Pearson New International Edition

McKnight's Physical Geography
A Landscape Appreciation
Darrel Hess Dennis Tasa
Eleventh Edition

ALWAYS LEARNING

PEARSON

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INTRODUCTION TO EARTH

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IF YOU OPENED THIS BOOK EXPECTING THAT THE STUDY OF geography was going to be memorizing names and places on maps, you'll be surprised to find that geography is much more than that. Geographers study the location and distribution of things—tangible things such as rainfall, mountains, and trees, as well as less tangible things such as language, migration, and voting patterns. In short, geographers look for and explain patterns in the physical and human landscape.

In this text you'll learn about fundamental processes and patterns in the natural world—the kinds of things you can see whenever you walk outside: clouds in the sky, mountains, streams and valleys, and the plants and animals that inhabit the landscape. You'll also learn about human interactions with the natural environment—how events such as hurricanes, earthquakes, and floods affect our lives and the world around us, as well as how human activities are increasingly altering our environment. You'll understand—in other words you'll appreciate—the landscape in new ways.

This chapter sets the stage for your study of physical geography. Here we introduce concepts and terms.

As you study this chapter, think about these key questions:

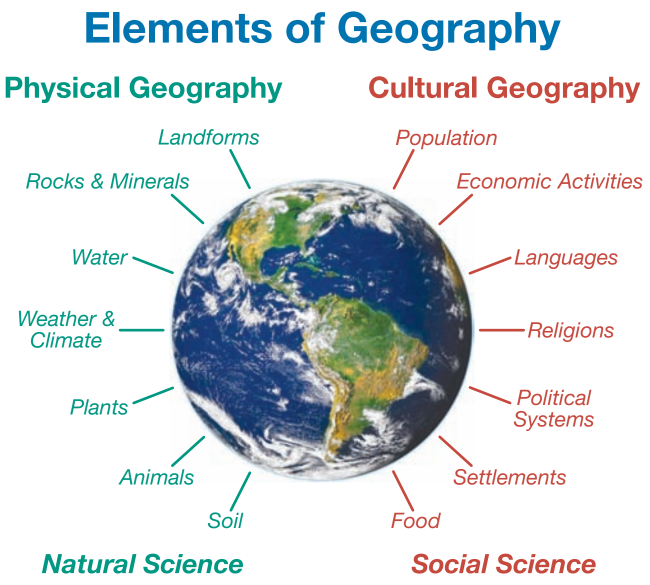
- **How do geographers study the world and use science to explain and understand the natural environment?**
- **What are the overlapping environmental "spheres" of Earth, and how does the concept of Earth systems help us understand the interrelationships of these spheres?**
- **How does Earth fit in with the solar system, and how does the size of Earth compare with the size of its surface features?**
- **How does the system of latitude and longitude describe location on Earth?**
- **What causes the annual change of seasons, and how do patterns of sunlight around Earth change during the year?**
- **How is the system of time zones used to establish times and dates around the world?**

GEOGRAPHY AND SCIENCE

The word *geography* comes from the Greek words meaning "Earth description." Several thousand years ago many scholars were indeed "Earth describers," and therefore geographers, more than anything else. Nonetheless, over the centuries there was a trend away from generalized Earth description toward more specialized disciplines—such as geology, meteorology, economics, and biology—and so geography as a field of study was somewhat overshadowed. Over the last few hundred years, however, geography reaffirmed its place in the academic world, and today geography is an expanding and flourishing field of study.

Seeing Geographically

This is a natural color, composite satellite image of Earth created by NASA. In the image can you see any indications of human presence? What might explain the differences in the color of land areas? What might explain the differences in the color of ocean areas?



▲ **Figure 1** The elements of geography can be grouped into two broad categories. Physical geography primarily involves the study of natural science, whereas cultural geography primarily entails the study of social science.

Studying the World Geographically

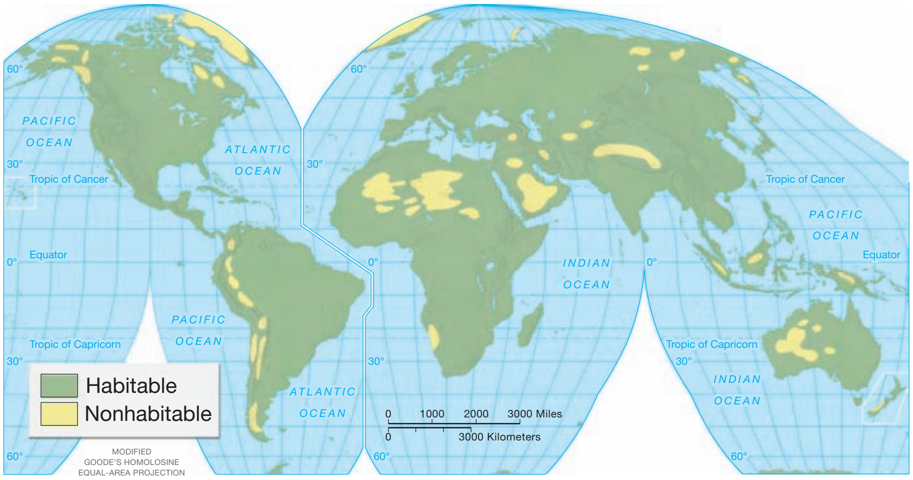
Geographers study how things differ from place to place—the distributional and locational relationships of things around the world (what is sometimes called the "spatial" aspect of things). Figure 1 shows the kinds of "things" geographers study, divided into two groups representing the two principal branches of geography. The elements of **physical geography** are natural in origin, and for this reason physical geography is sometimes called *environmental geography*. The elements of **cultural geography** are those of human endeavor, so this branch is sometimes referred to as *human geography*. The almost unlimited possible combinations of these various elements create the physical and cultural landscapes of the world that geographers study.

All of the items shown in Figure 1 are familiar to us, and this familiarity highlights a basic characteristic of geography as a field of learning: Geography doesn't have its own body of facts or objects that only geographers study. The focus of geology is rocks, the attention of economics is economic systems, demography examines human population, and so on. Geography, on the other hand, is much broader in scope than most other disciplines, "borrowing" its objects of study from related fields. Geographers, too, are interested in rocks and economic systems and population—especially in describing and understanding their location and distribution. We sometimes say that geography asks the fundamental question, "Why what is where and so what?"

Learning Check 1 **What are the differences between physical geography and cultural geography?**

Another basic characteristic of geography is its interest in interrelationships. One cannot understand the distribution of soils, for example, without knowing something about the rocks from which the soils were derived, the slopes on which the soils developed, and the climate and vegetation under which they developed. Similarly, it is impossible to comprehend the distribution of agriculture without an understanding of climate, topography, soil, drainage, population, economic conditions, technology, historical development, and many other factors, both physical and cultural. Because of its wide scope, geography bridges the academic gap between natural science and social science, studying all of the elements in Figure 1 in an intricate web of geographic interrelationships.

In our study of physical geography, our emphasis is on understanding the surface environment of Earth and the ways in which humans utilize and alter this environmental home. The habitable environment for humans exists over almost the entire land surface of Earth (Figure 2). It is only in the most extremely dry, cold, and rugged places that humans rarely venture, and even in such locations,



◀ **Figure 2** Most of Earth's land surface is habitable. The uninhabitable areas are too hot, too cold, too wet, too dry, or too rugged to support much human life—such as parts of the Arctic, most of Greenland, Antarctica, various mountainous regions, and several deserts.

other forms of life may be found. Earth's "life zone," encompassing oceanic, terrestrial, and atmospheric life, extends from the bottom of the deepest oceanic trench to the atmosphere above the highest mountain peaks—a zone perhaps 30 kilometers (20 miles) deep. It is primarily within this shallow life zone that geographers focus their interests and do their work.

In this text we concentrate on the physical elements of the landscape, the processes involved in their development, their distribution, and their basic interrelationships. As we proceed, this notion of landscape development by natural processes and landscape modification by humans serves as a central focus. We will pay attention to elements of cultural geography only when they help to explain the development or patterns of the physical elements—especially the ways in which humans influence or alter the physical environment.

