LABORATORY 9

Topographic Maps and Orthoimages

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Oblique Google Earth™ view of the Italian volcano, Vesuvius, which destroyed the Roman city of Pompeii in AD 79. Pliny the Younger described his eyewitness account of the eruption in two letters to Tacitus. (© Google Earth™)

PRE-LAB VIDEO

BIG IDEAS

Topographic maps are two dimensional (flat) representations of three-dimensional landscapes, viewed from directly above. Horizontal (two-dimensional) positions of landscape features are represented with symbols, colors, and lines relative to geographic grid systems, specific scales, and directional data. The third dimension, elevation (height) of the landscape, is represented with contour lines marking certain elevations in feet or meters above sea level. The three-dimensional and quantitative aspect of topographic maps makes them valuable to geologists and other people who want to know the shapes and elevations of landscapes. They are often used in combination with orthoimages (aerial photographs that have been adjusted to the same scale as the map).

FOCUS YOUR INQUIRY

THINK About It How are specific places and quadrangles located using the latitude-longitude coordinate system, and how could geologists use Google Earth™ to study them?

THINK About It What are topographic quadrangle maps, and what geographic grid systems, scales, directional data, and symbols are represented on them?

THINK About It How are topographic maps constructed and interpreted?

THINK About It How are topographic maps used to calculate the relief and gradients (slopes) of landscapes?

THINK About It How is a topographic profile constructed from a topographic map, and what is its vertical exaggeration?

ACTIVITY 9.1 Map and Google Earth™ Inquiry

THINK About It How are specific places and quadrangles located using the latitude-longitude coordinate system, and how could geologists use Google Earth™ to study them?

OBJECTIVE Apply the latitude-longitude coordinate system to locate a country, quadrangle, and place of your choice, and then explore it in greater detail using Google Earth™ tools, layers, ruler, and historical imagery.

PROCEDURES

1. **Before you begin**, do not look up definitions and information. Use your current knowledge, and complete the worksheet with your current level of ability. Also, this is **what you will need** to do the activity:
   _____ Activity 9.1 Worksheet (p. 249) and pencil
   _____ computer with Internet access (on which Google Earth™ software is, or can be, loaded)
2. **Complete the worksheet in a way that makes sense to you.**
3. **After you complete the worksheet**, be prepared to discuss your observations and ideas with others.

ACTIVITY 9.2 Map Locations, Distances, Directions, and Symbols

THINK About It What coordinate systems, scales, directional data, and symbols are used on maps?

OBJECTIVE Identify and characterize features on topographic maps using printed information, compass bearings, scales, symbols, and three geographic systems: latitude and longitude, the U.S. Public Land Survey System (PLSS), and the Universal Transverse Mercator System (UTM).

PROCEDURES

1. **Before you begin**, read the following topics below: Introduction, Latitude-Longitude and Quadrangle Maps, Map Scales, Declination and Compass Bearings, Global Positioning System (GPS), UTM—Universal Transverse Mercator System, and Public Land Survey System. Also, this is **what you will need:**
   ___ Activity 9.2 Worksheet (p. 251) and pencil
   ___ calculator
2. **Then follow your instructor's directions** for completing the worksheet.

Introduction

Imagine that you are seated with a friend who asks you how to get to the nearest movie theater. To find the theater, your friend must know locations, distances, and directions. You must have a way of communicating your current location, the location of the movie theater, plus directions and distances from your current location to the movie theater. You may also include information about the topography of the route (whether it is uphill or downhill) and landmarks to watch for along the way. Your directions may be verbal or written, and they may include a map, satellite image, or aerial photograph (picture taken from an aircraft). Geologists are faced with similar circumstances in their field (outdoor) work. They must often characterize geologic features, the places where they occur, and their sizes, shapes, elevations, and locations in relation to other features. Satellite images and aerial photographs are used to view parts of Earth's surface from above (FIGURE 9.1A), and this information is summarized on maps.

A **map** is a flat representation of part of Earth's surface as viewed from above and reduced in size to fit a sheet of paper or computer screen. A **planimetric map** (FIGURE 9.1B) is a flat representation of Earth's surface that shows horizontal (two-dimensional) positions of features like streams, landmarks, roads, and political boundaries. A **topographic map** shows the same horizontal information as a planimetric map but also includes *contour lines* to represent elevations of hills and valleys. The contour lines are the distinguishing features of a topographic map and make it appear three dimensional. Thus topographic maps show the shape of the landscape in addition to horizontal directions, distances, and a system for describing exact locations.

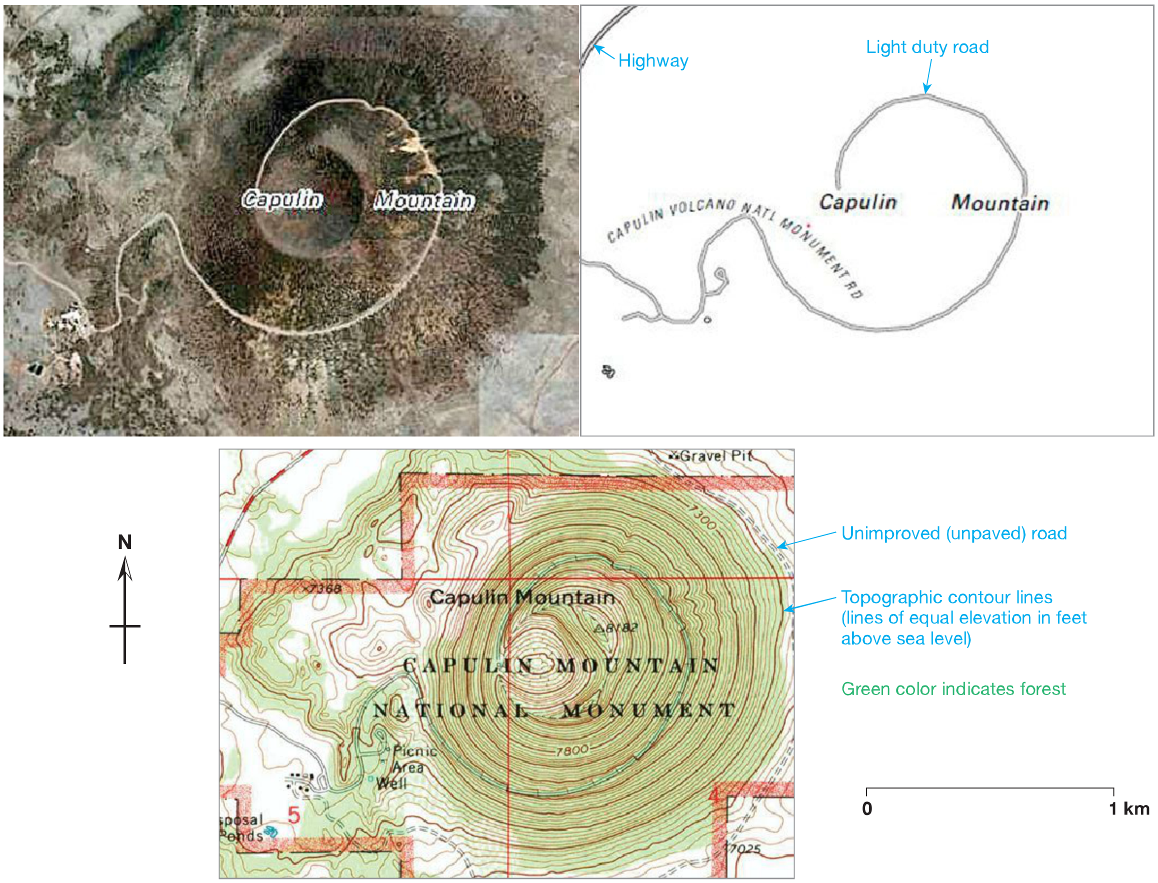
Most United States topographic maps are published by the U.S. Geological Survey (USGS) and available at their US Topo website (**http://store.usgs.gov**). Canadian topographic maps are produced by the Centre for Topographic Information of Natural Resources Canada (NRCAN: **http://maps.nrcan.gc.ca**). State and provincial geological surveys, and the national geological surveys of other countries, also produce and/or distribute topographic maps.

Latitude-Longitude and Quadrangle Maps

Earth is a spherical body or globe, and specific points on the globe can be defined exactly using a geographic coordinate system in which points are defined by the

A. AERIAL PHOTOGRAPH: a flat picture or image of Earth's surface.

B. PLANIMETRIC MAP: a flat representation of Earth's surface showing horizontal positions of feature.



C. TOPOGRAPHIC MAP: a flat representation of Earth's surface showing horizontal positions of features plus elevations of the landscape.

FIGURE 9.1 Comparison of an aerial photograph with planimetric and topographic maps. (Courtesy of USGS)

intersection of imaginary reference lines. The most traditional geographic coordinate system consists of reference lines of geographic latitude and longitude.

Latitude-Longitude Coordinate System

Earth's spherical surface is divided into lines of latitude (*parallels*) that go around the world parallel to the Equator, and lines of longitude (*meridians*) that go around the world from pole to pole (**FIGURE 9.2**). There are 360 degrees (360°) around the entire Earth, so the distance from the Equator to a pole (one-fourth of the way around Earth) is 90° of latitude. The Equator is assigned a value of zero degrees (0°) latitude, the North Pole is 90 degrees north latitude (90°N), and the South Pole is 90 degrees south latitude (90°S). The *prime meridian* is zero degrees of longitude and runs from pole to pole through Greenwich, England. Locations in Earth's Eastern Hemisphere are located in degrees east of the prime meridian, and points in the Western Hemisphere are located in degrees west of the prime meridian. Therefore, any point on Earth (or a map) can be located by its latitude-longitude coordinates. The latitude coordinate of the point is its position in degrees north or south of the Equator. The longitude coordinate of the point is its position in degrees east or west of the prime meridian. For example, point **A** in **FIGURE 9.2** is located at coordinates of: 20° north latitude, 120° west longitude. For greater detail, each degree of latitude and longitude can also be subdivided into 60 minutes 60′, and each minute can be divided into 60 seconds (60″).

Quadrangle Maps. Most depict rectangular sections of Earth's surface, called quadrangles. A **quadrangle** is a relatively rectangular area of Earth's surface, bounded by lines of latitude at the top (north) and bottom (south) and by lines of longitude on the left (west) and right (east)—see **FIGURE 9.2**. A *quadrangle map* is the map of a quadrangle.

Quadrangle maps are published in many different sizes but the most common USGS sizes are 15-minute and 7.5-minute quadrangle maps (**FIGURE 9.2**). The numbers refer to the amount of area that the maps depict, in degrees of latitude and longitude. A 15-minute topographic map represents an area that measures 15 minutes of latitude by 15 minutes of longitude. A 7.5-minute topographic map represents an area that measures 7.5 minutes of latitude by 7.5 minutes of longitude. Therefore, four 7.5-minute quadrangle maps (**FIGURE 9.2**) comprise one 15-minute quadrangle map.

A reduced copy of a 7.5-minute USGS topographic map is provided in **FIGURE 9.3**. Notice its name (Ritter Ridge, CA) and size (7.5 Minute Series, SW 1/4 of the

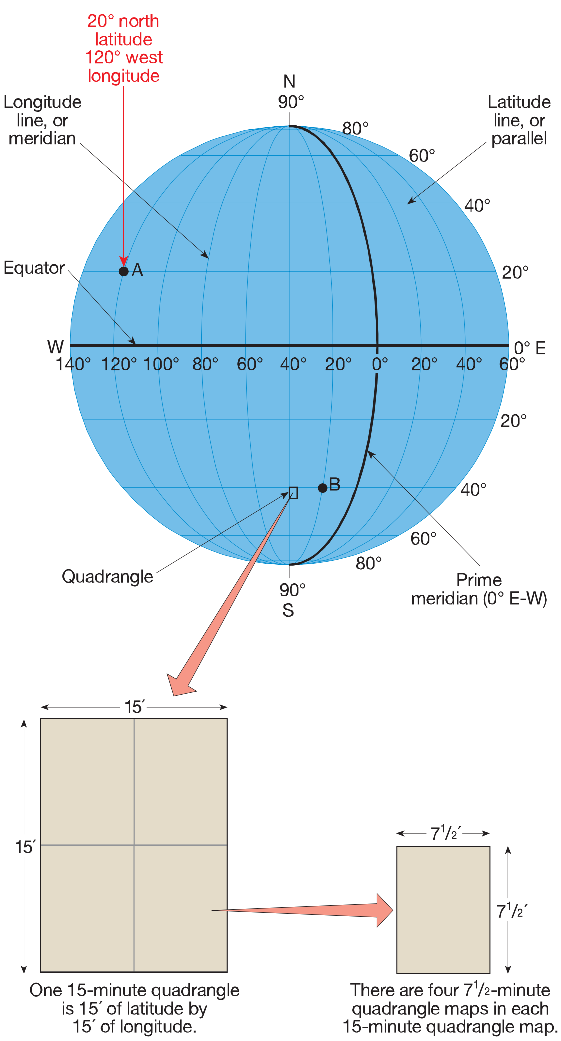


FIGURE 9.2 Latitude and longitude coordinate system and quadrangles. Point **A** is located at coordinates of 20° north latitude, 120° west longitude. Refer to text for discussion.

Lancaster 15' Quadrangle) in the upper right and lower right corners of the map, respectively. Also notice that the map has colors, patterns, and symbols (**FIGURE 9.4**) that are used to depict water bodies, vegetation, roads, buildings, political boundaries, place names, and other natural and cultural features of the landscape. The lower right corner of the map indicates that the map was originally published in 1958, but it was photorevised in 1974. *Photorevised* means that aerial photographs (from airplanes) were used to discover changes on the landscape, and the changes are overprinted on the maps in a standout color like purple, red, or gray. The main new features shown on this 1974 photorevised map are the California Aqueduct (that carries water south, from the Sierra Nevada Mountains to the southern California desert) and several major highways.

Map Scales

Maps are representations of an area of Earth's surface. The real sizes of everything on a map have been reduced so they fit a sheet of paper or computer screen. So maps are scale models. To understand how the real world is depicted by the map, you must refer to the map scales. Topographic maps commonly have any or all of the following kinds of scales.

Bar Scales for Measuring Distances on the Map

The most obvious scales on topographic maps are the **bar scales (graphic scales)** printed in their lower margins (**FIGURE 9.3**). Bar scales are rulers for measuring distances on the map. U.S. Geological Survey topographic maps generally have four different bar scales: miles, feet, kilometers, and meters.

Scales That Tell How the Map Compares to Actual Sizes of Objects

Ratio scales are commonly expressed above the bar scales in the bottom margins of topographic maps and express the ratio of a linear dimension on the map to the actual dimension of the same feature on the ground (in real life). For example, the ratio scale of the map in **FIGURE 9.3** is written as "SCALE 1:24,000." This indicates that any unit (inch, centimeter, foot, etc.) on the map is actually 24,000 of the same units (inches, centimeters, feet) on the ground. So 1 cm on the map represents 24,000 cm on the ground, or your thumb width on the map represents 24,000 thumb widths on the ground. The ratio scale can also be interpreted as a **fractional scale**, which indicates how much smaller something is than its actual size on the ground. A map ratio scale of 1:24,000 equals a fractional scale of 1/24,000. This means that everything on the map is 1/24,000th of its actual size on the ground.

Verbal Scales Express Map Proportions in Common Terms

Verbal scales are sentences that help readers understand map proportions in relation to common units of measurement. For example, reconsider the map in **FIGURE 9.3** with "SCALE

1:24,000." Knowing that 1 inch on the map equals 24,000 inches on the ground is not very convenient, because no one measures big distances in thousands of inches! However, if you divide the 24,000 inches by 12 to get 2000 ft, then the scale suddenly becomes useful: "1 in. on the map = 2000 ft on the ground." An American football field is 100 yards (300 ft) long, so: "1 in. on the map = $6\frac{2}{3}$ football fields."

On a map with a scale of 1:63,360, "1 inch equals 63,360 inches" is again not meaningful in daily use. But there are 63,360 inches in a mile. So, the verbal scale, "1 inch equals 1 mile" is very meaningful. A standard 1:62,500 map (15-minute quadrangle map commonly used in parts of Alaska) is very close to this scale, so "one inch equals approximately one mile" is often written on such a map. Note that verbal scales are often approximate because their sole purpose is to help the reader make general sense of how the map relates to sizes of real objects on the ground.

