Lab 1: Geologic Techniques:
Maps and Remote Imagery

Introduction

Geoscientists utilize many different techniques to study the Earth. Many of these techniques do not always involve fieldwork or direct sampling of the Earth's surface. Before a geoscientist completes work in the field he or she will often review maps or remote images to learn about the study area. For example, when a geoscientist is assessing landslide hazards for a proposed housing development near a steep slope, they would need to use maps and aerial imagery to understand the local topography and geology, because steep slopes and rock types influence slope stability. Aerial imagery provides historical data, such as vegetation age or other evidence of landslide activity and erosion. Geoscientists record their field data on maps so that it can be interpreted within a spatial context and shared with other geoscientists or the general public.

In today's laboratory we will explore map-reading, aerial photo interpretation, and remote sensing techniques that are utilized by geoscientists to study the geologic landscapes and processes operating at Earth's surface. Many of these techniques will be integrated into future laboratory exercises.

History of Maps

A map is a two-dimensional representation of a portion of the Earth's surface. Civilizations have used maps for over three thousand years; the earliest known map was made by the Babylonians in the 6th century BCE. The earliest maps were largely drawn to denote place names and general directions, often neglecting accuracy and scale. Figures 1-1A and 1-1B illustrate the simplicity of these early maps.[1]

---

[1] Figure 1-1A taken from *History of Cartography Volume One: Cartography in Prehistoric, Ancient, and Medieval Europe and the Mediterranean.* Edited by J. B. Harley and David Woodward (1987), The University of Chicago Press, Chicago and London. Figure 1-1B redrawn from Erwin Raisz, 1948. *General Cartography.* McGraw Hill.
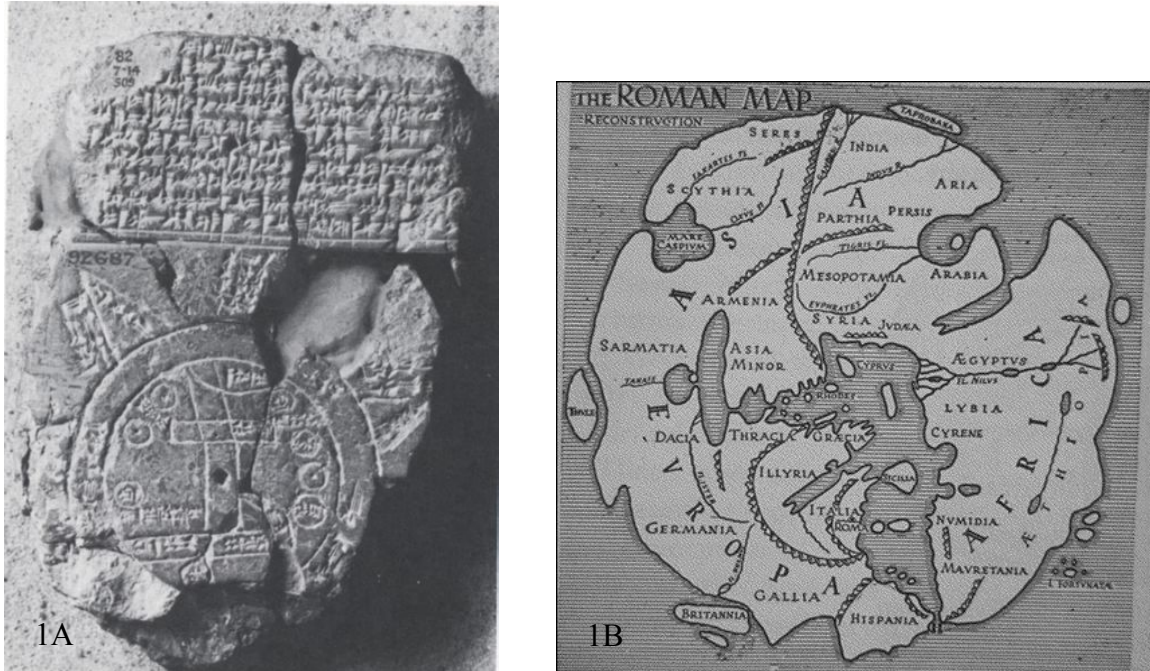
Figures 1-1A and 1-1B: Babylonian map of the world (Fig. 1-1A) drawn on a clay tablet circa 500 B.C. The map represents ancient Babylon, the Euphrates River and surrounding ocean, which today comprises modern Iraq. Fig. 1-1B is a representation of an original Roman map entitled, *Orbis Terrarum,* drawn by Marcus Vipsanius Agrippa in 20 A.D. The ancient Roman map shows Europe, Asia and Africa surrounding the Mediterranean Sea.

