COMPASS & TAPE

Volume 9   *Number 3,4*   *Winter, Spring 1992*

<u>Compass</u> <u>&</u> <u>Tape</u> is the quarterly newsletter of the Survey and Cartography Section of the National Speleological Society. Section membership is open to anyone interested in surveying and mapping caves. Membership includes a Compass & Tape subscription and costs $4.00 per year. Organizations may subscribe for the same price. The Compass & Tape volume starts with the issue following the NSS Convention; those paying later will receive all back issues in the current volume. Your mailing label indicates the last volume and number that you will receive. Please make all checks payable to "SACS". Foreign subscriptions are welcome, but payment must be in US$ and checks must be drawn on a U.S. bank. Back issues of all volumes are available at a cost of $4.00 per volume plus $1.00 per order for postage. Single issues are available for $1.00 each plus $.50 per issue for postage. Membership checks, back issue requests, and address changes should be sent to the Treasurer.

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Cover: A portion of the working map of Carol's Crack, Hardy Co., WV by Ed Devine

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THE NORTH ARROW - AN IMPORTANT DIRECTIONAL STANDARD

by Ed Devine

I have noticed that many cave cartographers provide only a magnetic north arrow to establish direction on their maps. While discussing this observation with a prominent cave cartographer, I found that this mapper was unaware of the changing nature of magnetic north, which can vary considerably over relatively short time periods.

True north, of course, is an appropriate reference direction for a final map. Magnetic north, on the other hand, is a temporary expediency for field measurement and working maps and is inappropriate for archival maps. Cavers frequently neglect the important measurements and conversions of data necessary to correctly reference true north. Thus, most of the archival cave maps we produce are not quite complete, and this may cause problems for future users of these maps.

Like the wind direction, magnetic north is dynamic, variable and hard to predict.[1] With time, an observed magnetic azimuth can become meaningless. Magnetic north varies by date, latitude, longitude, elevation and even the time of day, to a small degree. In addition, geologic structures can cause sharp, localized anomalies in observed magnetic declination. Currently, magnetic declination varies by about 45 degrees from the northern tip of Maine to the Olympic Peninsula in Washington, and it varies a full 360 degrees within Canada (yes, the compass needle actually points **due south** in parts of the Northwest Territories!). Tabulated estimations of magnetic declination are available from the USGS and some examples are included in Table 1. In addition, an **isogonic chart**, or map of magnetic declination, is shown in Figure 1. Table 1 clearly illustrates the variability, nonuniformity and dynamics of the magnetic north meridian.

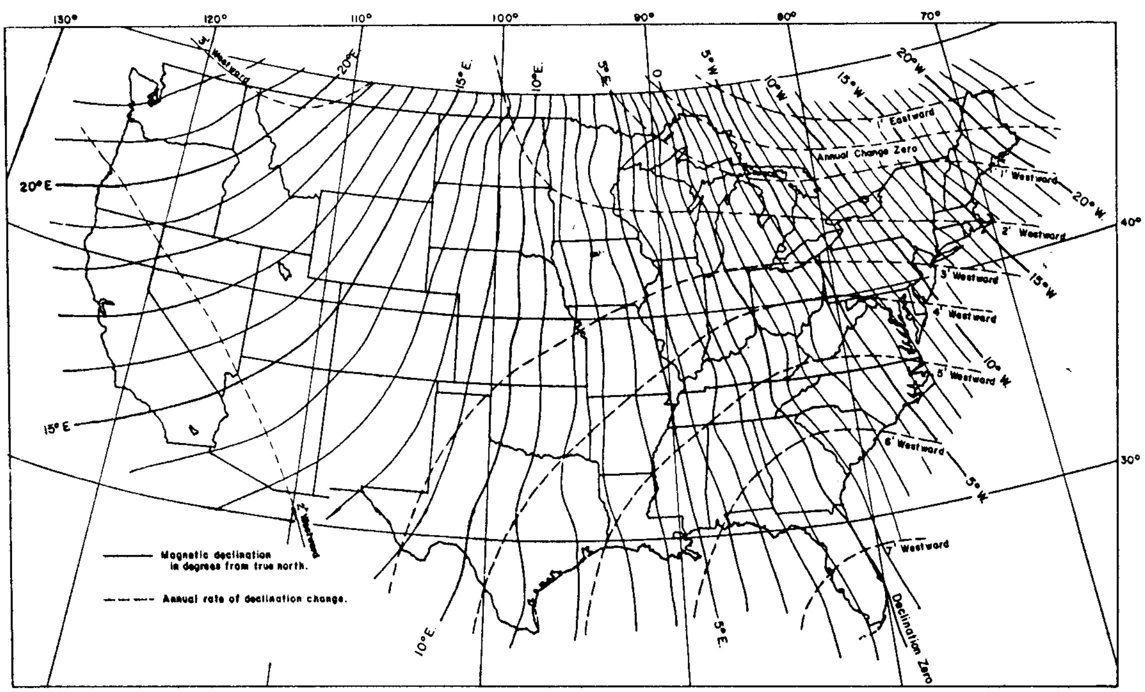

Figure 1 - Isogonic chart for the United States for 1965 (From References 2 and 3)

The nature of cave maps must be considered. Broadly, we deal with working maps and archival maps. Working maps, which are temporary documents developed from field notes, are continuously changed and updated. These maps are typically penciled with hand-written notes, and are rarely displayed or published. They are transitional documents which usually lack the polish seen in the NSS Cartographic Salon. Archival maps, on the other hand, are finished, presentation documents intended for library archiving, publication, display, navigation and occasionally, competition.

As a general rule, working cave maps use magnetic north as a reference direction because it corresponds to the compass readings in the field notes and is thus easier to work with. For short-term projects, the magnetic north direction is approximately constant. However, for long-term projects, the magnetic north direction may change significantly, and this change must be accounted for. There is only one way to properly describe the magnetic north direction and that is to reference it to some standard, such as true north. Thus, at best, magnetic north is redundant information which has very little use on an archival map.

Cartography requires a flat approximation of the earth's curved surface. As a result, on a state-by-state basis, the U.S. is divided into a series of state plane coordinate systems based on either transverse Mercator projections or Lambert conic projections.[4] For each system, the actual geodetic (latitude/longitude) grid is distorted to a flat, right-angled grid for ease of application. The size of each state plate coordinate system is limited so as to reduce the distortion to minimal values. **Grid** north is the approximation to true north for such a system and will be parallel at all points on the map. Direction of **true** north, of course, will vary and generally not be parallel from point to point on the map. USCG 7½-minute topographic maps, in contrast, are conic projections with slightly varying north meridian. These maps cover such small areas that distortion is essentially insignificant.

Fortunately, most caves are so localized so that the geodetic grid can be assumed flat and right-angled, and the complications with conversion to state or other planar grid systems can be ignored. For this reason cave cartographers rarely concern themselves with grid north. However, the cave cartographer should be aware of grid north and must be careful about using survey data, such as topographic overlays, which might have been converted to a plane coordinate system.

For cave mappers, the relevant aspect of all this is that our **grid** north should be true north rather than magnetic north. For practical purposes, true north can be interpolated using the tick marks on a USGS topo map. True north direction should be referenced on the map with magnetic north as a secondary reference. The main purpose in showing the magnetic direction on the map lies with avoiding confusion and with verification of the cartographer's calculations. If only one north arrow is shown, then it is uncertain whether the cartographer is showing a true or a magnetic north meridian. Also, the cartographer could easily have miscalculated direction of true north, and it will be impossible to verify this if both arrows are not clearly shown with declination listed.

