# Field Surveying

Geographic research requires that the researcher knows *where* the data is being collected. In other words, the spatial data (i.e. place) must be married to the associated attribute/aspatial data (i.e. details and descriptions).

Frequently during field observation, there are no landmarks or easily identifiable features that appear on a map. There is nothing that you can relate to an existing map in the space of your study area. For this reason, it is necessary that you understand the basic concepts of *Field Surveying* and its application.

**Field Surveying:** The measurement of locations, distances, angles, elevations and direction to determine the absolute and relative positions of existing and new points or objects.

# Continuous Geo-Referencing

## PROBLEM:

What method do you use to define a point on the surface of the earth, and how do you locate the same point on a map given spatial distortion associated with map projections?

- *Continuous Geo-Referencing*: The definition and measurement of coordinates on a continuous scale with no effective limit to precision; absolute location or position.
- *Discrete Geo-Referencing*: The definition and measurement of the location of discrete areal or spatial units on the earth's surface; relative location or position.

# Examples of Continuous Geo-Referencing

**1. Spherical Coordinates (Latitude, Longitude or $\Phi$, $\Gamma$)**

- Defined by a network of lines that form the *Graticule*.
- The graticule consists of:
    - Lines parallel to the equator (parallels or latitude - $\Phi$) that range from -90 degrees through 0 degrees at the equator to +90 degrees).
    - Lines connecting the poles (meridians or longitude - $\Gamma$) that range from 0 degrees (Greenwich) to ±180 degrees where "-" is westerly and "+" is easterly.
- APPLICATION: suitable for small-scale mapping.

**Degrees Minutes Seconds to Digital Degrees**

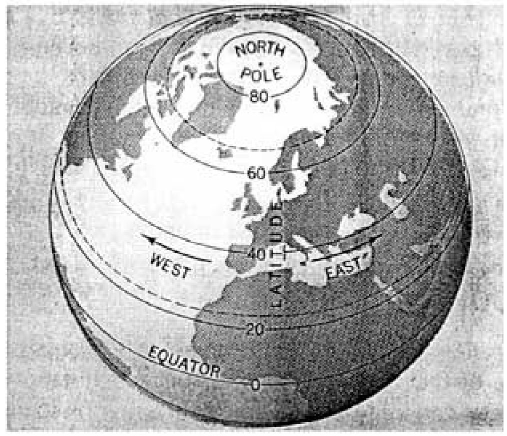
***In simple arithmetic:***

1. Divide the minutes by 60;
2. Divide the seconds by 3600;
3. Add the two results to the degrees.

***Example:*** 35 degrees, 30 minutes, 30 seconds

1. Divide the minutes by 60 30/60 = .500;
2. Divide the seconds by 3600 30/3600 = .0083333;
3. Add the two results to the degrees 35+.5+.008333 = 35.5083.

**Parallels of latitude, meridians of longitude**



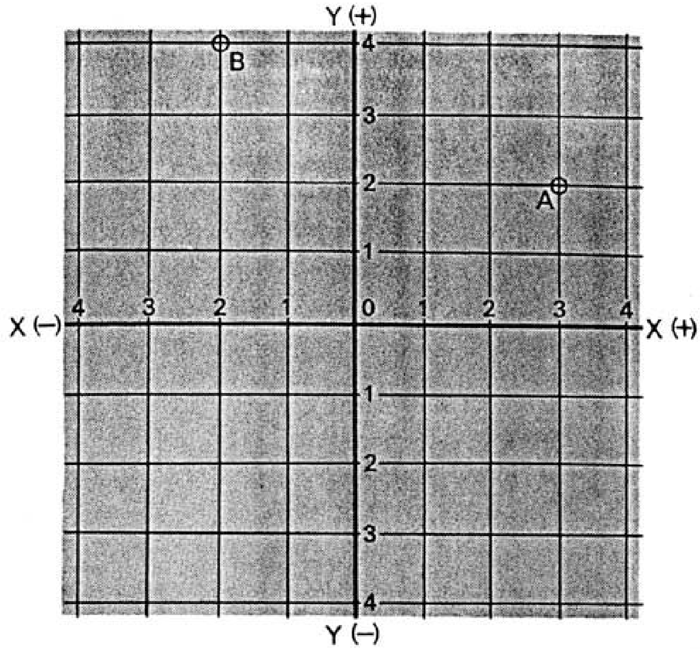

The parallels of latitude (showing distance north-south) specify the directions east-west. (from Trewartha, Robinson, Hammond and Horn, *Fundamentals of Physical Geography*, 3d ed., New York: McGraw-Hill Book Company, 1977.)


The meridians of longitude (showing distance east-west) specify the directions north-south. (from Trewartha, Robinson, Hammond and Horn, *Fundamental of Physical Geography*, 3d ed., New York: McGraw-Hill Book Company, 1977.)

## 2. Cartesian Coordinates (X,Y)

- Definition:
  - Define an origin
  - Define a positive X direction
  - Define a positive Y direction orthogonal to X
  - Define linear displacement from the origin in X and Y

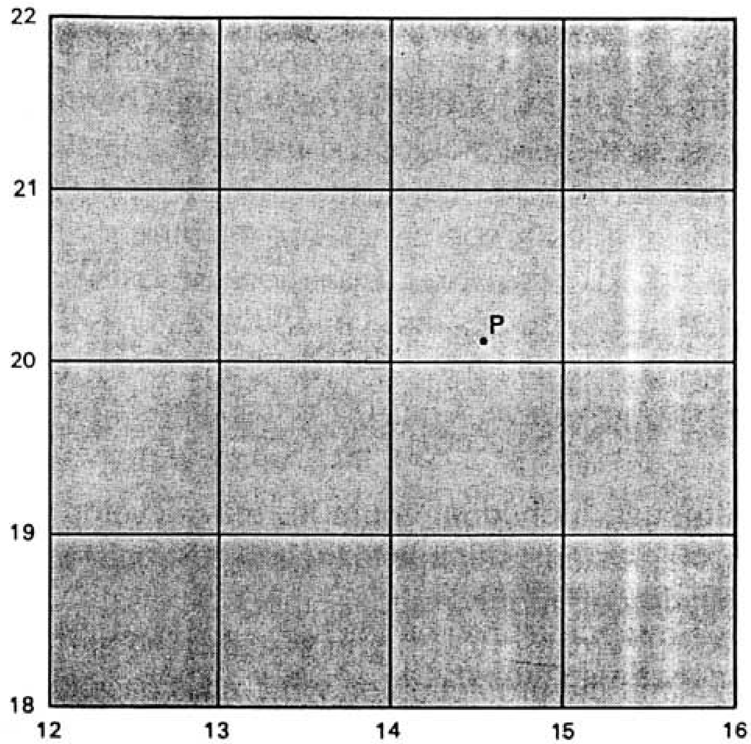
## Rectangular (Cartesian) coordinate system




A rectangular coordinate system. The origin is 0. The abscissa values are -X, 0, +X and the ordinate values are -Y, 0, +Y. The postion of point A is 3,2; the postion of point B is -2,4. In the geographical coordinate system, Y values correspond to latitude north and south and X values to longitude east and west of the origin (0° latitude and 0° longitude). In designating position in a plane rectangular coordinate system, the X value is always given first; in the geogrpahical coordinate sytem, latitude is usually given first.

## Locating a point within a rectangular grid

A portion of a rectangular grid. If the squares are 1km on a side, then point P may be located to within a 10 m² with the grid reference 14562011.




- Euclidian Distance (Pythagorean Distance)
  - The distance, D, between two points ($X_1$, $Y_1$) and ($X_2$, $Y_2$) can be calculated as follows:

$$D^2 = (X_1 - X_2)^2 + (Y_1 - Y_2)^2$$

- Precision: Precision is expressed using real numbers (e.g. 3.473 m), which are often shown as a *floating point* numbers defined by two sets of digits. For example:

| | | | |
|---|---|---|---|
| 67.34 | → | $0.6734*10^2$ | +6734E+2 |
| 498.30 | → | $0.4983*10^3$ | +4983E+3 |
| 1,560,000 | → | $0.1560*10^7$ | + 156E+7 |
| -0.0032 | → | $-0.32*10^{-2}$ | - 32E-2 |

- APPLICATION: Suitable for large-scale mapping.

**Geodetic Polar Coordinates (r, θ)**

- Definition:
    - Define an origin (0,0).
    - Define a fixed direction (usually north).
    - Measure distance (r) from a point along a vector.
    - Measure an angle (θ) between the fixed direction and the vector.
- To translate from polar coordinates (r, θ) to cartesian coordinates (X, Y):

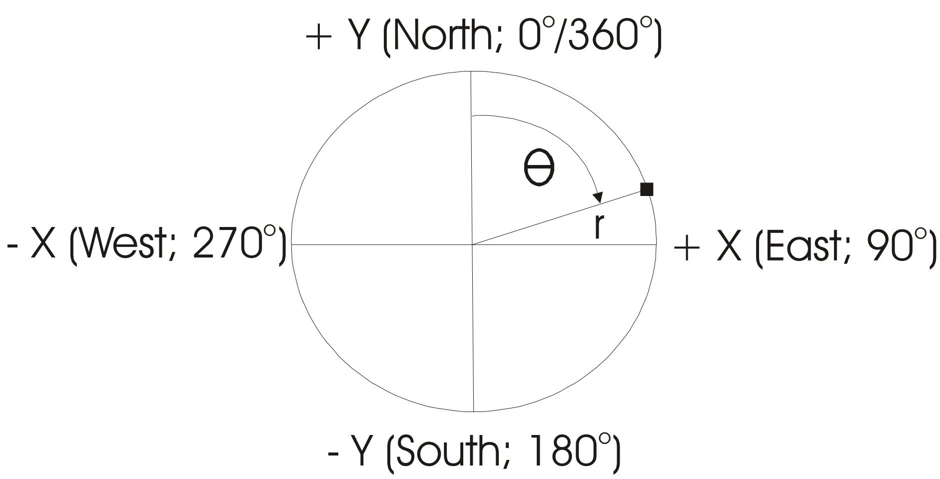
  $X = r * \sin(\theta)$
  $Y = r * \cos(\theta)$

- To translate from cartesian coordinates (X, Y) to polar coordinates (r, θ):

$$r = \sqrt{X^2 + Y^2}$$

$$\theta = \arctan\left\langle \frac{X}{Y} \right\rangle \quad \text{or} \quad TAN^{-1}\left\langle \frac{X}{Y} \right\rangle$$

- APPLICATION: Suitable for large-scale mapping.




**Important Note:** In <u>surveying applications</u>, the angle (or azimuthal direction), Θ, is measured clockwise from North.

**Example of converting Polar to Cartesian:**

Change X = 3 m and Y = 4 m to Polar coordinates

Part 1: $r = \sqrt{X^2 + Y^2}$

$r = 3^2 + 4^2 = 9 + 16 = 25$; then take the square root of 25.

r = 5 m

Part 2 : $\Theta = \arctan\left\langle \frac{X}{Y} \right\rangle$ or $TAN^{-1} \left\langle \frac{X}{Y} \right\rangle$

$\Theta = TAN^{-1}$ (3/4) = $TAN^{-1}$ (0.75)

$\Theta = 36.9^o$

Therefore, the point is (5 m, $36.9^o$)

**Example of converting Polar to Cartesian:**

Change (4 m, $75^o$) to Cartesian/rectangular coordinates

Part 1: X = r * sin ($\theta$)

X = 4 * sin ($75^o$) = 4 * 0.97

X = 3.88 m

Part 2: Y = r * cos ($\theta$)

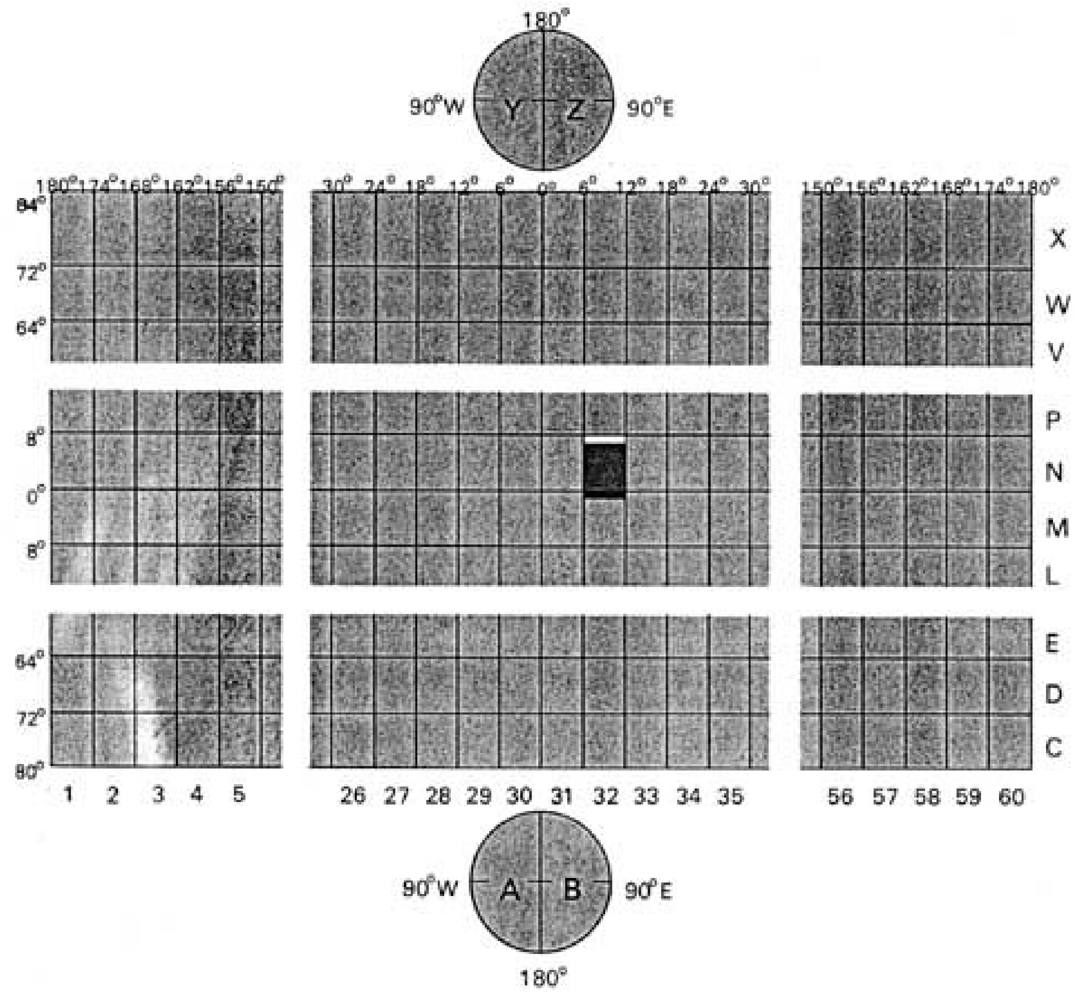
Y = 4 * cos ($75^o$) = 4 * 0.26

Y = 1.04 m

Therefore, the point is (3.88 m, 1.04 m)

