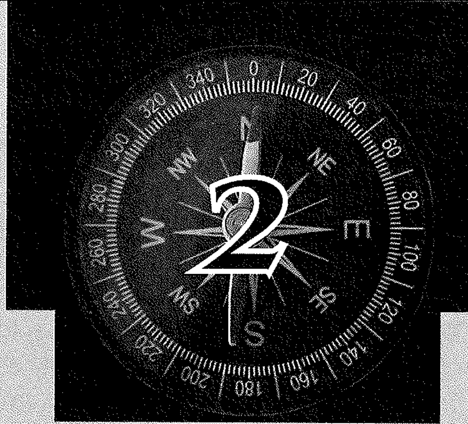
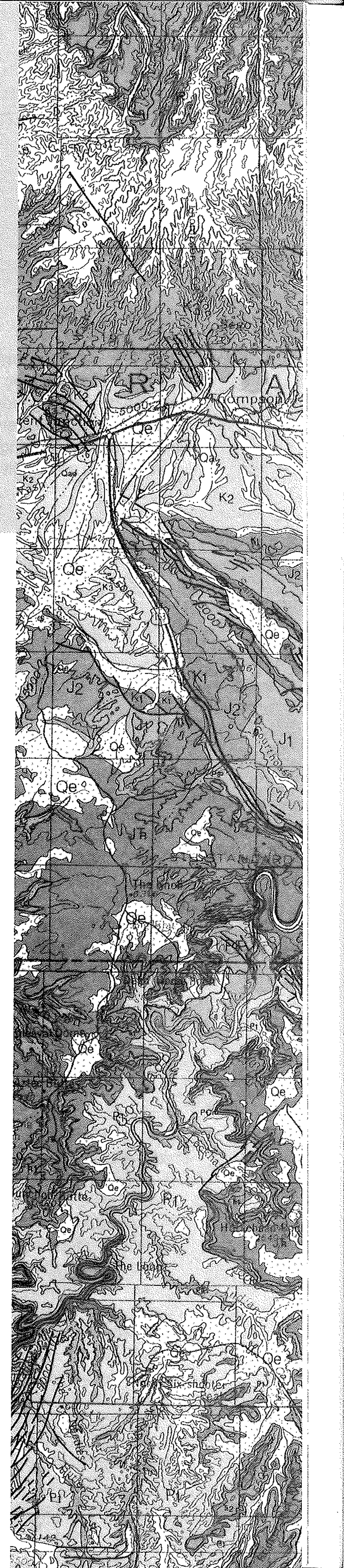


Base Maps



Map Projections

Maps are the most widely used method of depicting portions of the surface of the Earth. While many maps are used to record the location of cultural features such as roads, buildings, towns, pipelines, or property boundaries, the types of maps used by geologists commonly depict the shape of the surface of the Earth or the distribution of various rock types or rock units. Because of the problems involved in representing the surface of the Earth—essentially a spherical surface—on a flat surface, maps generally contain certain distortions. Distortion of directions, areas, or both is inevitable, and the question facing the mapmaker is what type of distortion will present the fewest problems when considering the purpose for which the map is intended. If the area represented by the map is small (e.g., a few square kilometers or miles), the distortion may not be significant. But maps that cover large areas contain significant distortions. The amount of distortion generally increases with the size of area represented on the map.

The surface of the Earth is subdivided by means of lines of latitude and longitude. Because the Earth is nearly spherical, planes drawn through the equator or through the poles intersect the Earth's surface in a circle. The center of the Earth is the center of all such circles. Lines of longitude are imaginary lines located where planes that pass through the poles of rotation of the Earth intersect the Earth's surface. All lines of longitude are true north–south lines and are called meridian lines. The zero or prime meridian is the one that passes directly over Greenwich, England. Their angular distance (measured in degrees, minutes, and seconds) identifies other lines of longitude in the plane of the equator (Figure 2-1a), east or west from the prime meridian. From the sketch in Figure 2-1b, it is clear that lines of longitude converge toward the poles and are a maximum distance apart at the equator. Because topographic maps generally are bound on their east and west sides by lines of longitude, they are almost rectangular, but the width of the map is slightly different at the top and bottom.

Lines of latitude are lines formed by the intersection of the surface of the Earth with planes that are parallel to the plane containing the equator. Unlike lines of longitude, these lines do not intersect one another. The angular distance of the line (measured in a meridian plane) distinguishes them from the equator. Thus, the latitude of a place on the surface of the Earth is expressed as the number of degrees this place is north or south of the equator. Because all east–west lines on the Earth's sur-

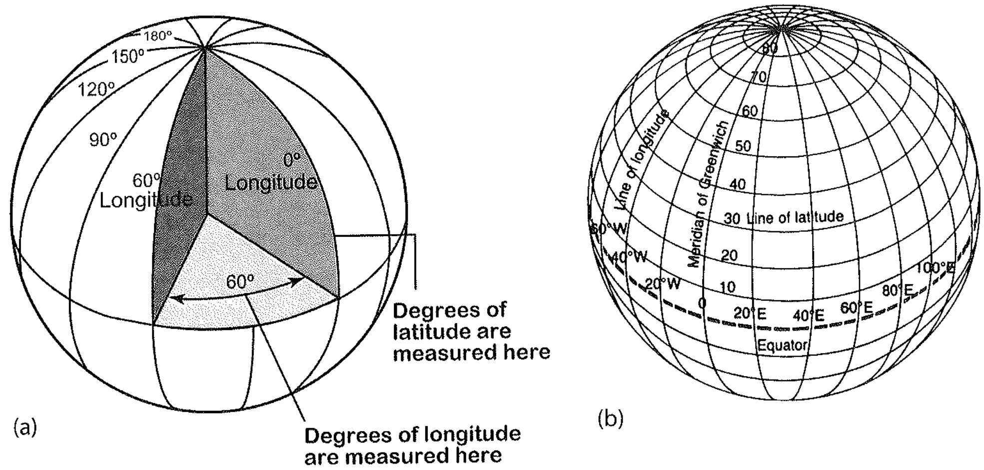


Figure 2-1 (a) A cutaway view of the Earth showing how latitude and longitude are measured. (b) An external view of the globe showing lines of latitude and longitude.

face are parallel to one another, lines of latitude are commonly referred to as parallels of latitude.