It is the responsibility of the survey team and the cartographer to establish the magnetic declination for the cave location. For long-term surveys, this must be done periodically in order to establish the variation in declination. The survey data and declination must therefore be keyed to the survey date.

Measurement of the magnetic declination and calibration of the survey compasses is easily the most important measurement that the survey team can make, and precision is very important. For example, if the declination measurement is off by 2 degrees, then a point 1000 feet in horizontal distance from the cave entrance will be misplaced by 35 feet when plotted on an overlay map. Such errors can cause big problems for complex cave systems with multiple caves, entrances and near-connections. It is ironic that most cavers either ignore the declination or use the obsolete declination listing from the USGS topo map. The problem with this listing is that it applies only to the published date and the center location of the map. After just a few years, this published declination can become meaningless.

The declination, by itself, is of limited use to the cave cartographer. It is primarily of importance for compass calibration. In other words, true north direction, or another known direction is determined, the compass is sighted along this line, an **apparent** declination is determined, and the data is corrected by this **apparent** declination, as shown Figure 2. Conceivably, this apparent declination could differ from the actual declination due to compass setting or compass error. This doesn't really matter as the calibration corrects the data to true north.

There are several methods available to determine the magnetic declination. The best way is to simply measure the declination at or above cave. Alternately, **estimated** declinations can be obtained from the U.S. Geological Survey for any given location.[5]

To measure declination, a compass azimuth is read along a line of known direction. Because there is almost never a line of known direction available, a timed sighting on a star or the sun must be made. Precise angular coordinates for major celestial bodies are available in ephemeris tables which can be acquired at low cost[6,7]. Simple equations provide azimuths which can be used to establish precise baselines.

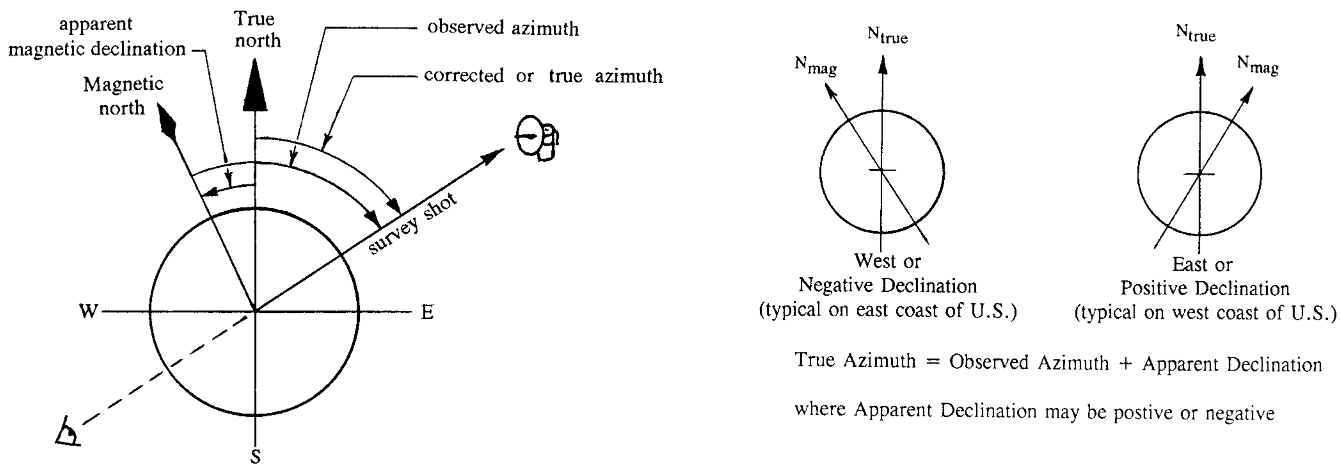

Figure 2 - Sight Azimuth Correction Procedure

The USGS states that its 1990 estimated declinations are "generally good to within 20 minutes"[5] which suggests that the earlier data is possibly much less precise than this. The data is compiled from many different sources and there is no way to check older declinations. Therefore, it should be considered a close estimate, and it should be used with caution by cave cartographers.

The USGS willingly provides these declinations for specific locations, elevations and dates through either a mail or phone inquiry. Such inquiries can be made to the following USGS office (November, 1991):

U.S. Geological Survey
Branch of Global Seismology and Geomagnetism
Mail Stop 968
Box 25046, Denver Federal Center
Denver, CO 80225-0046

Contact (November, 1991):
Jill Caldwell, 1-303-236-1369
or Norm Peddie, 1-303-236-1364
or John Wood, 1-303-236-1512

I spoke with Ms. Kathy Sikes in Ms. Caldwell's office who provided me with the declination data I needed for several Virginia and West Virginia cave locations and also sent me a sizable packet of information.

This USGS office also maintains an online computer system on a 1-800 number which can be accessed via modem to get declinations. The information sheet for this service has been included at the end of this article.

I took a portion of the declination matrix (declination based on latitude, longitude and date) provided by USGS and incorporated it into a FORTRAN program which performs a cubic-spline interpolation of declination for any location within the Virginia, West Virginia, Pennsylvania, Kentucky, North Carolina Region for any date from 1940 to the present. This interactive program will work on PC systems and could easily be expanded to work with the declination data matrix for the whole country. I'll gladly provide a executable copy to anyone interested. However, program bugs are always possible and the user is warned to use the results with caution.

Table 1

Selected Magnetic Declinations for Latitude 37° North†

Year	Longitude 76° W	77° W	78° W	79° W	80° W	81° W
1750	01°39'W	01°13'W	00°46'W	00°20'W	00°07'E	00°33'E
1760	01 03 W	00 37 W	00 08 W	00 19 E	00 46 E	01 12 E
1770	00 32 W	00 04 W	00 26 E	00 54 E	01 22 E	01 49 E
1780	00 09 W	00 21 E	00 53 E	01 22 E	01 52 E	02 20 E
1790	00 06 E	00 38 E	01 12 E	01 44 E	02 15 E	02 45 E
1800	00 11 E	00 46 E	01 23 E	01 56 E	02 30 E	03 01 E
1810	00 08 E	00 45 E	01 24 E	01 59 E	02 34 E	03 07 E
1820	00 04 W	00 35 E	01 16 E	01 53 E	02 29 E	03 04 E
1830	00 25 W	00 16 E	00 58 E	01 37 E	02 15 E	02 51 E
1840	00 53 W	00 12 W	00 32 E	01 12 E	01 52 E	02 30 E
1850	01 29 W	00 46 W	00 01 W	00 41 E	01 23 E	02 02 E
1860	02 05 W	01 22 W	00 36 W	00 07 E	00 49 E	01 29 E
1870	02 45 W	02 02 W	01 16 W	00 33 W	00 11 E	00 52 E
1880	03 22 W	02 40 W	01 55 W	01 12 W	00 30 W	00 12 E
1890	03 55 W	03 14 W	02 31 W	01 49 W	01 07 W	00 27 W
1900	04 32 W	03 50 W	03 07 W	02 24 W	01 42 W	01 02 W
1905	04 52 W	04 09 W	03 24 W	02 40 W	01 56 W	01 15 W
1910	05 16 W	04 31 W	03 45 W	03 00 W	02 14 W	01 31 W
1915	05 37 W	04 51 W	04 02 W	03 16 W	02 29 W	01 44 W
1920	05 51 W	05 04 W	04 14 W	03 26 W	02 38 W	01 52 W
1925	06 12 W	05 23 W	04 32 W	03 43 W	02 54 W	02 07 W
1930	06 30 W	05 40 W	04 48 W	03 58 W	03 07 W	02 20 W
1935	06 43 W	05 52 W	04 59 W	04 07 W	03 15 W	02 27 W
1940	06 42 W	05 50 W	04 56 W	04 04 W	03 11 W	02 21 W
1945	06 45 W	05 52 W	04 57 W	04 04 W	03 10 W	02 20 W
1950	06 45 W	05 52 W	04 56 W	04 02 W	03 08 W	02 17 W
1955	06 53 W	06 00 W	05 04 W	04 09 W	03 15 W	02 24 W
1960	07 05 W	06 12 W	05 17 W	04 23 W	03 28 W	02 37 W
1965	07 24 W	06 31 W	05 37 W	04 44 W	03 50 W	03 00 W
1970	07 46 W	06 55 W	06 01 W	05 08 W	04 15 W	03 26 W
1975	08 16 W	07 27 W	06 35 W	05 43 W	04 52 W	04 03 W
1980	08 53 W	08 05 W	07 15 W	06 25 W	05 35 W	04 47 W
1985	09 28 W	08 40 W	07 51 W	07 01 W	06 11 W	05 21 W
1990	10 02 W	09 15 W	08 27 W	07 39 W	06 50 W	06 00 W