**4. Universal Transverse Mercator [UTM] Coordinates (easting, northing)**

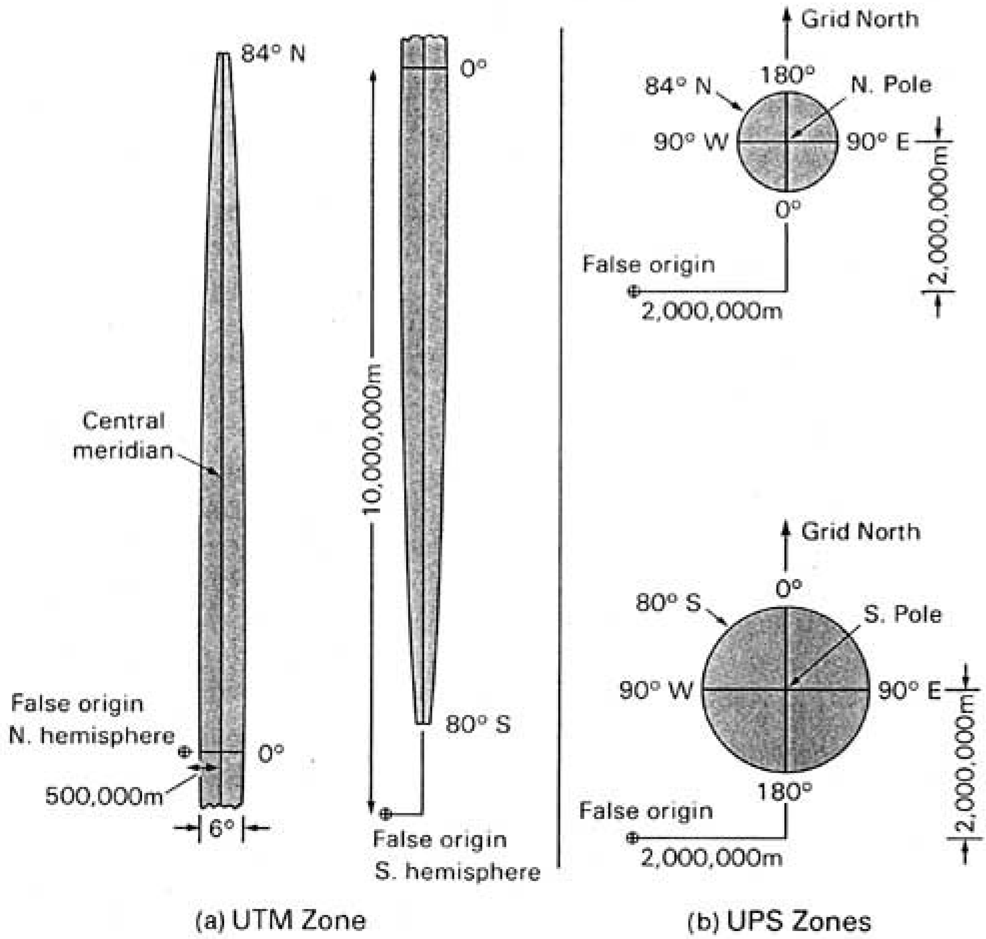
- Provides geo-referencing at high levels of precision for the entire globe.
- Established in 1936 by the International Union of Geodesy and Geophysics.
- Now adopted as a standard by most nations and agencies in the world.
- Definition:
    - The world is divided into 60 zones




The System of UTM and UPS grid zone designations. Each quadrilateral is identified by its column number and row letter (I and O are omitted). The tinted zone is 32N. The UPS grid zones in the polar areas are sectors on each sde of the 0°-180° meridians.

- Zones are numbered eastward from 1 to 60 beginning at 180 degrees west.
- The central meridian of each zone is given an easting of 500,000 m.
- Must note if the point lies in the northern or southern hemispheres.

    - For the northern hemisphere, the equator has a northing of 0 m.
    - For the southern hemisphere, the equator has a northing of 10,000,000 m.




Universal Transverse Mercator and Universal Polar Stereographic zones. (a) UTM Zone; (b) UPS Zone.

    - Coordinates are defined by adding or subtracting actual distances relative to easting or northing for a given zone and a given hemisphere.
- UTM coordinates only apply between 80°S and 84°N. The *Universal Polar Stereographic* (UPS) coordinate system is used in the polar regions.
- Scale distortion within a UTM zone ranges from .9996 to 1.0003.
- APPLICATION: Suitable for intermediate mapping; commonly used in topographic mapping and for referencing satellite imagery.

# Scale

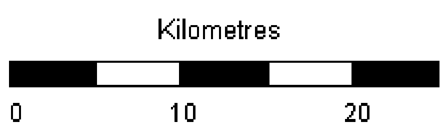
Scale is the ratio of map distance to actual distance.

- Each map has a defined dimensional relationship between reality and the map; this relationship is called scale and it is of primary importance (Robinson et al, 1984).
- The map scale is the ratio between the distance on the map and the corresponding distance on the ground:
- Here's the ratio in geographic term:

$$1: \frac{\text{Ground Distance}}{\text{Map Distance}}$$

NOTE: Make certain that the units of measurement are the same for both the numerator (map distance) and the denominator (actual distance).

### Statement of Scale

| | |
|---|---|
| Representative Fraction | $1: \frac{\text{Actual distance}}{\text{Map distance}}$ |
| Verbal Scale | 1 inch represents 1 mile<br>1 cm represents 1 km |
| Graphic or Bar Scale |  |

- Verbal – Not as valuable as others.
- Scale Bar – Valuable for quick *estimations* of on the ground distance.
- Representative Fraction – Valuable for more *accurate estimations* of on ground distances.

## The Scale Problem

"Map scale is an elusive thing because by the very nature of the necessary transformation when going from the sphere to the plane, the scale of a map must vary from place to pace and will vary in different directions at a point." (*Robinson, et al.*, 1984, pg. 60).

## Key Issues

Scanning and Photocopying

- If you photocopy a section of a map and do not note either its representative fraction or copy the scale bar **any** measurements are of little if any value.
- If you enlarge or reduce (Change the Scale) the same is true.
- To work around this problem involves lots of extra calculations.

## Large Scale versus Small Scale

- This confuses everyone at some stage – you are not alone! It seems counter–intuitive.
- 'Large scale' refers to maps on which objects are relatively large, 'small scale' to maps on which objects are relatively small.
- The ratio 1:50 000 - size of objects on the map is 1/50,000 of their size on the ground.
- The ratio 1:250 000 - size of objects on the map is 1/250,000 of their size on the ground.
- 1/50 000 is a larger fraction than 1/250 000, so 1:50 000 is the large-scale map.
  - Example: 1/2 of an apple pie is larger when compared to 1/4 of an apple pie. Which would you rather have (assuming you like apple pie)?
  - Example: Which would you rather get? A ¼ share of a lottery win or a ½ share?

**Here is a 'trick' to aid in remembering large scale versus small scale**:

Large scale covers a small area *Or* Small scale covers a large area.



## Examples: Which is which?


Both Maps are the same physical size.

- One is 1:50,000
- One is 1:250,000
- Which is which?

## Key Conversions to Remember

- Straightforward:
  - – 1km has 1000m
  - – 1m has 100cm
  - – 1cm has 10mm
- More Involved:
  - – 1km has 100,000cm
  - – 1km has 1,000,000mm
  - – 1m has 1000mm

## Here are some examples we will do in class:

**Example 1:** On a map a road measures 2 cm; in reality, the same road measures 1 km. What is the scale of the map?

**Example 2:** There has been a gas explosion. We know that it will spread by a radius of 1.5km. What is the distance (cm) on a 1:10000 map?

**Example 3:** You have a 1:250,000 map and have measured on it the distance from your home to the Ferries (4cm). What is the actual distance (km)?

## Scales from Large to Small

| Map scale | 1 cm represents | Name |
|---|---|---|
| 1:1 | 1 cm | → no proportional change |
| 1:100 | 1 m | → plan - large scale maps |
| 1:10,000 | 100 m | → large scale maps |
| 1:25,000 | 250 m | → large to medium scale maps |
| 1:50,000 | 500 m | → medium scale maps |
| 1:100,000 | 1 km | → medium scale maps |
| 1:250,000 | 2.5 km | → small scale maps |
| 1:1,000,000 | 10 km | → small scale maps |
| 1:100,000,000 | 1,000 km | → world fits on 8”x11” page |

## Rounding and Significant Figures

When calculating scale, it is important to round the number to the appropriate number of significant digits.

Example: As an example we will use the following information: 12 cm on a map representing 3.5 KM

- **12 cm represents 3.5 km**
- **12 cm represents 350,000 cm**
- **1 : 29,166.667**

Which of the following scales is rounded correctly?
**A. 1:29,167** **B. 1: 29,200** **C. 1:29,000**

## Rules

- Trailing zeros are significant only if the decimal point is specified; 12, 1200, or 12000, all have 2 significant figures, whereas 12.0 has 3.
- Leading zeros are never significant. For example 0.04 has only 1 significant figure, whereas 0.04000 has four.
- The answer can contain no more significant figures than the **least** accurate measurement (i.e., the smallest number of significant figures).

## So, how many significant figures do we have?

**TWO:** 12 and 350,000 both have two significant figures.

This means our scale should be rounded to two significant figures.

- Start counting from the left and proceed to the right…or you can change 29167.667 into scientific notation $2.9167667 \times 10^4$
- *Scientific notation is the most reliable way of expressing a number to a given number of significant figure*s].
- Either way, the answer should be rounded to the second digit (because we have two significant figures).
- So, the answer is **C. 1:29,000**

## Accuracy

- Degree to which data agree with the values or descriptions of the real-world features that they represent
- How ‘close’ the data match the true values or descriptions
- Spatial and attribute

## Precision

- How ‘exact’ data are measured and stored
  - ◊ Mapsheet 92B.044
  - ◊ 48o26’00’’N, 123o22’00”W
  - ◊ 5363155mN, 473593mE

## Relationship between, Precision and Accuracy

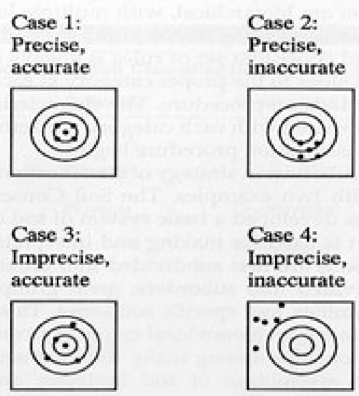



**FIGURE 2.1**
The Measurement Concepts of Precision and Accuracy: The Target Analogy

## Detail and Precision

Scale determines the detail and precision of information to be mapped. The difference between a spherical and elliptical model of the earth is irrelevant at scales smaller than 1:10,000,000. Geodetic Variation becomes significant for scales larger then 1:100,000. An average line on a map has a dimension of 0.5 mm. On a map at a scale of 1:25,000 this translates into a true line dimension (width) 12.5 metres. This controls precision of location.

| Map scale | 0.5 mm represents | 1 cm represents | 1 km is represented by |
|---|---|---|---|
| 1:2,000 | 1.0 m | 0.02 km | 50.0 cm |
| 1:10,000 | 5.0 m | 0.10 km | 10.0 cm |
| 1:25,000 | 12.5 m | 0.25 km | 4.0 cm |
| 1:250,000 | 125.0 m | 2.50 km | 0.4 cm |
| 1:1,000,000 | 500.0 m | 10.00 km | 0.1 cm |

- CAUTION: Since scale determines precision and detail, we should not use a smaller scale to make larger decisions. For example, combining a 1:100,000 scale map with a 1:20,000 scale map to reach a planning decision at the 1:20,000 violates the laws of spatial data management.

# Surveying and Collecting Data

**Primary Data**

Primary data collected for the purpose of specific research. The researcher is in control of the data quality and data collection strategy.

**Secondary**

Archival data is where the researcher is not in control of the data collection. The researcher must rely on someone else's primary data. There is less control over data quality.

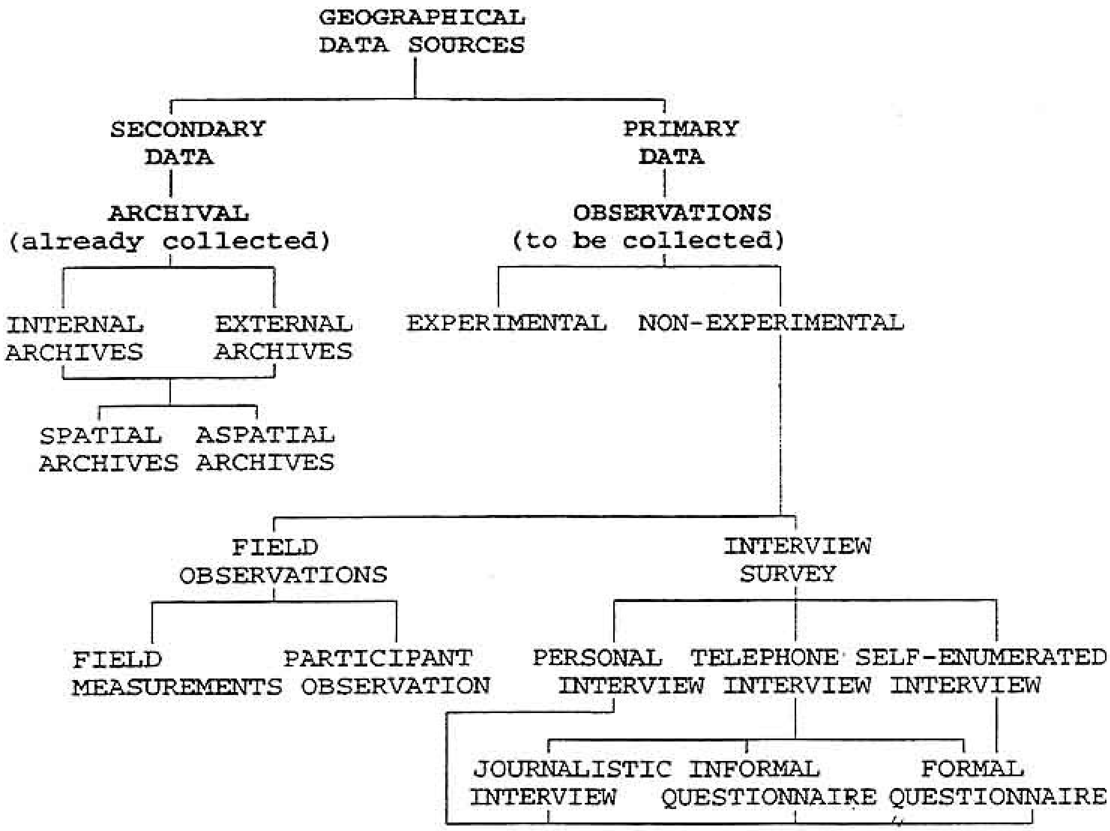
NOTE: Primary data for one research project may be secondary data for another project.

