The Dynamic Earth

CHAPTER **3**

PRE-READING ACTIVITY

FOLDNOTES

Pyramid Before you read this chapter, create the **FoldNote** entitled "Pyramid" described in the Reading and Study Skills section of the Appendix. Label the sides of the pyramid with "Geosphere," "Atmosphere," "Hydrosphere," and "Biosphere." As you read the chapter, write information you learn about each category under the appropriate flap.

Landmasses are moving slowly across our planet's surface. The atmosphere is a swirling mix of gases and vapor. Our planet, which may appear placid from space, is not stable and unchanging.

SECTION 1
The Geosphere

Molten rock from Earth's interior flows over the surface of the planet, and violent eruptions blow the tops off of volcanoes. Hurricanes batter beaches and change coastlines. Earthquakes shake the ground and topple buildings and freeway overpasses. None of this activity is caused by people. Instead, it is the result of the dynamic state of planet Earth. What are the conditions that allow us to survive on a constantly changing planet?

Objectives

- Describe the composition and structure of the Earth.
- Describe the Earth's tectonic plates.
- Explain the main cause of earthquakes and their effects.
- Identify the relationship between volcanic eruptions and climate change.
- Describe how wind and water alter the Earth's surface.

Key Terms

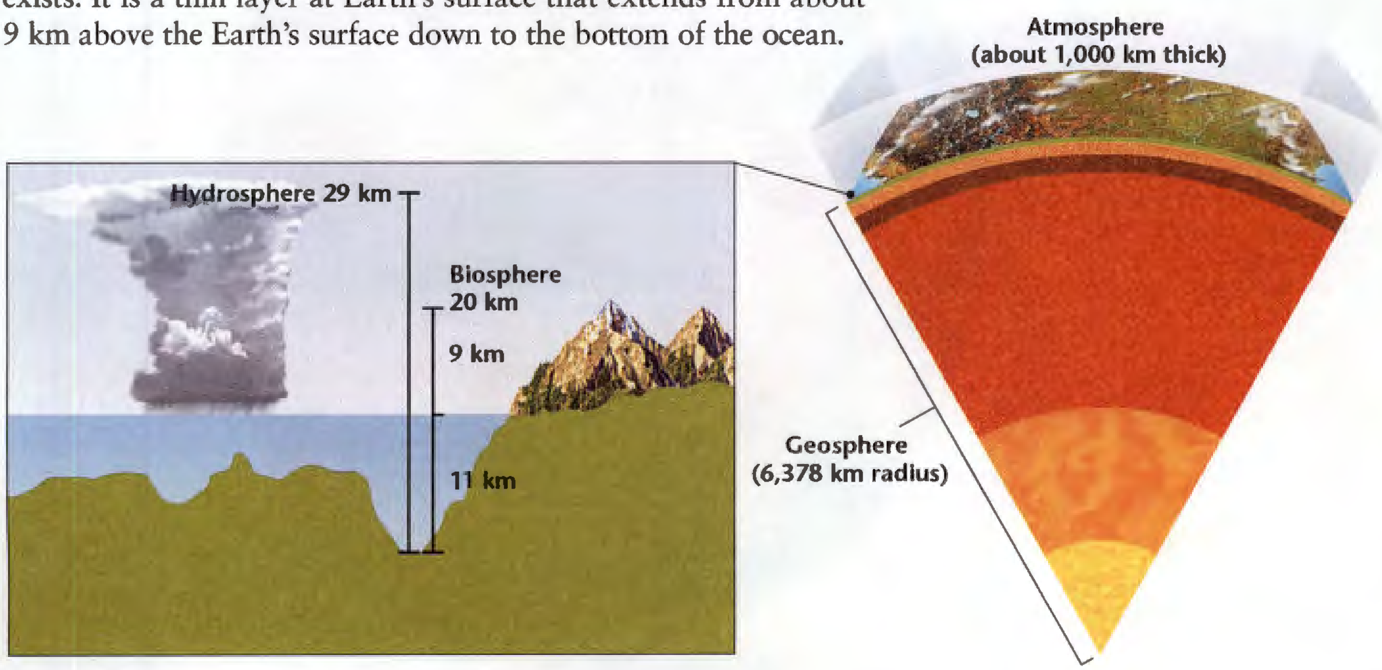
geosphere
crust
mantle
core
lithosphere
asthenosphere
tectonic plate
erosion

The Earth as a System

The Earth is an integrated system that consists of rock, air, water, and living things that all interact with each other. Scientists divide this system into four parts. As shown in **Figure 1,** the four parts are the geosphere (rock), the atmosphere (air), the hydrosphere (water), and the biosphere (living things).

The solid part of the Earth that consists of all rock, and the soils and sediments on Earth's surface, is the **geosphere.** Most of the geosphere is located in Earth's interior. At the equator, the average distance through the center of the Earth to the other side is 12,756 km. The atmosphere is the mixture of gases that makes up the air we breathe. Nearly all of these gases are found in the first 30 km above the Earth's surface. The hydrosphere makes up all of the water on or near the Earth's surface. Much of this water is in the oceans, which cover nearly three-quarters of the globe. Water is also found in the atmosphere, on land, and in the soil. The biosphere is made up of parts of the geosphere, the atmosphere, and the hydrosphere. The biosphere is the part of the Earth where life exists. It is a thin layer at Earth's surface that extends from about 9 km above the Earth's surface down to the bottom of the ocean.

Figure 1 ▶ The Earth is an integrated system that consists of the geosphere, the atmosphere, the hydrosphere, and the biosphere (inset).



Discovering Earth's Interior

Studying the Earth beneath our feet is not easy. The deepest well that has been drilled into Earth's interior is only about 12 km deep and gives us no direct information about conditions farther beneath the surface. An alternative method must be used to study the interior of the Earth. Scientists can use *seismic waves* to learn about Earth's interior. Seismic waves are the same waves that travel through Earth's interior during an earthquake. If you have ever tapped a melon to see if it is ripe, you know how this process works. The energy of your tap travels through the melon, and the state of the melon's interior affects the sound you detect. A seismic wave is also altered by the nature of the material through which it travels. As shown in **Figure 2**, seismologists measure changes in the speed and direction of seismic waves that penetrate the interior of the planet. In this way seismologists have learned that the Earth is made up of different layers and have inferred what substances make up each layer.

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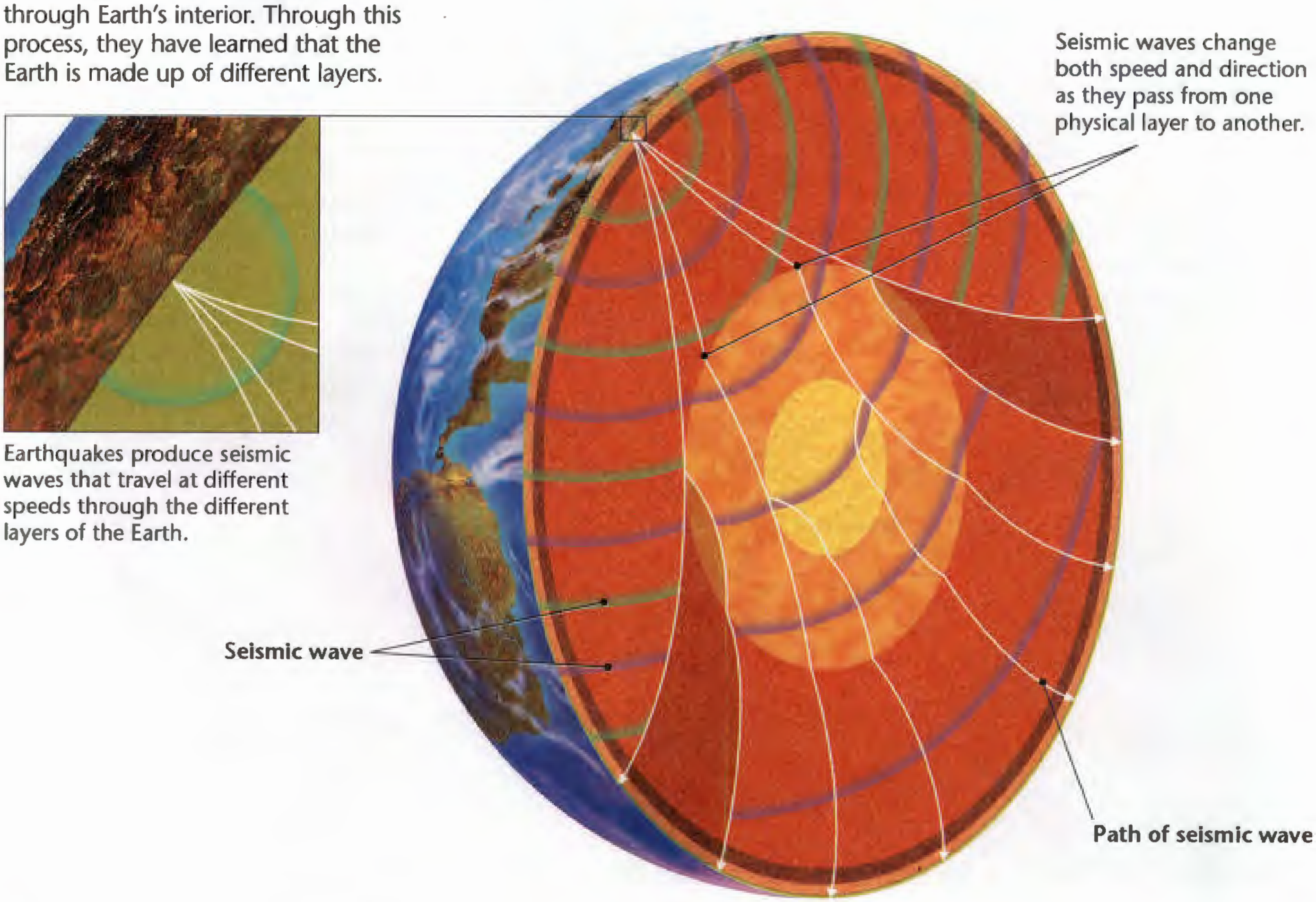
The Composition of the Earth Scientists divide the Earth into three layers—the crust, the mantle, and the core—based on the composition of each layer. These layers are made up of progressively denser materials toward the center of the Earth. **Figure 3** shows a cross section of the Earth. Earth's thin outer layer, the **crust,** is made almost entirely of light elements. It makes up less than 1 percent of the planet's mass. The crust is Earth's thinnest

Figure 2 ▶ Seismologists have measured changes in the speed and direction of seismic waves that travel through Earth's interior. Through this process, they have learned that the Earth is made up of different layers.



layer. It is 5 km to 8 km thick beneath the oceans and is 20 km to 70 km thick beneath the continents. The **mantle,** which is the layer beneath the crust, makes up 64 percent of the mass of the Earth. The mantle is approximately 2,900 km thick and is made of rocks of medium density. Earth's innermost layer is the **core.** The core is composed of the densest elements. It has a radius of approximately 3,400 km.

The Structure of the Earth The Earth can be divided into five layers based on the physical properties of each layer. Earth's outer layer is the **lithosphere.** It is a cool, rigid layer that is 15 km to 300 km thick that includes the crust and uppermost part of the mantle. It is divided into huge pieces called *tectonic plates*. The **asthenosphere** is the layer beneath the lithosphere. The asthenosphere is a plastic, solid layer of the mantle made of rock that flows very slowly and allows tectonic plates to move on top of it. Beneath the asthenosphere is the mesosphere, the lower part of the mantle.

The Earth's outer core is a dense liquid layer. At the center of the Earth is the dense, solid inner core, which is made up mostly of the metals iron and nickel. The temperature of the inner core is estimated to be between 4,000°C to 5,000°C. Even though the inner core is so hot, it is solid because it is under enormous pressure. Earth's outer and inner core together make up about one-third of Earth's mass.

Geofact

Pangaea Two hundred and forty-five million years ago almost all the land on Earth was joined into one supercontinent known as *Pangaea*, which is Greek for "all earth." Pangaea was surrounded by a world ocean called *Panthalassa*, which means "all sea." By the time the dinosaurs became extinct 65 million years ago, Pangaea had separated into all the present continents with positions close to the present positions.

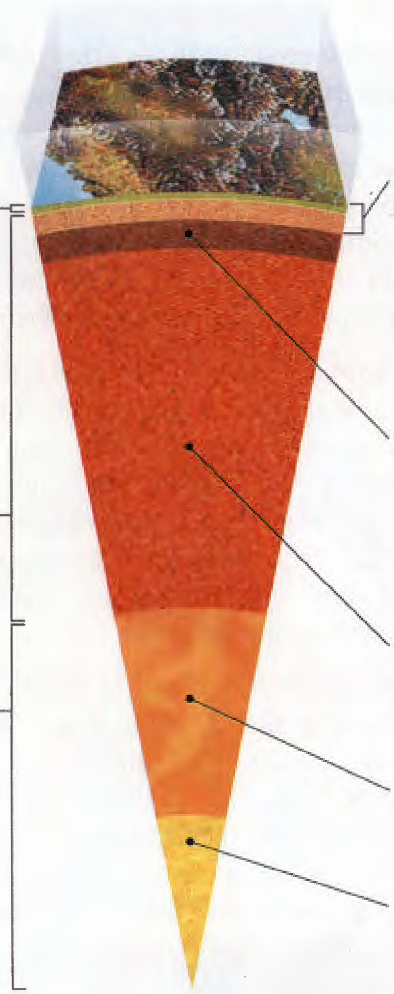


Figure 3 ▶ Earth's Layers Scientists divide the Earth into different layers based on composition and physical properties.