Following the decline of the Roman Empire, near the end of the 5th century A.D., innovation and advancement in cartography declined for almost 1000 years until the start of the Renaissance Period in the late 14th century. During the Renaissance Period the Age of Exploration and Discovery brought about a need for increased accuracy in maps, particularly for navigational purposes as global trade and colonization increased. Figure 1-2 shows a world map, originally published by the Flemish cartographer Gerard Mercator in 1595, and subsequently published in Henricus Hondius' *Atlas* in 1633 (image taken from the U.S. Library of Congress web site. *An Illustrated Guide to Geography and Maps*., URL: **www.loc.gov/rr/geogmap/guide/gmillatl.html**). Such maps provided valuable navigational information, such as latitude and longitude coordinates and the seasonal position of the overhead sun for sea faring explorers and traders.
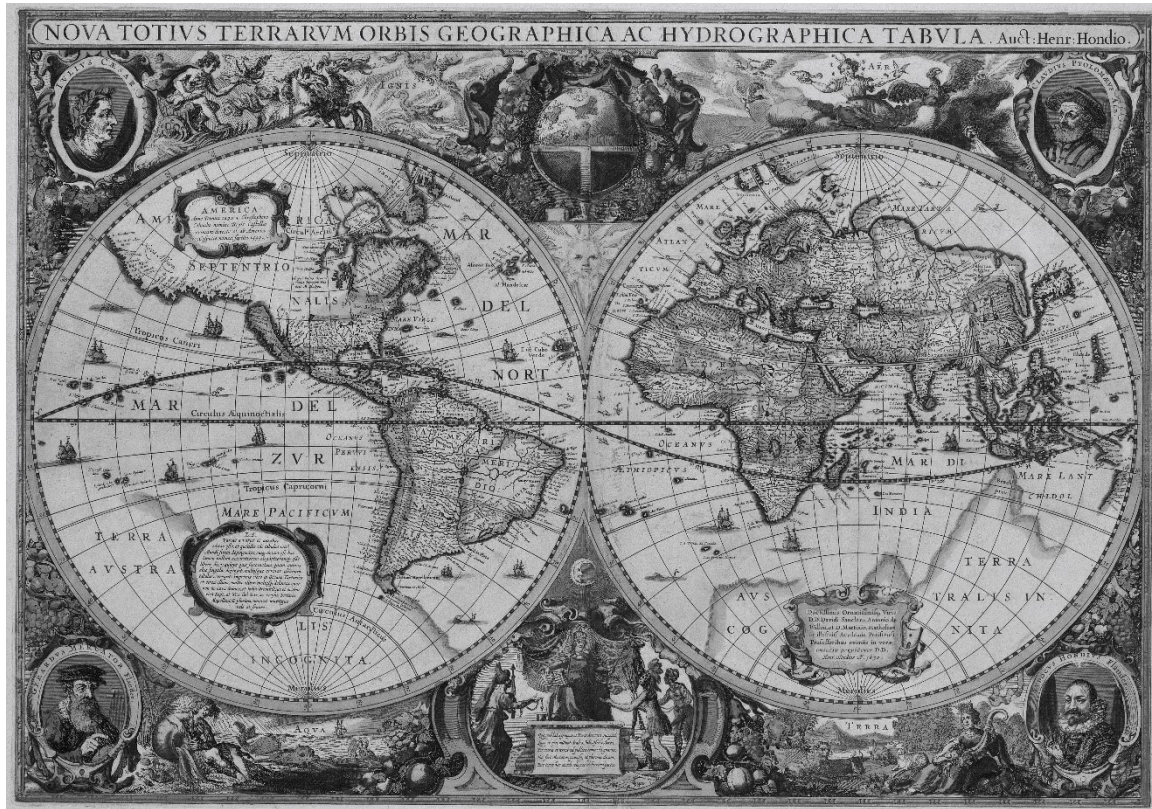
Figure 1-2: Hondius' map of the world was depicted in two hemispheres bordered by the representation of the four elements of fire, air, water and land. Portraits of the Roman Emperor Julius Caesar, Claudius Ptolemy, a 2nd century A.D. geographer, and the atlas's first two publishers, Mercator and Hondius also adorn the map's border.

Over the subsequent 500 years the accuracy and detail of maps has improved greatly with technological advances in surveying equipment and the advent of aerial and satellite imagery.

The map below (Figure 1-3) shows a portion of the University of Washington campus that includes Johnson Hall.