# Common Field Data Collection Techniques

- *Experimental:* Experimental data collection implies that some variables in research problem are controlled to allow information to be collected about the behaviour of other variables.
- *Non-experimental:* Non-experimental data collection implies that no variables are controlled for.
- *Field observations:* Observation and monitoring of an ongoing activity in the field, and/or direct recording of data about it.
    - Participant observation
    - Field measurement
- *Interviews:* Data collected by informal or formal interview process.

| | |
|---|---|
| Types of Interviews | ○ personal interview<br>○ telephone interview<br>○ self-enumerated interview (e.g. questionnaire) |
| Styles of Interviewing | ○ journalistic interview style<br>○ informal questionnaire style<br>○ formal questionnaire style |

TYPOLOGY OF ASSOCIATED ATTRIBUTE DATA SOURCES




# Field Observations and Field Surveying

Geographic research requires that the researcher knows *where* the data is being collected. In other words, the spatial data must be married to the associated attribute/aspatial data usually through a discrete geo-referencing system.

You have been introduced to some common continuous geo-referencing systems such as spherical, cartesian, polar and UTM. These systems are great if you can match your research location to a map showing any one of these geo-referencing systems. Frequently in field observation, there are no landmarks or easily identifiable features that appear on a map. There is nothing that you can relate to in the space of your study area. For this reason, it is necessary that you understand the basic concepts of *Field Surveying* and its application.

**Field Surveying:** The measurement of locations, distances, angles, elevations and direction to determine the absolute and relative positions of existing and new points or objects.

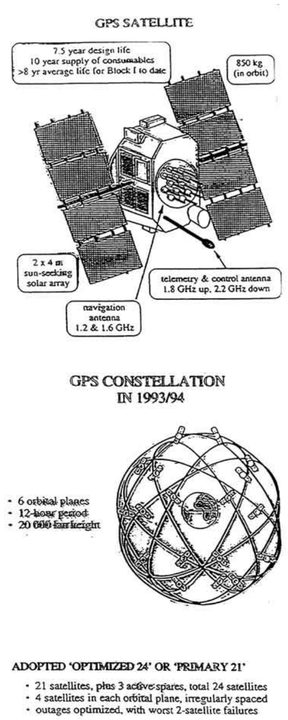
A systematic description of land units using records and maps is called a *Cadastre*.

# Types of Surveys

**Geodetic Surveys:** to determine absolute position using the principles of geodesy and incorporating the earth curvature. These surveys are considered “legal” in that the surveyor may be liable if positions are misrepresented.

- Determination of Location:
  a. *The location of stars or planets:* It is possible to determine absolute position if you know the angle between a known star or planet and the horizon line, celestial tables and local time relative to Greenwich time.
  b. *Global Positioning Systems:* It is possible to locate a position in three dimensions to a very high precision using signals which are continuously transmitted by a set of GPS satellites that travel around the earth along fixed orbits. All you need is a GPS receiver and access to GPS control station data.

**The GPS Constellation**




*Source: Canadian GPS Associates*

- Geodetic Surveys yield a set of locations on the surface of the earth for which we know the exact latitude, longitude and altitude. These points, identified by permanent markers, can be connected by straight lines to yield a network of control points - sometimes called *ground control points*. This network of ground control points exists at different levels of a hierarchy ranging from primary networks (geodetic control points) to municipal networks (reference benchmarks). All cadastral surveys concern the location of points *relative* to this ground control network.

**Cadastral Surveys:** to determine relative location assuming the earth is flat. These surveys are also considered "legal".

- Determination of Location:
  - Measurements are taken relative to known locations derived from geodetic control points or reference benchmarks using trigonometry, and taking a combination of distance, direction and angular measurements.
  - NOTE: Location can be measured to varying degrees of accuracy and precision. Always question locational accuracy and precision when conducting geographical analysis.
- Horizontal Controls: Cadastral Surveying requires measuring the following phenomena in order to accurately determine and map location:
  - Distance
    - Horizontal distance
    - Slope distance
  - Direction
- Vertical Controls: Cadastral Surveying requires measuring the following phenomena in order to accurately determine elevation and changes in vertical distance:
  - Vertical angles
  - Differential vertical heights

**Local Surveys:** to determine relative location assuming the earth is flat. These surveys are **NOT** considered "legal". Rather, they are research specific. Local surveys can make use of existing Geodetic and Cadastral surveys.

# Surveying and Horizontal Control

When considering Horizontal Control, our goal is to locate points on the plane for mapping purposes. This requires an understanding of Polar Coordinates, and how radius relates to distance and angle relates to direction.

**Distance:** The radius in Polar Coordinates is that "distance" from a starting to point to a secondary point. In mapping, the critical distance is the *horizontal* distance. This represents the distance along a horizontal plane where variations in terrain have been removed. It is the distance between two points that we might view if looking down from an elevated platform (e.g. balloon or airplane). In some cases, it is possible to take direct measurements of horizontal distance. Due to the nature of the Earth's terrain, we usually have to derive it by other means.

## Distance over flat terrain

### 1. Pacing

It is possible to estimate distance if you know your *pace*. A pace is the distance you travel every second step (i.e. the distance between your right foot hitting the ground and the next time your right foot hits the ground while walking at your normal speed). Understandably, few people share the same pace.

You can determine your pace by laying out a 50 or 100 meters tape along a level surface. Then, at a casual walk, count the number of steps to cover the 50 (or 100) meters. Reverse your direction, and count the number of steps going back. Average the two step counts, then apply the result to the following formula:

Formula: $$\text{Pace} = \frac{\text{50(or 100) metres}}{\text{Average number of steps/2}}$$

Example: $1^{st}$ Count = 115 steps; $2^{nd}$ Count = 117 steps
Average steps = (115+117)/2 = 116 steps
$$\text{Pace} = \frac{\text{100 metres}}{116/2} = 1.72 \text{ metres}$$

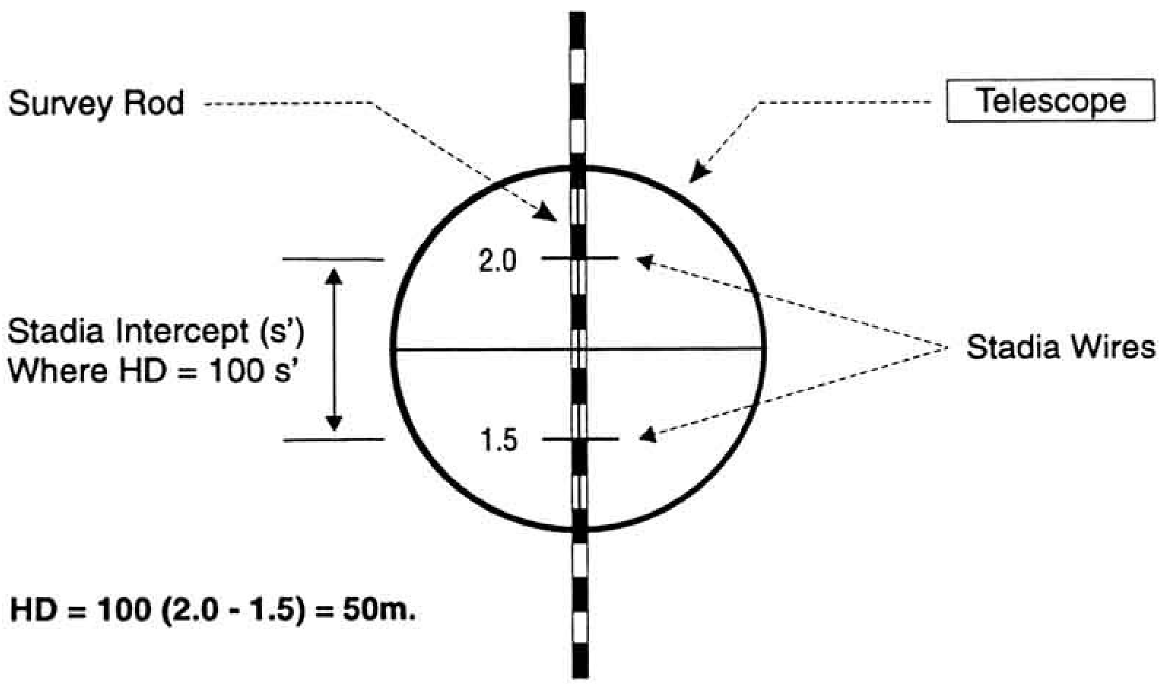
This method is remarkably accurate over short distances (< 50 meters) when there are no obstructions between the two points. Obstructions, greater distances and varying terrain can significantly lower accuracy.

## 2. Tacheometry (Stadia)

Tacheometry is an instrument-based procedure for determining horizontal distances. It requires a transit, tripod and stadia rod, and a very simple formula.

A transit is made up of several very important components. For tacheometry, the most important component is the telescope. When looking through the telescope, the viewer sees upper, centre and lower cross-hairs.

**The crosshair configuration as seen through the telescope**



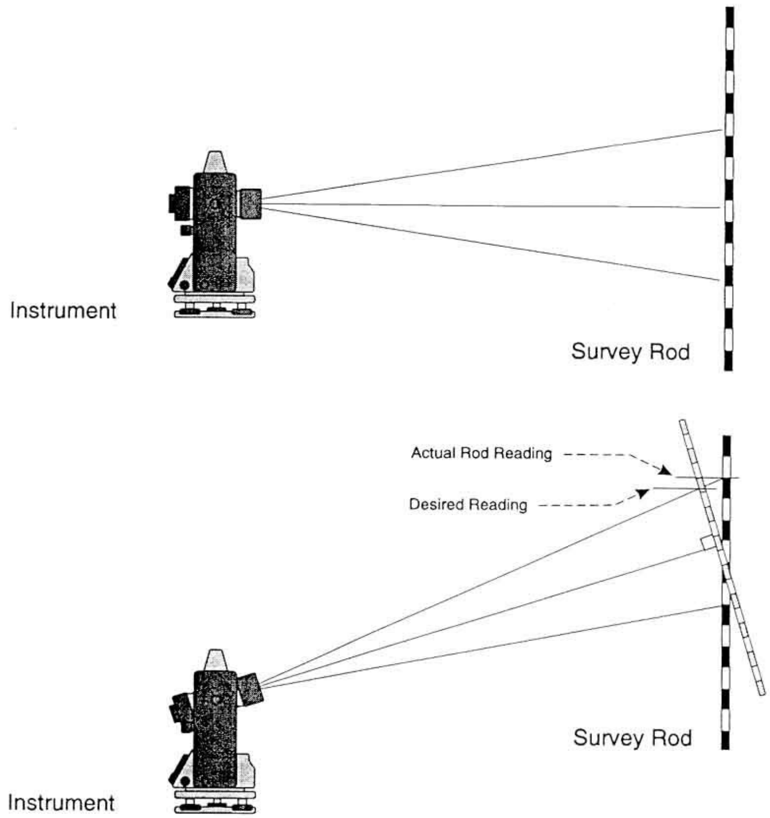

Calculating distance using the stadia intercept (s').

The transit is attached to the tripod, and set up directly above the starting point. The telescope is then *leveled* using a leveling bubble attached to the telescope. A *rod person* is then sent to the secondary point with the stadia rod. The stadia rod is marked off in either feet/inches or meters/centimeters (sometimes both). The stadia rod is placed on the secondary point at the vertical (straight up and down). A plumb bob can help the rod person keep the rod vertical.

The *instrument person* then sights through the telescope onto the rod making adjustments to the focus until the rod is clearly visible. The instrument person should be able to take direct readings off the rod noting the rod readings associated with the upper and lower crosshairs (the center crosshair should read the same as the height of the instrument assuming a perfectly horizontal surface).

If we were to look at this process from the side, and imagine lines projecting from the telescope associated with the upper, lower and center crosshairs, we would see that the upper and lower lines diverge with distance from the telescope.

**Telescope and stadia rod**




Stadia intercept calculations are easy when observing a horizontal point, but complicated when observing angles above or below 90°.

Note: The top view shows the diverging lines when the instrument is horizontal; the bottom view shows how the geometry changes when the telescope is not level.

The difference between the upper and lower rod readings are used to determine the horizontal distance between the two points, along with an *adjustment factor* associated with the transit. This adjustment factor is set by the manufacturer, and corresponds to how the upper/lower crosshairs are placed in the telescope. The Department of Geography instruments all have an adjustment factor of 100. Horizontal distance (HD) is calculated using the following formula:

Formula: HD = (adjustment factor) * (difference between the U/L readings)

Example: HD = 100 * (2.13 metres – 1.47 metres)
= 100 * (0.66 metres) = 66 metres

The method of measuring horizontal distance is great when pacing or using a tape measure is inconvenient or impossible. It requires a clear line of sight between the points and a steady hand by the rod person. Accuracy decreases significantly as distances exceed 50 meters, terrain begins to vary and weather conditions deteriorate.

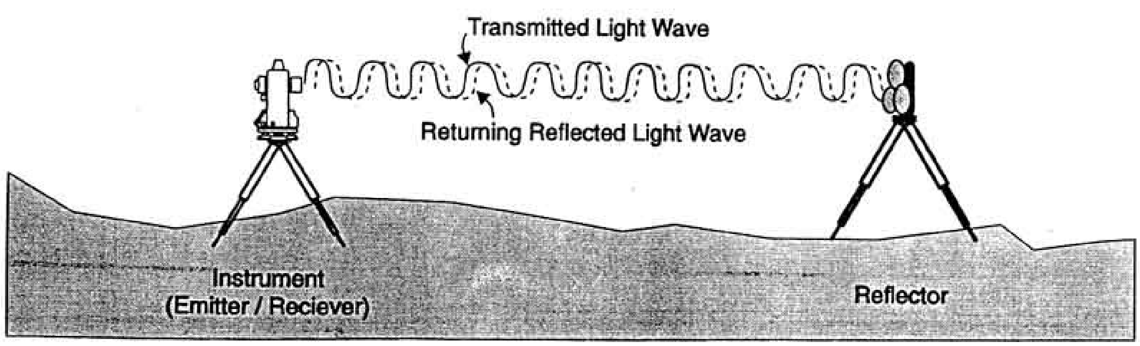
## 3. Taping

Still the most reliable and accurate “low tech” method for measuring distances, a tape can give distance measurements to the nearest centimeter within a 50 meter range, and 10 centimeters between 50 and 100 meters. The trick is keeping the tape horizontal over varying terrain and obstructions, and during windy weather.

