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Issue 30

Compass Points

March 2003

BCRA

Comments on the revised BCRA survey grades

GPS co-ordinate transformations

Proving survey accuracy

The Journal of the BCRA Cave Surveying Group

COMPASS POINTS INFORMATION

Compass Points is published three times yearly in March, July and November. The Cave Surveying Group is a Special Interest Group of the British Cave Research Association. Information sheets about the CSG are available by post or by e-mail. Please send an SAE or Post Office International Reply Coupon.

NOTES FOR CONTRIBUTORS

Articles can be on paper, but the preferred format is ASCII text files with paragraph breaks. If articles are particularly technical (i.e. contain lots of sums) then Latex, OpenOffice.org or Microsoft Word documents are probably best. We are able to cope with many other formats, but please check first. We can accept most common graphics formats, but vector graphic formats are much preferred to bit-mapped formats for diagrams. Photographs should be prints, or well-scanned photos supplied in any common bitmap format. It is the responsibility of contributing authors to clear copyright and acknowledgement matters for any material previously published elsewhere and to ensure that nothing in their submissions may be deemed libellous or defamatory.

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The group aims, by means of a regular Journal, other publications and meetings, to disseminate information about, and develop new techniques for, cave surveying.

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courtesy of Doug Dotson, Speleotechnologies.

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The CSG runs an e-mail list for cave surveyors around the world. To join send a message containing the word 'subscribe' in the body text to `cave-surveying-request@survex.com`

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The journal of the BCRA Cave Surveying Group

Cover photo: Sighting the compass during a calibration experiment (see "Sightseeing" article). Photo by Jos Burgers.

Editorial

Following the rather thin issue 29, this issue is fairly bursting at the seams – thanks to all the contributors for making this happen. Thanks also to Jos Burgers for digging me out of a hole for the second issue in a row by providing a cover photo. If anyone has any suitable surveys or surveying related images that could be used on the cover of future issues, please get in touch.

The publication of the revised BCRA surveying grades in the last issue has attracted comment. Although the new edition of "Cave Surveying" has been published, there is scope for making changes via the BCRA surveying web page and the updatable centre-fold if it is generally agreed that this is necessary, though the default position is that the revised grades will stand. I therefore encourage anyone with strong opinions on this subject to air their views via the pages of Compass Points.

CSG Admin

There have been a few minor changes to the masthead details. Firstly, the option to receive Compass Points by surface mail to destinations outside Europe has been removed for simplicity as it was hardly used. Secondly, the pricing of back issues has been simplified. All back issues cost £1.25 plus a single postage and packing charge of £0.50 (UK), £1.00 (Europe) or £1.50 (worldwide) irrespective of the number of back issues ordered. Also, now that Compass Points is back on a regular publication schedule, anyone who renews their subscription at the "final reminder" stage (i.e. one issue after the subscription expires) will receive two issues at the time the next issue comes out. For further clarification, please contact the secretary ("Subscription and enquiries" in the masthead).

Snippets

Instrument Problems at Altitude

Wookey

In recent years I have been recommending Silva instruments rather than the long-popular Suuntos as they are much cheaper and generally just as good. However, recent experience in China has shown that there is at least one significant disadvantage: Silva Sightmaster/Clinomaster/Surveymaster instruments (the Aluminium-bodied instruments we are all familiar with) are much less tolerant of high altitude/low pressure than Suuntos or (apparently) Silva Type80s.

On various trips in China, Erin Lynch reported that all the Silva Sightmaster/Clinomaster got bubbles in their capsules above 1800m, and two instruments got very large bubbles during a month at 1800m, significantly affecting the use of the instruments. The team described these as "almost unusable". Of the four Suunto instruments on this trip one got a small bubble but the others were fine. The bubble size increased slowly during time at altitude, so at 1800m the Silvas started with medium sized bubbles which grew larger over the month. On returning to sea level the bubbles disappeared. There is also some variation between instruments, which may depend on age or manufacturing variation.

A query to Silva tech. support turned up the information that the devices are indeed likely to get bubbles over 2000m and are not designed for use above this altitude. This seems rather a low design limit as there are an awful lot of places above this altitude where you might very well want to use a quality compass. The reason for the problem is that the capsule expands slightly in the lower pressure but the volume of the liquid inside remains almost constant, hence a bubble forms.

The Silva man told me that the usual reason for this problem is people putting their instruments in hold luggage, which can be subjected to very low pressures, and that you should never do this. How many of you knew that and always carried instruments in hand luggage? I know I didn't. He also said that he'd be surprised if Suunto's instruments were significantly different in this regard.

I tried to find out what Suunto had to say on the subject but didn't manage to talk to anyone competent and could only leave a query. This resulted simply in a photocopy of the normal instruction sheet, which says nothing about altitude or pressure limits. However, in practice they do seem to be rather better in this regard. As a result of this information the CSG recommends that you avoid taking Silva Clinomaster and Sightmaster instruments to destinations over 1700m for more than a week or two.

It seems that the Type 80 (plastic, prismatic) Silva compasses are better than the aluminium-bodied ones as this problem has not been observed in these instruments on the China trips, although we only have one sample.

It is worth noting that aeroplane cabins are pressurised to the equivalent of about 2400m - so that's above the critical altitude, but not for very long, which presumably explains why it doesn't usually cause problems.

CUCC have had some Silva clinometers in Austria (at 1600m) for the last couple of years (staying up high for maybe 4 weeks) and have not noticed any problems, so it seems that problems will not occur this low. I'd be interested in any feedback that others can provide on the susceptibility of various instruments to bubbles at altitude.

Here are the detailed observations so far:

- Duncan's new Silva Surveymaster compass developed two bubbles on arrival which steadily increased in size during a month in Hongchiba (1800m)
- Duncan's new Silva Surveymaster clino developed a large bubble which rendered it useless for anything below about -20 degrees during a month in Hongchiba (1800m).
- Taco's Silva Sightmaster compass, which is a lot older than Duncan's Surveymaster, developed a small bubble in less than a week in Kunming (2100m).
- Hilary's new Silva Clinomaster clinometer developed a small bubble in less than a week in Kunming (2100m). Hils reports no problems in Zhongdian (4000m), but then they only surveyed about 40m so may not have noticed.
- Hilary's Silva Type 80 compass had no problems in Kunming or Zhongdian (4000m).
- Erin's 2-year-old Suunto compass developed a small bubble towards the end of a month in Hongchiba (1800m), but it was still usable. The compass was retired when it started sticking in Tian Xing, so no info. for Kunming.
- Erin's new Suunto clino didn't have any problems in Hongchiba (1800m) or Kunming (2100m).
- TSG's Suunto compass went to Hongchiba (1800m), and had minor problems but was usable.
- TSG's Suunto clino went to Hongchiba (1800m) and had minor problems but was usable.
- CUCC's 2 new Silva Clinomasters went to Loser (1600m) and had no problems.
- I have one second-hand report of a Silva Type 80 user having a problem with bubbles in the Alps (altitude unknown).
- Michael Laumanns has experienced problem with bubbles in Suuntos in Iran at heights well over over 2000m, but these may have been caused by unpressurised transport on flights.

Press Round-up

Speleology, Issue 1 (Jan. 2003)

The first issue of BCRA's new magazine "Speleology" was published in January 2003. This publication is a replacement for "Caves & Caving", and is intended to be a "popular science" journal.

Issue 1 contained a few items of interest to surveyors, most notably "Ogof Cnwc: a new entrance to Daren Cilau" by Stuart France. In this article, Stuart describes how radiolocation assisted the connection of Price's Dig (now renamed Ogof Cnwc) to the Busman's Holiday extensions in Daren Cilau (South Wales). Radiolocation experiments were carried out at the end of Price's Dig and also in Price's Folly, a side passage in Busman's Holiday that was thought to be the closest point to Price's Dig. These experiments suggested that the two passages were only 3m apart laterally, and 7m vertically. On the basis of this information, a new dig was started resulting in the connection.

Also in this issue is a short piece from Chris Wood describing the work of the 2000 and 2001 expeditions to the Laki lava field in Iceland that won the Arthur Butcher Award for 2002.

Compass and Tape Reviews

Reviewed by Wookey

With the Compass Points publication gap from Feb 2000 - June 2002 the press round-up has got rather behind. The US publication Compass & Tape has been appearing reasonably regularly during the hiatus; C&T issue 45 was covering in CP25 (Sept 1999) and C&T #51 in CP28. So that leaves you all uninformed about issues 46-50. Here we start to fix that.

Issue 49 (May 2001)

Letters to the Editor

John Halleck points out some facts about copyrighting cave maps in the US, which had been incorrectly detailed in issue #48

You don't need to write "Copyright blah" for copyright to exist - it's intrinsic in a created document, nor do you have to use the symbol. Filing the copyright with the authorities is not required but doing it after an infringement means that you lose the rights to claim certain losses, including legal fees, so it makes it difficult to defend any infringement in practice.

Garry Petrie writes in to compliment the concept of an issue devoted to the cartography salon, including the judges critiques, and discuss and rebut a few of their points with respect to his entries.

The 2001 Cartographic Salon

Announcement that the judging guidelines and forms for the salon have changed, and can be found online at `http://www.Deep-secrets.com/html/cartography.html`

Survey and Cartography Session - Call for Papers; 2001 conference

Linear Symbols for Cave Maps in Freehand

John Ganter describes how to define line types in Freehand (for pitch edges and the like). He started off drawing the dashes in by hand one by one, but soon wanted a better way. The first suggestion was to combine a normal line with a wide line consisting of a 1-on, 15-off pattern (to get perpendicular dashes). This works OK for gentle curves but not tight ones (the lines get out of sync.).

