CHAPTER 2: MAPS, TIME, GIS, AND REMOTE SENSING

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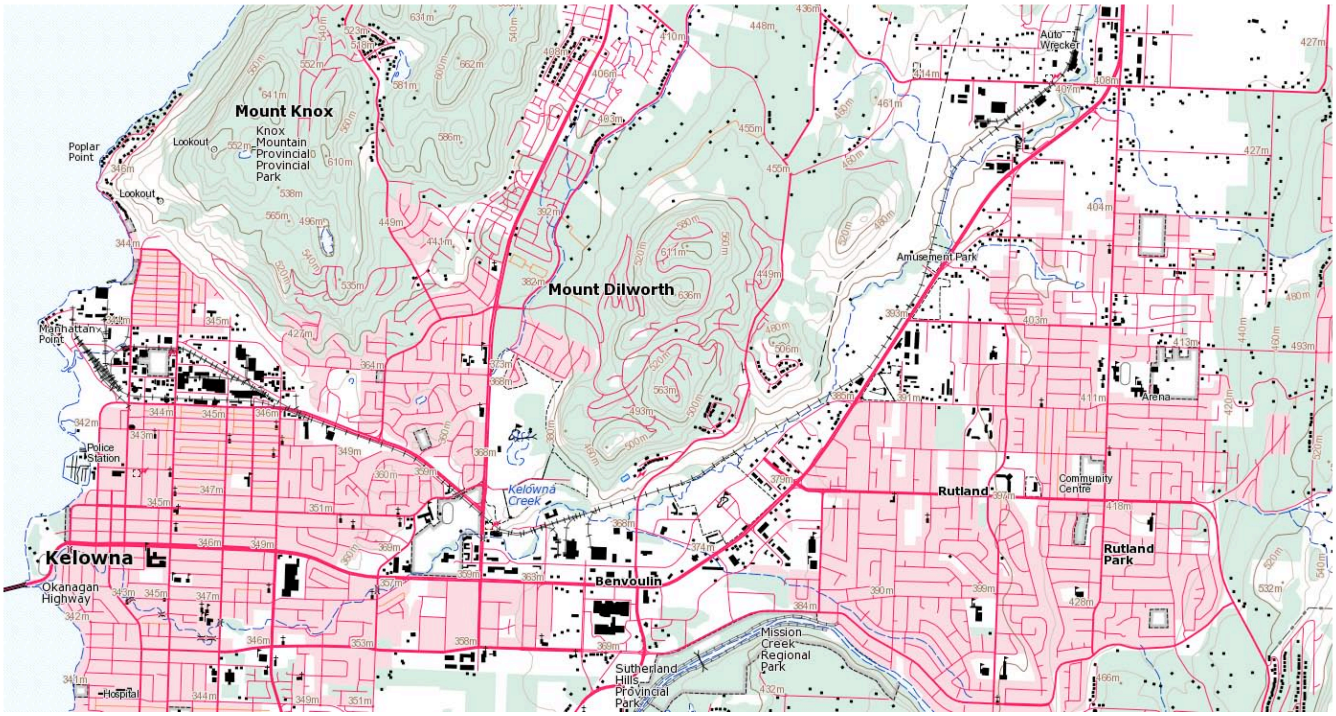

National Topographic System of Canada 1:50,000 topographic map. Part of the National Topographic System of Canada 1:50,000 topographic map sheet 082E14. On this topographic map, we can see how color is used to generally define land-use. Areas colored green are covered by natural vegetation. Pink represents urban built-up areas, light blue is used to depict water bodies, and white indicates a land surface that is devoid of natural vegetation. *(Source: Natural Resources Canada - Toporama)*

STUDENT LEARNING OUTCOMES

After reading this chapter you should be able to:

- Explain how maps are used to spatially depict cultural and physical features found on the Earth.
- Describe the various systems that are used to determine location on our planet.
- Illustrate the various projections that are used to create two-dimensional maps from a three-dimensional world.
- Define topographic maps and explain how they are used.
- Outline the method used to define time geographically on the Earth.
- Explain two important tools of physical geographers: Geographic Information Systems (GIS) and remote sensing.

MAPS: MODELS OF REALITY

A **map** can be simply defined as a graphic representation of the real world. This graphic representation is always an abstraction or generalization of reality because it is impossible to capture all of the complexity found around us. **Topographic maps** are designed to abstract the three-dimensional real world on a two-dimensional plane of paper. This abstraction removes much of the detail found in the area depicted. For example, vegetated areas on a topographic map are often colored a shade of green to represent the general presence of plants . Yet, in the real world we know that these areas are populated by a variety of different sized plants belonging to a number of different species.

Maps are used to display both cultural and physical features of the environment. Standard topographic maps show a variety of information including roads, land-use classification, elevation, rivers and other water bodies, political boundaries, and the identification of houses and other types of buildings. Some maps are created with very specific goals in mind. **Figure 2.1** displays a weather map showing the location of low and high pressure centers and fronts over most of North America. The intended purpose of this map is considerably more specialized than a topographic map.

The construction and use of maps has a long history. Some academics believe that the earliest maps date back to the fifth or sixth century BC. Even in these early maps, the main goal of this tool was to communicate information. Early maps were quite subjective in their presentation of spatial information. Maps became more objective and accurate with the use of mathematics and science in cartography. Today, the art of map making is quite a sophisticated science employing methods from cartography, engineering, computer science, mathematics, and psychology.

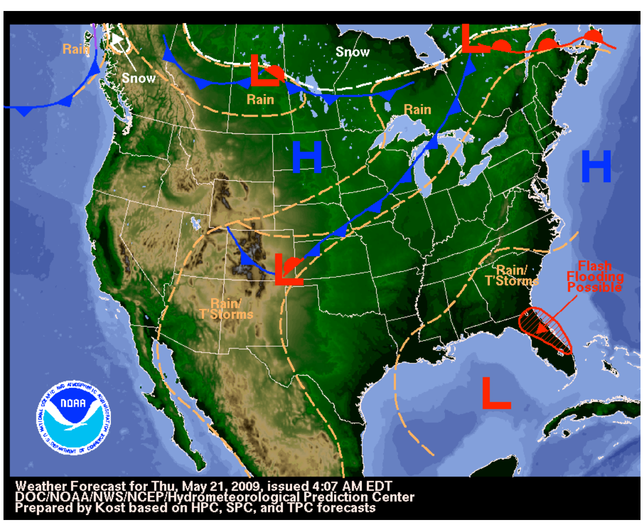

FIGURE 2.1 National Oceanic and Atmospheric Administration (NOAA) weather map. The following specialized weather map displays the surface location of pressure centers and fronts for Thursday, May 21, 2009 over a portion of North America. *(Source: NOAA)*

Cartographers, the individuals who construct maps, classify maps into two broad categories: reference maps and thematic maps. **Reference maps** normally show natural and human-made objects from the geographical environment with an emphasis on location. Examples of general reference maps include maps found in atlases and topographic maps. **Thematic maps** are used to display the geographical distribution of one phenomenon or the spatial associations that occur between different phenomena (**Figure 2.2**).

MAP SCALE

Maps are rarely drawn at the same scale as the real world. Most maps are made at a scale that is much smaller than the area of the actual surface being depicted. The amount of reduction that has taken place is normally identified somewhere on the map. This measurement is commonly referred to as the **map scale**. Conceptually, we can think of map scale as the ratio of the distance between any two points on the map compared to the actual ground distance represented. This concept can also be expressed mathematically as:

$$\text{Map Scale} = \frac{\text{Map Distance}}{\text{Earth Distance}}$$

On most maps, the map scale is represented by a simple fraction or ratio. This type of description of a map's scale is called a **representative fraction**. For example, a map where one unit (centimeter, meter, inch, kilometer, etc.) on the illustration represents 1,000,000 of these same units on the actual surface of the Earth would have a representative fraction of 1/1,000,000 (fraction) or 1:1,000,000 (ratio). Of these mathematical representations of scale, the ratio form is most commonly found on maps. Most maps also use graphic scale to portray the distance relationships between the map and the real world. In a **graphic scale**, an illustration is used to depict distances on the map in common units of measurement (**Figure 2.4**). Graphic

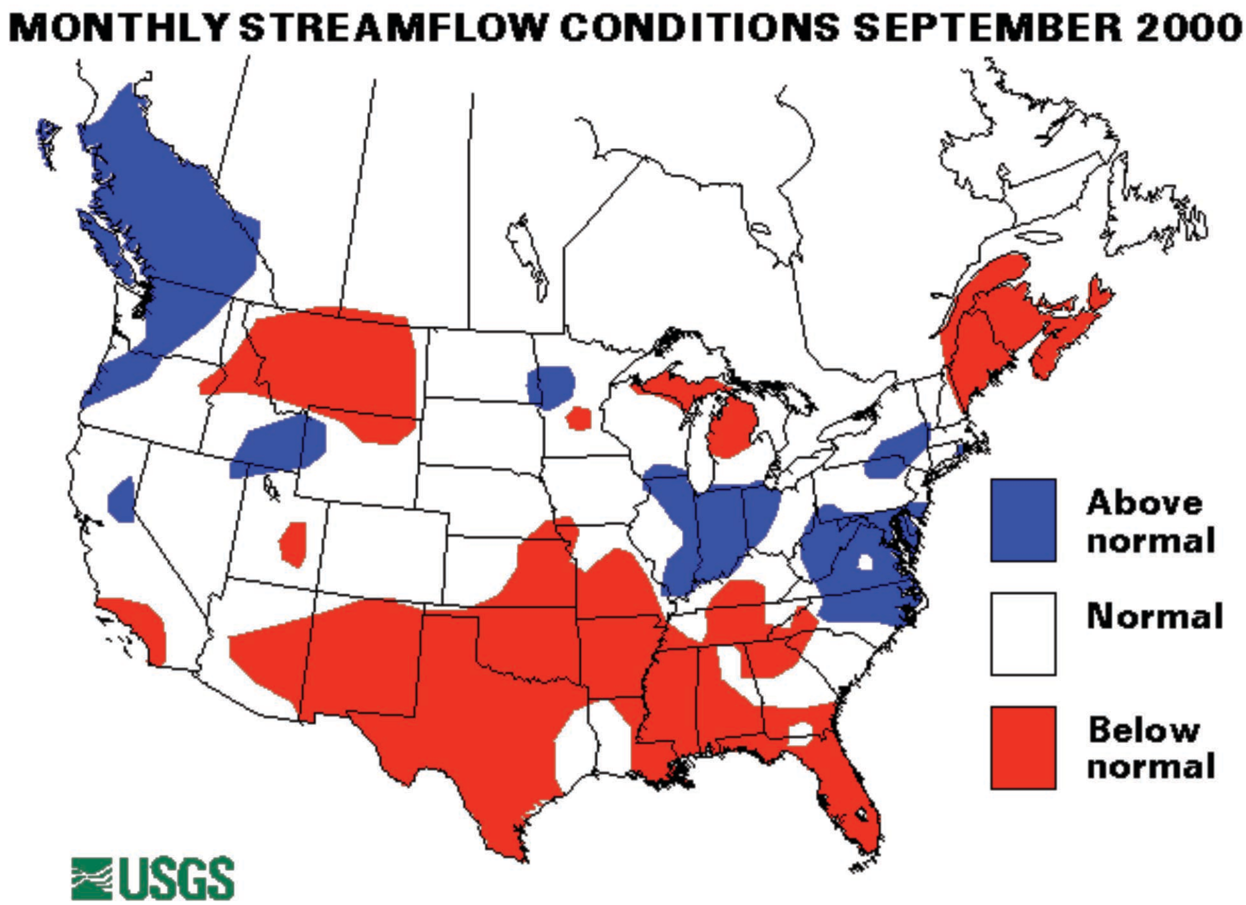

FIGURE 2.2 Thematic map showing streamflow conditions in southern Canada and the United States for September, 2000. *(Source: United States Geological Survey)*

scales are quite useful because they can be used to measure distances on a map quickly. Scale can also be represented on a map by a verbal statement. For example, 1:1,000,000 could be verbally described as 1 cm on the map equals 10 km on the Earth's surface or 1 in. represents approximately 16 mi.

Maps are often described, in a relative sense, as being either small scale or large scale. **Figure 2.4** helps to explain this concept. In this figure, we have three maps representing an area of the world at scales of 1:100,000, 1:50,000, and 1:25,000. Of this group, the map drawn at 1:100,000 has the smallest scale relative to the two other maps. The map with the largest scale is Map C, which is drawn at a scale of 1:25,000.

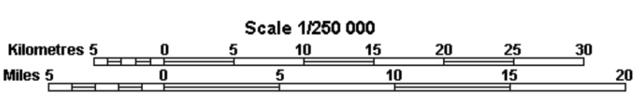

FIGURE 2.3 The following graphic scale was drawn for map with a scale of 1:250,000. In the illustration, distances in miles and kilometers are graphically shown.

MAP LOCATION SYSTEMS

Most maps allow us to specify the location of points on the Earth's surface using a coordinate system. For a two-dimensional map, this coordinate system can use simple geometric relationships between the perpendicular axes on a grid system to define spatial location (**Figure 2.5**). Two types of spatial coordinate systems are currently in general use: the geographical coordinate system and the rectangular coordinate system.

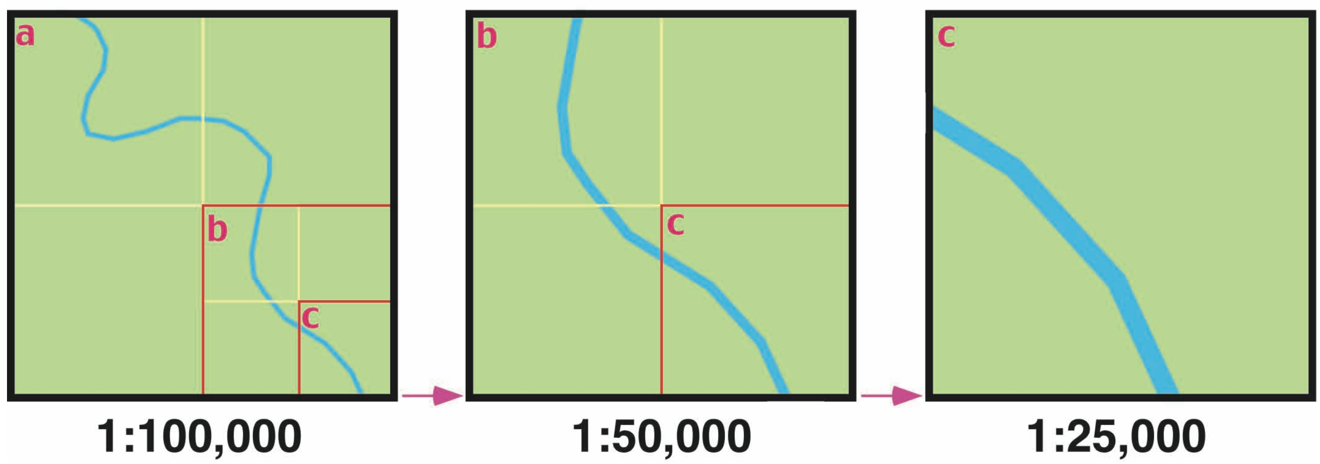

FIGURE 2.4 The following three illustrations describe the relationship between map scale and the size of the ground area shown at three different map scales. The map on the far left has the smallest scale, while the map on the far right has the largest scale. Note what happens to the amount of area represented on the maps when the scale is changed. A doubling of the scale (1:100,000 to 1:50,000 and 1:50,000 to 1:25,000) causes the area shown on the map to be reduced by 25% or one-quarter. *(Image Copyright: Michael Pidwirny)*

Geographical Coordinate System

The **geographical coordinate system** measures location from only two values, despite the fact that the locations are described for a three-dimensional surface. These values used to define location are both measured relative to the polar axis of the Earth. The two measures used in the geographic coordinate system are called latitude and longitude. Both of these measures are expressed as an angle measured in degrees (°), minutes ('), and seconds (").

Latitude measures the north-south position of locations on the Earth's surface relative to a point found at the center of the Earth (**Figure 2.6**). This central point is also located on the Earth's rotational or polar axis. The **equator** is the starting point for the measuring latitude. The equator has a value of 0°. A line of latitude or **parallel** of 30° North has an angle that is 30° north of the plane represented by the equator (**Figure 2.7**). The maximum value that latitude can attain is either 90° North or South. These lines of latitude run parallel to the rotational axis of the Earth.

