loop is as follows, where the

Dip	L	FB	d_H	d_E	D_N	d_V	$\sigma_L$	$\sigma_B$	$\sigma_I$	$\sigma_E$	$\sigma_N$	$\sigma_V$
-24.5	1.72	166.5	1.57	0.37	-1.52	-0.71	0.03	1.9	1.0	0.05	0.03	0.03
-6	29.44	132	29.28	21.76	-19.59	-3.08	0.17	1.4	0.6	0.49	0.54	0.32
-23	4.94	113	4.55	4.19	-1.78	-1.93	0.04	1.9	1.0	0.08	0.14	0.08
-13	1.92	131	1.87	1.41	-1.23	-0.43	0.03	1.6	0.8	0.04	0.04	0.03
0	0.13	55	0.13	0.11	0.07	0.00	0.02	1.2	0.5	0.02	0.01	0.00
90	3.47	45	0.00	0.00	0.00	3.47	0.04	3.9	2.3	0.10	0.10	0.04
41	1.87	134	1.41	1.02	-0.98	1.23	0.03	2.4	1.3	0.05	0.05	0.04
18	7.35	133	6.99	5.11	-4.77	2.27	0.06	1.7	0.9	0.15	0.16	0.11
-13.5	7.99	137	7.77	5.30	-5.68	-1.87	0.06	1.6	0.8	0.16	0.16	0.11

Table 1: Extract of Calculated Station Errors

fourth column,  $\sigma_R$ , is the total loop closure that would be expected based on the stated instrument errors.

$\sigma_E$	$\sigma_N$	$\sigma_V$	$\sigma_R$	%
1.15m	1.09m	0.71m	1.73m	0.6%

The actual loop closure is 2.38m over 313m surveyed length (0.8%). As I suspected, this is worse than the calculated value. However, as the value 1.73 is a standard error, it is possible for the actual error to be double or even treble this, so the result here is still consistent. Following in the spirit of Larry Fish's article, it could be that there are blunders in this loop, or that I have underestimated the individual errors. Considering the latter, the errors only have to be increased slightly to increase the overall loop error. For example, using the following arbitrary values

$$\sigma_{\beta} = 1.3^{\circ} + 0.05 \iota$$

$$\sigma_{\iota} = 0.7^{\circ} + 0.04 \iota$$

$$\sigma_L = 0.03 + 0.01 L \text{ (m)}$$

(compass 5%, clino 4% and tape 1%) results in a calculated loop error of 2.36m. These instrument errors may seem small, but they are consistent with the apparent instrument errors found in my other articles in this issue (references [5] & [8]).

In reference [3], Larry Fish proposed a number of other possible instrument error values. I found it instructive to try these in my spreadsheet for comparison. The initial instrument error he used is 2° and 0.1 foot (3cm). For my loop, this gives a calculated error of 2.87m (0.9%), slightly greater than the actual loop closure error, but still consistent with it. The proposed effective instrument error of Lechuguilla, however, is of 7.5° and 11.4 cm, which gives a calculated error of 10.8m (3%) for my loop. Perhaps my survey data is not so bad, after all!

## References

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- [2] Tsingy de Bemaraha Caves Expedition Report, Mendip Caving Group, in preparation
- [3] How Common are Blunders in Cave Survey Data?, Larry Fish, CP25
- [4] CSG Web Site - <http://www.sat.dundee.ac.uk/~arb/surveying/>
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- [6] Data Reduction and Error Analysis for the Physical Sciences, Bevington & Robinson, McGraw-Hill, 1992
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# CSG Field Meet, Bull Pot Farm, 2-3<sup>rd</sup> October 1999

*Ray Duffy*

Well it was my choice of date, venue and objective, and as the day got closer it became more and more worrying. Marble Steps pot could, with a good turnout, be almost surveyed in total in one big effort. I'd been there the week before and tagged several important junctions so that we could send in the teams with a simple objective. Come Friday night and the weather wasn't going to play the game. Several people had expressed a wish to take part but having seen the forecast I did not expect them all to turn up, just as well as it turned out.