Declination and Compass Bearings

Directional information is summarized as a trident-shaped symbol like the one in the lower left corner of **FIGURE 9.3** (Ritter Ridge Quadrangle). Because longitude lines form the left and right boundaries of a topographic map, north is always at the top of the quadrangle. This is called grid north (GN) and is usually very close to the same direction as *true north* on the actual Earth. Unfortunately, magnetic compasses are not attracted to grid north or true north (the geographic North Pole). Instead, they are attracted to the *magnetic north pole* (MN), currently located northwest of Hudson Bay in Northern Canada, about 700 km (450 mi) from the true North Pole.

What Is Declination?

The trident-shaped symbol on the bottom margin of topographic maps shows the **declination** (difference in degrees) between compass north (MN) and true north (usually a *star* symbol). Also shown is the declination between true north (*star* symbol) and grid north (GN). The magnetic pole migrates very slowly, so the declination is exact only for the year listed on the map. You can obtain the most recent magnetic data for your location from the NOAA National Geophysical Data Center (**http://www.ngdc.noaa.gov/geomag-web/#declination**).

What Is a Compass Bearing?

A **bearing** is the *compass direction* along a line from one point to another. If expressed in degrees east or west of true north or south, it is called a *quadrant bearing*. Or it may be expressed in degrees between 0 and 360, called an *azimuth bearing*, where north is 0° (or 360°), east is 90°, south is 180°, and west is 270°. Linear geologic features (faults, fractures, dikes), lines of sight and travel, and linear property boundaries are all defined on the basis of their bearings. But because a compass points to Earth's *magnetic north* (MN) pole rather than the true North Pole, one must correct for this difference. If the MN arrow is to the east of true north (star symbol), then subtract the degrees of declination from your compass reading (imagine that you are rotating your compass counter-clockwise to compensate for declination). If the MN arrow is to the west of true north, then add the degrees of declination to your compass reading (imagine that you rotated your compass clockwise). These adjustments will mean that your compass readings are synchronized with the map (so long as you used the latest declination values obtained from NOAA).

How to Set a Compass for Declination

Some compasses allow you to rotate their basal ring graduated in degrees to correct for the magnetic declination. If the MN arrow is 5° east (right) of true north, then you would rotate the graduated ring 5° east (clockwise, to subtract 5° from the reading). If the MN arrow is 5° west (left) of true north, then you would rotate the graduated ring 5° west (counter-clockwise, to add 5° to the reading).

How to Determine a Compass Bearing on a Map

To determine a compass bearing on a topographic map, follow the directions in **FIGURE 9.5**. Then imagine that you are buying a property for your dream home. The boundary of the property is marked by four metal rods driven into the ground, one at each corner of the property. The location of these rods is shown on the map in **FIGURE 9.5** (left side) as points ***A, B, C,*** and ***D.*** The property deed notes the distances between the points *and* bearings between the points. This defines the shape of the property. Notice that the northwest edge of your property lies between two metal rods located at points ***A*** and ***B.*** You can measure the distance between the points using a tape measure. How can you measure the bearing?

First, draw a line (very lightly in pencil so that it can be erased) through the two points, ***A*** and ***B.*** Make sure the line also intersects an edge of the map. In both parts of **FIGURE 9.5**, a line was drawn through points ***A*** and ***B*** so that it also intersects the east edge of the map. Next, orient a protractor so that its 0° and 180° marks are on the edge of the map, with the 0° end toward geographic north. Place the origin of the protractor at the point where your line ***A–B*** intersects the edge of the map. You can now read a bearing of 43° east of north. We express this as a quadrant bearing of "North 43° East" (written N43°E) or as an azimuth bearing of 43°. If you were to determine the opposite bearing, from ***B*** to ***A,*** then the bearing would be pointing southwest and would be read as "South 43° West," or as an azimuth of 223°. Remember that a compass points to Earth's *magnetic north* pole (MN) rather than true north or grid north (GN). When comparing the bearing read directly from the map to a bearing read from a compass, you must adjust your compass reading to match true north or grid north (GN) of the map, as described above.

You also can use a compass to read bearings, as shown in **FIGURE 9.5** (right). Ignore the compass needle and use the compass as if it were a circular protractor.

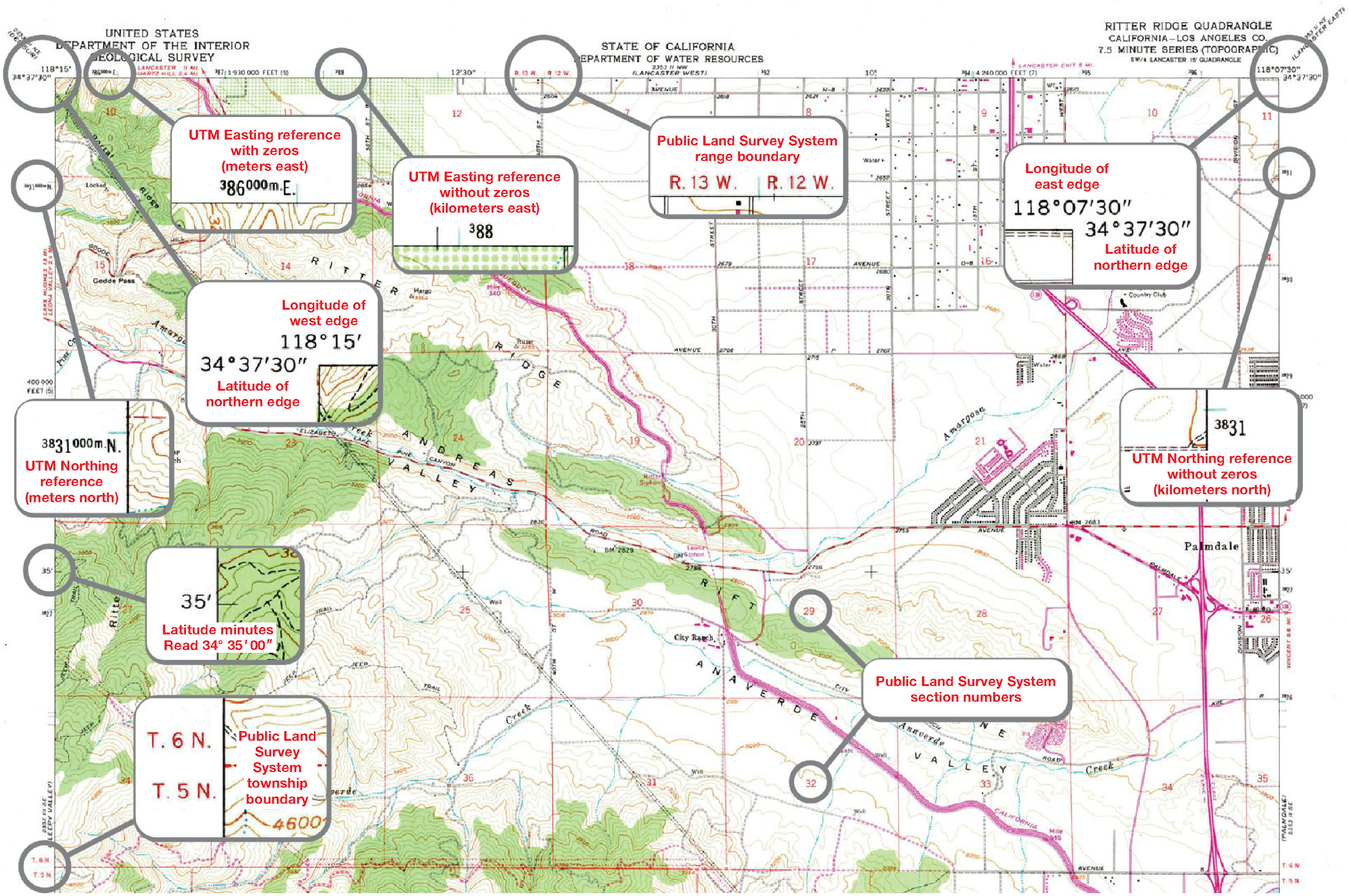


FIGURE 9.3 (NORTHERN HALF) **USGS (US Topo) Ritter Ridge, CA 7.5–minute topographic quadrangle map.** (Northern half of map reduced to about 55% of its actual size)
(Courtesy of USGS)

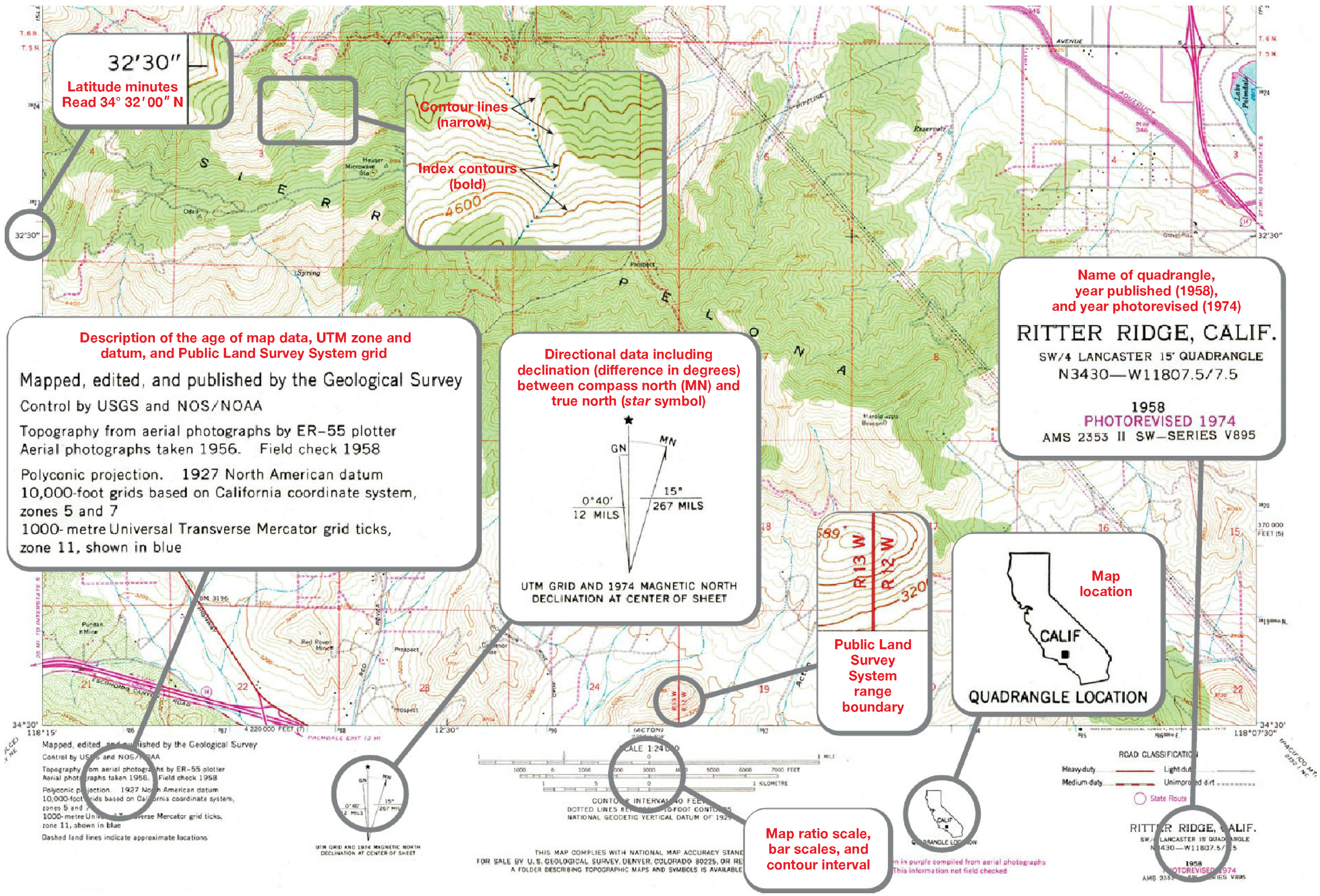


FIGURE 9.3 (SOUTHERN HALF) **USGS Ritter Ridge, CA 7.5–minute topographic quadrangle map.** (Southern half of map reduced to about 55% of its actual size) (Courtesy of USGS)

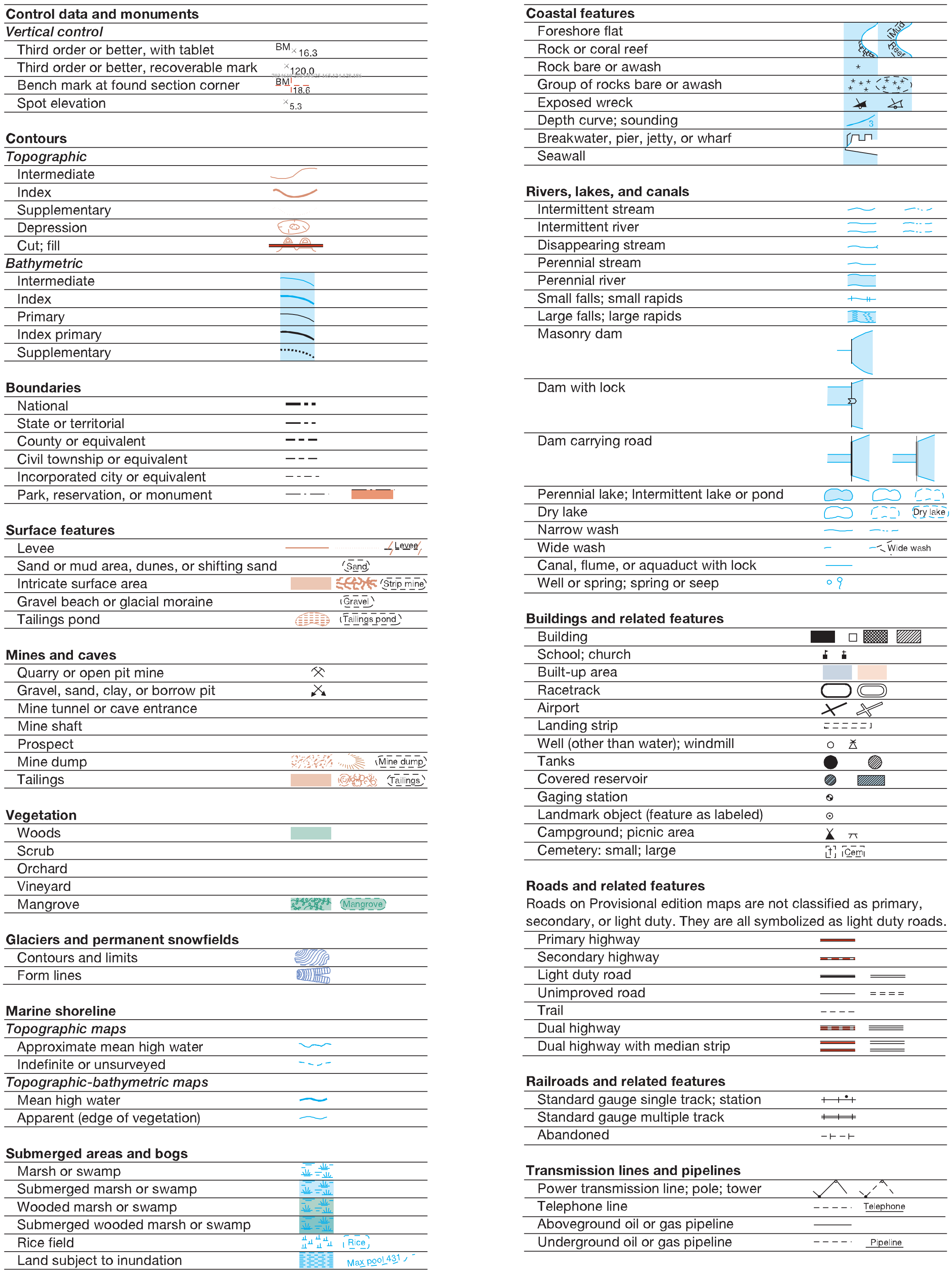


FIGURE 9.4 **Symbols used on U.S. Geological Survey topographic quadrangle maps.**