Longitude measures the west-east position of locations on the Earth's surface relative to a circular arc called the prime meridian (**Figure 2.6**). The position of the **prime meridian** was determined by international agreement to be a line of longitude that is aligned with the location of the former astronomical observatory at Greenwich, England. Because the Earth's circumference is similar to circle, it was decided to measure longitude in degrees. The number of degrees found in a circle is 360. The prime meridian has a value of zero degrees. A line of longitude or **meridian** of 45° West has an angle that is 45° west of the plane represented by the prime meridian (**Figure 2.7**). The maximum value that a meridian of longitude can have is 180°, which is the distance halfway around a circle. This meridian is called the **International Date Line**. Designations of west and east are used to distinguish where a location is found relative to the prime

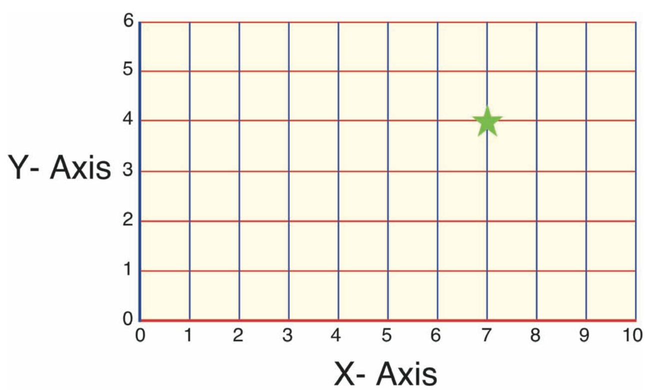

FIGURE 2.5 A grid coordinate system defines the location of points from the distance traveled along two perpendicular axes from some stated origin. In the example above, the two axes are labeled X and Y. The origin is located in the lower left hand corner. Unit distance traveled along each axis from the origin is shown. In this coordinate system, the value associated with the X-axis is given first, following by the value assigned from the Y-axis. The location represented by the star has the coordinates 7 (X-axis), 4 (Y-axis). *(Image Copyright: Michael Pidwirny)*

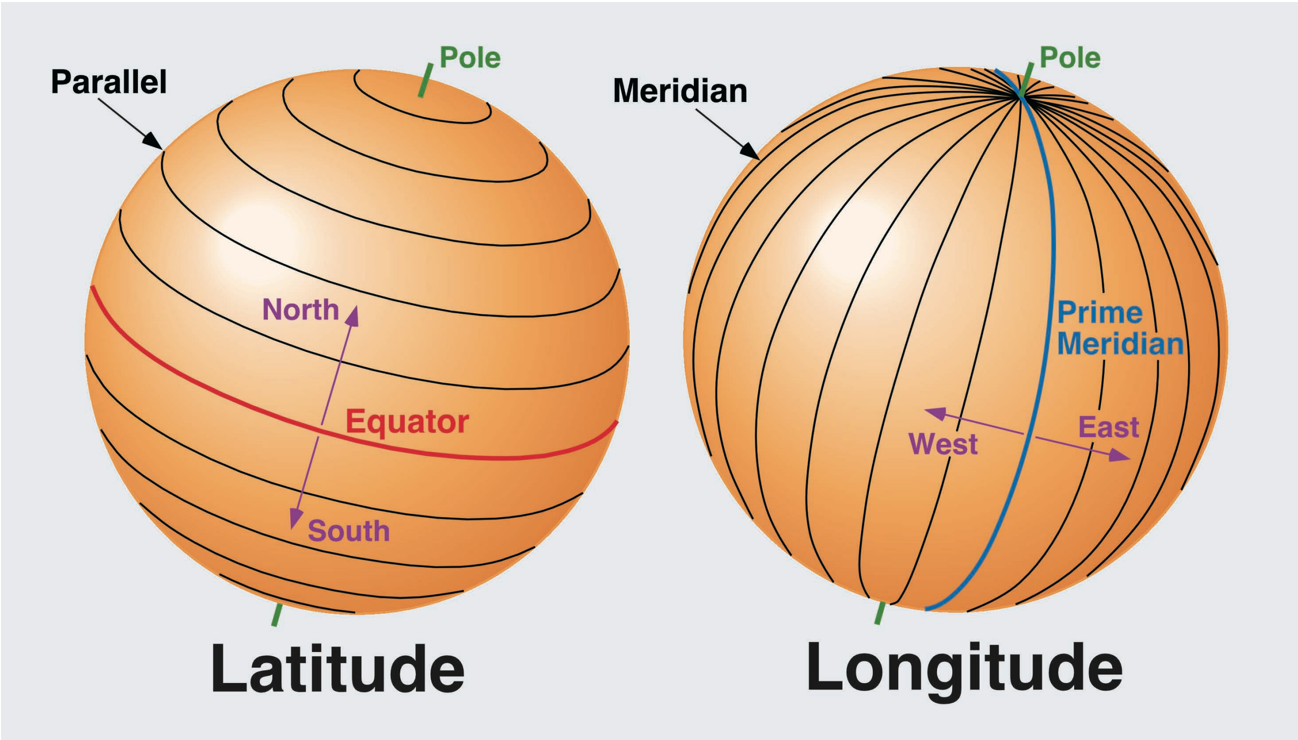

FIGURE 2.6 Lines of latitude or parallels are drawn parallel to the equator (shown in red) as circles that span the Earth's surface. These parallels are measure in degrees. There are 90 angular degrees of latitude from the equator to each of the poles. The equator has an assigned value of 0°. Measurements of latitude are also defined as being either north or south of equator to distinguish the hemisphere of their location. Lines of longitude or meridians are circular arcs that meet at the poles. There are 180 degrees of longitude either side of a starting meridian which is known the prime meridian (shown in blue). The prime meridian has a designated value of 0°. Measurements of longitude are also defined as being either west or east of the prime meridian. *(Image Copyright: Michael Pidwirny)*

meridian. For example, all of the locations in North America have a longitude that is designated west.

Rectangular Coordinate System

Rectangular coordinate systems are used to define geographical location on two-dimensional surfaces like maps. Most topographic maps use a specific type of rectangular coordinate system called the **Universal Transverse Mercator (UTM) grid system**. The Universal Transverse Mercator grid system uses the meter (m) as its basic unit of measurement. UTM also employs the **Transverse Mercator projection** system to model the Earth's spherical surface onto a two-dimensional plane.

The UTM system divides the world's surface into 60 six-degree longitude wide zones that run north to south (**Figure 2.8**). These zones start at the International Date Line and are successively numbered in an eastward direction. Each zone stretches from 84° North to 80° South. In the center of each of these zones is a central meridian. Location is measured in these zones from a false origin that is determined relative to the intersection of the equator and the central meridian for each zone (**Figure 2.9**). For locations in the Northern Hemisphere, the false origin is 500,000 meters west of the central meridian on the equator. Coordinate measurements of location in the Northern Hemisphere using the UTM system are made relative to this point in meters in **eastings** (longitudinal distance) and **northings** (latitudinal distance). The point defined by the intersection of 50° North and 9° West would have a UTM coordinate of Zone 29, 500000 m East (E), 5538630 m North (N) (see **Figure 2.8** and **2.9**). In the Southern Hemisphere, the origin is 10,000,000 m south of the equator and 500,000 m west of the central meridian. The location found at 50° South and 9° West would have a UTM coordinate of Zone 29, 500000 m E, 4461369 m N (remember that northing in the Southern Hemisphere is measured from 10,000,000 m south of the equator - see **Figure 2.8** and **2.9**).

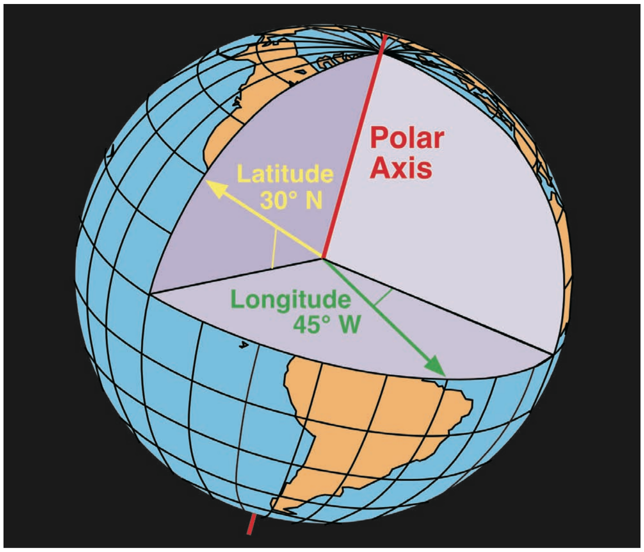

FIGURE 2.7 Measurement of latitude and longitude on the Earth. Latitude is measured relative to a point found on the center of the polar axis. Measurements of latitude range from 0 to 90°. Latitudes greater than zero are recognized as being either north or south of the equator. Longitude is measured relative to the equator plane and the prime meridian. Measurements of latitude range from 0 to 180°. Longitudes greater than zero are identified as being either west or east of the prime meridian. *(Image Copyright: Michael Pidwirny)*

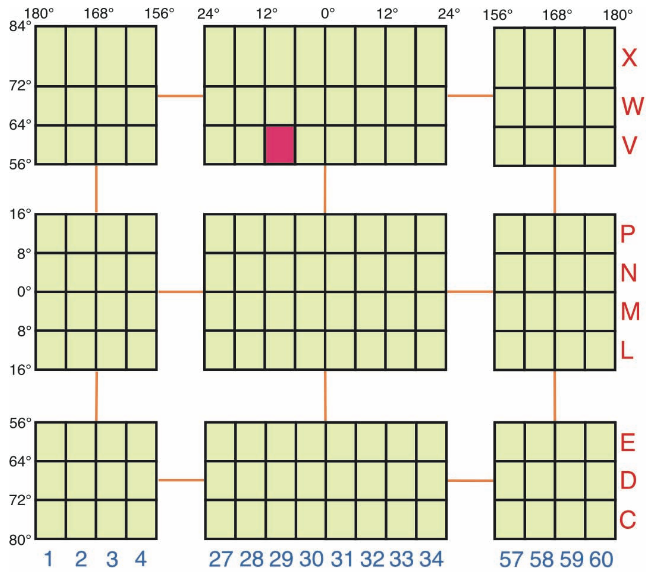

FIGURE 2.8 The UTM system also uses a grid system to break the Earth up into 1200 quadrilaterals. To keep the illustration manageable, most of these zones have been excluded. Designation of each quadrilaterals is accomplished with a number-letter system. Along the horizontal bottom, the six-degree longitude wide zones are numbered, starting at 180 degrees West longitude, from 1 to 60. The twenty vertical rows are assigned letters C to X with I and O excluded. The letter, C, begins at 80° South latitude. Note that the rows are 8° of latitude wide, except for the last row X which is 12° wide. According to the reference system, the bright green quadrilateral has the grid reference 29V (note that in this system west-east coordinate is given first, followed by the south-north coordinate). This grid zone is found between 56 and 64° North latitude and 6 and 12° West longitude. *(Image Copyright: Michael Pidwirny)*

The UTM system has been modified to make measurements less confusing. In this modification, the six-degree wide zones are divided into smaller pieces or quadrilaterals that are eight degrees of latitude tall. Each of these rows is labeled, starting at 80° South, with the letters C to X consecutively and with I and O being omitted (**Figure 2.8**). The last row X differs from the other rows and extends from 72 to 84° North latitude (twelve degrees tall). Each of the quadrilaterals or grid zones is identified by their number/letter designation. In total, 1200 quadrilaterals are defined in the UTM system.

The quadrilateral system allows us to further define location using the UTM system. For the location 50° North and 9° West, the UTM coordinate can now be expressed as Grid Zone 29U, 500000 m E, 5538630 m North. Each UTM quadrilateral is further subdivided into a number of 100,000 by 100,000 m zones. These subdivisions are coded by a system of letter combinations where the same two-letter combination is not repeated within 18° of latitude and longitude. Within each of the 100,000 by 100,000 m squares one can specify location to one-meter accuracy using a 5-digit eastings and northings reference system.

The UTM grid system is displayed on all United States Geological Survey (USGS) and National Topographic Series of Canada (NTS) maps. On USGS 7.5-minute quadrangle maps (1:24,000 scale), 15-minute quadrangle maps (1:50,000, 1:62,500, and standard-edition 1:63,360 scales), and Canadian 1:50,000 maps the UTM grid lines are drawn at intervals of 1000 meters, and are shown either with blue ticks at the edge of the map or by full blue grid lines. On USGS maps at 1:100,000 and 1:250,000 scale and Canadian 1:250,000 scale maps a full UTM grid is shown at intervals of 10,000 meters. **Figure 2.10** describes how the UTM grid system can be used to determine location on a 1:50,000 National Topographic Series of Canada map.

GLOBAL POSITIONING SYSTEMS

Determination of location in field conditions was once a difficult task. It often required the use of a topographic map and the recognition of landscape features to roughly

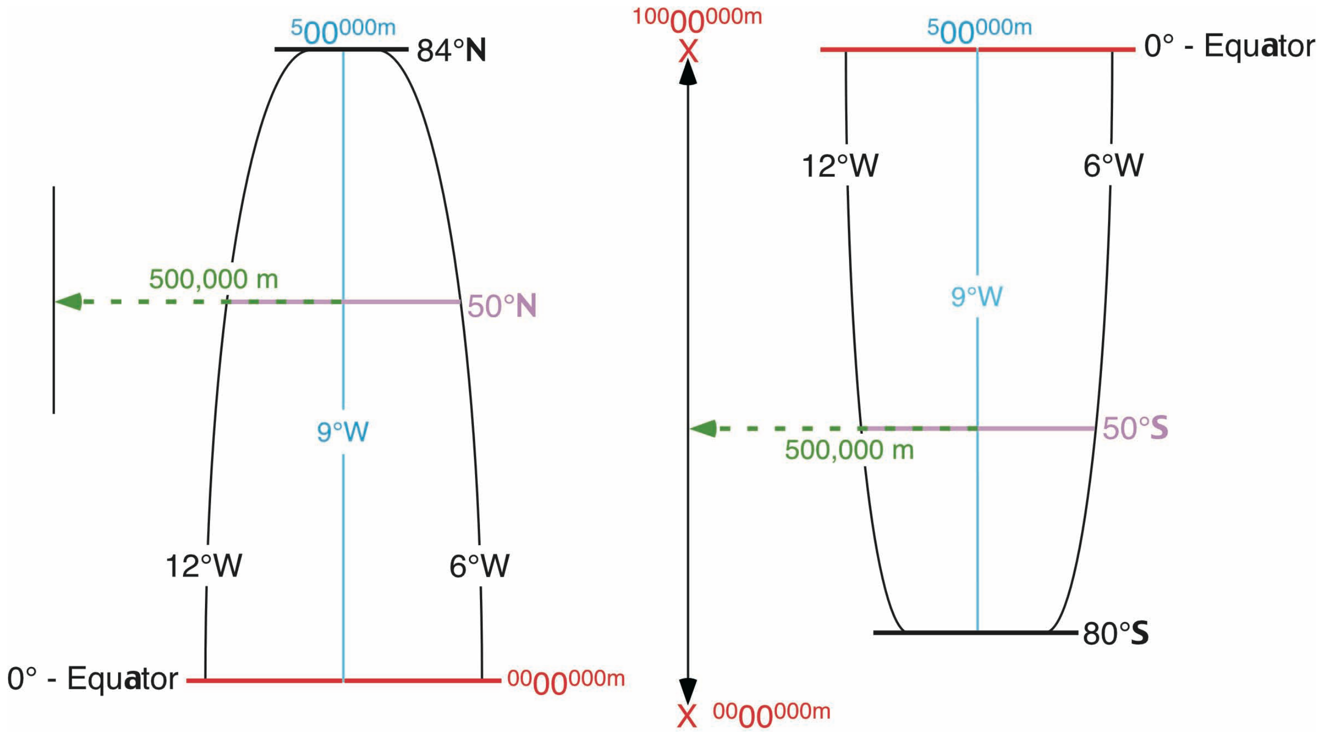

FIGURE 2.10 The following illustration describes the characteristics of the UTM zone "29" found between 12 to 6° West longitude. Note that the zone has been split into two halves. The half on the left represents the area found in the Northern Hemisphere. The Southern Hemisphere is located on the right. The blue line represents the central meridian for this zone. Locations measurements for this zone are calculated relative to a false origin. In the Northern Hemisphere, this origin is located 500,000 meters west of the equator. The Southern Hemisphere UTM measurements are determined relative to an origin located at 10,000,000 meters south and 500,000 meters west of the equator and central meridian, respectively. *(Image Copyright: Michael Pidwirny)*

estimate location. However, technology has now made this task very simple and precise. **Global Positioning Systems** (GPS) can calculate one's location anywhere on our planet to an accuracy of between 10 to 3 m (33 to 10 ft) (**Figure 2.11**). GPS systems consist of two parts: a GPS receiver and a network of satellite orbiting our planet. Radio transmissions from these satellites are broadcasted continually. A GPS receiver must receive the signal of at least three satellites to calculate a two-dimensional position (latitude and longitude). With four or more satellites, the GPS receiver can determine the three-dimensional position (latitude, longitude, and altitude) of an individual. The heart of GPS technology is the ability of the transmitting satellites to keep extremely precise time and position information. GPS satellites measure time with atomic clocks that are accurate to within one second every 70,000 years.

GPS was first developed for military use. Originally, the military thought this location technology would be extremely useful for navigation on land, on the ocean, and in the air. The technology was then applied to other tasks including troop location monitoring and weapon guidance. The first solar powered GPS satellite was launched in 1978 and by 1980 a network of six satellites was in operation. Today, a total of 24 satellites make up the GPS space network orbiting the Earth at an altitude of around 20,000 km above us. These satellites circle the Earth twice a day, traveling at speeds of about 11,000 kph.

In the mid-1980s, the technology became available for civilian use. At first, the accuracy of civilian GPS units was deliberately degraded by the US military for national security reasons. This degradation was turned off in May 2000. Additional accuracy and a reduction in receiver costs have caused civilian use to expand rapidly. GPS has proven to be an extremely valuable tool in forestry, agriculture, mineral exploration, and other forms of field activities.