Global Environmental Change: Several broad geographic themes run through this book. One of these themes is *global environmental change*—both the human-caused and natural processes that are currently altering the landscapes of the world. Some of these changes can take place over a period of just a few years, whereas others require many decades or even thousands of years (Figure 3). We pay special attention to the accelerating impact of human activities on the global environment.

Rather than treat global environmental change as a separate topic, we integrate this theme throughout the text. To help with this integration, we supplement the main text with short boxed essays, such as those entitled "People and the Environment" that focus on specific cases of human interaction with the natural environment, as well as boxes entitled "Energy for the 21st Century" that focus on the challenge of supplementing—and perhaps eventually replacing—fossil fuels with renewable sources of energy. These essays serve to illustrate the connections between many aspects of the environment, such as the relationships between changing global temperatures, changing sea level, changing quantities of polar ice, and the changing distribution of plant and animal species, and the global economy and human society.

Globalization: A related but less obvious theme running through this text is *globalization*. In the broadest terms, globalization refers to the processes and consequences of an increasingly interconnected world—connections between the economies, cultures, and political systems of the world. Although globalization is most commonly associated with the cultural and economic realms of world, it is important to recognize the environmental components of globalization as well. For example, the loss of tropical rainforest for timber or commercial agriculture in some regions of the world is driven in part by growing demand for commodities in countries far away from the tropics (Figure 4). Similarly, rapid economic growth in newly industrialized countries is contributing to the already high atmospheric greenhouse gas emissions of industrialized countries—the interconnected economies of the world are thus interconnected in their influence on the natural environment.

Because of geography's global perspective and its interest in both the natural and human landscape, geographers are able to offer insights into many of the world's most pressing problems—problems too complex to address from a narrower perspective. For example, the detrimental consequences of climate change cannot be addressed if we ignore the economic, social, historical, and political aspects of the issue. Similarly, global inequities of wealth and political power cannot be addressed if we ignore environmental and resource issues.

Just about everything in the world is in one way or another connected with everything else! Geography helps us understand these connections.

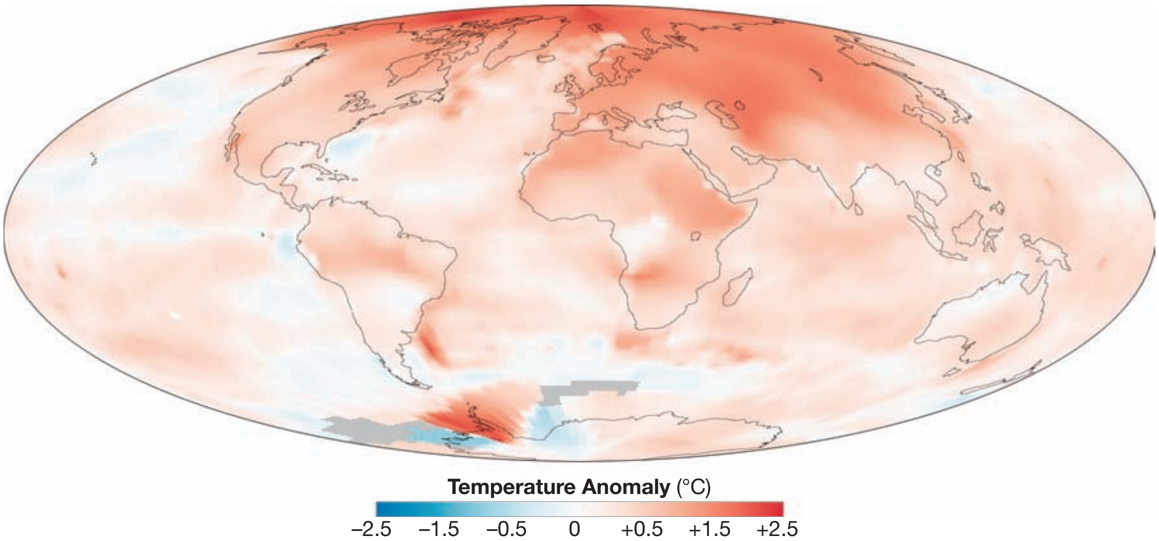


Figure 3 Earth's climate is changing. This image shows the difference in temperature (the *temperature anomaly* in °C) during the period 2000 to 2009 compared with the average temperatures for the baseline period 1951 to 1980. *(NASA)*

▲ **Figure 4** Deforestation in some parts of the tropics is influenced by consumer demand in other parts of the world. This logging operation is in Perak, Malaysia.

Learning Check 2 **Why are physical geographers interested in globalization?**

The Process of Science

Because physical geography is concerned with processes and patterns in the natural world, knowledge in physical geography is advanced primarily through the study of science, and so it is useful for us to say a few words about science in general.

Science is often described—although somewhat simplistically—as a process that follows the *scientific method*:

1. Observe phenomena that stimulate a question or problem.
2. Offer an educated guess—a *hypothesis*—about the answer.
3. Design an experiment to test the hypothesis.
4. Predict the outcome of the experiment if the hypothesis is supported, and if the hypothesis is not supported.
5. Conduct the experiment and observe what actually happens.
6. Draw a conclusion or formulate a simple generalized "rule" based on the results of the experiment.

In practice, however, science doesn't always work through experimentation; in many fields of science, data collection through observation of a phenomenon is the basis of knowledge. In some regards science is best thought of as a process—or perhaps even as an attitude—for gaining knowledge. The scientific approach is based on observation, experimentation, logical reasoning, skepticism of unsupported conclusions, and the willingness to modify or even reject long-held ideas when new evidence contradicts them. For example, up until the 1950s most Earth scientists thought it impossible that the positions of continents could change over time; however, by the late 1960s enough new evidence had been gathered to convince them that their earlier ideas were wrong—the configuration of continents has changed, and continues to change!

Although the term "scientific proof" is sometimes used by the general public, strictly speaking, science does not "prove" ideas. Instead, science works by eliminating alternative explanations—eliminating explanations that aren't supported by evidence. In fact, in order for a hypothesis to be "scientific," there must be some test or possible observation that could *disprove* it—if there is no way to disprove an idea, then that idea simply cannot be supported by science.

The word "theory" is often used in everyday conversation to mean a "hunch" or conjecture. However, in science a *theory* represents the highest order of understanding for a body of information—a logical, well-tested explanation that encompasses a wide variety of facts and observations. Thus, the "theory of plate tectonics" represents an empirically supported, broadly accepted, overarching framework for understanding processes operating within Earth.

The acceptance of scientific ideas and theories is based on a preponderance of evidence, not on "belief" and not on the pronouncements of "authorities." New observations and new evidence often cause scientists to revise their conclusions and theories or those of others. Much of this self-correcting process for refining scientific knowledge takes place through peer-reviewed journal articles. Peers—that is, fellow scientists—scrutinize a scientific report for sound reasoning, appropriate data collection, and solid evidence before it is published; reviewers need not agree with the author's conclusions, but they strive to ensure that the research meets rigorous standards of scholarship before publication.

Because new evidence may prompt scientists to change their ideas, good science tends to be somewhat cautious in the conclusions that are drawn. For this reason, the findings of many scientific studies are prefaced by phrases such as "the evidence suggests," or "the results most likely show." In some cases, different scientists interpret the same data quite differently and so disagree in their conclusions. Frequently, studies find that "more research is needed." The kind of uncertainty sometimes inherent in science may lead the general public to question the conclusions of scientific studies—especially when presented with a simple, and perhaps comforting nonscientific alternative. It is, however, this very uncertainty that often compels scientists to push forward in the quest for knowledge and understanding!

In this text we present the fundamentals of physical geography as it is supported by scientific research and evidence. In some cases, we will describe how our current understanding of a phenomenon developed over time; in other cases we will point out where uncertainty remains, where scientists still disagree, or where intriguing questions still remain.