†Notes: Provided by USGS Branch of Global Seismology Geomagnetism from table prepared by National Geophysical Data Center, NESDIS, NOAA, 11/04/1987 where:

- Declinations prior to 1955 derived from Table 4 of Coast and Geodetic Survey Publication 40-2, "United States Mangetic Tables for 1960".
- Declinations for 1955, 1960 and 1965 derived from the 3077 Magnetic Chart Series of the Coast and Geodetic Survey.
- Declinations for 1970 through 1990 derived from USGS Models.
- Accuracy of 1990 data "generally within 20 minutes" but local distubances "could cause differences of several degrees"[5].

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3. U.S. Geological Survey National Atlas, 1965.

4. Moffitt, F.H. and H. Bouchard, Surveying, 6th Edition, Intext Educational Publishers, NY, 1975, pp 455-499.

5. U.S. Geological Survey Branch of Global Seismology and Geomagnetism Tables of Magnetic Declination, USGS (GS&G), Mail Stop 968, Box 25046, Denver Federal Center, Denver CO, 80225-0046.

6. The 1992 Astronomical Almanac, Nautical Almanac Office, U.S. Naval Observatory.

7. Elgin, R.L, D.R. Knowles and J.H. Senne, 1992 Celestial Observation Handbook and Ephemeris, Elgin, Knowles & Senne, Inc., 1991.

NATIONAL GEOMAGNETIC INFORMATION CENTER

U.S. GEOLOGICAL SURVEY
BRANCH OF
GLOBAL SEISMOLOGY AND GEOMAGNETISM
BOX 25046, MS 968
DENVER FEDERAL CENTER
DENVER CO, 80225

GEOMAG

GEOMAG is a user-friendly online computer system that provides model values of the Earth's magnetic field elements, such as declination and field intensity. To access it,

1. Set your terminal and modem for full-duplex operation, 7 data bits, 1 stop bit, space (or zero) parity, and either 300 or 1200 baud.

2. Dial the toll-free number (outside Colorado only)
   800-358-2663 (300 or 1200 baud)
   or one of the commercial numbers
   (303) 279-2062 (1200 baud)
   (303) 279-6374 (300 baud)

3. After the modem detects a carrier signal, press **Enter** once or twice. If you do not get a response or the modem loses the carrier, go back to step 2.

4. *If using the toll-free number, skip to step 5.* For each of the following prompts type the response (shown underlined) and press **Enter**:
   enter class <u>**neis**</u>
   class neis start
   (here you may have to press **Enter** once or twice)
   Username: <u>**QED**</u>

5. The system will respond with a welcome message, and offer the following options:
   Q for Quick Epicenter Determinations (QED)
   H for Historical Epicenter File Searches (EDBS)
   M for Geomagnetic Field Values (GEOMAG)

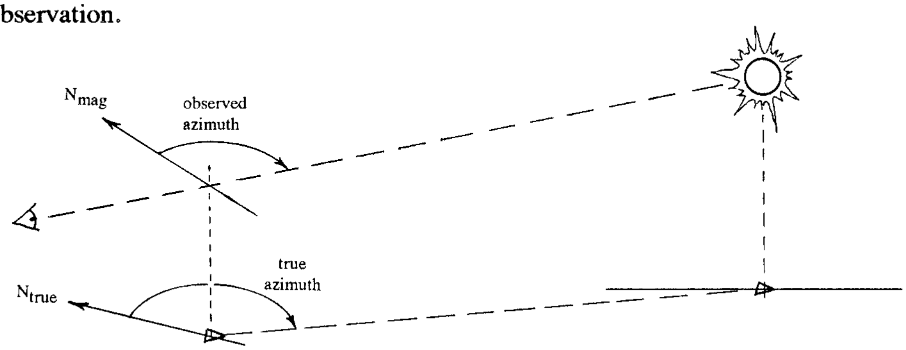
6. Type M to select *GEOMAG*, and follow the instructions. First-time users should read the information offered at the start. Online help can be obtained at any time by typing a question mark. To exit, press **Ctrl-Z**.

Use of *GEOMAG* is free except for whatever charges may be incurred for telephone service. Response will be quickest if you avoid the hours 9 a.m. to 4 p.m. (mountain time), Monday through Friday. If you have trouble or suggestions please write or call Norman Peddie, U.S. Geological Survey, Mail Stop 968, Federal Center, Box 25046, Denver, CO 80225-0046. Telephone: (303) 236-1364 (FTS 776-1364).

BASELINE MEASUREMENT BY SOLAR OBSERVATION

by Ed Devine

To measure magnetic declination or calibrate a caving compass, it is necessary to sight along a line of precisely known direction and compare the observed azimuth with the known azimuth for that line, as is shown in Figure 1. Unfortunately, such established baselines are rarely available, especially near cave entrances. However, by applying methods of celestial observation, it is fairly easy to establish the exact sight azimuth to any major celestial body at any given time. The sun is probably the easiest of these bodies to sight. In this article, methods, procedures and background will be described for performing such an observation.



Apparent Declination = True Azimuth - Observed Azimuth

Figure 1 - Sun Shot to Observe Apparent Magnetic Declination

The solar observation is normally done using a theodolite, and high-precision results can be directly obtained. However, when significantly lower precision is acceptable, such as with cave surveying, simple methods can be used to sight the sun and establish adequate baselines and directions.

Determination of solar or stellar azimuth requires precise measurement of latitude, longitude, and time of the observation. The celestial body, usually the sun, must be located and precisely sighted. Calculations apply solar or stellar coordinates taken from an **ephemeris table**, which provides this data as a function of date. These calculations require high-precision trigonometric math, but are easy to perform using a calculator or computer.

Ephemeris tables are available from several sources. The Nautical Almanac Office of the U.S. Naval Observatory annually publishes The Astronomical Almanac which contains ephemerides of the sun, moon, stars and other celestial bodies (order from SUPERINTENDENT OF DOCUMENTS, U.S. GOVERNMENT PRINTING OFFICE, WASHINGTON, D.C. 20402, Stock No. 008-054-00141-6, cost $24.00). This document has been incorporated into The Floppy Almanac 1992/1993, which is a user-friendly PC program (order from the National Audiovisual Center, 8700 Edgeworth Drive, Capitol Heights, MD 20743; 1-800-788-6282; cost $30.00). An example ephemeris table has been derived from The Floppy Almanac and is presented in Table 1. Unfortunately, ephemeris data from this source is only provided to a tenth of an arc-minute and is therefore limited for high-precision survey work, although it is adequate for any conceivable caving application.