Next he used the facility to make characters follow a curve. Finding a character/font that looked like a pitch "tick" and applying a wheel-spaced row of these to a line the right effect is given, but the character was a bit too 'tall' so the next thing was to make a custom font containing pitch ticks and traverse 'T's. This worked quite well although there are still some imperfections on tight curves - the font is called "Ganterfont" and is available at his website in TTF format.

He also made a flowstone font - ganterfont2. He observes that the "right" way to solve this problem is with postscript, but various practical problems mean that he has not pursued this approach.

This article is reprinted from `http://nerve-net.zocalo.com/jg/c/`

<?Cave Survey Data in XML?>

Devon Kouts describes the XML data format and gives examples of how it could be used to store and describe cave survey data. He gives an example DTD corresponding to the example data file and suggests that with some co-operation from the cave surveying community a standard DTD could be developed which would greatly help with the interchange of survey data.

[Your reviewer feels that this article, whilst informative about XML and DTDs, suffers from the "XML will solve everything" malaise that is far too common these days - it solves the really simple problems, like which line-end character to use, but doesn't help with the more serious fundamental difficulties in survey data interchange like mapping between hierarchical and flat station-naming conventions, or different units, LRUD and station position conventions.]

Computer Modelling of Cave Passages

Larry Fish describes some of the problems of making 2 and 3D cave models with existing centreline+LRUD survey data, and some of the techniques that can be used to overcome/ameliorate them, using examples from Compass. 2D first: Simply drawing perpendicular LRUD lines produces a rather confusing image, but joining each to the next produces severe distortion at sharp corners. This can be dealt with by using splined curves to smooth off the corners. In practice this is quite fiddly to get right with different treatment needed for inside and outside corners but the finished results are quite pleasing. They can also be filled to produce the classic "Mendip blob" style surveys.

Moving to 3D a mesh is needed. The square cross sections produced from LRUD measurements are not very cave-like so Compass creates octagonal sections from the data. Corners have the same problems in 3D as in 2D but using the splines in 3D is a much harder problem so a different approach is used. Each corner is split into 2-4 corners to smooth out the transition. The rectangular faces are then split into triangles to get better smoothing and shading. Goroud shading and limestone texturing is used to give realistic-looking curved surfaces. A reasonably modern accelerated graphics card is needed to be able to display reasonable-sized caves using this technique but those are pretty standard these days.

In the future better data collection of the shapes of passages will allow much more realistic cave models.

Compass Brands and their Manufacturers

Bob Thrun provides fascinating information on which compass manufacturers have bought each other and the strange effects of US trademark law. He finds that in the U.S "Silva" instruments are now actually made by Suunto, whereas real Silva instruments are marketed under the "Nexus" brand. It seems that Silva acquired the Finnish Sisteco company in 1990 and then the US manufacturer Brunton in 1996. At that time they dropped their US importer "Johnson Worldwide Associates" (JWA) and started importing via Brunton. Unfortunately JWA owned the Silva trademark in the US and Canada and insisted on keeping it. Unable to buy Silva instruments they got Suunto to make theirs with Silva branding instead! The Brunton pocket transit was patented in 1894 and was sold by Wm. Ainsworth & Sons until 1965 when it got bought and sold regularly by conglomerates until a group of businessmen bought the company in 1972. It stayed there until the 1996 Silva purchase.

Overall a fine issue with something for everyone.

Issue 50 (December 2001)

NSS SACS meeting minutes, July 27 2001

Publication and finances fine, 2 issues a year agreed, electronic publishing put off for reconsideration next year, entering previously-entered maps in the salon discussed and the committee re-elected.

2001 Cartographic Salon Report

32 entries from 23 cavers. Prominently displayed in a thoroughfare. High standard especially amongst "apprentices". The gold medal was won by Carlene Allred for Wonderland, a portion of Kazamura Cave.

Pen and Ink: A new salon category?

Steve Reames considers how the categories have changed over the years. For many years it was done by cave length, reflecting the increased difficulty of drawing larger caves. Several other categorisations were tried and discarded before moving to the current categories of Apprentice, Experienced and Master/Professional. A computer maps category was introduced a few years ago to allow the then-inferior maps to compete, but as more and more such maps win prizes, perhaps it is time to create a "Pen and Ink" category to preserve this dying art, in much the same way that the vertical section still have a "knots" ascending category.

Experiments in Creating High Fidelity Cave Models, Part 1 - getting the Data

Greg Passmore from 3D pipeline Corp. presents an examination of techniques for producing detailed 3D cave models by collecting high-resolution passage data and using wall photography to get highly realistic models. The current state of the art works well on phreatic and canyon passages, but not breakdown areas, and there are problems with very large rooms. The core of the process is the conventional survey. Around that are large numbers of passage profiles. Ultrasonics have been used with some success but problems on some surfaces such as water and wet mud. Laser ranging devices "LIDARs" are effective but expensive and large. One of the most effective techniques is to use a camera to record the passage profile, using a laser pen to mark the profile location. This technique does require post-processing to get the numbers out and can suffer from occlusion of parts of the profile.

One lesson learnt is that many interesting features must be captured separately and integrated into the model, and LIDAR is very useful for this. Stitching data together in the model can be tedious and complex - software is still developing in this area. Drag and drop boulders and formations is the ideal solution. At the level of small detail (e.g. gravel) texture and bump maps are best as a full geometric model becomes excessive and rendering times would become impractically long.

To generate texture and bump maps the lighting in the photos must be done in a specific way. First a no-shadows photo is taken to get the colour, and another is taken with lighting to highlight the geometry. A very wide-angle lens is needed to keep the umber of photos sensible - a 180 degree fisheye lens is good. Anyone wanting to get involved with this work is welcome.

The International Foot versus the U.S. Survey Foot, or The Case of the Galloping Caves

Larry Fish offers a discussion of the effects of the 0.000024 inch difference between the International Foot and the US Survey Foot. This can cause problems with large numbers such as UTM co-ordinates - up to 35 feet within the US. Larry describes the history of mapping standards which mean that now 11 states mandate the US Survey Foot for mapping, 6 the International Foot and the rest the metre. Problems don't arise unless you convert large numbers such as distance from the equator in feet, which in practice normally happens if moving data between programs (AutoCad, Arcinfo, Cave survey software, which may be using different feet definitions).

Tunnel Reconstruction from Sparse Range Data Using Interpolated Implicit Surfaces

(Thomas Lesperance, 3D pipeline Corp.) Implicit surfaces are used for complex shape modelling in CAD systems. These surfaces can be generated using interpolation functions if given a set of boundary constraint points and at least one interior constraint point. The interior points are survey stations (which are always within the tunnel) and points on the walls measured from these stations (LRUD-style) form the boundary points. Given these data "an implicit function representation of the surface can be created by solving a system of equations representing a sum of weighted radial basis functions at each constraint point", and the result can be polygonised. A couple of impressive examples are given, which generate a fine-grained polygon mesh dealing well with such things as T-junctions. Unlike most cave surface representations the facets length is much smaller than the distance between stations - this gives a much more consistent and realistic-looking surface. This looks like a useful technique for 3D cave modelling.

Letters

Revised BCRA Survey Grades

Arthur Millet

I have just read the article in Compass Points on the revised BCRA survey grades.

May I ask where was the consultation before such a fundamental shift on existing policy. If there are people who find it impossible to prove that a survey has attained G5 requirements, may I suggest that they speak to surveyors who can and do.

If there are beginners/surveyors who would like to know the practicalities of attaining the accuracy of individual measurements then come and join a couple of surveyors who will not be dropping their standards.

You dumb down if you wish, I am not for dumbing down.

Reply from the Principal Author of "Cave Surveying"

Anthony Day

The revised survey grades were put together in consultation with my co-authors - Paul Deakin, John Eyre and David Judson - and others who are listed in the acknowledgements section of the new "Cave Surveying" booklet. I would have preferred to consult more widely, and regret that this did not prove possible, mostly due to time constraints - the old version was out of print before I found the time to start work in earnest on the revision. Nevertheless, there was unanimous agreement amongst those who were involved in putting the booklet together that the grading system was in need of revision in this way to bring it in line with the recommended practice for performing a Grade 5 survey described in the booklet.

I would not expect the Chelsea surveyors to lower their standards of surveying due to a change in the wording of an artificial grading system. With my editor's hat on I am keen to promote good surveying practice through the pages of Compass Points. I therefore invite you to share with the readership how you go about attaining the rigorous standards of the old Grade 5 and verifying that this standard has been achieved. It is by sharing the knowledge and expertise of experienced surveyors such as yourself that the general standard of cave surveying will improve, regardless of the wording of the BCRA grades.

Comments on the BCRA Booklet "Cave Surveying"

The publication of the new BCRA booklet "Cave Surveying", in particular the revision of the BCRA survey grades as presented in issue 29 of Compass Points, has attracted some comment. This article is split into three parts. In the first part, John Stevens proposes an alternative scheme for grading surveys. In the second, he presents the case for recommending leap-frog surveying over forward surveying with back checks as advocated in "Cave Surveying". In the third part, the authors of "Cave Surveying" outline the thinking behind the changes they introduced. These viewpoints are presented alongside each other in the hope of stimulating debate on these issues amongst readers of Compass Points and the wider cave surveying community.