Learning Check 3 **Why is the phrase "scientific proof" somewhat misleading?**

Numbers and Measurement Systems

Because so much of science is based on observation and measurable data, any thorough study of physical geography entails the use of mathematics. Although this text introduces physical geography primarily in a conceptual way without the extensive use of mathematical formulas, numbers and measurement systems are nonetheless important for us. Throughout the text, we use numbers and simple formulas to help illustrate concepts—the most obvious of which are numbers used to describe distance, size, weight, and temperature.

Two quite different systems of measurement are used around the world today. In the United States much of the general public is most familiar with the so-called *English System* of measurement—using measurements such as miles, pounds, and degrees Fahrenheit. However, most of the rest of the world—and the entire scientific community—uses the **International System** of measurement (abbreviated **S.I.** from the French *Système International*; also sometimes called the "metric system")—using measurements such as kilometers, kilograms, and degrees Celsius.

You will notice that this text gives measurements In both S.I. and English units. If you are not familiar with both systems, Table 1 provides some quick approximations to help you learn the basic equivalents in each.

TABLE 1 **Unit Conversions—Quick Approximations**

	S.I. to English Units	English to S.I. Units
Distance:	1 centimeter = a little less than ½ inch	1 inch = about 2½ centimeters
	1 meter = a little more than 3 feet	1 foot = about ⅓ meters
	1 kilometer = about ⅔ mile	1 yard = about 1 meter
		1 mile = about 1½ kilometers
Volume:	1 liter = about 1 quart	1 quart = about 1 liter
		1 gallon = about 4 liters
Mass:	1 gram = about 1/30 ounce	1 ounce = about 30 grams
	1 kilogram = about 2 pounds	1 pound = about ½ kilogram
Temperature:	1°C change = 1.8°F change	1°F change = about 0.6°C change

ENVIRONMENTAL SPHERES AND EARTH SYSTEMS

From the standpoint of physical geography, the surface of Earth is a complex interface where four principal components of the environment meet and to some degree overlap and interact (Figure 5). These four components are often referred to as Earth's *environmental spheres*.

Earth's Environmental Spheres

The solid, inorganic portion of Earth is sometimes called the **lithosphere**[1] (*litho* is Greek for "stone"), comprising the rocks of Earth's crust as well as the unconsolidated particles of mineral matter that overlie the solid bedrock. The lithosphere's surface is shaped into an almost infinite variety of landforms, both on the seafloors and on the surfaces of the continents and islands.

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[1] In the context of *plate tectonics* and our study of landforms, the term "lithosphere" is used specifically to refer to large "plates" consisting of Earth's crustal and upper mantle rock.

▲ **Figure 5** The physical landscape of Earth is composed of four overlapping and interacting systems called “spheres.” The atmosphere is the air we breathe. The hydrosphere is the water of rivers, lakes, and oceans, the moisture in soil and air, as well as the snow and ice of the cryosphere. The biosphere is the habitat of all earthly life, as well as the life forms themselves. The lithosphere is the soil and bedrock that cover Earth’s surface. This scene shows Wonder Lake and Mt. McKinley (Denali) in Denali National Park, Alaska.

The gaseous envelope of air that surrounds Earth is the **atmosphere** (*atmo* is Greek for “air”). It contains the complex mixture of gases needed to sustain life. Most of the atmosphere is close to Earth’s surface, being densest at sea level and rapidly thinning with increased altitude. It is a very dynamic sphere, kept in almost constant motion by solar energy and Earth’s rotation.

The **hydrosphere** (*hydro* is Greek for “water”) comprises water in all its forms. The oceans contain the vast majority of the water found on Earth and are the moisture source for most precipitation. A subcomponent of the hydrosphere is known as the **cryosphere** (*cry* comes from the Greek word for “cold”)—water frozen as snow and ice.

The **biosphere** (*bio* is Greek for “life”) encompasses all the parts of Earth where living organisms can exist; in its broadest and loosest sense, the term also includes the vast variety of earthly life forms (properly referred to as *biota*).

These “spheres” are not discrete and separated entities but rather are considerably interconnected. This intermingling is readily apparent when considering an ocean—a body that is clearly a major component of the hydrosphere and yet may contain a vast quantity of fish and other organic life that are part of the biosphere. An even better example is soil, which is composed largely of bits of mineral matter (lithosphere) but also contains life forms (biosphere), along with air (atmosphere), soil moisture (hydrosphere), and perhaps frozen water (cryosphere) in its pore spaces.

The environmental spheres can serve to broadly organize concepts for the systematic study of Earth’s physical geography and are used that way in this text.

Learning Check 4 **Briefly define the lithosphere, atmosphere, hydrosphere, cryosphere, and biosphere.**

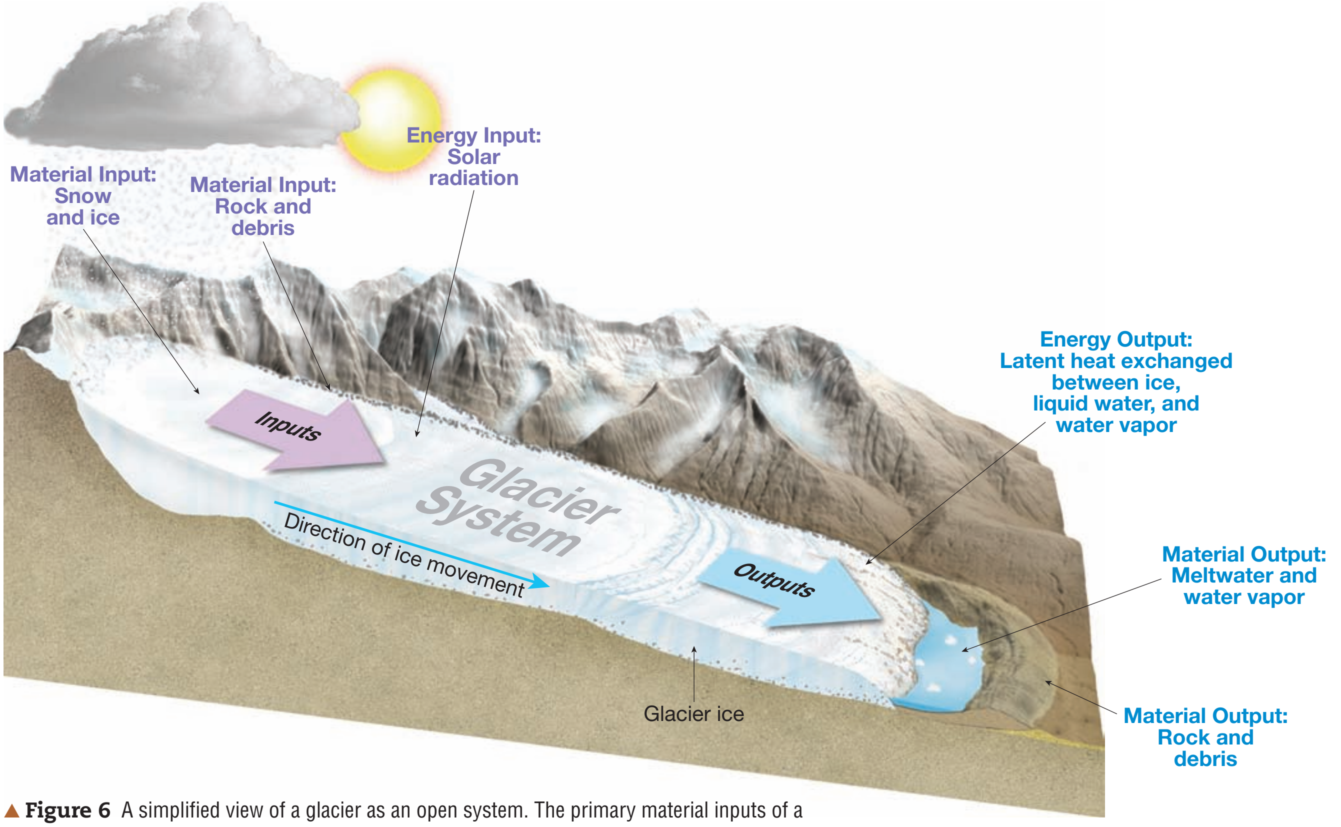
Earth Systems

Earth’s environmental spheres operate and interact through a complex of *Earth systems*. By “system” we mean a collection of things and processes connected together and operating as a whole. In the human realm, for example, we talk of a global “financial system” that encompasses the exchange of money between institutions and individuals, or of a “transportation system” that involves the movement of people and commodities. In the natural world, systems entail the interconnected flows and storage of energy and matter.