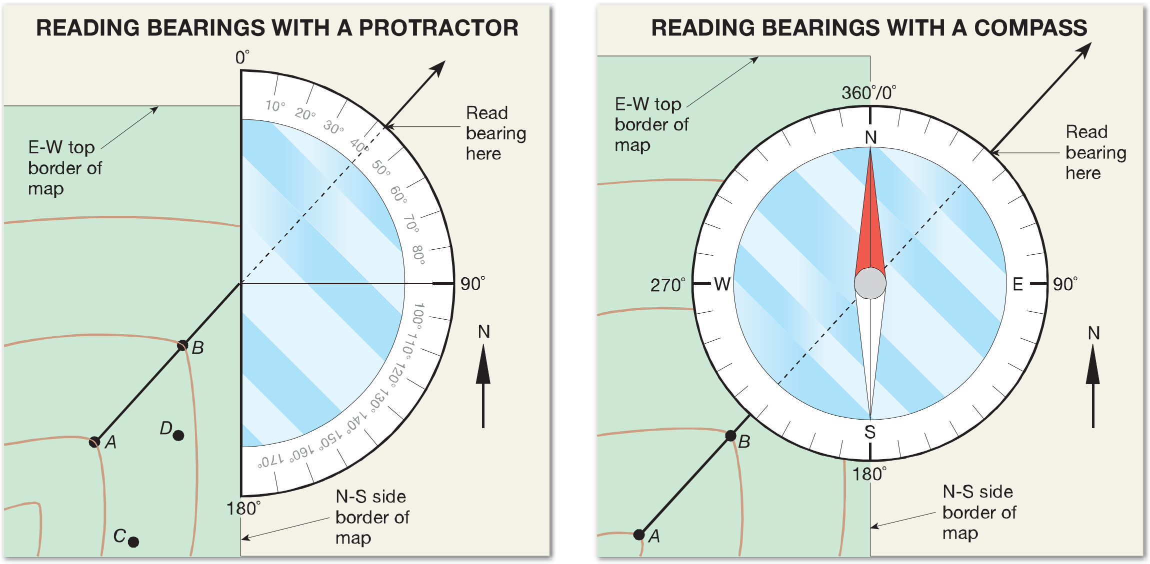


FIGURE 9.5 How to read a bearing (compass direction) on a map. A bearing is read or plotted on a map, from one point to another, using a protractor (left) or compass (right). To determine a bearing on a map, draw a straight line from the starting point to the destination point and also through any one of the map's borders. For example, to find the bearing from ***A*** to ***B***, a line was drawn through both points and the east edge of the map. Align a protractor (left drawing) or the N-S or E-W directional axis of a compass (right drawing) with the map's border and read the bearing in degrees toward the direction of the destination. In this example, notice that the *quadrant bearing* from point ***A*** to ***B*** is North 43° East (left map, using protractor) or an *azimuth bearing* of 43°. If you walked in the exact opposite direction, from ***B*** to ***A***, then you would walk along a quadrant bearing of South 43° West or an azimuth bearing of 223° (i.e., 43° + 180° = 223°). Remember that a compass points to Earth's magnetic north pole (MN) rather than true north (GN, grid north). When comparing the bearing read directly from the map to a bearing read from a compass, you must adjust your compass reading to match grid north (GN) of the map, as described in the text.

Some compasses are graduated in degrees, from 0–360, in which case you read an azimuth bearing from 0–360°. Square azimuth protractors for this purpose are provided in GeoTools Sheets 3 and 4 at the back of this manual.

GPS—Global Positioning System

The Global Positioning System (GPS) is a technology used to make *precise* (exact) and *accurate* (error free) measurements of the location of points on Earth. It is used for geodesy—the science of measuring changes in Earth's size and shape, and the position of objects, over time. GPS technology is based on a constellation of about 30 satellites that take just 12 hours to orbit Earth. They are organized among six circular orbits (20,200 km, or 12,625 mi above Earth) so that a minimum of six satellites will be in view to users anywhere in the world at any time. The GPS constellation is managed by the United States Air Force for operations of the Department of Defense, but they allow anyone to use it anywhere in the world.

How GPS Works

Each GPS satellite communicates simultaneously with fixed ground-based Earth stations and other GPS satellites, so it knows exactly where it is located relative to the center of Earth and Universal Time Coordinated (UTC, also called Greenwich Mean Time). Each GPS satellite also transmits its own radio signal on a different channel, which can be detected by a fixed or handheld GPS receiver. If you turn on a handheld GPS receiver in an unobstructed outdoor location, then the receiver immediately acquires (picks up) the radio channel of the strongest signal it can detect from a GPS satellite. It downloads the navigational information from that satellite channel, followed by a second, third, and so on. A receiver must acquire and process radio transmissions from at least four GPS satellites to triangulate a determination of its exact position and elevation—this is known as a **fix**. But a fix based on more than four satellites is more accurate. In North America and Hawaii, the accuracy of the GPS constellation is enhanced by WAAS (Wide Area Augmentation System) satellites operated by the Federal Aviation Administration. WAAS uses ground-based reference stations to measure small variations in GPS satellites signals and correct them. The corrections are transmitted up to geostationary WAAS satellites, which broadcast the corrections back to WAAS-enabled GPS receivers on Earth.

GPS Accuracy

The more channels a GPS receiver has, the faster and more accurately it can process data from the most satellites. The best GPS receivers have millimeter accuracy, but handheld WAAS-enabled GPS receivers and smartphones with GPS are accurate to within 3 meters. Receivers lacking WAAS are only accurate to within about 9 meters.

UTM—Universal Transverse Mercator System

The U.S. National Imagery and Mapping Agency (NIMA) developed a global military navigation grid and coordinate system in 1947 called the **Universal Transverse Mercator System (UTM).** Unlike the latitude-longitude grid that is spherical and measured in degrees, minutes, seconds, the UTM grid is rectangular and measured in decimal-based metric units (meters, km).

UTM Zones and Designator Letters

The UTM grid (top of FIGURE 9.6) is based on sixty north–south **zones,** which are strips of longitude having a width of 6°. The zones are consecutively numbered from Zone 01 (between 180° and 174° west longitude) at the left margin of the grid, to Zone 60 (between 174° and 180° east longitude) at the east margin of the grid. Each zone has a north-south **central meridian** that is perfectly perpendicular to the equator (see FIGURE 9.6). Newer USGS topographic maps and handheld GPS instruments use the U.S. Department of Defense, Military Grid Reference System (MGRS) that divides the zones into east-west (horizontal) rows identified by designator letters (FIGURE 9.6). These rows are 8° wide and lettered consecutively from C (between 80° and 72° south latitude) through X (between 72° and 84° north latitude). Letters I and O are not used, because they could be confused with numbers 0 and 1.

UTM Coordinates

The UTM coordinates of a point on Earth's surface include the zone, designator letter, easting, and northing (FIGURE 9.6). The **easting** coordinate is the west-to-east distance in meters within the zone, where the Central Meridian is assigned a false easting of 500,000 meters. The **northing** coordinate is the distance from the Equator measured in meters. In the Northern Hemisphere, northings are given in meters north of the Equator (from 0 m at the Equator to 9,300,000 m at 84° North latitude). To avoid negative numbers for northings in the Southern Hemisphere, NIMA assigned the Equator a reference northing of 10,000,000 meters. So northings in the southern hemisphere range from 1,100,000 m at 80° South latitude, to 10,000,000 m at the Equator. When recording UTM coordinates, it is commonplace to write the zone number and designator letter, then the easting, and then the northing (i.e., 18S 384333 4455250 in FIGURE 9.6). It is also wise to note what UTM datum was used to define the coordinates.

UTM Datums

Because satellites did not exist until 1957, and GPS navigational satellites did not exist until decades later, the UTM grid was applied for many years using regional ground-based surveys to determine locations of the grid boundaries. Each of these regional or continental surveys is called a **datum** and is identified by its location and the year it was surveyed. Examples include the *North American Datum 1927 (NAD27)* and the *North American Datum 1983 (NAD83)*, which appear on many Canadian and U.S. Geological Survey maps. The Global Positioning System (GPS) relies on an Earth-centered UTM datum called the *World Geodetic System 1984* or *WGS84*, which is essentially the same as *NAD83*. However, GPS receivers can be set up to display regional datums like *NAD27* and *NAD 83*. When using GPS with a topographic map that has a UTM grid, be sure to set the GPS receiver to display the UTM datum of that map. Otherwise, your locations may be incorrect by up to hundreds of meters. Google Earth™ uses the *WGS84* UTM datum.

Locating Points Using UTM

Study the illustration of a GPS receiver in FIGURE 9.6. Notice that the receiver is displaying UTM coordinates (based on *NAD27*) for a point **X** in Zone 18S (north of the Equator). Point **X** has an easting coordinate of 384333, which means that it is located 384,333 meters from west to east in Zone 18 relative to the Central Meridian value of 500,000 meters. Point **X** also has a northing coordinate of 4455250, which means that it is located 4,455,250 meters north of the Equator. Therefore, point **X** is located in southeast Pennsylvania. To plot point **X** on a 1:24,000 scale, $7\frac{1}{2}$-minute topographic quadrangle map, see FIGURE 9.7.

Point **X** is located within the Lititz, PA $7\frac{1}{2}$-minute (USGS, 1:24,000 scale) topographic quadrangle map (FIGURE 9.7). Information printed on the map margin indicates that the map has blue ticks spaced 1000 m apart along its edges that conform to *NAD27*, Zone 18. Notice how the ticks for northings (blue) and eastings (green) are represented on the northwest corner of the Lititz map—FIGURE 9.7B. One northing label is written out in full (4456000m N) and one easting label is written out in full (384000m E), but the other values are given in UTM shorthand for kilometers (i.e., they do not end in 000m). Because point **X** has an easting of 384333 within Zone 18S, it must be located 333 m east of the tick mark labeled 384000m E along the top margin of the map. Because Point **X** has a northing of 4455250, it must be located 250 m north of the tick mark labeled as 4455 in UTM shorthand (which stands for 4455 km or 4,455,000 m). Distances east and north can be measured using a ruler and the map's graphic bar scale as a reference (333 m = 0.333 km, 250 m = 0.250 km). However, you can also use the graphic bar scale to construct a UTM grid like the one in FIGURE 9.7C. If you construct such a grid and print it onto a transparency, then you can use it as a UTM *grid overlay*. To plot a point or determine its coordinates, place the grid overlay on top of the square kilometer in which the point is located. Then use the grid as a two-dimensional ruler for the northing and easting. Grid overlays for many different scales of UTM grids are provided in GeoTools Sheets 2–4 at the back of the manual for you to cut out and use.

Public Land Survey System

The **U.S. Public Land Survey System (PLSS)** was initiated in 1785 when the U.S. government required a way to divide public land of the Western Frontier (land west of the thirteen original colonies) into small parcels that could be transferred to ownership by private citizens. The U.S. Bureau of

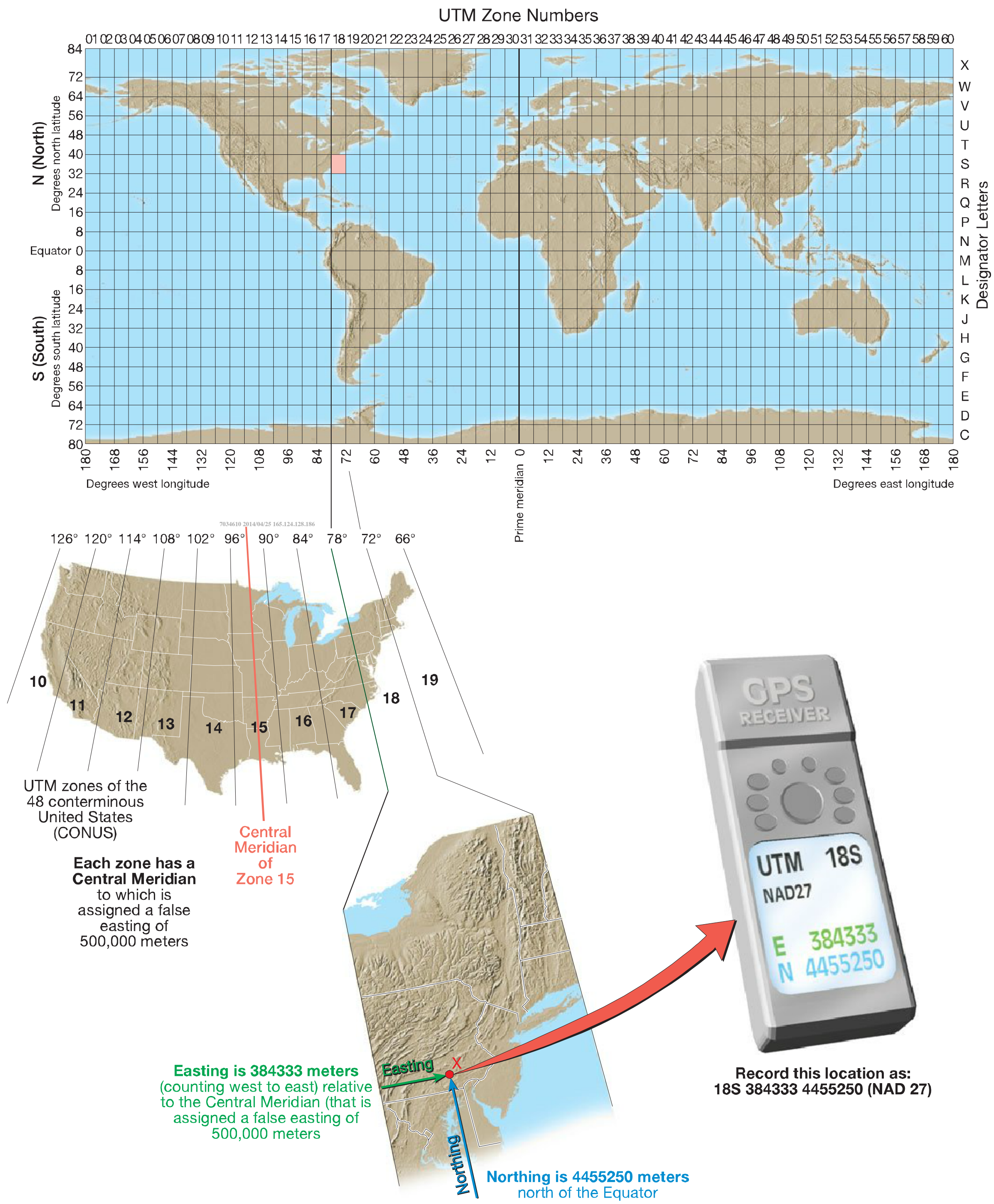


FIGURE 9.6 UTM with GPS. A handheld Global Positioning System (GPS) receiver is set to display the Universal Transverse Mercator (UTM) grid and coordinate system called *North American Datum 1927* (*NAD27*), same as the map grid in **FIGURE 9.8**. When operated at point **X**, it displays its exact location as a zone and designator letter (18S) plus an easting and northing. Most hand-held GPS devices use the *World Geodetic System of 1984* (*WGS84*) instead of *NAD27*. Be sure your grid system is the same as that of any map on which you may plot the GPS coordinates. Refer to the text for explanation.