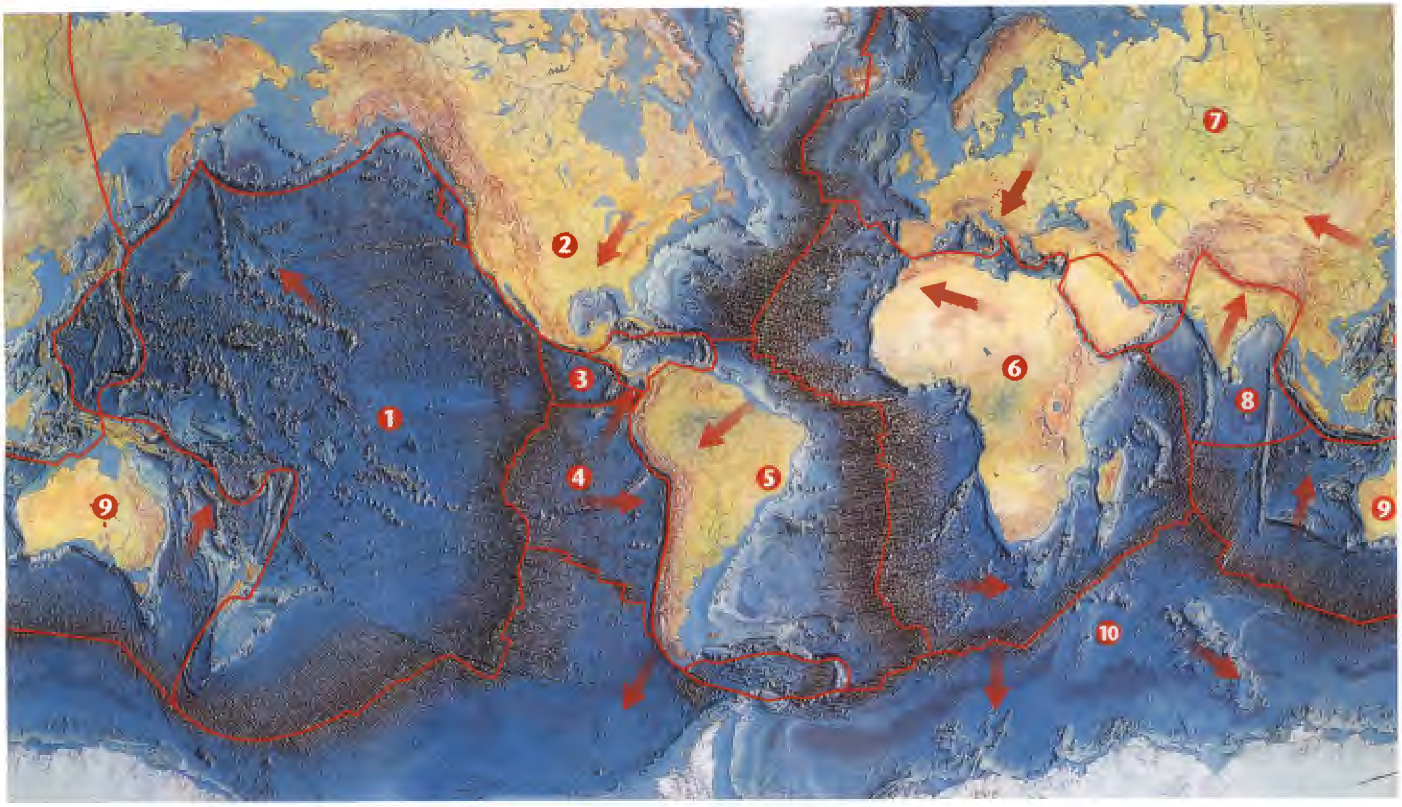


Figure 4 ▶ Earth's lithosphere is divided into pieces called *tectonic plates.* The tectonic plates are moving in different directions and at different speeds.

Major Tectonic Plates
1. Pacific plate
2. North American plate
3. Cocos plate
4. Nazca plate
5. South American plate
6. African plate
7. Eurasian plate
8. Indian plate
9. Australian plate
10. Antarctic plate

Plate Tectonics

You learned that the lithosphere—the rigid, outermost layer of the Earth—is divided into pieces called tectonic plates. These plates glide across the underlying asthenosphere in much the same way as a chunk of ice drifts across a pond. The continents are located on tectonic plates and move around with them. The major tectonic plates include the Pacific, North American, South American, African, Eurasian, and Antarctic plates. **Figure 4** illustrates the major tectonic plates and their direction of motion.

Plate Boundaries Much of the geologic activity at the surface of the Earth takes place at the boundaries between tectonic plates. Plates may separate from one another, collide with one another, or slip past one another. Enormous forces are generated at tectonic plate boundaries, where the crust is pulled apart, is squeezed together, or is constantly slipping. The forces produced at the boundaries of tectonic plates can cause mountains to form, earthquakes to shake the crust, and volcanoes to erupt.

Plate Tectonics and Mountain Building Tectonic plates are continually moving around the Earth's surface. When tectonic plates collide, slip by one another, or pull apart, enormous forces cause rock to break and buckle. Where plates collide, the crust becomes thicker and eventually forms mountain ranges. The Himalaya Mountains, as shown in **Figure 5,** began to form when the tectonic plate containing Asia and the tectonic plate containing India began to collide 50 million years ago.

Earthquakes

A *fault* is a break in the Earth's crust along which blocks of the crust slide relative to one another. When rocks that are under stress suddenly break along a fault, a series of ground vibrations is set off. These vibrations of the Earth's crust caused by slippage along a fault are known as *earthquakes*. Earthquakes are occurring all of the time, but many are so small that we cannot feel them. Other earthquakes are enormous movements of the Earth's crust that cause widespread damage.

The Richter scale is used by scientists to quantify the amount of energy released by an earthquake. The measure of the energy released by an earthquake is called *magnitude*. The smallest magnitude that can be felt is approximately 2.0, and the largest magnitude that has ever been recorded is 9.5. Each increase of magnitude by one whole number indicates the release of 31.7 times more energy than the whole number below it. For example, an earthquake of magnitude 6.0 releases 31.7 times the energy of an earthquake of magnitude 5.0. Earthquakes that cause widespread damage have magnitudes of 7.0 and greater.

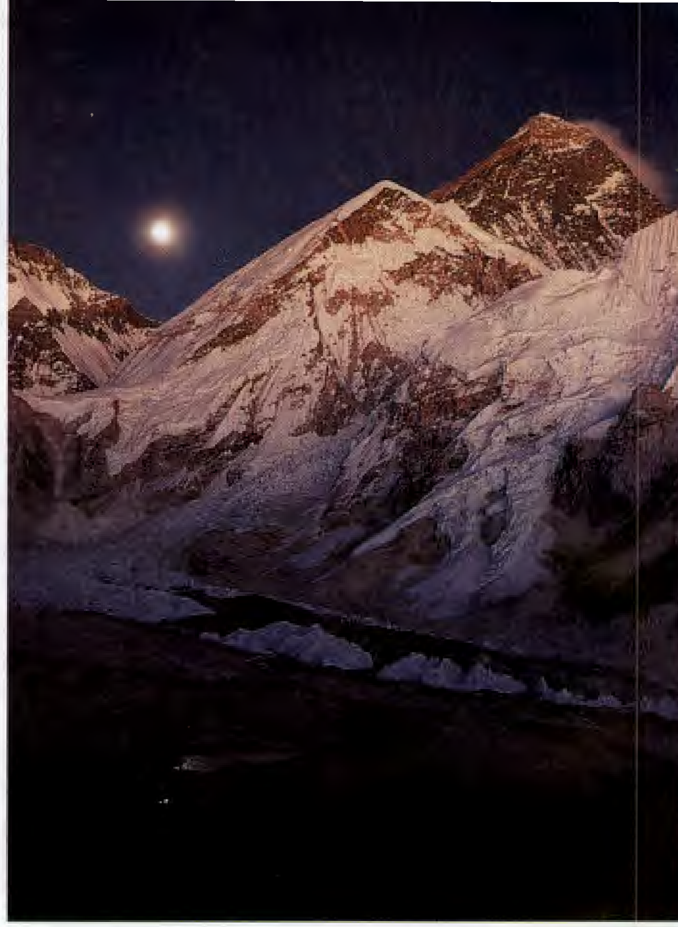


Figure 5 ▶ The Himalaya Mountains are still growing today because the tectonic plate containing Asia and the tectonic plate containing India continue to collide.

Where Do Earthquakes Occur? Areas of the world where earthquakes occur are shown on the map in **Figure 6.** As you can see from the map, the majority of earthquakes take place at or near tectonic plate boundaries because of the enormous stresses that are generated when tectonic plates separate, collide, or slip past each other. Over the past 15 million to 20 million years, large numbers of earthquakes have occurred along the San Andreas fault, which runs almost the entire length of California. The San Andreas fault is the line where parts of the North American plate and the Pacific plate are slipping past one another.

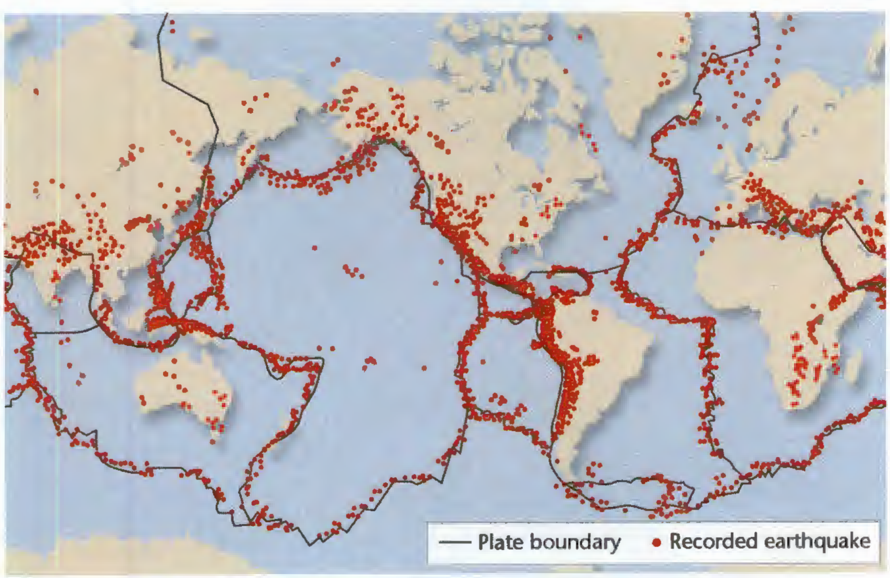


Figure 6 ▶ The largest and most active earthquake zones lie along tectonic plate boundaries.

Connection to Biology

Can Animals Predict Earthquakes? Can animals that live close to the site of an earthquake detect changes in their physical environment prior to an earthquake? Documentation of unusual animal behavior prior to earthquakes can be found as far back as 1784. Examples of this odd behavior include zoo animals refusing to enter shelters at night, snakes and small mammals abandoning their burrows, and wild birds leaving their usual habitats. These behaviors reportedly happened within a few days, hours, or minutes of earthquakes.

Earthquake Hazard Despite much study, scientists cannot predict when earthquakes will take place. However, information about where they are most likely to occur can help people prepare for them. An area's earthquake-hazard level is determined by past and present seismic activity. The Maps in Action activity located at the end of this chapter shows earthquake-hazard levels for the contiguous United States.

Earthquakes are not restricted to high-risk areas. In 1886, an earthquake shook Charleston, South Carolina, which is considered to be in a medium-risk area. Because the soil beneath the city is sandy, this earthquake caused extensive damage. During shaking from a strong earthquake, sand acts like a liquid and causes buildings to sink. In areas that are prone to earthquakes, it is worth the extra investment to build bridges and buildings that are at least partially earthquake resistant. Earthquake-resistant buildings are slightly flexible so that they can sway with the ground motion.

Volcanoes

A *volcano* is a mountain built from magma—melted rock—that rises from the Earth's interior to the surface. Volcanoes are often located near tectonic plate boundaries where plates are either colliding or separating from one another. Volcanoes may occur on land or under the sea, where they may eventually break the ocean surface as islands. As **Figure 7** shows, the majority of the world's active volcanoes on land are located along tectonic plate boundaries that surround the Pacific Ocean.