*ESS 101 field trips this quarter will leave from Johnson Circle. Locate this point on the map below (Fig. 1-3) for future reference.
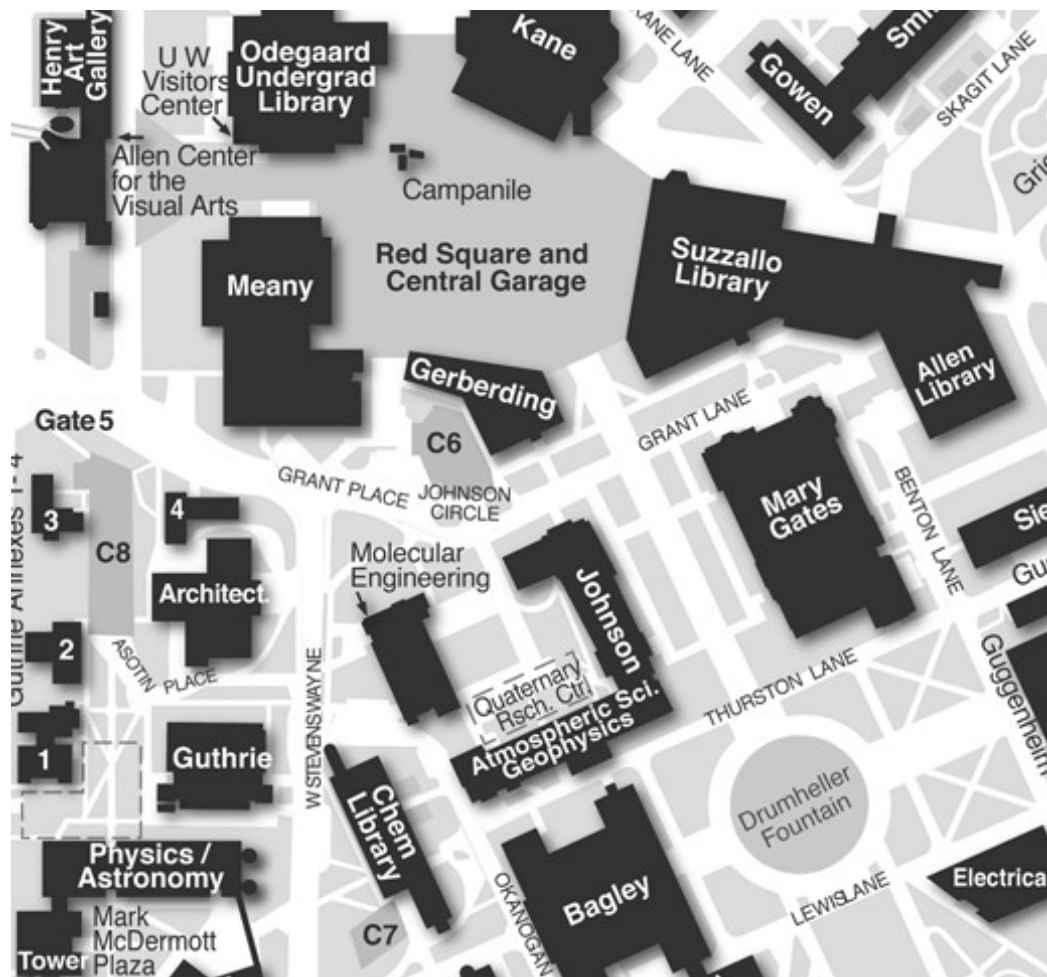

Figure 1-3: This map represents a portion of the University of Washington campus that includes Johnson Hall.

A. Topographic Maps

A **topographic map is** a three-dimensional representation of the Earth's surface, where surface elevation or topography is represented by **contour lines**. Topographic maps are used in the earth sciences because they present a reduced view of the Earth's surface and show the size, shape, and interrelationships of the natural landscape. Being able to use topographic maps is an invaluable tool to many different professions, as well as recreational hiking. This laboratory will help acquaint you with the different components of topographic maps and their potential application to geologic problems.

Location
Latitude and Longitude

Most maps have a geographic coordinate grid, which can be used to determine location. The most commonly used coordinate system is latitude and longitude. **Latitude** is an angular distance measured north or south of the Earth's **equator,** which is 0° latitude. It varies from 0° to 90° north and from 0° to 90° south (Figure 1-4). Lines of latitude encircle the Earth parallel to the equator and are called **parallels** because they are parallel to one another. Lines of **longitude** represent the angular distance measured east or west from the **prime meridian** (0° longitude), which passes through the Royal Astronomical Observatory in Greenwich, England. Lines of longitude range from 0° to 180° east and 0° to 180° west (Figure 1-4). The **international date line** is the line represented by both 180° east and 180° west longitude. Lines of longitude are termed **meridians** and encircle the Earth in a direction perpendicular to the equator. Meridians of longitude converge at the North and South poles; thus, they are neither parallel nor equally spaced except along a given line of latitude. Ground distance represented by a degree or minute of longitude decreases poleward from the equator because of this convergence.