Closed Systems: Some systems are effectively self-contained and therefore isolated from influences outside that system—and so are called *closed systems*. It is rare to find closed systems in nature. Earth as a whole is essentially a closed system with regard to matter—currently there is no significant increase or decrease in the amount of matter (the “stuff”) of Earth, although relatively small but measurable amounts of meteoric debris arrives from space, and tiny amounts of gas are lost to space from the atmosphere. Energy, on the other hand, does enter and exit the Earth system constantly.

Open Systems: Most Earth systems are *open systems*—both energy and matter are exchanged across the system boundary. Matter and energy that enter the system are called *inputs*, and losses from the system to its surroundings are called *outputs*. For example, a glacier behaves as an open system (Figure 6). The material inputs to a glacier include water in the form of snow and ice, along with rocks and other materials picked up by the moving ice; the material outputs of a glacier include the meltwater and water vapor lost to the atmosphere, as well as the rock transported and eventually deposited by the ice. The most obvious energy input into a glacial system is solar radiation that melts the ice by warming the surrounding air and by direct absorption into the ice itself. But also at work are less obvious exchanges of energy that involve *latent heat*—energy stored by water during melting and evaporation, and released during freezing and condensation.

Equilibrium: When inputs and outputs are in balance over time, the conditions within a system remain the same; such a system can be described as being in *equilibrium*. For



▲ **Figure 6** A simplified view of a glacier as an open system. The primary material inputs of a glacier include snow, ice, and rock, whereas its outputs include meltwater, water vapor, and rock transported by the flowing ice. The energy interchange includes incoming solar radiation and the exchange of latent heat between ice, liquid water, and water vapor.

instance, a glacier will remain the same size over many years if its inputs of snow and ice are balanced by the loss of an equivalent amount of ice through melting. If, however, the balance between inputs and outputs changes, equilibrium will be disrupted—increasing snowfall for several years, for example, can cause a glacier to grow until a new equilibrium size is reached.

Interconnected Systems: In physical geography we study the myriad of interconnections between Earth's systems and subsystems. Continuing with our example of a glacier: The system of an individual glacier is interconnected with many other Earth systems, including Earth's solar radiation budget, wind and pressure patterns, and the hydrologic cycle—if inputs or outputs in those systems change, a glacier may also change. For instance, if air temperature increases through a change in Earth's solar radiation budget, both the amount of water vapor available to precipitate as snow and the rate of melting of that snow, may change, causing an adjustment in the size of the glacier.

Learning Check 5 **What does it mean when we say a system is in equilibrium?**

Feedback Loops: Some systems produce outputs that "feedback" into that system, reinforcing change. Over the last few decades increasing temperatures in the Arctic have reduced the amount of highly reflective, summer sea ice. As the area of sea ice has diminished, the darker, less reflective ocean has absorbed more solar radiation, contributing to the temperature increase—which in turn has reduced the amount of sea ice even more, further reducing reflectance and increasing absorption. Were Arctic temperatures to decrease, an expanding cover of reflective sea ice would reduce absorption of solar radiation and so reinforce a cooling trend. These are examples of *positive feedback loops*—change within a system continuing in one direction.

Conversely, *negative feedback loops* tend to inhibit a system from changing—in this case increasing a system input tends to *decrease* further change, keeping the system in equilibrium. For example, an increase in air temperature may increase the amount of water vapor in the air; this greater amount of water vapor may in turn condense and increase the cloud cover—which can reflect incoming solar radiation and so prevent a further temperature increase.

Although systems may resist change through negative feedback loops, at some point a system may reach a *tipping point* or *threshold* beyond which the system becomes unstable and changes abruptly until it reaches a new equilibrium. For instance, it is possible that the increasing freshwater runoff from melting glaciers in the Arctic could disrupt the energy transfer of the slow, deep ocean *thermohaline circulation* in the Atlantic Ocean, triggering a sudden change in climate.

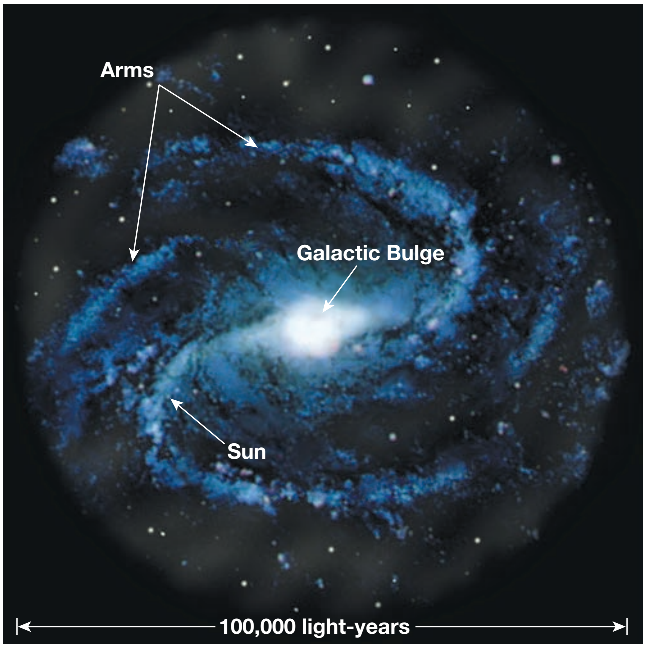
The preceding examples are not intended to confuse you, but rather to illustrate the great complexity of Earth's interconnected systems! Because of this complexity, in this text we often first describe one process or Earth system in isolation before presenting its interconnections with other systems.

Learning Check 6 **What is the difference between a positive feedback loop and a negative feedback loop?**

EARTH AND THE SOLAR SYSTEM

Animation
Solar System Formation

Earth is part of a larger *solar system*—an open system with which Earth interacts. Earth is an extensive rotating mass of mostly solid material that orbits the enormous ball of superheated gases we call the Sun. The geographer's concern with spatial relationships properly begins with the relative location of this "spaceship Earth" in the universe.



▲ **Figure 7** The structure of the Milky Way Galaxy showing the approximate location of our Sun on one of the spiral arms.

The Solar System

Earth is one of eight planets of our solar system, which also contains more than 160 natural satellites or "moons" revolving around the planets, an uncertain number of smaller *dwarf planets* such as Pluto, scores of comets (bodies composed of frozen liquid and gases together with small pieces of rock and metallic minerals), more than 500,000 asteroids (small, rocky, and sometimes icy objects, mostly less than a few kilometers in diameter), and millions of meteoroids (most of them the size of sand grains).

The medium-massed star we call the Sun is the central body of the solar system and makes up more than 99.8 percent of its total mass. The solar system is part of the Milky Way Galaxy, which consists of at least 200,000,000,000 stars arranged in a disk-shaped bared-spiral that is about 100,000 light-years in diameter (1 light-year equals about 9.5 trillion kilometers—the distance a beam of light travels over a period of one year) and 10,000 light-years thick at the center (Figure 7). The Milky Way Galaxy is only one of hundreds of billions of galaxies in the universe.