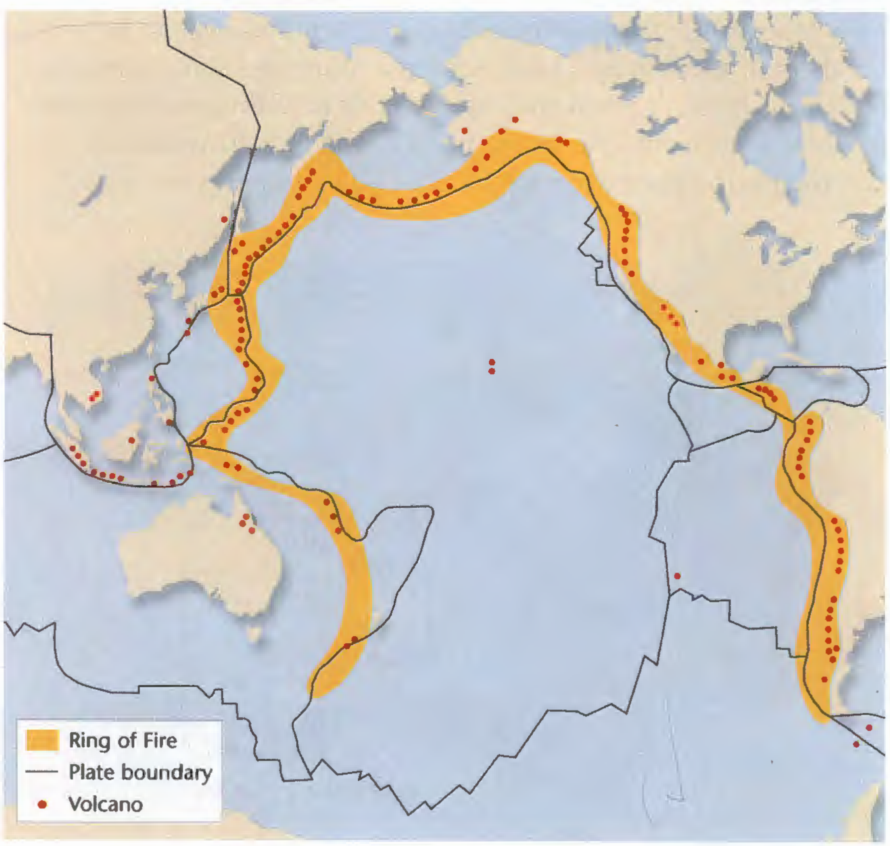


Figure 7 ▶ The Ring of Fire Tectonic plate boundaries are places where volcanoes usually form. The Ring of Fire contains nearly 75 percent of the world's active volcanoes that are on land. A large number of people live on or near the Ring of Fire.

Figure 8 ▶ On May 18, 1980, Mount St. Helens in Washington State erupted. Sixty-three people lost their lives, and 400 km^2 of forest were destroyed in an eruption that blew away the top 410 m of the volcano.

Local Effects of Volcanic Eruptions Volcanic eruptions can be devastating to local economies and can cause great human loss. Clouds of hot ash, dust, and gases can flow down the slope of a volcano at speeds of up to 200 km/hr and sear everything in their path. During an eruption, volcanic ash can mix with water and produce a mudflow. In 1985, Nevado del Ruiz in Colombia erupted, melting ice at the volcano's summit. A mudflow raced downhill and engulfed the town of Armero. In addition, ash that falls to the ground can cause buildings to collapse under its weight, bury crops, and damage the engines of vehicles. Volcanic ash may also cause breathing difficulties.

Global Effects of Volcanic Eruptions Major volcanic eruptions, such as the eruption of Mount St. Helens shown in Figure 8, can change Earth's climate for several years. In large eruptions, clouds of volcanic ash and sulfur-rich gases may reach the upper atmosphere. As the ash and gases spread across the planet, they can reduce the amount of sunlight that reaches the Earth's surface. This reduction in sunlight can cause a drop in the average global surface temperature. In the 1991 eruption of Mount Pinatubo in the Philippines, large clouds of ash and gases entered the Earth's atmosphere. The amount of sunlight that reached the Earth's surface was estimated to have decreased by 2 to 4 percent. As a result, the average global temperature dropped by several tenths of a degree Celsius over a period of several years.

Graphic Organizer **Comparison Table**

Create the **Graphic Organizer** entitled "Comparison Table" described in the Appendix. Label the columns with "Local Effects" and "Global Effects." Label the rows with "Volcanic Eruptions" and "Earthquakes." Then, fill in the table with details about the characteristics and the effects of each type of natural disaster.

Erosion

Forces at the boundaries of tectonic plates bring rock to the surface of the Earth. At the Earth's surface, rocks are altered by other forces. The Earth's surface is continually battered by wind and scoured by running water, which moves rocks around and changes their appearance. The removal and transport of surface material is called **erosion.** Erosion wears down rocks and makes them smoother as time passes. The older a mountain range is, the longer the forces of erosion have acted on it. This information helped geologists learn that the round-topped Appalachian Mountains in the eastern United States are older than the jagged Rocky Mountains in the west.

Figure 9 ▶ Over long periods of time, erosion can produce spectacular landforms on Earth's surface.

Water Erosion Erosion by both rivers and oceans can produce dramatic changes on Earth's surface. Waves from ocean storms can erode coastlines to give rise to a variety of spectacular landforms. Over time, rivers can carve deep gorges into the landscape, as shown in **Figure 9.**

Wind Erosion Like moving water, wind can also change the landscape of our planet. In places where plants grow, their roots hold soil in place. But in places where there are few plants, wind can blow soil away very quickly. Beaches and deserts, which have loose, sandy soil, are examples of places where few plants grow. Soft rocks, such as sandstone, erode more easily than hard rocks, such as granite, do. In parts of the world, spectacular rock formations are sometimes seen where pinnacles of hard rock stand alone because the softer rock around them has eroded by wind and/or water.

SECTION 1 Review

1. **Name** and describe the physical and compositional layers into which scientists divide the Earth.
2. **Explain** the main cause of earthquakes and their effects.
3. **Describe** the effects that a large-scale volcanic eruption can have on the global climate.
4. **Describe** how wind and water alter the Earth's surface.

CRITICAL THINKING

5. **Analyzing Processes** How might the surface of the Earth be different if it were not divided into tectonic plates?
6. **Compare and Contrast** Read about the effects of erosion on mountains on this page. From what you have read, describe the physical features you would associate with a young mountain range and an old mountain range. READING SKILLS

SECTION 2

The Atmosphere

Objectives

- Describe the composition of the Earth's atmosphere.
- Describe the layers of the Earth's atmosphere.
- Explain three mechanisms of heat transfer in Earth's atmosphere.
- Explain the greenhouse effect.

Key Terms

atmosphere
troposphere
stratosphere
ozone
radiation
conduction
convection
greenhouse effect

Earth is surrounded by a mixture of gases known as the **atmosphere.** Nitrogen, oxygen, carbon dioxide, and other gases are all parts of this mixture. Earth's atmosphere changes constantly as these gases are added and removed. For example, animals remove oxygen when they breathe in and add carbon dioxide when they breathe out. Plants take in carbon dioxide and add oxygen to the atmosphere when they produce food. Gases can be added to and removed from the atmosphere in ways other than through living organisms. A volcanic eruption adds gases. A vehicle both adds and removes gases.

The atmosphere also insulates Earth's surface. This insulation slows the rate at which the Earth's surface loses heat. The atmosphere keeps Earth at temperatures at which living things can survive.

Composition of the Atmosphere

Figure 10 shows the percentages of gases that make up Earth's atmosphere. Nitrogen makes up 78 percent of the Earth's atmosphere. It enters the atmosphere when volcanoes erupt and when dead plants and animals decay. Oxygen, the second most abundant gas in Earth's atmosphere, is primarily produced by plants. Gases including argon, carbon dioxide, methane, and water vapor make up the rest of the atmosphere.

In addition to gases, the atmosphere contains many types of tiny, solid particles, or atmospheric dust. Atmospheric dust is mainly soil but includes salt, ash from fires, volcanic ash, particulate matter from combustion, skin, hair, bits of clothing, pollen, bacteria and viruses, and tiny, liquid droplets called *aerosols*.

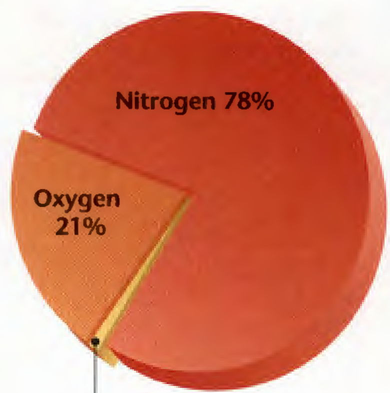


Figure 10 ▶ Ninety-nine percent of the air we breathe is made up of nitrogen and oxygen.

Figure 11 ▶ This sunrise scene that was taken from space captures the tropopause, the transitional zone that separates the troposphere (yellow layer) from the stratosphere (white layer). The tropopause is the illuminated brown layer.

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Air Pressure Earth's atmosphere is pulled toward Earth's surface by gravity. As a result of the pull of gravity, the atmosphere is denser near Earth's surface. Almost the entire mass of Earth's atmospheric gases is located within 30 km of our planet's surface. Fewer gas molecules are found at altitudes above 30 km; therefore, less pressure at these altitudes pushes downward on atmospheric gases. The air also becomes less dense as elevation increases, so breathing at higher elevations is more difficult.

Layers of the Atmosphere

The atmosphere is divided into four layers based on temperature changes that occur at different distances above the Earth's surface. **Figure 12** shows the four layers of Earth's atmosphere.

The Troposphere The atmospheric layer nearest Earth's surface is the troposphere. The **troposphere** extends to 18 km above Earth's surface. Almost all of the weather occurs in this layer, as shown in **Figure 13.** The troposphere is Earth's densest atmospheric layer. Temperature decreases as altitude increases in the troposphere.

Geofact

The Mesosphere In geology, the term *mesosphere,* which means "middle sphere," refers to the 2,550 km thick compositional layer of the Earth that lies below the asthenosphere. The mesosphere is also the name of the atmospheric layer that extends from 50 to 80 km above Earth's surface.

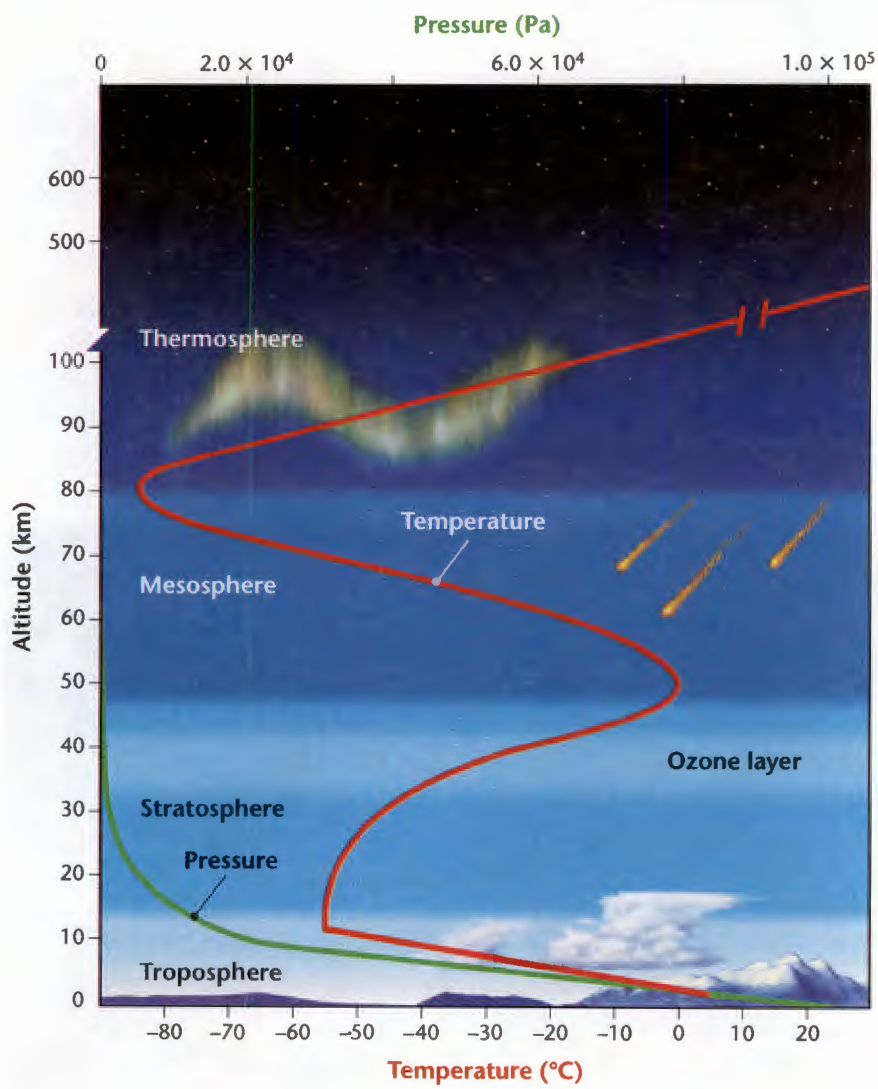


Figure 12 ▶ The layers of the atmosphere are defined by changes in temperature and pressure. The red line indicates temperature, and the green line indicates pressure in pascals.