GPS is now being combined with a variety of computerized technologies to increase its usefulness. Some handheld GPS units are being merged with computers for the purpose of recording and storing location and other

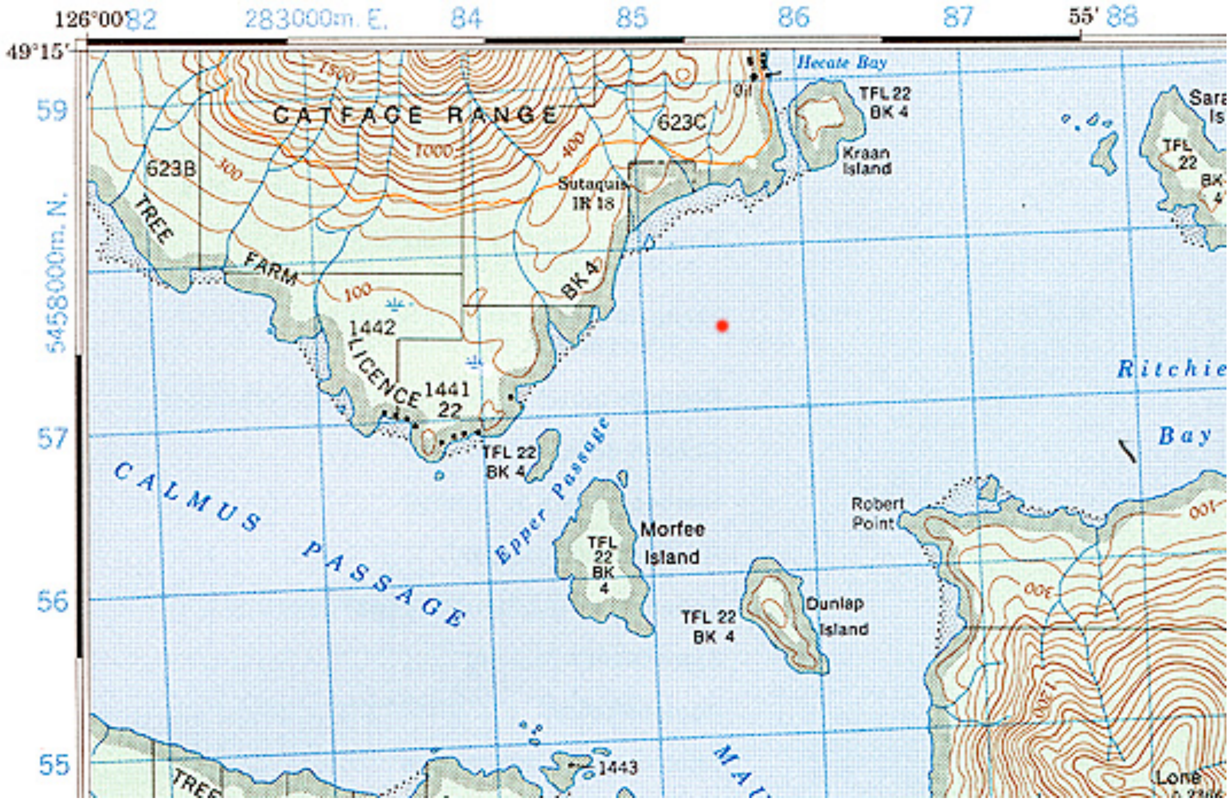

FIGURE 2.10 The top left hand corner the "Tofino" 1:50,000 National Topographic System of Canada map is shown above. The blue lines and associated numbers on the map margin are used to determine location by way of the UTM grid system. Abbreviated UTM 1,000-meter values or principle digits are shown by numbers on the map margin that vary from 0 to 100 (100 is actually given the value 00). In each of the corners of the map, two of the principle digits are expressed in their full UTM coordinate form. On the image we can see 283000 m E. and 5458000 m N. The red dot is found in the center of the grid defined by principle numbers 85 to 86 easting and 57 to 58 northing. A more complete UTM grid reference for this location would be 285500 m E. and 5457500 m N. Information found on the map margin also tells us (not shown) that the area displayed is in Grid Zone 10U and the 100,000 m squares BK and CK are located on this map. *(Source: Natural Resources Canada - Toporama)*

FIGURE 2.11 GPS receivers can determine latitude, longitude, and elevation anywhere on or above the Earth's surface from signals transmitted by a number of satellites. These units can also be used to reveal direction, distance traveled, and determine routes of travel in field situations. *(Courtesy of Garmin)*

related field data. Once back in the office, the data stored in the unit can be transferred into a Geographic Information System for processing and analysis. GPS is also being used to display and track an individual's location on software driven digital maps. In these units, mapping software is combined with the GPS to allow users to monitor their position and movement on topographic or street maps. These real time navigation systems are now available for use in cars, mobile phones, and with handheld computers (**Figure 2.12**).

MAP PROJECTION SYSTEMS

The shape of the Earth's surface can be described as an ellipsoid. An ellipsoid is a three-dimensional shape that departs slightly from a purely spherical form (**Figure 2.13**). The Earth takes this form because rotation causes the

FIGURE 2.12 Garmin's nüvi™ 855 GPS navigator comes with detailed maps of North America specially designed for assisting automobile travel. *(Courtesy of Garmin)*

region near the equator to bulge outward to space. The angular motion caused by the Earth spinning on its axis also forces the polar-regions to be somewhat flattened.

Representing the true nature of the Earth's surface on a map is plagued by a single major problem. The Earth's surface exists in three-dimensional space, while maps exist in two-dimensional space. To overcome this problem, cartographers have developed a number of standardized transformation processes for creating two-dimensional maps. These transformation processes are all based on simply projecting the three-dimensional surface of the Earth onto a two-dimensional surface that has either been kept flat or rolled into a cone or cylinder. All of these transformation processes create some type of distortion artifact. The nature of this distortion is related to how the transformation process modifies specific geographic properties of the real world. Some of the geographic properties affected by projection distortion include: distance, area, straight-line direction between points on the Earth, and the bearing of cardinal points from locations on our planet.

Cylindrical Projections

Projecting the Earth's surface onto a cylinder creates a **cylindrical projection** (**Figure 2.14**). This technique for creating maps was first employed by the Flemish cartographer Gérardus Mercator in 1569. Mercator's cylindrical projection system quickly became the standard for maritime mapping in the 16th, 17th and 18th centuries

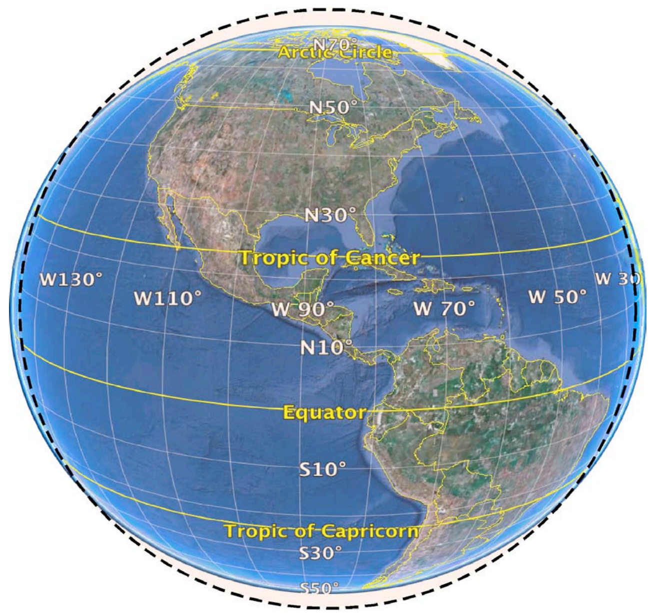

FIGURE 2.13 The Earth is not perfectly spherical but has a ellipsoid shape. The dashed circle shows a perfectly circle for reference. From this reference we can see that the Earth bulges at the equator and is compressed at the poles. *(Image Copyright: Michael Pidwirny)*

(**Figure 2.15**). The U.S. National Ocean Service has been using the **Mercator projection** system for creating nautical charts for well over 90 years.

On a Mercator projection, the north-south scale increases from the equator at the same rate as the corresponding east-west scale (**Figure 2.16**). Because of this geometric feature, lines drawn on this type of map have true direction, making Mercator maps extremely useful for navigation. This type of line is known as a **rhumb line**. No other map projection represents the angles of drawn lines correctly. However, this line may not denote the shortest distance between its two end points. In fact, distance is only true along the equator and distance distortion becomes more exaggerated as you move away towards the poles. Mercator maps also suffer from severe area distortion. This deformation causes areas to become disproportionately large as one moves to the poles. For example, Greenland is overstated by about 700% when compared to areas near the equator.

Conic Projections

In the **conic projection**, the surface of the Earth is projected onto a cone (**Figure 2.17**). The cone can be placed on the globe so that its edge runs parallel to a line of latitude. Another variation of the conic projection positions

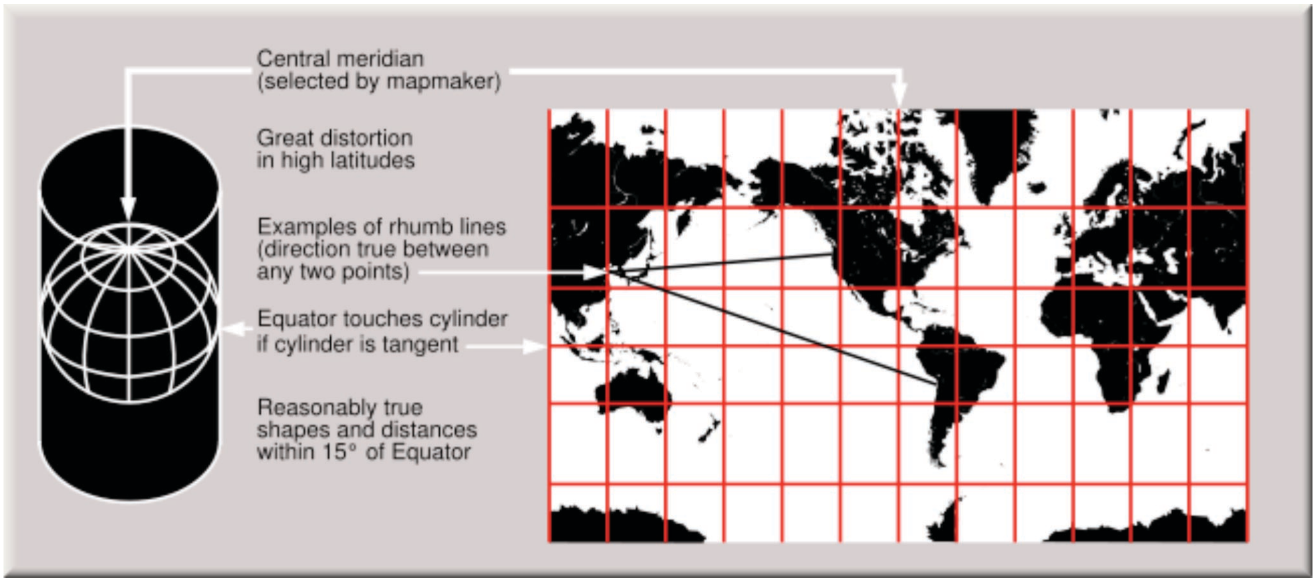

FIGURE 2.14 Cylindrical projections are drawn as if the Earth's surface were projected onto a cylinder. Note how this projection distorts the Earth's lines of longitude and latitude. On the true spherical surface of the Earth, the lines of longitude or meridians converge on each other as one goes from the equator to the poles. However, the cylindrical projection portrays the meridians as being equally spaced apart from the equator to the poles. Lines of latitude retain the property of being parallel to each other but are distorted in terms of distance. The distance between consecutive lines of latitude becomes progressively greater as one moves from the equator to the poles. *(Source: United States Geological Survey)*

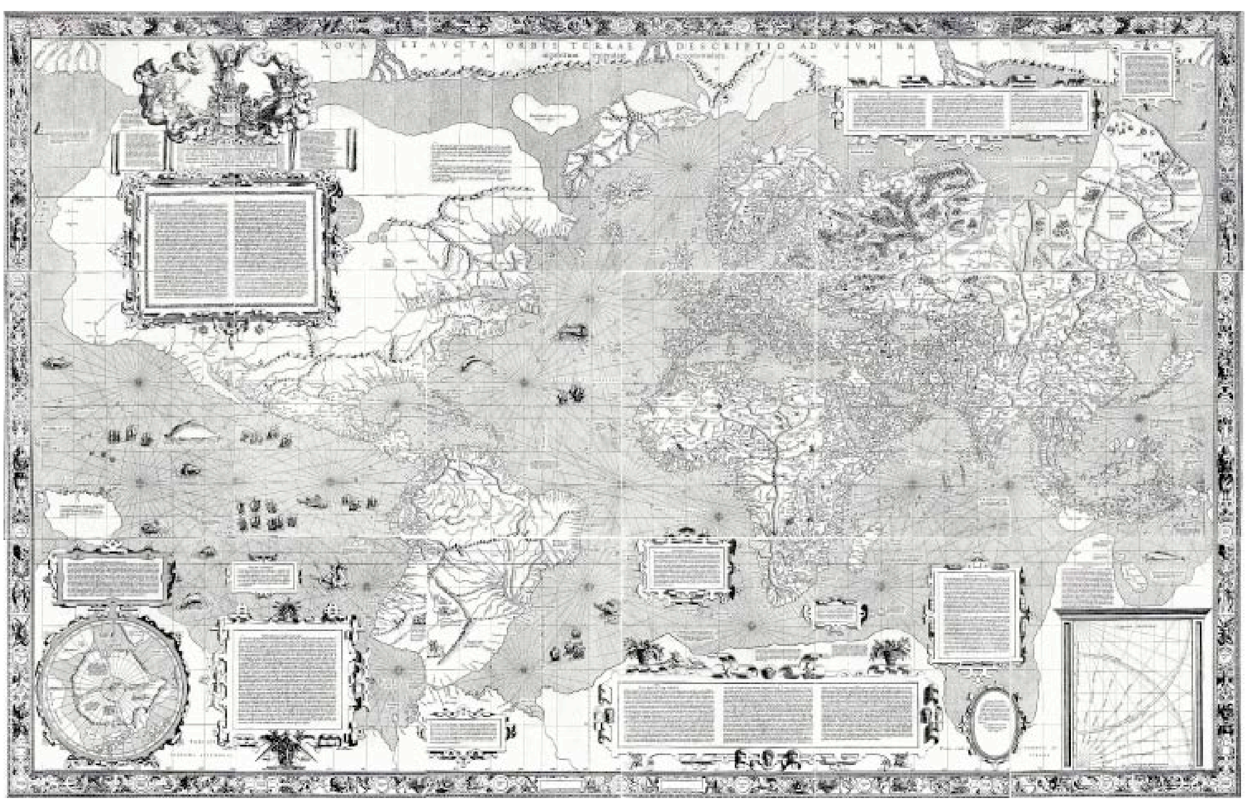

FIGURE 2.15 This map was constructed using the Mercator projection system and illustrates the Americas, Africa, Europe, and Asia. This projection was extremely valuable to sailors because it permitted accurate directional navigation. *(Source: Wikipedia)*

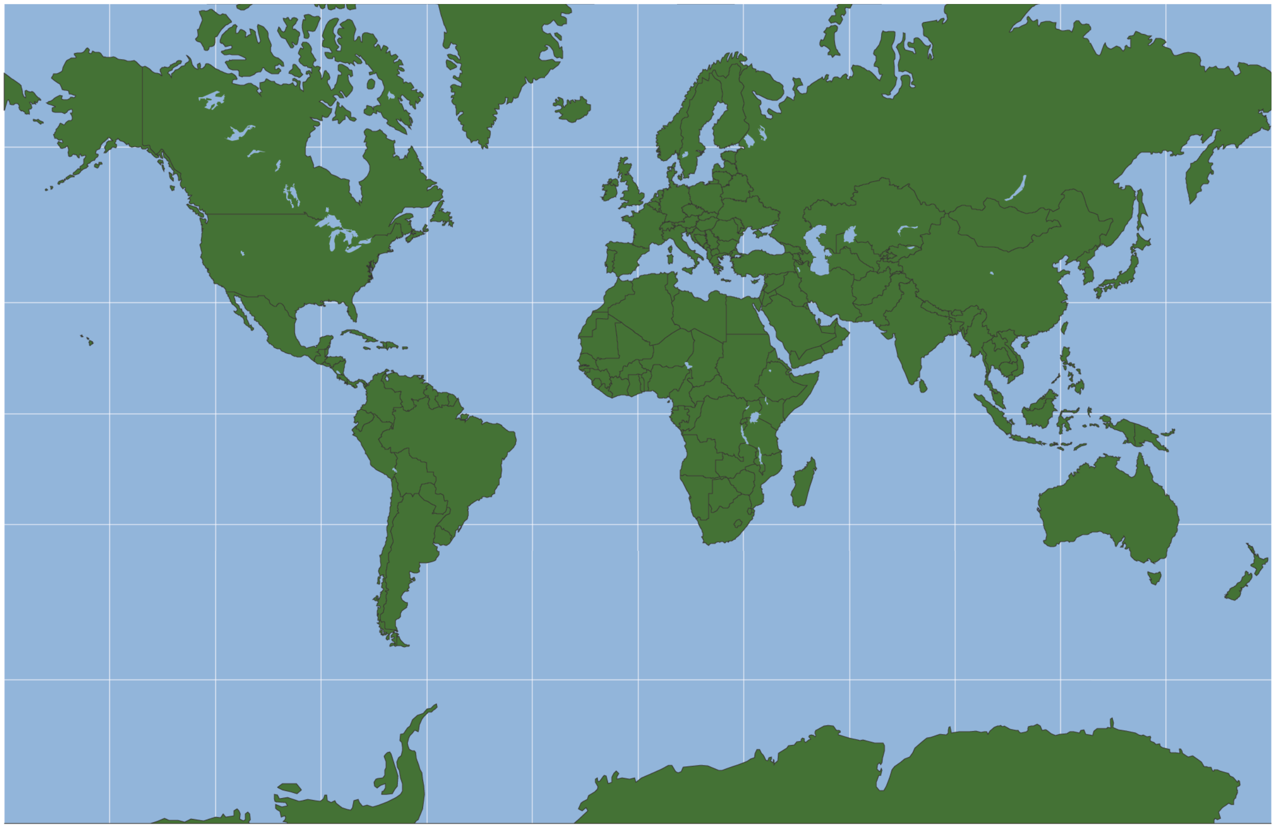

FIGURE 2.16 World map based on the Mercator projection system. *(Image Copyright: Michael Pidwirny)*

the cone so that its surface intersects the Earth at two parallels. This later case is more frequently used because it increases area depicted on the map that has reasonable accuracy. Conic projections are best suited for maps of mid-latitude regions. The United States, Europe, and Asia are frequently mapped with this system. Conic projects are also common in atlases.