## 4. Electronic Distance Measurement (EDM)

EDM, like tacheometry, is an instrument-based method for determining horizontal distance. The EDM emits a low intensity laser or infrared beam that is bounced off a prism back to the instrument. The time it takes for the beam leave and bounce back to the instrument is used to determine the distance.

**EDM and prism configuration**




Light beam phase shift allows accurate distance measurements using Electro-optical survey instruments.

The principle upon which the technology is based follows a very simple formula:

Formula: HD = (velocity of light) * (time)

Since the velocity of light is a constant ($3.0 * 10^8$ meters per second), we need only measure time to determine distance.

Example: HD = ($3.0 * 10^8$ metres/second) * ($300 * 10^{-9}$ seconds) = 90 meters

NOTE: The seconds in the equation cancel out. Also, $10^{-9}$ seconds is also referred to as a nanosecond - a standard unit of measure).

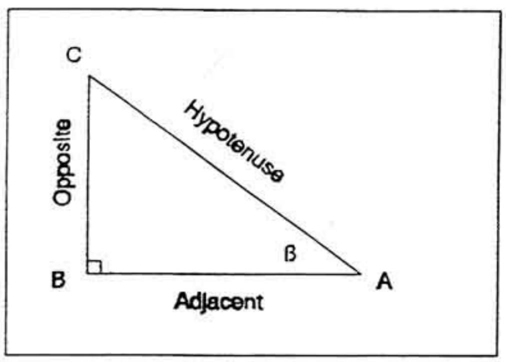
EDM is accurate to the nearest millimeter over several kilometers, but accuracy can deteriorate depending upon atmospheric conditions. Also, the technology associated with millimeter accuracy is NOT cheap ($6,500 Canadian and up).

# Distance over varying terrain

Since there are few places on the Earth's surface that are truly flat, we find ourselves having to compensate for variations in terrain. Deriving horizontal distances is no exception. Techniques involving pacing, pedometers or vehicle odometers quickly fall victim to variations in terrain since they are incapable of compensating for these variations. Techniques that are capable of yielding horizontal distances while compensating for variations in terrain are based upon the fundamental relationships of the right triangle, and the concept of a *slope distance*.

**Fundamental relationships of the right triangle**

*BASIC TRIGONOMETRY*




$$\mathrm{SIN}\ \beta = \frac{\mathrm{OPP}}{\mathrm{HYP}} = \frac{BC}{AC}$$

$$\mathrm{COS}\ \beta = \frac{\mathrm{ADJ}}{\mathrm{HYP}} = \frac{AB}{AC}$$

$$\mathrm{TAN}\ \beta = \frac{\mathrm{OPP}}{\mathrm{ADJ}} = \frac{BC}{AB}$$

$$\mathrm{COT}\ \beta = \frac{\mathrm{ADJ}}{\mathrm{OPP}} = \frac{AB}{BC}$$

$$\mathrm{SEC}\ \beta = \frac{\mathrm{HYP}}{\mathrm{ADJ}} = \frac{AC}{AB}$$

$$\mathrm{COSEC}\ \beta = \frac{\mathrm{HYP}}{\mathrm{OPP}} = \frac{AC}{BC}$$

*PYTHAGOREAN THEOREM*

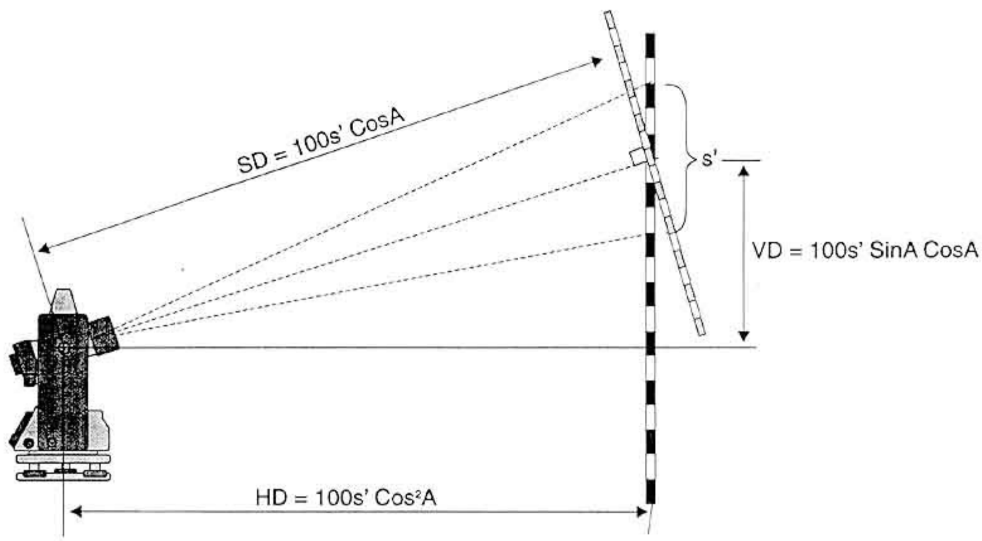
$$\mathrm{ADJ}^2 + \mathrm{OPP}^2 = \mathrm{HYP}^2 \quad \text{or}$$

$$|AB|^2 + |BC|^2 = |AC|^2$$

## 1. Tacheometry

Tacheometry (stadia) can be used when the secondary point is higher or lower than the starting point (instrument location). The telescope is no longer level. Rather, the center crosshair is aligned on the stadia rod to the height of the instrument (i.e. if the distance from the ground to the center of the telescope is 1.45 meters, the telescope is set so the center crosshair reads 1.45 meters on the rod). The telescope must also be equipped with a scale that reads vertical angles in degrees/minutes/seconds since will no longer be level. The vertical angle along with the difference between the upper/lower rod readings and adjustment factor can be used to determine horizontal and slope distances using some simple formulas.

**Formulas and configuration for determining distances using stadia**



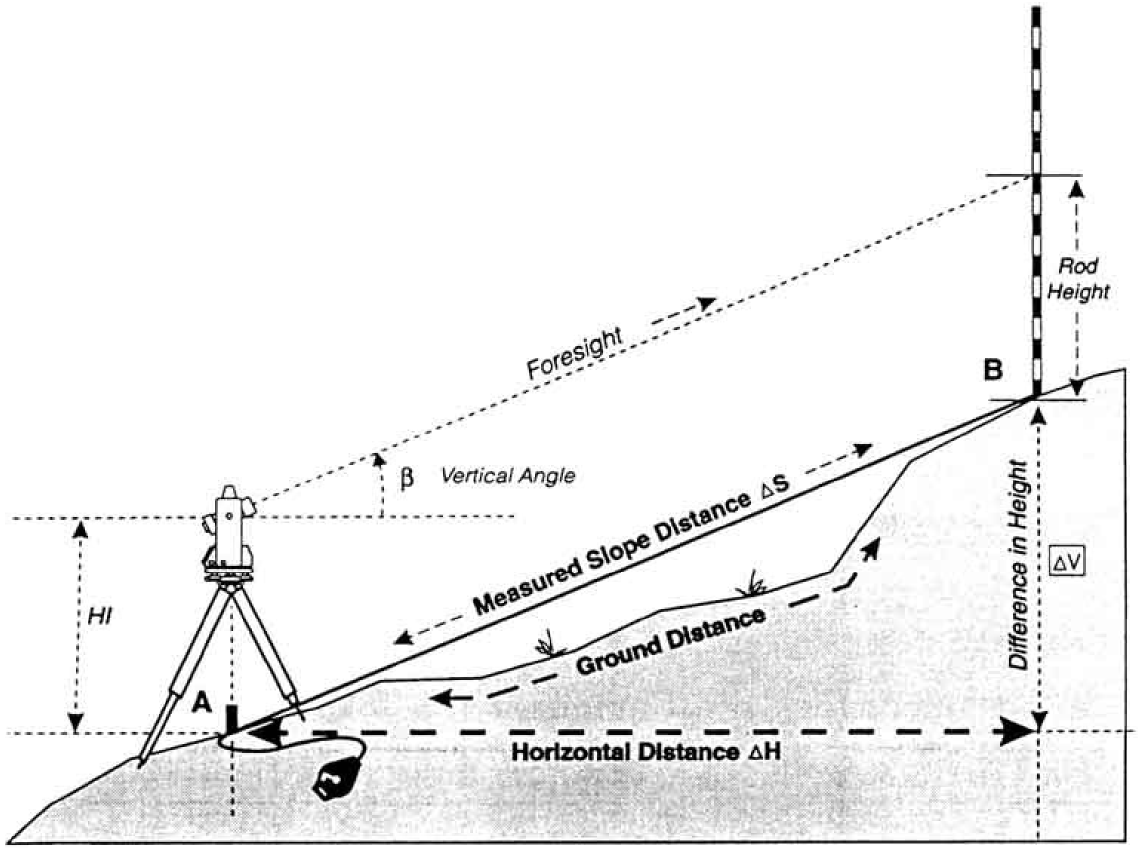

The stadia formulas used to calculate horizontal and vertical distances.

Tacheometry yields horizontal and slope distance with a 1 meter accuracy. However, the instrumentation id affordable, and it works great in any terrain that affords a clear line of sight.

## 2. Trigonometry

Trigonometry can be applied to various measurement techniques and instrumentation to determine horizontal distance. The key elements for determining horizontal distances are measurements of the slope distance and vertical angle. Slope distance can be measured with anything from a tape to an EDM. Vertical angle can be measured with anything from an Abney level to a theodolite (similar to a transit but employing internal prisms and mirrors). Everything is based on the right triangle.

**The right triangle applied to surveying practice**




The relationship between ground, slope and horizontal distances.

A major requirement for using trigonometry is making certain that you can find the sine, cosine and tangent of various angles. Note: *Never trust your calculator until you have compared results to a standard trignometric table!*

# Values of Trigonometric Functions

**APPENDIX J**

TRIGONOMETRIC FUNCTIONS

| Radians | Degrees | Sines | Cosines | Tangents | Cotangents | | |
|---|---|---|---|---|---|---|---|
| .0000 | 0 | .0000 | 1.0000 | .0000 | ∞ | 90 | 1.5708 |
| .0175 | 1 | .0175 | .9998 | .0175 | 57.29 | 89 | 1.5533 |
| .0349 | 2 | .0349 | .9994 | .0349 | 28.64 | 88 | 1.5359 |
| .0524 | 3 | .0523 | .9986 | .0524 | 19.08 | 87 | 1.5184 |
| .0698 | 4 | .0698 | .9976 | .0699 | 14.30 | 86 | 1.5010 |
| .0873 | 5 | .0872 | .9962 | .0875 | 11.430 | 85 | 1.4835 |
| .1047 | 6 | .1045 | .9945 | .1051 | 9.514 | 84 | 1.4661 |
| .1222 | 7 | .1219 | .9925 | .1228 | 8.144 | 83 | 1.4486 |
| .1396 | 8 | .1392 | .9903 | .1405 | 7.115 | 82 | 1.4312 |
| .1571 | 9 | .1564 | .9877 | .1584 | 6.314 | 81 | 1.4137 |
| .1745 | 10 | .1736 | .9848 | .1763 | 5.671 | 80 | 1.3963 |
| .1920 | 11 | .1908 | .9816 | .1944 | 5.145 | 79 | 1.3788 |
| .2094 | 12 | .2079 | .9781 | .2126 | 4.705 | 78 | 1.3614 |
| .2269 | 13 | .2250 | .9744 | .2309 | 4.332 | 77 | 1.3439 |
| .2443 | 14 | .2419 | .9703 | .2493 | 4.011 | 76 | 1.3265 |
| .2618 | 15 | .2588 | .9659 | .2679 | 3.732 | 75 | 1.3090 |
| .2793 | 16 | .2756 | .9613 | .2867 | 3.487 | 74 | 1.2915 |
| .2967 | 17 | .2924 | .9563 | .3057 | 3.271 | 73 | 1.2741 |
| .3142 | 18 | .3090 | .9511 | .3249 | 3.078 | 72 | 1.2566 |
| .3316 | 19 | .3256 | .9455 | .3443 | 2.904 | 71 | 1.2392 |
| | | Cosines | Sines | Cotangents | Tangents | Degrees | Radians |

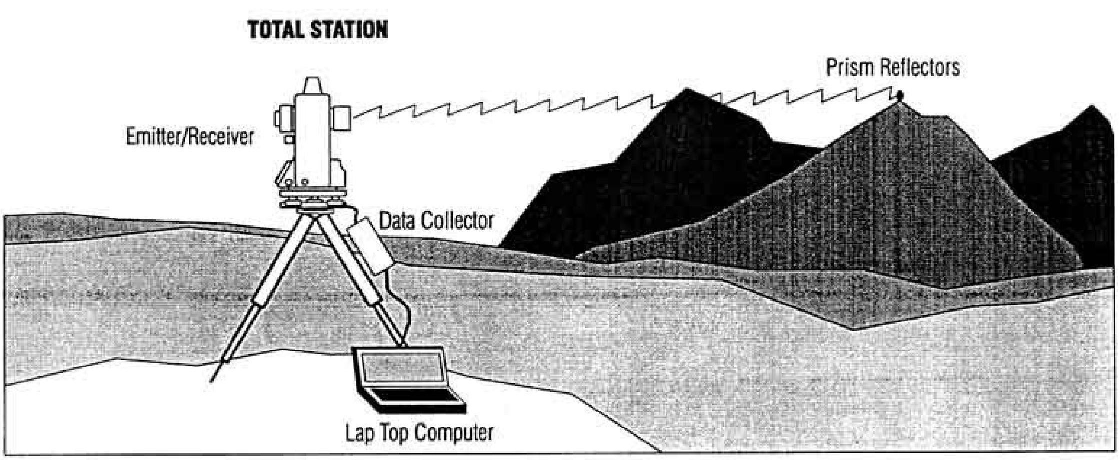
TRIGONOMETRIC FUNCTIONS (*Continued*)

| Radians | Degrees | Sines | Cosines | Tangents | Cotangents | | |
|---|---|---|---|---|---|---|---|
| .3491 | 20 | .3420 | .9397 | .3640 | 2.748 | 70 | 1.2217 |
| .3665 | 21 | .3584 | .9336 | .3839 | 2.605 | 69 | 1.2043 |
| .3840 | 22 | .3746 | .9272 | .4040 | 2.475 | 68 | 1.1868 |
| .4014 | 23 | .3907 | .9205 | .4245 | 2.356 | 67 | 1.1694 |
| .4189 | 24 | .4067 | .9135 | .4452 | 2.246 | 66 | 1.1519 |
| .4363 | 25 | .4226 | .9063 | .4663 | 2.144 | 65 | 1.1345 |
| .4538 | 26 | .4384 | .8988 | .4877 | 2.050 | 64 | 1.1170 |
| .4712 | 27 | .4540 | .8910 | .5095 | 1.963 | 63 | 1.0996 |
| .4887 | 28 | .4695 | .8829 | .5317 | 1.881 | 62 | 1.0821 |
| .5061 | 29 | .4848 | .8746 | .5543 | 1.804 | 61 | 1.0647 |
| .5236 | 30 | .5000 | .8660 | .5774 | 1.732 | 60 | 1.0472 |
| .5411 | 31 | .5150 | .8572 | .6009 | 1.664 | 59 | 1.0297 |
| .5585 | 32 | .5299 | .8480 | .6249 | 1.600 | 58 | 1.0123 |
| .5760 | 33 | .5446 | .8387 | .6494 | 1.540 | 57 | 0.9948 |
| .5934 | 34 | .5592 | .8290 | .6745 | 1.483 | 56 | 0.9774 |
| .6109 | 35 | .5736 | .8192 | .7002 | 1.428 | 55 | 0.9599 |
| .6283 | 36 | .5878 | .8090 | .7265 | 1.376 | 54 | 0.9425 |
| .6458 | 37 | .6018 | .7986 | .7536 | 1.327 | 53 | 0.9250 |
| .6632 | 38 | .6157 | .7880 | .7813 | 1.280 | 52 | 0.9076 |
| .6807 | 39 | .6293 | .7771 | .8098 | 1.235 | 51 | 0.8901 |
| .6981 | 40 | .6428 | .7660 | .8391 | 1.192 | 50 | 0.8727 |
| .7156 | 41 | .6561 | .7547 | .8693 | 1.150 | 49 | 0.8552 |
| .7330 | 42 | .6691 | .7431 | .9004 | 1.111 | 48 | 0.8378 |
| .7505 | 43 | .6820 | .7314 | .9325 | 1.072 | 47 | 0.8203 |
| .7679 | 44 | .6947 | .7193 | .9657 | 1.036 | 46 | 0.8029 |
| .7854 | 45 | .7071 | .7071 | 1.0000 | 1.000 | 45 | 0.7854 |
| | | Cosines | Sines | Cotangents | Tangents | Degrees | Radians |