Part 1: Proposed Revision to the BCRA Survey Grades

John Stevens

I was disappointed to learn from the latest Compass Points that the BCRA Survey Grades (Day [1]) have been revised without wider consultation.

Those published by Ellis ([2] and [3]) gave a uniform increase in quality and accuracy. Unfortunately the definition of a couple of the grades was rather "woolly" and thus these were not used as they should have been. The main problem was the definition of the Grade 4. My understanding of the Grade 4 was that this included two quite different categories of surveys. The most obvious from the definition was those that failed to meet the accuracy criteria of the Grade 5, i.e. the loop closures of the survey were too large and thus it was downgraded to a Grade 4. This gave the feeling that a Grade 4 was for failed Grade 5 surveys and few wished to use it.

This was not the case with the other group that should have been labelled Grade 4. These were surveys done with "horizontal and vertical angles measured to ±1º and distances recorded to 1cm, station positions to be to <10cm," but for which the survey could not be proved accurate because of the type of cave system, i.e. the cave had no significant loopage - it was a linear type system. By a visual look at the end Grade 4 survey it should be obvious which of these two cases a survey fell into by looking at the type of system. Thus the woolly definition of Ellis Grade 4 was to try and cover both groups.

A second omission was probably due to the lack of computing and plotting power when the grades were first drawn up, that was that any survey published to Ellis Grade 5 standard should include its proof of accuracy. I would recommend the main closed loop details be added as a table, i.e. loop name/description, loop length, number of survey legs in loop, closure error (which could be split into its three components), percentage error (closure error/loop length). In complex systems, this may be quite a table but only the main large loops need be shown. A by-product of this will be that a survey may then claim a mixture of grades as different areas meet the Grade 4, 5 or 6 criteria.

I welcome the increase in detail of the Day Grade 6, and I feel it hits the right mark. I think it very important to keep the accuracy factor in the Ellis Grade 5. The Ellis grades were also backward compatible to the CRG grades [4], i.e. CRG Grade 4 was Ellis Grade 4 = Day Grade 5. The survey grades need to show a smooth linear progression through the grades. With far fewer surveys falling into Day Grade 4, the scale will lose the smooth progression but have a jump.

Thus a combination of the Day and Ellis Grades would be best, with the Ellis Grade 5 left but a note added to require that the closure details be published. Greater detail of Grade 2 could also be given to remove that unclear area, as I have seen many surveys claiming to be Grade 3 surveys but having no altitudes, i.e. they should be Grade 2.

As with all grading systems, some surveys will fall between two grades or fail to meet all the criteria for the grade it justly deserves because of the physical properties of the cave system. One that springs to my mind is the Warburton/Cousins Grade 6 centreline of a large part of Agen Allwedd. As this does not have any loops, by the letter of the grades it would only be a Grade 4, but having seen the data, instruments and techniques used, it definitely warrants its Grade 6 status.

The proposed revision to the BCRA survey grades is given in Table 1 and Table 2 below. A method for presenting survey accuracy information derived from loop closure errors is given in a separate article "Proving Survey Accuracy" elsewhere in this issue.

Grade 1	Sketch of low accuracy where no measurements have been made.
Grade 2	Sketch that is intermediate between 1 & 3. Measurements and bearings taken.
Grade 3	Rough Magnetic survey. Horizontal & vertical angles measured to ±2.5º; distances measured to ±50cm; station position error < 50cm.
Grade 4	Magnetic Survey. Horizontal & vertical angles measured to ±1º; distances measured to ±1cm; station position error < 10cm.
Grade 5	Magnetic Survey. Horizontal & vertical angles to be **accurate** to ±1º; distances measured to ±1cm; station position error < 10cm.
Grade 6	Magnetic Survey. Horizontal & vertical angles to be **accurate** to ±0.5º; distances measured to ±1cm; station position error < 2.5cm. This will require all stations to be fixed or tripods used.
Grade X	Survey that is based primarily on the use of a theodolite or total station instead of a compass.

Notes

1. The above table is a summary and is intended only as an aide memoire; the definitions of the survey grades given above must be read in conjunction with these notes.
2. In all cases it is necessary to follow the spirit of the definition and not just the letter.
3. To attain a Grade 3 it is necessary to use a clinometer in passages having appreciable slope.
4. To attain Grade 4, 5 (& 6) it is essential for instruments to be properly calibrated, and all measurements must be taken from a point within a 10cm (2.5cm) sphere centred on the station.
5. On a Grade 5 (& 6) survey, details of the accuracy attained should be given, i.e. loop length, number of legs, closure error, percentage error <0.87% (<0.44%) [closure error/loop length].
6. A Grade X survey must include on the drawings notes descriptions of the instruments and techniques used, together with an estimate of the probable accuracy of the survey compared with Grades 3-6.
7. Caving organisations etc. are encouraged to reproduce Table 1 and Table 2 in their own publications; permission is not required from BCRA to do so, but the tables must not be reprinted without these notes.
8. Grade X is only potentially more accurate than Grade 6. It should never be forgotten that the theodolite/total station is a

complex precision instrument that requires considerable training and regular practice if serious errors are not to be made through its use!

9. In drawing up, the survey co-ordinates must be calculated and not hand drawn with a scale rule and protractor to obtain Grade 4 and above.

Table 1: Gradings for a cave line survey

Class A	All passage details on memory.
Class B	Passage details estimated and recorded in the cave.
Class C	Measurements of details made at survey stations only.
Class D	Measurements of details made at survey stations and wherever else needed to show significant changes in passage dimensions. ±10cm

Notes:

1. The accuracy of the detail should be similar to the accuracy of the line survey.
2. Normally only one of the following combinations should be used :- 1A, 2A, 3B or 3C, 4C or 4D, 5C or 5D, 6D, XA, XB, XC, or XD.

Table 2: Gradings for recording cave passage detail

Part 2: To Leap, or Not to Leap, that is the Question

John Stevens

The review of "Cave Surveying" by Anthony Day in Compass Points issue 29 [5] gives the indication that it is now recommended to do surveys using only forward legs rather than the leap-frog method. Even with back checks on the legs, this forward method is the wrong recommendation mathematically. The following section will illustrate, without going into detailed mathematics, the two main reasons why leap-frog should be used over the forward only method.

Repeatable Errors

As we all are aware, any survey has errors of various types in it. These are caused by many different factors (reading precision, magnetic influences, rounding errors…) Errors are always accumulative except for one type of repeatable errors. The repeatable errors are the calibration errors of the compass and clino.

If a compass is calibrated to the nearest 1º, then we have a rounding error of up to ±0.5º. (i.e. grid bearing 0º, magnetic bearing 4.56º, reading taken 5º, rounding error = 0.44º) This error in calibration is then present and is the same for every reading, as the leg bearing is converted to a grid bearing (e.g. leg bearing 78.34º, reading taken 78º, corrected to 73º, true grid bearing 73.78º). This example shows that the grid bearing could be ±1º from the true grid bearing if the calibration and compass were read to ±0.5º. Errors accumulate! Always **calibrate to the limit of the instruments precision**.

What impact does this have on a survey? Take a simple task of surveying round a level square, which has a side aligned north-south. For illustration purposes I will exaggerate the compass calibration error to -10º.

As the survey is done using forward bearings, it produces a survey that is square and closes but is skewed by the calibration error, from the start point (Figure 1). If this was done using the leap-frog method the results would be identical!

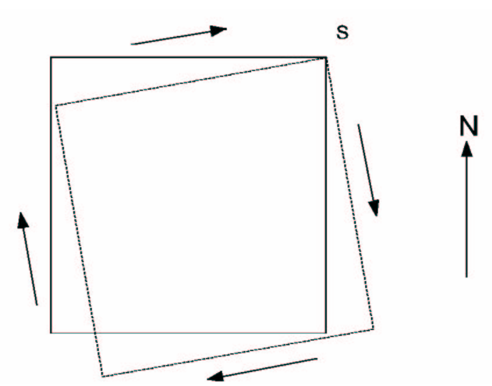

Figure 1: Forward surveying with a compass calibration error.

For a clinometer, the way a calibration error is generated is the same (i.e. rounding) but its impact can be quite different. If we repeat the task with a 10º calibration error in the clinometer, the forward method produces a survey that spirals up, with the end point above the start point (Figure 2). In contrast, the leap frog method produces a saw tooth survey and closes with the start point (Figure 3)

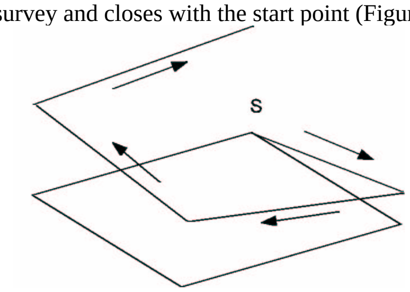

Figure 2: Forward surveying with a clinometer calibration error.

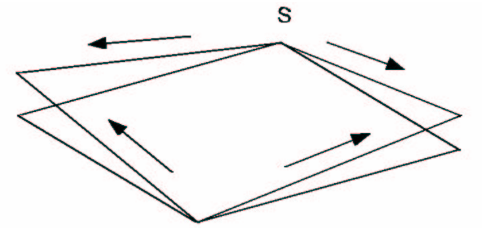

Figure 3: Leap-frog surveying with a clinometer calibration error.