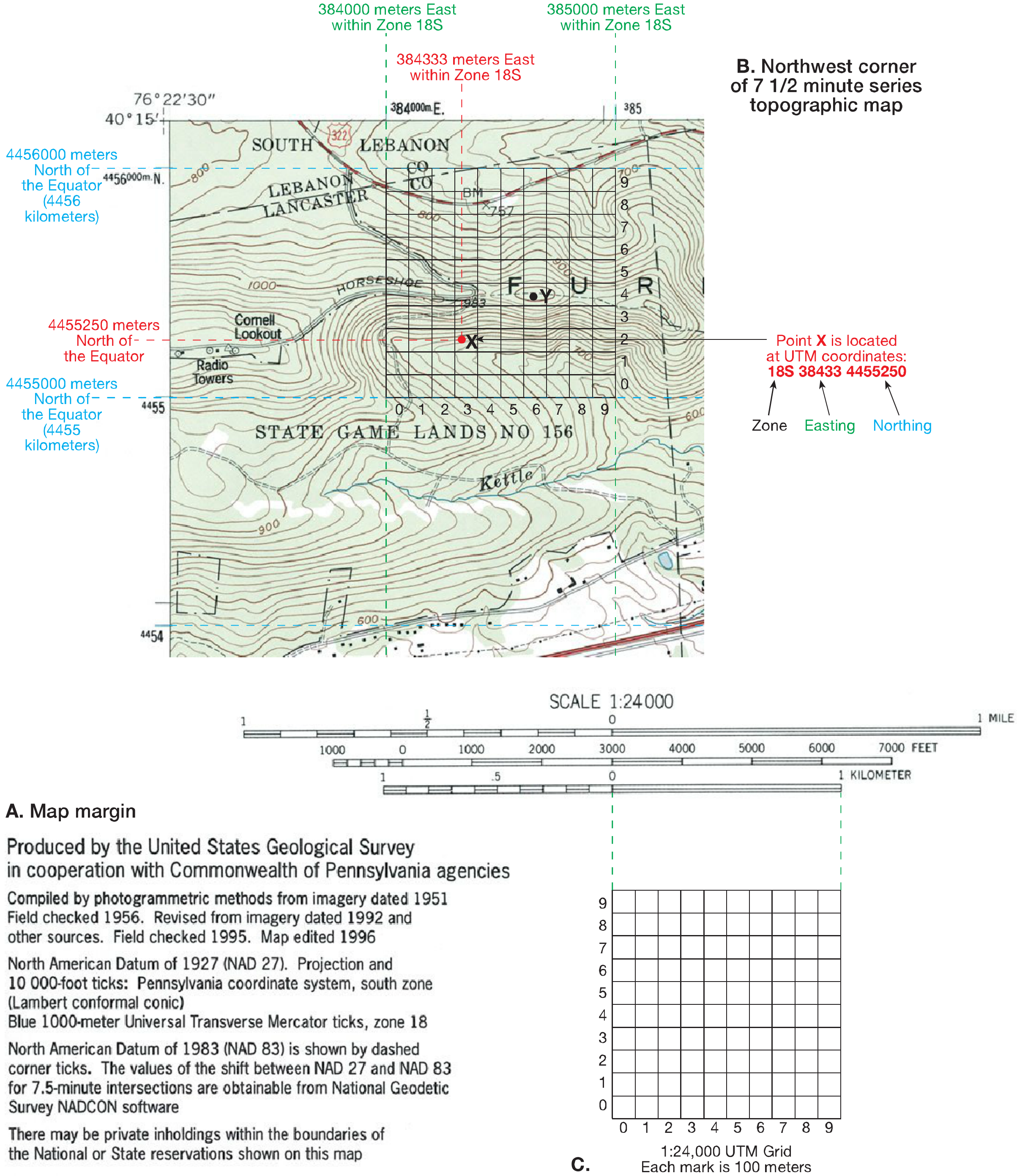


FIGURE 9.7 UTM with topographic maps. Refer to the text for discussion. Point **X** (from **FIGURE 9.7**) is located within the Lititz, PA 7½-minute (USGS, 1:24,000 scale) topographic quadrangle map. **A.** Map margin indicates that the map includes UTM grid data based on North American Datum 1927 (NAD27, Zone 18) and represented by blue ticks spaced 1000 meters (1 km) apart along the map edges. **B.** Connect the blue 1000-m ticks to form a grid square, each representing 1 square kilometer. Northings (blue) are read along the N-S map edge, and eastings (green) are located along the E-W map edge. **C.** You can construct a 1-km grid (1:24,000 scale) from the map's bar scale, then make a transparency of it to form a grid overlay (see GeoTools Sheets 2 and 4 at back of manual). Place the grid overlay atop the 1-kilometer square on the map that includes point **X**, and determine the NAD27 coordinates of **X** as shown (red).

Land Management (BLM) regulates and maintains public land using the PLSS. It is also used as the basis for many legal surveys of private land that was once publicly owned.

PLSS Township-and-Range Grids

The PLSS is a square grid system centered on any one of dozens of **principal meridians** (lines running north and south) and **base lines** established among all but the thirteen original states and a few states derived from them. Once a principal meridian and base line was established, additional lines were surveyed parallel to them and 6 miles apart. This created a grid of 6 mi by 6 mi squares of land (FIGURE 9.8). The north–south squares of the grid are called **townships** and are numbered relative to the base line (Township 1 North, Township 2 North, etc.). The east–west squares of the grid are **ranges** and are numbered relative to the principal meridian (Range 1 West, Range 2 West, etc.). Each 6 mi by 6 mi square is, therefore, identified by its township and range position in the PLSS grid. For example, the township in FIGURE 9.8B is located at T1S (Township 1 South) and R2W (Range 2 West). Although each square like this is identified as both a township and a range within the PLSS grid, it is common practice to refer to the squares as townships rather than township-and-ranges.

Defining Land Areas Using PLSS

The PLSS is designed to define the location of square or rectangular subdivisions of land. The 6 mi by 6 mi townships are used as political subdivisions in some states and often have place names. Each township square is also divided into 36 small squares, each having an area of 1 square mile (640 acres). These square-mile subdivisions of land are called **sections.**

Sections are numbered from 1 to 36, beginning in the upper right corner of the township (FIGURE 9.8B). Sometimes these are shown on topographic quadrangle maps, like the red-brown grid of square numbered sections in FIGURE 9.3. Any tiny area or point can be located precisely within a section by dividing the section into quarters (labeled NW, NE, SW, SE). Each of these quarters can itself be subdivided into quarters and labeled (FIGURE 9.8C).

ACTIVITY 9.3 Topographic Map Construction

THINK About It How are topographic maps constructed and interpreted?

OBJECTIVE Construct topographic maps by drawing contour lines based on maps showing elevations of specific points and a digital terrain model.

PROCEDURES

1. **Before you begin**, read the Introduction, What Are Topographic Maps, US Topo Maps and Orthoimages, and Rules for Contour Lines, (p. 228). Also, this is **what you will need:**

   ___ Activity 9.3 Worksheet (p. 253) and pencil
   ___ calculator

2. **Then follow your instructor's directions** for completing the worksheet.

ACTIVITY 9.4 Topographic Map and Orthoimage Interpretation

THINK About It How are topographic maps constructed and interpreted?

OBJECTIVE Interpret ("read") topographic maps and determine their effectiveness in comparison to, and combination with, US Topo orthoimages.

PROCEDURES

1. **Before you begin**, read the Introduction, What Are Topographic Maps, US Topo Maps and Orthoimages, and Rules for Contour Lines (p. 228) if you have not already done so. Also, this is **what you will need:**

   ___ Activity 9.4 Worksheet (p. 254) and pencil

2. **Then follow your instructor's directions** for completing the worksheet.

What Are Topographic Maps?

Topographic maps are miniature models of Earth's three-dimensional landscape, printed on two-dimensional pieces of paper or displayed on a flat computer screen. Two of the dimensions are the lengths and widths of objects and landscape features, similar to a planimetric map (FIGURE 9.1B). But the third dimension, elevation (height), is shown using the *contour lines*, which are lines of equal elevation used to represent hills and valleys (FIGURES 9.1C, 9.3). But how are the contour lines determined, and how does one interpret them to "read" a topographic map?

Aerial Photographs and Stereograms

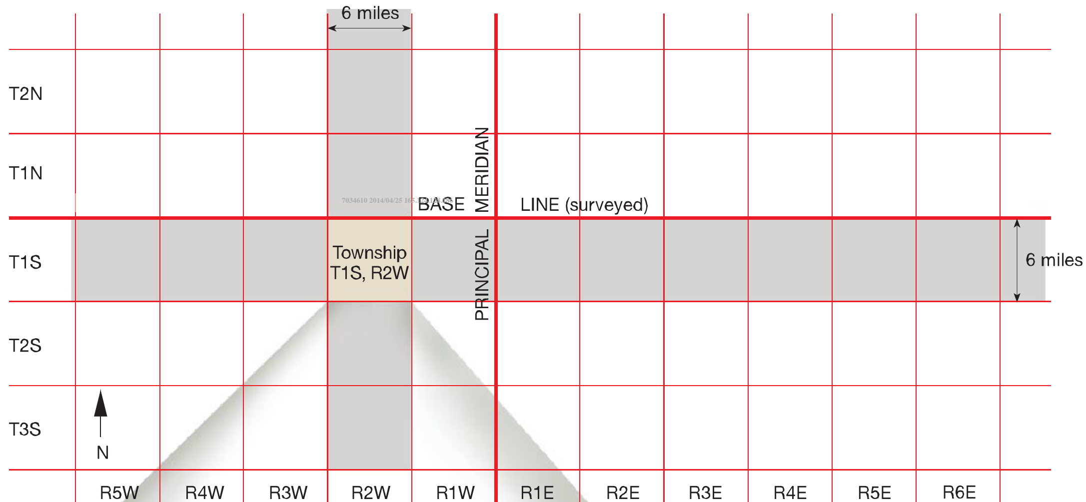
The production of a topographic map begins with overlapping pairs of aerial photographs, called *stereo pairs*. Each stereo pair is taken from an airplane making two closely spaced passes over a region at the same elevation. The passes are flown far enough apart to provide the stereo effect, yet close enough to be almost directly above the land that is to be mapped. Aerial photos commonly are overlapped to form a **stereogram** (FIGURE 9.9), which appears three-dimensional (stereo) when viewed through a stereoscope.

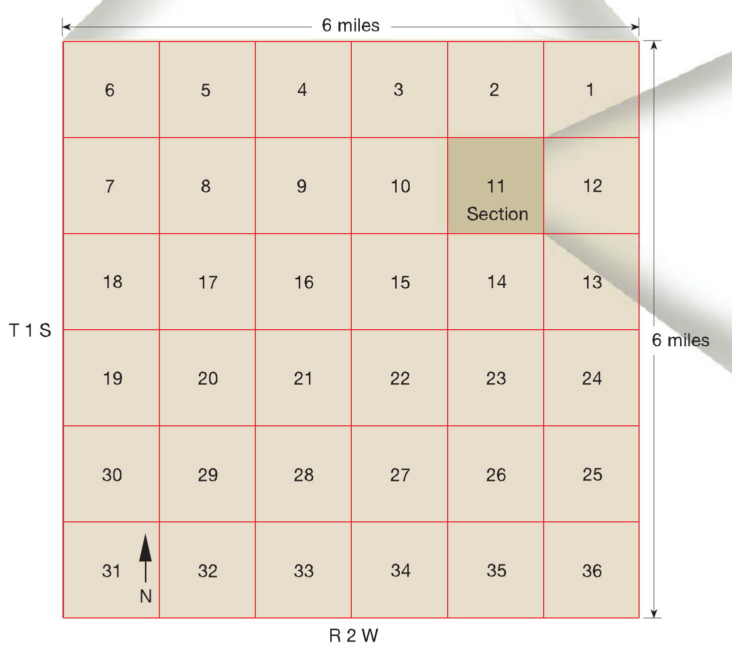
Topographic Map Construction

Stereo pairs of aerial photographs are used to build a digital file of terrain elevations that is converted into the first draft of contour lines for the topographic map. Angular

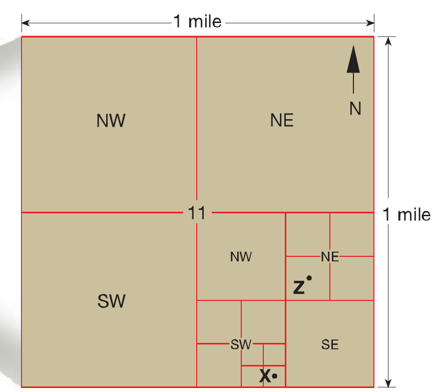
PUBLIC LAND SURVEY SYSTEM (PLSS)

A. The Township-and-Range Grid.
The grid is made of E-W *township* strips of land and N-S *range* strips of land (columns of land) surveyed relative to a *principal meridian* (N-S line) and its *base line* (E-W line). Township strips are 6 miles high and numbered T1N, T2N, and so on north of the base line and T1S, T2S, and so on south of the base line. Range strips (rows) of land are 6 miles wide and numbered R1E, R2E, and so on east of the principal meridian and R1W, R2W, and so on west of the principal meridian. Each intersection of a township strip of land with a range strip of land forms a square, called a *township*. Note the location of Township T1S, R2W.



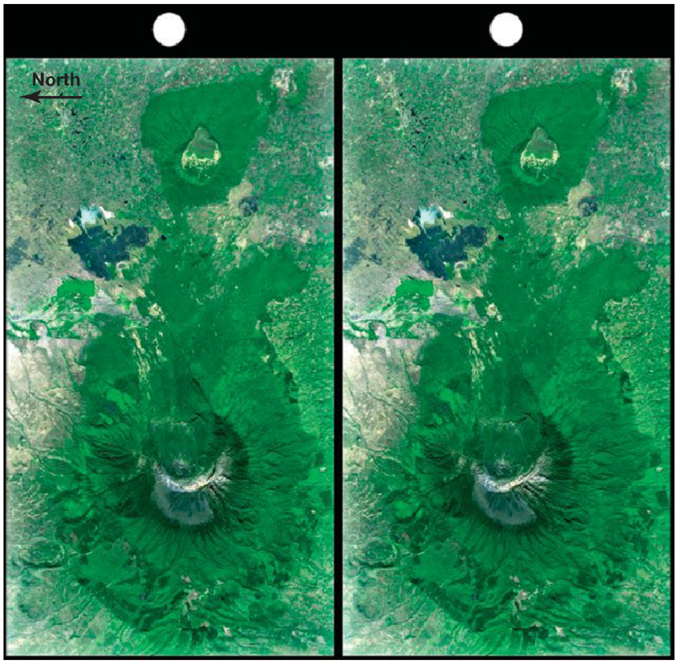


B. A Township Contains 36 Sections.
Each township is 6 miles wide by 6 miles long (36 square miles) and subdivided into 36 sections. Each section is 1 square mile (640 acres), called a *section*, and numbered as shown here.



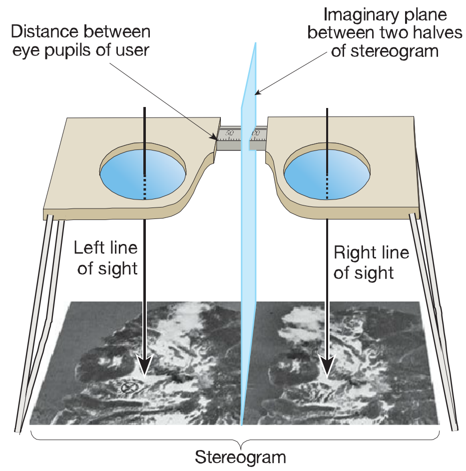
C. How Sections are Subdivided.
Sections are subdivided according to a hierarchy of square *quarters* listed in order of increasing size and direction. For example, point **X** is located in the southeast quarter, of the southeast quarter, of the southwest quarter, of the southeast quarter, of section 11. This is written:
SE ¼, SE ¼, SW ¼, SE ¼, sec. 11, T1S, R2W

FIGURE 9.8 U.S. Public Land Survey System (PLSS). This survey system is based on grids of square townships, which are identified relative to *principal meridians* (N-S lines) of longitude and *base lines* (E-W lines, surveyed perpendicular to the principal meridian) that are unique to specific states or regions.



To view this stereogram without a stereoscope, cross your eyes until a third white dot appears between the first two. The image should then appear three-dimentional.

HOW TO USE A POCKET STEREOSCOPE



First have a partner measure the distance between the pupils of your eyes, in mm. Set that distance on the stereoscope as shown above. Then center the stereoscope over the stereogram, as above. Look through the stereoscope, and move it around slightly until the image becomes three-dimensional.

FIGURE 9.9 Stereogram (left) of Mount Meru region and how to view it. There are two methods used to view a stereogram so it appears to be three-dimensional: use a pocket stereoscope or cross your eyes. The tallest feature in this stereogram is Mount Meru, a 4,566-meter-high volcano located in east Africa (Tanzania), about 70 km (44 mi.) west of Mount Kilimanjaro. Both images in the stereogram are 20 km wide and 37 km tall (courtesy of NASA/PJL/NIMA). To view Mount Meru In Google Earth™, search: 03 14 36S, 36 45 41E.

distortion is then removed, and the exact elevations of the contour lines on the map are "ground truthed" (checked on the ground) using very precise altimeters and GPS. The final product is a topographic map like the one in **FIGURE 9.10**.

Notice how the contour lines in **FIGURE 9.10** occur where the landscape intersects horizontal planes of specific elevations: 0, 50, and 100 feet. Zero feet of elevation is sea level, so it is the coastline of the imaginary island. You can think of the contour lines for 50 and 100 feet above sea level as additional water levels above sea level. An "x" or triangle is often used to mark the highest point on a hilltop, with the exact elevation noted beside it. The highest point on the map in **FIGURE 9.10** is above the elevation of the highest contour line (100 feet) but below 150 feet (because there is no contour line for 150 feet). In this case, the exact elevation of the highest point on the island is marked by spot elevation ("x" labeled with the elevation of 108 feet).