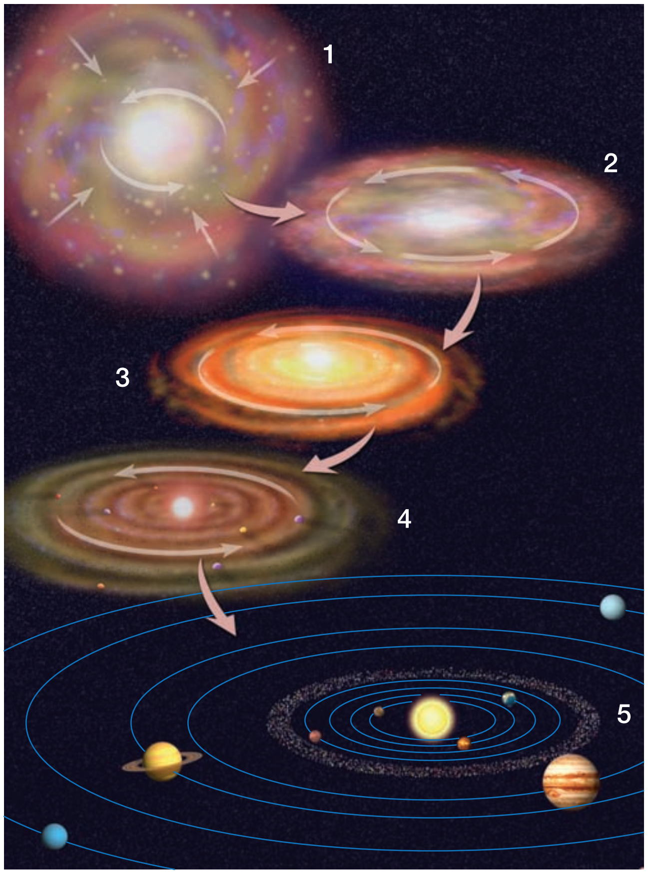
To begin to develop an understanding for astronomical distances, we might consider a reduced-scale model of the universe: if the distance between Earth and the Sun, which is about 150,000,000 kilometers (93,000,000 miles), is taken to be 2.5 centimeters (1 inch), then the distance from Earth to the nearest star would be 7.2 kilometers (4.5 miles), and the distance from Earth to the next similar-sized galaxy beyond the Milky Way would be about 240,000 kilometers (150,000 miles)!

Origins: The origin of Earth, and indeed of the universe, is incompletely understood. It is generally accepted that the universe began with a cosmic event called the *big bang*. The most widely held view is that the big bang took place some 13.7 billion years ago—similar to the age of the oldest known stars. The big bang began in a fraction of a second as an infinitely dense and infinitesimally small bundle of energy containing all of space and time started to expand away in all directions at extraordinary speeds, pushing out the fabric of space and filling the universe with the energy and matter we see today.

Our solar system originated between 4.5 and 5 billion years ago when a *nebula*—a huge, cold, diffuse cloud of gas and dust—began to contract inward, owing to its own gravitational collapse, forming a hot, dense *protostar* (Figure 8). This hot center—our Sun—was surrounded by a cold, revolving disk of gas and dust that eventually condensed and coalesced to form the planets.

All of the planets revolve around the Sun in elliptical orbits, with the Sun located at one focus (looking "down" on the solar system from a vantage point high above the North Pole of Earth, the planets appear to orbit in a counterclockwise direction around the Sun). All the planetary orbits are in nearly the same plane (Figure 9), perhaps revealing their relationship to the original spinning direction of the nebular disk. The Sun rotates on its axis from west to east. Moreover, most of the planets rotate from west to east on their own axes (Uranus rotates "sideways" with its rotational axis almost parallel to its orbital plane; Venus rotates from east to west). The planets revolve more slowly and generally have a lower temperature as their distance from the Sun increases.

The Planets: The four inner *terrestrial planets*—Mercury, Venus, Earth, and Mars—are generally smaller, denser, and less oblate (more nearly spherical), and they rotate more slowly on their axes than the four outer



▲ **Figure 8** The birth of the solar system. (1) Diffuse gas cloud, or nebula, begins to contract inward. (2) Cloud flattens into nebular disk as it spins faster around a central axis. (3) Particles in the outer parts of the disk collide with each other to form protoplanets. (4) Protoplanets coalesce into planets and settle into orbits around the hot center. (5) The final product: a central Sun surrounded by eight orbiting planets (solar system not shown in correct scale). The original nebular disk was much larger than our final solar system.

Jovian planets—Jupiter, Saturn, Uranus, and Neptune. Also, the inner planets are composed principally of mineral matter and, except for airless Mercury, have diverse but relatively shallow atmospheres.

By contrast, the four Jovian planets tend to be much larger, more massive (although they are less dense), and much more oblate (less perfectly spherical) because they rotate more rapidly. The Jovian planets are mostly composed of elements such as hydrogen and helium—liquid near the surface, but frozen toward the interior—as well as ices of compounds such as methane and ammonia. The Jovian planets generally have atmospheres that are dense, turbulent, and relatively deep.

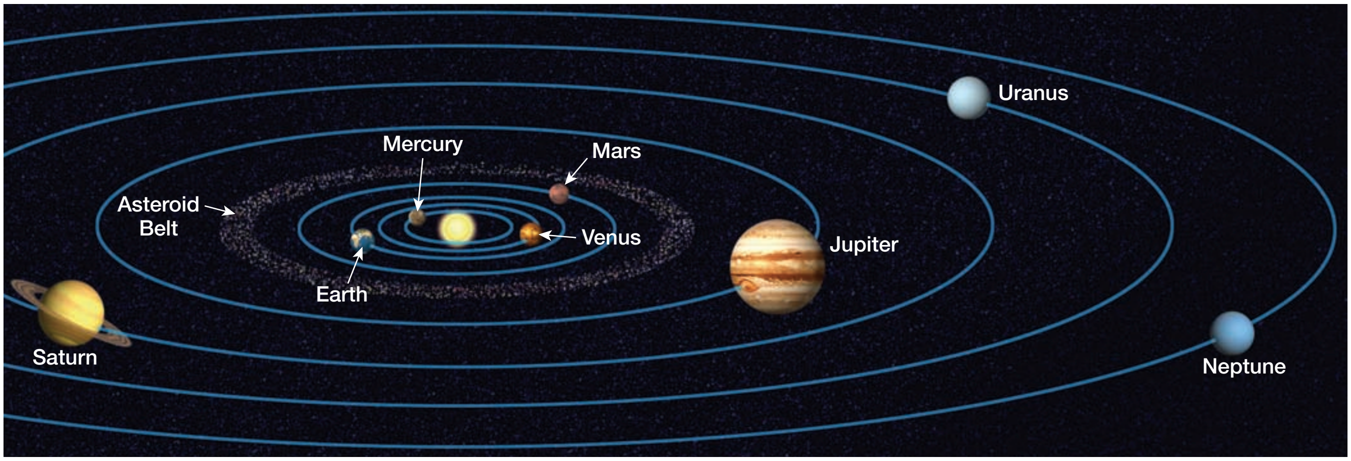
It was long thought that tiny Pluto was the ninth and outermost planet in the solar system. In recent years, however, astronomers have discovered other icy bodies, such as distant Eris, Makemake, and Haumea that are similar to Pluto and orbiting the Sun beyond Neptune in what is referred to as the *Kuiper Belt* or *trans-Neptunian region*. In June 2008 the International Astronomical Union reclassified Pluto as a special type of dwarf planet known as a *plutoid*. Some astronomers speculate that there may be several dozen yet-to-be-discovered plutoids and other dwarf planets in the outer reaches of the solar system.

Learning Check 7 **Contrast the characteristics of the terrestrial and Jovian planets in our solar system.**