Albers Equal Area is a popular conic projection that was developed by H.C. Albers in 1805 (**Figure 2.18**). This projection system mathematically projects the cone so that its surface intersects the Earth at two standard parallels. On this projection, all areas on the map are proportional to the same areas on the globe. Directions are only moderately accurate where the cone cuts the Earth's surface. Distance and scale are correct just along the standard parallels.

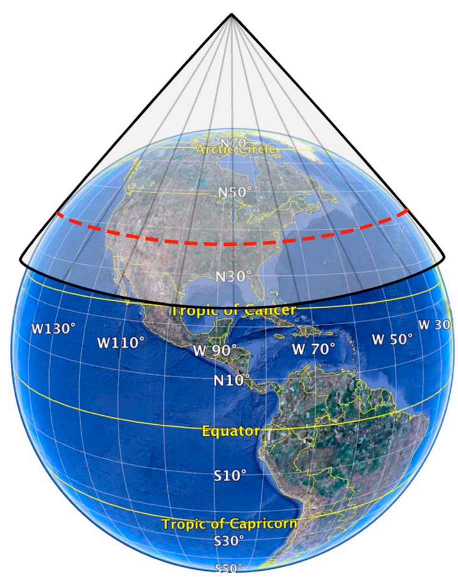

FIGURE 2.17 Conic projections are drawn as if the Earth's surface were projected onto a cone. In this illustration, the cone touches the Earth's surface at one standard parallel. More complex versions can intersect the globe at two standard parallels. This projection is best suited for constructing maps of regions in the middle latitudes. *(Image Copyright: Michael Pidwirny)*

Planar Projections

Planar or **Azimuthal projections** are systems that project the Earth onto a flat surface or plane (**Figure 2.19**). The Earth's surface touches this plane at only one single point or tangent. The alternative name for this projection, azimuthal, is derived from one of its important properties. Lines of compass **bearing** or **azimuths** are true only from

FIGURE 2.18 Map of North America created with the Albers Equal AREA PROJECTION. his map uses two standard parallel in the projection process: 20 and 60° North. Distances are true only along these lines of latitude. Areas are proportional to the same areas on the Earth's surface. Directions are reasonably accurate in the regions around the standard parallels. *(Image Copyright: Michael Pidwirny)*

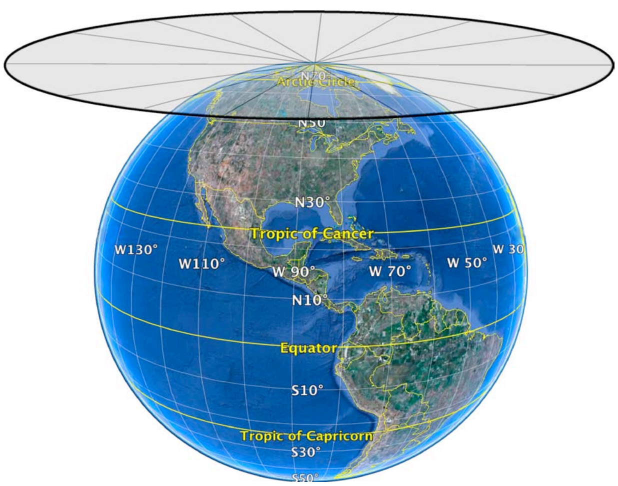

FIGURE 2.19 Planar projections are drawn as if the Earth's surface were projected onto a flat surface or plane. In this illustration, the plane touches the Earth's surface at only one point of the Earth's surface – the North Pole. More complex versions of this projection can be created by geometrically varying the way the Earth's surface is projected onto the plane. *(Image Copyright: Michael Pidwirny)*

the center of the map. The ancient Greeks constructed the first planar maps in about 600 BC. Modern versions of this projection are often used to illustrate the planet's polar regions. However, these maps are plagued by area and shape distortion that increases from the tangent point. Some navigators use a geometrically altered form of this projection called gnomonic (**Figure 2.20**). The gnomonic map projection allows one to determine the shortest path (not distance) between two points and is therefore suited for some forms of navigation

Other Projections

Mathematical techniques have been developed to project the Earth's surface on a variety of two-dimensional shapes. Many of these projections have been created to compensate for some type of distortion artifact. **Figure 2.21** displays the **Robinson projection** which projects the globe on a somewhat oval shape. This projection was developed by Arthur H. Robinson in 1963 to show the entire Earth with less distortion of area.

TOPOGRAPHIC MAPS

A **topographic map** is a detailed and accurate two-dimensional representation of natural and human-made features on the Earth's surface. These maps are used for a number of applications, from camping, hunting, fishing, and hiking to urban planning, resource management, and surveying. The most distinctive characteristic of a topographic map is that the three-dimensional shape of the Earth's surface is modeled by the use of **contour lines**.

FIGURE 2.20 Map of the region around the North Pole. This map was created with a Gnomonic planar projection. In this projection, lines of longitude appear as straight-lines that radiate out from the North Pole. Lines of latitude appear as circles. Scale distortion increases rapidly away from the central point (North Pole) of this projection. This map can be used by navigators to find the shortest path between two points. *(Image Copyright: Michael Pidwirny)*

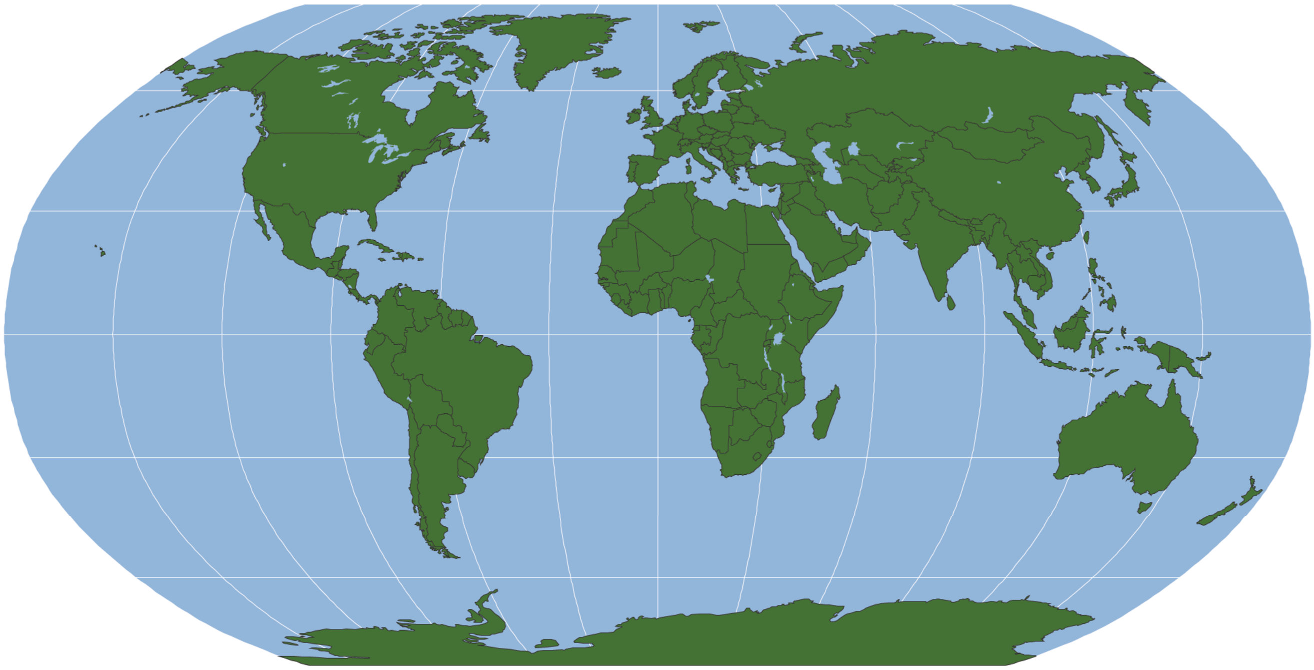

FIGURE 2.21 The Robinson projection is commonly used in maps that require a somewhat accurate representation of area. This map projection was originally developed for atlas producer Rand McNally in the early 1960s. *(Image Copyright: Michael Pidwirny)*

Contours are imaginary lines that connect locations of similar elevation. Contours make it possible to represent the height of mountains and steepness of slopes on a two-dimensional map surface. Topographic maps also use a variety of symbols to describe both natural and human-made features such as roads, buildings, quarries, lakes, streams, and vegetation.

Topographic maps have been made by the United States Geological Survey (USGS) since 1879 (**Figure 2.22**). Coverage of the United States is available at scales of 1:20,000 (Puerto Rico only), 1:24,000, 1:25,000 (metric), 1:30,000 (Puerto Rico only), 1:62,250, 1:63,360 (Alaska only), 1:100,000 and 1:250,000. Canadian topographic maps produced by the National Topographic System of Canada (NTS) are generally available in two different scales: 1:50,000 and 1:250,000. Topographic maps with a scale of 1:25,000 are relatively large-scale and a typical map sheet covers an approximate area of between 125 to 165 km^2. At this scale, features as small as a single home can be easily shown (**Figure 2.23**). The smaller scale 1:250,000 topographic map is more for general reconnaissance-type purposes (**Figure 2.24**). A map of this scale covers the same area of land as sixty-four 1:25,000 scale maps.

Topographic Map Symbols

Topographic maps use a variety of symbols to represent natural and human constructed features found in the environment. The symbols used to represent features can be of three types: points, lines, and polygons. Points are used to depict features like bridges and buildings. Lines are used to graphically illustrate features that are linear, such as roads, railways, and rivers. Polygons are used to characterize features like buildings, water bodies, or areas of specific land-use. Some polygons are identified only through the use of color. For example, urban land-use is often shaded pink, natural vegetation - green, glaciers - pale blue, and cropland - white.

The set of symbols used on topographic maps has been standardized to simplify the map construction process. Standardization also makes using topographic maps easier because only one system of symbolization needs to be learned by the map user. A description of some of the symbols used can be seen in **Figure 2.25**. Despite the existence of standardization, we can sometimes find topographic maps that use different symbols to depict a feature. This occurs because the symbols used in these maps are continuously refined over time.

Contour Lines

Topographic maps can describe vertical information through the use of contour lines (contours). A **contour line** is an isoline that connects points on a map that have the same elevation. Contours are often drawn on a map at a uniform vertical distance. This distance is called the contour interval. The map in **Figure 2.26** shows contour lines with an interval of 100 meters (m). Note that every fifth brown contour line is drawn bold and has the appropriate elevation labeled on it. These contours are called **index contours**. On **Figure 2.26** they represent elevations of 100, 200, 300, 400 m and so on. The interval at which contours are drawn on a map depends on the amount of the relief depicted and the scale of the map.

Contour lines provide us with a simple effective system for describing landscape configuration on a two-dimensional map. The arrangement, spacing, and shape of the contours provide the user of the map with some idea of what the actual topographic configuration of the land surface looks like. Contour intervals that are spaced closely together describe a steep slope. Gentle slopes are indicated by widely spaced contours. Contour lines that V upwards indicate the presence of a river valley. Ridges are shown by contours that V downwards.

Topographic Map Profiles

A topographic profile is a two-dimensional diagram that describes the landscape in vertical cross-section. Topographic profiles are often created from the contour information found on topographic maps. The simplest way to construct a topographic profile is to place a sheet of blank paper along a horizontal transect of interest. From the map, elevations of the various contours are transferred on to the edge of the paper from the map. On a sheet of graph paper we use the x-axis to represent the horizontal distance covered by a transect. The y-axis is used to represent the vertical dimension and measures the change in map elevation. Most people exaggerate the measure of elevation on the y-axis to make changes in relief stand out. We then place the beginning of the transect, as copied on the piece

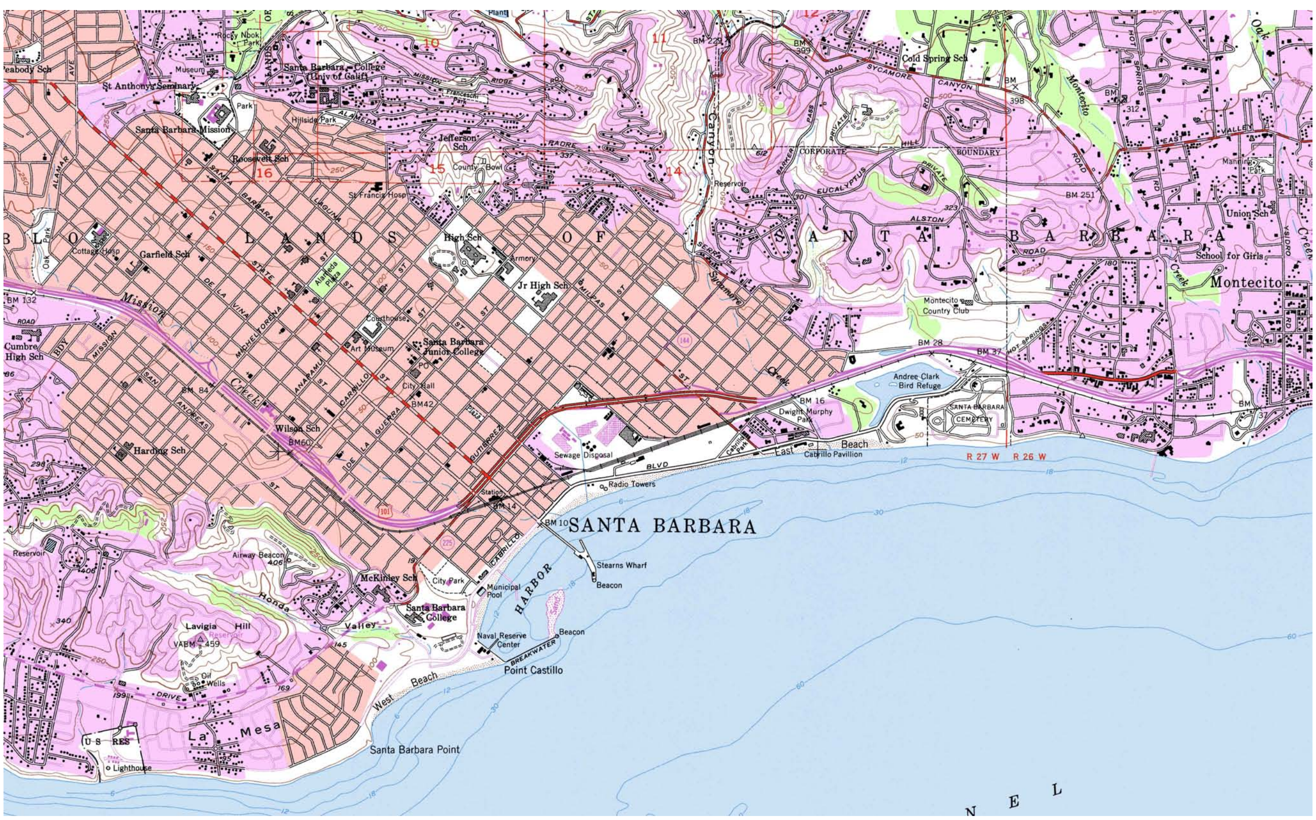

FIGURE 2.22 Part of the 1:24,000 United States Geological Survey topographic map of Santa Barbara, California. On this map we can see that many different symbols are used to display natural and human-made features in this landscape. Color shading is used to categorize land-use. Pink indicates urban built area, blue is used to show ocean and other water bodies, light purple depicts extensions of urban areas, and green is used to define areas of natural vegetation. *(Source: United States Geological Survey)*

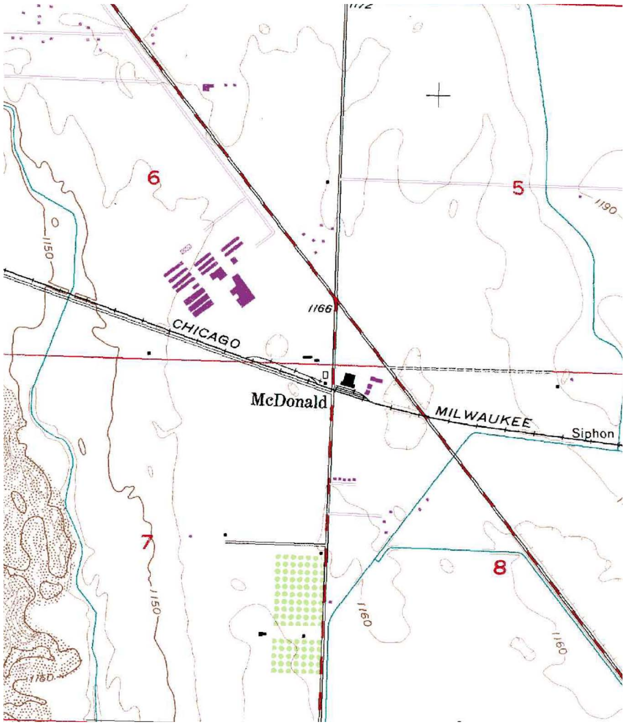

FIGURE 2.23 A portion of the 1:24,000 United States Geological Survey topographic map of Sieler, Washington. Note that at this scale, houses and other buildings are clearly illustrated. *(Source: United States Geological Survey)*

of paper, at the intersect of the x and y-axis on the graph paper. The contour information on the paper's edge is now copied onto the piece of graph paper. **Figure 2.27** describes a topographic profile drawn from the information found on the transect A-B.