US Topo Maps and Orthoimages

Historic USGS map series (**FIGURES 9.1C** and **9.3**), and those of most other countries, are one-page paper maps. However, the latest series of USGS topographic maps are layered digital maps called "US Topo" maps (**FIGURE 9.11**). The map layers can be turned on or off, including an aerial photograph layer called an *orthoimage*. The digital products can be downloaded free of charge (no registration required) or they can be ordered as printed paper maps.

Aerial photographs (taken from airplanes) are usually taken at angles oblique to the landscape, but topographic maps are representations of the landscape as viewed from directly above. **Orthoimages** are digitized aerial photographs or satellite images that have been orthorectified, corrected for distortions until they have the same geometry and uniform scale as a topographic map. Therefore, an orthoimage correlates exactly with its topographic map and reveals visual attributes of the landscape that are not visible on the topographic map. The topographic map, orthoimage, and other orthorectified "layers" of data can be added or removed to give the viewer extraordinary perspectives of the landscape. All of this can be done at US Topo, courtesy of the USGS and their partners. One can display features like hydrography (water bodies), roads, and UTM grid lines on a topographic base (**FIGURE 9.11A**), or display the topographic map layer on an orthoimage base (**FIGURE 9.11B**). All layers can be enlarged with outstanding resolution (**FIGURE 9.11C**). To learn more about obtaining and using US Topo products, watch a 6-minute USGS video (**http://gallery.usgs.gov/videos/663**).

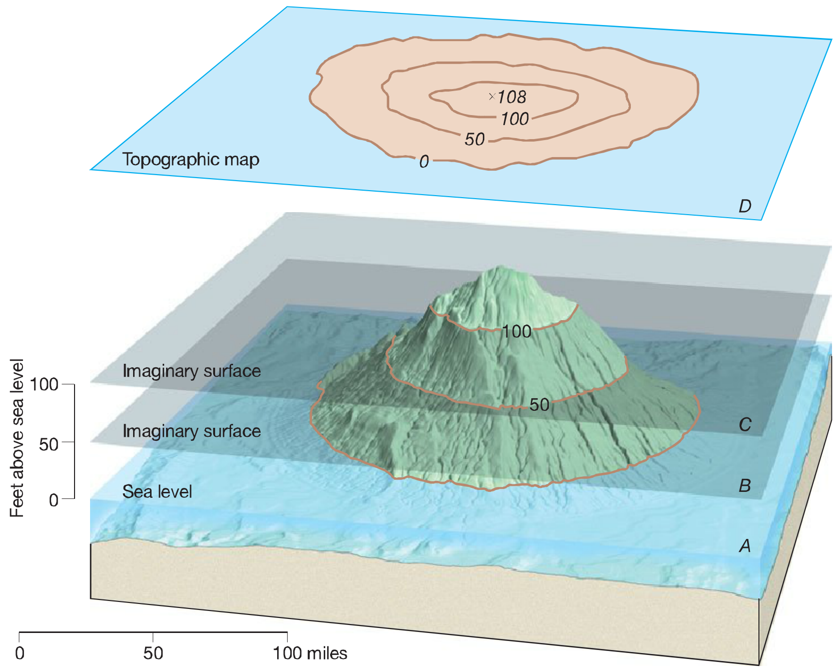


FIGURE 9.10 Topographic map construction. A *contour line* is drawn where a horizontal plane (**A, B,** or **C**) intersects the land surface. Where sea level (plane **A**) intersects the land, it forms the 0-ft contour line. Plane **B** is 50 ft above sea level, so its intersection with the land is the 50-ft contour line. Plane **C** is 100 ft above sea level, so its intersection with the land is the 100-ft contour line. **D** is the resulting topographic map of the island. It was constructed by looking down onto the island from above and tracing the 0, 50, and 100-ft contour lines. The elevation change between any two contour lines is 50 ft, so the map is said to have a 50-ft *contour interval*.

All contour lines on this map represent elevations in feet above sea level and are *topographic contour lines*. (Contours below sea level are called *bathymetric contour lines* and are generally shown in blue.)

Rules for Contour Lines

Each **contour line** connects all points on the map that have the same elevation above sea level (**FIGURE 9.12**, rule 1). Look at the topographic map in **FIGURE 9.3** and notice the light brown and heavy brown contour lines. The heavy brown contour lines are called **index contours**, because they have elevations printed on them (whereas the lighter contour lines do not; **FIGURE 9.12**, rule 6). Index contours are your starting point when reading elevations on a topographic map. For example, notice that every fifth contour line on **FIGURES 9.3** is an index contour. Also notice that the index contours are labeled with elevations in increments of 200 ft. This means that the map has five contours for every 200 ft of elevation, or a **contour interval** of 40 ft. This contour interval is specified at the center of the bottom margin of the map (**FIGURE 9.3**). All contour lines are multiples of the contour interval above a specific surface (almost always sea level). For example, if a map uses a 10-ft contour interval, then the contour lines represent elevations of 0 ft (sea level), 10 ft, 20 ft, 30 ft, 40 ft, and so on. Most maps use the smallest contour interval that will allow easy readability and provide as much detail as possible.

Additional rules for contour lines are also provided in **FIGURE 9.12** and the common kinds of landforms represented by contour lines on topographic maps (**FIGURE 9.13**). Your ability to use a topographic map is based on your ability to interpret what the contour lines mean (imagine the topography).

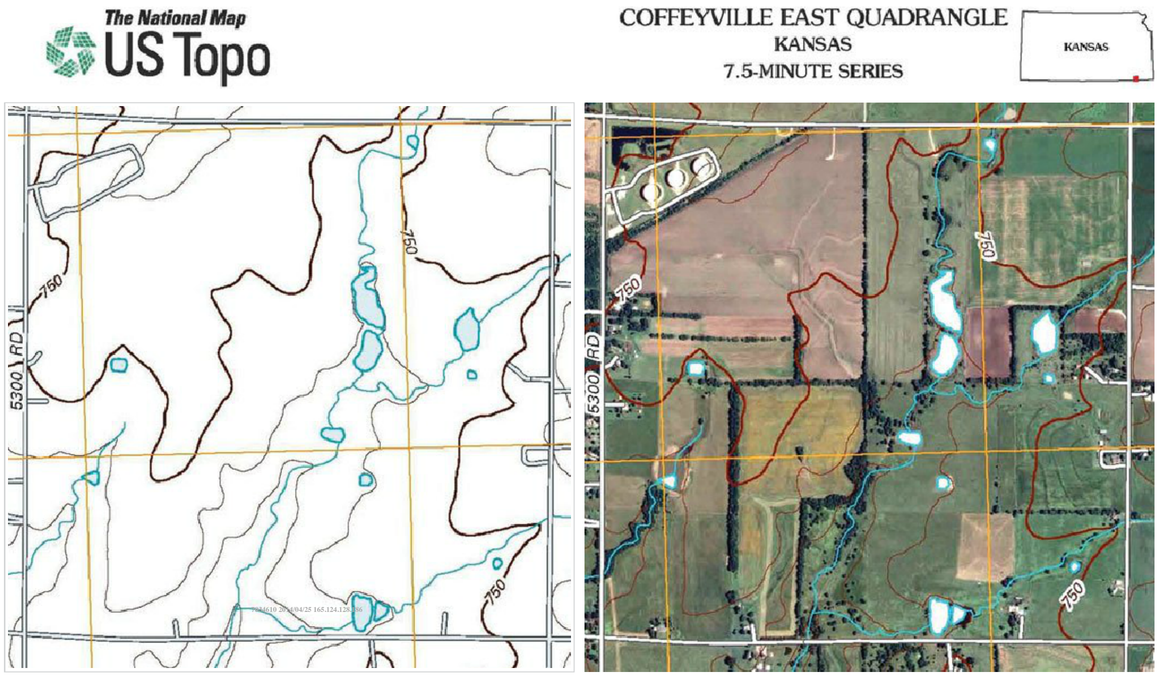
Reading Elevations

If a point on the map lies on an index contour, you simply read its elevation from that line. If the point lies on an unnumbered contour line, then its elevation can be determined by counting up or down from the nearest index contour. For example, if the nearest index contour is 300 ft, and your point of interest is on the fourth contour line *above* it, and the contour interval is 20 ft, then you simply count up by 20s from the index contour: 320, 340, 360, 380. The point is 380 ft above sea level. (Or, if the point is three contour lines *below* the index contour, you count down: 280, 260, 240; the point is 240 ft above sea level.)

If a point lies between two contour lines, then you must estimate its elevation by interpolation (**FIGURE 9.12**, rule 2). For example, on a map with a 20-ft contour interval, a point might lie between the 340 and 360-ft contours, so you know it is between 340 and 360 ft above sea level. If a point lies between a contour line and the margin of the map, then you must estimate its elevation by extrapolation (**FIGURE 9.12**, rule 3).

Depressions

FIGURE 9.14 shows how to read topographic contour lines in and adjacent to a depression. *Hachure marks* (short line segments pointing downhill) on some of the contour lines in these maps indicate the presence of a closed



A. Topographic map base (contour lines), UTM grid lines (WGS84, Zone 15S), hydrography, and transportation features.

B. Orthoimage base with all other data layers: contour lines, UTM grid lines (WGS84, Zone 15S), geographic names and boundaries, hydrography, and transportation features.

C. Enlarged portion of B.

FIGURE 9.11 US Topo (USGS) digital topographic maps and orthoimages of quadrangles. The latest series of USGS topographic maps are digital maps with data layers for planimetric features and an orthoimage. Choose layers displayed on a topographic map base **(A)**, or else combine the topographic base as one layer of data on an orthoimage base **(B)** that can be enlarged with high resolution **(C)**. Use Adobe Reader® (or Adobe Acrobat®) to print products in GeoPDF® format. To learn about US Topo GeoPDFs, watch a 6-minute USGS video (**http://gallery.usgs.gov/videos/663**). Using Adobe Acrobat®, you can save products as JPEG images for enhancement with any photo processing software. However, the location of all roads is ©TomTom.

depression (a depression from which water cannot drain) (**FIGURE 9.12**, rule 12). At the top of a hill, contour lines repeat on opposite sides of the rim of the depression. On the side of a hill, the contour lines repeat only on the downhill side of the depression.

Ridges and Valleys

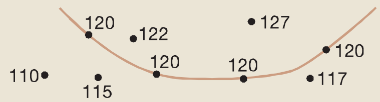
FIGURE 9.15 shows how topographic contour lines represent linear ridge crests and valley bottoms. Ridges and valleys are roughly symmetrical, so individual contour lines repeat on each side (**FIGURE 9.12**, rule 14). To visualize this, picture yourself walking along an imaginary trail across the ridge or valley (dashed lines in **FIGURE 9.15**). Every time you walk up the side of a hill or valley, you cross contour lines. Then, when you walk down the other side of the hill or valley, you recross contour lines of the same elevations as those crossed walking uphill.

Spot Elevations and Benchmarks

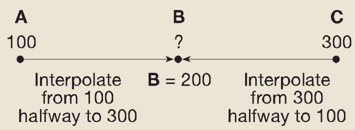
Elevations of specific points on topographic maps (tops of peaks, bridges, survey points, etc.) sometimes are indicated directly on the maps as **spot elevations** beside a small triangle, black dot, or **x**-symbol at the exact spot of the elevation indicated. The elevations of prominent hilltops, peaks, or other features are often identified. For example, the highest point on the ridge in the west central part of **FIGURE 9.13B** has an elevation of 266 ft above sea level. The notation "BM" denotes a **benchmark,** a permanent marker (usually a metal plate) placed by the U.S. Geological Survey or Bureau of Land Management at the point indicated on the map (**FIGURE 9.7**).

RULES FOR CONTOUR LINES

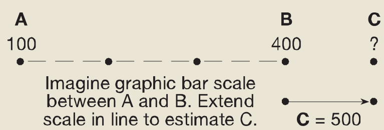
1. Every point on a contour line is of the exact same elevation; that is, contour lines connect points of equal elevation. The contour lines are constructed by surveying the elevation of points, then connecting points of equal elevation.



2. Interpolation is used to estimate the elevation of a point B located in line between points A and C of known elevation. To estimate the elevation of point B:



3. Extrapolation is used to estimate the elevations of a point C located in line beyond points A and B of known elevation. To estimate the elevation of point C, use the distance between A and B as a ruler or graphic bar scale to estimate in line to elevation C.

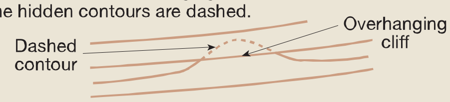


4. Contour lines always separate points of higher elevation (uphill) from points of lower elevation (downhill). You must determine which direction on the map is higher and which is lower, relative to the contour line in question, by checking adjacent elevations.

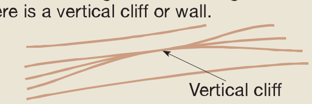
5. Contour lines always close to form an irregular circle. But sometimes part of a contour line extends beyond the mapped area so that you cannot see the entire circle formed.

6. The elevation between any two adjacent contour lines of different elevation on a topographic map is the *contour interval*. Often every fifth contour line is heavier so that you can count by five times the contour interval. These heavier contour lines are known as *index contours*, because they generally have elevations printed on them.

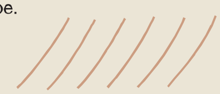
7. Contour lines never cross each other except for one rare case: where an overhanging cliff is present. In such a case, the hidden contours are dashed.



8. Contour lines can merge to form a single contour line only where there is a vertical cliff or wall.



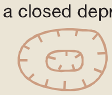
9. Evenly spaced contour lines of different elevation represent a uniform slope.



10. The closer the contour lines are to each other the steeper the slope. In other words, the steeper the slope the closer the contour lines.

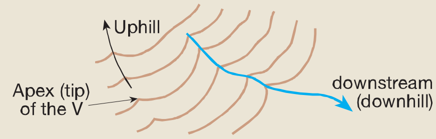
11. A concentric series of closed contours represents a hill:

12. *Depression contours* have hachure marks on the downhill side and represent a closed depression:



See Figure 9.14

13. Contour lines form a V pattern when crossing streams. The apex of the V always points upstream (uphill):



14. Contour lines that occur on opposite sides of a valley or ridge always occur in pairs. See Figure 9.13.

FIGURE 9.12 Rules for constructing and interpreting contour lines on topographic maps.