Figure 13 ▶ Scientists on board a research plane from the National Oceanic and Atmospheric Administration (NOAA) are making measurements of temperature, humidity, barometric pressure, and wind speed as they fly over the eye of a hurricane.

The Stratosphere Above the troposphere is the stratosphere. The **stratosphere** extends from 18 km to an altitude of about 50 km. Temperatures rise as altitude increases in the stratosphere. This change happens because ozone in the stratosphere absorbs the sun's ultraviolet (UV) energy and warms the air. **Ozone,** O_3, is a molecule that is made up of three oxygen atoms. Almost all the ozone in the atmosphere is concentrated in the ozone layer in the stratosphere. Because ozone absorbs UV radiation, it reduces the amount of UV radiation that reaches the Earth. UV radiation that reaches Earth can damage living cells.

The Mesosphere The layer above the stratosphere is the *mesosphere*. This layer extends to an altitude of about 80 km. The mesosphere is the coldest layer of the atmosphere, and its temperatures have been measured as low as –93°C.

The Thermosphere The atmospheric layer located farthest from Earth's surface is the *thermosphere*. In the thermosphere, nitrogen and oxygen absorb solar radiation, which results in temperatures that have been measured above 2,000°C. Even though air temperatures in this layer are very high, the thermosphere would not feel hot to us. Air particles that strike one another transfer heat. The air in the thermosphere is so thin that air particles rarely collide, so little heat is transferred.

Nitrogen and oxygen atoms in the lower region of the thermosphere (about 80 km to 550 km above Earth's surface) absorb harmful solar radiation, such as X rays and gamma rays. This absorption causes atoms to become electrically charged. Electrically charged atoms are called *ions*. The lower thermosphere is called the *ionosphere*. Sometimes ions radiate energy as light. These lights often glow in spectacular colors in the night skies near the Earth's North and South Poles, as shown in **Figure 14.**

Figure 14 ▶ The *aurora borealis,* or Northern Lights, can be seen in the skies around Earth's North Pole.

QuickLAB

The Heat Is On!

Procedure

1. Fill two **250 mL beakers** with **water.** Use a **thermometer** to record the initial temperature of the water in both beakers. The temperature of the water should be the same for both beakers.
2. Wrap one beaker with **white paper,** and wrap one with **black paper.** Secure the paper with a piece of **tape.**
3. Place a **150 W floodlight** 50 cm away from the beakers, and turn the light on.
4. Record the temperature of the water in both beakers at 1 min, 5 min, and 10 min.

Analysis

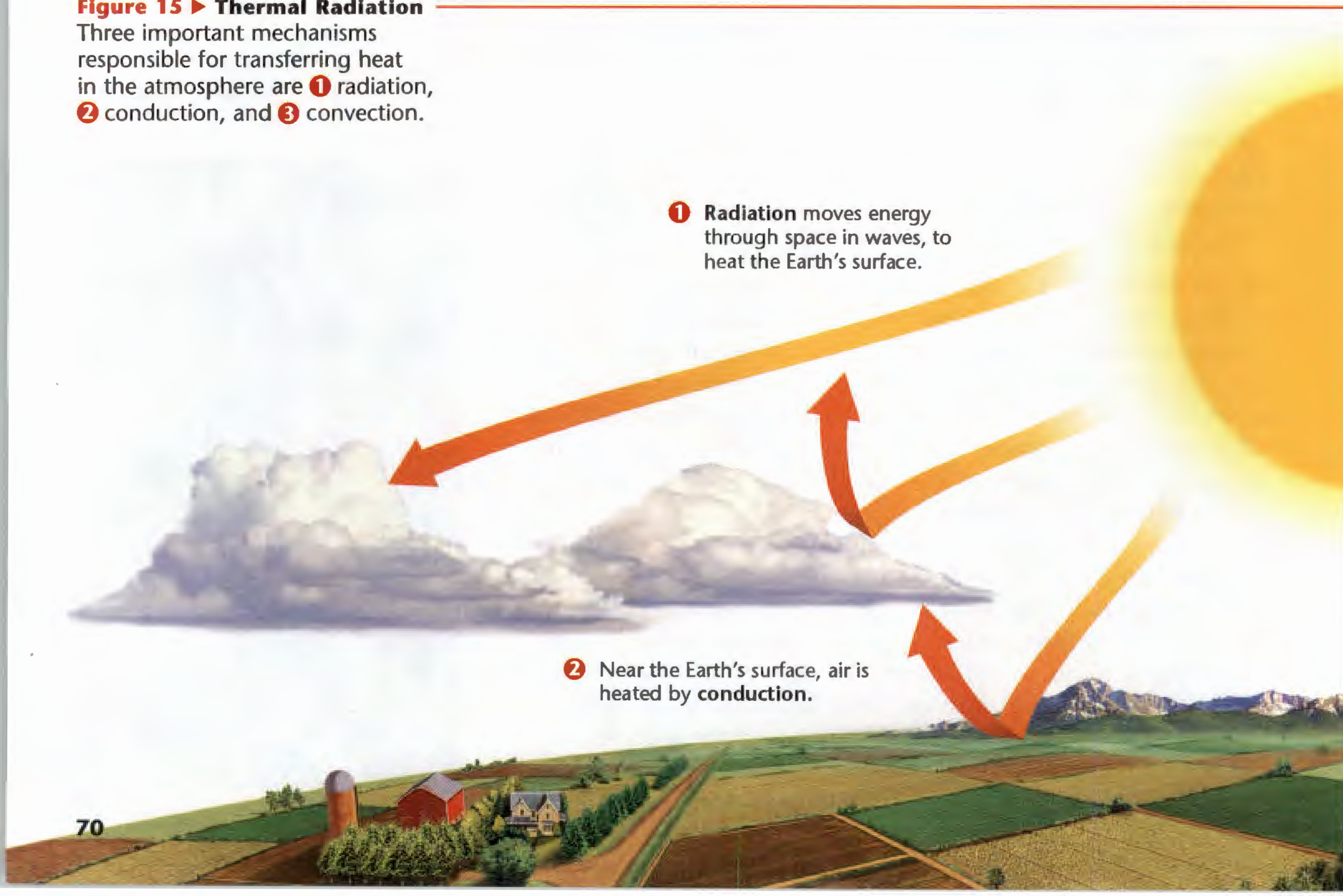
1. By what mechanism is energy being transferred to the beakers? Explain your answer.

Energy in the Atmosphere

As shown in **Figure 15,** energy from the sun is transferred in Earth's atmosphere by three mechanisms: radiation, convection, and conduction. **Radiation** is the transfer of energy across space and in the atmosphere. When you stand before a fire or a bed of coals, the heat you feel has reached you by radiation. **Conduction** is the flow of heat from a warmer object to a colder object when the objects are placed in direct physical contact. **Convection** is the transfer of heat by air currents. Hot air rises and cold air sinks. Thus, if you hold your hand above a hot iron, you will feel the heat because a current of hot air rises up to your hand.

Heating of the Atmosphere Solar energy reaches the Earth as electromagnetic radiation, which includes visible light, infrared radiation, and ultraviolet light. The sun releases a vast amount of radiation, but our planet only receives about two-billionths of this energy. This seemingly small amount of radiation contains a tremendous amount of energy, however. As shown in **Figure 15,** about half of the solar energy that enters the atmosphere passes through the atmosphere and reaches Earth's surface. The rest of the energy is absorbed or reflected in the atmosphere by clouds, gases, and dust, or it is reflected by the Earth's surface. On a sunny day, rocks may become too hot to touch. If the Earth's

Figure 15 ▶ Thermal Radiation Three important mechanisms responsible for transferring heat in the atmosphere are ❶ radiation, ❷ conduction, and ❸ convection.



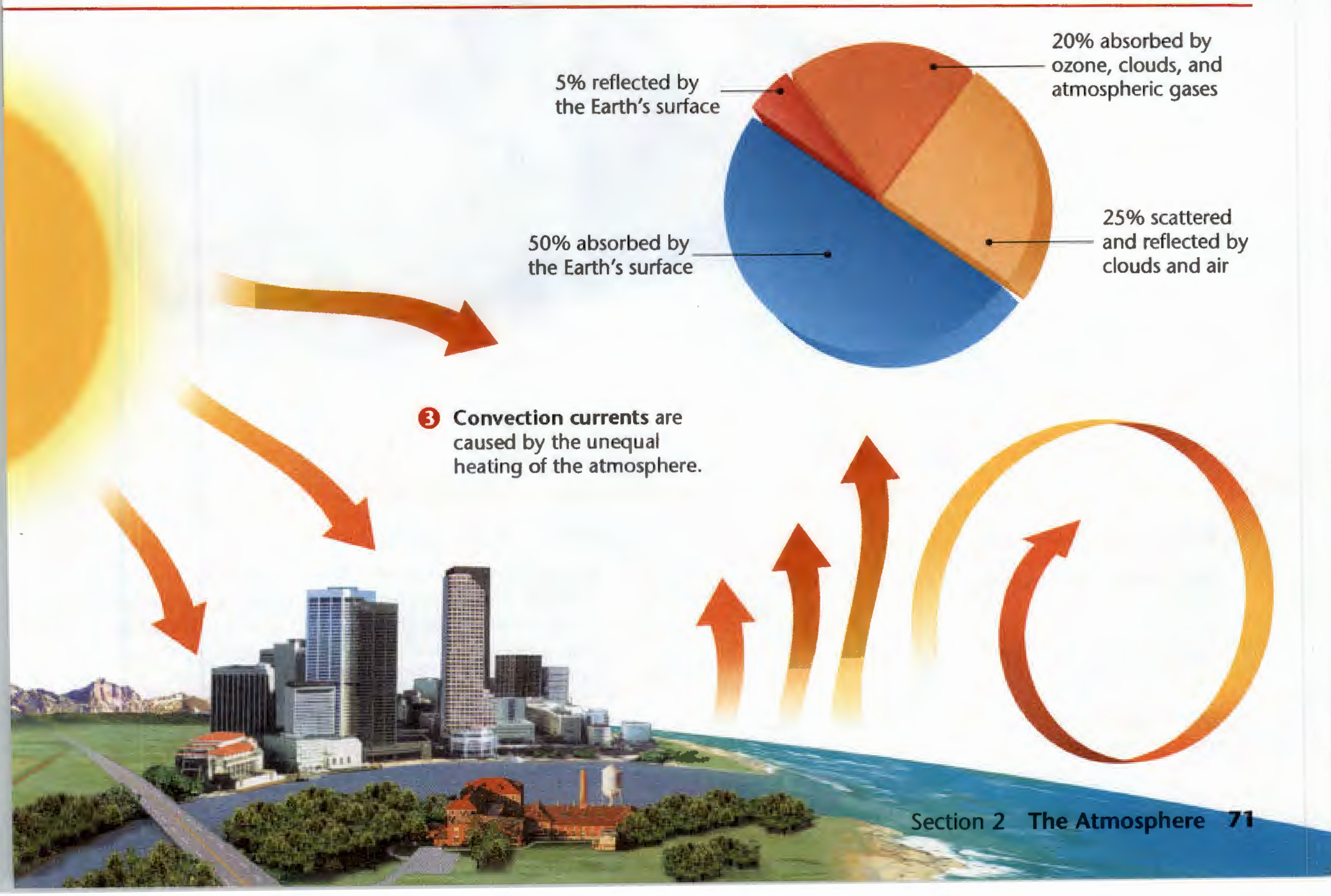
surface continually absorbed energy, the Earth would get hotter and hotter. The Earth does not continue to get warmer, because the oceans and the land radiate the energy they have absorbed back into the atmosphere.

You may have noticed that dark-colored objects become much hotter in the sun than light-colored objects. Dark-colored objects absorb more solar radiation than light-colored objects, so dark-colored objects have more energy to release as heat. This is one reason the temperature in cities is higher than the temperature in the surrounding countryside.

The Movement of Energy in the Atmosphere Air that is constantly moving upward, downward, or sideways causes Earth's weather. In the troposphere, currents of less dense air, warmed by the Earth's surface, rise into the atmosphere and currents of denser cold air sink toward the ground. As a current of air rises into the atmosphere, it begins to cool. Eventually, the air current becomes more dense than the air around it and sinks instead of continuing to rise. So, the air current moves back toward Earth's surface until it is heated by the Earth and becomes less dense. Then, the air current begins to rise again. The continual process of warm air rising and cool air sinking moves air in a circular motion, called a *convection current*. A convection current is shown in **Figure 15**.

Ecofact

Lost Weekend Have you ever complained about how it always seems to rain on the weekends? If you live on the East Coast, you might actually have a point. Researchers recently found that the mid-Atlantic states have a 30 to 40 percent greater chance of rain on the weekends. Why? Researchers suggest that the automobile exhaust that accumulates in the atmosphere over the course of the work week has actually caused weather patterns in this area to shift. By Friday, the exhaust levels are high enough to trigger rain over the weekend, which cleanses the atmosphere for another week.