By Saturday morning everything was soaked, Marble Steps was out of the question as it floods dramatically, so we were scating about for alternatives. The trouble with the Easegill survey at present is the amount of areas which need doing that are miserable or flood-prone.



**Figure 2: Trig 1**

Two parties were dispatched, one to survey the Dinnertime series in Mistral, and the other to survey the available parts of The Crumbles, the remainder and unlucky lot, including myself, headed up to the trig point on top of Brownthwaite Fell (Figure 2)



**Figure 3: Trig 2**

We had just arrived at the summit as the surrounding area was enveloped in gale driven rain (Figure 3) and Iain Miller's

expensive laser equipment could not lock onto a point only 100 metres away.

Fortunately, at this stage the rain wasn't continuous so we did get a few breaks which just allowed us to complete a survey to Lancaster Hole and beyond, until just overlooking the gill. We did, however, have to call at the farm on the way past, to thaw out from the hailstones and even Pete Hall was seen to be cold. Well he was wearing shorts.



**Figure 4: John Cordingley**

In the meantime the others who had been nice and warm underground had completed their allotted tasks and we all met back at the farm for 'afternoon tea and biscuits', how quaint! Early evening saw me flying backward and forward from home to farm ferrying the slide projector and screen that I'd promised would be available. John Cordingley needed them to give his illuminating talk on underwater surveying, (Figure 4) though some of had tried it that afternoon. He posed a few good problems for the CREG people, unfortunately, they were all in the pub by then. He should that by a little ingenuity and care his surveys could be as accurate if not more so than above water surveys.

Next morning was a late affair as the water levels had not improved a great deal but it did allow us to spend some time looking at various bits of software being used to produce surveys (Figure 5).



**Figure 5: Using the Computer**

Overview: 125m of cave and over 1.7km of surface surveyed

My thanks to all those who put up with the inclement weather and brought equipment etc. along to help with the organisation.

*(Photos by Ray Duffy)*

# Bryan Ellis and Cave Surveying - A Brief Review

*Dave Irwin*

Having known Bryan Ellis since 1962 his one passion overriding all else was the techniques required to produce a cave survey. One of his earliest forays into the topic was the survey of Sanctimonious Passage in Hunter's Hole on Mendip and was published in 1958 in the BEC Belfry Bulletin. At this time he also developed a survey drawing instrument simulating the drafting machines commonly used today. During his National Service Ellis found himself stationed near enough to another SMCC (Shepton Mallet Caving Club) member, Fred Davies, who was then living in north Wales close to the, then, little known caving area. The pair were able to explore the caves of this region and their activity resulted in a number of surveys and descriptions of these caves that eventually appeared as a SMCC report in 1960. Within the next three years Ellis had surveyed and published surveys of various caves, digs and cave extensions including Bottlehead Slocker, the unpublished Blake's Farm Swallet, Hunters' Hole, Lamb Leer Cavern (part of St. Valentine's Landing) and Swildon's Hole (part of Shatter Series with Fred Davies). One of his large scale presentations was also published during this period – the compilation of the outline survey of St. Cuthbert's Swallet. Because of the complexity and scale of the work Ellis and others divided the field work into sections and his primary responsibility was to carry out the survey of the Rabbit Warren and Rabbit Warren Extension. Though the combined fieldwork was known to be far from complete, the Long Chamber Series and September Series had not been surveyed, Ellis compiled the survey and added a sketch plan of the Long Chamber and Coral Series produced by Roy Bennett. However, the multi-level and multi-circuit nature of the system caused him problems relating to the closure of the traverses. He solved the problem by the simple method of closing the loops by eye using conventional drawing techniques.

In 1966 due to the existence of two widely differing surveys of Holwell Cavern, nr. Bridgwater, Somerset, by Christopher F.D. Long (1923) and Charles Bryant (1960) he commenced a CRG Grade 6 survey of the cave. The two earlier surveys were of the known cave which was basically the West Series and Andrew Crosse's Chamber. The discovery of the East Series, by a Taunton based group of cavers in 1963 and extended by the SMCC 1964, more than doubled the length of this relatively short and constricted cave. To carry out a CRG Grade 6 survey was not an easy task and the whole work took over four years to complete comprising mainly of midweek caving trips. The result of this work was later published in the SMCC Journal and was also made available as a separate sheet to a larger scale in the Mendip Survey Scheme.