For greater precision, current-year ephemeris tables may be purchased at low-cost from distributors of surveying equipment. The Celestial Observation Handbook and Ephemeris, by Elgin, Knowles & Senne, Inc., provides ephemeris coordinates to a tenth of an arc-second and is therefore sixty times more precise than the Naval Observatory ephemeris. Unfortunately, example tables from this ephemeris are copyrighted and cannot be included with this article.

The required precision for solar azimuth measurement for cave-survey purposes must be considered. The individual cave survey shots are probably no more precise than a degree, or so, based on observed backsight and loop closure data from typical cave surveys. By comparison, the diameter of the moon or sun is about one-half degree. It is probably easy to view the moon or sun, on the horizon, to half of its diameter. With care, the object can be more precisely sighted, by eye. Therefore, it is probably possible to read a sun shot to possibly a tenth of a degree with a Suunto. The shot could probably be read to no closer than a half degree with a Brunton compass. Therefore, a quarter-degree is probably sufficient for caving purposes. The average of multiple shots may be necessary to achieve this level of precision with a hand-held compass.

The precision of a SUUNTO or Brunton compass is uncertain. Although a SUUNTO can easily be read to a quarter-degree, this is misleading precision because of sighting errors and possible compass errors such as off-center card pivot, misalignments of compass card magnets or variations in the markings on the card. This subject needs further consideration. However, for expediency, I will arbitrarily suggest one-quarter degree as a target precision for solar azimuth measurement for cave survey purposes.

METHODS FOR SIGHTING THE SUN

There are a variety of simple methods which can be used to read the sun. Most of these methods will work best in the late afternoon, when the sun is low in the sky and dim. It is noted that although the vertical position of the sun is significantly distorted by atmospheric refraction, the azimuth will be true. Direct viewing of the sun is very hazardous and should not be attempted without caution.

The best way to observe the sun is with a transit or theodolite using standard surveying procedures for such an operation. Rather than sighting the sun with the instrument, which would be dangerous, the instrument is inverted and a projection of the sun on a card is used. This procedure will not be discussed further here as it is explained in detail in any surveying textbook. Use of a theodolite or transit can permit the establishment of an extremely precise baseline.

In the simplest method of approximate sun sighting, a distant reference point on the horizon is established at the instant of sunrise or sunset. In this method, the observer moves about until a distant tree trunk or other prominent object is directly centered on the rising/setting sun, which is relatively safe to briefly view as it is greatly dimmed. A station is set at the point of observation and a precise baseline is thus established.

As an alternative to this method, when sunset is inconvenient or impractical, the top of a building or hill or the crotch of a large tree can be used to center the sun. The observer moves about until the top edge of the sun just begins to appear, and a baseline is established for later use. Caution should be exercised to prevent burning of the eyes!

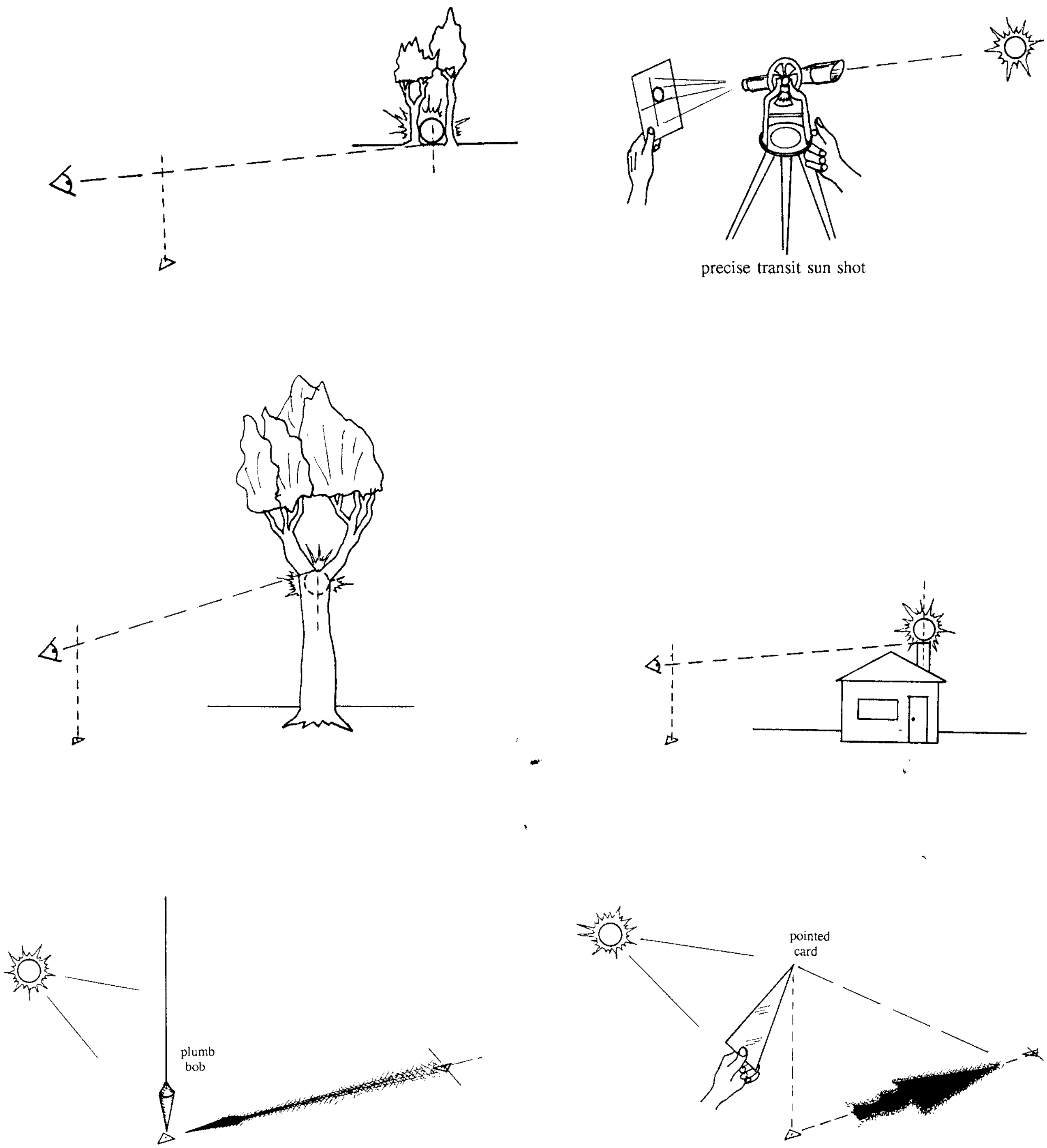
It is possible to hang a plumb line and sight the approximate shadow of the cord on the ground or other target surface. In this case, the baseline is defined by the point directly below the plumb line and a point on the shadow. However, precision is fairly low due to the diffuse nature of the solar shadow and this limits the length of the baseline. By making several shadow sightings, statistical methods can be applied to improve the precision of the reading. As an alternative, a pointed card can be used instead of a cord to cast the shadow. Despite the diffuse pattern, the shadow from the pointed card will have a distinct center which can be more clearly observed.