3 Convection currents are caused by the unequal heating of the atmosphere.

FIELD ACTIVITY

Exploring the Greenhouse Effect Some of your classmates and teachers probably drive to school. Given what you know about the reflection and absorption of heat, go to the parking lot on a sunny day and hypothesize which cars will have the hottest interiors. Base your hypothesis on such variables as the color of car interiors and whether the windows are tinted or untinted. Record your observations in your ***Ecolog.***

The Greenhouse Effect

The gases in Earth's atmosphere act like the glass in the car shown in **Figure 16.** Sunlight that penetrates Earth's atmosphere heats the surface of the Earth. The Earth's surface radiates heat back to the atmosphere, where some of the heat escapes into space. The remainder of the heat is absorbed by greenhouse gases, which warms the air. Heat is then radiated back toward the surface of the Earth. This process, in which gases trap heat near the Earth, is known as the **greenhouse effect.** Without the greenhouse effect, the Earth would be too cold for life to exist.

The gases in our atmosphere that trap and radiate heat are called *greenhouse gases.* None of the greenhouse gases have a high concentration in Earth's atmosphere. The most abundant greenhouse gases are water vapor, carbon dioxide, methane, and nitrous oxide. The quantities of carbon dioxide and methane in the atmosphere vary considerably as a result of natural and industrial processes, and the amount of water varies because of natural processes.

Figure 16 ▶ The gases in the atmosphere act like a layer of glass. Both glass and the gases in the atmosphere allow solar energy to pass through. But glass and some of the gases in the atmosphere absorb heat and stop the heat from escaping to space.

SECTION 2 Review

1. **Describe** the composition of Earth's atmosphere.
2. **Describe** a characteristic of each layer of the atmosphere.
3. **Explain** the three mechanisms of heat transfer in Earth's atmosphere.
4. **Describe** the role of greenhouse gases in Earth's atmosphere.

CRITICAL THINKING

5. **Analyzing Processes** Read about the density of Earth's atmosphere under the heading "Air Pressure." Write a paragraph that explains why Earth's atmosphere becomes less dense with increasing altitude above Earth. WRITING SKILLS
6. **Analyzing Processes** How does human activity change some greenhouse-gas levels?

SECTION 3

The Hydrosphere and Biosphere

Life on Earth is restricted to a very narrow layer around the Earth's surface. In this layer, called the *biosphere,* everything that organisms need to survive can be found. One of the requirements of living things is liquid water.

Objectives

- Name the three major processes in the water cycle.
- Describe the properties of ocean water.
- Describe the two types of ocean currents.
- Explain how the ocean regulates Earth's temperature.
- Discuss the factors that confine life to the biosphere.
- Explain the difference between open and closed systems.

Key Terms

water cycle
evaporation
condensation
precipitation
salinity
fresh water
biosphere
closed system
open system

The Hydrosphere and Water Cycle

The hydrosphere includes all of the water on or near the Earth's surface. The hydrosphere includes water in the oceans, lakes, rivers, wetlands, polar ice caps, soil, rock layers beneath Earth's surface, and clouds.

The continuous movement of water into the air, onto land, and then back to water sources is known as the **water cycle,** which is shown in **Figure 17**. **Evaporation** is the process by which liquid water is heated by the sun and then rises into the atmosphere as water vapor. Water continually evaporates from Earth's oceans, lakes, streams, and soil, but the majority of the water evaporates from the oceans. In the process of **condensation,** water vapor forms water droplets on dust particles. These water droplets form clouds, in which the droplets collide, stick together, and create larger, heavier droplets. These larger droplets fall from clouds as rain in the process called **precipitation.** Precipitation may also take the form of snow, sleet, or hail.

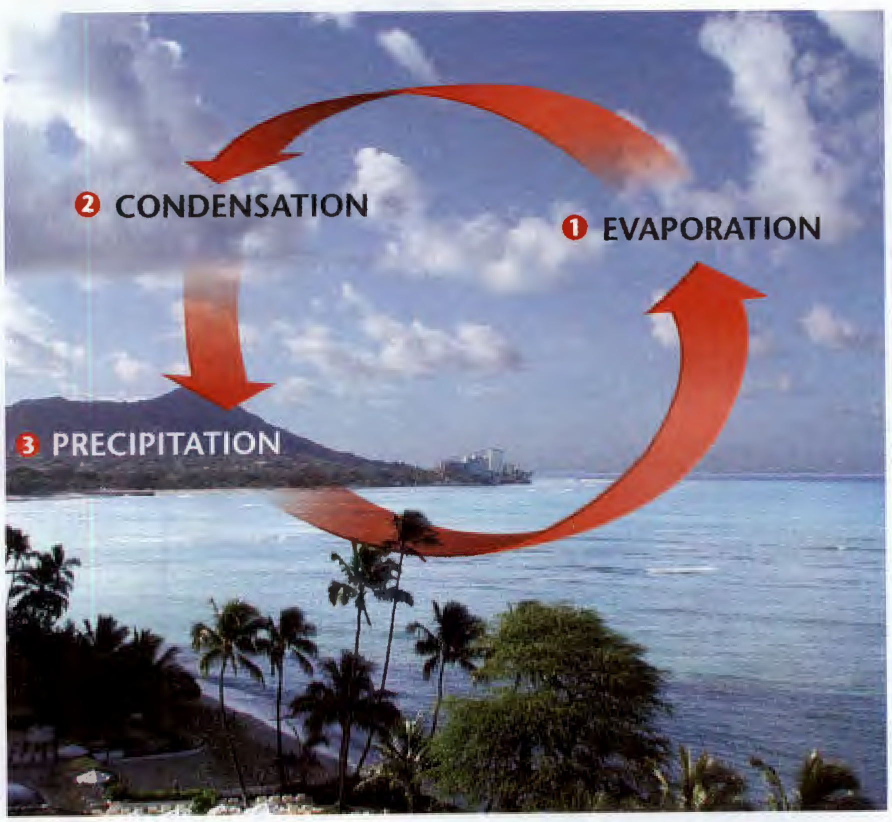


Figure 17 ▶ The major processes of the water cycle include ❶ evaporation, ❷ condensation, and ❸ precipitation.

Connection to Geology

Submarine Volcanoes Geologists estimate that approximately 80 percent of the volcanic activity on Earth takes place on the ocean floor. Most of this activity occurs as magma slowly flows onto the ocean floor where tectonic plates pull away from each other. But enormous undersea volcanoes are also common. Off the coast of Hawaii, a submarine volcano called the *Loihi Seamount* rises 5,185 m from the ocean floor. Loihi is just 915 m below the ocean's surface, and in several thousand years, this volcano may become the next Hawaiian Island.

Earth's Oceans

We talk about the Atlantic Ocean, the Pacific Ocean, the Arctic Ocean, and the Indian Ocean. However, if you look at **Figure 18,** you see that these oceans are all joined. This single, large, interconnected body of water is called the *world ocean.* Its waters cover a little over 70 percent of the Earth's surface. As we will see, the world ocean plays many important roles in regulating our planet's environment.

The largest ocean on Earth is the Pacific Ocean. It covers a surface area of approximately 165,640,000 km^2 and has an average depth of 4,280 m. The deepest point on the ocean floor is in the Pacific Ocean. The point is called the Challenger Deep and is located east of the Philippine Islands at the bottom of the Mariana Trench. The Challenger Deep is 11,033 m below sea level, which is deeper than Mount Everest is tall. Oceanographers often divide the Pacific Ocean into the North Pacific and South Pacific based on the direction of surface current flow in each half of the Pacific Ocean. Surface currents in the Pacific move in a clockwise direction north

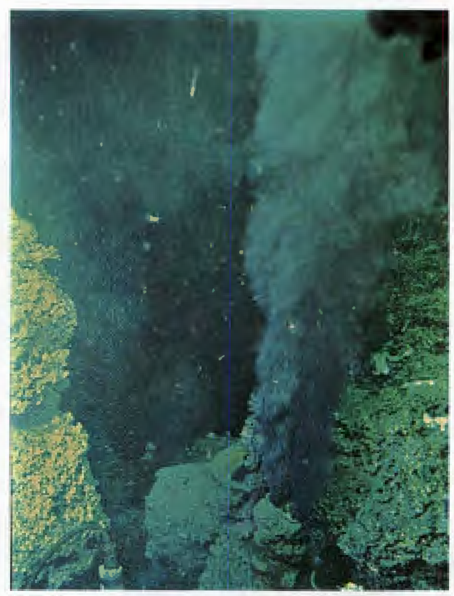
CASE STUDY

Hydrothermal Vents

The light from your tiny research submarine illuminates the desert-like barrenness of the deep-ocean floor. Suddenly, the light catches something totally unexpected—an underwater oasis teeming with sea creatures that no human has laid eyes on before. At the center of this community is a tall chimney-like structure from which a column of black water is rising.

This scene is much like the one which John Corliss and John Edmond witnessed when they discovered the first deep-sea hydrothermal vents and the odd community of creatures that inhabit them. Corliss's and Edmond's discovery was made during a dive in the submarine *Alvin* in early 1977. The dive site was in the eastern Pacific Ocean near the Galápagos Islands. Since the original dive, many more hydrothermal vents have been located on the ocean bottom.

Hydrothermal vents are openings in the ocean floor where super-hot, mineral-rich waters stream into the ocean. Hydrothermal vents form where tectonic plates are separating and where deep fractures are opening in the Earth's crust. Water seeps down into some of these fractures to a depth where it is heated by molten rock and enriched with minerals. The water returns to the ocean floor through other fractures and then pours into the ocean. Water often streams through structures called *chimneys*. Chimneys form when the minerals in the vent water—mostly iron and sulfur—precipitate as the



▶ Superheated, mineral-rich water streams through a chimney at a hydrothermal vent on the floor of the Pacific Ocean.

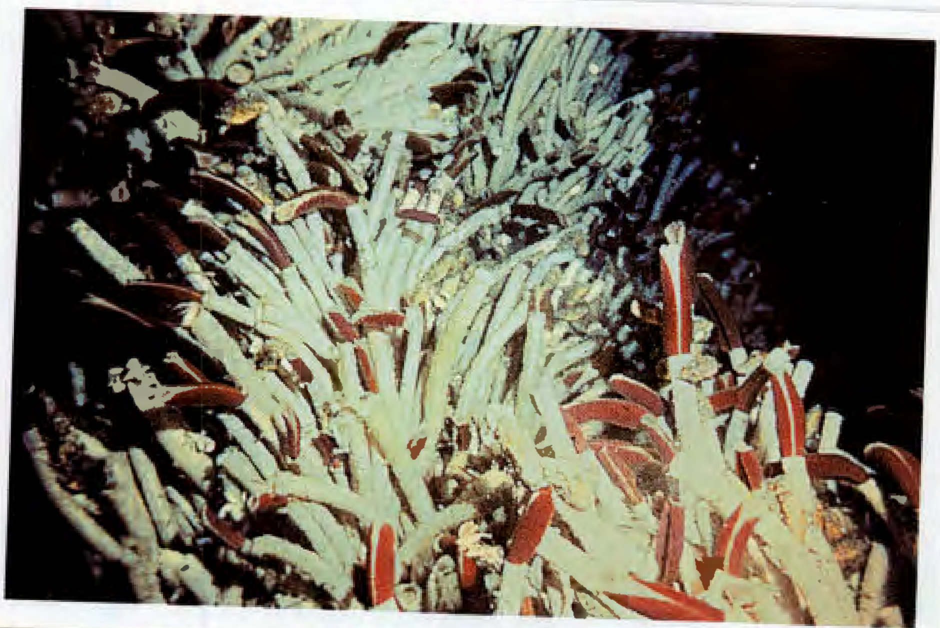
water cools from above 100°C to less than 50°C. The tallest chimney reported to date is 49 m. Vent of the equator, whereas surface currents flow in a counterclockwise direction south of the equator.

The second largest ocean on Earth is the Atlantic Ocean. It covers a surface area of 81,630,000 km^2, which is about half the area of the Pacific Ocean. Like the Pacific Ocean, the Atlantic Ocean can be divided into a north and south half based on the directions of surface current flow north and south of the equator.

The Indian Ocean covers a surface area of 73,420,000 km^2 and is the third-largest ocean on Earth. It has an average depth of 3,890 m.

The smallest ocean is the Arctic Ocean, which covers 14,350,000 km^2. The Arctic Ocean is unique because much of its surface is covered by floating ice. This ice, which is called *pack ice*, forms when either waves or wind drive together frozen seawater, known as sea ice, into a large mass.

Figure 18 ▶ The Pacific, Atlantic, Indian, and Arctic Oceans are interconnected into a single body of water, the world ocean, which covers 70 percent of Earth's surface.



▶ Over 300 species of organisms have been found in hydrothermal vent communities, including species of tube worms that may grow to a length of 3 m.

water can reach temperatures as high as 400°C.