Units of latitude and longitude are expressed in **degrees** (°), and further subdivided into **minutes** (60 minutes ['] = one degree), and **seconds** (60 seconds ["] = one minute). For example, Seattle is located at 47°27'00" N, 122°18'00" W. To accurately convey a specific location on the Earth's surface, it is important to state whether its latitude lies north or south of the equator and longitude lies east or west of the prime meridian. By convention, a location's latitude is stated first, followed by its longitude coordinate.
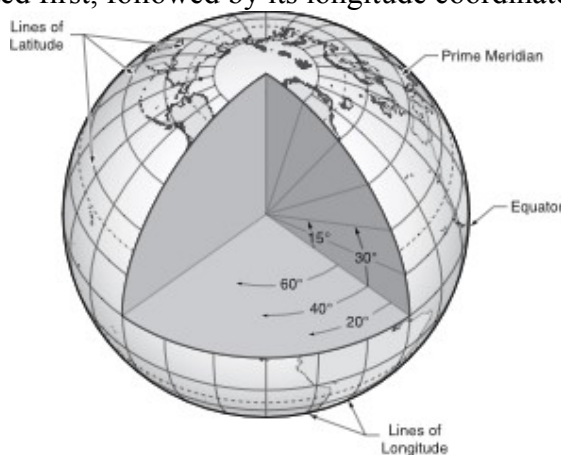

Figure 1-4: World globe showing latitude and longitude coordinates.

Scale

Most maps represent a reduced image of a larger area. The amount of reduction is defined by a map's **scale** and may be expressed in the following ways:

(1) **Graphic Scale**: Scale is indicated by a calibrated bar or line. For example, the bar scale shown in Figure 1-5 represents a distance of two kilometers on the Earth's surface.
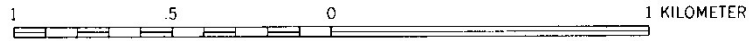
Figure 1-5: Example of a graphic scale from a topographic map.

(2) **Fractional Scale**: Scale is expressed as a fixed ratio between a distance measured on a map and an equal distance measured on the Earth's surface. This ratio is termed the **representative fraction**. For example, a fractional scale of 1:24,000 indicates that one distance unit on the map (inches, feet, centimeters, etc.) equals 24,000 of the same distance units on the surface of the Earth.

Magnetic Declination

On the surface of the Earth the **magnetic north pole** (where a compass needle will point) is not the same location as the "true" or **geographic north pole**, which defines the earth's axis of rotation. The angular distance between geographic and magnetic north at a given location represents its **magnetic declination.** Because magnetic declination varies over time and space, a symbol and explanation are provided on the lower margin of most U.S. Geological Survey (USGS) topographic maps (Figure 1-6). This symbol shows the magnetic declination for the center area of a topographic map at the time it was published or revised.
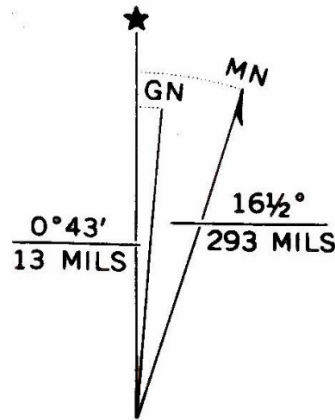

Figure 1-6: USGS magnetic declination symbol. The star represents geographic north, GN is grid north, and MN is magnetic north. This symbol shows a magnetic declination of 16½°.

Within the conterminous United States, magnetic declination varied between 20° west in Maine and 20° east in Washington in around 1995 (Figure 1-7). Because the magnetic poles migrate over time, in 2018 the magnetic declination in Seattle was almost 16° east. Up to date magnetic declination measurements are needed to determine accurate directions when mapping and navigating over large distances. Geoscientists and backpackers alike require accurate magnetic declination data to set their compasses appropriately when using base maps.

Up to date declination data within the conterminous United States can be acquired using an online declination calculator found on the National Geophysical Data Center's (NGDC) web site: ***https://www.ngdc.noaa.gov/geomag-web/***