Measuring Distance on Topographic Maps

Early in this chapter, we learned that depicting the Earth's three-dimensional surface on a two-dimensional map creates a number of distortions that involve distance, area, and direction. It is possible to create maps that are somewhat equidistant. However, even these types of maps have some form of distance distortion. Equidistance maps can only control distortion along either lines of latitude or lines of longitude. Distance is often correct on equidistance maps only in the direction of latitude.

On a map that has a large scale, 1:125,000 or larger, distance distortion is usually insignificant. An example of a large-scale map is a standard topographic map. On these maps measuring straight-line distance is simple. Distance is first measured on the map using a ruler. This measurement is then converted into a real world distance using the map's scale. For example, if we measured a distance of 10 cm on

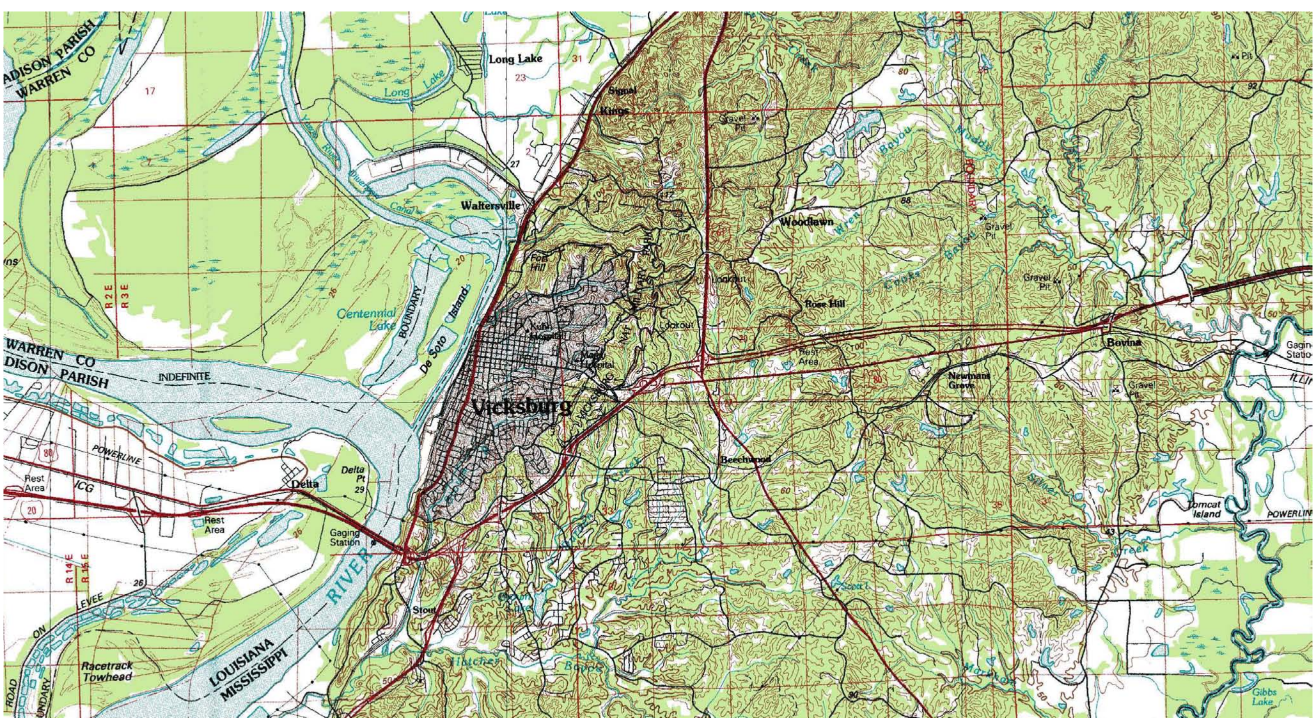

FIGURE 2.24 Part of the 1:250,000 United States Geological Survey topographic map of Jackson, Mississippi and Louisiana. Note that at this scale, some urban settlements appear as a single point on the map. *(Source: United States Geological Survey)*

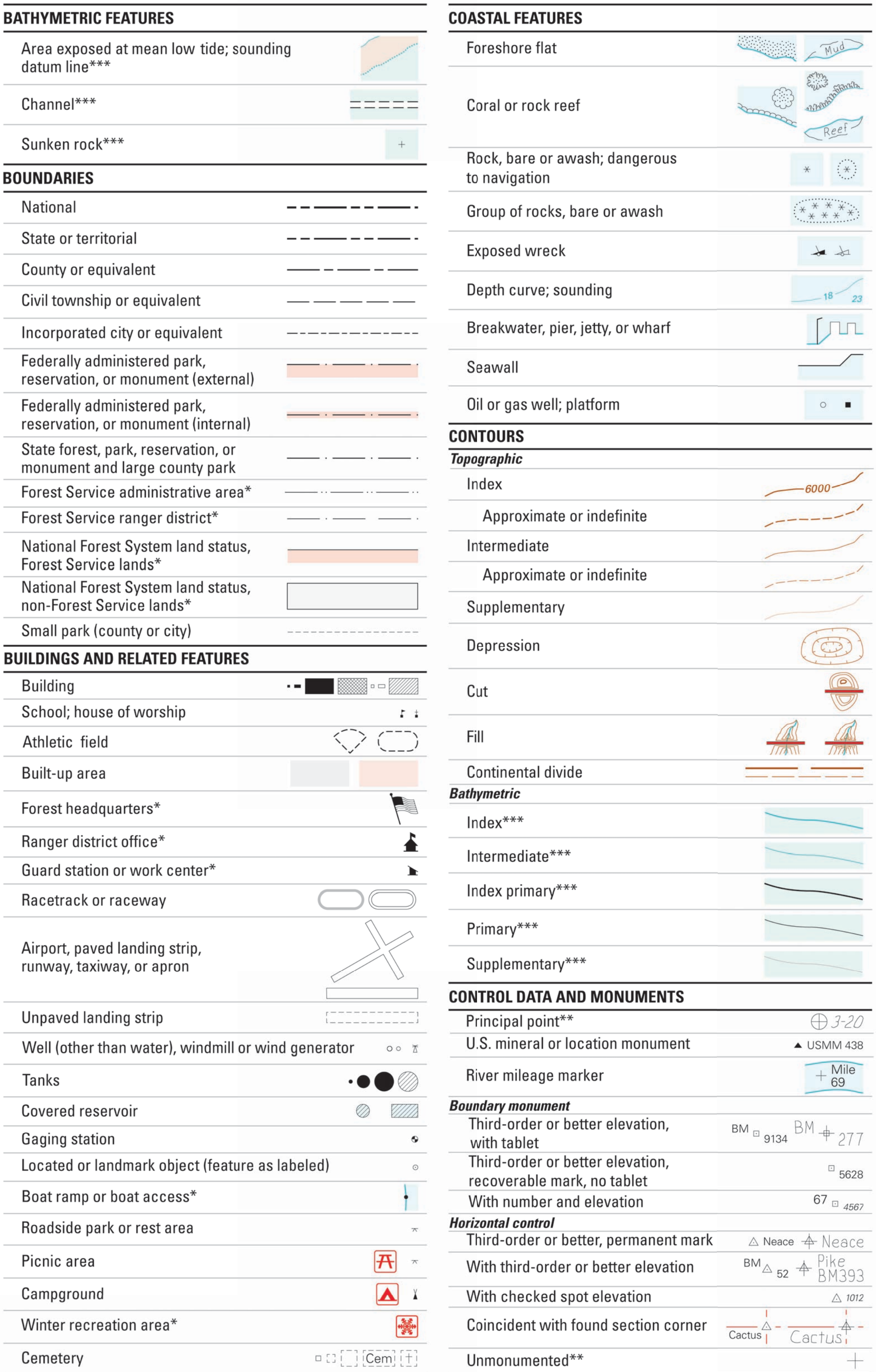

FIGURE 2.25 Some of the symbols used in United States Geological Survey topographic maps.. *(Source: United States Geological Survey)*

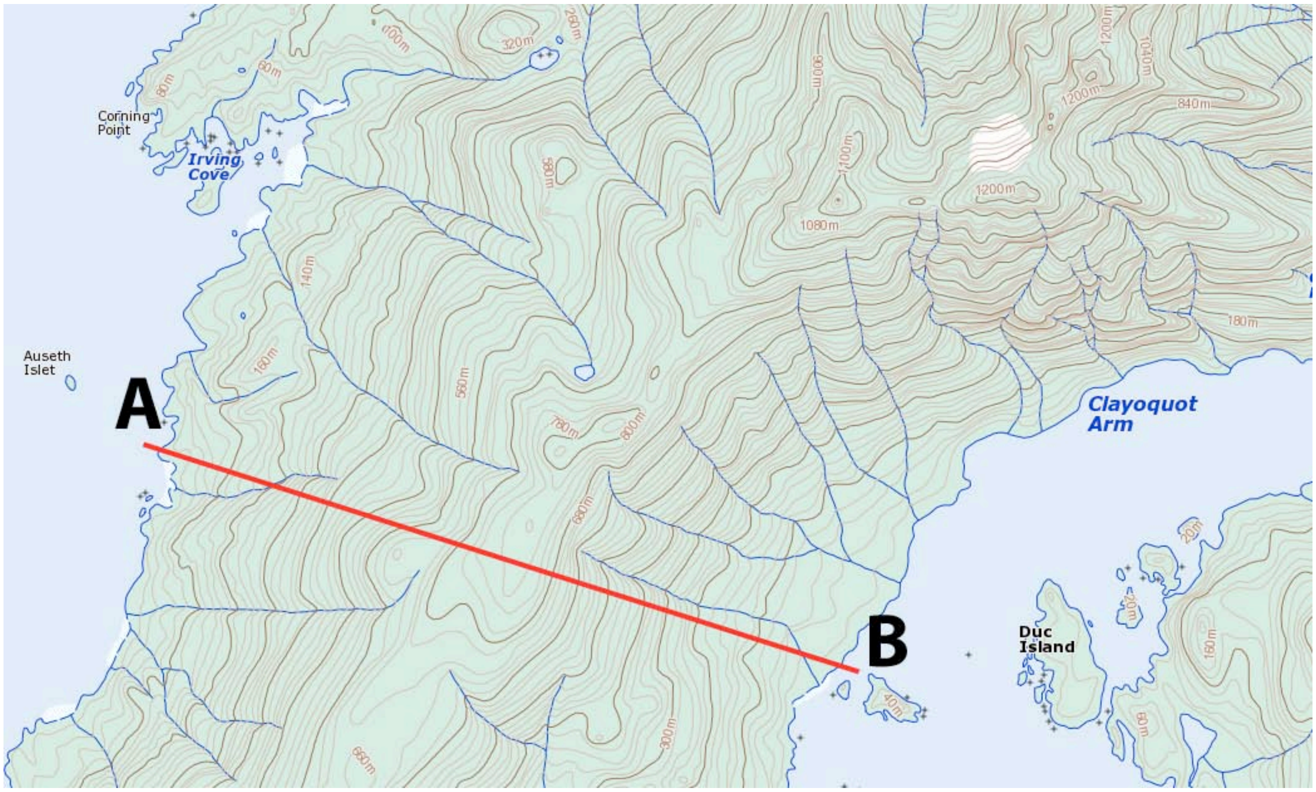

FIGURE 2.26 Topographic map - contour lines. portion of the Tofino 1:50,000 National Topographic System of Canada map sheet 092F4. The brown lines drawn on this map are contour lines. Each line represents a vertical increase in elevation of 25 meters (m). The bold brown contour lines are called index contours. The index contours are labeled with their appropriate elevation which increases at a rate of 100 meters (m). Note the blue line drawn to separate water from land represents an elevation of 0 meters or sea level. *(Source: Natural Resources Canada - Toporama)*

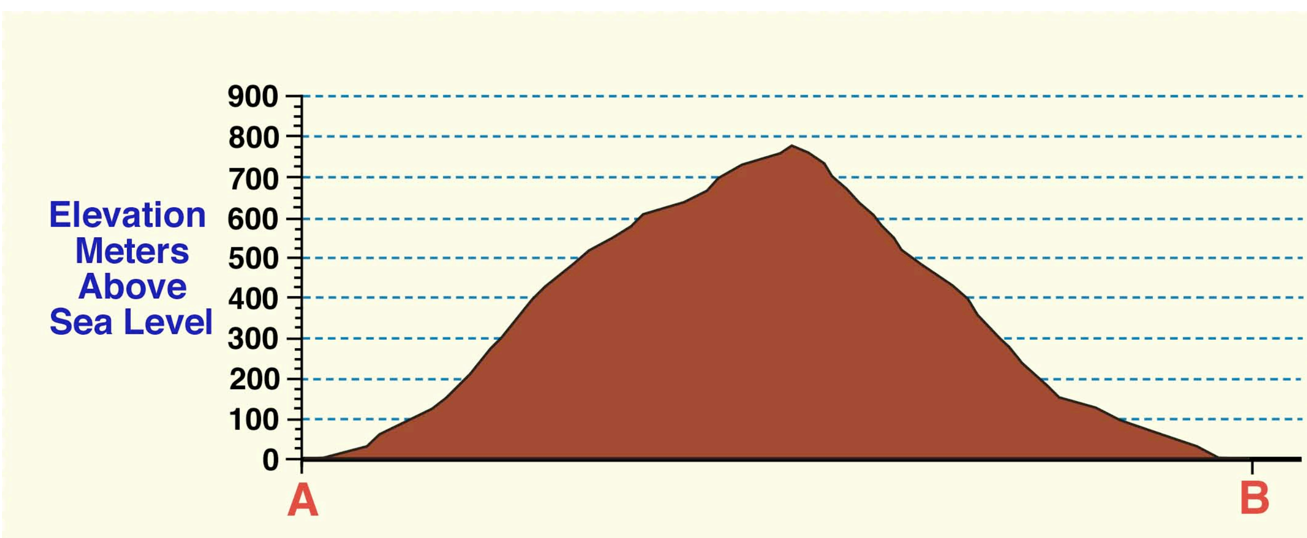

FIGURE 2.27 The following topographic profile shows the vertical change in surface elevation along the transect A-B from Figure 2.27. A vertical exaggeration of about 4.2 times was used in the profile (horizontal scale = 1:50,000, vertical scale = 1:12,000 and vertical exaggeration = horizontal scale/vertical scale). *(Image Copyright: Michael Pidwirny)*

a map that had a scale of 1:10,000, we would multiply 10 (distance) by 10,000 (scale). Thus, the actual distance in the real world would be 100,000 cm.

Measuring distance along map features that are not straight is a little more difficult. One technique that can be employed for this task is to use a number of straight-line segments. The accuracy of this method is dependent on the number of line segments used (**Figure 2.28**). Another method for measuring curvilinear map distances is to use a mechanical device called an **opisometer** (**Figure 2.29**). This device uses a small rotating wheel that records the distance traveled.

Measuring Direction on Topographic Maps

Like distance, direction is difficult to measure on maps because of the distortion produced by projection systems. However, this distortion is quite small on maps with scales larger than 1:125,000. Direction is usually measured relative to the location of North or South Pole. Directions determined from these locations are said to be relative to **True North** or **True South**. The magnetic poles can also be used to measure direction. However, these points on the Earth are located in spatially different spots from the geographic North and South Pole. The **North Magnetic Pole** is located at 82° 42' North, 104° 24' West near Ellef Ringnes Island, Canada. In the Southern Hemisphere, the **South Magnetic Pole** is located in Commonwealth Day, Antarctica and has a geographical location of 64° 30' south, 137° 52' east. The magnetic poles are also not fixed overtime and shift their spatial position overtime.