## 3. Total Station

The total station incorporates all the best features of the transit and EDM distance measurement and vertical angles. It can instantly calculate slope and horizontal distances along with several functions. Many total stations have storage and download capabilities that permit automated computer mapping.

**The Total Station system**




A total Station system, showing the emitter/receiver, the reflective prisms and the digital data recorder operating in conjunction with the laptop computer.

The downside of the total station is the initial and maintenance costs. Initial costs start at $6,500. These are very sensitive instruments, and maintenance costs are high.

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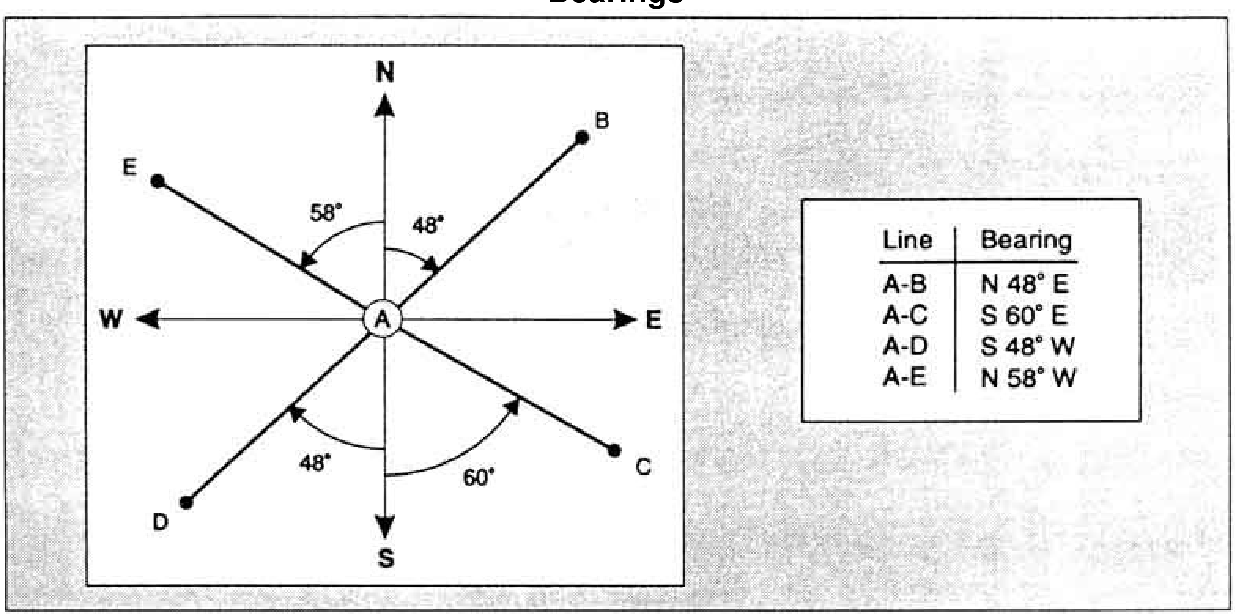
**Direction:** The angle in Polar Coordinates is that “direction” from a starting point to a secondary point relative to a “north” on a horizontal plane. Directions can be expressed as *bearings* or *azimuths*.

## 1. Bearings

Bearings use a system of primary and secondary directions to describe the angles between points. The primary directions are North and South. The secondary directions are East and West. All angles are based on a combination of primary and/or secondary directions.

**Bearings**

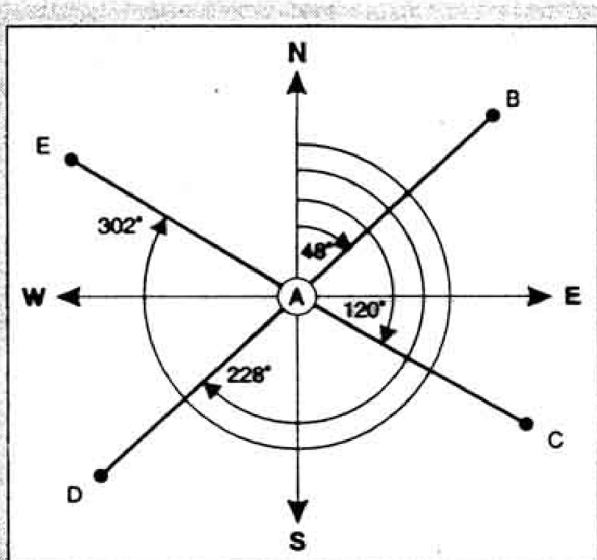



A bearing of a line or course is the angle swung from the north or south meridian in one of the four quadrants.

## 2. Azimuths

Azimuths use a system of directions based on a *full circle* to describe the angles between points. A full circle is defined as 360 degrees, and angles are swung clock-wise. Zero degrees is associated with a *North*.

**Azimuths and bearings**




| Line | Bearing | North Azimuth |
|---|---|---|
| A-B | N 48° E | 48° |
| A-C | S 60° E | 120° |
| A-D | S 48° W | 228° |
| A-E | N 58° W | 302° |

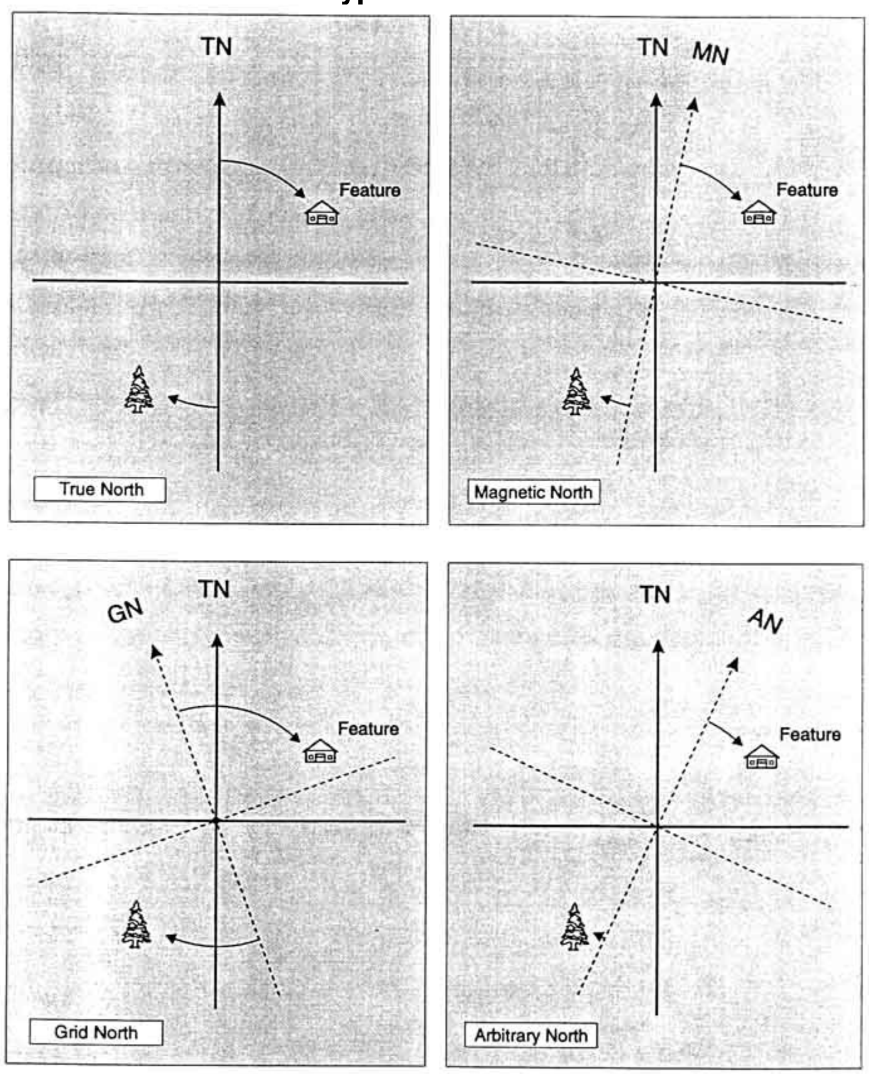
An example of the relationship between bearings and true north azimuths.

It is important that you know how to convert bearings to azimuths and vice versa as you may need to convert two or more sources of secondary data into a standard format. You will get some practice with this in lab.

## 3. North

- True North - all angles and directions are related to the North Pole.
- Magnetic North - all angles and directions are related to Magnetic North.
- Grid North - all angles and directions are related to a grid system.

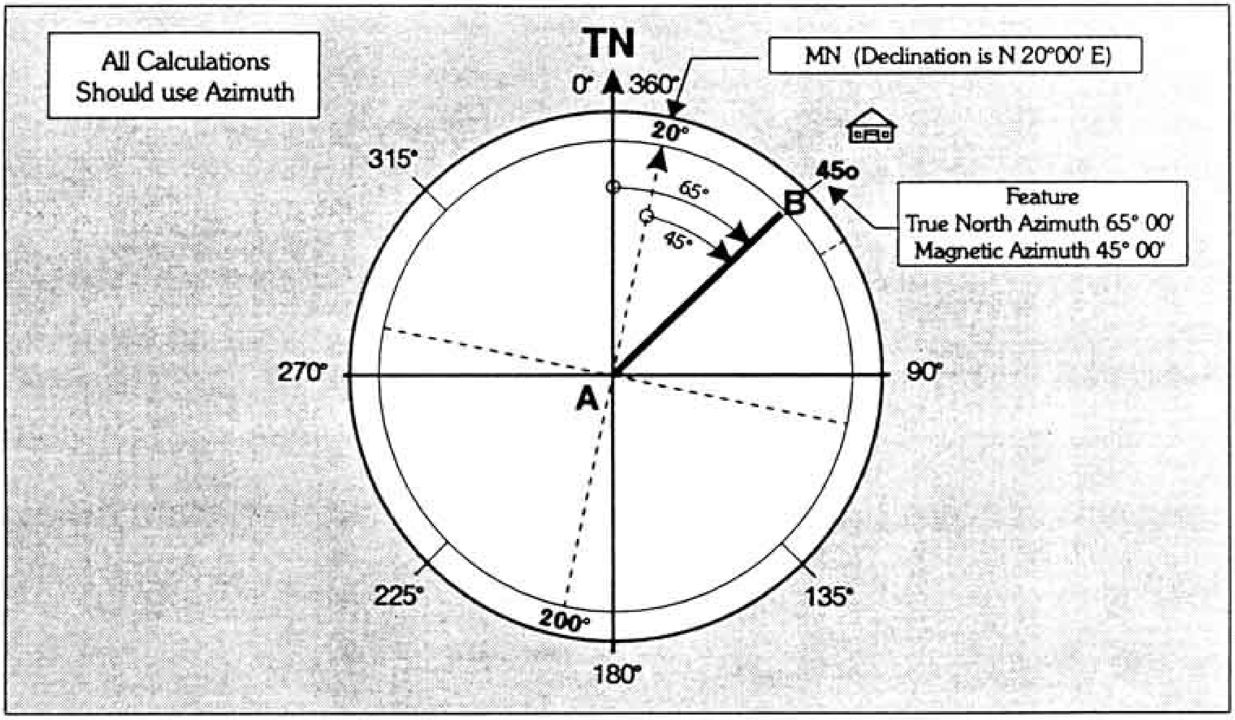
**Types of North**




The true north azimuth and the feature are fixed, but other axes can be used as a reference.

It is important that you be able to switch from one type of “north” to another as you may need to convert two or more sources of secondary data into a standard format.

**Adjusting for magnetic declination**




The true north azimuth and the feature are fixed, but the angle to the feature from the magnetic meridian is different.

By determining the horizontal distance and relative direction from one point to another, we are in a position to start mapping the locations of features on the Earth's surface over short distances. There is still much more to learn before we can create a detailed map of a study area.

# Surveying and Vertical Control

Vertical Control considers two components of the surveying process: compensating for variations in terrain when determining horizontal distances, and finding relative and absolute elevations. In Lecture 6: we covered some common methods for determining horizontal distance in varying terrain. Finding relative and absolute elevations is an important part of slope determination and terrain analysis.

**Absolute elevation** refers to that group of methods and instruments that yield direct measurements of elevation *above mean sea level* (AMSL).

**Relative elevation** refers to that group of methods that give relative changes in elevation between points. Assuming we have the absolute elevation of at least one of these points, we can determine the absolute elevation of all the points.

The following are common methods for determining absolute and/or relative elevations. Some of these techniques have been discussed in previous lectures, but now we apply them to vertical control.