The pressure at the ocean bottom is tremendous. No sunlight penetrates these depths, and hydrothermal vents spew minerals into their surroundings. Still, at least 300 species of organisms—all new to scientists—live near hydrothermal vents. These organisms include tube worms, giant clams, mussels, shrimp, crabs, sea anemones, and octopuses.

How is life at hydrothermal vents possible? Bacteria that live in vent communities can use hydrogen sulfide escaping from the vents as an energy source. Some animals that live in vent communities consume these bacteria to obtain their energy. Other animals have bacteria living inside their bodies that supply them with energy.

CRITICAL THINKING

1. Applying Processes Some scientists have suggested that life may have originated in or near hydrothermal vents because vent organisms are able to obtain their energy from chemicals in the absence of sunlight. Does this suggestion seem realistic?

2. Making Predictions How might the creatures that live in hydrothermal vent communities be of benefit to humankind in the future?

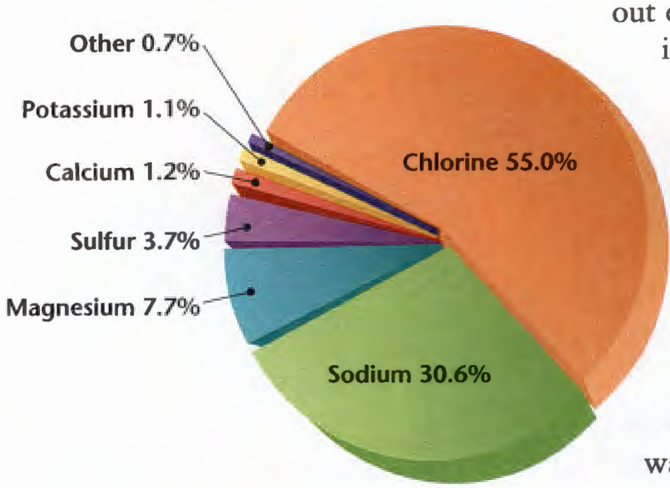


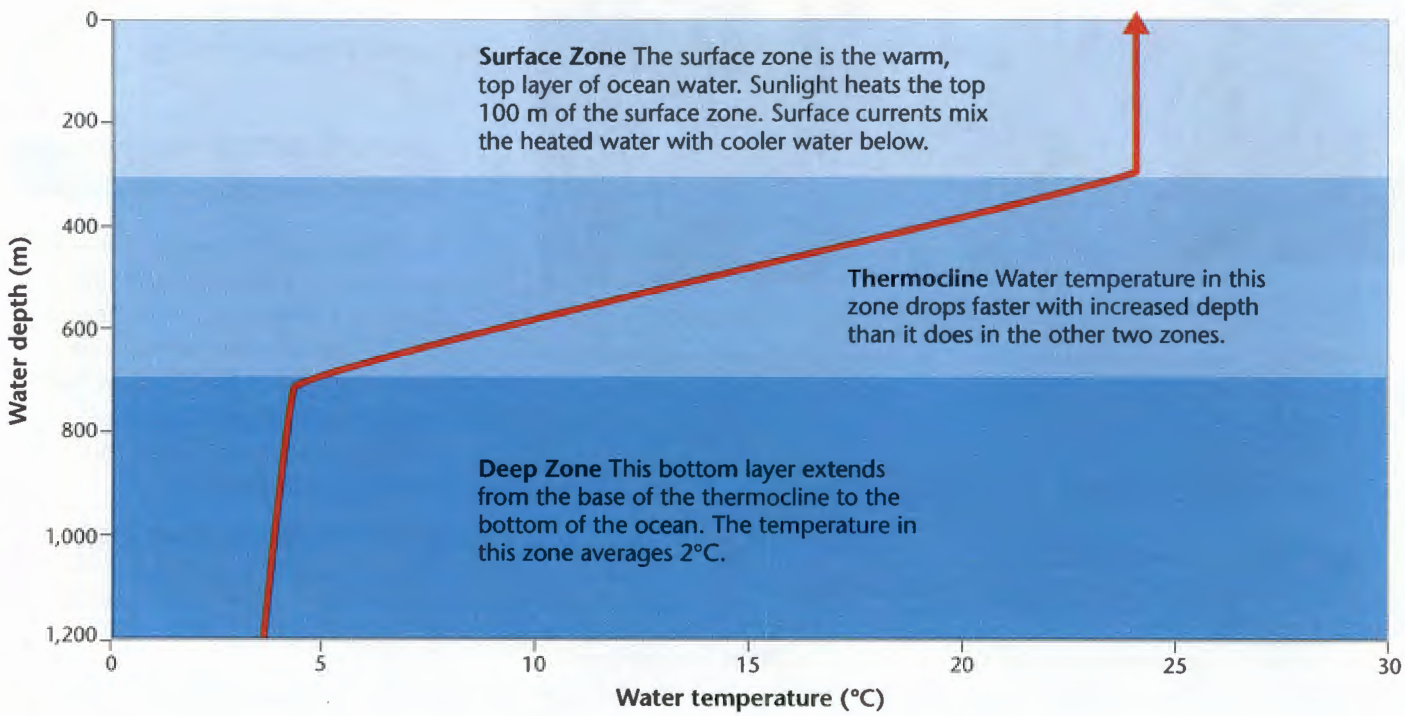
Figure 19 ▶ This pie graph shows the percentages by weight of dissolved solids found in ocean water. Sodium and chlorine, the two elements that form salt, are the most important dissolved solids in ocean water.

Ocean Water The difference between ocean water and fresh water is that ocean water contains more salts. These salts have dissolved out of rocks on land and have been carried down rivers into the ocean over millions of years. Underwater volcanic eruptions also add salts to the ocean.

Most of the salt in the ocean is sodium chloride, which is made up of the elements sodium and chlorine. Figure 19 shows the concentration of these and other elements in ocean water. The **salinity** of ocean water is the concentration of all the dissolved salts it contains. The average salinity of ocean water is 3.5 percent by weight. The salinity of ocean water is lower in places that get a lot of rain or in places where fresh water flows into the sea. Salinity is higher where water evaporates rapidly and leaves the salts behind.

Temperature Zones Figure 20 shows the temperature zones of the ocean. The surface of the ocean is warmed by the sun. In contrast, the depths of the ocean, where sunlight never reaches, are very cold and have a temperature only slightly above freezing. Surface waters are stirred up by waves and currents, so the warm surface zone may be as much as 350 m deep. Below the surface zone is the thermocline, which is a layer about 300 to 700 m deep where the temperature falls rapidly with depth. If you have ever gone swimming in a deep lake in the summer, you have probably encountered a shallow thermocline. Sun warms the surface of the lake to a comfortable temperature, but if you

Figure 20 ▶ Water in the ocean can be divided into three zones based on temperature.



drop your feet, they fall into cold water that may be only slightly above freezing. The boundary between the warm and cold water is the thermocline.

A Global Temperature Regulator One of the most important functions of the world ocean is to absorb and store energy from sunlight. This capacity of the ocean to absorb and store energy from sunlight regulates temperatures in Earth's atmosphere.

The world ocean absorbs over half the solar radiation that reaches the planet's surface. The ocean both absorbs and releases heat more slowly than land does. As a consequence, the temperature of the atmosphere changes much more slowly than it would if there were no ocean on Earth. If the ocean did not regulate atmospheric and surface temperatures, the temperature would be too extreme for life on Earth to exist.

Local temperatures in different areas of the planet are also regulated by the world ocean. Currents that circulate warm water cause the land areas they flow past to have a more moderate climate. For example, the British Isles are warmed by the waters of the Gulf Stream, which moves warm waters from lower latitudes toward higher latitudes, as in **Figure 21.**

MATHPRACTICE

The Influence of the Gulf Stream The temperature of the British Isles is moderated by the Gulf Stream. Falmouth, England, and Winnipeg, Canada, are located at approximately 50° north latitude. Falmouth, which is located in extreme southwest England near the Atlantic Ocean, has average high temperatures of 18°C in June, 19°C in July, and 19°C in August. Winnipeg, which is located in the interior of North America, has average high temperatures of 22°C in June, 25°C in July, and 23°C in August. What is the difference in average high temperatures in degrees Celsius between Falmouth and Winnipeg?

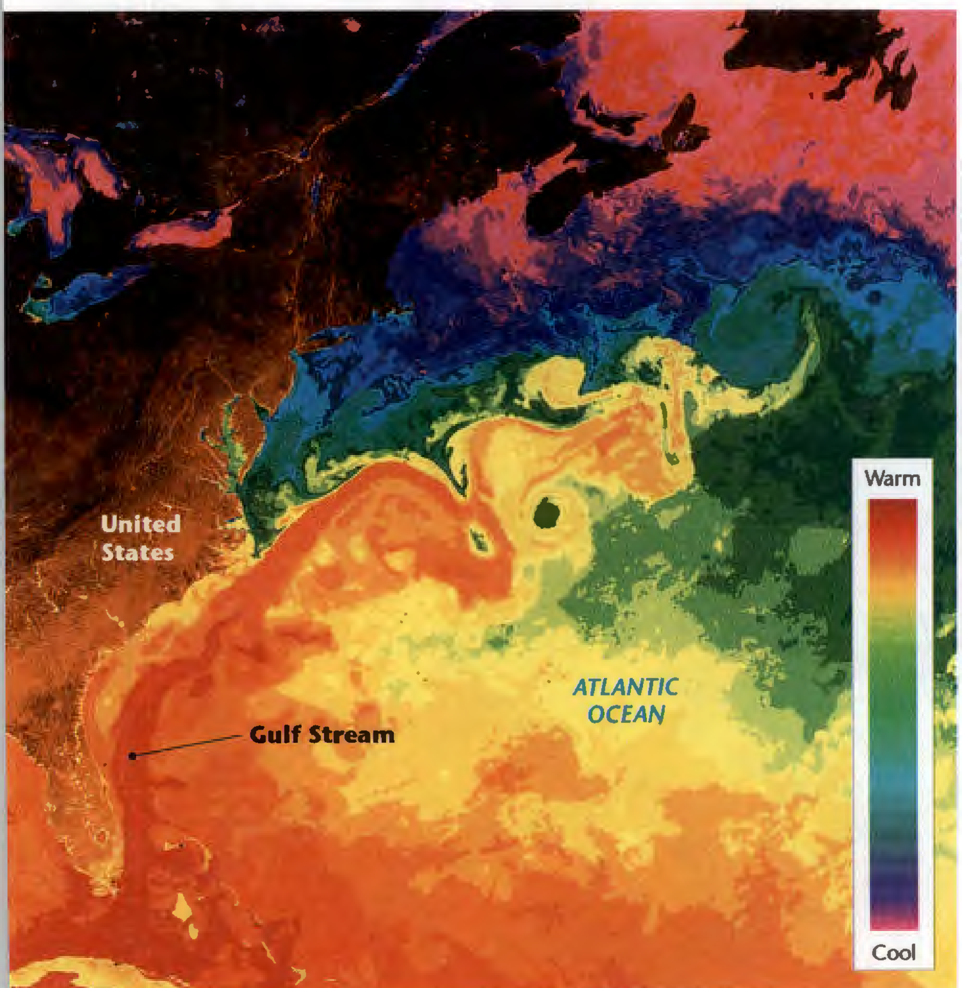


Figure 21 ▶ In this infrared satellite image, the Gulf Stream is moving warm water (shown in red, orange, and yellow) from lower latitudes into higher latitudes. The British Isles are warmed by the waters of the Gulf Stream.

QuickLAB

Make a Hydrothermal Vent

Procedure

1. Fill a **large glass container** or **aquarium** with very **cold water.**
2. Tie one end of a **piece of string** around the neck of a **small bottle.**
3. Fill the small bottle with **hot water,** and add a few drops of **food coloring.**
4. Keep the small bottle upright while you lower it into the glass container until it rests flat on the bottom.

Analysis

1. Did the food coloring indicate that the hot water and cold water mixed?

Ocean Currents Streamlike movements of water that occur at or near the surface of the ocean are called surface currents. Surface currents are wind driven and result from global wind patterns. **Figure 22** shows the major surface currents of the world ocean. Surface currents may be warm-water currents or cold-water currents. Currents of warm water and currents of cold water do not readily mix with one another. Therefore, a warm-water current like the Gulf Stream can flow for hundreds of kilometers through cold water without mixing and losing its heat.

Surface currents can influence the climates of land areas they flow past. As we have seen, the Gulf Stream moderates the climate in the British Isles. The Scilly Isles in England are as far north as Newfoundland in northeast Canada. However, palm trees grow on the Scilly Isles, where it never freezes, whereas Newfoundland has long winters of frost and snow.

Deep currents are streamlike movements of water that flow very slowly along the ocean floor. Deep currents form when the cold, dense water from the poles sinks below warmer, less dense ocean water and flows toward the equator. The densest and coldest ocean water is located off the coast of Antarctica. This cold water sinks to the bottom of the ocean and flows very slowly northward to produce a deep current called the Antarctic Bottom Water. The Antarctic Bottom Water creeps along the ocean floor for thousands of kilometers and reaches a northernmost point of approximately 40° north latitude. It takes several hundred years for water in this deep current to make this trip northward.