Many different types of map projections are in use. Selection of a base depends on the size and location of the area to be depicted. Since no map projection is totally free of distortion, a choice is often made that will minimize distortion of area or direction or will keep the combination of distortions at a minimum.

Mercator Projection

Most maps are rectangular or nearly rectangular in shape. One of the most widely used rectangular projections is one delineated by Gerardus Mercator in 1569, on which lines of latitude and longitude are laid out in a grid pattern. Lines of longitude (oriented north–south) are evenly spaced along the equator, and lines of latitude (east–west) are spaced farther and farther apart toward the poles (Figure 2-2a). Because of this distortion toward the poles, Mercator projections rarely show much of the polar regions. Despite this shortcoming, the Mercator projection is useful for navigation because bearings (compass directions) are straight lines on this projection.

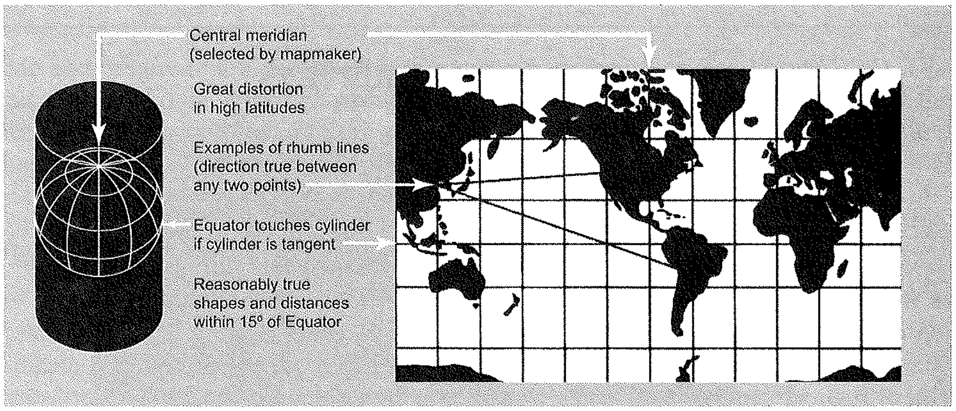
The problems with the Mercator projection may be partially overcome by curving the lines of longitude toward the top and bottom of the map. This allows the areas to be kept under control, but at the cost of distorting directions.

Transverse Mercator Projection

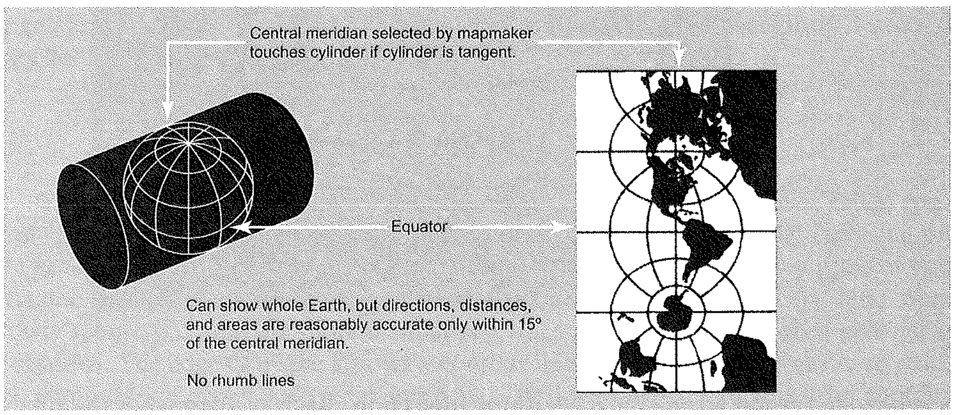
This projection is similar to the Mercator, but the orientation of the cylinder on which the globe is projected is different (Figure 2-2b). Note that one meridian line on the globe touches the surface of the cylinder. Along that line and up to 15 degrees on either side, distortion is not excessive, but at greater distances from that line, distortion becomes a serious problem. This projection is used by the USGS for many quadrangle maps covering areas that range in size from 7½ minutes to 1 degree.

Universal Transverse Mercator (UTM) Coordinates

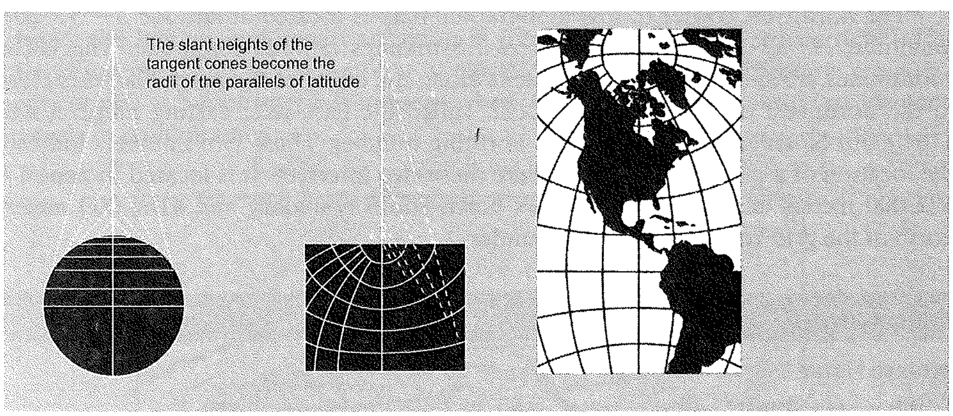
The UTM system of coordinates is widely used as a way of defining locations. UTM coordinates are given on all maps produced by the USGS. The map is divided into a square grid with lines drawn 1 km apart. The lines are designated along the edge of the map by a series of numbers. Each map is part of a universal zone; the number for each is provided in the description of the projection used for the map. For example, the map illustrated in Figure 2-3 (on p. 18) is published by the USGS for Arnold Valley, Virginia. It is a polyconic projection for zone 17. The system divides the Earth into 60 zones, each of which covers a 6 degree band of longitude. Each zone