So we can conclude that, if the length of the forward legs equals the length of the backward legs then the errors caused by calibrating the clinometer are cancelled out. This means that, instead of doing survey legs of 15m,5m,15m,5m, it is better to do legs of 10m,10m,10m,10m. **It is more accurate to do survey legs of consistent lengths** and generally less than 20m (an arc of 0.25º at 20m is heading out of the station position accuracy criteria).

In practice the calibration error may only be 0.5º (or 0.25º) but that could still mean an error reduction of as much as 8.73m (4.36m) per kilometre.

Blunder detection

This is a by-product of the fact that the vertical error has one less error component in it compared with the horizontal error. The main error factors are:

- horizontal component – compass calibration error, reading error, station position error, tape error;
- vertical component – reading error, station position error, tape error.

With the clinometer calibration error component having been greatly reduced by the use of the leap-frog method, when a loop closes we can expect the vertical error to be significantly less than the horizontal components (about 1/3 less). (In mainly horizontal systems this effect can be even larger).

With this fact in our minds we can quickly check the loop closure components to see if they match what we expect. If the vertical error was larger than the horizontal component then we might expect to find a blunder in the legs of the loop that have mainly vertical components (i.e. plumb legs or ones with high clinometer readings). The reverse is also true - that if the horizontal component of the loop error is much larger than the vertical we can check for blunders in the legs that have little vertical impact. This can then be split into northings and eastings to further reduce the number of legs to check for blunders. The northings may be within bounds compared to the vertical but the eastings are out etc. So not only does it give us a quick check to see if we have a blunder in a loop but it also reduces the number of legs we have to search through to find it.

So the leap-frog method has many advantages, some obvious (accuracy, non-instrument stations…) and others turn up as a by-product of the error reduction.

Finally, what happens to the clinometer calibration error if you use the forward method with back checks? The error is still in the vertical component. But if you did leap-frog with forward and back checks then the error would be cancelled out. (These are less obvious but try repeating the square traverse with a calibration error that will require rounding, say 1.3º)

So the conclusion should be that **the leap-frog method should be adopted for all high grade surveying**, with the extra option of forward and back checks if time allows. (Booking these extra readings can get messy if you don't organise it very carefully).

Part 3: Comments from the Authors of "Cave Surveying"

Anthony Day, Paul Deakin and John Eyre

In writing "Cave Surveying" it was certainly not our intention to "downgrade" the expected standards of cave surveying. The emphasis on taking back checks whenever it is practical to do so is intended to increase the chances of gross errors being spotted. The recommended practice for calibrating instruments now advocates the use of multiple points, which will help to mitigate the effects of quantisation error in calibration values as well as helping to identify gross errors in calibration readings. Therefore, we would contend that if the advice in the booklet is followed, the inexperienced surveyor – who is the primary audience for this work - will produce surveys of a higher standard than would be achieved if the instructions in earlier versions of the booklet were followed.

We seek to encourage a disciplined, methodical and yet pragmatic approach to collecting cave survey data. The revised survey grades reflect this philosophy by stating the accuracies to which stations should be established and compass, clinometer and tapes read in order to achieve the appropriate grades. By following the procedures and steps outlined in the text of the book and by integrating that system of observation with instruments of the appropriate standard and skills of the observer, the highest standards of accuracy will follow. The survey equipment, although simple, needs practice and discipline to achieve good results - a well-practised cave surveyor is likely to get good results and easily achieve the appropriate grade, whilst a novice may not achieve such good results. The important thing is to understand what is needed and apply the necessary/appropriate skill and discipline. The novice surveyor should read the table of survey grades in the context of rest of the book – hence the comment that "in all cases it is necessary to follow the spirit of the definition and not just the letter" which has been a long-standing feature of these tables of grades.

In the previous version of the survey grades, Grade 5 was defined in terms of the accuracy of individual measurements. For this definition to be useful, it is necessary to independently check the accuracy of your survey. Whilst this is obviously good practice wherever possible, in practice very few cave surveys are independently checked. They are usually either checked against other compass work or against radiolocation. We are unaware of any rigorous studies of the intrinsic accuracy of the radiolocation method, and a further potential source of inaccuracy is the identification of the surface position. In the UK, the accuracy of the detail on the OS 1/2,500 plans can be up to 30 metres out and this sort of error is more likely in remote rural areas. Surveys can be tied to the National Grid directly from passive stations in the national GPS network whose locations are available for free from the Ordnance Survey [6], though this may not be simple in all areas. The recent advent of GPS has helped picking up surface detail, but the small hand held units cannot guarantee results better than ~15m. Sub 0.1m accuracy is possible using more sophisticated units but these are expensive (£35k plus) and the base station has to be operated for about 4 hours to achieve National Grid co-ordinates to this level of accuracy. Nevertheless radiolocation is probably good enough to confirm that a compass survey is not drastically in error.

Often the only measure of the accuracy of a survey comes from loop closures, but again caution must be exercised. Paul Deakin has undertaken several theodolite surveys in caves/old mines in recent years, and has thus been able to check compass surveys independently. This exercise does not give us a great deal of confidence in compass surveys. One closed loop compass survey, which had tied in to less than a metre, was over 10 metres out part way round the loop. This was not an isolated incident, and the general observation is that many compass surveys are very good over much of their length, but severe anomalies can occur. An understanding of surveying principles is therefore desirable and the surveyor should always be making mental notes the directions and cave shape to check that readings accord with the cave. If in doubt, compass and clinometer fore and back sights should be taken and recorded for each leg. This is the recommended best practice in "Cave Surveying" and should, where time permits, be employed as a matter of course .

Taking all this into account, the conclusion is that, in practical terms, under the old system Grade 5 could only realistically be claimed for cave systems with a large number of interconnected loops, or some other independent verification of the accuracy. Even where these criteria are satisfied, great caution must be exercised when making claims about the supposed accuracy of the survey. It seems incongruous that two caves which have been surveyed by the same people using identical instruments and techniques should fall into different grades purely because the nature of the caves allows one to make an estimate of the accuracy (which may be highly dubious in light of the discussion above) for one cave but not the other. Furthermore, this booklet (and previous versions) set out to instruct the reader on how to perform a survey of Grade 5 standard, yet even strict adherence to the instructions therein does not guarantee that the resulting survey will meet that standard under a strict interpretation of the old grading system. The revised grading scheme is therefore a pragmatic response to these perceived anomalies. It represents a set of guidelines for indicating the degree of care that has been taken over a particular survey, which in itself provides a qualitative assessment of the likely accuracy. In this context, the "spirit" of the grades is all-important.

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The UIS Survey Grades and their Use in Sweden

Erik Agrell

The standard way to specify the accuracy of a Swedish cave survey is by means of the so-called UIS grades, a grading system apparently unheard of outside Sweden. This speleohistorical essay offers a partial explanation to this curiosity, tracing the origin of the grades to a recommendation by a UIS commission, which was published in 1978 but never adopted by the wider caving community.

Introduction

Ask any British cave surveyor how the accuracy of a survey is specified and the natural answer would be the BCRA grades. Cavers in many regions around the world would give the same answer, except in Australia, where the ASF grades dominate [17], and, strangely, in Sweden, a country that hardly plays any leading role in the world of speleology. Practically all not-too-old Swedish cave maps are marked with the so-called UIS (Union Internationale de Spéléologie) grades, which is the standard supported by the Swedish Speleological Society. Perhaps surprisingly to the international caving community, it is also widely believed in Sweden that this is an international standard for survey grades, recommended by the UIS. As far as I know, however, the term "UIS grades" is not used or even recognized anywhere else in the world, not even by the UIS.

The history of the UIS grading system is the topic of this article. A number of intriguing speleohistorical questions arise. What exactly are these elusive UIS grades? Why are they used in Sweden and nowhere else? And is there really, or was there, a standard for survey grades approved by the UIS?

Background: the CRG and BCRA Grades

The UIS grades used in Sweden today are a seven-grade system, which bears a striking resemblance to the BCRA grades and their predecessor, the CRG grades. It is evident that they have the same origin. Let us therefore go back to 1950, when the history of survey grades can be said to begin.

In 1950, the Cave Research Group (CRG) of Great Britain published a 40-page report by A. L. Butcher called "Cave Survey" [1]. It suggests that the accuracy of cave maps should be classified according to a grading system in seven steps, ranging from 1 for a sketch from memory to 7 for theodolite surveys.

A revised version was published in 1966 by Butcher and Railton [2]. The main contribution therein is the introduction of the letters A–D to indicate the accuracy of passage detail. Some more numerical values than in [1] were given to indicate the measurement errors for various grades.

A substantial revision was produced by Bryan Ellis in 1973 [3]. The significant changes in this version are the definitions of grades 2 and 4 as intermediate grades, not recommended for general use, and the replacement of grade 7 with grade X, to acknowledge the fact that a theodolite survey may yield an accuracy corresponding to any grade from 3 to 6. The requirements are given in terms of precision for the lower grades and accuracy for the higher grades, which was not explicitly done in earlier versions. Another novelty is that station position error is considered.

Soon after the CRG merged with the British Speleological Association to form the BCRA, the grades were revised again. The BCRA grades, also developed under Ellis' leadership, were first published in 1975 [4] but were disseminated to a wider audience through Ellis' book "Surveying Caves" [5] which was published the following year. A list of notes was included to clarify some aspects of the grade definitions, and the notation for the required precision/accuracy was modified.