Relief and Gradient (Slope)

Recall that **relief** is the difference in elevation between landforms, specific points, or other features on a landscape or map. *Regional relief* (total relief) is the difference in elevation between the highest and lowest points on a topographic map. The highest point is the top of the highest hill or mountain; the lowest point is generally where the major stream of the area leaves the map, or a coastline. **Gradient** is a measure of the steepness of a slope. One way to determine and express the gradient of a slope is by measuring its steepness as an angle of ascent or descent (expressed in degrees). On a topographic map, gradient is usually determined by dividing the relief (rise or fall) between two points on the map by the distance (run) between them (expressed as a fraction in feet per mile or meters per kilometer). For example, if points **A** and **B** on a map have elevations of 200 ft and 300 ft, and the points are located 2 miles apart, then:

$$\text{gradient} = \frac{\text{relief (amount of rise or fall between } \mathbf{A} \text{ and } \mathbf{B}\text{)}}{\text{distance between } \mathbf{A} \text{ and } \mathbf{B}}$$

$$= \frac{100 \text{ ft}}{2 \text{ mi}} = 50 \text{ ft/mi}$$

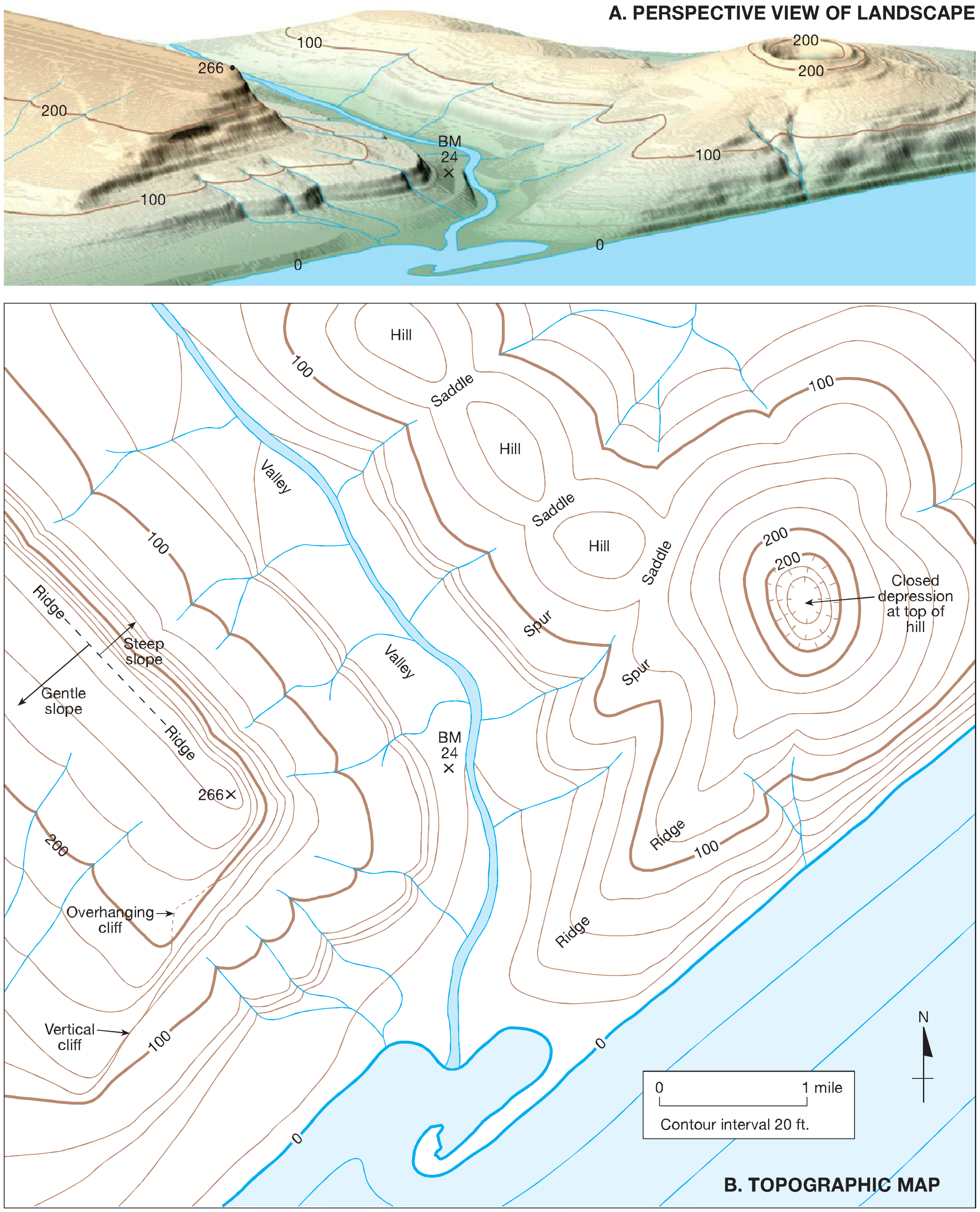


FIGURE 9.13 Names of landscape features observed on topographic maps. Note perspective view (**A**) and topographic map (**B**) features: **valley** (low-lying land bordered by higher ground), **hill** (rounded elevation of land; mound), **ridge** (linear or elongate elevation or crest of land), **spur** (short ridge or branch of a main ridge), **saddle** (low point in a ridge or line of hills; it resembles a horse saddle), **closed depression** (low point/area in a landscape from which surface water cannot drain; contour lines with hachure marks), **steep slope** (closely spaced contour lines), **gentle slope** (widely spaced contour lines), **vertical cliff** (merged contour lines), **overhanging cliff** (dashed contour line that crosses a solid one; the dashed line indicates what is under the overhanging cliff).

ACTIVITY

9.5 Relief and Gradient (Slope) Analysis

THINK About It **How are topographic maps used to calculate the relief and gradients (slopes) of landscapes?**

OBJECTIVE Calculate relief and gradients from a topographic map and apply the gradient data to determine a driving route.

PROCEDURES

1. **Before you begin**, read Relief and Gradient (Slope) on p. 244. Also, this is **what you will need:**

   ___ Activity 9.5 Worksheet (p. 257) and pencil
   ___ calculator

2. **Then follow your instructor's directions** for completing the worksheet.

ACTIVITY

9.6 Topographic Profile Construction

THINK About It **How is a topographic profile constructed from a topographic map, and what is its vertical exaggeration?**

OBJECTIVE Construct a topographic profile from a topographic map using the graph paper, and then calculate its vertical exaggeration.

PROCEDURES

1. **Before you begin**, read Topographic Profiles and Vertical Exaggeration below. Also, this is **what you will need:**

   ___ Activity 9.6 Worksheet (p. 258) and pencil
   ___ ruler and calculator

2. **Then follow your instructor's directions** for completing the worksheet.

Calculating Gradient (Slope)—The Math You Need

You can learn more about calculating slope (gradient) at this site featuring *The Math You Need, When You Need It* math tutorials for students in introductory geoscience courses: **http://serc.carleton.edu/mathyouneed/slope/index.html**

Topographic Profiles and Vertical Exaggeration

A topographic map provides an overhead (aerial) view of an area, depicting features and relief by means of its symbols and contour lines. Occasionally a cross section of the topography is useful. A **topographic profile** is a cross section that shows the elevations and slopes along a given line (**FIGURE 9.16**). To construct a topographic profile, follow the steps in **FIGURE 9.16**.

Topographic Profiles—The Math You Need

You can learn more about constructing topographic profiles at this site featuring *The Math You Need, When You Need It* math tutorials for students in introductory geoscience courses: **http://serc.carleton.edu/mathyouneed/slope/topoprofile.html**

How to Obtain a US Topo Map or Orthoimage

Watch a 6-minute USGS video (**http://gallery.usgs.gov/videos/663**) and follow these steps:

Step 1: Go to the USGS Store (http://store.usgs.gov). Select "Map Locator and Downloader."

Step 2: At the Map Locator and Downloader site, you will see a map of the United States.

A. To the right of the map, select "MARK POINTS: Click on a place to add a marker."

B. Also to the right of the map, select "SHOW US TOPO" (orange bar).

C. All of the US Topo maps and images are displayed in GeoPDF® format and can only be viewed with Adobe Reader® or Adobe Acrobat®. If your computer does not have Adobe Reader® (or Adobe Acrobat®), then download and install it by selecting the "Get Adobe Reader" bar at the bottom of the page or go to Adobe (**http://get.adobe.com/reader/**).

Step 3: Search for a place/quadrangle in US Topo. You can use the "Search" bar above the map to search for an address, place name, or a specific quadrangle (by name). You can also zoom in or out on the map and change it to a satellite or topographic view. As you zoom in, the outlines of quadrangles will appear

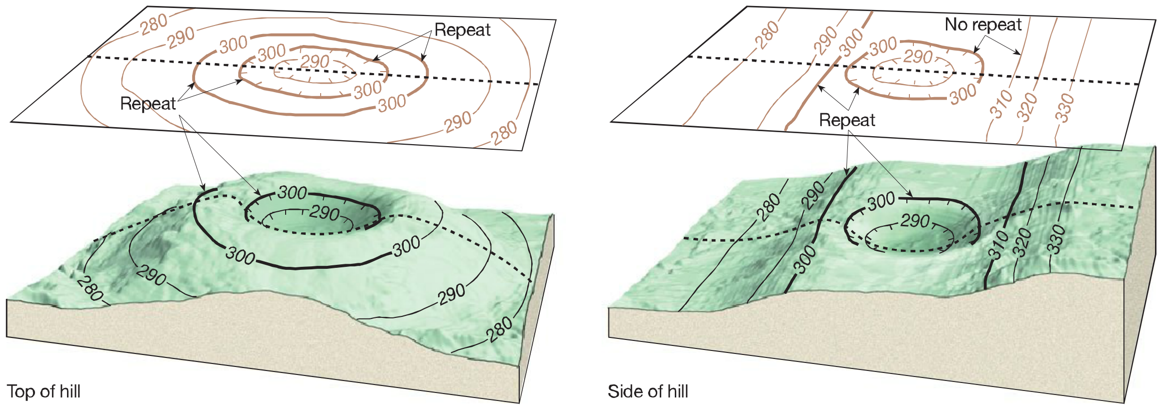


FIGURE 9.14 Contour lines for depressions. Contour lines repeat on opposite sides of a depression (left illustration), except when the depression occurs on a slope (right illustration).

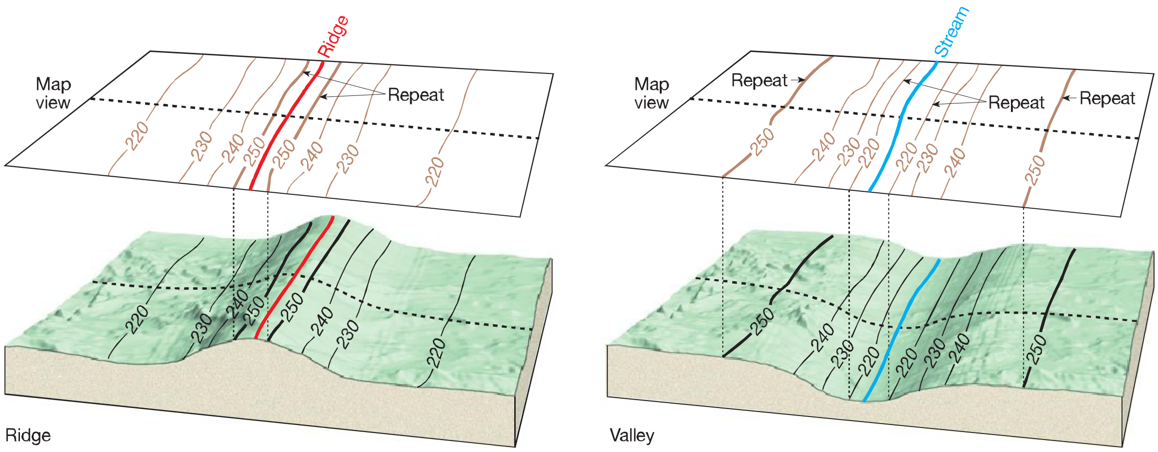


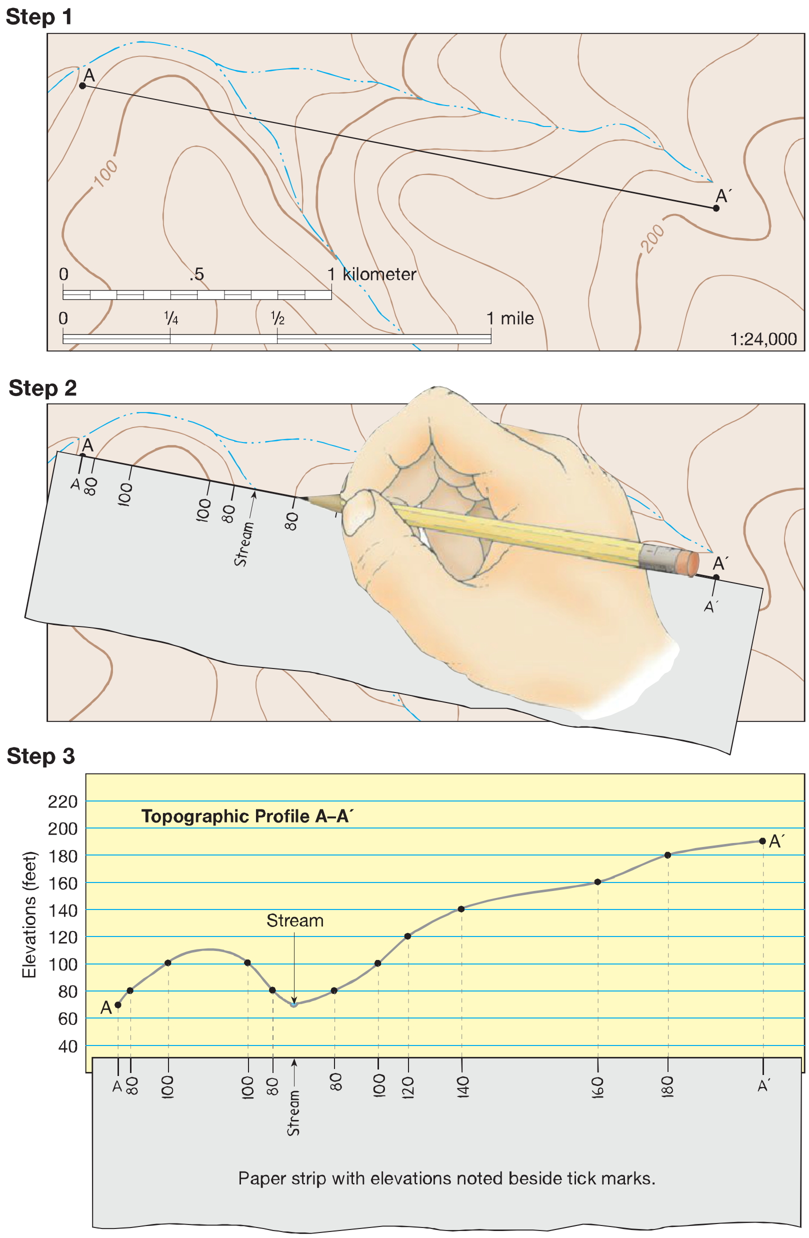
FIGURE 9.15 Contour lines for ridges and valleys. Contour lines repeat (occur in pairs) on opposite sides of linear ridges and valleys. For example, in the left illustration, if you walked the dashed line from left to right, you would cross the 220, 230, 240, and 250-ft contour lines, go over the crest of the ridge, and cross the 250, 240, 230, and 220-ft contour lines again as you walk down the other side. Note that the 250-ft contour lines on these maps are heavier than the other lines because they are *index contours*. On most maps, every fifth contour line above sea level is an index contour, so you can count by five times the contour interval. The *contour interval* (elevation between any two contour lines) of these maps is 10 ft, so the index contours are every 50 feet of elevation.

in black, with their names in black with yellow highlighting. Click on a quadrangle name to set a red balloon marker.

Step 4: Obtain digital products for the location of the balloon marker. Left click on the black dot in the center of the red balloon marker to obtain a list of products available for the Step-3 location. The latest map series is US Topo, but older maps are also listed. Left click on "download" to display or save your selection. The US Topo files are large (7–20 MB) and may take some time to download and open.

When you obtain and open a US Topo $7\frac{1}{2}$-minute quadrangle, then you can add or subtract layers from them by using the menu along the left-hand side of the image. You will also be given the option of downloading a free TerraGo Toolbar that allows you to measure distances, add comments, and merge products with Google Maps™ or your GPS. The older series of topographic maps are single-layer products scanned from paper maps.

Step 5: Printing Tips. You can print all or parts of the maps and orthoimages that you display in US Topo. The GeoPDF® files are very large (10–20 MB), so be patient and allow time for them to load, display, and print. To print an entire map or orthoimage on letter-size paper, be sure to set your printer to the "shrink to fit" setting. If you have a snipping tool on your computer, then you can also snip the images as low-resolution JPEG files.



Step 4 Vertical Exaggeration

On most topographic profiles, the vertical scale is exaggerated (stretched) to make landscape features more obvious. One must calculate how much the vertical scale (V) has been exaggerated in comparison to the horizontal scale (H).

The horizontal scale is the map's scale. This map has an H ratio scale of 1:24,000, which means that 1 inch on the map equals 24,000 inches of real elevation. It is the same as an H fractional scale of 1/24,000.

On the vertical scale of this topographic profile, one inch equals 120 feet or 1440 inches (120 feet x 12 inches/foot). Since one inch on the vertical scale equals 1440 inches of real elevation, the topographic profile has a V ratio scale of 1:1440 and a V fractional scale of 1/1440.

The vertical exaggeration of this topographic profile is calculated by either method below:

Method 1: Divide the horizontal ratio scale by the vertical ratio scale.

$$\frac{\text{H ratio scale}}{\text{V ratio scale}} = \frac{1{:}24{,}000}{1{:}1440} = \frac{24{,}000}{1440} = 16.7\times$$

Method 2: Divide the vertical fractional scale by the horizontal fractional scale.

$$\frac{\text{V fractional scale}}{\text{H fractional scale}} = \frac{1/1440}{1/24{,}000} = \frac{24{,}000}{1440} = 16.7\times$$

FIGURE 9.16 Topographic profile construction and vertical exaggeration. Shown are a topographic map (Step 1), topographic profile constructed along line **A–A′** (Steps 2 and 3), and calculation of vertical exaggeration (Step 4). **Step 1**—Select two points (**A, A′**), and the line between them (line **A–A′**), along which you want to construct a topographic profile. **Step 2**—To construct the profile, the edge of a strip of paper was placed along line **A–A′** on the topographic map. A tick mark was then placed on the edge of the paper at each point where a contour line and stream intersected the edge of the paper. The elevation represented by each contour line was noted on its corresponding tick mark. **Step 3**—The edge of the strip of paper (with tick marks and elevations) was placed along the bottom line of a piece of lined paper, and the lined paper was graduated for elevations (along its right margin). A black dot was placed on the profile above each tick mark at the elevation noted on the tick mark. The black dots were then connected with a smooth line to complete the topographic profile. **Step 4**—*Vertical exaggeration* of the profile was calculated using either of two methods. Thus, the vertical dimension of this profile is exaggerated (stretched) to 16.7 times greater than it actually appears in nature compared to the horizontal/map dimension.