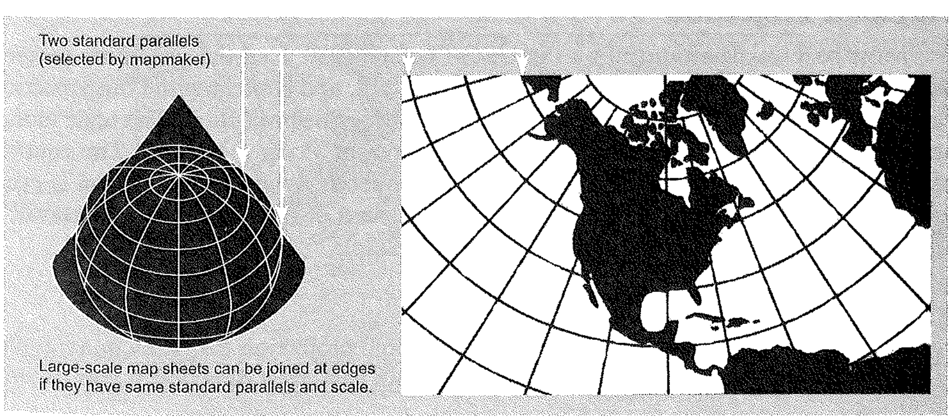
(a)



(b)



(c)



(d)

Figure 2-2 Four types of map projections: (a) the Mercator projection, (b) the transverse Mercator projection, (c) the polyconic projection, and (d) the Lambert conformal conic projection. All map projections contain distortion. Some distort areas, other distort directions. Note that areas of the same size on a globe vary in size as depicted on the Mercator projection. On a Mercator projection a surface area of any given size will appears six times larger at latitude 75 degrees than a comparable area near the equator. (From the US Geological Survey.)

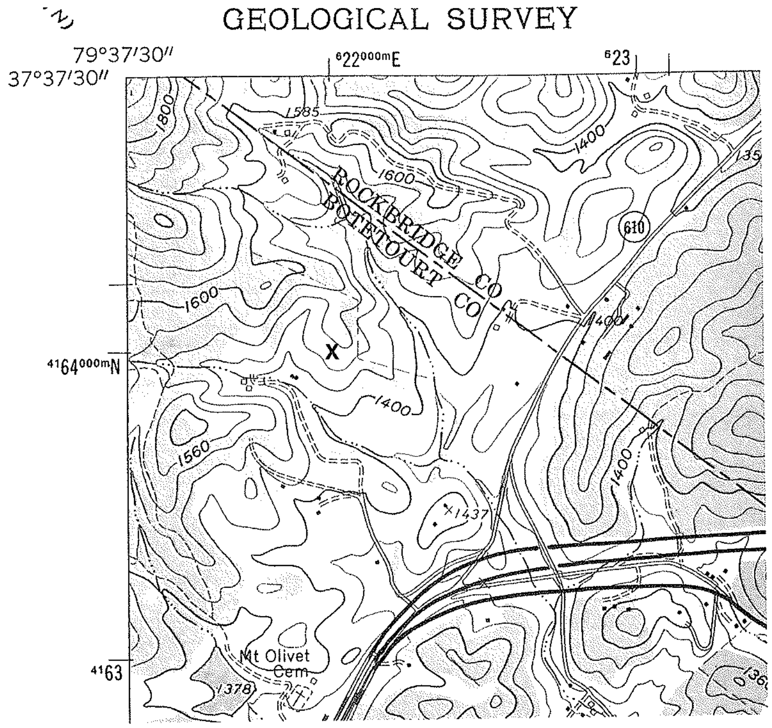


Figure 2-3 The upper left corner of the Arnold Valley, Virginia Quadrangle. Latitude and longitude for the corner are indicated. The easting and northing numbers are indicated along the borders of the map.

is subdivided using a transverse Mercator projection. Each of these zones is subdivided into 20 latitude bands, each of which is 8 degrees high. The intersection of these two lines produces **grid zones**. These are often designated by use of N, S, E, and W.

The northwest corner of this topographic map is located at latitude 37° 37′ 30″, longitude 79° 37′ 30″. The map covers 7.5 minutes latitude–longitude. The UTM coordinates are shown by blue tick marks along the edges of the map. The lines close to the northwest corner are 622000m E, called the east–west easting number, and 4164000m N, called the north–south northing number. These two numbers indicate the location of a point on the map where these two intersect. It is located in zone 17, 622 000 meters east of the grid zone's north–south boundary and 4164 000 meters north of the grid zone's horizontal boundary.

Exercise 2-1 UTM Coordinates

Refer to Figure 2-3.

1. What are the UTM coordinates of point X? Zone 17 ____E ____N

Polyconic Projection

Most base maps produced by the USGS before 1950 used the polyconic projection. Taking strips from the globe, flattening them out, and stretching the outer part of each strip until it forms a continuous surface produces this projection. The scale along any line of latitude is constant, but the scale increases along meridians. The central part of this projection has little distortion. Consequently, when the projection is centered on the central United States, the maps of all parts of the country except Hawai'i and Alaska are only slightly distorted (see Figure 2-2c).

Lambert Conformal Conic Projection

Cartographers use the Lambert conformal conic projection for many quadrangle maps and for maps of areas that are elongated in an east–west direction. Lines of latitude and longitude are projected onto a cone-shaped surface (see Figure 2-2d). Distances are true only along two parallels of latitude, called standard parallels, where the surface of the cone intersects the surface of the globe. Distortion of directions and shapes is minimal. The standard parallels for the conterminous United States are 33N and 45N.

Planimetric Maps

These two-dimensional maps show the horizontal position of features such as buildings, roads, streams, lakes, and other natural and cultural objects. They do not indicate the elevation of the ground surface or other features shown. Road maps and maps found in atlases are commonly planimetric maps. Shading may be used to give some sense of shape of the ground surface, but precise information about elevation is found only if the elevation for specific points on the ground such as bench marks, triangulation stations, or peaks is indicated. Any of the projections previously described may be used for these maps.