His last systematic survey was carried out during the SMCC Expedition to Iceland in 1970. Ellis' task was to organise the survey of the large lava tube - Raufarholshellir to the highest available grade. The work involved using non-magnetic equipment because of the magnetic anomalies arising from the lava. To overcome the magnetic problem a home-made theodolite was constructed. [Figure 1, on the front cover depicts Ellis using his home-made theodolite, and is

reproduced with kind permission from Martin Mills. It also appeared in the SMCC newsletter, September 1999] Details of the equipment and techniques employed were published as a number of papers by various expedition members, including Ellis, in CRG Transactions during 1971.

From about 1966 Ellis began to involve himself with the organisation and running of several groups including the Mendip Cave Registry and the Mendip Survey Scheme, spending less time underground. Apart from the 1970 SMCC expedition to Iceland and his innovative approach to the configuration of surveying equipment his active participation was effectively at an end. However, that was not the end of his interest in the subject. In 1976 he was involved with the manuscript for the revised BCRA surveying standard that was published as Surveying caves in that year. This was later revised and shortened to the currently available Introduction to Surveying Caves in the BCRA Cave Studies Series which was published in 1987. By this time though he realised that the introduction of computer generated graphics and a number of specialised programs having been developed for the computation of the field work data it was time for others to produce an update of the surveying textbooks.

However, there were several points that he constantly brought to the attention of surveyors and these transcended the 'marvels' of modern technology. One was the importance of calibration, not only of the compass but also that of the clinometer. Though the latter instrument now in common use (Suunto) was not adjustable the instrument should still be regularly checked and the error, if any, should be included in the computing of the data. The second point that he stressed was that the grading system was not to be misused as many have done by claiming a higher grade than that actually achieved, but keep to the spirit of the limits defined for each grade and follow-up with a report of how the survey fieldwork was carried out in practice and published in a readily available publication. The one point where he and the writer were in complete agreement was that no matter how good the modern computing equipment and programs may be the survey was only as good as the work carried out in the field.

Organising field data was Ellis' primary concern and his approach to the presentation of the survey was one of secondary interest. His work in this aspect of cave surveying never developed and remained such that it became an easily recognisable hallmark to the point that an unsigned presentation would be readily recognisable as that drawn by him. He paid little detail to passage profile and tended to 'round' the contours instead of showing joint features and the many forms that a passage may take. Elevations were usually prepared using the extended form which was often the subject of disagreement between him and the writer of this note.

In addition to his interest in the theoretical aspect of cave surveying he was interested in developing and testing new equipment when it first came onto the market. To reduce the

problems associated with the reading of the compass on steep inclines he developed the idea of combining the compass and clinometer onto a common base which was itself attached to a tripod. This became known on Mendip as the Surveying Unit. Ellis' design became quite robust and sophisticated but had the basic problem of not being able to remove the instruments enabling them to be used separately when the occasion arose. The idea has not been widely accepted as there has been for some time a general tendency to only produce up to BCRA Grade 5 surveys. The improvement in transmitting equipment has helped to position cave passages to surface features with adequate precision thus reducing the increased work required by the BCRA Grade 6 requirements.

It is far too early to be able to carry out an assessment of Bryan Ellis' contribution to cave surveying, least of all it being carried out by the writer who was far too close to observe his work and views. For the time being the intention of this note is to outline his practical and theoretical work in relation to the topic. A short bibliography is appended; it is not claimed to be complete!