Photography may be a good way to rapidly perform a solar observation. With the camera centered over a station, the sun is directly photographed while it is being eclipsed by some distinctive landmark, such as a building, crotch of a tree, hill or other stable object. The camera must be greatly stopped down or somehow filtered to provide a clear image. This method will work better with the sun low in the sky. Using a blow-up of the photo, an angular correction can be established from the landmark to the center of the sun. Exact time of the photograph must be carefully recorded, of course.

These are only a few of the possible methods which can be employed to observe the sun. By applying some ingenuity and creativity, more practical methods are probably possible.

PROCEDURES FOR CALCULATION OF SOLAR AZIMUTH

The Celestial Handbook and Ephemeris provides an excellent discussion of the background, methods and procedures relating to celestial observation for the purposes of surveying, and this text was the principal reference source for the following discussion. The **Hour-Angle Method** for calculation of solar azimuth will be described. This is a relatively new method of direct celestial azimuth observation which replaces older methods which required precise measurement of the vertical angle to the sun. The Hour-Angle Method requires extremely precise time measurement and high-precision trig math computations which were difficult and impractical some years ago. However, the direct nature of this method makes it possible to determine solar azimuth using the relatively simple methods previously described.



Approximate Methods for Observing the Sun

A step-by-step procedure is provided. For expediency, the background discussion is minimized. However, the references may be consulted for a more-detailed description.

Several important terms are defined ...

Solar Declination - The earth's axis is tilted about 23.5 degrees relative to its orbit around the sun. As a result, the **declination** is defined as the angle between the plane of the earth's equator and the sun at a given instant of time. It varies continuously between -23.5 degrees at winter solstice to +23.5 degrees at summer solstice and is zero at fall or spring equinox. The value of the declination at any instant of time is interpolated from the solar ephemeris table. Note that this has nothing to do with **magnetic declination.**

Equation of Time - If the earth's orbit was perfectly circular and exactly 365 days long, then when you stood at a standard time meridian (i.e. 75 degrees west longitude) and corrected for daylight savings time, the sun would be at its **transit**, or highest point at exactly noon. However, because the earth is slightly wobbly with a slightly elliptical orbit that's really about 365.24 days long, transit will occur slightly before or after noon. The precise value for this time correction is interpolated from the solar ephemeris table.

Transit - This is the time, around noon, when the sun passes its highest point in the sky. At this time, the sun is passing through the local meridian or longitude. At this instant, the sun is due south (unless you are south of the tropics, in which case the sun will be due north).

Local meridian - The meridian or longitude where the observation is made. In this hemisphere, it is measured in degrees west from the Greenwich Meridian.

Standard Meridian - 24 Standard Time Zones have been established. The time in each of these zones it the mean time at an associated Standard Meridian spaced 15 degrees of longitude from the Greenwich or zero-degree Meridian. Thus, the Standard Meridian for the Eastern Time Zone is 75 degrees West Longitude, the Standard Meridian for the Central Time Zone is 90 degrees West Longitude, and so on.

Mean Standard Time - To obtain precise time, call the following U.S. Naval Observatory Time Announcement number:

1-(202)-653-1920 or 1-(202)-653-1800

A recorded voice at this number will alternately provide Corrected Universal Time or Eastern Standard Time/Daylight Savings Time at 5-second intervals for easy synchronization of watches. Eastern Standard Time is exactly 5 hours less than Corrected Universal Time.

Corrected Universal Time may also be obtained from radio station WWV on 2.5, 5, 10, 15 and 20 MHz (requires special weather/time radio - check Radio Shack). This signal can also be received over the phone by dialing the following number:

1-(303)-499-7111

The precise time must be recorded exactly when a sun shot is made. The sun moves a distance equal to its diameter in about 2 minutes. For precise work, an error of a few seconds in time can cause a significant error in azimuth. However, this is less critical for caving applications.

To summarize, the azimuth observation requires the following:

- Precise, calibrated time piece (inexpensive digital watches very good for this),
- Exact latitude and longitude at point of observation,
- Solar ephemeris tables,
- Calculator or computer with high-precision trig functioning (watch out - use double-precision!).

STEP-BY-STEP PROCEDURE

1. Define **latitude, LAT**, and **longitude, LONG**. This must be read as closely as possible from a USGS topographic quadrangle and must be precise.

2. Define **Time Zone Factor, T_1**, where ...

T_1 = 0 hours for Greenwich Zone	= 6 hours for Central Zone	= 9 hours for Alaska
= 4 hours for Atlantic Zone	= 7 hours for Mountain Zone	= 10 hours for Hawaii
= 5 hours for Eastern Zone	= 8 hours for Pacific Zone	= -5½ hours for India
= -3 hours in Moscow, Russia	= -8 hours in Beijing, China	= -13 hours for Tonga, South Pacific
	etc.	

note: T_1 will be negative for East longitudes (Europe, Asia) and positive for West longitudes (Americas) and will range from -13 to 12. A map of international time zones should be consulted.[5]

3. Define **Daylight Savings Time Adjustment Factor, T_2**, where ...

T_2 = 0 hour for Standard Time (winter, etc.)
= -1 hour for Daylight Savings Time (summer, etc.)

4. Identify **Mean Time of Observation, T_{mean}**. This is observed clock time, i.e., Eastern Standard Time and is defined as 24-hour time.

For example, T_{mean} = 09:30 for 9:30 in the morning
= 13:30 for 1:30 in the afternoon

5. Calculate **coordinated universal time, GMT**, for observation ...

$$GMT = T_{mean} + T_1 + T_2$$

6. Identify **ephemeris date** ...

- if GMT between 0.0 and 24.0, ephemeris date is current date,
- if GMT less than 0.0 (i.e., in China, early in the day), ephemeris date is one day prior to current date,
- if GMT greater than 24.0 (i.e., U.S. west coast, late in afternoon), ephemeris date is day after current date.

7. From ephemeris table, identify **Greenwich Hour Angle, GHA**, terms ...

- GHA_1 is GHA for sun for ephemeris date. It is read directly from table.
- GHA_2 is GHA for sun for the day following the ephemeris date.

8. From ephemeris table, identify **Solar Declination** angles ...

- $DECL_1$ is Declination of sun for ephemeris date. It is read directly from table.
- $DECL_2$ is Declination of sun for the day following the ephemeris date.

9. Calculate solar declination, DECL, at time of observation ...

$$DECL = DECL_1 + (DECL_2 - DECL_1) \times GMT / 24.0 + 0.0000395 \times DECL_1 \times \sin(7.5 \times GMT)$$

10. Calculate **Greenwich Hour Angle, GHA** ...

$$GHA = GHA_1 + (GHA_2 - GHA_1 + 360) \times GMT / 24.0$$

correct ... If GHA greater than 360°, subtract 360°
If GHA less than 0°, add 360°

11. Calculate **Local Hour Angle, LHA** ...

$$LHA = GHA - LONG$$

correct ... If LHA greater than 360°, subtract 360°,
If LHA less than 0°, add 360°

12. Calculate **Uncorrected Azimuth** ...

$$Azimuth = \tan^{-1} (-\sin(LHA) / (\cos(LAT) \times \tan(DECL) - \sin(LAT) \times \cos(LHA)))$$

13. Correct the azimuth, if necessary ...

- if azimuth positive and LHA less than 180°, add 180° to azimuth
- if azimuth negative and LHA less than 180°, add 360° to azimuth
- if azimuth negative and LHA greater than or equal to 180°, add 180° to azimuth

after this... if azimuth greater than 360°, subtract 360°
if azimuth less than 0°, add 360°

Azimuth to center of sun has now been established!