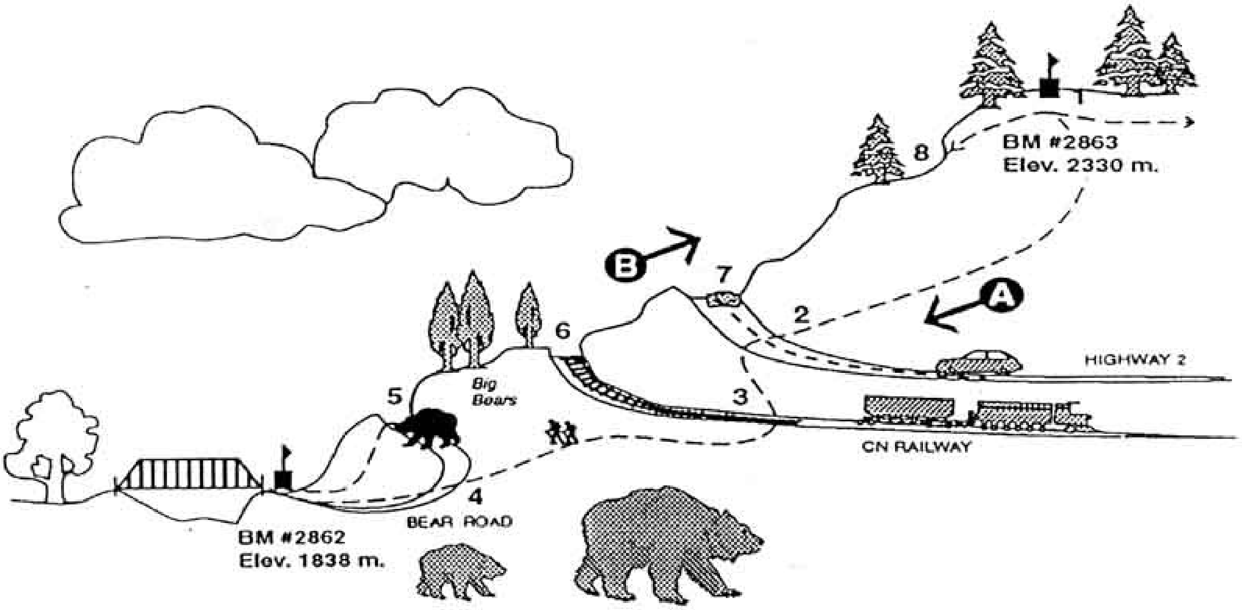
## Barometric leveling

Barometric leveling uses the principal of changes in atmospheric pressure to determine absolute elevation. In its simplest form, we know that warm air is lighter than cold air, and warm air can hold more moisture. We apply these principles to measurements of air pressure. The main instrument used is an *altimeter*. Altimeters are barometers (used to measure air pressure), but rather than obtaining readings in inches/millimeters of mercury or kPa, readings are given in meters or feet.

Two other measurements are required when using barometric leveling: air temperature and time. Both are used to make corrections to the original elevation readings taken from the altimeter. Air temperature is required in order to gage the type of air mass in which you might be working (i.e. cold versus warm). Rules of barometric pressure change depending upon the temperature of the air mass. Time is required because air masses, and thus air temperature and air pressure, are dynamic entities. Over the course of a data collection session, a storm could move into the area or the weather could dry up and warm up. These will significantly affect the altimeter readings. Tables and booking forms have been developed for applying barometric leveling.

Barometric leveling can provide elevation measurements accurate within 5 meters. This method does NOT yield any locational information. It is assumed that altimeter readings are taken at points that have already been marked and mapped.

**Sample route for barometric leveling**



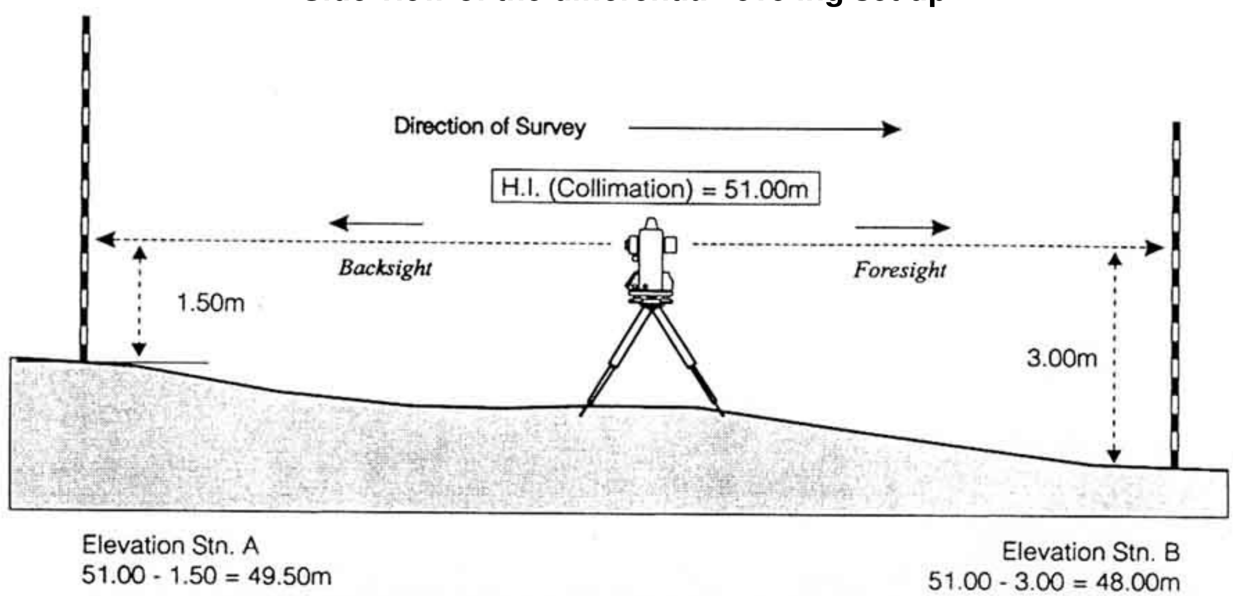

# Differential leveling

Differential leveling is a method for determining relative changes in elevation. This method requires a transit, tripod and stadia rod. Differential leveling is described as follows:

> The transit is set up approximately half way between two points so that there is a clear view of both points. The transit telescope is leveled. The rod person places the rod over the first or starting point. Ideally, we know the absolute elevation of the starting point.
>
> The instrument person sights "back" onto the rod at the starting point, and records the rod reading (known as the back-sight reading). By adding the back-sight reading to the absolute elevation of the starting point, the elevation of the center of the telescope is determined. The elevation of the center of the telescope is referred to as the *Height of Collimation*.
>
> The rod person then sets up over the second point. No changes are made to the telescope other than swinging the telescope so that it now views the rod over the secondary point. The instrument person swings the telescope "forward" onto the rod, and records the rod reading (known as the fore-sight reading). By subtracting the fore-sight from the Height of Collimation, the elevation of the secondary point is determined.

Differential leveling gives centimeter, and sometimes sub-centimeter, accuracy over distances not exceeding 50 meters. Like barometric leveling, it does not yield locational data, but assumes that locations have already been marked and mapped. Judging by the accuracy, this is an extremely accurate method for determining elevation. It does, however, have limitations. Where there are extremes in elevation between the two points, differential leveling can become awkward. The method is limited by the length of the stadia rod which generally extends to about 4 meters. Determining relative elevations outside this range are not possible without establishing temporary points (i.e. it's like making steps up/down a hill side).

**Side view of the differential leveling set up**

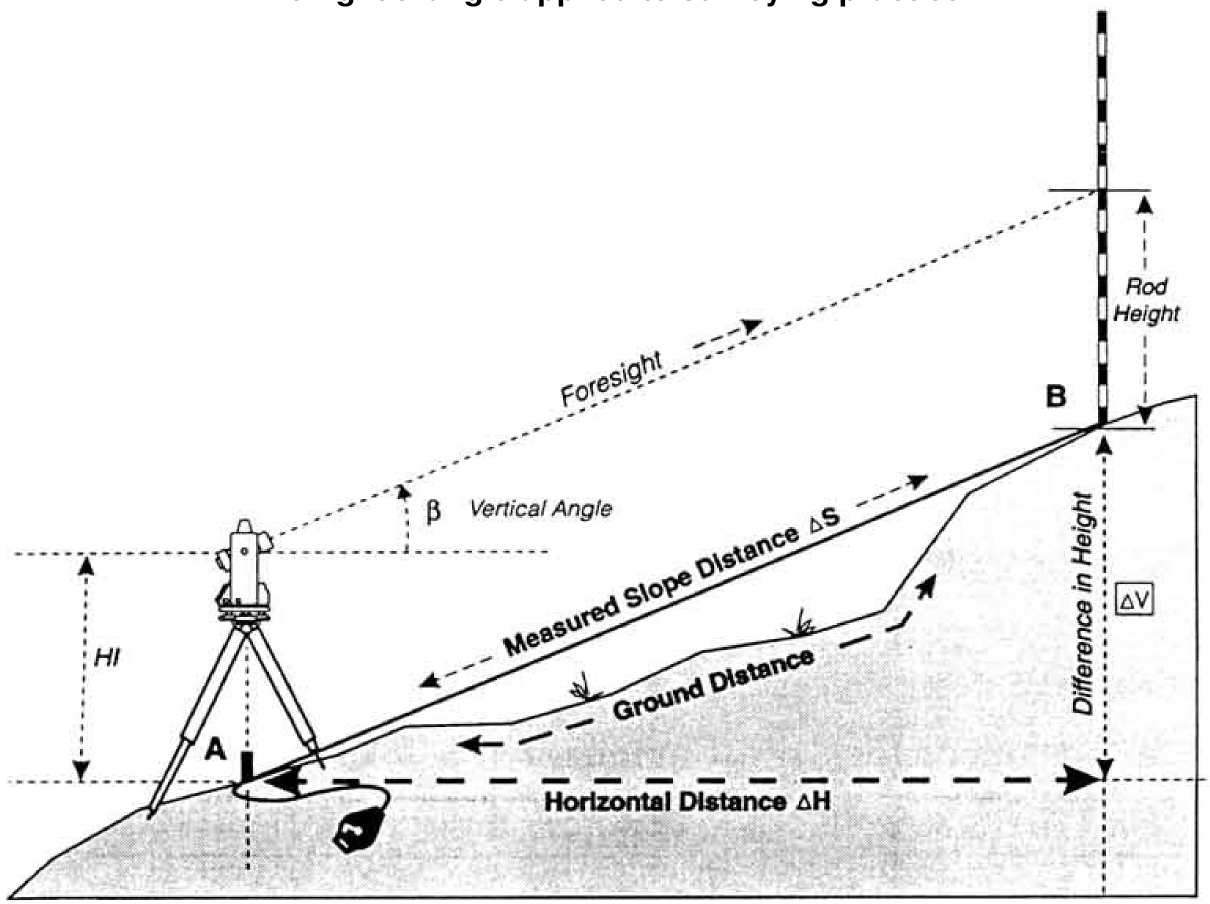



Differential levelling, where the change in elevation between two points is calculated by the difference in backsight and foresight readings.

# Trignometric leveling

Trignometric leveling carries on from the principles we have already learned regarding right triangles.

**The right triangle applied to surveying practice**




The relationship between ground, slope and horizontal distances.

This time, rather than using slope distance (SD) and vertical angle to determine horizontal distance (HD), trignometric leveling uses SD and vertical angle to determine vertical distance. Assuming that the absolute elevation for the starting point is known, we can determine the absolute elevation for a secondary point by adding or subtracting the vertical distance (VD) to the absolute elevation of the starting point.

The advantage of trignometric leveling for determining vertical control is that all the measurements we need for determining elevation have already been acquired when we established the horizontal control. It too can be accurate to the sub-centimeter depending upon how the slope distances and vertical angles were measured.

## Total Station

Since the total station represents a compilation of the transit and EDM, determining relative changes in elevation, or vertical distance, is just one more internal function of the system.

Methods for measuring vertical control, combined with those for horizontal control, form the foundation for accurately mapping points and features within a study area.

# Surveying and Local Surveys

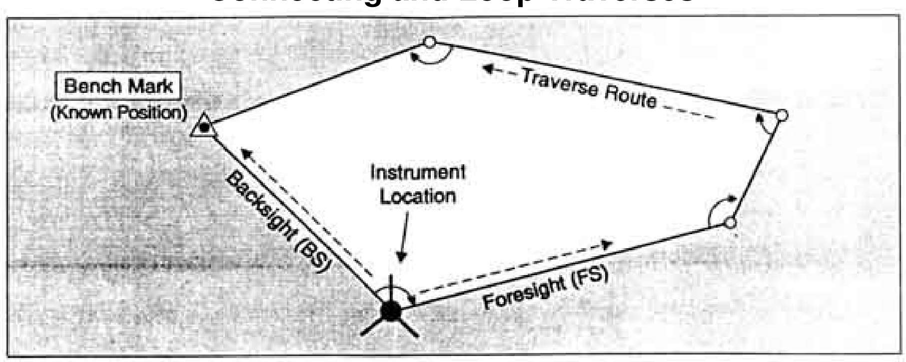
## Types of Local Surveys

**Open Surveys:** Surveys that begin at one point and end at another point. Exact locations of any end or intermediate points may or may not be known.

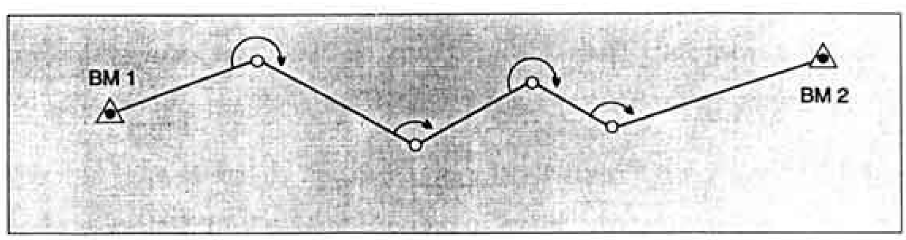
**Closed Surveys:** Surveys that start and end a point at a point of known location.

- **Connecting Traverse:** Survey starts at one point of known location, and finishes on a different point of known location.
- **Loop Traverse:** Survey starts at a point of known location, and finishes at the same point (always the preferable method of traversing if possible).

**Connecting and Loop Traverses**




(a) Loop Traverse




(b) Connecting Traverse

Angles are typically swung to the right in the direction of the traverse.

Closed Surveys are always more preferable than open surveys because there are many internal methods of checking for inaccuracy and mistakes some of which will be discussed here. All you can hope to do with Open Surveys is make certain that you are as accurate as possible with your measurements and booking the data.

Errors can be reduced by double booking certain measurements. These will be discussed.

**Pre-Planning:** Before starting any project in the field, surveyors always do a field check by walking around the area. They look for benchmarks or prominent features where they can start the survey, and they look for prominent features that might be used for intermediate points (or Turning Points). Surveyors may also consult previous surveys or any variety of maps for the study area that may have been done by others.