TOPOGRAPHIC MAPS

The surface of the Earth is represented on topographic maps by lines, called **contour lines**, that are map projections of lines connecting points of equal elevation on the ground (Figure 2-4). It may help to envision what a topographic map is like if you imagine that contours mark the position a lake shore would have if the land were slowly submerged, and the shoreline mapped when the water level reached successive elevations. The edge of a lake follows a contour line. To make the map easier to read, the contours are drawn at regular intervals. The interval, referred to as the contour interval, is the difference in elevation between adjacent contours. Sea level is the zero contour, and other contours are usually drawn at 5-, 10-, 20-, 40-, or even 100-foot (or meter) intervals. The contour interval is selected on the basis of the difference between the highest and lowest elevation in the area (which is known as relief), the scale of the map, and on the amount of elevation data available. Contours are commonly drawn at 5-foot intervals in areas where the relief is not great and at 100-foot intervals in high mountains.

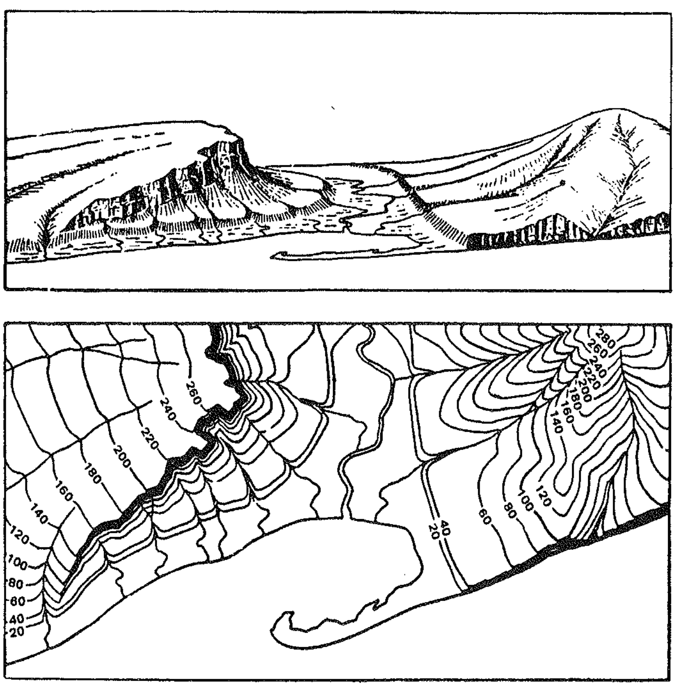


Figure 2-4 Landscape drawing (top) and a topographic map (bottom) of the same area. (From the US Geological Survey.)

For small areas, contour maps are commonly prepared by conventional surveying techniques such as running a level line with a transit or level, but most topographic maps, such as those prepared by the USGS or the National Geodetic Survey, are made from vertical aerial photographs, supplemented by precise elevation control data obtained by surveying along roads and streams.

Location

Topographic maps produced by government agencies are generally named for a prominent locality (town or landmark). More precise information about the location of the map may be obtained by noting the longitude and latitude of the corners. Most of the recent maps produced in the United States cover an area that is 7.5 minutes of longitude wide by 7.5 minutes of latitude long. An older series of maps, which cover 15-minute areas at a scale of 1 inch to 1 mile (1:62,500), is also still widely available; a third series covers areas 2 degrees (120 minutes) wide by 1 degree (60 minutes) long. Points within a map area may be specified in terms of their longitude and latitude, by means of the public land survey described subsequently, or in terms of their direction (bearing) and distance from a known locality.

Location by Means of the Public Land Survey

Most of the land in the United States has been subdivided by government surveys, as shown in Figure 2-5. The first step in these surveys was selection of an initial point (IP). This point was chosen at the intersection of a particular meridian and parallel, referred to as the principal meridian and base line, respectively.

The principal meridian and base line were then divided into 6-mile intervals, establishing a grid of townships, each 6 miles on a side. Each successive township north or south of the IP was given a township number, and each successive township east or west of the IP was given a number called the range number. Thus, Township 4 South, Range 3 East (T4S, R3E) refers to the block between 18 and 24 miles south of the IP and between 12 and 18 miles east of the IP.

Since meridians converge northward (in the Northern Hemisphere), it was necessary to offset range lines periodically in order to maintain the 6-mile width of the

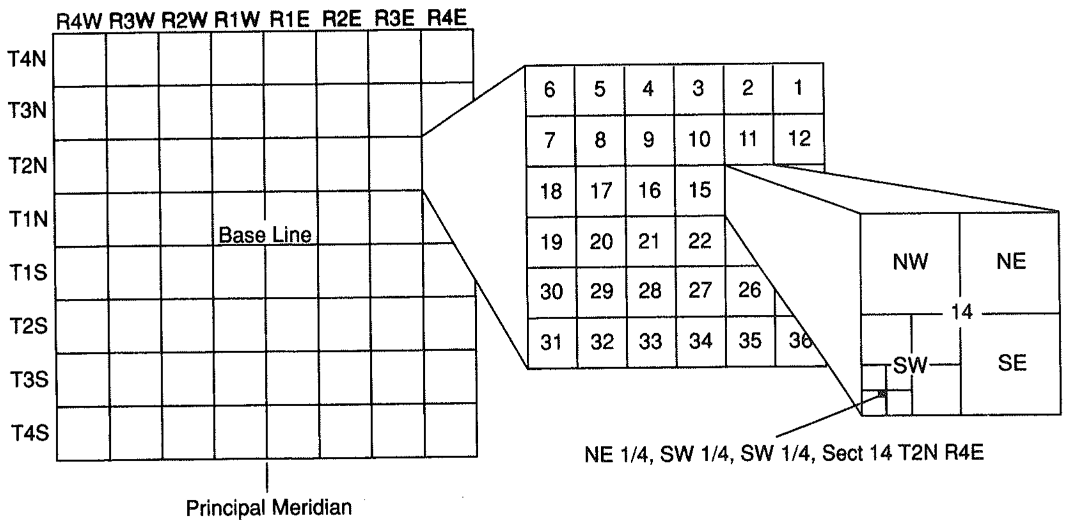


Figure 2-5 The public land survey grid is widely used in the United States. Areas are subdivided into townships and ranges. Each township is subdivided into 36 sections; each section is subdivided into quarters. Because grids do not fit perfectly on the curved surface of the Earth, many of the grid lines of this system are not perfectly north–south and east–west. For the same reason, sections are often not perfectly square. Note the section lines shown on some of the geologic maps in Appendix B.

townships. This was usually done at 24-mile intervals north and south of the IP along parallels called standard parallels. All north–south lines in the survey (range lines), except the principal meridian, are offset in this manner. East–west lines (township lines, standard parallels, and base lines) are continuous.