Now, to calculate **time of solar transit** (apparent local noon or sun due south) at point of observation, first, calculate approximate **Equation of Time, T_{eq1}** ...

$$T_{eq1} = ((GHA_1 + (GHA_2 - GHA_1) \times GMT/24.0) - 180.0) \times 4.0/60.0$$

Then, calculate approximate time of solar transit, T_{appr} ...

$$T_{appr} = (12.0 + (LONG - (T_1 \times 15.0)) \times 4.0/60.0 - T_{eq1}) - T_2$$

Next, calculate exact equation of time, Teq2, based on the approximate value ...

$$T_{eq2} = ((GHA_1 + (GHA_2 - GHA_1) \times (GMT + T_{corrn}) / 24.0) - 180.0) \times 4.0/60.0$$

where, $T_{corrn} = T_{appr} - T_{mean}$

Finally, calculate exact time of solar transit, TRANS ...

$$TRANS = (12.0 + (LONG - (T_1 \times 15.0)) \times 4.0/60.0 - T_{eq2}) - T_2$$

COMPUTER APPLICATIONS

This procedure is well-suited to computer solution. I have incorporated it into a user-friendly FORTRAN program for PC application. The program includes a 1992/1993 ephemeris database. One version comprises a database from the copyrighted Celestial Observation Handbook and Ephemeris, which is good to 1/10 arc-second. A second version comprises a database from the Naval Observatory Almanac Office Floppy Almanac, which is good to 1/10 arc-minute.

I will gladly provide an executable copy of this program to anyone interested, although I can only provide the lower-precision database because of copyright restrictions. Contact me if interested.

Of course, as with any computer software, I must warn that bugs and errors are possible. The program should be considered developmental, and users are responsible for validating the results of its use.

EXAMPLE

A sun sighting is made in Vienna Virginia, on July 6, 1992 at 5:23:13 in the afternoon. What is the azimuth, and at what time was the sun due south?

- From the USGS topo map, LAT = N 38°54'42.2" = 38.911722°
  and LONG = W 77°14'32.1" = 77.242250°

- Eastern Daylight Savings Time applies; therefore, T_1 = 5 hours and T_2 = -1 hour

- T_{mean} = 17:23:13.0 = 17.3869444 hours

- GMT = 17.3869444 + 5 - 1 = 21.3869444 hours

- Ephemeris Date = current date = 7/6/92

- From Ephemeris tables, GHA_1 = 178°49'51.1" = 178.8308611°
  GHA_2 = 178°47'22.8" = 178.7896667°
  $DECL_1$ = 22°41' 7.5" = 22.6854166°
  $DECL_2$ = 22°34'53.2" = 22.5814444°

- DECL = 22.6854166 + (22.5814444 - 22.6854166) x 21.3869444 / 24.0 + 0.0000395 x 22.6854166 x sin(7.5 x 21.3869444)

  = 22.593069°

- GHA = 178.8308611 + (178.7896667 - 178.8308611 + 360) x 21.3869444 / 24.0

  = 499.59832° This is greater than 360°; therefore,
  correct to GHA = 499.59832 - 360.0 = 139.59832°

- LHA = 139.59832 - 77.24225 = 62.35607°

- Uncorrected Azimuth = $\tan_{-1}$ (-sin(62.35607) / (cos(38.911722) x tan(22.593069) - sin(38.911722) x cos(62.35607))) = -87.908294°

- **Therefore, corrected azimuth** = -87.908294 + 360.0 = 272.09171°

- **Time of Solar Transit:**

$$T_{eq1} = ((178.8308611 + (178.7896667 - 178.8308611) \times 21.3869444 / 24.0) - 180.0) \times 4.0 / 60.0 = -0.0803898$$

$$T_{appr} = (12.0 + (77.24225 - (5.0 * 15.0)] * 4.0 / 60.0 - (-0.0803898) - (-1.0) = 13.229873 \text{ hours}$$

$$T_{corrn} = 13.229873 - 17.3869444 = -4.1570714$$

$$T_{eq2} = ((178.8308611 + (178.7896667 - 178.8308611) \times (21.3869444 - 4.1570714) / 24.0) - 180.0) \times 4.0 / 60.0 = -0.0799141$$

$$T_{RANS} = (12.0 + (77.24225 - (5.0 * 15.0)] * 4.0 / 60.0 - (-0.0799141) - (-1.0)$$

$$= 13.229398 \text{ hours} = \underline{1{:}13{:}45.8 \text{ p.m.}}$$

At this precise time, the sun is exactly due south from the observer's position.

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4. Elgin, R.L, D.R. Knowles and J.H. Senne, 1992 Celestial Observation Handbook and Ephemeris, Elgin, Knowles & Senne, Inc., 1991.

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Table 1 - SOLAR EPHEMERIS TABLE FOR 1992†

GREENWICH HOUR ANGLE, GHA, AND DECLINATION FOR SUN FOR ZERO HOUR UNIVERSAL TIME

JULY, 1992

DAY	GHA °	GHA '	DECLINATION °	DECLINATION '
1 WE	179	03.5	23	06.4
2 TH	179	00.6	23	02.1
3 FR	178	57.8	22	57.5
4 SA	178	55.1	22	52.4
5 SU	178	52.4	22	47.0
6 MO	178	49.9	22	41.1
7 TU	178	47.4	22	34.9
8 WE	178	45.0	22	28.3
9 TH	178	42.7	22	21.2
10 FR	178	40.6	22	13.8
11 SA	178	38.5	22	06.1
12 SU	178	36.6	21	57.9
13 MO	178	34.8	21	49.4
14 TU	178	33.1	21	40.5
15 WE	178	31.5	21	31.2
16 TH	178	30.1	21	21.5
17 FR	178	28.7	21	11.5
18 SA	178	27.5	21	01.2
19 SU	178	26.5	20	50.4
20 MO	178	25.6	20	39.4
21 TU	178	24.8	20	27.9
22 WE	178	24.1	20	16.2
23 TH	178	23.6	20	04.1
24 FR	178	23.2	19	51.6
25 SA	178	23.0	19	38.8
26 SU	178	22.9	19	25.7
27 MO	178	23.0	19	12.3
28 TU	178	23.2	18	58.6
29 WE	178	23.5	18	44.5
30 TH	178	24.0	18	30.1
31 FR	178	24.7	18	15.5

AUGUST, 1992

DAY	GHA °	GHA '	DECLINATION °	DECLINATION '
1 SA	178	25.5	18	00.5
2 SU	178	26.5	17	45.2
3 MO	178	27.6	17	29.7
4 TU	178	28.9	17	13.9
5 WE	178	30.3	16	57.8
6 TH	178	31.9	16	41.4
7 FR	178	33.6	16	24.7
8 SA	178	35.5	16	07.8
9 SU	178	37.5	15	50.6
10 MO	178	39.7	15	33.2
11 TU	178	42.1	15	15.6
12 WE	178	44.5	14	57.6
13 TH	178	47.2	14	39.5
14 FR	178	49.9	14	21.1
15 SA	178	52.8	14	02.5
16 SU	178	55.8	13	43.7
17 MO	178	59.0	13	24.6
18 TU	179	02.2	13	05.3
19 WE	179	05.6	12	45.9
20 TH	179	09.2	12	26.2
21 FR	179	12.8	12	06.3
22 SA	179	16.5	11	46.2
23 SU	179	20.4	11	26.0
24 MO	179	24.3	11	05.5
25 TU	179	28.4	10	44.9
26 WE	179	32.5	10	24.1
27 TH	179	36.8	10	03.1
28 FR	179	41.1	9	42.0
29 SA	179	45.6	9	20.7
30 SU	179	50.1	8	59.3
31 MO	179	54.7	8	37.8