Topographic maps normally have a declination diagram drawn on them (**Figure 2.30**). On Northern Hemisphere maps, declination diagrams describe the angular difference between Magnetic North and True

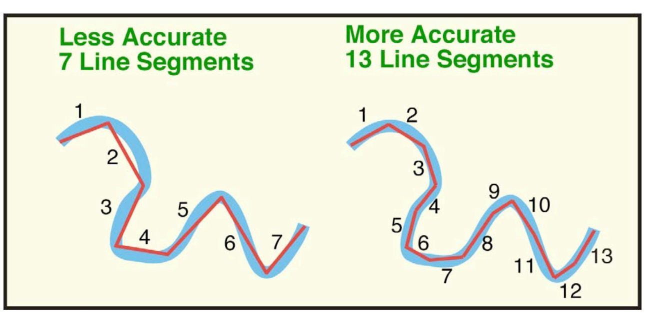

FIGURE 2.28 Measurement of distance on a map feature using straight-line segments. Accuracy increases with the number of segments used. *(Image Copyright: Michael Pidwirny)*

FIGURE 2.29 An opisometer is a mechanical instrument used to measure distance on maps. *(Image Copyright: Michael Pidwirny)*

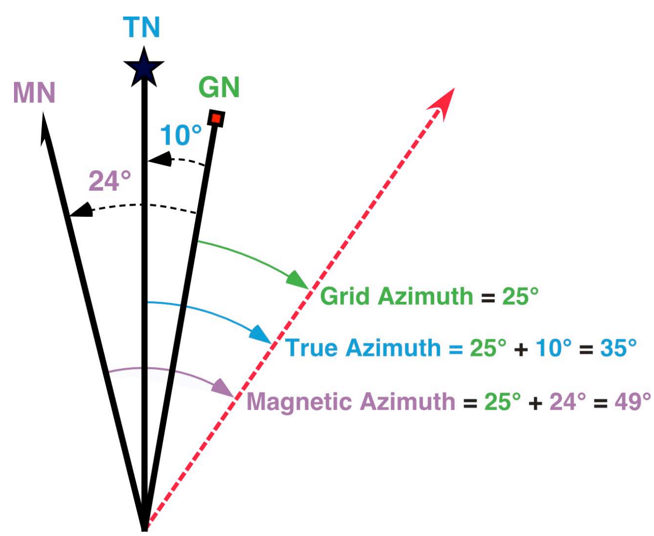

FIGURE 2.30 This declination diagram describes the angular difference between Grid, True, and Magnetic North. The declination diagram shows the angular difference between Grid North and true North, and between Grid North and Magnetic North. Angles on maps are usually measured relative to Grid North. Using the declination diagram, one can then convert the Grid angle or azimuth into its True or Magnetic equivalents. *(Image Copyright: Michael Pidwirny)*

North. On the map, the angle of True North is parallel to the depicted lines of longitude. Declination diagrams also show the direction of **Grid North**. Grid North is an angle that is parallel to the easting lines found on the Universal Transverse Mercator (UTM) grid system.

In the field, the direction of features is often determined by a magnetic compass that measures angles relative to Magnetic North. Using the declination diagram found on a map, individuals can convert their field measures of magnetic direction into directions that are relative to either Grid or True North. Compass and map directions can be described by using either the azimuth system or the bearing system. The **azimuth system** calculates direction in degrees of a full circle. A full circle has 360° (**Figure 2.31**). In the azimuth system, north has a direction of either the zero or 360°. East and west have an azimuth of 90° and 270°, respectively. Due south has an azimuth of 180°.

The **bearing system** divides direction into four quadrants of 90°. In this system, north and south are the dominant directions. Measurements are determined in degrees from one of these directions to either east or west. The measurement of two angles based on this system is described in **Figure 2.32**.

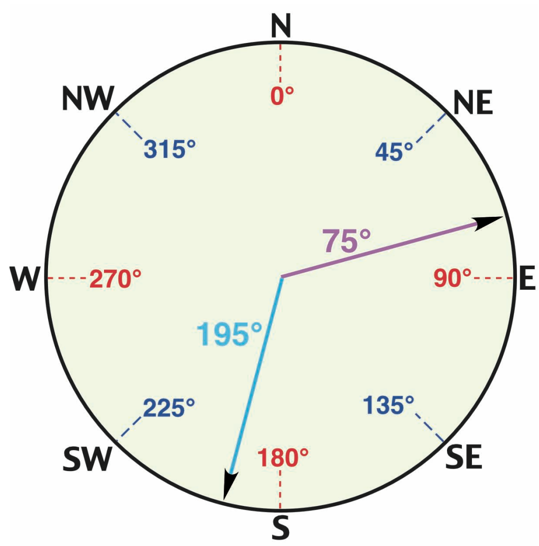

FIGURE 2.31 Azimuth system for measuring direction is based on the 360 degrees found in a full circle. The illustration shows the angles associated with the major cardinal points of the compass. Note that angles are determined clockwise from north. *(Image Copyright: Michael Pidwirny)*

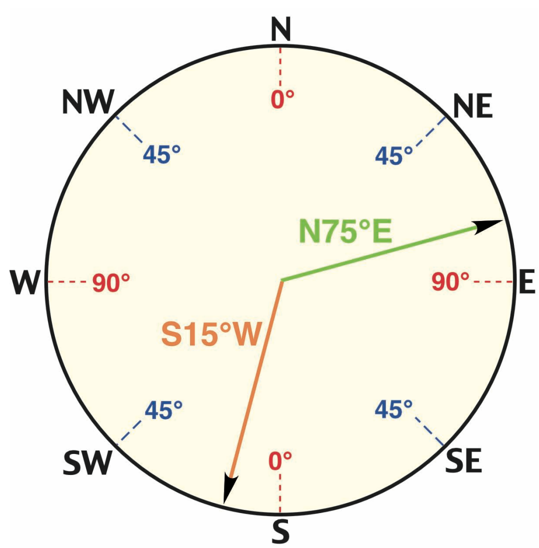

FIGURE 2.32 The bearing system uses four quadrants of 90° to measure direction. The illustration shows two direction measurements. These measurements are made relative to either north or south. North and south are given the measurement o degrees. East and west have a value of 90°. The first measurement (green) is found in the north - east quadrant. As a result, its measurement is north 75° to the east or N75°E. The first measurement (orange) is found in the south - west quadrant. Its measurement is south 15° to the west or S15°W. *(Image Copyright: Michael Pidwirny)*

TIME ZONES

Before the late nineteenth century, time keeping was essentially a local phenomenon. Each town would set their clocks according to the motions of the Sun. Noon was defined as the time when the Sun would reach its maximum altitude above the horizon. A day was defined as the time it took the Sun to complete one cycle of day and night and return to the same place in the sky. Cities and towns would assign an individual to calibrate a sundial or clock to these solar motions. This timepiece would then represent official time and the citizens would set their watches and clocks accordingly.

The later half of the nineteenth century was a time of increased movement of humans. In the United States and Canada, large numbers of people were moving west and settlements in these areas began expanding rapidly. To support these new settlements, railroads moved people and resources between the various cities and towns. However, because of the nature of how local time was kept, the railroads experienced major problems in constructing timetables for the various stops. The railroad companies tried to simplify time keeping by establishing railroad time along sections of their routes. This procedure failed to make things simpler, and by 1883 there were about 100 different railroad times. Timetables could only become more efficient if the towns and cities adopted some type of standard method of keeping time based on broader geographical units.

Coordinating Time

In 1878, Canadian Sir Sanford Fleming suggested a system of worldwide time zones that would simplify the keeping of time across the Earth. Fleming proposed that the globe be divided into 24 time zones, each 15° of longitude in width. Since the world rotates once every 24 hr on its axis and there are 360° of longitude, each hour of Earth rotation represents 15° of longitude. Under Fleming's system, Canada and the United States would have five time zones over their geography.

Railroad companies in Canada and the United States began using Fleming's time zones in 1883. In 1884, an International Prime Meridian Conference was held in Washington D.C. to adopt a standardized method of time keeping and to determine the location of the prime meridian. Conference members agreed that the longitude of Greenwich, England would become 0° longitude and established the 24 time zones relative to the prime meridian. It was also proposed that the measurement of time on the Earth would be made relative to the astronomical measurements at the Royal Observatory at Greenwich. This time standard was called **Greenwich Mean Time** (GMT).

Today, many nations operate on variations of the time zones suggested by Sir Fleming. **Figure 2.33** describes the various time zones currently used on the Earth. In this system, time in the various zones is measured relative the **Coordinated Universal Time** (UTC) standard at the prime meridian. Coordinated Universal Time became the standard legal reference of time all over the world in 1972. UTC is determined from six primary atomic clocks that are coordinated by the International Bureau of Weights and Measures (BIPM) located in France. The numbers located at the bottom of **Figure 2.33** indicate how many hours each zone is ahead (negative sign) or behind (positive sign) the Coordinated Universal Time standard. Note that the prime

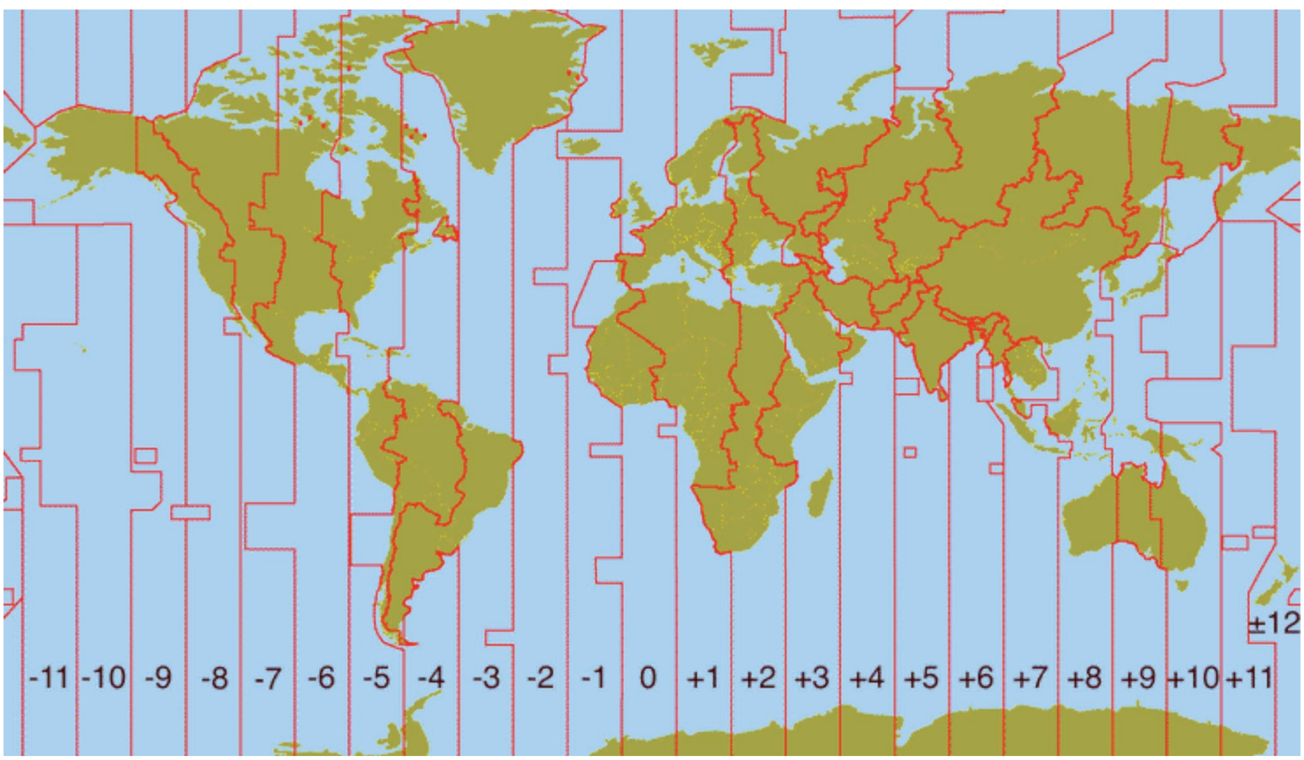

FIGURE 2.33 The world's modern standard time zones are measured relative to Coordinated Universal Time. Each time zone is about 15° wide. Some local variations occur to accommodate political boundaries. The numbers located at the bottom of the map indicate how many hours each zone is ahead (negative sign) or behind (positive sign) the time zone centered at the prime meridian. Some nations (for example, Australia and India) have offset their time zones by half an hour. Other nations, like China, have collapsed several times zones into a single zone across the Expanse of their country. *(Image Copyright: Michael Pidwirny)*

meridian is given a standardized time of zero. Also notice that some national boundaries and political matters influence the shape of the time zone boundaries. For example, China uses a single time zone (eight hours ahead of Coordinated Universal Time) instead of five different time zones.

International Date Line

Because time depends on longitude, there exists at any moment in time a meridian on the Earth that divides one day from another. The standardized location of this meridian is on the opposite side of the prime meridian. This meridian is appropriately named the **International Date Line**. Most of the International Date Line runs along the 180th meridian, except for a detour that separates Alaska and Siberia, and two other bypasses that avoid the Aleutian Islands and a group of islands in the South Pacific (**Figure 2.33**). These detours have been created to circumvent the problem of having two different dates within the same country or island group.

GEOGRAPHIC INFORMATION SYSTEMS

The advent of cheap and powerful computers over the last few decades has allowed for the development of innovative software applications for the storage, analysis, and display of geographic data. Many of these applications belong to a group of software known as a **Geographic Information System** (GIS). Many definitions have been proposed for what constitutes a GIS. Each of these definitions conforms to the particular task that is being performed. Instead of repeating each of the definitions, we should broadly define GIS according to what it does. Thus, the activities normally carried out on a GIS include:

- The measurement of natural and human made phenomena and processes from a spatial perspective. These measurements emphasize three types of properties commonly associated with the types of systems: elements, attributes, and relationships.

- The storage of measurements in digital form in a computer database. These measurements are often linked to features on a digital map. These features can be of three types: points, lines, or polygons (areas).

- The analysis of collected measurements to produce more data and to discover new relationships by numerically manipulating and modeling different pieces of data.

- The depiction of the measured or analyzed data in some type of display - maps, graphs, lists, or summary statistics.

Components of a GIS

A Geographic Information System combines computer cartography with a database management system. **Figure 2.34** describes some of the major components of GIS. This diagram suggests that a GIS consists of three subsystems: (1) an input system that allows for the collection of data to be used and analyzed for some purpose; (2) computer hardware and software systems that store the data, allow for data management and analysis, and can be used to display data manipulations on a computer monitor; (3) an output system that generates hard copy maps, visual images, and other types of output.

Two basic types of data are normally entered into a GIS. The first type of data consists of real world phenomena and features that have some kind of spatial dimension. Usually, these data elements are depicted mathematically in the GIS as points, lines, or polygons that are referenced geographically (or **geocoded**) to some type

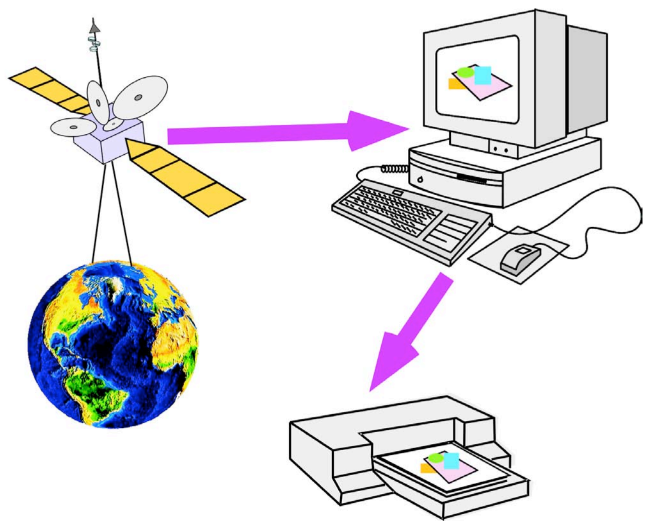

FIGURE 2.34 Three major components of a Geographic Information System. These components consist of input, computer hardware and software, and output subsystems. *(Image Copyright: Michael Pidwirny)*

of coordinate system. This type of data is entered into the GIS by devices like scanners, digitizers, GPS, air photos, and satellite imagery. The other type of data is sometimes referred to as an attribute. Attributes are pieces of data that are connected or related to the points, lines, or polygons mapped in the GIS. This attribute data can be analyzed to determine patterns of importance. Attribute data is entered directly into a database where it is associated with element data.

The difference between element and attribute data can be illustrated in **Figure 2.35** and **2.36**. **Figure 2.35** shows the locations of some of the earthquakes that have occurred in the last century. These plotted data points can be defined as elements because their main purpose is to describe the location of the earthquakes. For each of the earthquakes plotted on this map, the GIS also contains data on their depth. These measurements can be defined as attribute data because they are connected to the plotted earthquake locations in **Figure 2.35**. **Figure 2.36** shows the attribute earthquake depth organized into three categories: shallow, intermediate, and deep. This analysis indicates a possible relationship between earthquake depth and spatial location - deep earthquakes do not occur at the mid-oceanic ridges.

Within the GIS database a user can enter, analyze, and manipulate data that is associated with a spatial element in the real world. The cartographic software of the GIS enables one to display the geographic information at any scale or projection and as a variety of layers which can be turned on or off. Each layer would show some different aspect of a place on the Earth. These layers could show things like a road network, topography, vegetation cover, streams and water bodies, or the distribution of annual precipitation received. The output illustrated in **Figure 2.37** merges data layers for vegetation community type, glaciers and ice fields, and water bodies (streams, lakes, and ocean).