## **B.M. Ellis - A bibliography of surveying topics**

Some abbreviations:

*BCRA* - British Cave Research Association; *BEC Bel Bul* - Bristol Exploration Club Belfry Bulletin; *Cav Rep* - Caving Report; *CRG* - Cave Research Group of Great Britain; *Jnl* - Journal; *MNRC* - Mendip Nature Research Committee; *Occ Pap* - Occasional Paper; *SMCC* - Shepton Mallet Caving Club

1958 Hunters Hole, Sanctimonious Passage. *BEC Bel Bul* 12(127)6-7(Aug), survey

1960 Surveying in St. Cuthbert's. *BEC Bel Bul* 14 (145) 4-6(Mar), survey

1960 A survey drawing instrument *SMCC Jnl* 2(3)5-6(May), illus

1960 Caving in North Wales. *SMCC Occ Pap* (2)38 + [iii](Dec), surveys, map

1961 Hunters' Hole, Priddy [in] Some Smaller Mendip Caves. *BEC Cav Rep* (6)13-22(Oct), fig, survey

1961 Some notes on the survey of Shatter Passage [Swildon's Hole] [in] The Exploration of Shatter Passage [by] J.M. Boon. *SMCC Jnl* 3(1)3-9(May), survey

1962 A preliminary survey plan of St. Cuthbert's Swallet. *BEC Cav Rep* (8)10pp(Feb)

1962 A second report on St. Cuthbert's Swallet. *BEC Cav Rep* (7)38pp(Feb), illus, figs.

1962 Bottlehead Slocker [in] Bottlehead Slocker, Downhead, Eastern Mendip [by] M..M. Thompson. *SMCC Jnl* 3(4)15-19(Nov), survey

1963 Mendip Cave Survey Colloquium *ACG Ntr* 117-118(Dec)

1963 Notes on the survey [Lamb Leer Cavern] [in] St. Valentines Landing, the dig and other projects [by] R.W. Mansfield *MNRC Jnl* 1(1)8-13(Jan), map, survey

1963 Mendip Cave Survey Colloquium *MNRC Jnl* 1(3)6-7(Jan)

1963 Mendip Cave Survey Colloquium Priddy : *MCSC Report*, 2pp (13-8-1963)

1963 Mendip Cave Survey Colloquium Priddy : *MCSC Report*, 10pp (13-8-1963)

1963 Steepholme - 1963 [Window Cave] *SMCC Jnl* 3(6)3-6(Nov), survey

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1964 Two caves at Cannington, near Bridgwater. *SMCC Jnl* 3(8)3-6(Nov), surveys p.18

1964 Holwell Cavern, the East Series *SMCC Jnl* 3(8)7-12(Nov), survey

1966 A survey of Cfen Cave, Denbighshire. *SMCC Jnl* 4(1)18 + insert (Jun), survey

1966 Traverse Closure (and other Errors) in Cave Surveying. *SMCC Jnl* 4(2)10-19(Dec), figs

1967 A new survey of Holwell Cavern *SMCC Jnl* 4(3)11-19(Jun), surveys

1968 Survey of Holwell Cavern 1964-1968 Bridgwater : B.M. Ellis, MS, 126ff [field notes]

1969 Hawthorn Hole *NGR ST/5585 5365 SMCC Jnl* 4(7)11(Jun), survey

1970 Symposium on Cave Surveying - The Survey Unit – Equipment used on Mendip, England. *CRG Trans* 12(3)139-148(Jul), figs, illus

1971 The Survey of Raufarholshellir. *CRG Trans* 13(4)235-240(Nov), survey

1976 Surveying Caves *BCRA*, 88pp, figs, tables

1987 Cave surveying in Britain - an historical review. *BCRA Cav Sci* 14(2)52-55(Aug), illus

1987 Using a spreadsheet to reduce survey data. *BCRA Cav Sci* 14(2)75-79(Aug), tables

1988 Introduction to Surveying Caves *BCRA Cav Stud Ser.* (2), figs, illus, tables

1990 The Cannington Caves *SMCC Jnl* 8(9)353-359(Autumn), survey

1991 Extracts from the Hut Log Volume Four: July 1960-December 1964: 1961. *SMCC Jnl* 8(10)404-418(Spring), surveys

# CSG Spring Field Meet, Compass Trial - Addenda

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In re-reading my article “Cave Surveying Group Spring Field Meet Compass Trail”, in *Compass Points* 25, I realise that I missed out some key intermediate data, which is presented below. Please also note that my email address was incorrect. Apologies on both counts.