Once a tentative traverse route has been established, the surveyor must decide upon the appropriate procedures and instruments to use. In addition, a decision must be made on how to survey any features that may lie on either side of the traverse route. Obviously, a lot of pre-planning is required before any data is collected.

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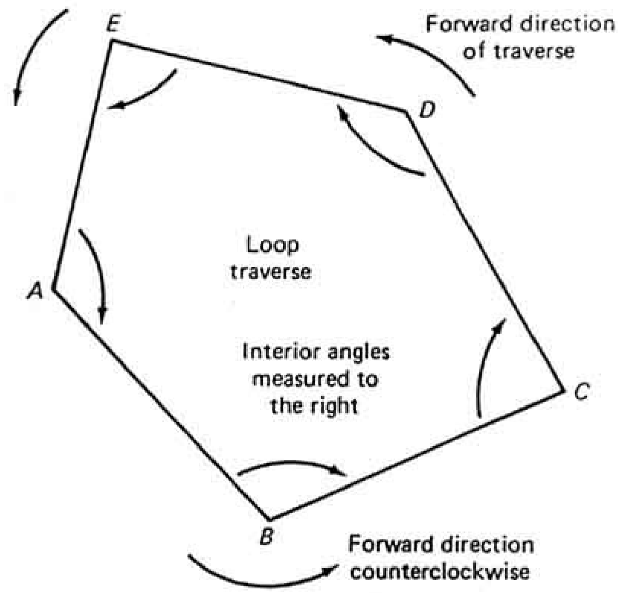
The remainder of this discussion on surveying will focus on the use of standard surveying procedures applicable to a **Closed Loop Traverse** using *Pace and Compass* techniques.

A **Close Loop Traverse** begins at one point and ends on the same point. These traverses are surveyed in the *counterclockwise* direction, while any horizontal angles are surveyed *clockwise*. In this way, we never confused traverse direction with horizontal angles. Note that the surveyor may or may not know the exact location of the starting point, but a point should be selected whose exact location can be found at a later date such as a benchmark, bridge abutment, manhole cover, or other prominent feature. For convenience, we will refer to the starting point as the *Benchmark*.

**Loop Traverse with directions**

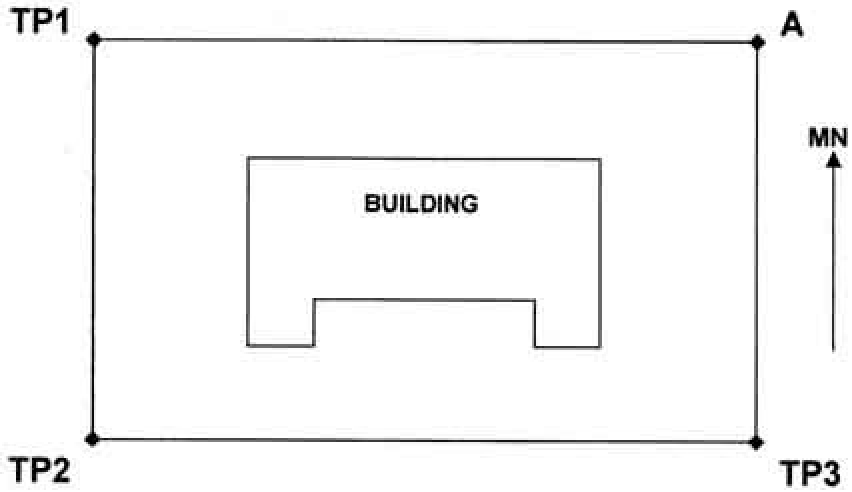



Loop traverses are best surveyed in a counterclockwise direction, with interior angles "turned" to the right.

Note: Terminology varies greatly between one surveying textbook and another, as it does between surveyors. The terminology offered here is designed for your use solely.

The next step is to decide on intermediate points that will form the remainder of the actual traverse route. The traverse route itself should be laid out so that it circumnavigates the study area (that core area where any observations or measurements will be taken). These intermediate points are commonly referred to as *Turning Points*, and they are essential to completing the traverse route. Since the traverse under discussion has only one known point, its start and finish, turning points must be chosen that are easily identifiable on the ground surface. A turning point should be visible from at least two other points on the route (preferably the presiding point and the next point along the route).

**A traverse route circumnavigating a building**




**Field Measurements:** For a Pace and Compass traverse, the actual field measurements are very straightforward. They include the Station (STN), the Magnetic North Azimuthal Direction (AZIM), the distance in paces (DIST), and any notes about the benchmark and turning points (NOTES).

- **Station (STN):** The point where the surveyor is standing related to the point the surveyor is looking at.
- **Magnetic North Azimuthal Direction (AZIM):** The compass reading when the surveyor is looking at another point or feature.
- **Distance in Paces (DIST):** That distance measured by the surveyor when travelling from one point to another using the pacing method (every other step).
- **Notes about Points/Features (NOTES):** These are descriptors that make it easier for the surveyor to identify or locate prominent features on or along the route. Notes may include a freehand sketch of the traverse with all points marked on.

**Headings applied to a traverse field book**

| STN | AZIM (degrees) | DIST (paces) | NOTES |
|---|---|---|---|
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |

**Booking:** Booking field measurements requires that the surveyor prepare the book as much as possible before starting the actual measurements. This requires that headings are placed on the book, that benchmark/turning point relationships are identified on the book, and that descriptions of the points have been recorded. Wherever possible, plan on taking AZIM and DIST measurements between two adjacent points in two directions both to and from each of the points. When measurements are taken from one point to another in the counterclockwise direction following along the route, they are referred to as *foresight* measurements. Measurements taken in the clockwise direction along the route are referred to *backsight* measurements.

**Sample lay out for Traverse Route**

| STN | AZIM (degrees) | DIST (paces) | NOTES |
|---|---|---|---|
| A - 3 | | | backsight onto base of light standard |
| A - 1 | | | foresight onto base of tree |
| | | | |
| 1 - A | | | backsight onto manhole cover/benchmark |
| 1 - 2 | | | foresight onto small metal plate |
| | | | |
| 2 - 1 | | | backsight |
| 2 - 3 | | | foresight |
| | | | |
| 3 - 2 | | | backsight |
| 3 - A | | | foresight |

A completed book should be detailed, organized and legible. NEVER ERASE ANYTHING ON THE FIELD BOOK. Errors are crossed out, and written above.

**A completed Traverse Book**

| STN | AZIM (degrees) | DIST (paces) | NOTES |
|---|---|---|---|
| A - 3 | 180 | 57 | backsight onto base of light standard |
| A - 1 | 270 | 65 | foresight onto base of tree |
| | | | |
| 1 - A | 90 | 65 | backsight onto manhole cover/benchmark |
| 1 - 2 | 180 | 59 | foresight onto small metal plate |
| | | | |
| 2 - 1 | 0 | 57 | backsight |
| 2 - 3 | 88 | 65 | foresight |
| | | | |
| 3 - 2 | 272 | 65 | backsight |
| 3 - A | 0 | 59 | foresight |

**Check (balancing the books):** The importance of doing backsight and foresight measurements when using Pace and Compass cannot be over emphasized. They provide *internal* checks and balances of the accuracy of your measurements.

Azimuthal directions can be checked for accuracy. For example, if a foresight azimuth reads 90°, then the corresponding backsight azimuth should be 180° in the opposite direction, that is 270°. If the two readings are very close, but not exactly the same, then the two can be averaged. For example, the foresight reading is 88° , while the corresponding backsight reading is 272°. Subtracting 180° from 272° yields a direction of 92°. If we were to average 88° and 92°, then the resulting 90° may be a more accurate representation of the foresight azimuth.

Directions can also be checked for accuracy and then averaged. For example, if the foresight distance is 57 paces and the backsight distance is 59 paces, the average distance between the two points is 58 paces. The average distance may be more representative of the actual distance.

## Corrected Traverse Book

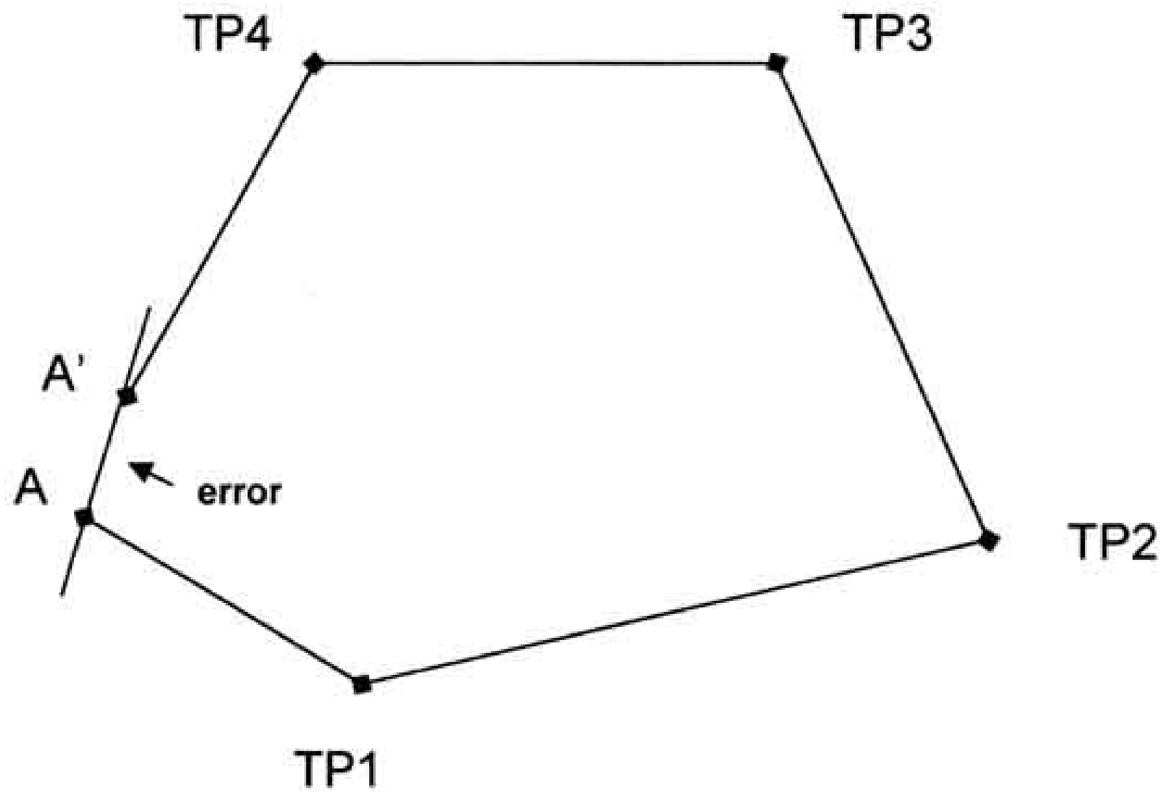
| STN | AZIM (degrees) | DIST (paces) | NOTES |
|---|---|---|---|
| A - 3 | 180 | 58 ~~57~~ | backsight onto base of light standard |
| A - 1 | 270 | 65 | foresight onto base of tree |
| | | | |
| 1 - A | 90 | 65 | backsight onto manhole cover/benchmark |
| 1 - 2 | 180 | 58 ~~59~~ | foresight onto small metal plate |
| | | | |
| 2 - 1 | 0 | 58 ~~57~~ | backsight |
| 2 - 3 | 90 ~~88~~ | 65 | foresight |
| | | | |
| 3 - 2 | 270 ~~272~~ | 65 | backsight |
| 3 - A | 0 | 58 ~~59~~ | foresight |

**Plotting:** Plotting the traverse requires a protractor, graph paper (preferably metric), a scale and a pencil. Do some freehand sketches on a piece of scrap paper to get the feel and orientation of the traverse so that it can be placed on the graph paper correctly (north is at the top) and in its entirety. Convert your paces to meters. Calculate a representative fraction (RF) so that your entire traverse will fit onto the graph paper making optimum use of the space provided (e.g. 1:1000).

Establish Magnetic North (MN) and the benchmark location on the graph paper. Starting at the benchmark, use the protractor to mark the azimuthal direction from the benchmark to the first turning point. Draw a faint line from the benchmark through this mark. Next, use the distance in meters between the benchmark and the first turning point, and the RF to determine the map distance between the two points. Use the scale to mark this distance on the map following the line corresponding to the azimuthal direction. Use a symbol to mark this point and label it TP1. Repeat for TP1 to TP2, TP2 to TP3, etc. until you return to the benchmark.

When you are finished you should return to the benchmark. If all goes well the last symbol you mark will correspond exactly with the benchmark symbol.

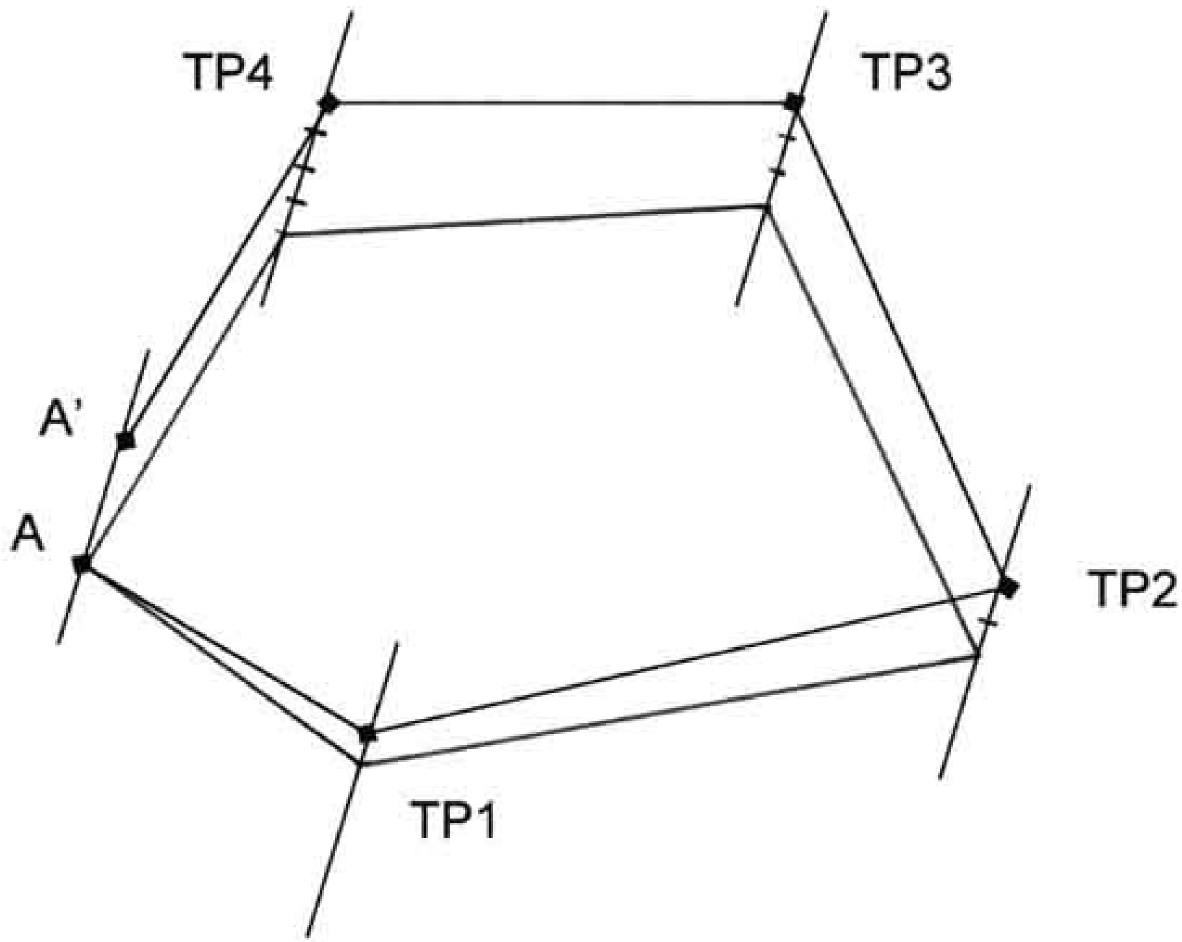
**Uncorrected sample plot**




**Corrections:** Of course, plotting rarely goes well. There are just too many inaccuracies inherent in the process. However, if the last symbol does not match up with the benchmark, it can be corrected using the *proportion to station* method. This method is applied directly on the plot:

- Measure the map distance between the benchmark, A, and the final point, A'. This is the closing error.
- Divide the error by the total number of stations. This is the correction factor.
- Following lines parallel to a line joining A to A', apply one correction factor to TP1, two correction factors to TP2, etc. until the total closing error is applied between A and A'.
- If A' lies above A, then all correction factors are applied below the TPs. If A' is below A, then they are applied above.