REMOTE SENSING

INTRODUCTION TO REMOTE SENSING

Remote sensing can be defined as the collection of data about an object from a distance. Humans and many other types of animals accomplish this task with the aid of eyes or by the sense of smell or hearing. Geographers use the technique of remote sensing to monitor or measure phenomena found in the Earth's lithosphere, biosphere, hydrosphere, and atmosphere. Remote sensing of the environment by geographers is usually done with the help of mechanical devices known as remote sensors. These gadgets have a greatly improved ability to receive and record information about an object without physical

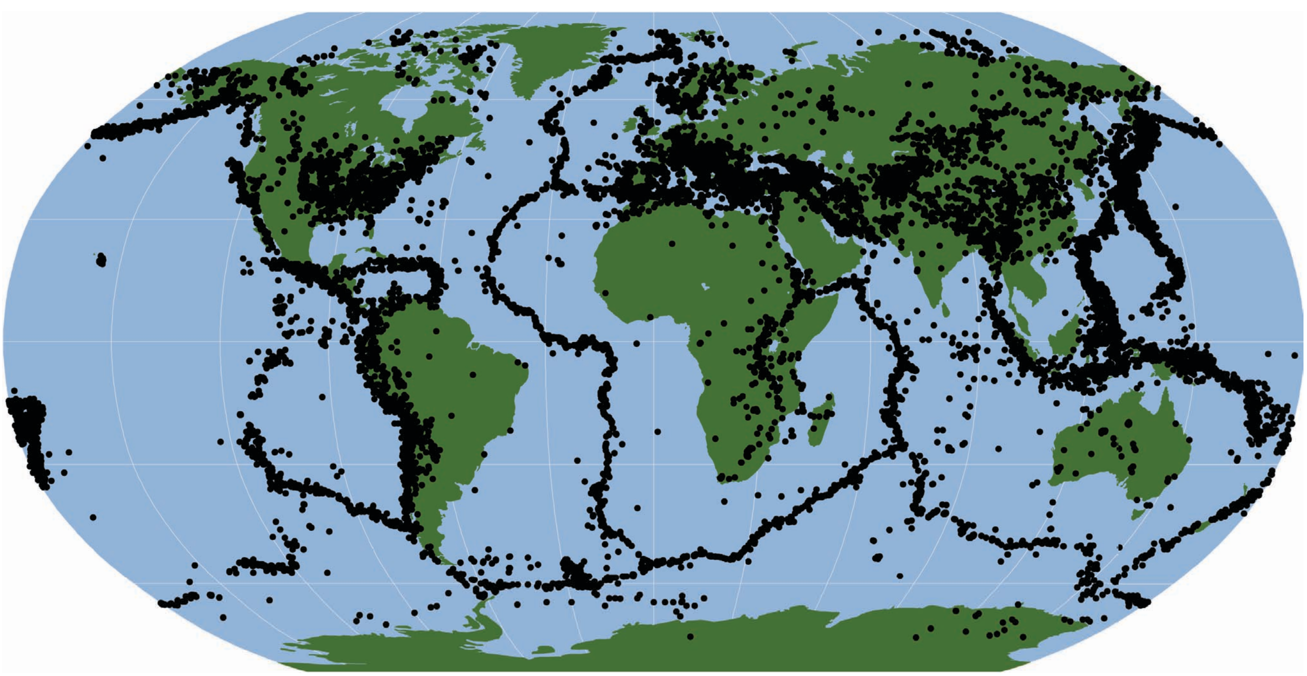

FIGURE 2.35 Global distribution of earthquake events that have occurred over the last century. *(Image Copyright: Michael Pidwirny)*

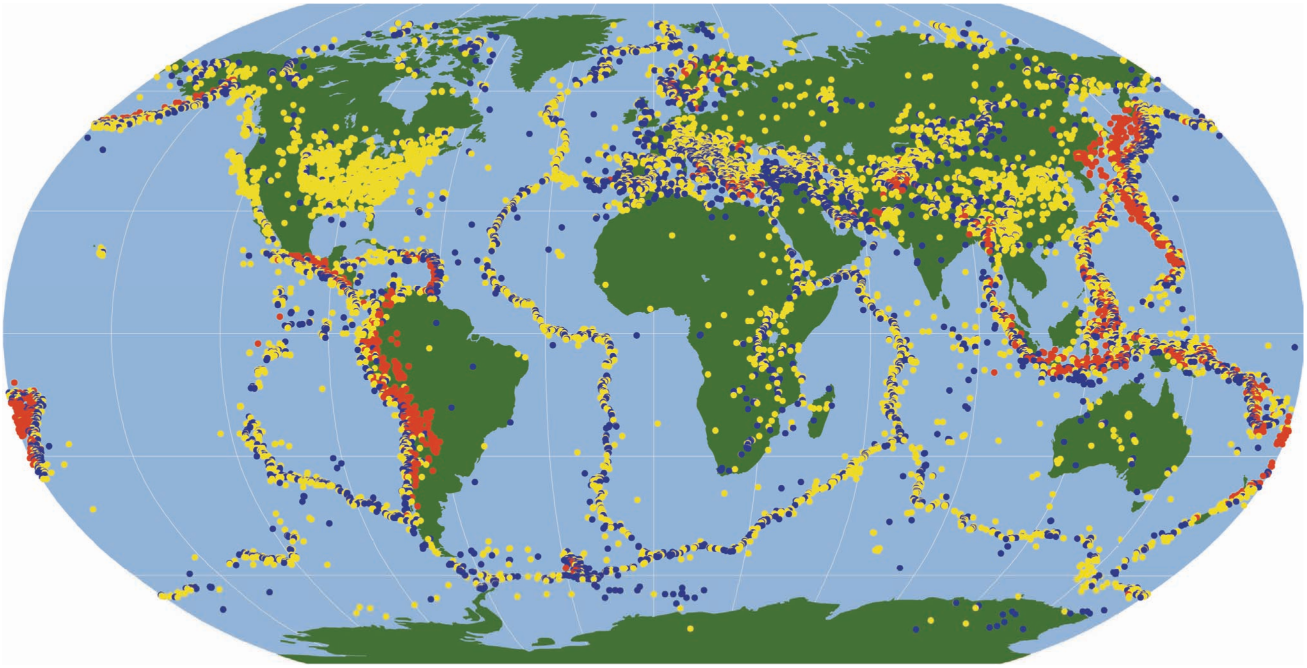

FIGURE 2.36 Earthquake events organized according to depth (yellow = surface to 25 kilometers below the surface, red = 26 to 75 kilometers below the surface, and black = 76 to 660 kilometers below the surface). *(Image Copyright: Michael Pidwirny)*

contact. Often, these sensors are positioned away from the object of interest by using helicopters, planes, and satellites. Most sensing devices record information about an object by measuring an object's transmission of electromagnetic radiation from reflecting and radiating surfaces.

Remote sensing imagery has many applications in mapping land-use and cover, agriculture, soils mapping, forestry, city planning, archaeological investigations, military observation, and geomorphologic surveying, among other uses. For example, foresters use aerial photographs for preparing forest cover maps, locating possible access roads, and measuring quantities of trees harvested. Specialized photography using color infrared film has also been used to detect disease and insect damage in forest trees.

The simplest form of remote sensing uses a photographic camera for imaging. This camera contains film that records information from visible or near infrared wavelengths (**Table 2.1**). In the late 1800s, cameras were positioned above the Earth's surface in balloons or kites to take oblique aerial photographs of the landscape. During World War I, aerial photography played an important role in gathering information about the position and movements of enemy troops. These photographs were often taken from airplanes. After the war, civilian use of aerial photography

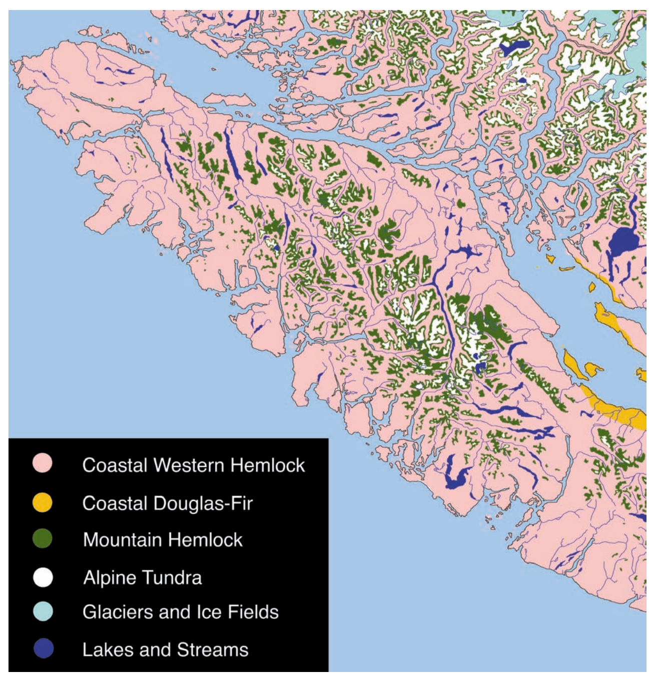

FIGURE 2.37 Graphic output from a GIS. This GIS contains information about the major plant communities, lakes and streams, and glaciers and ice fields found occupying the province of British Columbia, Canada. The output shows southern Vancouver Island and part of the British Columbia mainland. *(Image Copyright: Michael Pidwirny)*

TABLE 2.1 Major regions of the electromagnetic spectrum. See Appendix 1 for definitions of the various units of measurement used below.

Region Name	Wavelength	Comments
Gamma Ray	< 0.03 nanometers (nm)	Entirely absorbed by the Earth's atmosphere and not available for remote sensing.
X-ray	0.03 to 30 nanometers (nm)	Entirely absorbed by the Earth's atmosphere and not available for remote sensing.
Ultraviolet	0.03 to 0.4 micrometers (µm)	Wavelengths from 0.03 to 0.3 micrometers absorbed by ozone in the Earth's atmosphere.
Photographic Ultraviolet	0.3 to 0.4 micrometers (µm)	Available for remote sensing the Earth. Can be imaged with photographic film.
Visible	0.4 to 0.7 micrometers (µm)	Available for remote sensing the Earth. Can be imaged with photographic film.
Infrared	0.7 to 100 micrometers (µm)	Available for remote sensing the Earth. Can be imaged with photographic film.
Reflected Infrared	0.7 to 3.0 micrometers (µm)	Available for remote sensing the Earth. Near Infrared 0.7 to 0.9 micrometers. Can be imaged with photographic film.
Thermal Infrared	3.0 to 14 micrometers (µm)	Available for remote sensing the Earth. This wavelength cannot be captured with photographic film. Instead, mechanical sensors are used to image this wavelength band.
Microwave or Radar	0.1 to 100 centimeters (cm)	Longer wavelengths of this band can pass through clouds, fog, and rain. Images using this band can be made with sensors that actively emit microwaves.
Radio	> 100 centimeters (cm)	Not normally used for remote sensing the Earth.

from airplanes began with the systematic vertical imaging of large areas of Canada, the United States, and Europe. Many of these images were used to construct topographic and other types of reference maps of the natural and human-made features found on the Earth's surface.

The development of color photography following World War II gave a more natural depiction of surface objects. Color aerial photography also greatly increased the amount of information gathered from an object. The human eye can differentiate many more shades of color than tones of gray (**Figure 2.38** and **2.39**). In 1942 Kodak developed color infrared film, which records wavelengths in the near-infrared part of the electromagnetic spectrum. This film type had good haze penetration and the ability to determine the type and health of vegetation.

Satellite Remote Sensing

In the 1960s, a revolution in remote sensing technology began with the deployment of space satellites. From their high vantage point, satellites have a greatly extended view of the Earth's surface. The first meteorological satellite, TIROS-1 (**Figure 2.40**) was launched by the United States using an Atlas rocket on April 1, 1960. This early weather satellite used vidicon cameras to scan wide areas of the Earth's surface. Satellite remote sensors generally do not use conventional film to produce their images. Instead, these sensors digitally capture the images using a device similar to a television camera. Once captured, this data is then transmitted electronically to receiving stations found on the Earth's surface. The image in **Figure 2.41** is from TIROS-7 of a mid-latitude cyclone off the coast of New Zealand.

Today, the GOES (Geostationary Operational Environmental Satellite) system of satellites provides most of the remotely sensed weather information for North America. To cover the complete continent and adjacent oceans two satellites are employed in a geostationary orbit. The western half of North America and the eastern Pacific Ocean is monitored by GOES-10, which is directly above the equator and 135° West longitude. The eastern half of North America and the western Atlantic are cover by

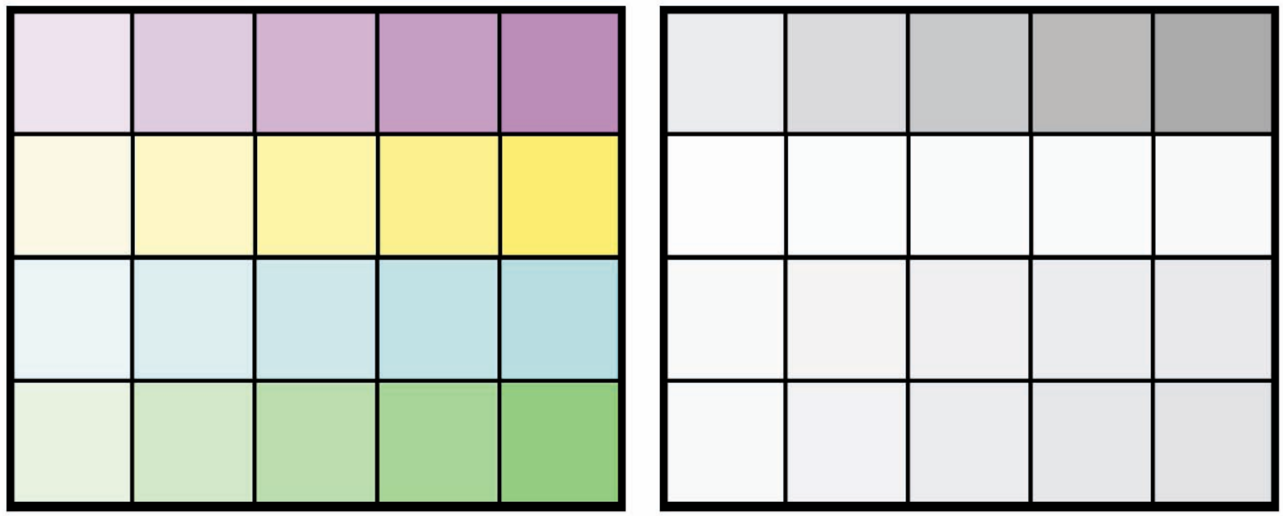

FIGURE 2.38 Differentiating shades in color and tones of gray. The rows of color tiles are replicated in the right as complementary gray tones. On the left, we can make out 18 to 20 different shades of color. On the right, only 7 shades of gray can be distinguished. *(Image Copyright: Michael Pidwirny)*

FIGURE 2.39 Comparison of black and white and color images of the same scene. Note how the increased number of tones found on the color image make the scene much easier to interpret. *(Source: University of California at Berkley - Earth Sciences and Map Library)*

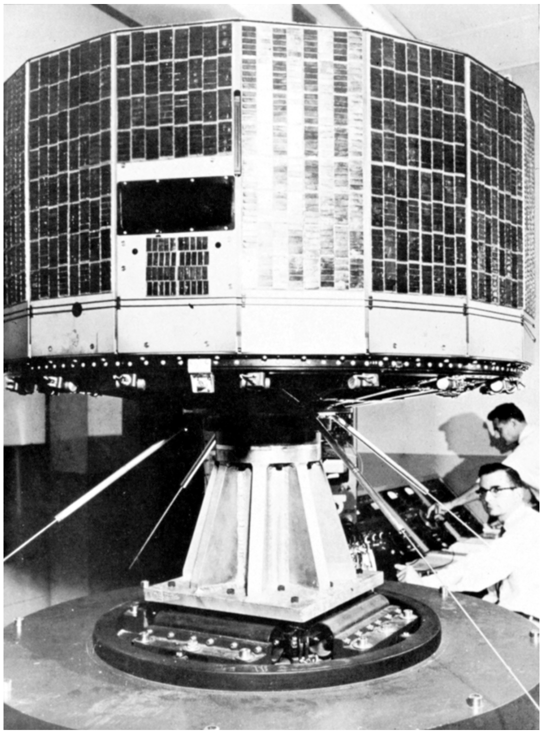

FIGURE 2.40 TIROS-1 meteorological satellite *(Source: NASA)*

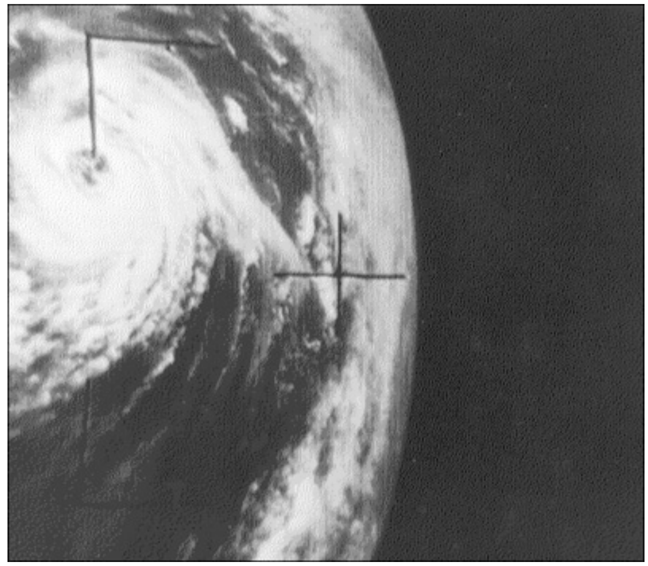

FIGURE 2.41 TIROS-7 image of a mid-latitude cyclone off the coast of New Zealand, August 24, 1964. *(Source: NASA - Looking at Earth From Space)*

GOES-8. The GOES-8 satellite is located overhead of the equator and 75° West longitude. Advanced sensors aboard the GOES satellite produce a continuous data stream so images can be viewed at any instance. The imaging sensor produces visible and infrared images of the Earth's terrestrial surface and oceans (**Figure 2.42**). Infrared images can depict weather conditions even during the night. Another sensor aboard the satellite has the ability to determine vertical temperature profiles, vertical moisture profiles, total precipitable water, and atmospheric stability.