Townships are subdivided into 36 sections or blocks of land measuring 1 mile on each side (1 square mile in area). The system used to number sections within townships is shown in Figure 2-5. Location within a section is specified as closely as desired by quartering. By convention, the smallest quarter is given first. Thus, a point on a map might be specified as being in the NW quarter of the SE quarter of the SW quarter of section 10 in Township 9S Range 10E. This may be abbreviated as NW.SE.SW 10, T9S, R10E.

Ground Distance and Map Distance

We commonly measure distances by pacing, by using a tape measure that is placed on the ground, or by using a calibrated wheel that records distance as the wheel turns. Such distances are called ground distances. They are equal to the horizontal distance between points only if the ground is level. Thus, ground distances rarely correspond to map distances between the same points. The difference between ground and map (horizontal) distance increases with relief. Where precise measurements of horizontal distances are required, more sophisticated instruments than the ones just mentioned may be used. These include surveying instruments that measure the distance by using telescopes, the velocity of sound, laser beams, or other electronic methods. These instruments are generally used to measure horizontal rather than ground distances.

Scales of Quadrangle Maps

The USGS publishes maps that cover areas of different sizes and at different scales. The scale is represented by a fraction (e.g., 1:50,000) and a bar scale (Figure 2-6) printed at the bottom of the map. Bar scales show the map distance that is equivalent to a certain number of miles, feet, kilometers, or meters measured horizontally across the ground. The scale fraction indicates the number of units of length (meters, inches, kilometers, meters, yards, etc.) measured horizontally across the ground that are equivalent to one such unit measured across the map. For example, a map drawn at a scale

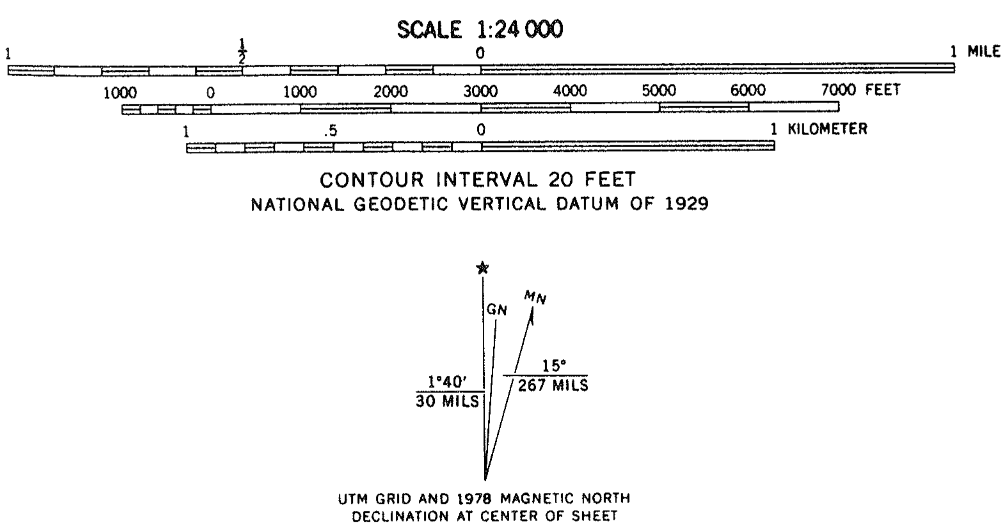


Figure 2-6 Most topographic and geologic maps contain metric and English unit bar scales, the angular difference between true and magnetic north (called declination), the contour interval and datum, and the scale shown as a fraction.

of 1:100 is scaled so 1 meter across the map is equivalent to 100 meters measured across the ground. The scales most commonly used on topographic maps are 1:24,000, 1:62,500, 1:100,000, and 1:250,000. The 1:62,500 scale produces a map on which 1 inch on the map is equivalent to 1 mile across the ground. This scale, which was commonly used in the past, is not used on more recent maps.

The area covered is represented by the latitude and longitude of the boundaries of the area. People using these maps often refer to them in terms of their scale. The most common areas and the scales used for each are:

Area Size (expressed by minutes or degrees of longitude and latitude)	**Scale**
7.5 minutes × 7.5 minutes (7.5-minute quadrangle)	1:24,000
15 minutes × 15 minutes (15-minute quadrangle) (older maps)	1:62,500
1 degree longitude × 1 degree latitude (1 degree quadrangle >)	1:100,000
2 degrees longitude × 1 degree latitude	1:250,000

Exercise 2-2 Map Scales

Refer to Figure 2-7.

1. Without referring to the caption, determine the contour interval on each of the three maps shown in Figure 2-7.

   a. ______________________________

   b. ______________________________

   c. ______________________________

2. List the types of cultural features shown on the 1:24,000-scale map that are not present on the other two.

   ____

   ____

True and Magnetic North—Declination

The side margins of government topographic maps are oriented in the direction of true north–south. Because these maps are projections on which lines of longitude converge, the distance across the top of maps in the Northern Hemisphere is somewhat less than the distance across the bottom of the same map.

Both true north and magnetic north are indicated on topographic maps. The magnetic north pole is not located near the geographic north pole (the pole of rotation). The angle between the direction of true north and magnetic north as shown by a compass is called the declination. The declination is given as part of the margin information on topographic maps. True north is the direction to the northerly pole of rotation of the Earth from any given point, and it does not change. In contrast, magnetic north is typically the direction a compass points. Since the rates of change in the magnetic field are generally low, the direction of magnetic north as indicated by a compass within the area of a topographic quadrangle is essentially constant.