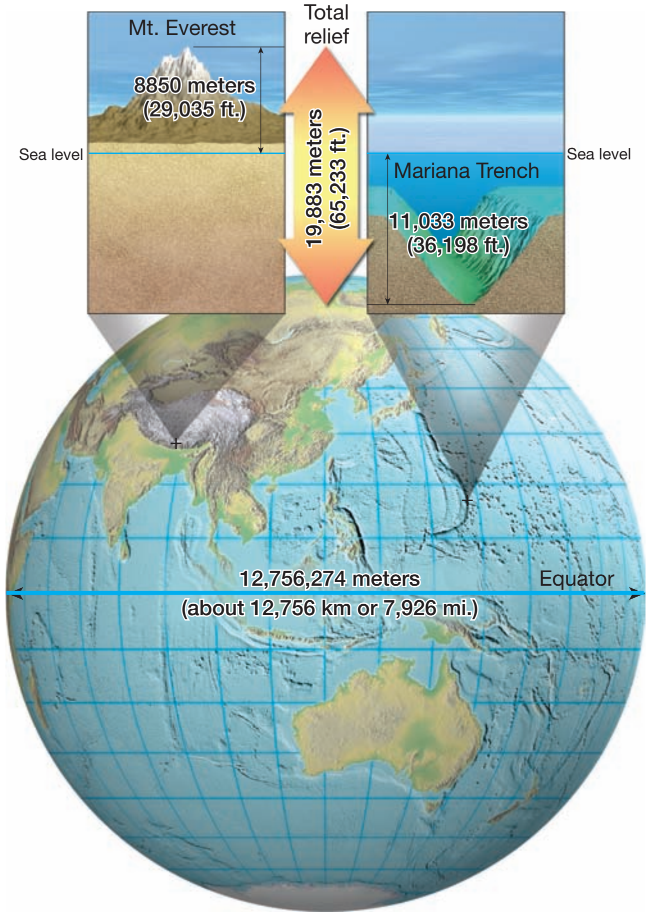
The Size and Shape of Earth

Is Earth large or small? The answer to this question depends on one's frame of reference. If the frame of reference is the universe, Earth is almost infinitely small. The diameter of our planet is only about 13,000 kilometers (7900 miles), a tiny distance at the scale of the universe—for instance, the Moon is 385,000 kilometers (239,000 miles) from Earth, the Sun is 150,000,000 kilometers (93,000,000 miles) away, and the nearest star is 40,000,000,000,000 kilometers (25,000,000,000,000 miles) distant.

The Size of Earth: In a human frame of reference, however, Earth is impressive in size. Its surface varies in elevation from the highest mountain peak, Mount Everest, at 8850 meters (29,035 feet) above sea level, to the deepest oceanic trench, the Mariana Trench of the Pacific Ocean, at



▲ **Figure 9** The solar system (not drawn to correct scale). The Sun is not exactly at the center of the solar system—the planets revolve around the Sun in elliptical orbits. The Kuiper Belt, which includes dwarf planets such as Pluto, begins beyond Neptune.



▲ **Figure 10** Earth is large relative to the size of its surface features. Earth's maximum relief (the difference in elevation between the highest and lowest points) is 19,883 meters (65,233 feet) or about 20 kilometers (12 miles) from the top of Mount Everest to the bottom of the Mariana Trench in the Pacific Ocean.

11,033 meters (36,198 feet) below sea level, a total difference in elevation of 19,883 meters (65,233 feet).

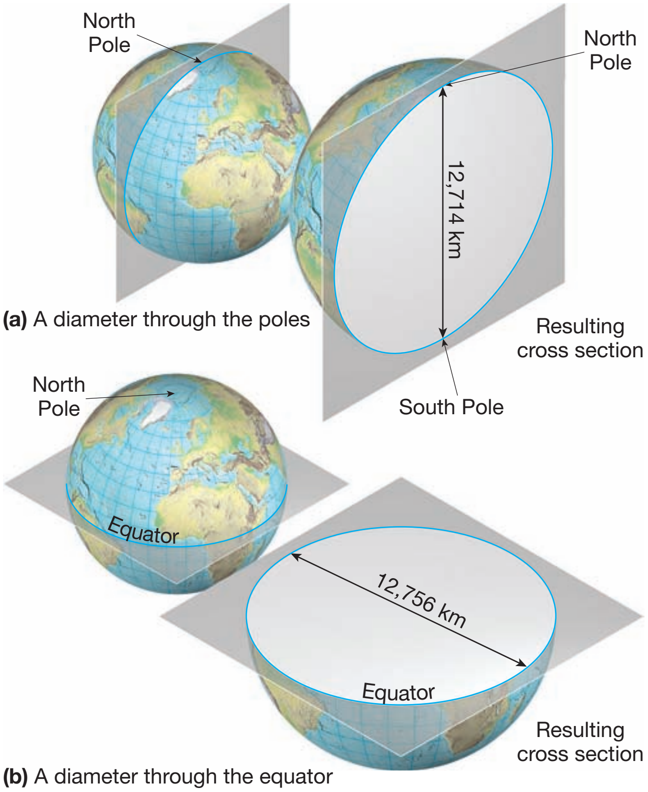
Although prominent on a human scale of perception, this difference is minor on a planetary scale, as Figure 10 illustrates. If Earth were the size of a basketball, Mount Everest would be an imperceptible pimple no greater than 0.17 millimeter (about 7 thousandths of an inch) high. Similarly, the Mariana Trench would be a tiny crease only 0.21 millimeter (about 8 thousandths of an inch) deep—this represents a depression smaller than the thickness of a sheet of paper.

Our perception of the relative size of topographic irregularities on Earth is often distorted by three-dimensional wall maps and globes that emphasize such landforms. To portray any noticeable appearance of topographic variation, the vertical distances on such maps are usually exaggerated 8 to 20 times their actual proportional dimensions—as are many diagrams used in this text. Further, many diagrams illustrating features of the atmosphere also exaggerate relative sizes to convey important concepts.

More than 2600 years ago Greek scholars correctly reasoned Earth to have a spherical shape. About 2200 years ago, Eratosthenes, the director of the Greek library at Alexandria, calculated the circumference of Earth trigonometrically. He determined the angle of the noon Sun rays at Alexandria and at the city of Syene, 960 kilometers (600 miles) away. From these angular and linear distances he was able to estimate an Earth circumference of almost 43,000 kilometers (26,700 miles) which is reasonably close to the actual figure of 40,000 kilometers (24,900 miles).

The Shape of Earth: Earth is almost, but not quite, spherical. The cross section revealed by a cut through the equator would be circular, but a similar cut from pole to pole would be an ellipse rather than a circle (Figure 11). Any rotating body has a tendency to bulge around its equator and flatten at the polar ends of its rotational axis. Although the rocks of Earth may seem quite rigid and immovable to us, they are sufficiently pliable to allow Earth to develop a bulge around its middle. The slightly flattened polar diameter of Earth is 12,714 kilometers (7900 miles), whereas the slightly bulging equatorial diameter is 12,756 kilometers (7926 miles), a difference of only about 0.3 percent. Thus, our planet is properly described as an *oblate spheroid* rather than a true sphere. However, because this variation from true sphericity is exceedingly small, in most cases in this text we will treat Earth as if it were a perfect sphere.

Learning Check 8 **What are Earth's highest and lowest points, and what is the approximate elevation difference between them?**



(a) A diameter through the poles

(b) A diameter through the equator

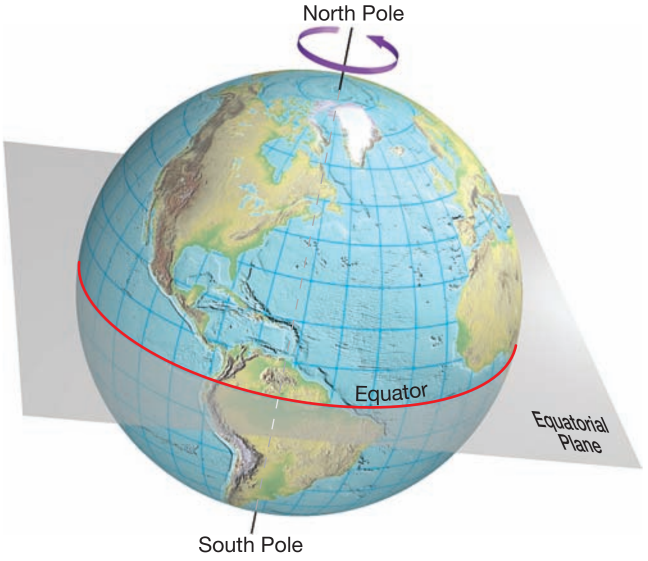
▲ **Figure 11** Earth is not quite a perfect sphere. Its surface flattens slightly at the North Pole and the South Pole and bulges out slightly around the equator. Thus, a cross section through the poles, shown in (a), has a diameter slightly less than the diameter of a cross section through the equator, shown in (b).

THE GEOGRAPHIC GRID—LATITUDE AND LONGITUDE

Any understanding of the distribution of geographic features over Earth's surface requires some system of accurate location. The simplest technique for achieving this is a grid system consisting of two sets of lines that intersect at right angles, allowing the location of any point on the surface to be described by the appropriate intersection, as shown in Figure 12. Such a rectangular grid system has been reconfigured for Earth's spherical surface.