In the 1970s, the second revolution in remote sensing technology began with the deployment of the **Landsat** satellites by the USA. Since this 1972, several generations of Landsat satellites with their image sensors have been providing continuous coverage of the Earth for almost 30 years. Currently, Landsat satellites orbit the Earth's surface at an altitude of approximately 700 kilometers. Spatial resolution of objects on the ground surface is 79 x 56 meters. Complete coverage of the globe requires 233 orbits and occurs every 16 days. Landsat's main imaging sensor, called a **multispectral scanner**, records a zone of the Earth's surface that is 185 km wide in four wavelength bands: band 4 at 0.5 to 0.6 µm (micrometers), band 5 at 0.6 to 0.7 µm, band 6 at 0.7 to 0.8 µm, and band 7 at 0.8 to 1.1 µm. Bands 4 and 5 receive the green and red wavelengths in the visible light range of the electromagnetic spectrum. The last two bands image near-infrared wavelengths. A second sensing system was added to Landsat satellites launched after 1982. This imaging system, known as the **thematic mapper**, records seven wavelength bands from the visible to far-infrared portions of the electromagnetic spectrum (**Figure 2.43**). In addition, the ground resolution of this sensor was enhanced to 30 x 20 m (98 x 66 ft). This modification allows for greatly improved clarity of imaged objects.

The usefulness of satellites for remote sensing has resulted in several other organizations launching their own devices. In France, the **SPOT** (Systeme de l'Observation

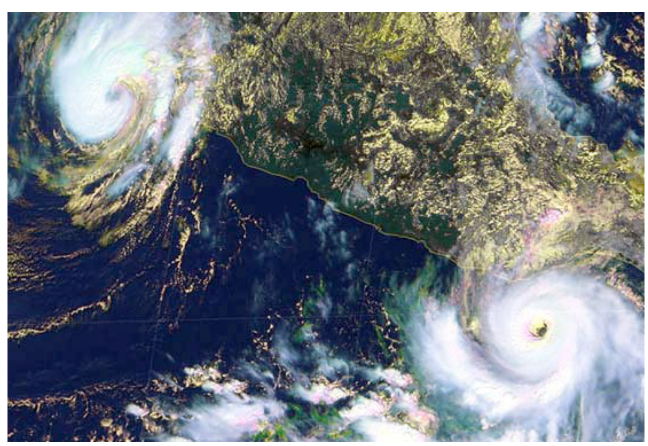

FIGURE 2.42 Color enhanced image from GOES-8 of hurricanes Madeline and Lester off the coast of Mexico, October 17, 1998. *(Source: NASA - Looking at Earth From Space).*

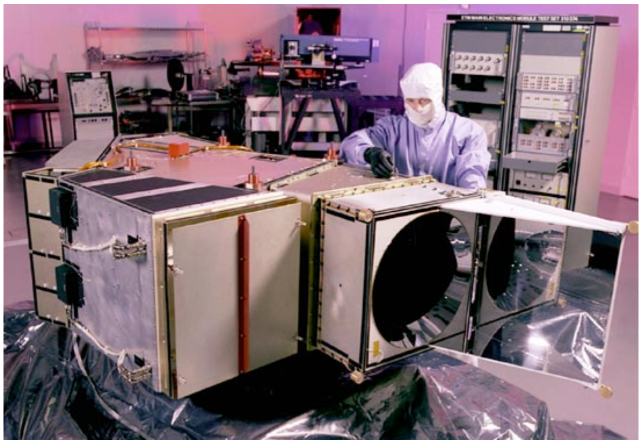

FIGURE 2.43 The Landsat 7 enhanced Thematic Mapper instrument. *(Source: Landsat 7 Home Page)*

de la Terre) satellite program has launched five satellites since 1986. Since 1986, SPOT satellites have produced more than 10 million images of our planet. The first four SPOT satellites employed two different sensing systems to image the Earth's surface. One sensing system produces black and white panchromatic images from the visible band (0.51 to 0.73 µm) with a ground resolution of 10 x 10 m (33 x 33 ft). The other sensing system is a multispectral imaging device that captures green, red, and reflected infrared bands at 20 x 20 m (66 x 66 ft) (**Figure 2.44**). SPOT-5 launched on May 4, 2002, was much improved in comparison to its siblings. This satellite has a ground resolution as fine as 2.5 x 2.5 m (8.2 x 8.2 ft) in both panchromatic mode and multispectral operation.

Radarsat-1 was launched by the Canadian Space Agency in November, 1995. As a remote sensing device, Radarsat is quite different from the Landsat and SPOT satellites. Radarsat is an **active remote sensing** system that transmits and receives microwave emissions. In contrast, Landsat and SPOT sensors measure the reflected radiation at wavelengths roughly equivalent to those detected by our eyes (**passive remote sensing**). Radarsat's microwave energy penetrates clouds, rain, dust, or haze and can produce images in total darkness. Radarsat images have a resolution between 8 to 100 m. This sensor has found important applications in crop monitoring, defense surveillance, disaster monitoring, geologic resource mapping, sea-ice mapping and monitoring, oil slick detection, and digital elevation modeling (**Figure 2.45**). An improved Radarsat-2 was launched in the spring of 2007.

FIGURE 2.44 SPOT false-color image of Harrisburg, Pennsylvania. *(Source: SPOT Image)*

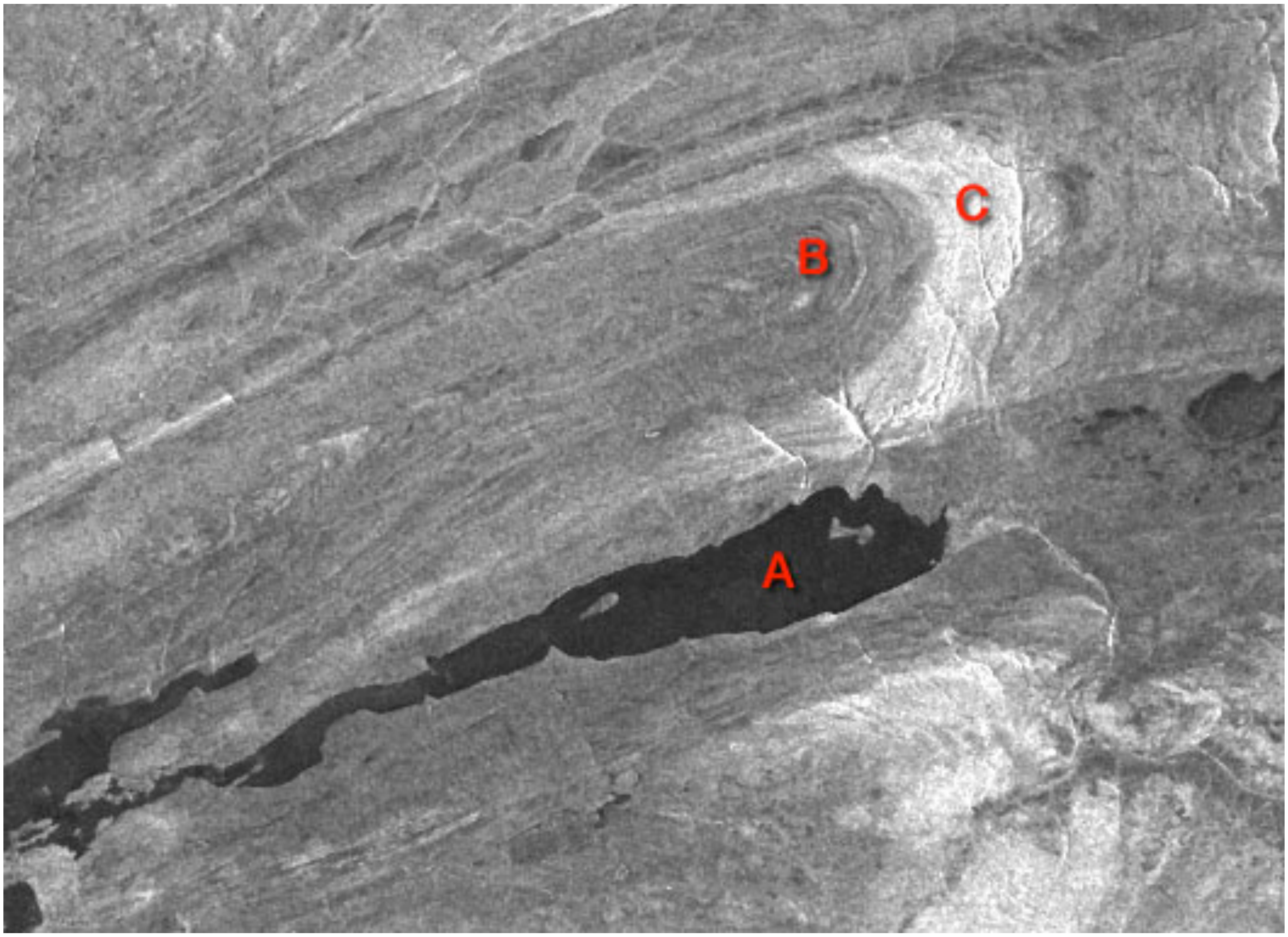

FIGURE 2.45 Radarsat image taken on March 21, 1996, over Bathurst Island in Nunavut, Canada. This image shows Radarsat's ability to distinguish different types of bedrock. The light shades on this image (C) represent areas of limestone, while the darker regions (B) are composed of sedimentary siltstone. The very dark area marked A is Bracebridge Inlet which joins the Arctic ocean. *(Source: Canadian Centre for Remote Sensing)*

CHAPTER SUMMARY

- A map can be defined as a graphical abstraction of the real world. Some maps describe both cultural and physical features found on the Earth's surface in two-dimensions.
- Maps can be of two general types: reference maps and thematic maps.
- An example of a reference type map is the topographic map. This type of map focuses on providing location based information.
- Thematic maps usually display the spatial distribution of one geographical phenomenon or the geographical relationship that occur between two or more phenomena.
- It is extremely difficult to draw maps true to life. For this reason, maps are normally drawn at a reduced scale.
- Map scale can be expressed as the ratio between map and actual ground distance. On most maps, the scale is described as representative fraction. Scale can also be described as a verbal statement or a graphic illustration.
- Cartographers use a variety of techniques in the process of map creation. A number of mathematical transformations can be employed to best depict the three-dimensional surface of the Earth on a flat map. However, these transformations do create some type of distortion artifact.
- Map distortion is usually manifested in the following geographic properties: distance, area, shape, straight-line direction, and the bearing of cardinal direction from locations on the Earth.
- Some map projections have the ability to minimize the distortion of one of these properties. For example, maps based on the Mercator projection have true angles between two points and are therefore useful in navigating the Earth’s surface.
- Finding locations on maps is usually done with a coordinate system. The two most common systems found on maps are Geographical Coordinate System and the Universal Transverse Mercator System.
- The Geographic Coordinate System places a three-dimensional grid system over the Earth's surface and locations are determined relative to two coordinates: latitude and longitude.
- Measurements of latitude determine location in a north-south direction relative to a point at the center of the Earth's polar axis.
- Longitude measures the west-east position of points on the Earth's surface relative to a circular arc called the prime meridian.
- The Universal Transverse Mercator System uses a two-dimensional grid for find location of the Earth's surface. It is also based on the Transverse Mercator projection system. This system is more complicated than geographic coordinates as location is determined relative to 60 six-degree longitude wide zones that run north-south.
- One useful field instrument for determining location on the Earth's surface under field conditions is a GPS. A GPS uses triangulation and a network of satellites to calculate location to an accuracy of less than 10 m (33 ft).
- Topographic maps are detailed two-dimensional representations of the natural and human world. These maps are used for a number of activities. One important feature found on topographic maps is contour lines.
- A contour line is an isoline that connects all points on the Earth's surface that have the same elevation. Contour lines are used to visually model spatial changes in elevation.
- On topographic maps, contour lines are drawn at a uniform vertical distance known as the contour interval. Many maps also use index contours. The interval used on a particular map depends on the amount of relief depicted.
- Topographic maps also use a system of symbols to describe the features found on the Earth's surface.
- Distance can be difficult to measure on maps because of the distortions produced by map projections. However, if the map has a scale larger than 1:125,000 these distortions are insignificant. Most topographic maps have a scale equal to or greater than 1:125,000. When measuring distance one must be aware of the map's scale in order to convert map measurements into real world distances.
- Direction on maps and the real world can be measured relative to true, grid, or magnetic north.
- On maps, the easiest way to measure direction is relative to the lines produced by the Universe Transverse Mercator System. These grid lines are aligned relative to grid north. Finally, compass direction can described either by using the azimuth or the bearing systems.
- A system has been developed that uses 24 time zones to standardize and simplify the observance of time. Fleming's time zone system has undergone a number of modifications since it was first proposed in 1878. The current version, called Coordinated Universal Time (UTC), became the standard legal reference of time for the world in 1972.

- UTC is determined from six atomic clocks and this time is then applied relative to the 24 time zones found on our planet.
- Geographic Information Systems (GIS) are another important tool used by Geographers. These systems combine computer cartography with database management software.
- GIS is used to: a) measure natural and human phenomena and processes from a spatial perspective; b) store these measurements in digital form used a computer database and digital maps; c) analyze collected measurements to produce new data or discover relationships; and d) depict the measured or analyzed data in some type of display.
- Remote sensing is any process that collects data about an object from a remote location.
- Geographers use a variety of mechanical devices for remote sensing of the Earth. These devices contain advanced sensors that can capture information via the reflection or emission of radiation from objects.
- Devices used for remote sensing are constructed to sense certain wavelength bands.
- The objects that are often monitored by physical geographers have particular spectral signatures and one has to match the object to the sensor.
- The simplest and most common type of image used by geographers to carry out remote sensing is aerial photographs. Humans have used balloons, planes, and satellites to carry cameras above the ground surface.
- In the 1960s, the deployment of high altitude satellite caused a revolution in remote sensing. Many orbiting objects were outfitted with sensors to complete specific remote sensing jobs.
- Remote sensing of the Earth's climate for weather forecasting began with the launching of a number of satellites called TIROS.
- Over time sensors became more sophisticated and some of them were used to monitor the Earth's surface for a number of applications outside of weather forecasting (Landast, SPOT, and Radarsat).

IMPORTANT TERMS

Active remote sensing
Albers Equal Area projection
Azimuth
Azimuthal projection
Azimuth system
Bearing
Bearing system
Cartographer
Conic projection
Contour line
Coordinated Universal Time (UTC)
Cylindrical projection
Eastings
Equator
Geocoded
Geographic Information System
Geographical coordinate system
Greenwich Mean Time (GMT)
Grid North
Index contour
International Date Line
Landsat
Latitude
Longitude
Map
Mercator projection
Meridian
Multispectral scanner
Northings
North Magnetic Pole
Opisometer
Parallel
Passive remote sensing
Planar
Prime meridian
Radarsat
Reference map
Rhumb line
Robinson projection
South Magnetic Pole
SPOT
Thematic mapper
Topographic map
True North
True South
Transverse Mercator projection
Universal Transverse Mercator (UTM) grid system

CHAPTER REVIEW QUESTIONS

1. What is a map?
2. Why do we consider maps to be abstractions of reality?
3. What two basic forms do maps come in?
4. How is map scale related to the size of objects in the real world?
5. What different methods are used to identify the scale of a map.
6. Describe the characteristics of the three projection systems commonly used to map the earth's surface?
7. What problems are associated with projecting the Earth's surface on a two-dimensional map?
8. Describe how the geographical coordinate system is used to find the location of features found on the Earth's surface.
9. Describe how the Universal Transverse Mercator grid system references the location of features found on the Earth's surface.
10. How does a Global Positioning System determine location on our planet?
11. Discuss the relationship between map scale and map distance.
12. What techniques are commonly used to measure distance on maps?
13. Describe the various ways direction is measured on a map.
14. How are directions measured in the real world with a compass used on a map?
15. How do the azimuth and bearing system differ in depicting direction?
16. How was the measurement of time standardized for the world?
17. What is a topographic map? How does this type of map use points, lines, and polygons to represent natural and human constructed features found in the environment?
18. What is a contour line? How are they used on topographic maps to illustrate changes in elevation?
19. What is a GIS? What types of activities are carried out on these computerized systems?
20. Describe the difference between the following components of a GIS: data elements and attributes.
21. What is remote sensing? What types of remote sensors have been developed to monitor the Earth?

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