Bearings and Azimuths

A bearing is the direction of a straight line between two points, expressed as the number of degrees the line between the two points lies east or west of a north–south line. If the bearing from point B to C is N70W (Figure 2-8 on p. 24), the bearing from C to B is S70E. Bearings may be expressed relative to either true or magnetic north, and if the declination is known, it is possible to convert from one to the other. Many surveying instruments, including most transits and levels, measure magnetic bearings.

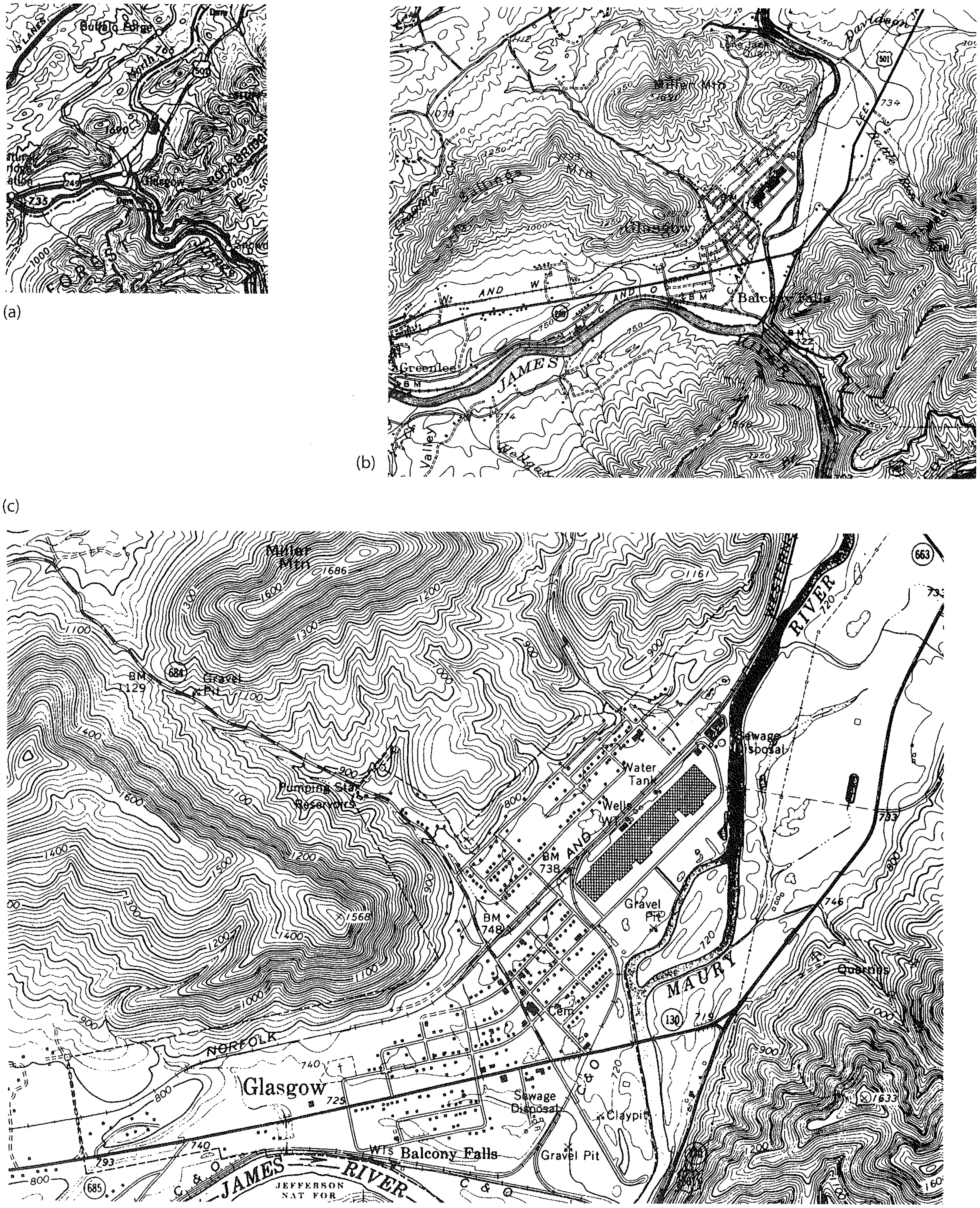


Figure 2-7 Topographic maps of portions of the same area. (a) Part of a 1:250,000-scale map. The contour interval is 100 feet. (b) Part of a 1:62,500-scale map. The contour interval is 50 feet. (c) Part of a 1:24,000-scale map. The contour interval is 20 feet.