ACTIVITY 9.1 Map and Google Earth™ Inquiry

Name: ____________________ **Course/Section:** ____________________ **Date:** __________

A. Imagine that a friend has asked you, "Where are you located right now?" Give three different answers below:

1.

2.

3.

B. **REFLECT & DISCUSS** One of the oldest ways of describing a location on our spherical Earth is by using a coordinate system of latitude and longtude like the one below. Latitude and longitude are both measured in degrees (°). Latitude is measured from 0° at the Equator to 90°N (the North Pole) or 90°S (the South Pole). Longitude is measured in degrees east or west of the prime meridian, an imaginary line that runs on Earth's surface from the North Pole to the South Pole through Greenwich, England. When viewed from above, locations between 0 and 180° east of the prime meridian are in the Eastern Hemisphere, and locations between 0 and 180° west are in the Western Hemisphere. On the map below, notice how the red location is identified as 30°N, 150°W. For points between labeled lines, the position can be estimated as done for the blue location.

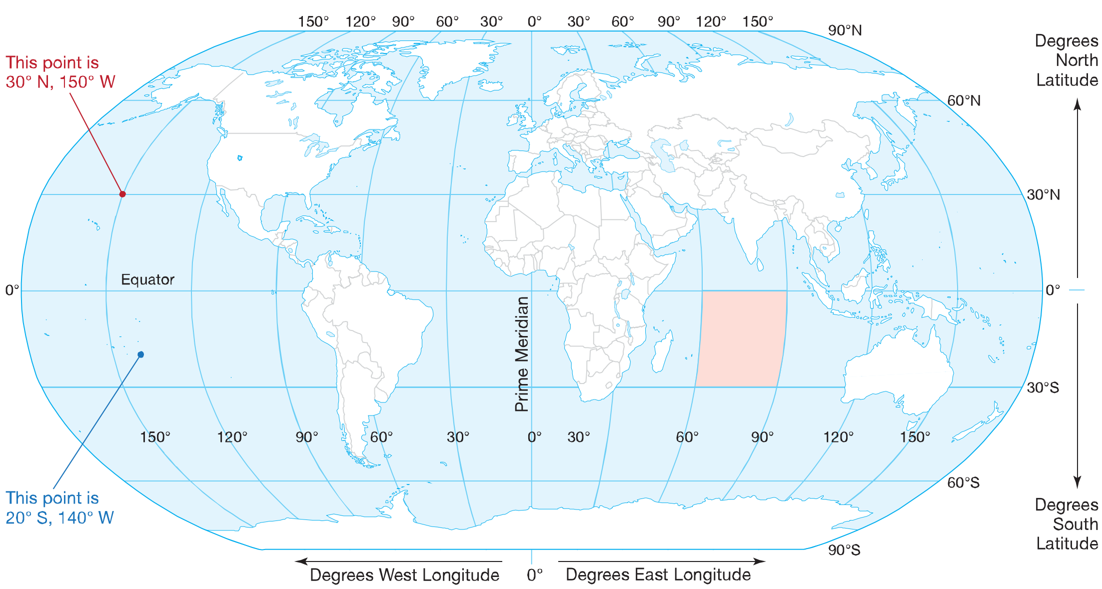
1. On the map below, lightly color in the country where you live. Refer to the reference map at the back of the lab manual as needed.

2. Name a place of your choice to locate on the map (your current location, home, school, place of work, or other location). This will be referred to as your "**home place**" in the inquiry items below.

3. Place a dot on the map to show approximately where your home place is located, then estimate its latitude and longitude as already done for the red and blue points on the map.

Latitude: ______________________ Longitude: ______________________

4. Notice that the lines of latitude and longitude outline somewhat rectangular areas called **quadrangles**, like the one shaded pale red on the map. Describe the location of the red quadrangle based on its latitude and longitude.



C. Use Google Earth™ to locate places on Earth. If you do not have Google Earth™ loaded on your computer, then do so now. Go to **http://www.google.com/earth/index.html** and click on "Dowload Google Earth". Read the Google Maps/Earth Terms of Service (and uncheck the Google Chrome browser option of you do not want to install it), then click "Agree and Download". The installation will begin immediately and takes just a few minutes to complete on most computers. Open Google Earth™ and do the following:

1. Determine exactly the latitude, longitude, and elevation of your home place.

a. Start by using the Google Earth™ "Search" option located in the upper lefthand corner of the screen. You can type in the name (e.g., Washington Monument) or address of your home place, then click on the "Search". Google Earth™ will then zoom in on the location. You can then change the zoom (in or out) using your mouse wheel or the plus-minus slide bar in the upper righthand corner of the screen.

b. Next, place your cursor over your home place to locate its latitude and longitude more exactly. As you move the cursor, notice along the bottom righthand edge of your screen that the latitude and longitude coordinates of the cursor location are identified. (If you do not see degrees of latitude North or South and longitude East or West, then go to the top of the Google Earth™ screen and choose "Tools", then "Options". On that menu, under "Show Lat/Long", choose "Degrees, minutes, seconds". Then click on "Apply" and "OK".) Notice that more than just degrees of latitude and longitude are indicated. For finer measurements of latitude and longitude, each degree can be subdivided (like a clock) into 60 subdivisions called minutes (‘), and the minutes can be divided into 60 equal subdivisions called seconds ("). Record the exact location of your home place below in degrees, minutes, and seconds.

Latitude: ______________________________ Longitude: ______________________________

c. Notice that elevation above sea level (elev) is indicated to the right of latitude and longitude at the bottom righthand edge of the Google Earth™ screen. What is the elevation of your home place? ________________________

2. Experiment with the Layers of Google Earth™ to learn more about your home place. From the menu on the lefthand side of the Google Earth™ screen, open "Layers". Experiment with turning layers on and off to see how it affects what Google Earth™ displays. For example, you may want to start by choosing Roads, Borders and Labels, Gallery, or More to see what is available to display. When you are done, describe something that you learned about your home place or the region around it by experimenting with the Layers.

3. Measure a distance in Google Earth™. Move your cursor over the toolbar icons at the top of the screen until you identify the "Show Ruler" icon, then click on it to open the Ruler menu. Select the "Line" tab, and use the pull down menu to select units of measurement. Then use your mouse to make a measurement using the ruler (by clicking on a starting location and an ending location. Describe something that you measured and note the measurement.

4. Explore historical imagery. Again, move your cursor over the toolbar icons at the top of the screen until you identify the "Show historical imagery" icon (a clock symbol), then click on it to open the slider of dates. Use your mouse to move the slider, and observe changes in the Google Earth™ images. Explore the region where your home place is located. Describe something that you learned using this feature of Google Earth™.

D. REFLECT & DISCUSS Based on your knowledge of Google Earth™, suggest how it could be used to study the geology of a region.

ACTIVITY 9.2 Map Locations, Distances, Directions, and Symbols

Name: ______________________________ **Course/Section:** ____________________ **Date:** __________

A. What are the latitude-longitude coordinates of point **B** in FIGURE 9.2? Latitude: ____________ Longitude: ______________

B. Refer to FIGURE 9.8 (PLSS).

1. Review FIGURE 9.8 to understand how the location of point **x** in FIGURE 9.8C was determined using PLSS shorthand. What is the location of point **z** in FIGURE 9.8C in PLSS shorthand?

2. How many acres are present in the township in FIGURE 9.8B? (*Hint:* There are 640 acres in 1 mi^2.) Show your work.

3. Imagine that you wanted to purchase the NE 1/4 of the SE 1/4 of section 11 in FIGURE 9.8C. If the property costs $500 per acre, then how much must you pay for the entire property?

C. USGS 30 × 60 minute quadrangle maps have a scale of 1:100,000.

1. One inch on such maps equals about how many miles? Show your work.

2. One cm on such maps equals about how many meters? Show your work.

D. Most handheld 12-channel parallel GPS receivers have an error of about 5 m when they fix on their position, and most geologists plot their data on $7\frac{1}{2}$-minute topographic quadrangle maps that have a ratio scale of 1:24,000. If an object is 5 meters long in real life, then exactly how long (in millimeters) would it be on the 1:24,000 scale map?

E. Refer to FIGURE 9.4.

1. What is the bearing from point C to point D? ______________

2. What is the bearing from point D to point C? ______________

F. Refer to the Ritter Ridge, California, $7\frac{1}{2}$-Minute topographic quadrangle map in FIGURE 9.3.

1. What are the latitude-longitude coordinates of the NW corner of the map?

2. What is the UTM zone and designator letter for the location of this map?

3. In what year was this map originally made? ___________ In what year was it photorevised? ___________

4. What is the magnetic declination for this region according to the map?

5. What is the PLSS location of section 21 in the southwest corner of the map?

G. Refer to the following SW corner of the Ritter Ridge, California, $7\frac{1}{2}$-minute topographic quadrangle map.

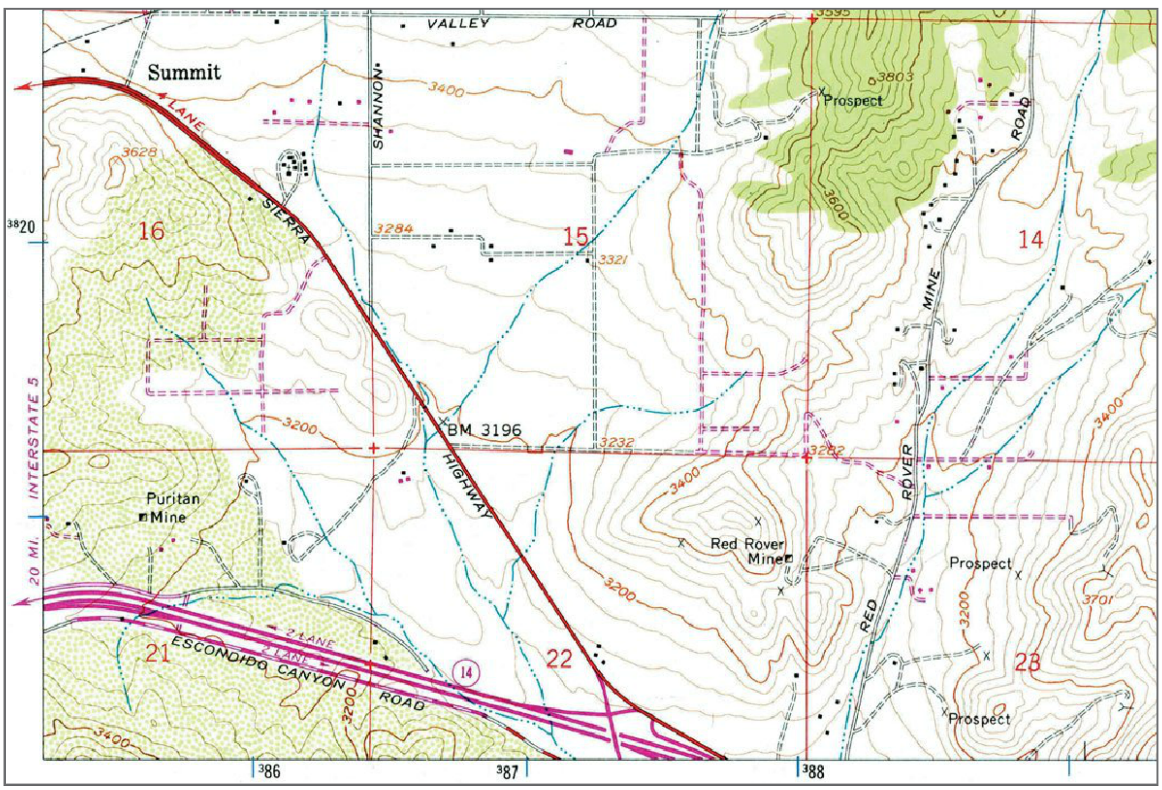
1. What two kinds of vegetation occur in the area represented by this map? (Refer to symbols in **FIGURE 9.4**)

2. Name the specific kinds of roads located on the map, based on the symbols identified in **FIGURE 9.4**.

3. Gold, copper, and titanium were mined here until the early 1900s. Notice that there are three different symbols used to indicate the kind of mining activity that occurred here. Draw the mine symbols below and identify what they mean using **FIGURE 9.4** (p. 234).

4. What are the UTM (NAD27) coordinates of Puritan Mine near the southwest corner of the map? (*Hint*: Cut out and use the 1:24,000 UTM Grid from Geotools Sheet 4 at the back of the manual.)

5. Notice that the square UTM grids in GeoTools Sheet 4 at the back of the manual are square protractors that you can use to determine bearings. What is the azimuth bearing from Red Rover Mine to Puritan Mine? (Courtesy of USGS)

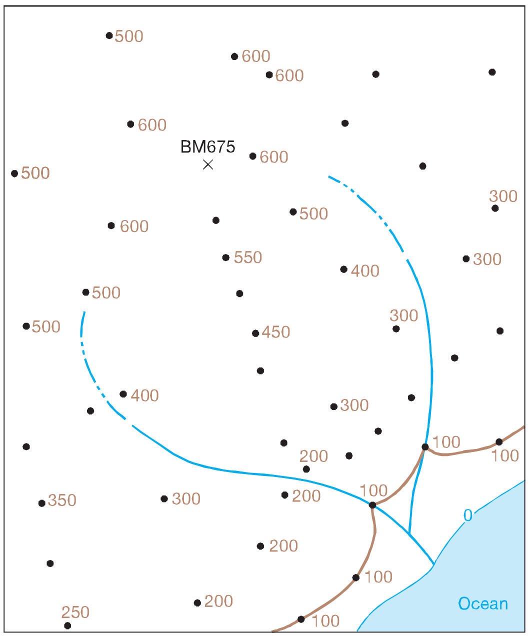


H. **REFLECT & DISCUSS** Below the map above, add bar scales to show how long 1 mile and 1 kilometer are on the map, then explain how you determined the lengths of the bars in your bar scales.

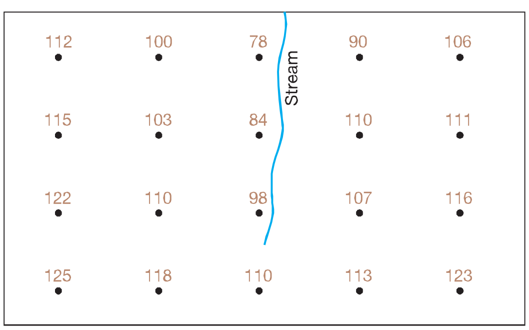
ACTIVITY 9.3 Topographic Map Construction

Name: ______________________________ **Course/Section:** ____________________ **Date:** __________

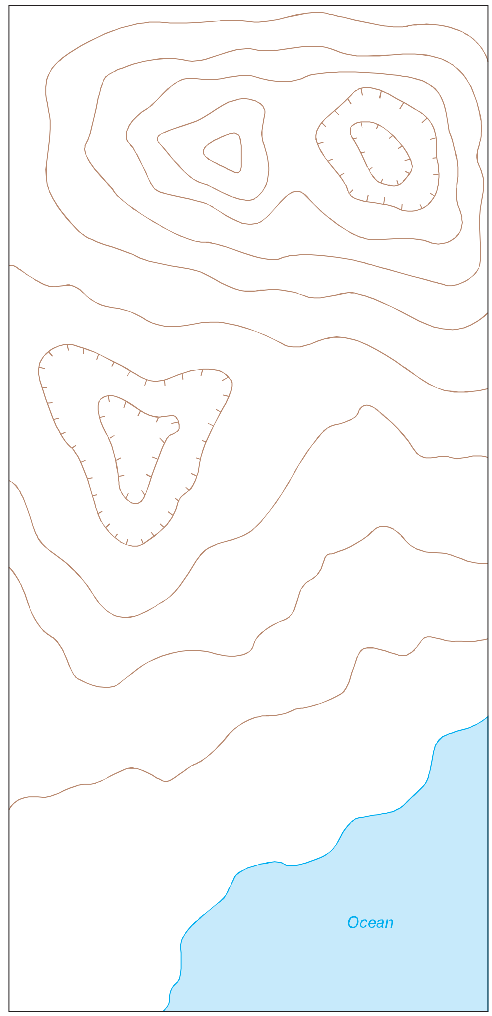
A. Use interpolation and extrapolation to estimate and label elevations of all points below that are not labeled (see **FIGURE 9.12** for help). Then add contour lines using a contour interval of 100 feet. Notice how the 0-foot and 100-foot contour lines have already been drawn.