Thereafter the BCRA grades were reprinted many times, notably in Ellis' booklet "An Introduction to Cave Surveying" in 1988 [11]. The strength of these grades is manifested by the fact that they remained unrevised until 2002, when the next edition of this booklet appeared (see [19]). The popularity of the BCRA grades has spread far outside Great Britain and they are today the most used survey grades in the world. Exceptions are Australia and Sweden, as mentioned above, and the U.S.A., where the accuracy of a cave survey is normally denoted by means other than survey grades [12].

The Green Report

Until 1977, there was a UIS commission called the "Sub-Commission of Conventional Signs", whose purpose was to standardize map symbols for caves and karst landscapes. A set of symbols was adopted and revised several times over the years. At the 1977 UIS congress in Sheffield, the UIS commissions were reorganised and the standardization of map symbols was taken over by the Commission for Topography and Cartography. In 1978, a multilingual 44-page report entitled "Speleological conventional signs" was published [6]. The report presents the final revision of the symbol set by the outgoing Sub-Commission of Conventional Signs, according to its two forewords, one by the UIS president Arrigo A. Cigna and the other by the authors Maurice Audetat and Guilhem Fabre. Incidentally, this symbol set differs substantially from that which is commonly used today [16]. The top of the green cover reads "International Speleological Union: Sub-Commission of Conventional Signs", which may give the impression of an official UIS publication, but on the other hand, it is published in the report series of the Centre d'Etudes et de Recherches Géologiques et Hydrogéologiques in Montpellier, France.

The report [6] appears to be little known among cavers today, in Sweden as well as internationally. Nevertheless, one detail in the report has had a tangible impact on Swedish caving, and still has. This is Table 1 on page 21, called "System for grading surveys of cave plans", which defines a scale in seven steps for the accuracy of cave maps. The source is not explicitly acknowledged and no organisation is associated with the grades, neither CRG nor BCRA, but they are not called UIS grades either. Seven names are listed above the table, including A. L. Bucher, E. B. Ellis and C. L. Railton. "Bucher" obviously refers to Butcher, mentioned above. Is E. B. Ellis a relative of Bryan M. Ellis, also mentioned above? Most likely not. No Ellis with the initials E. B. is known among British cavers today, but, as Olly Betts suggested to the cave-surveying email list in March 2002, the initials might have been a misinterpretation of "Ed. B. Ellis" in reference to one of Bryan's publications, where "Ed." means editor but might have been read as the first name.

It is perhaps not too surprising that the survey grades in the report [6] resemble the British survey grades a lot. What is more surprising is the fact that they resemble the original British grades of 1950 [1] more closely than any of the revisions 1966, 1973 or 1975. In fact, the grades in [6] are almost identical to those in [1], except that two specifications of station error and one of angular error have been added in [6]. (It is possible that these details were added to the CRG recommendations between 1950 and 1966—the reference list of [6] lists three publications by Butcher or Railton in the period, which I have not had the opportunity to read.) Why the grades were crafted after such an early version is hard to explain. One would have expected leading speleologists to have been aware of the revisions, even though the British grades were likely not as widely known internationally in the 1970s as they are today. One might suspect that the British cavers were not personally much involved with producing the table of survey grades in [6], contrary to the impression conveyed by the list of names above the table. Further evidence for the same conclusion is the mistyped names.

The Introduction of the UIS Grades in Sweden

A group of Swedish cavers attended the 1977 UIS congress in Sheffield and one of them met Dr. Guilhem Fabre, who informed about the UIS commission he was leading and the report to be published. The Swedish caver asked Dr. Fabre to send the report, having no reason to doubt that it was an official UIS document, and when it was received, he encouraged its adoption by Swedish cavers [20]. In 1979 there was a short notice in Grottan, the quarterly journal of the Swedish Speleological Society [8], pointing out that the report had been published and could be borrowed from the Society's library or ordered from Montpellier. At that time, Swedish cave surveyors generally used BCRA grades.

The first mention of the term "UIS grades" known to me is in the first issue of Grottan in 1980, in a long article about karst caves in the far north of Sweden [10]. It says, translated from Swedish, "For the cave maps to be presented, the survey accuracy is given in a new seven-grade scale, which differs slightly from the BCRA scale used earlier. This new scale is recommended by the UIS (International Speleological Union) in a newly published survey manual", referring to [6]. The article continues with a translation into Swedish of Table 1 in [6], in which the grades are called UIS grades. (Recall that they were not even in [6] called "UIS grades".) The same article contains the first known (to me) cave maps marked with UIS grades.

There was a vague recommendation already in the last issue of Grottan in 1978 that "measurements and survey should obviously be done according to the UIS norms" in an article soliciting input for a forthcoming cave catalogue [7], with a reference to Bryan Ellis' "Surveying Caves" [5]. It is not clear if "UIS norms" refers to the map symbols only or to the survey grades, nor where the reader was supposed to have learnt about either. The grades recommended in "Surveying Caves" are, of course, the BCRA grades and the UIS is not mentioned anywhere in this book. It seems possible that the author of [7], who was in contact with the cavers who attended the congress in Sheffield [20], might have been aware that a recommendation of the UIS grades would soon be published in Grottan and was implicitly referring to this future publication.

After 1980, the UIS grades penetrated the Swedish caving community rapidly. A few scattered surveys marked with CRG or BCRA grades were still seen in the early 1980s, but since then, all Swedish cave surveys that I am aware of use the UIS grades. The main topic of the report [6], however, was not the survey grades but the set of map symbols. This set does not appear to have been similarly announced to the Swedish caving community.

Twenty years have passed and we have now recently seen another UIS working group complete its work on cave map symbols, namely, the working group of Basic Cave Mapping Symbols within the UIS Informatics Commission, which completed its work in 1999 [18]. The proposal was thoroughly debated at the 1997 UIS congress and the final decision was taken by voting among the delegates [16]. Contrary to the 1978 recommendation, the new set of cave map symbols has attained wide acceptance worldwide, including in Sweden, where it was published in [14]. The symbol set does not say anything about survey grades, but there have been some informal discussions within the UIS on the possibility of having a working group look at the standardization of survey grades too in the future, taking into account not only the accuracy of measurements but also that of the map drawing [15]. If this happens, the new UIS grades will definitely be different from what we today know as UIS grades in Sweden, which may cause some confusion.

Reflections, Part 1: Why in Sweden?

After this historical overview, we are now better prepared to look into the intriguing question of why the grades of [6] were adopted in Sweden but apparently not anywhere else. This is where the fun part begins, at least for the author, extending dry facts to relations of cause and effect. Questions of "why" are generally harder to answer than "when" and "where" and more open to subjective judgement. This section and the next summarise the factors that I have identified as significant in the development. Other cavers are welcome to share their thoughts and experiences.

In retrospect, it seems natural that Sweden adopted the recommendations of the green report [6] unquestioningly, once a copy of the report found its way there in 1978 or 1979. The following factors may have contributed to this result.

1. The report gives the impression of being an official UIS report. It says "UIS" prominently on the front cover and has a foreword by the UIS president. It would not be obvious to a reader without access to other sources that the report does not follow standard channels for dissemination of UIS information.
2. Dr. Fabre, in an informal conversation with a Swedish caver in 1977, conveyed the impression that the report was an official UIS document. Even though the Swedish cavers at the time had contacts with the BCRA, including Bryan Ellis personally, an international standard was supposed to supersede a national one.
3. No one wants to adopt a standard alone. Only if a sufficient number of people, a "critical mass", simultaneously decide to adopt a change will there be a new de facto standard. Since Swedish speleology at that time was centred around a small core group of cavers with very close contact with each other, the critical mass was lower here than in larger caving nations or organisations.
4. At the time, Swedish speleology may have interacted less closely with the leading European caving organisations than these did with each other, at least regarding surveying projects. Even today, few foreign cavers find their way to Sweden to join survey projects, presumably for geological reasons. (The longest and deepest Swedish caves known in 1979 were 2320 and 135 metres long and deep respectively [9].)
5. It is sometimes said that respect for rules and authorities is an integral part of the national character of the Swedish people. If there is some truth to the statement, which may well be debated, it may have played a role in the ready acceptance of what appeared to be a UIS standard. In this case, however, the Swedish desire to follow international conventions paradoxically led to the opposite result.

Reflections, Part 2: Why not Elsewhere?

The second side of the enigma is why countries other than Sweden appear to have ignored the green report [6] and, in particular, why the major caving nations and organisations did so. The following factors may have played roles in this development.

1. The proposed standard was published in a relatively unknown series of reports from a French university. From what I have heard, it was not published in any of the major caving journals or "marketed" in other ways. The lesson to be learnt is that in a successful standardization project, deciding the actual standard is just part of the work; there must also be a carefully prepared plan for the dissemination and realization of the standard.
2. Even if individual cavers obtained and read the report, people are reluctant to adopt a standard that is believed to be unknown to the majority. This boils down to the "critical mass" of people accepting a change, which, as indicated in the previous section, is higher for large organisations or groups of interacting organisations.
3. The table of survey grades in [6] reflects a very old scale and ignores decades of progress in Britain. Cave surveyors who read the report when it was published in 1978 may well have had the CRG/BCRA revisions 1973 and 1975 fresh in mind and therefore rejected the suggested grades.
4. Even disregarding the obsolete source, the table does not give the impression of being very carefully prepared, nor very respectful to its British originators. No explanatory text is given

with the table, CRG or BCRA is not acknowledged and the names of two of the alleged contributors are incorrectly written.