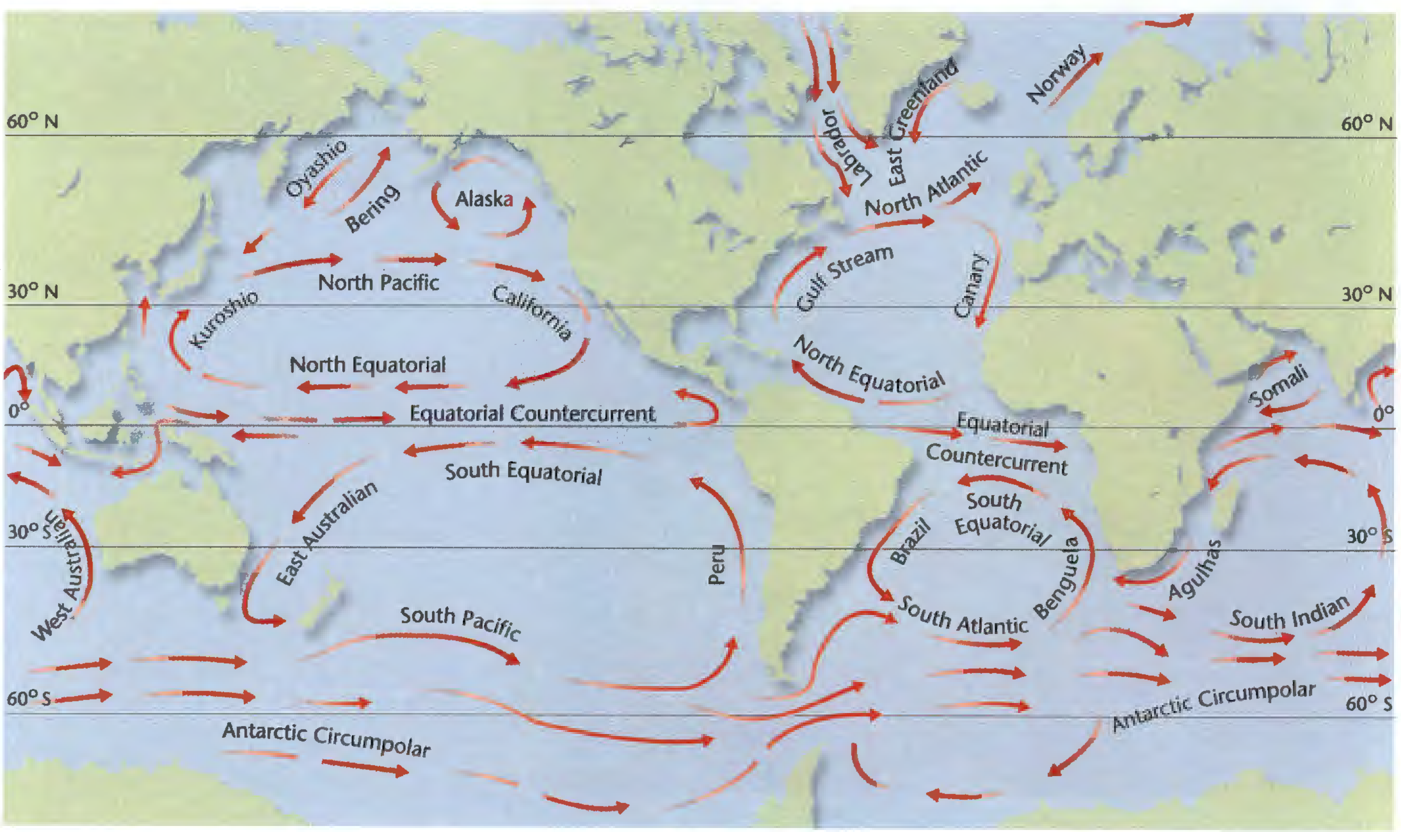


Figure 22 ▶ The oceans' surface currents circulate in different directions in each hemisphere.

Fresh Water

Most of the water on Earth is salt water in the ocean. A little more than 3 percent of all the water on Earth is fresh water. Most of the fresh water is locked up in icecaps and glaciers that are so large they are hard to imagine. For instance, the ice sheet that covers Antarctica is as large as the United States and is up to 3 km thick. The rest of Earth's fresh water is found in lakes, rivers, wetlands, the soil, rock layers below the surface, and in the atmosphere.

River Systems A river system is a network of streams that drains an area of land. A river system contains all of the land drained by a river, including the main river and all its tributaries. As shown in **Figure 23**, *tributaries* are smaller streams or rivers that flow into larger ones. Some river systems are enormous. For example, most of the precipitation that falls between the Rocky Mountains in the west and the Appalachian Mountains in the east eventually drains into the Mississippi River. The Mississippi River system covers about 40 percent of the contiguous United States.

Figure 23 ▶ This photo shows a network of tributaries flowing into a river in the wetlands of southern Louisiana.

Groundwater

Rain and melting snow sink into the ground and run off the land. Some of this water ends up in streams and rivers, but most of it trickles down through the ground and collects as *groundwater*. Groundwater fulfills the human need for fresh drinking water and supplies water for many agricultural and industrial uses. But groundwater accounts for less than 1 percent of all the water on Earth.

Aquifers A rock layer that stores and allows the flow of groundwater is called an *aquifer*. The surface of the land where water enters an aquifer is called a *recharge zone*. **Figure 24** shows the location of aquifers in the contiguous United States.

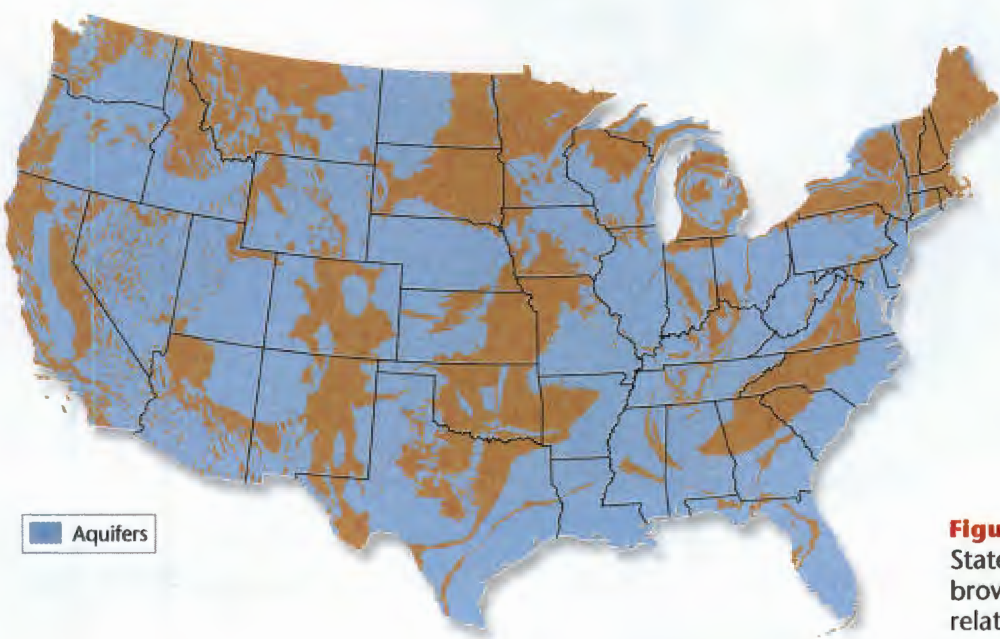


Figure 24 ▶ Much of the United States is underlain by aquifers. The brown areas are rocks that contain relatively little stored water.

internet connect

www.scilinks.org
Topic: The Biosphere
SciLinks code: HE4127

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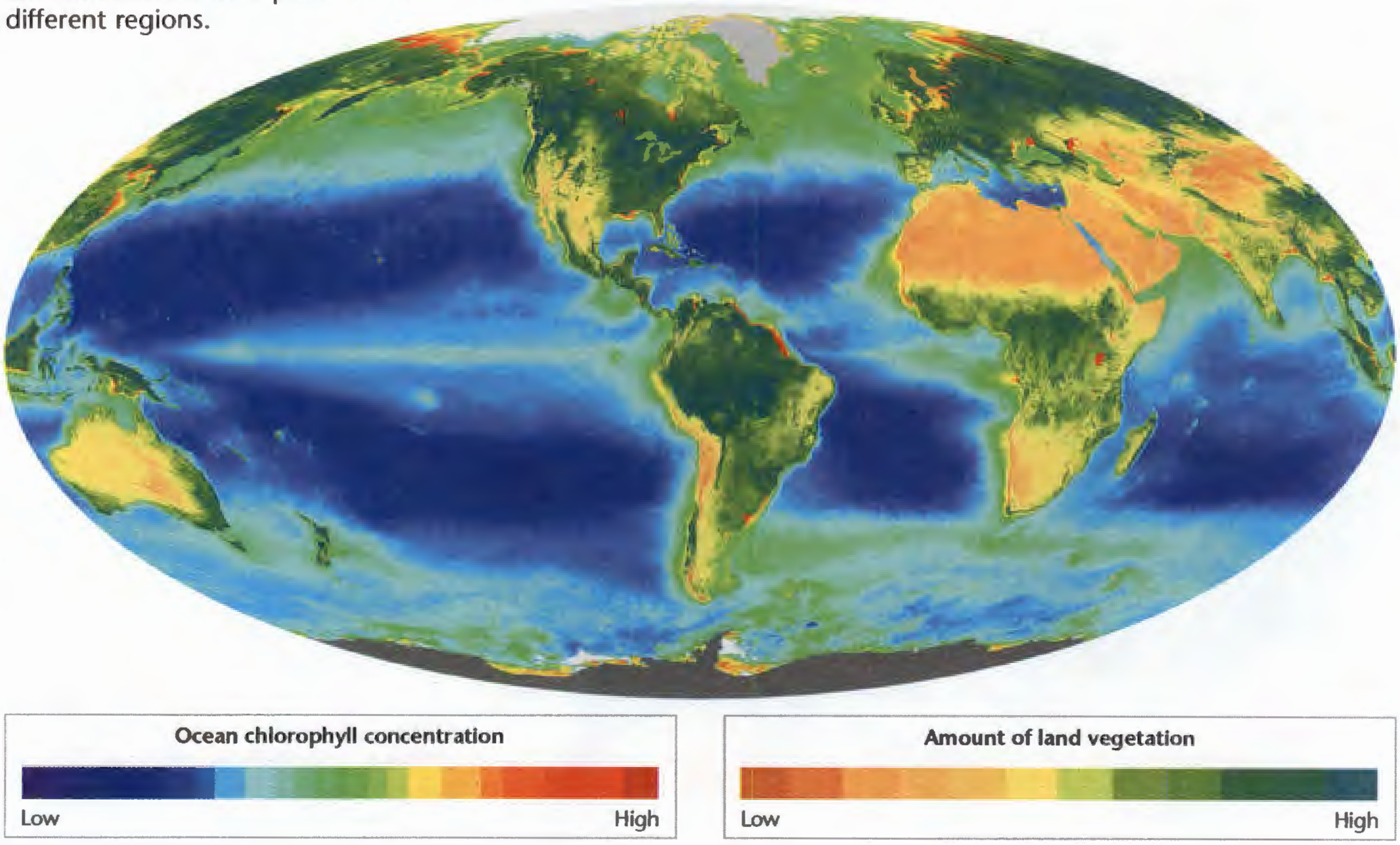
The Biosphere

The Earth is often compared to an apple, and the biosphere is compared to the apple's skin. This comparison illustrates how small the layer of the Earth that can support life is in relation to the size of the planet. Scientists define the **biosphere** as the narrow layer around Earth's surface in which life can exist. The biosphere is made up of the uppermost part of the geosphere, most of the hydrosphere, and the lower part of the atmosphere. The biosphere extends about 11 km into the ocean and about 9 km into the atmosphere, where insects, the spores of bacteria, and pollen grains have been discovered.

Life exists on Earth because of several important factors. Life requires liquid water, temperatures between 10°C and 40°C, and a source of energy. The materials that organisms require must continually be cycled. Gravity allows a planet to maintain an atmosphere and to cycle materials. Suitable combinations of the things that organisms need to survive are found only in the biosphere.

The biosphere is located near Earth's surface because most of the sunlight is available near the surface. Plants on land and in the oceans are shown in **Figure 25**. Plants need sunlight to produce their food, and almost every other organism gets its food from plants and algae. Most of these algae float at the surface of the ocean. These tiny, free-floating, marine algae are known as phytoplankton. Except for bacteria that live at hydrothermal vents, most of the organisms that live deep in the ocean feed on dead plants and animals that drift down from the surface.

Figure 25 ▶ This illustration of the biosphere shows the concentration of plant life on land and in the oceans. The colors represent different concentrations of plant life in different regions.