If our planet were a nonrotating body, the problem of describing surface locations would be more difficult than it is: imagine trying to describe the location of a particular point on a perfectly round, perfectly clean Ping-Pong ball. Because Earth does rotate, we can use its rotation axis as a starting point to describe locations.

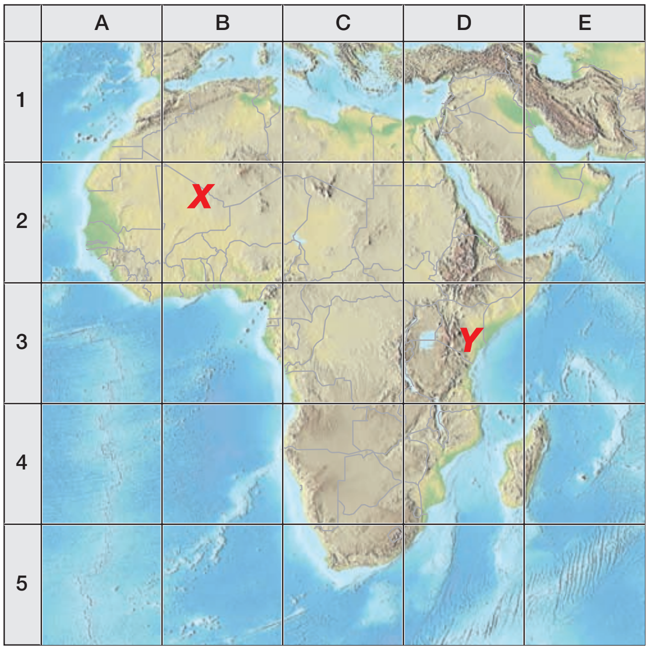
Earth's rotation axis is an imaginary line passing through Earth that connects the points on the surface called the **North Pole** and the **South Pole** (Figure 13). Further, if we visualize an imaginary plane passing through Earth halfway between the poles and perpendicular to the axis of rotation, we have another valuable reference feature: the *plane of the equator*. Where this plane intersects Earth's surface is the imaginary midline of Earth, called simply the **equator.** We use the North Pole, South Pole, rotational axis, and equatorial plane as natural reference features for measuring and describing locations on Earth's surface.



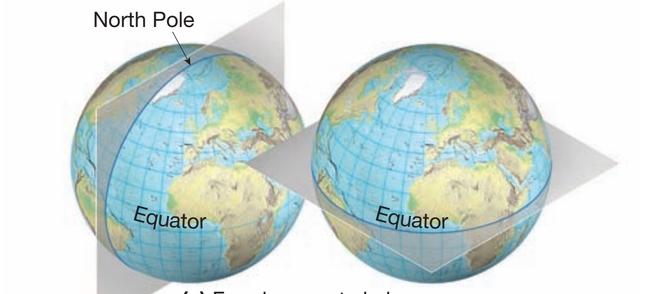
▲ **Figure 13** Earth spins around its rotation axis, an imaginary line that passes through the North Pole and the South Pole. An imaginary plane bisecting Earth midway between the two poles defines the equator.

Great Circles: Any plane that is passed through the center of a sphere bisects that sphere (divides it into two equal halves) and creates what is called a **great circle** where it intersects the surface of the sphere (Figure 14a). The equator is such a great circle. Planes passing through any other part of the sphere produce what are called *small circles* where they intersect the surface (Figure 14b). Great circles have two properties of special interest for us:

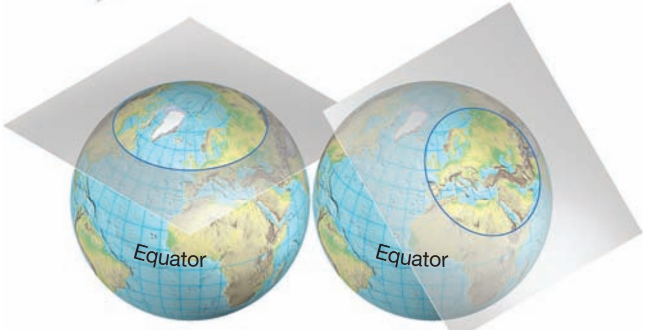
1. A great circle is the largest circle that can be drawn on a sphere; it represents the circumference of that sphere and divides its surface into two equal halves or *hemispheres*. As we'll see later in this chapter, the



▲ **Figure 12** An example of a grid system. The location of point X can be described as 2B or as B2; the location of Y is 3D or D3.



(a) Forming great circles



(b) Forming small circles

▲ **Figure 14** Comparison of great and small circles. (a) A great circle results from the intersection of Earth's surface with any plane that passes through Earth's center. (b) A small circle results from the intersection of Earth's surface with any plane that does not pass through Earth's center.

dividing line between the daytime and nighttime halves of Earth is a great circle.

2. A path between two points along the arc of a great circle is always the shortest route between those points. Such routes on Earth are known as *great circle routes*.

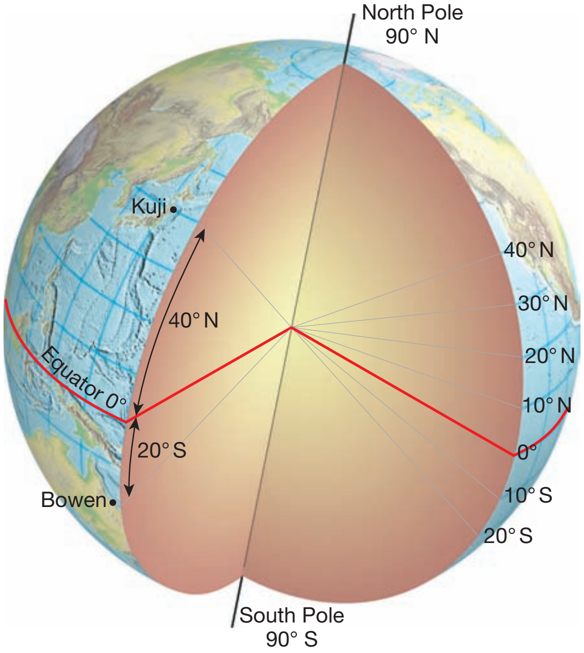
The geographic grid used as the locational system for Earth is based on the principles just discussed. Furthermore, the system is closely linked with the various positions assumed by Earth in its orbit around the Sun. The grid system of Earth is referred to as a *graticule* and consists of lines of latitude and longitude.

Learning Check 9 What is a great circle? Provide one example of a great circle.

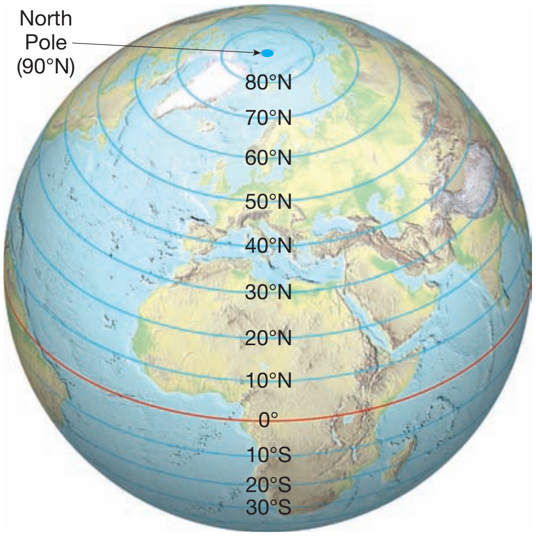
Latitude

Latitude is a description of location expressed as an angle north or south of the equator. As shown in Figure 15, we can project a line from any location on Earth's surface to the center of Earth. The angle between this line and the equatorial plane is the latitude of that location.

Latitude is expressed in degrees, minutes, and seconds. There are 360 degrees (°) in a circle, 60 minutes (') in one degree, and 60 seconds (″) in one minute. With the advent of GPS navigation, it is increasingly common to see latitude and longitude designated using decimal notation, for example, 38°22´47″ N can be written 38°22.78´ N or even 38.3797° N.