5. Among the few cave surveyors who remember the green report and its contents (I know only one), the proposed set of map symbols is not highly appreciated. The symbols are impractically numerous, especially the karst surface symbols. The set includes no less than 48 symbols for various kinds of cave entrances and other "exterior orifices". As Bryan Ellis himself pointed out, without discussing [6] specifically, "if a list of symbols is short there is a good chance that it will soon be learnt by heart and used but if it isn't, well...." [13].

6. Even though the report represents the output of an officially appointed UIS commission, there is no indication that the UIS delegates ever took a decision to support the recommendations published in the report. The authors represent a commission that had ceased to exist already at the time of publication [6].

Acknowledgements

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Proving Survey Accuracy

John Stevens

This article describes a method for determining the accuracy of your survey, for the purpose of assigning its grade according to the author's proposed grading scheme (see earlier article in this issue), using loop misclosures.

How do we determine the accuracy of a survey? In the Ellis definition of a Grade 5 survey, we have the following statements.

Grade 5 A Magnetic Survey. Horizontal & vertical angles accurate to ±1º; distances accurate to ±10cm; station position error less than 10cm.

***Accuracy** means the nearness of a result to the true value: it must not be confused with **precision** which is the nearness of a number of repeat results to each other, irrespective of their accuracy.*

When I first came across these, I was unsure how to prove a survey was accurate rather than just precise. I came to the conclusion that the only way to prove that a survey was accurate was by checking any loops in the survey - without loops it was not possible.

We have various items to check to prove accuracy, horizontal and vertical angles, distances from station to station and the station position.

Starting with a simple survey with one closed loop. When the loop is closed the misclosure (the distance between the beginning and end of the loop, which are known to be the same point in reality) is distributed around the legs of the loop. Various methods can be used to distribute this closure error. One way to check the accuracy would be to calculate the new bearing, declination and distance measurements that would be required for each new leg of the closed loop and compare these readings to the original measurements for each leg. These new measurements represent an estimate of the true values based on the closure error distribution model you have used.

The difference between the new and original measurements would then need to be within the Grade 5 criteria. What is seen in practice is that the longest leg in the loop is the closest to being out of range. The 10cm station position criterion is the mostly likely to be exceeded, whilst the angular measurements are still within their specified bounds. This is because most methods of distributing the closure error assign the longer legs with appropriately larger portions of the misclosure. For example, a leg of 30m, with bearings taken to the nearest degree means the bearing is accurate to ±0.5º, but the station position will be within an arc, 30 x tan(0.5) = 0.26m. This is well outside the station position criterion, hence I recommend the maximum survey leg length to be 20m. This would still be outside the range but is a practical large leg without adding too many legs to a survey whilst reducing the average leg length.

If a system of accuracy is to be adopted, it needs to be able to compare different loops without comparing hundreds of legs. To that end it was found that it is enough to generate some facts about the whole loop.

Loop length *L*, number of legs in loop *N*, Loop misclosure error *E*, (*dx*, *dy*, *dz* in its three dimensions).

A. Change in horizontal components, $\arctan\left(\frac{\sqrt{dx^2+dy^2}}{L}\right)$.

B. Change in vertical component, $\arctan\left(\frac{dz}{L}\right)$.

C. Overall angular error, $\arctan\left(\frac{\sqrt{dx^2+dy^2+dz^2}}{L}\right)=\arctan\left(\frac{E}{L}\right)$.

D. Change in average leg length, $\frac{\sqrt{dx^2+dy^2+dz^2}}{N}=\frac{E}{N}$.

B corresponds to an equivalent change in clinometer calibration for the loop to close vertically if we were using forward only readings. A and C are angular measurements relating to the horizontal and total movement of the misclosure.

A and B should be less than 0.5º as readings are required to be accurate to the nearest degree. C is just a combination of A and B to give a single figure that should also be less than 0.5º. tan 0.5 = 0.008727. Hence if the ratio of the loop misclosure to the loop length is less than 0.87% then the loop is within the Grade 5 angular criteria (*E*/*L* < 0.87%). D is an average, and experience has shown that the longest leg is normally 2.5 to 3 times the average leg length (using maximum 20m legs). As the longest leg should be within the 10cm position error, the average needs to be less (3-4cm).

So by using the above, we can check a single loop. However, things get a bit more complex when we start dealing with several interconnecting loops. Algorithms to close these again vary. A program like Survex uses a least-squares method, by cutting the loops into segments and then solves the equations. Each segment is then given a misclosure error that is distributed between its legs. Survex gives a nice overview figure for the movement of each leg in a segment. This should be less then 10cm to meet the accuracy criterion. Personally I still prefer to check each loop individually with the other loops removed as it gives a better overall idea of the accuracy of the whole loop rather than a segment of it. Some small segments can show up with large errors, even though the whole loops around it close well but that is due to the interconnectivity. (I would have liked to see an option for loop statistics in Survex, with each possible loop created and statistics generated. It could get messy for complex systems but it may be worth considering as part of a blunder detection option).

In summary, we can check each leg for accuracy but if we want a set of figures we can easily use to check accuracy of a survey loop we need to generate some loop facts. Table 3 illustrates what I would like to see published as the norm on all surveys claiming the higher grades, using Ogof Draenen as an example. This table is far from complete as the system has in excess of 100 loops. Many of these are small but several other 100+ and 50+ leg loops exist.

The first section of constructed loops covers very large loops that comprise several smaller loops. These then cover a larger area of the system and give a good idea of the whole survey accuracy. The next group are minimum sized loops, or loops using the shortest number of legs and distance to create. They may have other interconnecting loops but these do not create a shorter loop. They are then ordered by size. The longest will have a greater statistical significance on the accuracy of the work.

As is shown in Table 3, even small loops can have remarkably small closure errors. The other point worth noting is the consistent small vertical misclosure compared with the horizontal misclosure. I put this down to using the leap-frog method, careful bookkeeping and a general low gradient in the system.

Ogof Draenen										
Loop description	Loop length (m)	Loop error (m)	Error (%)	No. of legs	Error per leg (cm)	Grade Achieved (*)	Easting error (m) (*)	Northing error (m) (*)	Horiz. error (m) (*)	Vert. error (m) (*)
Constructed large loops										
"Long Round Trip, WA-indi-mega-fault rifts-wyvern-agent b-mainstream"	5082.55	11.23	0.22%	614	1.83	6	10.77	3.11	11.21	0.72
Minimum size loops: >100 legs										
"Short Round Trip, white arch-indi-mega-squirrel-agent b-mainstream"	4157.88	2.15	0.05%	481	0.45	6	0.45	2.1	2.15	0.14
Players – Squirrel –Haggis – Wyvern - Fault Rifts – Perseverance	2196.69	11.94	0.54%	292	4.09	5	10.89	4.8	11.90	0.97
The Score - Oo Crawl – Mainstream – BackPassage.	1314.02	2.40	0.18%	159	1.51	6	2.15	1	2.37	0.37
Aces High - Red Baron - Baron von Carno - Run.Com.	850.28	4.32	0.51%	138	3.13	5	4.01	1.45	4.26	0.72
Nevell Hall - Passchendaele - Baron von Carno	569.64	2.98	0.52%	102	2.92	5	0.97	2.77	2.93	0.49
Gone with the Wind-Gone in the Years-Rogered Senseless	861.81	8.29	0.96%	100	8.29	4-5? (1)	6.04	5.32	8.05	1.97
>50legs										
Violate - Running Com. – Kababarama	515.12	11.50	2.23%	97	11.86	4 (2)	10.81	3.66	11.41	1.44
Canyon East - Canyon West	610.31	3.44	0.56%	71	4.84	5	2.79	1.38	3.11	1.46
>25legs (*)										
"Megadrive, Northern Loop"	395.14	0.37	0.09%	38	0.96	6	0.14	0.32	0.35	0.11

Notes:

(1) This loop is close to being out of range to meet the criteria and probably contains an undetected blunder. As the loop has little interconnectivity with other loops, it has not been possible to find the blunder.

(2) This loop does contain a blunder and as the area has high interconnectivity, over half the loop has been cleared of containing the mistake. The easting misclosure shows the blunder to have large component in this direction.

Table 3: Proposed format for a table of loop closure statistics, using Ogof Draenen as an example. Columns marked (*) are optional.

To summarise, accuracy can be measured and surveys compared if we use a few simple facts to compare closed loops. We can use the detailed loop closure information (as provided by Survex) of multiple loops to help detect blunders but these give too much data to make easy comparisons.

So for ease of use and a slight relaxing of the old criteria, we can use:

- percentage of Misclosure Error/Loop Length < 1% and Misclosure Error/ Number of Legs in loop < 5cm, for Grade 5;
- percentage of Misclosure Error/Loop Length < 0.5% and Misclosure Error/ Number of Legs in loop < 2.5cm, for Grade 6.

As in the guidelines for the grades, it is the spirit of the work that counts not the precise letter of the grades. If you think that the data in Table 3 is unusual, then other projects have achieved similar closure percentages. It is not impossible; it just takes care and technique.

Sightseeing

Jos Burgers

The question “Is the compass error human or instrumental?” came up during a surveying session in OFD. Jos Burgers describes the statistical analysis of data obtained from twelve people and six compasses. The results show that it is an instrumental error, and the readings are normally distributed.