**Corrected sample plot**



# Plotting a Traverse from Hypothetical Field Notes

**Overview:**
Using the field notes given below, you are to make a simple map of a closed loop traverse that returns to its starting point. Use a scale of 1cm to 100 meters, and produce the map on 8 1/2" by 11" centimeter graph paper. All distances are in paces of 1.6 meters and the directions are magnetic azimuths.

**Note:** You will have to convert the paces in the field notes to centimeters so that you can map the distances between points. In order to do this, use the following formula:

- the size of the pace divided by the number of meters represented by 1 cm in the scale is equal to the pace-to-map distance conversion (in centimeters)

**For example:**

1.6 meters/100 meters = **0.016**. This is the conversion you will use for this project.

Orientate the graph paper with the long side toward you. Assume the top of the graph paper is Magnetic North. Start plotting at the very edge of the graph paper on the left hand edge and 8 centimeters from the bottom of the page.

Remember: All finished maps should have a title, a scale, directional arrows indicating both Magnetic and True north, and a legend describing what any lines, patterns or colors mean. Use a magnetic declination of $19^{o}$ 30' east of True North.

**Materials and Equipment:**
8 1/2" by 11" centimeter graph paper
a protractor
a straight edge or ruler
an HB pencil (with eraser)
a blue pen
colored pencils (optional)

**Procedure:**
1. Plot the skeleton of your traverse lightly in pencil (shown as underlined in Field Notes). As mentioned above, it should return to the starting point, however, even if you plotted carefully, the traverse should not close.

2. Adjust for the error of closure (see Lecture 4). Leave the uncorrected "skeleton" in pencil and ink in the corrected one.

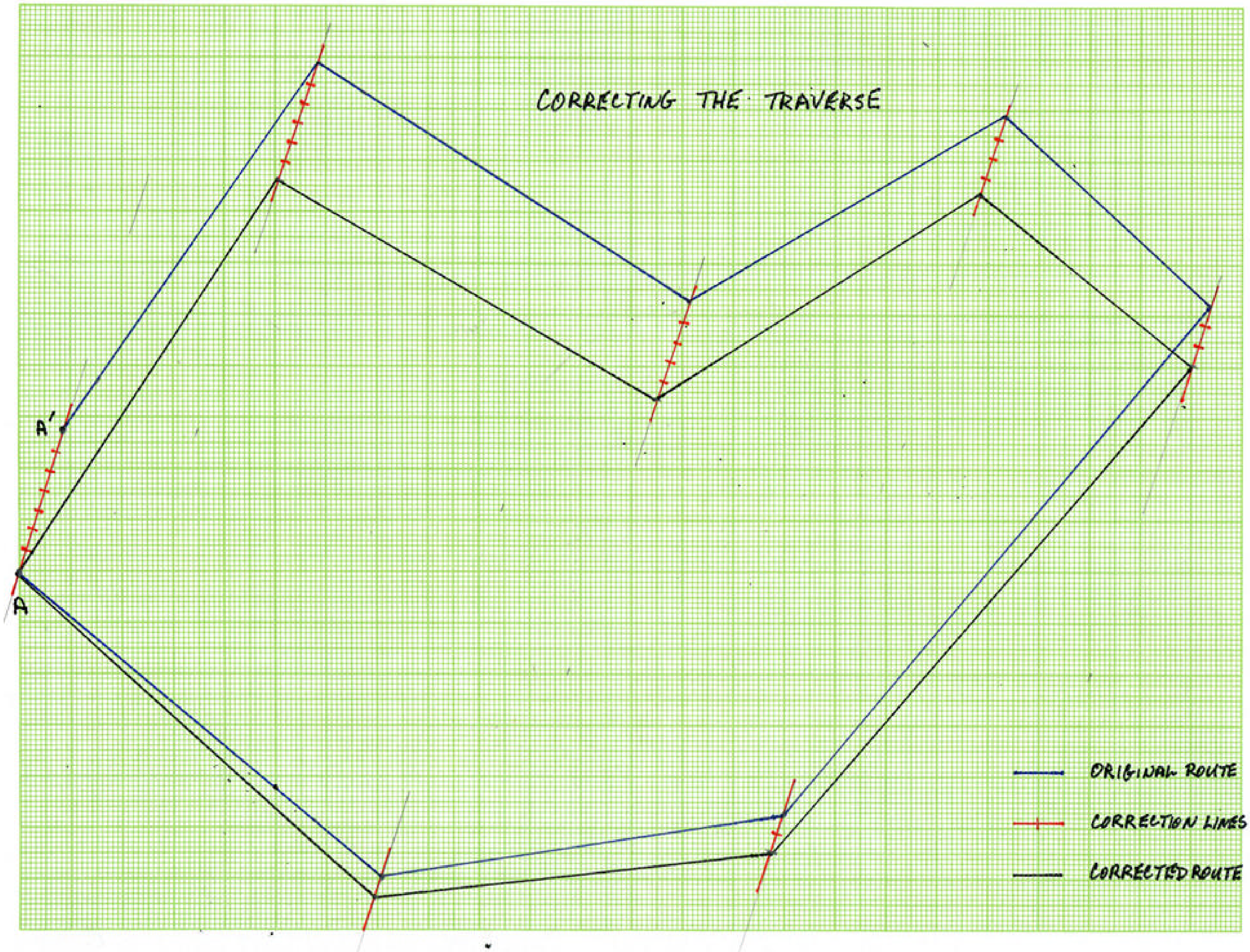
3. Now plot the details of the traverse on either side of the route. As most of the traverse legs are of approximately the same length and the error overall is not too large, the details can be plotted without any further corrections. Make minor adjustments only if necessary.

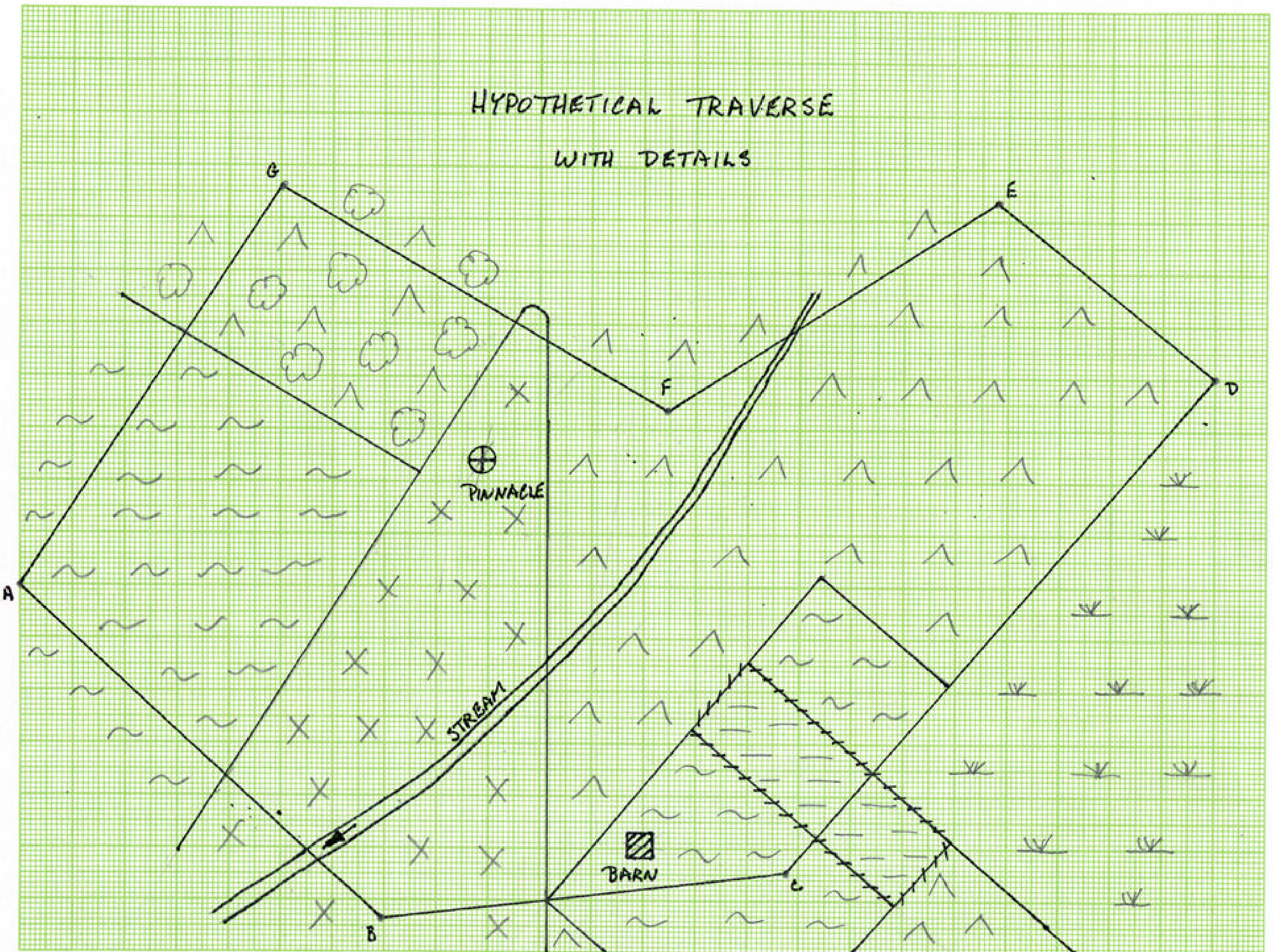
**Field Notes:**

| | | |
|---|---|---|
| A to B 130° | 580p | |
| A to A1 | 340p | Low brush vegetation on both sides. |
| A1 to A2 | 130p | Rock outcrop: black, rough, slaggy. At A1, edge of outcrop bears 33° to 213°. |
| A2 to B | 110p | Rock outcrop as before. At A2, stream 15p wide, fast flowing toward the southwest. Bears 55° through rock outcrop. |
| B to C 81° | 500p | |
| B to B1 | 200p | Rock outcrop as before. At B, can see peculiary shaped pinncle along bearing 12°. |
| B1 | | Edge of rock outcrop bears due North/South. Low brush similar to A-A1 lies east of 40° and 130°. Conifers approximately 0.3 meters in diameter in North-Northeast and South-Southeast quadrants bounded by rock outcrop and low brush. |
| B1 to C | 300p | Low brush on both sides (abandoned field?). Old barn can be seen on a bearing of 60° from B1 and 280° from C. |
| C to D 40° | 810p | |
| C to C1 | 60p | Low brush as before. At C1, fence bearing 130° to 310° marks the edge of a pasture. Pasture extends Northwest approximately 200p and marks the edge of brush. Pasture also extends to Southeast approximately 120p and also marking edge of brush. |
| C1 to C2 | 100p | Pasture. Appears rectangular. Fenced in Northwest and Southeast with conifers beyond. Fence at C2 also bearing 130° to 310°. Start of swamp on right of traverse route at C2 bearing 130°. Looks to extend about 200p. |
| C2 to C3 | 140p | Low brush as in B1 to C lying to left of traverse. Swamp lying to right of traverse. Brush ends at C3 bearing 310° for approximately 200p with conifers beyond. |
| C3 to D | 510p | Conifers approximately 0.3 meters in diameter to left of traverse. Swamp to right of traverse. Swamp ends at D with edge bearing 170° for at least 300p. Conifers east of swamp. |

| | | |
|---|---|---|
| D to E 312° | 340p | |
| D to E | 340p | Conifers 0.3 meters in diameter on both sides. |
| E to F 239° | 450p | |
| E to E1 | 285p | Conifers 0.3 meters in diameter on both sides. At E1, edge of stream 5p wide flowing 210°. |
| E1 to F | 165p | Conifers 0.3 meters in diameter. |
| F to G 302° | 540p | |
| F to F1 | 170p | Conifers 0.3 meters in diameter. |
| F1 to F2 | 40p | Rock outcrop as for A1 to B1. Starts at F1 and bears 180°. Ends on right approximately 20p with conifers beyond. Rises from right to left of traverse for at least 400p to peculiarly shaped pinnacle bearing 210° from F1 and 194° from F2. |
| F2 to G | 330p | Mixed deciduous-coniferous trees approximately 0.5 meters in diameter on both sides. Rock outcrop ends at F2 bearing 30° to 210°. |
| G to A 215° | 550p | |
| G to G1 | 210p | Mixed deciduous-coniderous trees on both sides. |
| G1 to A | 340p | Low brush starts at G1 bearing 120° to 300°. Brush similar to A to B1. |

**Purpose:**
Produce a corrected closed loop traverse overlayed with a map showing key features based on hypothetical field notes. This exercise will also teach you how important it is to be accurate with your descriptions.


CORRECTING THE TRAVERSE
A'
A
ORIGINAL ROUTE
CORRECTION LINES
CORRECTED ROUTE


HYPOTHETICAL TRAVERSE
WITH DETAILS
G
E
F
D
A
B
C
PINNACLE
STREAM
BARN