Name	Average Data – Forward Readings										Average Data – Back Readings									
	1F	2F	3F	4F	5F	6F	7F	8F	9F	10F	1B	2B	3B	4B	5B	6B	7B	8B	9B	10B
Theodolite	215.6	257.5	297.3	330.0	17.3	44.2	87.4	108.5	150.2	184.7	35.6	77.5	117.3	150.0	197.3	224.2	267.4	288.5	330.2	4.7
Average	214.4	255.5	295.4	328.1	15.5	43.0	86.9	107.3	149.1	183.7	30.1	76.1	116.1	149.1	196.5	220.5	266.3	286.9	328.6	3.3
Count	14	5	5	5	5	24	5	4	5	5	16	19	19	19	19	5	19	19	19	19
Sample SD	1.1	0.4	0.5	0.7	1.2	1.1	0.8	0.6	1.3	0.4	1.8	0.8	1.2	1.3	1.1	1.4	1.2	1.2	1.3	1.3
SD-ave	0.3	0.2	0.2	0.3	0.5	0.2	0.4	0.3	0.6	0.2	0.2	0.3	0.3	0.3	0.3	0.6	0.3	0.3	0.3	0.3
Deviation	-1.2	-2.0	-1.9	-1.9	-1.8	-1.2	-0.5	-1.3	-1.1	-1.0	-5.5	-1.39	-1.19	-0.92	-0.75	-3.68	-1.06	-1.57	-1.63	-1.42

**Table 2: Average Bearing at each Station, Compared against Theodolite**

The article presented the raw data and the calculated residuals, but omitted to give the average value of each back bearing from which the residuals were calculated. I think that this would have been helpful in explaining more clearly the steps that had been carried out, and more importantly this information may be of benefit to the Group in order to continue the experiment in future years. It is presented in Table 2, below, together with the average value of each Forward Bearing for comparison.

Finally, in response to Larry Fish’s article “How Common Are Blunders in Cave Survey Data” in the same issue of *Compass Points*, I thought it would be useful to state the overall compass error contained in the data gathered at the CSG field meeting. This is given in Table 3, below. For the avoidance of confusion, Table 6 in my original article contained only this information derived from the forward bearing data. The Overall Sample Standard Deviation is the standard deviation of both the forward and backward residuals presented in Tables 5 and 6. The residuals are calculated as given under “Bringing It All Together”

in the article. Please also note that in Table 6 in the previous article I wrongly stated that the Theodolite offset used was 1.0°. In fact, I used the exact value contained in the spreadsheet, which rounded to two decimal places is 1.14°.

**Table 3: Average of Differences against Theodolite – All Data**

Overall Number of Measurements	250
Overall Sample Standard Deviation	1.17°

The overall standard deviation of our sample of 250 measurements is thus (to one decimal place) 1.2°. That means that 68% of measurements will be within  $\pm 1.2^\circ$ , 95% within  $\pm 2.3^\circ$ . This is worse than I would have expected, given that our readings were taken under almost ideal conditions, but is further evidence in support of Larry Fish’s conjecture that our surveys are not as accurate as we would like to think.

## Estimating Instrument Errors from the “Blundered Loops Graph”

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In the last issue of *Compass Points*, Larry Fish presented an interesting article analysing the number of blunders in cave surveys in the US [1]. At the end of the article, he presented a discussion about how instrument errors might be extracted from this data. However, he did not explain the assertion that the standard error is represented at the point where the graph “goes flat”. I wondered whether there was another interpretation that might apply.

In summary, my suggestion is as follows. The graph gives the probability that a given measurement is less than a certain error value, and the shape of the graph appears to be similar to the shape of a normal distribution. For a normal distribution, the standard error is that value within which lie 68% of the measurements. Thus, my estimate of the standard error from Larry’s graph would be simply the point at which the graph drops to 32% (= 1 - 68%).