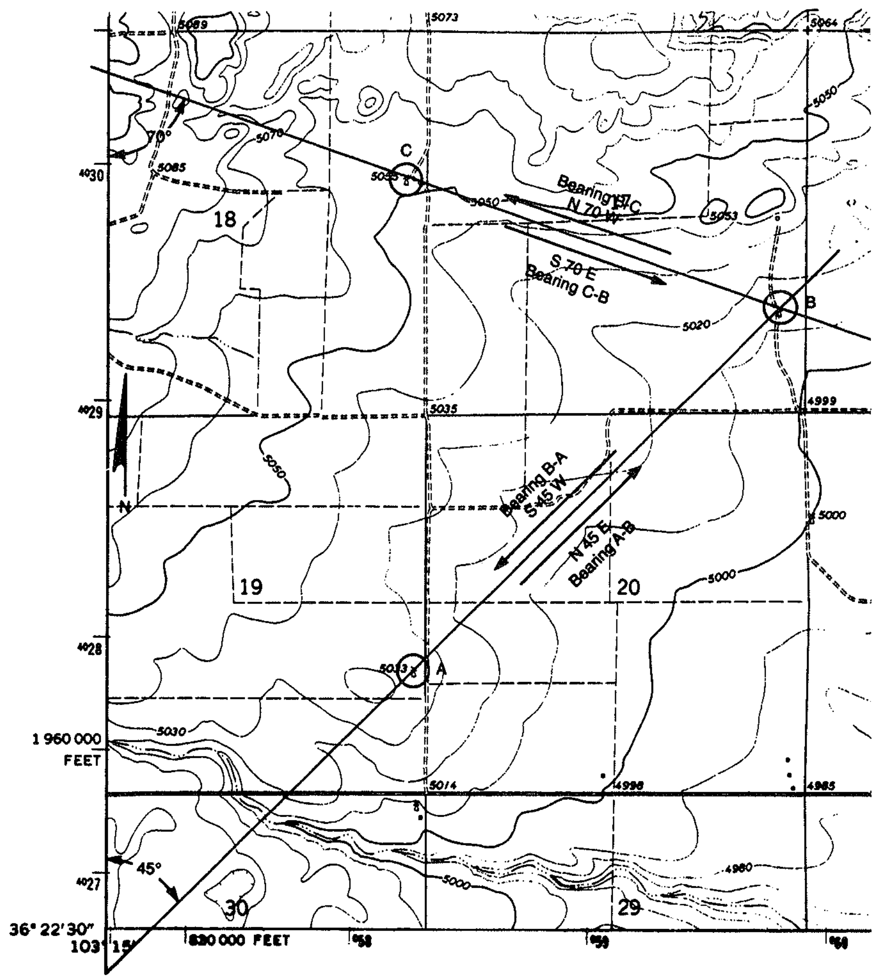


Figure 2-8 The bearing of a line is the compass direction of a line connecting two points along the line. On this topographic map, if you were standing at point A and taking a compass bearing to point B, your compass would indicate that the bearing to point B is N45E. If you were at point B taking a bearing on point A, the compass bearing would be S45W.

These must be converted to true readings. The small hand-held compasses used by geologists can be adjusted to read true bearings if the declination is known.

The azimuth of a line is the compass direction of that line expressed in degrees and measured clockwise. In some surveys, the angle is measured from north; in others, it is measured from south. If measured from north, a line with bearing N30°E would have an azimuth of 30 degrees; a line with bearing S30°W would have an azimuth of 210 degrees.

In laying off bearings or azimuths, be careful to notice the numbering on your protractor. Place the protractor on the map, as shown in Figure 2-9, to ensure that you do measure the bearing relative to north rather than the compliment to the angle of the bearing.

Exercise 2-3 Bearing and Azimuth

Refer to Figure 2-8.

1. What is the bearing from point B to point C? Express the answer as an azimuth (the number of degrees measured clockwise from north to the line of the bearing).

____

2. What is the bearing from point C to point A? Express the answer as an azimuth.

____

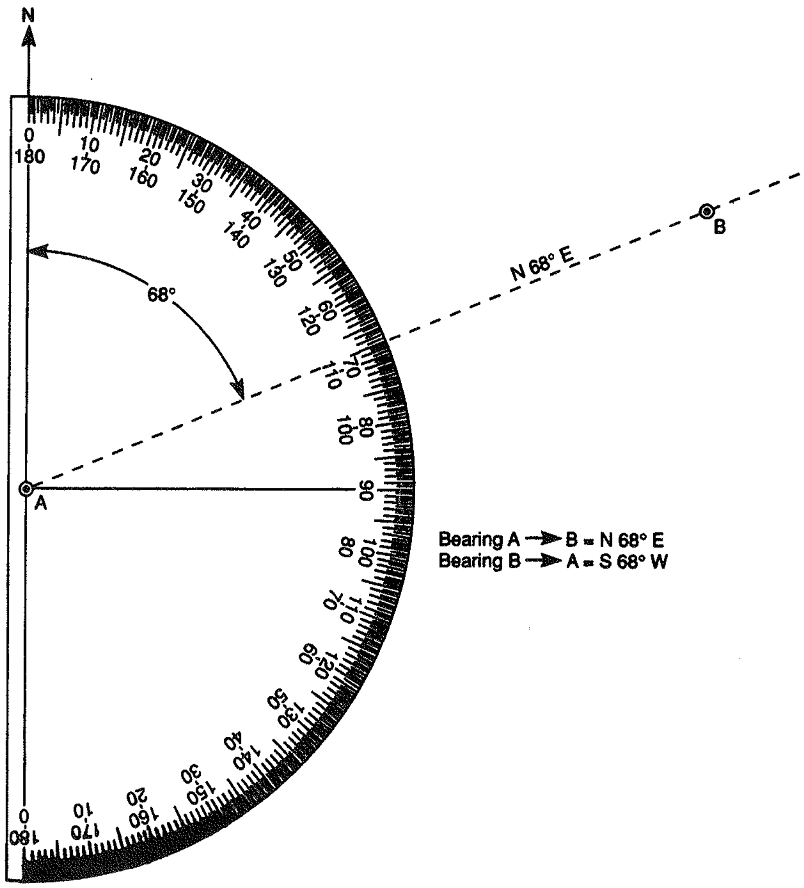


Figure 2-9 A protractor is used to lay off a bearing from point A to point B. Be sure to set the protractor as shown, with 0 and the center point on the protractor oriented in a north–south line.

Preparing a Topographic Profile

A profile of the topography is the outline of the land as it would appear in a vertical slice along a particular line (Figure 2-10). A topographic profile along a specified line can be prepared with relative ease if the horizontal scale used for the profile is the same as the horizontal scale of the map from which the profile is being prepared. Graph paper with line spacing suitable for the scale is also needed. The most realistic representation of the topography is obtained when the vertical scale selected for the profile is the same as the horizontal scale. However, it is common practice to exaggerate the vertical scale, especially in areas of low relief, in order to make the features stand out more clearly. It will help you grasp the true dimensions of the land if a profile is prepared so the horizontal and vertical scales are the same, even if a second profile with exaggeration is to be prepared. Follow the following procedure when constructing profiles.

Step 1. Select the vertical scale to be used and mark the scale divisions on a piece of graph paper.

Step 2. Place the edge of the graph paper along the line of profile on the map.

Step 3. Mark the point where each fifth contour (heavy contour) crosses the line of the profile, determine the elevation of each of these contours, and place a mark at that elevation. Also mark all stream crossings and ridge tops at the appropriate elevation. Finally, mark as many other contour crossings as are needed to clearly define the elevation of the land surface along the line of profile.