Isogonic Lines Show The Pattern of Magnetic Declination

20°East

20°West

15°East

15°West

AGONIC LINE

10°West
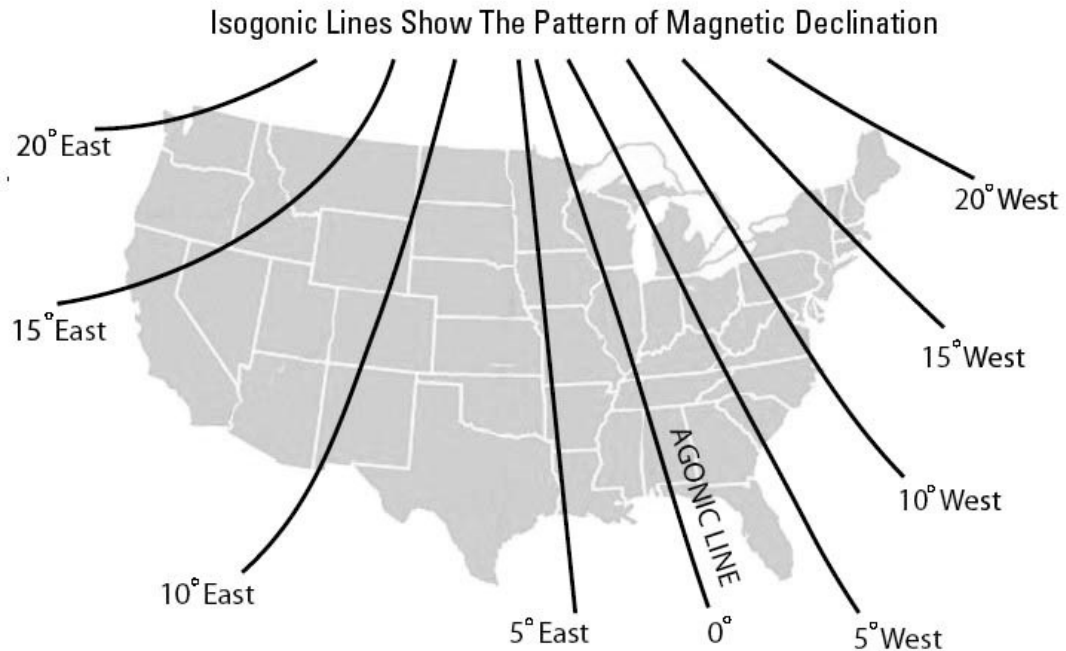
10°East

5°West

5°East

0°

Figure 1-7: Magnetic declination map for the conterminous United States, 1995 *(U.S. Geological Survey).*

Contour Lines

Topographic maps are important tools used by earth scientists because they show the three-dimensional configuration of the Earth's surface by means of **contour lines**, which connect points of equal elevation. Contour lines may be visualized as the intersection of a series of equally spaced, horizontal planes with the Earth's surface. The relationship between a topographic map and the land surface it represents is illustrated in Figure 1-8.
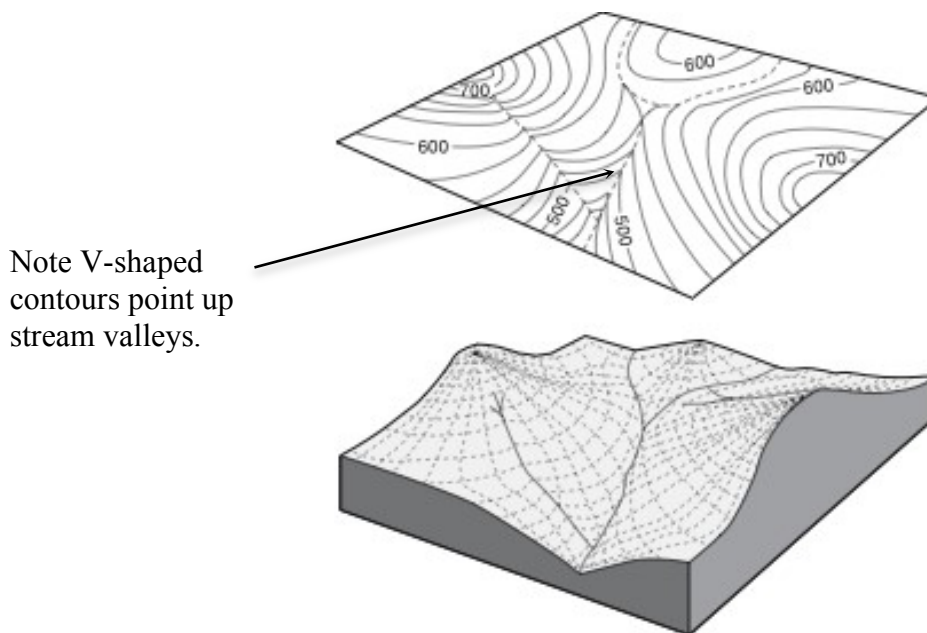
600

700

600

600

500

500

700

Note V-shaped
contours point up
stream valleys.

Figure 1-8: Block diagram illustrating the relationship between a topographic map and the land surface it represents.

Simple rules to follow when reading or constructing topographic maps
Figure 1-8 graphically illustrates how these rules apply to contour maps.

(1) Contour lines connect points of equal elevation.
(2) Contour lines do not cross (except in the rare case of an overhanging cliff).
(3) Contour lines never diverge.
(4) Contour lines do not end except at the edges of a map or by closing on themselves.
(5) The spacing of contour lines is related to the steepness of a slope: Widely spaced contour lines characterize gentle slopes and closely spaced contour lines indicate steep slopes.
(6) A rounded hill is represented by a concentric series of closed contours.
(7) A "closed depression" is represented by a concentric series of closed contours that have hachure marks (tick marks) on the downhill side.
(8) Contour lines **form V's which point upstream** when they cross stream valleys.