### Theory

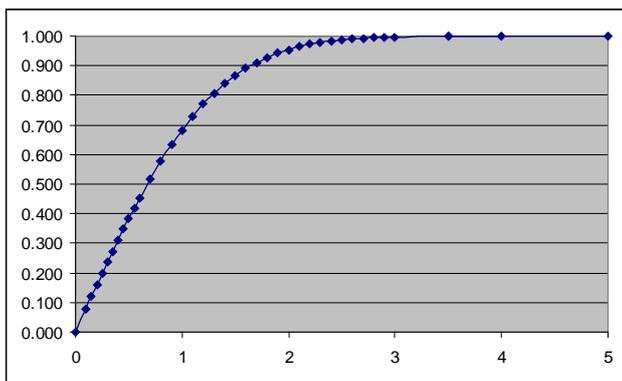
To explain my idea further, let’s imagine what we might expect for a theoretical survey containing no blunders, but subject to random instrument errors. Imagine a loop that is surveyed many times, or many loops that are surveyed to the same standard. The result of each survey will contain a loop closure error, and because each survey is subject to random errors, the loop closure error for each survey will be slightly different. The probability of obtaining a particular loop closure error should obey a normal distribution, all things being equal. The expected standard deviation of this distribution can be calculated from the standard deviations of the instrument measurements (the instrument error), as in reference [2]. The shape of the probability density function for a normal distribution is the well known bell-curve. Its formula, for a random variable of mean  $\mu$  and standard deviation  $\sigma$  is given by:

$$1 / (\sigma\sqrt{2\pi})^{-0.5} \cdot \exp(-(x-\mu)^2/(2\sigma^2))$$

To state the obvious, some errors will be greater than the standard deviation, and some will be smaller. In fact, according to the statistics of the normal distribution, about 68% should be within the standard deviation. This derives from the “sum under the curve” of the density function given above, and is given by the integral:

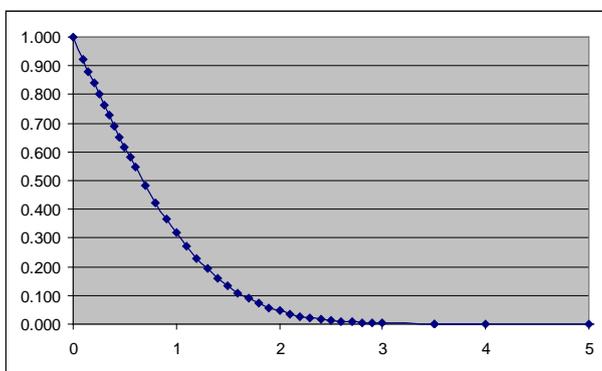
$$\frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^x \exp(-(t-\mu)^2/(2\sigma^2)) dt$$

There is no analytic solution to this integral, but it can be solved by numerical methods and the results are available from many statistical tables and spreadsheet functions. When plotted, the shape of the distribution curve is given in Figure 6, which has been plotted for  $\sigma=1, \mu=0$ .



**Figure 6: Probability that a measurement is within an error**

This gives the probability that a measurement is within a certain error value. The curve can be converted to give the probability that a measurement is greater than a certain error value quite easily, by simply subtracting the curve from unity. This curve is shown in Figure 7. This is now in the same format as the curves presented in reference [1]. Notice that the Roppel curve in reference [1] looks very similar, whereas the other curves do not go to zero quite so quickly.



**Figure 7: Probability that a measurement is greater than an error, for  $\sigma=1, \mu=0$**

It may not be obvious that the curves in reference [1] are the same as Figure 7, so let me justify that. In Figure 7, the x-axis is a loop closure error, and the y-axis is the probability that a measurement might be greater than that value. In reference [1], the x-axis is an instrument error, and the y-axis is the percentage of measurements that were greater than the loop closure error calculated for that instrument error. I’m sure everyone will agree that the y-axis is can be interpreted as the probability.

However, for the x-axis, the actual loop closure error used in Figure 7 is not quite the same as the instrument error used in Reference [1]. However the loop closure error is related to the instrument error by a function. Looking at my own raw data for reference [2], I calculated standard deviations for the loop for different values of instrument errors. I used the same range of instrument errors that Larry used, and found that the loop error was proportional to the instrument error – a linear relationship. Hence, the x-axis in the graph can be taken as a linear measure of the loop error. This is important, because it means that the curve has not been distorted by the act of plotting it against instrument error rather than loop error.