Step 4. Connect the points you have marked with a smooth line. Avoid using straight line segments unless you have reason to believe that the ground has a

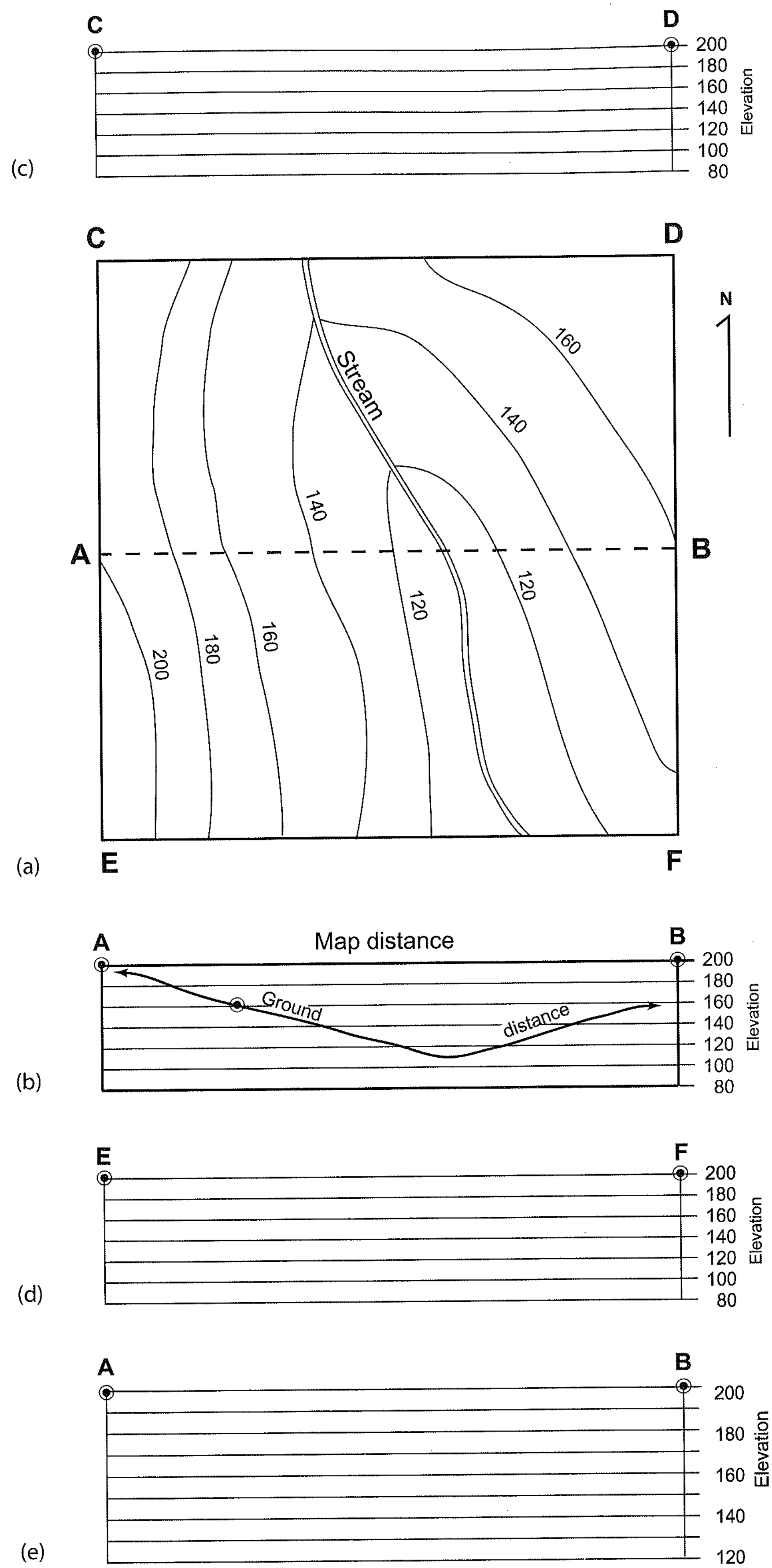


Figure 2-10 (a) A topographic map showing a stream valley and the lines along which topographic profiles are to be drawn. (b) A profile along the line A–B. Note that the distance from point A to point B is greater if measured on the ground than it is if measured on the map. (c) Draw a profile along the line C–D. (d) Draw a profile along the line E–F. (e) Draw a profile along the line A–B using a 2× vertical exaggeration.

uniform slope. (The contours will be uniformly spaced for areas that can be represented by a plane surface.)

Selecting Graph Paper for Topographic Profiles

When you are selecting a vertical scale, check the line of the profile and observe the highest and lowest elevations. The scale markings on your graph paper can begin with the lowest elevation along the line, and the vertical markings must be long enough to reach the highest elevation along the line. If you are working with a 7.5-minute (USGS) quadrangle drawn at a scale of 1:24,000, use graph paper divided into 1/10s of inches to draw a profile with horizontal = vertical scale. At this scale, 1/10 inch will equal 200 feet.

If you are working with a 15-minute (USGS) quadrangle drawn at a scale of 1:62,500, use graph paper divided into 1/10s. At this scale, 1/10 inch will equal about 530 feet. In this case, it will be easier to round off the scale to 1/10 inch equals 500 feet, although this will introduce a slight exaggeration.

The following is a guide to obtain vertical exaggerations:

2× vertical exaggeration	1/10″ = 100 feet	1 cm = 62 meters
4× vertical exaggeration	1/10″ = 50 feet	1 cm = 31 meters
8× vertical exaggeration	1/10″ = 25 feet	1 cm = 15 meters

Exercise 2-4 DRAW TOPOGRAPHIC PROFILES

1. Using Figure 2-10c, draw a topographic profile along the line C–D.
2. Using Figure 2-10d, draw a topographic profile along the line E–F.
3. Using Figure 2-10e, redraw the topographic profile along the line A–B using a 2× vertical exaggeration.
4. On which of the three profiles is the ground distance across the map closest to the map distance?

____

5. What are the advantages and disadvantages of using vertical exaggeration?

____

____

____