The vertical distance of separation between adjacent contour lines is called the **contour interval**. Selection of a contour interval is a function of map scale and the extent of topographic variation within an area. Typically, the greater the vertical relief that is represented on a map, the greater the contour interval. The contour interval, shown at the bottom of the map, remains constant throughout the map area.

On most topographic maps, every fifth contour line is printed darker for easy recognition and is labeled with its elevation. These **index contours** appear dark brown on U.S. Geological Survey topographic maps. **Intermediate contour** lines are lighter brown and elevation data are not given. Elevations of intermediate contour lines may be determined by interpolating between the nearest index contour and adding or subtracting the appropriate elevation as determined by the map's contour interval. If a point lies between two contour lines, then its elevation must also be interpolated. Elevations of specific points (tops of peaks, survey points, etc.) are sometimes indicated directly on the map. The notation "BM" denotes the location of a **benchmark**, a permanent marker placed by the U.S. Geological Survey or other governmental agencies at the point indicated on the map. Elevations are usually given for benchmarks.

Slope and Gradients
Topographic maps permit measurement of the **slope,** defined as the change in vertical distance divided by the horizontal distance (rise over run). For example, to calculate the slope of a hill that has a vertical rise of 80 feet and a horizontal run of 800 feet:

$$Slope = 80 \text{ ft} / 800 \text{ ft} = 0.1$$

Note that the units of measurement (in feet) cancel each other out; thus, the calculated slope is dimensionless. To calculate the slope in degrees you would take *arctangent* of rise over the run and convert radians to degrees.

The **gradient** of a slope is most often expressed as a change in vertical height (measured in feet or meters) compared to the horizontal length of the sloping surface (measured in miles or kilometers). Measurement of the gradient requires accurate determination of elevations and effective use of map scales. For example, if two separate points have elevations of 182 and 118 feet respectively, and are separated by a distance of 1.8 miles, the gradient between the two points may be calculated as follows:

$$gradient = \frac{difference\ in\ elevation\ (ft)}{horiztonal\ distance\ (mi)}$$

$$gradient = \frac{64\ ft}{1.8\ mi}$$

$$gradient = 35\ ft/mi$$

Stream and river gradients may be calculated in a similar fashion; however, map distances must be measured along stream channels, rather than as a straight line.

Relief
Relief refers to the difference between the highest and lowest point in a given area. Relief can be expressed either numerically (e.g. a mountain has 865 ft of relief above the valley floor), or in a relative sense (e.g. a plain would have low relief while a mountain range would have high relief).

Topographic Profiles
To better visualize topography, it is often advantageous to construct a **topographic profile**, which presents a "side-view," or cross-section, of the Earth's surface. Construction of a topographic profile is not difficult if the following guidelines are followed:

(1) Place a strip of paper along a selected profile line (Figures 1-9A and 1-9B).
(2) Mark on the paper the exact location where each index contour line, hill crest, and valley crosses the profile line. Label each mark with its elevation (Figure 19B). For very steep topography, where contour lines are very close together (e.g., a steep cliff), you may decide to only label the base of steep cliff and its top elevation before continuing to label the index contours.
(3) Make a vertical grid on graph paper. The horizontal axis should show units of horizontal distance along the profile line and be the same length as your profile line. The vertical axis should show elevation units ranging from the lowest to highest points on your profile line.
(4) Place the paper strip above the vertical grid and project each marked topographic feature downward to its proper elevation (Figure 1-9C).
(5) Connect all the points on the grid with a smooth line, which is consistent with topographic trends. The result is a silhouette of the topography along the profile line (Figure 1-9C).
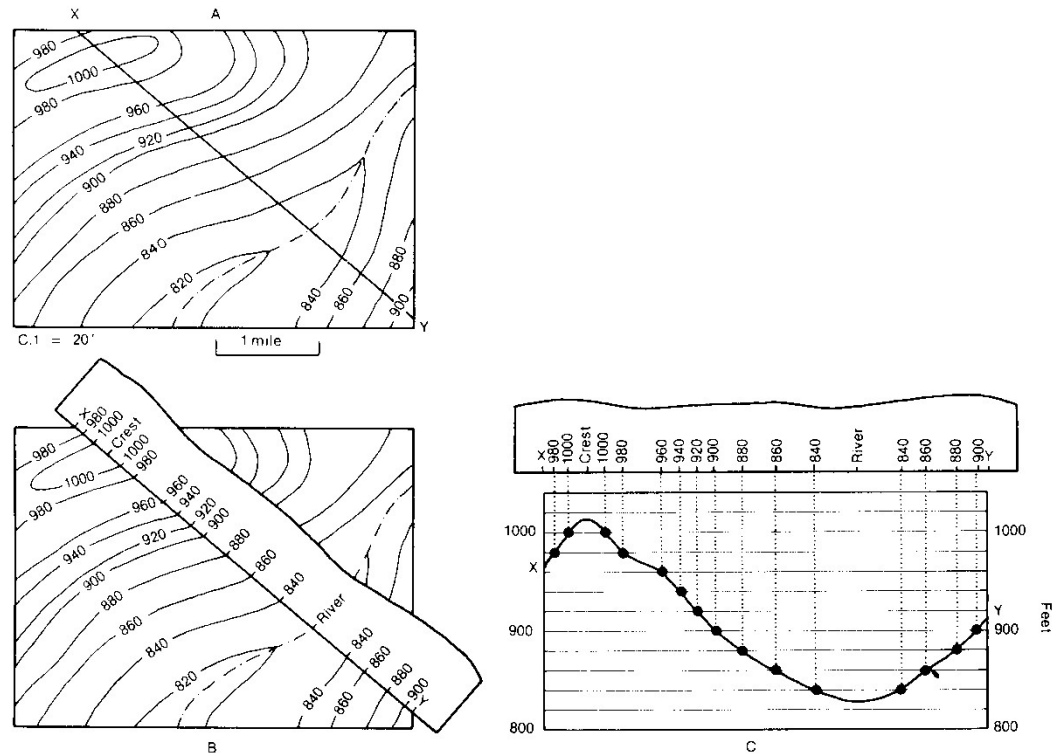
Figure 1-9A-C: Constructing a topographic profile.