Thus, it is reasonable as a first approximation to interpret Larry’s curves as normal distributions. The standard deviation is then simply that point at which the curve falls to 32%. In fact, the standard deviation can be determined from each individual data point. This is done by assuming that the curve is a normal distribution, and then for a given y-axis value (probability), comparing the value of the x-axis (error) with the value of the x-axis on the normal distribution curve. For example, for the Roppel cave from reference [1], let’s consider the data point at error 1.0°. 25.5% of loops have errors greater than 1.0°. In comparison for a normal distribution, 25.5% occurs at a ratio of 1.14 standard deviations, so the standard deviation for Roppel would appear to be  $1.0 / 1.14 = 0.88^\circ$ . In this way, I have calculated the implied standard deviations for a number of the data point from reference [1], which are presented in Table 4. In this table, the columns Error and % are from reference [1], Ratio is the number of standard deviations in a normal distribution that has this percentage, and SD is the implied SD, derived from Ratio and Error, as described above.

## Results

Apart from the first data point, the Roppel data set gives a consistent standard deviation. I would therefore conclude that it is normally distributed, and contains few blunders. The average value of the data points is  $0.86^\circ$  – significantly more optimistic than the conclusion in reference [1]. The first data point is a lower percentage than I would expect for this standard deviation, for which I would expect a percentage of 72% at  $0.5^\circ$ . I can’t think of an explanation for this, but would welcome suggestions. An even better analysis could be carried out with the original data. This would involve a proper curve fitting analysis, and would result in a more reliable estimate of the underlying instrument error.

The other curves do not produce a consistent standard deviation, as evidenced by the shape of the graphs, which, as mentioned earlier, do not approach zero quickly enough. My table shows that the derived standard deviation increases for loops with the biggest blunders. To my mind, this means that whatever is causing the error for the large-error loops, does not effect the small-error loops. If it did, and it was a random effect, then a consistent, albeit large, standard error would emerge from this analysis. I would agree with Larry Fish that this is the result blunders, which are absent in the more accurate loops, and have an effect in the less accurate loops (which is intuitive). Now, I do not suggest that the derived standard deviations for each data point are meaningful as a standard deviation at that point. However, I would suggest that the first two or three data points could be used to determine an indicative standard deviation underlying the effects of blunders. The reason for this is that the most accurate loops will be those without any blunders. In support of this suggestion, notice that the first three data points for Lechuguilla, Wind and Lillburn do not increase in the same way as the later values do. I have averaged these ‘stable’ values to give the underlying error for each cave, and presented the

Comp Error	Lechuguilla			Wind			Lilburn			Roppel		
	%	Ratio	SD	%	Ratio	SD	%	Ratio	SD	%	Ratio	SD
0.5	79.5	0.26	<b>1.92</b>	75.40	0.31	<b>1.59</b>	68.50	0.41	<b>1.23</b>	68.5	0.41	<b>1.23</b>
1	56.1	0.58	<b>1.72</b>	52.90	0.63	<b>1.59</b>	39.50	0.85	<b>1.18</b>	25.5	1.14	<b>0.88</b>
1.5	40.5	0.83	<b>1.80</b>	36.40	0.91	<b>1.65</b>	22.30	1.22	<b>1.23</b>	7.50	1.78	<b>0.84</b>
2	32	0.99	<b>2.01</b>	25.80	1.13	<b>1.77</b>	14.70	1.46	<b>1.37</b>	2.40	2.26	<b>0.89</b>
2.5	26	1.13	<b>2.22</b>	19.60	1.29	<b>1.93</b>	12.20	1.55	<b>1.62</b>	0.30	2.97	<b>0.84</b>
3	21.2	1.25	<b>2.40</b>	16.10	1.40	<b>2.14</b>	10.50	1.62	<b>1.85</b>	0.00	3.50	<b>0.86</b>
3.5	17.3	1.36	<b>2.57</b>	13.80	1.51	<b>2.32</b>	9.70	1.66	<b>2.11</b>			
4	14.1	1.47	<b>2.72</b>	11.80	1.56	<b>2.56</b>	8.80	1.71	<b>2.34</b>			
4.5	12.6	1.53	<b>2.94</b>	10.20	1.64	<b>2.75</b>	8.80	1.71	<b>2.64</b>			
5	11.4	1.58	<b>3.16</b>	9.20	1.69	<b>2.97</b>	8.40	1.73	<b>2.89</b>			
5.5	10.2	1.64	<b>3.36</b>	8.20	1.74	<b>3.16</b>	7.60					
6	9.2	1.69	<b>3.56</b>	7.70			7.60					
6.5	8.3	1.73	<b>3.75</b>	7.10			7.60					
7	8			6.40	1.85	<b>3.78</b>	7.60					
8.5	6.6	1.84	<b>4.62</b>	5.20			7.10					
9	6.4	1.85	<b>4.86</b>	4.90			7.10					
11.5	5.5			3.80			6.70	1.83	<b>6.28</b>			
12	5.1			3.60			6.70	1.83	<b>6.55</b>			
12.5	4.9			3.10			6.70	1.83	<b>6.82</b>			
13	4.7			2.90			6.70	1.83	<b>7.10</b>			