▲ **Figure 15** Measuring latitude. An imaginary line from Kuji, Japan, to Earth's center makes an angle of 40° with the equator. Therefore, Kuji's latitude is 40° N. An imaginary line from Bowen, Australia, to Earth's center makes an angle of 20°, giving this city a latitude of 20° S.



▲ **Figure 16** Lines of latitude indicate north-south location. They are called *parallels* because they are always parallel to each other.

Latitude varies from 0° at the equator to 90° north at the North Pole and 90° south at the South Pole. Any position north of the equator is north latitude, and any position south of the equator is south latitude (the equator itself is simply referred to as having a latitude of 0°).

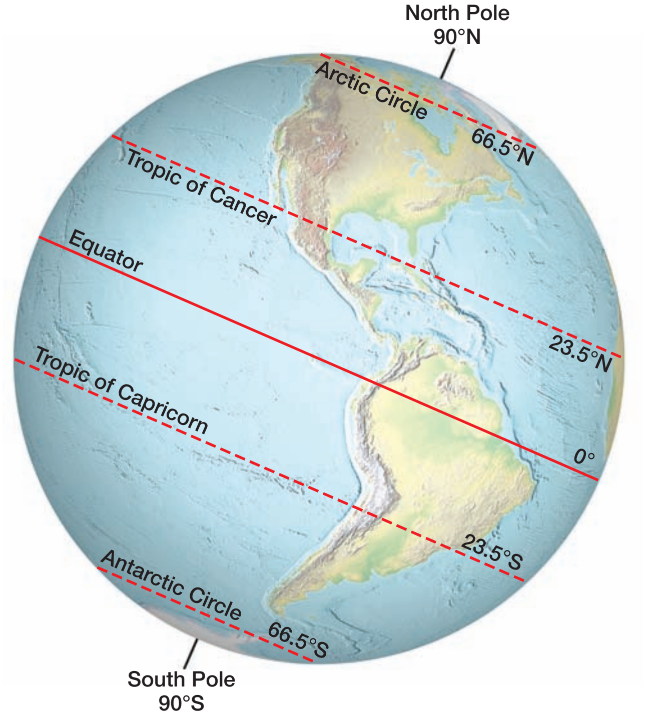
A line connecting all points of the same latitude is called a **parallel**—because it is parallel to all other lines of latitude (Figure 16). The equator is the parallel of 0° latitude, and it, alone of all parallels, constitutes a great circle. All other parallels are small circles—all aligned in true east–west directions on Earth's surface. Because latitude is expressed as an angle, it can be infinitely subdivided—parallels can be constructed for every degree of latitude, or even for fractions of a degree of latitude.

Although it is possible to either construct or visualize an unlimited number of parallels, seven latitudes are of particular significance in a general study of Earth (Figure 17):

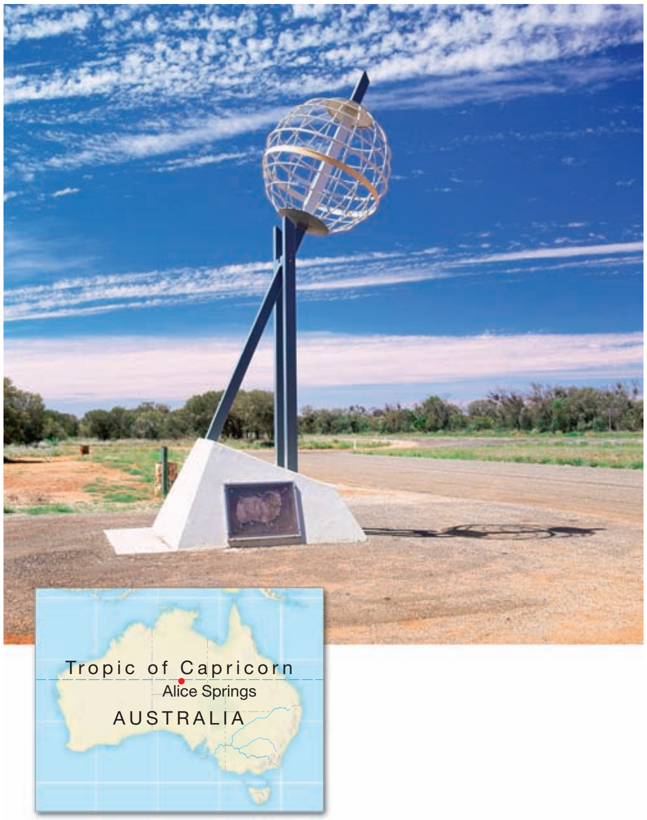
1. Equator, 0°
2. Tropic of Cancer, 23.5° N
3. Tropic of Capricorn, 23.5° S (Figure 18)
4. Arctic Circle, 66.5° N
5. Antarctic Circle, 66.5° S
6. North Pole, 90° N
7. South Pole, 90° S

The North Pole and South Pole are of course points rather than lines, but can be thought of as infinitely small parallels. The significance of these seven parallels will be explained later in this chapter when we discuss the seasons.

Learning Check 10 Why are lines of latitude called parallels?



▲ **Figure 17** Seven important parallels. As we will see when we discuss the seasons, these latitudes represent special locations where rays from the Sun strike Earth's surface on certain days of the year.



▲ **Figure 18** The Tropic of Capricorn; like all other parallels of latitude, is an imaginary line. As a significant parallel, however, its location is often commemorated by a sign. This scene is near Alice Springs in the center of Australia.

Descriptive Zones of Latitude: Regions on Earth are sometimes described as falling within general bands or zones of latitude. The following common terms associated with latitude are used throughout this text (note that there is some overlap between several of these terms):

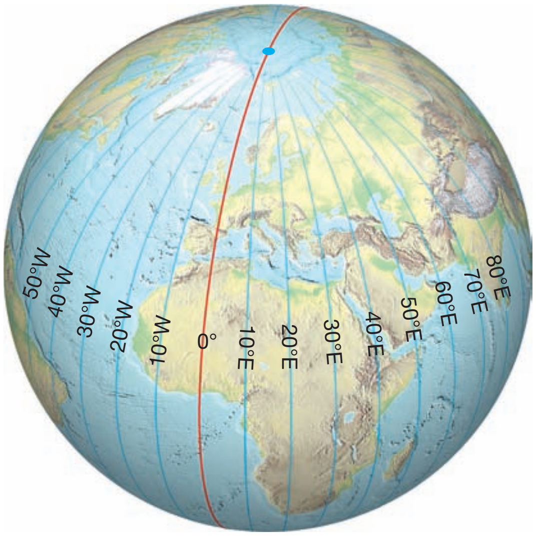
- *Low latitude*—generally between the equator and 30° N and S
- *Midlatitude*—between about 30° and 60° N and S
- *High latitude*—latitudes greater than about 60° N and S
- *Equatorial*—within a few degrees of the equator
- *Tropical*—within the tropics (between 23.5° N and 23.5° S)
- *Subtropical*—slightly poleward of the tropics, generally around 25–30° N and S
- *Polar*—within a few degrees of the North or South Pole

Nautical Miles: Each degree of latitude on the surface of Earth covers a north–south distance of about 111 kilometers (69 miles). The distance varies slightly with latitude because of the flattening of Earth at the poles. The distance measurement of a *nautical mile*—and the description of speed known as a *knot* (one nautical mile per hour)—is defined by the distance covered by one minute of latitude (1´), the equivalent of about 1.15 statute ("ordinary") miles or about 1.85 kilometers.

Longitude

Latitude comprises the north–south component of Earth's grid system. The other half is **longitude**—an angular description of east–west location, also measured in degrees, minutes, and seconds.

Longitude is represented by imaginary lines extending from pole to pole and crossing all parallels at right angles. These lines, called **meridians**, are not parallel to one another except where they cross the equator. Any pair of meridians is farthest apart at the equator, becoming increasingly close together northward and southward and finally converging at the poles (Figure 19).



▲ **Figure 19** Lines of longitude, or *meridians*, indicate east–west location and all converge at the poles.