Map Symbols

In the lower right corner of most U.S. Geological Survey (USGS) topographic maps, a legend is given that shows a few of the important symbols used on the map. The USGS has adopted standardized map symbols and color-coding to represent physiographic, cultural, and survey features shown on the map. A complete list of these symbols can be found at: ***pubs.usgs.gov/gip/TopographicMapSymbols/topomapsymbols.pdf***

B. *Aerial and LiDAR (Light Detection And Ranging) Imagery*

Aerial photographs and LiDAR both provide depictions of the earth's surface. Aerial photographs show the color of the surface, which can be interpreted in terms of vegetation, rock type, soil type, human development, and/or landforms.

LiDAR mapping, also described as Airborne Laser Swath Mapping (ALSM), utilizes an airborne scanning laser rangefinder to produce detailed topographic surveys. This modern mapping technique produces more comprehensive and precise topographic data than traditional methods. One of its unique properties is that airborne laser altimeter data can be used to accurately measure topography even when vegetation growth is extensive, such as in forested terrains.

Accurate topographic data is acquired by precisely timing the round-trip travel time of a pulse of laser light from the airplane to ground surface and back. The travel-time is converted to distance from the ground to the plane knowing that the laser pulse travels at the speed of

light. Laser transmitters fire thousands of pulses per second, which provides very detailed distance data of the surface below. The airplane's location at the time that a given set of laser pulses is emitted is accurately determined using a global positioning system (GPS). The distance measurements and GPS data are then converted to detailed map coordinates and elevation data coincident with individual laser pulses.

Large surface areas are mapped by flying many parallel flight lines, ensuring that there is adequate overlap for complete coverage. Newer laser technology can measure multiple reflected returns so that vegetation cover can be identified and "removed" from the mapped surface by comparing the multiple returns with the "last return" (inferred to be from the actual ground surface). High resolution LIDAR imagery has many applications important to the geo- and environmental sciences, as well as urban and rural planning.

For more detailed and complete information regarding LiDAR imagery, techniques and applications, and to view LiDAR maps, refer to the Washington state Department of Natural Resources LiDAR web site at: ***https://www.dnr.wa.gov/lidar***.

Lab 1: Geologic Techniques

Exercises

Group Members: _____

One answer sheet per group should be turned into your T.A.

Use the 7.5 minute topographic map of Mt. Rainier West Quadrangle, Washington to answer questions 1 to 9.

1. When, and by whom, was the map published?

2. List the bounding parallels of latitude (i.e. the latitude lines at the limits of the map area, shown at the top and bottom corners of the map).

3. List the bounding meridians of longitude (i.e. the longitude lines at the limits of the map area, shown at the left and right corners of the map).

4. Which is closer to this map area: the prime meridian or the international date line? (circle one).

5. Why is this topographic sheet called a 7.5' (seven-and-a-half-minute) quadrangle?

6. Horizontal scale bars at the bottom of the map are provided in what units?

7. The horizontal scale of this map is also given as a representative fraction, or ratio, of 1:24,000. This scale indicates that 1 **inch** on the map represents _____ **inches** on the Earth's surface. Using this ratio, 1 **inch** on the map represents _____ **feet** on the Earth's surface. Show all calculations.