SEPTEMBER, 1992

DAY	GHA °	GHA '	DECLINATION °	DECLINATION '
1 TU	179	59.4	8	16.1
2 WE	180	04.1	7	54.2
3 TH	180	09.0	7	32.3
4 FR	180	13.9	7	10.2
5 SA	180	18.9	6	48.0
6 SU	180	23.9	6	25.7
7 MO	180	29.0	6	03.3
8 TU	180	34.1	5	40.8
9 WE	180	39.3	5	18.2
10 TH	180	44.5	4	55.5
11 FR	180	49.8	4	32.7
12 SA	180	55.1	4	09.9
13 SU	181	00.4	3	47.0
14 MO	181	05.8	3	24.0
15 TU	181	11.1	3	00.9
16 WE	181	16.5	2	37.8
17 TH	181	21.8	2	14.6
18 FR	181	27.2	1	51.4
19 SA	181	32.5	1	28.2
20 SU	181	37.9	1	04.9
21 MO	181	43.2	0	41.6
22 TU	181	48.4	0	18.2
23 WE	181	53.7	-0	05.1
24 TH	181	58.9	-0	28.5
25 FR	182	04.1	-0	51.9
26 SA	182	09.2	-1	15.3
27 SU	182	14.3	-1	38.7
28 MO	182	19.3	-2	02.0
29 TU	182	24.3	-2	25.4
30 WE	182	29.2	-2	48.7

OCTOBER, 1992

DAY	GHA °	GHA '	DECLINATION °	DECLINATION '
1 TH	182	34.1	-3	12.0
2 FR	182	38.9	-3	35.3
3 SA	182	43.6	-3	58.5
4 SU	182	48.2	-4	21.7
5 MO	182	52.8	-4	44.8
6 TU	182	57.3	-5	07.8
7 WE	183	01.6	-5	30.8
8 TH	183	05.9	-5	53.7
9 FR	183	10.1	-6	16.6
10 SA	183	14.1	-6	39.3
11 SU	183	18.1	-7	02.0
12 MO	183	21.9	-7	24.6
13 TU	183	25.6	-7	47.0
14 WE	183	29.2	-8	09.4
15 TH	183	32.6	-8	31.7
16 FR	183	35.9	-8	53.8
17 SA	183	39.0	-9	15.8
18 SU	183	42.0	-9	37.7
19 MO	183	44.8	-9	59.4
20 TU	183	47.5	-10	21.0
21 WE	183	50.0	-10	42.5
22 TH	183	52.3	-11	03.8
23 FR	183	54.5	-11	24.9
24 SA	183	56.5	-11	45.8
25 SU	183	58.3	-12	06.6
26 MO	183	59.9	-12	27.2
27 TU	184	01.3	-12	47.6
28 WE	184	02.6	-13	07.8
29 TH	184	03.7	-13	27.8
30 FR	184	04.5	-13	47.6
31 SA	184	05.2	-14	07.1

† Tables derived from The Floppy Almanac 1992/1993, Nautical Almanac Office, U.S. Naval Observatory, 1992.

THEORY & EXPERIMENT IN TILT ERROR IN SUUNTO COMPASSES SIGHTED WITH THE GLASS ROD CYLINDRICAL LENS

by Roger V. Bartholomew NSS 9349

Robert Thrun (C&T, v9, no.1,2, p.5) renewed my interest in compass tilt errors when he compared the numbers I reported for tilt error when using the glass rod sight on the Suunto compass, (C&T, v.8, no.4, p.7) with the numbers from a theoretical equation derived by Lang Brod (C&T, v.2, no.1, p.11) for compass tilt error in general. It is important that Thrun brought up the subject of compass tilt error because no enough cave surveyors are aware or it. I only became aware of it when Lang Brod mentioned it to me at an NSS Convention and later sent me a pioneering article he wrote.

In the Spring of 1990, after taking the measurements of actual tilt error with the Suunto sighted by the glass rod, I consulted the article which Lang Brod had sent me on 27 Jan., 1986, "An Analysis of Instrument Errors" which had his equation: tan(e)=tan(i)tan(t), where i=inclination angle and t=tilt angle of the compass, and I noticed the quite large differences, especially for the small inclination angle sightings, between my experimental data and the values of tilt error "e" which his equation yielded. Please refer to the percent difference column in the table below.

Inclination Angle	Azimuth Error (deg.) per Deg. of CCW Tilt	$e=\tan^{-1}[\tan(i)\tan(10)]$ (Brod's Equation)	% diff.
+24.2	+0.27	+0.45	-67.%
+45.1	+0.83	+1.00	-20.%
+63.4	+1.79	+2.00	-12.%
+76.9	+3.99	+4.29	-7.5%

After I reported my experimental data and graph of tilt error for the Suunto Compass sighted with the glass rod at the 1990 NSS Convention in Yreka, CA, I spent about two weeks trying to derive a formula that would fit the experimental data. I was unsuccessful and had to shelve the project for lack of time, but I speculated on several reasons for the differences. Brod's derivation was for a plain compass such as the Brunton while I was using the Suunto with a glass rod sight. In sighting the Suunto compass with the glass rod a reflection of light is involved. In a reflection the light deflection angle is twice the mirror rotation angle. I thought that perhaps this effect might cause the difference.

On the other hand Brod's derivation involved some assumptions. He stated that for tilting on the compass to station axis (which is an inclined axis) the front of the compass will go up. For his derivation Brod assumed the front of the compass did not tilt upward. After his derivation Brod wrote, "A different set of assumptions might possibly lead to a slightly different result." As I was writing this article, I realized that in my apparatus the compass was tilted on a horizontal axis through the compass to a point directly below the target light and then rotated on the axis perpendicular to the Suunto case.

On 22 Feb., 1991 I sent a copy of my paper to Brod with his theoretical points plotted on the graph of my data and mentioned to him that I had not as yet explained the large differences at small angles of inclination. I have not yet received a reply from Brod. Robert Thrun in his comments on the difference between my numbers for the Suunto sighted with the glass rod and Brod's derivation for any compass hypothesized, "This [difference] might be due to the compass dial being read at a point above the optical axis of the compass eyepiece." I will be giving some thought to this and the other possibilities I thought of above if I ever get the time to start working on the derivation again.

Thrun wrote that I had mentioned using the Suunto compass drum as a level. I did not originate this idea. As far as I know Lang Brod did. Brod had commented in his article (C&T, v.7, no.2, p.16), "To prevent errors arising from compass tilt, the [Suunto] compass should be leveled so that the upper and lower edges of the drum dial are nominally parallel to the upper and lower edges f the rectangular inner window observed through the lens." During data taking on my tilt error experiments, I attempted to verify this idea of using the compass drum as a level. The few data I presented in my article (C&T, v.8, no.4, p.7) for the Suunto on a tripod showed a variability in the tilt errors and I mentioned that leveling with the Suunto compass drum "is not a good control on tilt error." I also wrote, "A situation in which the compass drum is not balanced for local magnetic dip will cause the drum to be out of level for east/west reading."