B. Contour the elevations on the map below using a contour interval of 10 feet. Refer to **FIGURE 9.12** as needed.



C. Using a contour interval of 10 feet, label the elevation of every contour line on the map below. (*Hint:* Start at sea level and refer to **FIGURES 9.13** and **9.14**.)



D. **REFLECT & DISCUSS** The elevations in **FIGURE 9.1C** are in feet above sea level. What is the the contour interval of the map, and how did you determine it?

ACTIVITY 9.4 Topographic Map and Orthoimage Interpretation

Name: ______________________________ **Course/Section:** ____________________ **Date:** __________

A. Below is a portion of the 1989 SP Mountain, AZ topographic quadrangle map (USGS), scale 1:24,000. The black 1 km by 1 km UTM grid is NAD27, Zone 12S. Also note the 1 mi. by 1 mi. PLSS grid sections with red numbers in their centers.

1. What is the point of highest elevation on the map, and how can you tell?

2. Draw a small triangle over the point of lowest elevation on the map, and label it with the elevation.

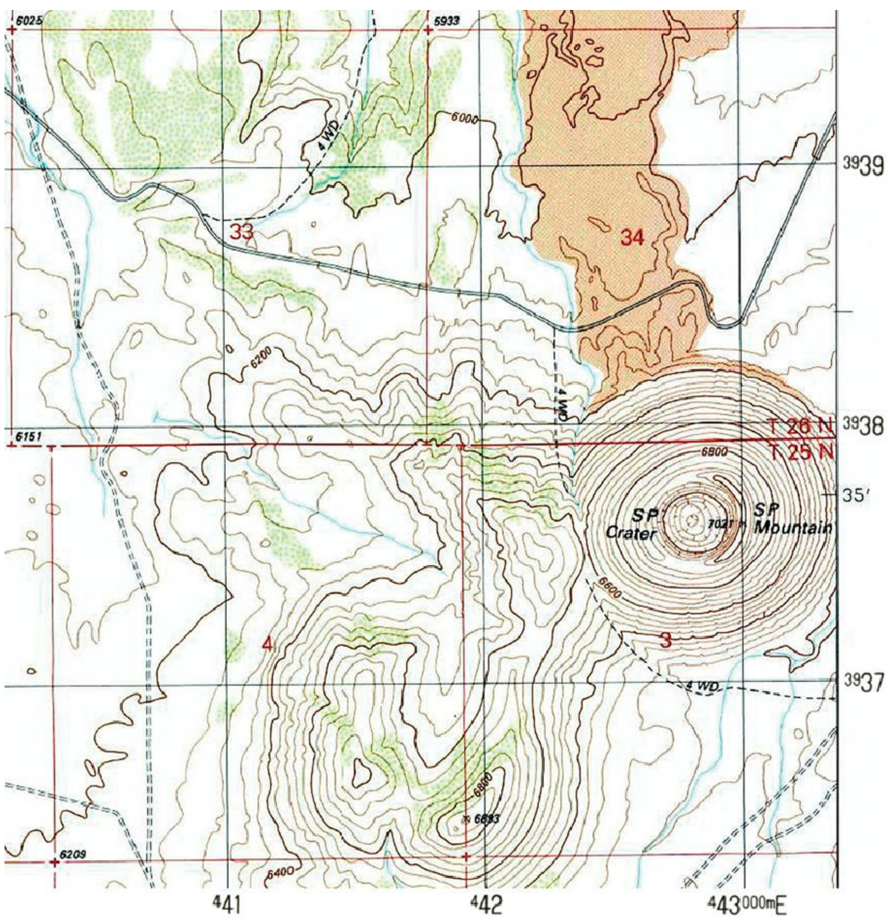
3. To the left of SP Mountain, do a subtraction problem that finds the mountain's total relief (from base to top) in feet.

4. Circle the five places in the map where streams (blue) begin. How can you tell which direction is upstream based on the contour lines?

5. Notice that there is an SP Mountain and an SP Crater. How can you tell which part is the crater? Color it red.

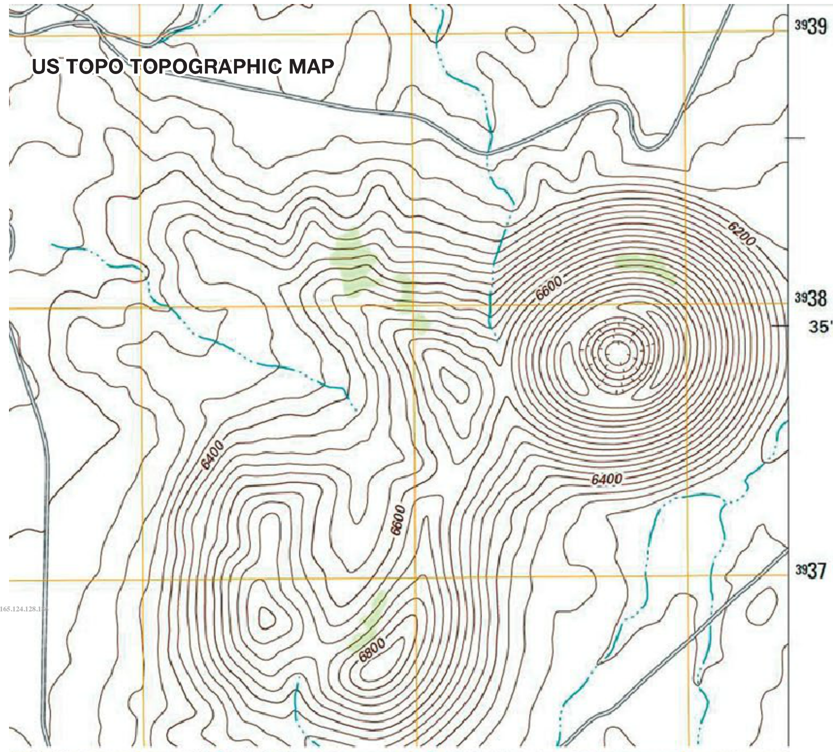
6. Describe the diameter (in km and miles) and three-dimensional shape of SP mountain, and suggest what kind of geological feature it may be.

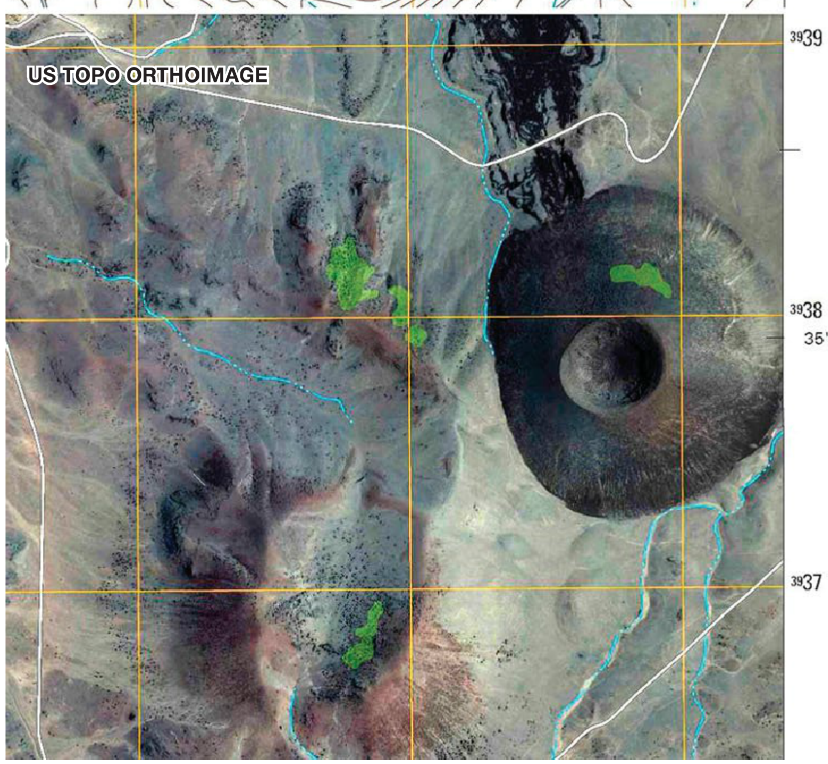
7. Based on your answer above, what material do you think is represented by the orange-brown color (section 34)? (Courtesy of USGS)



B. These are 2011 US Topo Series products. The digital map is matched with an orthoimage of the same area. (Courtesy of USGS)

1. The orthoimage reveals that SP Mountain is a volcano (cinder cone) with a very visible closed depression (crater) at its summit. The image also reveals an older, reddish volcano (cinder cone) that is very eroded (worn down). Draw a dashed line on the orthoimage and map to show the outline of this older volcano.
2. Draw a solid line on the orthoimage and map to show the outline of the crater of the older volcano. Why is it not shown with hachure lines on the map, like the crater for SP Mountain?





C. Compare the 2011 topographic map in part B with the 1989 map in part A.

1. How are the contour lines different in the 2011 map?

2. What is one thing that changed on the ground in this area from 1989 to 2011?

D. **REFLECT & DISCUSS** Which series of USGS products do you think is more useful: the 1989 paper maps series or the 2011 US Topo series of digital maps with matching orthoimages? List some advantages and disadvantages of your choice.

Advantages:

Disadvantages:

ACTIVITY 9.5 Relief and Gradient (Slope) Analysis

Name: ____________________________ **Course/Section:** _____________________________ **Date:** _____________

A. Analyze the topographic map below.

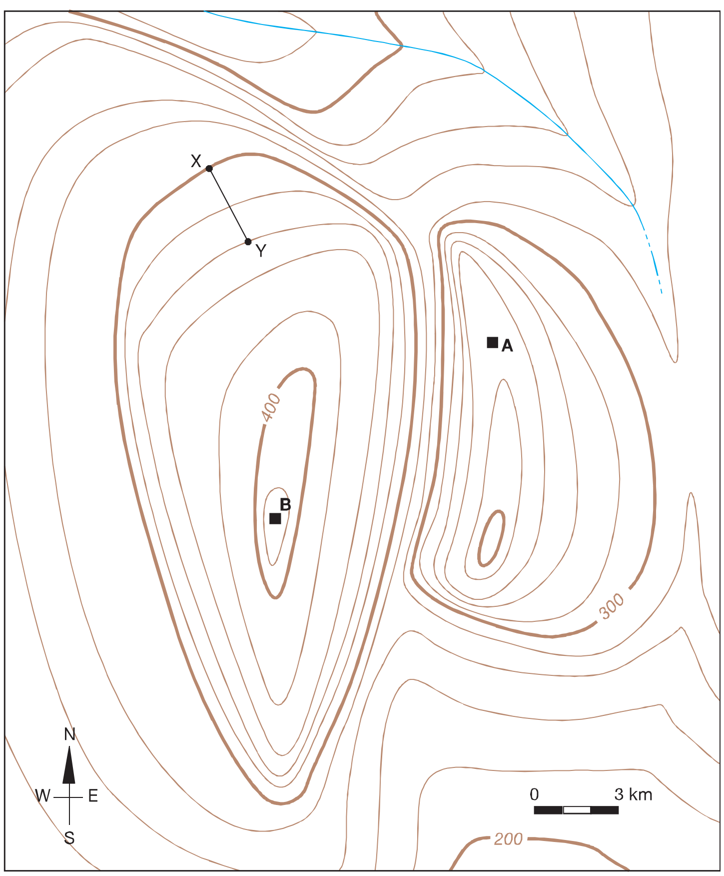
1. The contour lines on this map are labeled in meters.
What is the contour interval of this map in meters? ____________________

2. What is the regional (total) relief of the land represented in this map in meters? ____________________

3. What is the gradient (steepness of slope) from **Y** to **X**? Show your work.

4. **REFLECT & DISCUSS** Explain how you could find the areas of this map that have a gradient of 20 meters per kilometer or greater. (*Hint:* Think of the contour interval and how many contour lines of map elevation must occur along one kilometer of map distance.)

5. Apply your thinking from A4. Imagine that you need to drive a truck from point **A** to point **B** in this mapped area and that your truck cannot travel up any slopes having a gradient over 20 m/km. Trace a route that you could drive to get from point **A** to point **B** (More than one solution is possible).

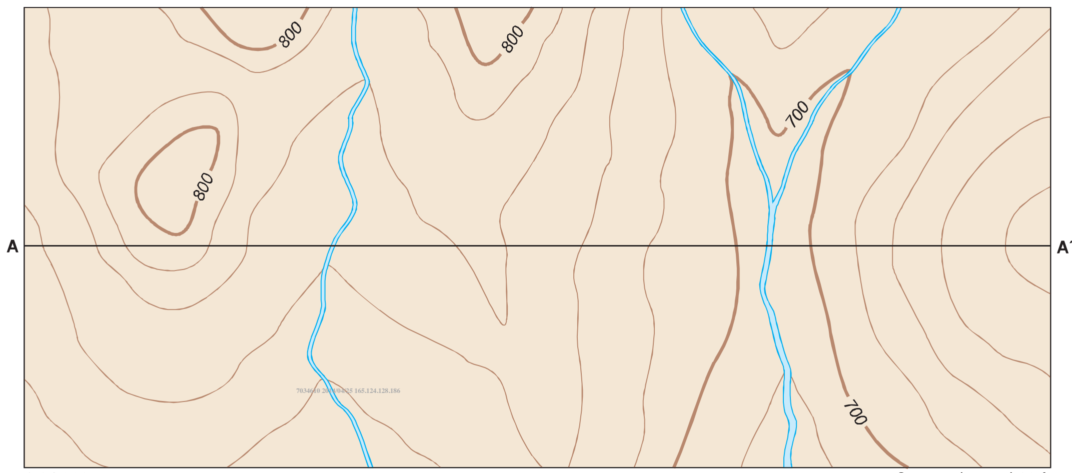


Elevations are in meters.

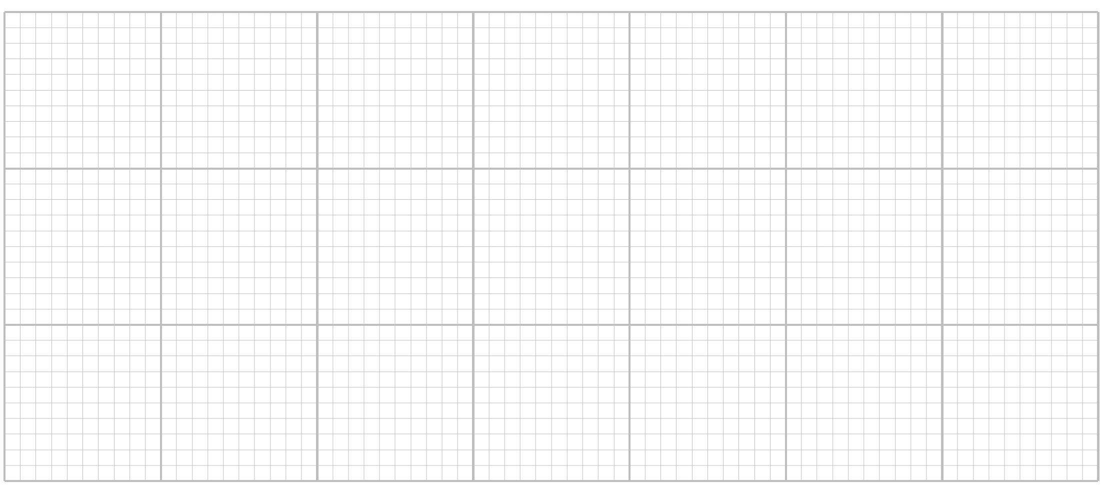
ACTIVITY 9.6 Topographic Profile Construction

Name: ______________________ **Course/Section:** ______________________ **Date:** ____________

A. Construct a topographic profile for **A–A’** on the graph paper provided. (Courtesy of USGS)



1:24,000 Contour interval 20 ft



B. What is the vertical exaggeration of the topographic profile that you constructed above? Show your work.

C. **REFLECT & DISCUSS** Why is it important to always know the vertical exaggeration of a topographic profile?