8a. What is the distance (in miles) represented by 7.5 minutes of angular distance of latitude on this map? _____ miles

8b. What is the distance (in miles) represented by 7.5 minutes of angular distance of longitude on this map? _____ miles

  8c. Are these values the same distance? _____ If not, explain your answer below.

9. What is the contour interval of this map? _____.

10. Make simple sketches to show how contour lines represent the following features. Use a 100-foot contour interval, and **label all contour lines and benchmarks.**

A steep 700-foot high cliff, rising above a nearly flat plain.

A meteorite impact crater (closed depression), 500 feet deep, with rim located 2500 feet above sea level.

A rounded hill, rising 500 feet above sea level.

A southward-flowing stream and stream valley, showing the "rule of V's" with at least 4 contour lines.

*Compare the Mt. Rainier National Park (**1:100,000 scale map**) and Mt. Rainier 7.5 minute topographic maps to answer questions 11 to 13.*

11a.   How many feet does one inch represent on the Mt. Rainier National Park map?

11b.   How many feet does one inch represent on the Mt. Rainier 7.5' quadrangle map (use answer calculated in question 7)?

12a.   Is the numeric scale of the Mt. Rainier National Park map larger or smaller than the scale of the Mt. Rainier 7.5 minute map? (Remember numeric scales are like fractions).

12b.   On which map does one square inch represent a larger area on the surface of the Earth?

13a.   What is the magnetic declination for each map (star represents geographic north)?
        Mt. Rainier National Park _____   Mt. Rainier 7.5' _____

13b.   Why are the two values different for each map?

Study the Leavenworth-Icicle Creek map. It is a composite map comprised of portions of several 7.5 minute U.S. Geological Survey topographic maps. The Leavenworth and Icicle Creek area represents a spectacular landscape created by the actions of glaciers, rivers, and mass wasting processes (landsliding). Use this map for questions 14 and 15.

14a.   What major topographic feature is located at approximately latitude 47°32'24" N
        and longitude 120°38'30" W?

14b.   What is the elevation of this feature?

14c.   What is the local relief of this feature relative to Peshastin Creek (located near the
        southeast (lower right) corner of the map)?

15a.   Compare the valley profiles of the lower Tumwater Canyon section of the
        Wenatchee River and the lower Icicle Creek drainage. Use the graph paper provided
        to construct a topographic profile for one of these two transects (A-A', B-B'). **To
        save time, divide your group in half, and each half complete only *one* of the
        transects. Following completion of the cross-section the two groups should
        compare their results. Turn in both cross-sections, clearly labeled, with your
        answer sheet.**

15b.   Glaciers tend to carve "U-shaped" valleys while streams carve "V-shaped" valleys.
        What agent, glacier or river, was responsible for eroding the Tumwater Canyon
        section of the Wenatchee River (Cross-section A-A')?

15c.   What agent, glacier or river, was responsible for eroding the lower Icicle Creek
        drainage (Cross-section B-B')?

15d.   Look at the glacial reconstruction of the Icicle Creek-Lower Wenatchee River
        region, published by Porter and Swanson (2008). According to Porter and Swanson,
        which of these two drainages was glaciated during the last glacial cycle? Are your
        reconstructions consistent with Porter and Swanson's interpretation?

Use the three images (provided by your lab instructor) of Possession Point, Whidbey Island, WA to compare the attributes of LIDAR imagery to conventional topographic maps and aerial photography. You will use LIDAR imagery in later laboratories to map and interpret geologic structures and features. Use these images for questions 16-18.

16. Look at the three images provided in lab. List the features that you can see on each image. Think about what features are visible on all images, and what features you can only see in one or two images.

    LIDAR imagery:

    7.5 minute topographic map:

    Vertical aerial photograph:

17. Study the LIDAR image. Compare the east-facing shoreline of Possession Point to the west-facing shoreline. If Island County Public Works hired you as a geoconsultant to assess shoreline retreat rates (how fast the shoreline is eroding), and to determine building setbacks from the bluff line (how close a building can be constructed to a bluff without being damaged from erosion over its expected life span), what recommendations would you make regarding construction about the west-facing versus east-facing shorelines of Possession Point?

18a. Observe the incised stream channels on the west side of Possession Point. Do they terminate at modern sea level?

18b. Propose your own hypothesis to explain how these channels formed based on their spatial distribution and termination elevation above modern sea level. Hint: Think about our discussion on *isostasy* in lecture and the fact that the Puget Lowland was inundated by a 3000 foot thick ice sheet that advanced and retreated from the lowland between 18,000 and 15,000 years ago.