In October last year, I went on a survey trip in OFD during the CSG field meet. It was nothing special, just a trip to map a chamber very near the top entrance. I had a wonderful trip and enjoyed the exchange of ideas and experience. Before we entered we did a kind of a calibration reading with the compass. I thought that the reference bearing was too far away - I could hardly see the point I had to aim on. As a civil surveyor we never take a reference bearing to points that are more than one and a half times the distance of the longest measurement taken during mapping. In fact we do this calculation the other way round; we never make a longer measurement than our longest reference bearing, and preferable within two thirds of that distance. It is usual practice to read a single bearing between known reference points to orient the grid, then, as in the army, calibrate the compass before and after surveying at a series of four closely spaced points.

But that was not the thing that puzzled me most. The guys stated that the compass error was related to the instrument man, the surveyor, as well as the compass. This was inconsistent with what I had learned before, which was that the error was entirely compass related. This did not matter much for this survey - the correction was linked to one person and one compass and corrected during the post-processing.

At home I gave it more thought and I remembered that I had a data set that could provide an answer. I had given a course on mapping, GPS and such. Handling the compass was one of the items. For this purpose the exercise was to read a bearing with the compass placed on a pole to a fixed point at a distance of 50m. This was done by all the twelve people and with six different compasses. The results are shown in Table 4.

	A	B	C	D	E	F
1	308.2	308.5	310	307.8	308.8	308.3
2	307.5	308.5	311.5	308.3	308.3	308.3
3	308	308	312	309	308.5	309
4	307	310	312.3	308.2	308.1	309.4
5	308	310	312.5	309.5	309	309
6	308	310	310	309	309	309
7	308	309.2	311.2	308	308.7	308.2
8	308	308.5	312	309	308	308
9	309	308	311.5	308.5	308	309.5
10	308	309	313	308	309.5	308
11	308.5	308.8	311.5	308.1	308.8	308.6
12	308	309	311.7	308.5	309	308

Table 4: Bearings read by 12 surveyors (1-12) using each of 6 compasses (A-F). All bearings are in grades.

By inspection of the data set, conclusions are easily drawn. (I corrected one person because he had very obviously misread the compass – I must give a few more instructions next time). But what would science have to say about this? Biologists are great with statistics, so I asked Martijn Boonman to put the data into his machine. This is what he came up with:

Hi Jos

I worked out the data. I analysed the stuff with analysis of variance (Anova). There was no significant effect related to the instrument reader (F=1.12 df=11.55 p=0.05). In other words, you can combine the data from different people. A survey may be composed from the measurements from different surveyors.

There is, however, a significant dependence on the compasses (F=51.22 df=5.55 p<0.01). This means that there are differences between the compasses. Consequently you cannot just combine data from different compasses, but have to look at them separately.

The mean compass reading was 309.05 grade with a standard deviation of 1.32. 95% of the readings where within the 2×standard deviation limits, i.e. 95% of all the readings are between 306.41 and 311.69 grades (the 95% confidence interval). Put the other way around you can say that the chance of a reading that deviates by more than 2.64 grades from the mean is less than 5%.

You must be careful with drawing conclusions with this set of data. For example, it is possible that one compass screws up the whole data set and if you leave this compass out you could end up with no compass error at all. Besides that, you took only one bearing. If you were to take a more difficult "to station" in a muddy cave it is possible that the standard deviation would be wider.

Grotjes Martijn

Anova works by grouping the data by a particular variable (instrument reader and compass in this example) and calculating the mean value for each group. The F value is the ratio of the actual variance in the mean values of the groups to the expected variance. Hence an F value of 1 indicates that the data are independent of the parameter being tested, whereas larger values of F indicate that at least one of the groups has a mean that is significantly different from that of the whole dataset. The p value denotes the probability of this discrepancy occurring by chance (hence small p values indicate a high degree of confidence in the result). The F value of 1.12 when the data are grouped by surveyor indicates no significant dependence on the surveyor, whilst the F value of 51.22 when grouped by compass implies a strong dependence on this variable.

This statistical analysis suggests that, for this data set, instrumental error is dominant over person error, and the readings are normally distributed. I think it would be useful to conduct a larger experiment with more people and more different bearings, for example at our annual meeting - with a little more instruction provided of course.

GPS Co-ordinate Transformations: an Overview

Lev Bishop

In Issue 27 of Compass Points, Michael Behm presented an introduction to geodesy with particular reference to GPS, highlighting the many opportunities for making mistakes when processing GPS data. This article illustrates how the concepts introduced in that earlier article are implemented in practice, and describes the capabilities and limitations of some of the available co-ordinate transformation tools.

A frequent problem that occurs when using GPS for locating surface features is the need to transform co-ordinates from the native GPS co-ordinates to some other co-ordinate system. For example, you might wish to obtain UK national grid co-ordinates so the features can be located on a map. Although hand-held GPS receivers of the kind that are available on a typical caver's budget can usually provide co-ordinates in many different systems, the transformations that they use internally are usually somewhat simplified. Hence, depending on the use to which the co-ordinates are to be put, the results obtained from a hand-held unit may not be sufficiently accurate. This article sets out to explain why what may appear to be a relatively simple co-ordinate transformation problem can, in practice, be horribly complicated or even impossible. Some of the tools that are available to help in this task are also briefly reviewed.

Before embarking on this discussion, it is necessary to introduce some terminology. Michael Behm presented an introduction to the basic concepts in geodesy including the geoid, ellipsoids, geodetic datums and map projections, in issue 27 of Compass Points [1] - this material will not be covered again here. Much of the additional introductory material in this article has been derived from a document produced by the Ordnance Survey of Great Britain (OSGB) entitled "A guide to co-ordinate systems in Great Britain" which is available online [2]. This document gives an excellent overview of grid systems, height datums, co-ordinate system conversions, various equations for converting latitude and longitude to and from grid co-ordinates, latitude-longitude to and from Cartesian co-ordinates, and so forth. It is very useful, non-mathematical and easy-to-read - anyone who needs to convert co-ordinates should read it to get the "big picture".

Terminology

When dealing with co-ordinate transformations, it is important to understand the difference between a Terrestrial Reference System and a Terrestrial Reference Frame. The distinction is described in detail, with examples, in the OSGB guide [2] - a brief overview is given here.

A Terrestrial Reference System (TRS) is simply a geometrical reference frame in which co-ordinates can be defined. WGS84, the co-ordinate system of GPS, is an example of a TRS. It is an alternative term for a geodetic datum as defined in [1], which also describes how co-ordinates may be converted between different TRSs by means of relatively simple transformations. The seven-parameter transformations described in [1] are termed Helmert transforms. An alternative method is to use a Molodensky transformation to convert between latitude-longitude co-ordinates in different TRSs - however this transformation cannot cope if the ellipsoid axes in the two TRSs have different orientations.

In order to realise a TRS in practice, we need a set of points whose positions are known. Such a set of points makes up a Terrestrial Reference Frame (TRF). The set of satellite stations used by the GPS system are an example of a TRF; another example is the network of triangulation points found across Great Britain. The critical difference between a TRF and a TRS is that the positions of these known points have been measured, and are therefore subject to error. By contrast, a TRS is simply a set of geometrical conventions, and as such is error free by definition. The amount of distortion that the errors in a particular TRF introduce will vary depending on the accuracy with which the positions of the reference points were determined.

This distinction between a TRF and a TRS becomes important when you want to convert co-ordinates between grid systems. For example, in Great Britain, National Grid references are obtained from a Transverse Mercator projection of latitude-longitude values that are defined with respect to the OSGB36 (Ordnance Survey Great Britain 1936) TRF, which was originally defined by triangulation. This TRF is a realisation of the OSGB36 TRS, which uses the Airy 1830 ellipsoid. Many hand-held GPS units can output co-ordinates in the British National Grid. In order to calculate these co-ordinates, the unit must perform some sort of transformation between WGS-84 co-ordinates (the TRS of the GPS network) and OSGB36. The problem is that, in order to convert precisely from WGS-84 to the OSGB36 TRF just under two million parameters are required due to the distortion of the TRF - and that's just for the UK. Clearly no GPS unit is going to devote several megabytes of RAM to doing precise conversions per country.

The manufacturers of GPS units do not provide details of the formulae they use, but it seems likely that they perform a TRS conversion rather than a TRF conversion. For the UK, if a full Helmert transformation is done you can achieve accuracies in the conversion of about 5m. For larger land masses than the UK, or in places where the surveying was not as careful as in the UK and the TRF is more distorted, the discrepancies could be much larger. Also bear in mind that many countries consider precise mapping a matter of national security and thus accurate TRS conversion parameters may not be available for all areas, let alone TRF parameters. On top of this, the actual equations for the full Helmert conversion require fairly complicated iterative procedures to calculate. It is likely that most receivers will instead use the simplified Molodensky transforms which do not proceed via Cartesian co-ordinates and are thus simpler and faster to evaluate, but less accurate still because they do not include the rotation parameters. A further problem with using the conversions built into GPS units (most of which are also limited to Transverse-Mercator/Gauss-Krüger type grids) is that they frequently do not use the official names for the datums, and, since you cannot access the underlying equations, you can never be sure whether the GPS units' "Europe" datum is supposed to be the ED50 datum or some other one. All in all it is almost certainly best to record GPS positions in WGS-84 and use some other software to convert co-ordinates - at least that way you know what is happening to your data.