**Table 4: Effective standard deviations derived from each data point**

results in Table 5. Once again, these appear to be much lower values than suggested by reference [1].

## Way Forward

Initially, I would have expected blunders to be effectively yet another source of random error, but with a much larger standard deviation. When two normal distributions with very different standard deviations are combined, the result is still a normal distribution, where the new, larger, standard deviation can be calculated using the propagation of errors formula. However, the analysis above suggests that the blundered data does not obey such statistics, and so in conclusion, the shape of the distribution curve cannot be normal.

There might be some scope for a theoretical analysis here. We could say that there is a certain probability of a blunder being made per measurement, or for some measurements to be blunder free. This matches our understanding of what is meant by a blunder. This can be expressed with a Poisson distribution, where a key parameter would be the number of blunders we might expect per, say, hundred measurements. When a blunder occurs, it will be a random error (I think) with a large standard deviation. So to express that lot mathematically, we would have to fold the underlying normal distribution together with the Poisson distribution (which would include the number of measurement in the loop), together with the normal distribution for the blunder. This could only be done with access to the original data – so I have let myself off the hook in having to solve this. Would anyone else like to have a go? The scheme might also fall down, because the probability of a blunder may not be constant for each survey team, and the data in reference [1] has been produced by many different people.

Reference [1] proposes a method for extracting an error based on first and second derivatives. If you agree with my mathematics, then it is not the underlying random error. So what might this value be? It is possibly an estimate of the turning point, the point at which the loop closure is dominated by blunders rather than the underlying error (which is what Larry Fish at first claims). In Table 5, I have compared the turning-point error with the underlying error. The ratio is about 4, and at four standard deviations, the probability of a random error is effectively zero. However, reference [1] started with the assumption that any loop with an error greater than two standard deviations is probably blundered, which is a more likely turning point. Perhaps the error extracted at the end of reference [1] is an estimate of the blundered standard error – in other words, the effective instrument error that takes into account blunders. However, as indicated earlier, this could be derived better directly from the data using a curve fitting approach.

## Conclusion

My approach seems to be able to extract the underlying (unblundered) error. Over and above that is an increased error caused by blunders, which only effects some loops. Reference [1] proposes a method for extracting an error based on first and second derivatives, but this is not the unblundered standard error, and it appears to be too big to be the turning point above which blunders are significant. It might be the effective blundered standard error, but I think that more work needs to be done with the original data to demonstrate this.

Cave	Underlying Error	Ref Error [1]	Ratio
Lechuguilla	1.8°	7.5°	4.2
Wind	1.6°	5.5°	3.5
Lilburn	1.2°	5.0°	4.1
Roppel	0.9°	3.0°	3.3

**Table 5: Underlying instrument errors (from selected data points – see text)**

## References

- [1] How common are Blunders in Cave Survey Data? by Larry Fish, CP 25
- [2] Cave Survey Errors, by Ben Cooper, CP26