At my presentation of the tilt error findings at the 1990 NSS Convention in Yreka, Robert Thrun told me about an article by Brod in 1984 (C&T, v.2, no.1, p.11) which warned about tilt error and gave the following method of control for the Suunto Compass. Brod wrote, "Figure A shows a bubble level installed in a Suunto Compass, which will greatly reduce this error." It was only through Thrun's keen memory that I found about this solution for Suunto compasses. Also, it seems to me that Brod's mention of using the Suunto compass drum alignment with the Suunto case as a method of level control was a suggestion intended to at least give some control of tilt error.

Brod described another innovative control of compass tilt error during high inclination angle sightings which is important. In his pioneering paper "An Analysis of Instrument Errors", Brod wrote, "Of course, the problem of a steeply inclined station line may be alleviated by dropping a plumb line either from the station or from some point along a line stretched between the two stations; the auxiliary station line between the lower station and the new station at the base of the plumb line can be essentially horizontal." I would add that this may not work well in cave passages having strong currents of moving air or falling water.

It is important that Lang Brod's pioneering work on compass tilt errors, his solutions: a bubble level inside the Suunto and plumb lines, and my data on the tilt errors with the glass rod sight on the Suunto be continually passed on to cave surveyors. It is also important that this article is about differences between theory and experiment in trying to describe tilt error. This discussion should not obscure the fact that as the inclination angle increases, tilt error increases at an enormous rate!

FUTURE CAVE SURVEY TECHNOLOGY

by Roger V. Bartholomew NSS 9349

In the 1968 Bulletin of the Geological Society of America, v.79, p. 735-742 an article "A Microwave Study of Buried Karst Topography" by J.M. Kennedy of Aerojet General Corp. gave me a sort of preview of future space age cave survey technology. Kennedy used a microwave radiameter at 13.4 GHZ, 37 GHZ and 94 GHZ to detect the presence of radiometric "cold" anomalies associated with void-space development beneath several tens of feet of soil cover. Kennedy speculated that microwave systems may be used to detect and rapidly map karst systems from a remote location. The problem for the average caver was that the instrumentation was housed in a 16 foot mobile laboratory on a one and a half ton flatbed truck. I have not followed this technique and it may be that the technology has advanced so that a smaller and less costly device is available.

The 16 September 1991 Aviation Week & Space Technology magazine, p. 66, reported that McDonnell Aircraft Company is testing a new sensor called a Gravity Detection and Ranging System (Gradars) which would detect objects from their gravitational effects. This super-cooled, superconducting gravity gradiometer represents an ultra-sensitive improvement over gravity meters or gravimeters. The detector consists of two magnetically levitated proof masses that are positioned in line with the object of interest. A superconducting quantum interference device (SQUID) detects very small movements of the masses as the object to be analyzed moves past the stationary proof masses. Although sufficient stabilization of the proof masses has not been achieved, the SQUID has detected movements as small as 10^{-7} cm. The last paragraph speculates that portable Gradars could be used to detect tunnels. The sensor would pass over and identify a tunnel by detecting a warp in the Earth's gravitational field.

The 17 February 1991 Aviation Week & Space Technology magazine, p. 41, reported that two-color infrared tomography developed to measure temperatures during underground nuclear explosions is being adapted for mine detection and archeological searches. I speculate that this may be useful for detecting cave passages near the surface, especially entrance areas.

LETTER TO THE EDITOR
by George Dasher
March 8, 1992

I read with interest Ed Devine's article on the Cartographic Salon in the Summer and Fall 1991 Compass and Tape. He presented many good arguments, two of which I would like to expound upon.

First, it is important that all cave maps have a date. This should not be a date of when the map was drafted, rather it should be the date (or dates) that the data was collected. In other words, the cartographer is saying, in this month or in these years, the cave looked like this.

Second is the matter of the cave's entrance location. A couple of years ago, a half dozen or so of us met during a Convention and devised standards for maps entered in the annual Cartographic Salon. These standards included seven required criteria, which were: A cave name, a marked entrance or connection with the rest of the cave, a north arrow (preferably aligned to True North), a bar scale (labeled with linear units!), some type of vertical delineation, a date, and the cartographer's name.

Obviously, some items of importance are missing. One of these is the cave's political location, i.e., Pocahontas County, West Virginia. Perhaps it was the xenophobe in us oozing out, but we felt that not all cave maps should include a political location.

Another item left out of the required criteria was a precise geographic location, i.e. the latitude and longitudes. UTMs, or State Plane coordinates of the cave's entrance. This was left off because most every caver today is petrified that a horde of cave vandals will enter every cave in the world and destroy it.

I have to be honest. It is possible that some caves will be damaged if we put the caves' precise locations on our maps. But why are we protecting our caves from ourselves? A couple of Speleo-Digests ago, I asked Scott Fee, then the editor of the Digest to block out the entrance coordinates on one cave I had mapped. I thought the cave location sensitive. A bunch of locals had been writing their names in the cave and Mike Dyas had said -in print- that the cave was one of the best forgotten secrets in West Virginia.

But on the other hand, this cave is located within one of the twenty or so locales picked during the Depression as possible dam sites for Washington D.C. water reservoirs. Now we all know, somewhere in downtown D.C., those plans are still stored in some filing cabinet. Suppose someone gets them out, dusts them off, and starts mixing concrete. The only people I have protected the cave from is the NSS, the very people best-suited to jump in front of the bulldozers. No one can protect what they can't find!

Also, to add insult to injury, when I made my request to yank the entrance coordinates off one map, Scott thought it was such a great idea he yanked the coordinates off all my maps in every Speleo-digest he edited. Most of these caves weren't much as caves go, and the only record of their existence is going to be the maps published in the West Virginia Caver and the Speleo-Digests. Twenty years from now, no one is going to be able to find these caves.

I know some cavers out there would think this would be a good thing. A cave lost is one that can not be trashed. A cave lost is one that can be discovered and explored a second time. A remapping project is just as relevant as a mapping project.

I can not agree with these opinions. I trust the NSS and Organized Cavers to protect the caves in the future, if they can find them. Every cave that is mapped, and every cave location known, is one more cave we can mark off our list of what's been checked in our search to find the really big cave we're all secretly looking for. I have not been crawling down all those muddy, miserable crawls all these years, so someone can check and remap my work. I've been doing it so that the next generation of cavers can, particularly in the backhoe factor is included, find more caves, bigger caves, caves unknown to us of this generation.

So, the bottom line, I personally feel we should be putting the political and precise geographic locations on our cave maps. I believe this so strongly that I feel that the political and geographic locations should be Cave Map Requirements Number 8 and 9. I do not want to lose this generation's caves!

CORRECTIONS

by Tom Kaye

Along with his two articles printed in this issue, Roger Bartholomew sent corrections to two of his former articles. It looks like the low level of my typing skill has been exposed once again. My apologies, Roger. The italicized portions were those that I left out.

Volume 8, Number 3, page 22:
Attaching a sighting device to the *Smartlevel module is made difficult by the odd cross sections of the* module package: oval in one plane and trapezoidal in another.

Volume 8, Number 4, page 7:
The glass rod is used on the Suunto case to help point the Suunto compass at the target light for high inclination *angle sightings, but it is at these high inclination* angles that the glass rod must be held more level precisely to avoid greater tilt errors which point the Suunto away from the target station!

Volume 8, Number 4, page 7:
The best way is to set up a light with a white string hanging down directly under the filament as in *figure 2 and take the Suunto with glass rod sight and try many* different sightings with various inclination angles and tilts using the white string and the correct aiming point.

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