Co-ordinate Transformation Tools

There are a number of tools available that can perform transformations between co-ordinate systems. Firstly, GEO [3] can do conversions between TRSs but cannot convert between TRFs. This means that it may or may not be very accurate in any given situation - for example, it could manage about 5m accuracy in the UK. It can only convert between grids that are a variant of Transverse Mercator (aka Gauss-Krüger) projections, which covers many national grids but not all of them (e.g. France has a Lambert conformal conic projection, Switzerland has a double projection first onto a sphere and then onto the plane, etc.). It is capable of 7-parameter Helmert transformations, but the `datum.cfg` file supplied with it has only 3-parameter transformations (almost certainly taken from NIMA technical report TR8350.2 [4]) in all but 2 cases - so you would have edit it with your own Helmert parameters. (One place to find them is from NATO [5]. For the UK the Helmert parameters are given in the OSGB guide [2].) GEO is also a bit difficult to use because it uses a scripting language that can be a bit cryptic.

An alternative is Tralaine [6], which is a bit easier to use and a lot more full-featured. It can deal with all sorts of crazy grid projections (oblique Mercator, Modified Polyconic Azimuthal

Equal Area, etc., etc.) has a nice windows interface but is definitely not Free. I think most, if not all, of its conversions are between TRSs and hence at the 5m or worse accuracy level but it might be able to do TRF conversions in special cases where it has the parameters (I haven't looked closely enough to be sure).

For the UK there is a program OSTN02 [7] which converts between WGS-84 (realised as ETRS-89 – a Europe-fixed version of WGS-84 - in high accuracy surveys) and OSGB36 (the reference frame of the national grid). This is a full TRF converter. In fact OSGB36 is now *defined* by the results of OSTN02 when applied to ETRS-89 co-ordinates. Since this tool is free and precise there is no reason not to use it for UK projects. Similar programs may be available from other countries' mapping agencies. I think Australia and the USA at least have a similar scheme whereby the national TRF is defined by such a program.

Heights

Height datums are traditionally separate to horizontal datums for practical surveying reasons. A distinction needs to be made between orthometric heights (heights relative to a geoid) and ellipsoid heights (heights relative to an ellipsoidal approximation to a geoid). Heights on British OS maps are orthometric heights relative to Ordnance Datum Newlyn (ODN) - mean sea level as measured at the tide gauge at Newlyn between 1915 and 1921 - and realised by a TRF obtained by a spirit level survey from this point. By contrast, GPS heights are relative to the WGS-84 ellipsoid. Since geoids are irregular in shape, the geoid ellipsoid separation is not constant over wide areas. For this reason, it is even trickier to convert between local and global height references than for the horizontal case.

Thankfully the height readings obtained from hand-held GPS units are usually not sufficiently accurate for this to be a problem, and instead you are stuck with reading contours off a map or using a barometric altimeter (calibrated of necessity to a height reference in the local system). There are differences of up to 100m between ellipsoid height and geoid height, but I think modern GPS receivers never output ellipsoid height but rather have their own geoid model internally (likely based on a truncated version of the order and degree 360 spherical harmonic expansion of EGM96 global geoid model (which has 130317 parameters in its full form)). This will give some kind of height-above-MSL output from the unit with unspecified conversion accuracy but almost certainly swamped by the receiver's height measurement error rather than the geoid model's accuracy (except perhaps when WAAS – wide-area augmentation system - or similar is used, or when the unit has a built in altimeter as well (as in the case of some of the Garmin eTrex models)). If we wanted to attempt to perform accurate height conversions it would be necessary to remove the GPS's built-in and unknown geoid model before applying our own vertical datum conversion to it. This will be near impossible unless we can discover the details of the internal geoid model from the manufacturer (unlikely). However, as I indicated all of this is frequently irrelevant because the measurement error of a consumer GPS unit in the vertical dimension is nearly always going to be the limiting factor. Calibrated altimeters are required to obtain improved accuracy – see [8] for data processing of those appropriate to cavers' uses.

For the UK, there is a programme OSGM02 [7] which converts from WGS-84 (ETRS-89) ellipsoid heights to ODN heights. ODN is not defined by OSGM02, but OSGM02 matches to within 2cm to ODN. If you use OSGM02, be aware that it needs ellipsoid heights as input and, as I stated above, I am pretty sure that no hand-held GPS units actually give you the ellipsoid height, so there may be no point in using OSGM02 or indeed in trying to convert the height datum at all.

Summary

At the end of the day, if all you want to do is to fix a bunch of entrances using GPS then, since only <u>relative</u> positions matter, you don't even need to convert co-ordinates. If you have a dataset where some fixes come from GPS and others come from a local TRF, e.g. surface surveys to triangulation points or mountain peaks, features read off maps, etc., then you will need to do some co-ordinate conversion. In the UK and some other countries there is software to do the conversion precisely because that is the definition of the conversion. In other cases you will have to use approximate conversions, which might be off by maybe 50m if all you have is Molodensky coefficients for a large area and are unlucky, or maybe 5m if you have the 7 Helmert coefficients. Still, doing the conversion is better than not doing the conversion because if you do not you could be as much as a kilometre out.

If your mapping area is small and thus TRF distortion is small across it, you can always measure the transformation from WGS-84 to local co-ordinates simply by taking GPS readings at four or more points with known co-ordinates in the local system and then fitting a translate-scale-rotate transformation between the systems. Taking more than 4 points will allow you to estimate the error in this process, and of course you will want to space these "control points" evenly across your area of interest.

To reiterate: read the OSGB guide and reach enlightenment.

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A Bibliography of Cave Radiolocation

David Gibson

Over the years, David Gibson has written a number of articles on cave radiolocation. Here he provides a bibliography of these articles, plus one or two other recent contributions by other authors.

As far as practical radiolocation goes, a definitive guide is still Dick Glover's contribution [1] which also includes some useful historical information. That reference is long out of print, but recently Stuart France wrote a description [2] of the technique in CREG's occasional series on radiolocation. That series is, essentially, my ongoing attempt to collate all the information, for eventual assembly into a textbook. The range of topics to be included was given in [3].

If your forays into radiolocation involve nothing more than "traditional" ground-zero determination then there is little else to say - but otherwise there is much else to discuss. For example, the subject of errors is hardly ever discussed; with surveyors sometimes stating - without due regard for the likely errors - that radiolocation can "correct" their survey. If performed properly, determination of ground zero is usually pretty accurate. In fact, it is more accurate than you might expect, for two reasons. Firstly, there is the "thirds rule" [4] which explains why the tilt of the transmitter does not affect the result as much as you might expect, and secondly, the fact that the care with which the wire is wound onto the antennas does not matter significantly [5].

Although GZ can be well-determined, the same is not true of depth determination. I outlined the reasons qualitatively in [6] where I mainly discussed electromagnetic and geophysical effects. I recently followed this up with a detailed analysis of these "secondary field" effects [7,8]. On the other hand, in [4] I described the errors in depth determination that were introduced simply by tilting the antenna.

Another contribution to errors in depth determination is caused by the geomorphology of the ground. Basically, radiolocation relies on the magnetic field from the antenna having a known shape. If the frequency is low enough, or the rock dry enough, or the distances small enough, then the rock is essentially 'transparent'. But if those conditions are not met, then the rock distorts the field (even in the absence of any magnetic ore bodies) and the distortion is likely to be different in different directions. Ian Drummond noticed this when he was making measurements at Lechuguilla Cave some time ago. His report, written for the National Park authorities, remained unpublished until last year, when I decided CREG readers ought to see it [9]. (On the theoretical side, as well as my analysis, given in [7,8] I should also mention Reno Lippold's work, [10,11]).

One result of my analysis of the field behaviour was to confirm a practical observation of Brian Pease's, which is that, although radiolocation can be inaccurate at depth, there are algorithmic methods to counteract this. I extended his scheme and devised a method that completely eradicated depth error due to ground conductivity, described in [8]. (Or, at least, I showed it in theory - practical confirmation I leave to others, who have not tried it yet).

Most radiolocation involves finding the location of a fixed underground transmitter from surface measurements. However, sometimes cave-to-cave location is required. Although the "experts" in practical radiolocation know how to do this, it is yet another area that is not well-documented - a generalised method is given in [12].

Another "advance" in radiolocation would be to implement a GPS-like system. Satellite GPS is clearly impossible underground, because the high frequencies do not penetrate. Even if very low frequencies were used it would be extremely difficult to implement because it relies on "time of flight" measurements, and the propagation speed underground is unknown and variable; and severely affected by phase errors in the equipment. However, a GPS-like system could be implemented by measuring field magnitude and angle. I described this in [13] although nobody seems to have taken up the challenge. Recently, Richard Rushton devised a variation on my method [14]. I extended this with some comments in [15] and we dubbed the method "trigonometric radiolocation". Essentially this works in one of two ways - either you use a single transmitter and make measurements from multiple surveyed receiver locations; or you use multiple transmitters and make measurements relative to each one from a single receiver location. Although, ultimately, I think it is possible to be able to use a single transmitter and a single receiver location and to get exact 3D position information, the maths is complicated and the method is fraught with problems due to the errors that arise if the stations are not ideally situated. We will probably be writing articles on this for the CREG journal in the future.

As you can see, there are plenty of avenues open for theoretical investigation, but what about practical topics? In the UK most people are using one of two beacon designs, from France & Mackin, or Pease. References to articles describing the construction of these devices are given in [16] and online at [17].

My on-line radiolocation page [18] has not been updated for some time, but I intend to get around to this soon, adding a history of radiolocation and an explanation of the basic principles, based on one I wrote for [19]. If anyone would like a copy of my articles listed below, please contact me.

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["*CREGJ*" refers to the Cave Radio and Electronics Group Journal.]

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