Energy Flow in the Biosphere

While energy is constantly added to the biosphere from the sun, matter is not. The energy used by organisms must be obtained in the biosphere and must be constantly supplied for life to continue. When an organism dies, its body is broken down and the nutrients in it become available for use by other organisms. This flow of energy allows life on Earth to continue to exist.

In a closed system, energy enters the environment, but matter does not. Today, the Earth is mostly a closed system with respect to matter but is still an open system for energy. Energy enters the biosphere in the form of sunlight, which plants use to make their food. When an animal eats a plant, the energy stored in the plant is transferred to the animal. Animals in turn eat other animals. At each stage in the food chain, some of the energy is lost to the environment as heat, which is eventually lost to space.

In an open system, both matter and energy are exchanged between a system and the surrounding environment. Matter was added to the early Earth through the collisions of comets and meteorites with our planet. Now, however, little matter reaches our planet in this way.

Figure 26 ▶ The Eden Project is an attempt to model the biosphere. In this project, plants from all over the world will live in a closed system. The Eden Project is housed within a series of domes that were constructed in an old clay pit in England.

SECTION 3 Review

1. **Name** and describe each of the three major processes in the water cycle.
2. **Describe** the properties of ocean water.
3. **Describe** the two types of ocean currents.
4. **Name** two factors that confine living things to the biosphere.

CRITICAL THINKING

5. **Analyzing Processes** Read about the ocean's role in regulating temperature under the heading "A Global Temperature Regulator." How might Earth's climate change if the land area on Earth were greater than the area of the world ocean? READING SKILLS
6. **Analyzing Relationships** Why is the human body considered an open system?

CHAPTER 3

Highlights

1 The Geosphere

Key Terms

geosphere, 59
crust, 60
mantle, 61
core, 61
lithosphere, 61
asthenosphere, 61
tectonic plate, 62
erosion, 66

Main Ideas

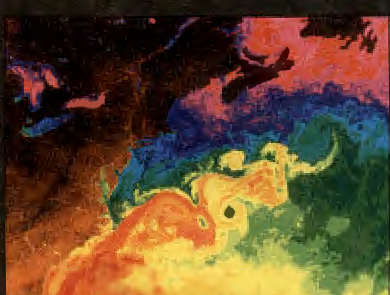
- The solid part of the Earth that consists of all rock, and the soils and sediments on Earth's surface, is the geosphere.
- Earth's interior is divided into layers based on composition and structure.
- Earth's surface is broken into pieces called *tectonic plates,* which collide, separate, or slip past one another.
- Earthquakes, volcanic eruptions, and mountain-building are all events that occur at the boundaries of tectonic plates.
- Earth's surface features are continually altered by the action of water and wind.

2 The Atmosphere

atmosphere, 67
troposphere, 68
stratosphere, 69
ozone, 69
radiation, 70
conduction, 70
convection, 70
greenhouse effect, 72

- The mixture of gases that surrounds the Earth is called the *atmosphere.*
- The atmosphere is composed almost entirely of nitrogen and oxygen.
- Earth's atmosphere is divided into four layers based on changes in temperature that take place at different altitudes.
- Heat is transferred in the atmosphere by radiation, conduction, and convection.
- Some of the gases in Earth's atmosphere slow the escape of heat from Earth's surface in what is known as the greenhouse effect.

3 The Hydrosphere and Biosphere



water cycle, 73
evaporation, 73
condensation, 73
precipitation, 73
salinity, 76
fresh water, 79
biosphere, 80
closed system, 81
open system, 81

- The hydrosphere includes all of the water at or near Earth's surface.
- Water in the ocean can be divided into three zones—the surface zone, the thermocline, and the deep zone—based on temperature.
- The ocean absorbs and stores energy from sunlight, regulating temperatures in the atmosphere.
- Surface currents in the ocean affect the climate of the land they flow near.
- The biosphere is the narrow layer at the surface of the Earth where life can exist.
- The Earth is largely a closed system with respect to matter but an open system with respect to energy.

CHAPTER 3 Review

Using Key Terms

Use each of the following terms in a separate sentence.

1. *tectonic plate*
2. *erosion*
3. *radiation*
4. *ozone*
5. *salinity*

For each pair of terms, explain how the meanings of the terms differ.

6. *lithosphere* and *asthenosphere*
7. *conduction* and *convection*
8. *crust* and *mantle*
9. *closed system* and *open system*

STUDY TIP

The Importance of Nouns Most multiple-choice questions center around the definitions of nouns. When you study, pay attention to the definitions of nouns that appear to be important in the text. These nouns will often be boldfaced key terms or italicized secondary terms.

Understanding Key Ideas

10. The thin layer at Earth's surface where life exists is called the
    a. geosphere.
    b. atmosphere.
    c. hydrosphere.
    d. biosphere.
11. The thin layer of the Earth upon which tectonic plates move around is called the
    a. mantle.
    b. asthenosphere.
    c. lithosphere.
    d. outer core.
12. Seventy-eight percent of Earth's atmosphere is made up of
    a. oxygen.
    b. hydrogen.
    c. nitrogen.
    d. carbon dioxide.
13. The ozone layer is located in the
    a. stratosphere.
    b. mesosphere.
    c. thermosphere.
    d. troposphere.
14. Convection is defined as the
    a. transfer of energy across space.
    b. direct transfer of energy.
    c. trapping of heat near the Earth by gases.
    d. transfer of heat by currents.
15. Which of the following gases is *not* a greenhouse gas?
    a. water vapor
    b. nitrogen
    c. methane
    d. carbon dioxide
16. Liquid water turns into gaseous water vapor in a process called
    a. precipitation.
    b. convection.
    c. evaporation.
    d. condensation.
17. Currents at the surface of the ocean are moved mostly by
    a. heat.
    b. wind.
    c. salinity.
    d. the mixing of warm and cold water.
18. Which of the following statements about the biosphere is *not* true?
    a. The biosphere is a system closed to matter.
    b. Energy enters the biosphere in the form of sunlight.
    c. Nutrients in the biosphere must be continuously recycled.
    d. Matter is constantly added to the biosphere.

CHAPTER 3 Review

Short Answer

19. How do seismic waves give scientists information about Earth's interior?

20. Explain the effect of gravity on Earth's atmosphere.

21. Explain how convection currents transport heat in the atmosphere.

22. Why does land that is near the ocean change temperature less rapidly than land that is located farther inland?

23. Why is life on Earth confined to such a narrow layer near the Earth's surface?

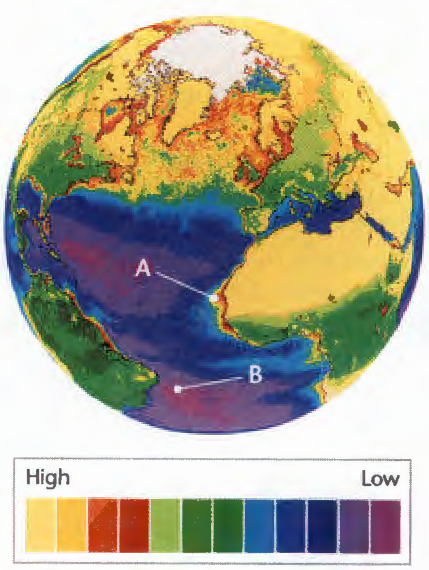
Interpreting Graphics

The map below shows the different amounts of chlorophyll in the ocean. Chlorophyll is the pigment that makes plants and algae green. Chlorophyll identifies the presence of marine algae. The red and orange colors on the map show the highest amounts of chlorophyll, the blue and purple colors on the map show the smallest amounts of chlorophyll. Use the map to answer questions 24–25.

24. Is there a greater concentration of marine algae at location A or at location B?

25. What conclusion can you reach about conditions in the parts of the ocean where marine algae may prefer to live?

Chlorophyll Content



Concept Mapping

26. Use the following terms to create a concept map: *geosphere, crust, mantle, core, lithosphere, asthenosphere,* and *tectonic plate.*

Critical Thinking

27. Making Predictions The eruption of Mount Pinatubo in 1991 reduced global temperature by several tenths of a Celsius degree for several years. Write a paragraph predicting what might happen to Earth's climate if several large-scale eruptions took place at the same time? WRITING SKILLS

28. Analyzing Processes Read about the heating of Earth's surface and the absorption of incoming solar radiation under the heading "Heating of the Atmosphere." How might the Earth be different if the Earth's surface absorbed greater or lesser percentages of radiation? READING SKILLS

29. Analyzing Processes Surface currents are deflected by continental landmasses. How might the pattern of Earth's surface currents change if the Earth had no landmasses? Where on the world ocean might the majority of warm surface currents be located? Where would the cold surface currents be located?

Cross-Disciplinary Connection

30. History Scientists believe that some human migration between distant landmasses may have taken place on rafts powered only by the wind and ocean currents. Look at Figure 22, which shows the Earth's surface currents. Hypothesize potential migratory routes these early seafarers may have followed.

Portfolio Project

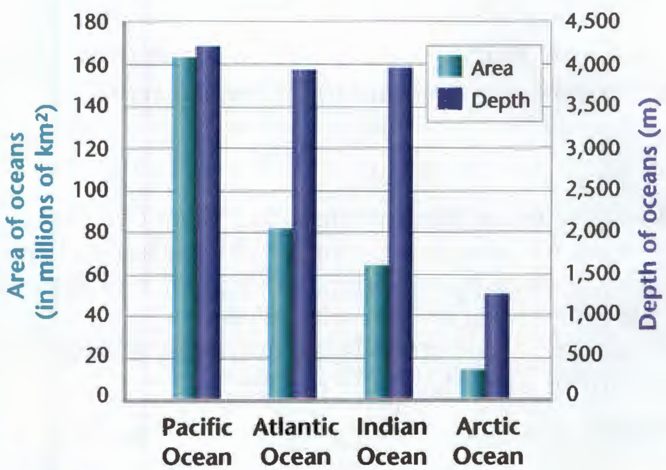
31. Plotting Seismic Activity Most earthquakes take place near tectonic plate boundaries. Using the encyclopedia, the Internet, or another source, find at least 20 locations where major earthquakes took place during the 20th century. Plot these locations on a map of the world that shows Earth's tectonic plates. Did the majority of earthquakes occur at or near tectonic plate boundaries?

MATH SKILLS

Use the graph below to answer questions 32–33.

32. **Analyzing Data** Rearrange the oceans in order of highest depth-to-area ratio to lowest depth-to-area ratio.

33. **Making Calculations** On the graph, you are given the average depths of the four oceans. From this data, calculate the average depth of the world ocean.



WRITING SKILLS

34. **Communicating Main Ideas** Describe the three important ways in which the movement of energy takes place in Earth's atmosphere.

35. **Writing Persuasively** Write a persuasive essay that explains why the Earth today should be regarded as a closed system for matter rather than an open system.

36. **Outlining Topics** Write a one-page outline that describes some of the important interactions that take place in the Earth system.

STANDARDIZED TEST PREP

For extra practice with questions formatted to represent the standardized test you may be asked to take at the end of your school year, turn to the sample test for this chapter in the Appendix.

READING SKILLS

Read the passage below, and then answer the questions that follow.

Researchers at Ohio State University have developed a video camera that photographs the foamy bubbles left when a wave breaks on a beach. Software analyzes images from the camera and uses the movement of the foam to calculate the speed and direction of currents along the shore. How do we know that the software produces an accurate picture of the currents? To test this process, researchers set up a video camera on the beach at Duck, North Carolina, where dozens of underwater sensors already measure currents directly. A comparison of the currents detected by the video camera and by the sensors showed a close match. The Ohio State University researchers believe data from the video camera would be even more accurate if the camera were directly above the breaking waves. The researchers' next step will be to mount the camera on a blimp suspended over a beach in Monterey, California.

1. According to the passage, which of the following conclusions is true?
   - **a.** The video camera uses wave speed to calculate the direction and speed of currents.
   - **b.** Underwater sensors are less accurate at measuring currents than video cameras.
   - **c.** Video cameras do not measure currents directly.
   - **d.** Underwater sensors detect the movement of foam.

2. What is the importance of foam in measuring currents?
   - **a.** Foam can be measured directly by both video cameras and underwater sensors.
   - **b.** The movement of foam can be used to calculate the direction and speed of a current.
   - **c.** Foam from breaking waves can be detected by placing a video camera at any point on a beach.
   - **d.** both (b) and (c)

CHAPTER 3

Exploration Lab: MODELING

Beaches

Almost one-fourth of all of the structures that have been built within 150 m of the U.S. coastline, including the Great Lakes, will be lost to beach erosion over the next 60 years, according to a June 2000 report released by the Federal Emergency Management Agency (FEMA). The supply of sand for most beaches has been cut off by dams built on rivers and streams that would otherwise carry sand to the sea. Waves generated by storms also erode beaches. Longshore currents, which are generated by waves that break at an angle to a shoreline, transport sediment continuously and change the shape of a shoreline.

You will now observe a series of models. These models will help you understand how beaches can be both washed away and protected from the effects of waves and longshore currents.

Objectives

- **Examine** models that show how the forces generated by wave action build, shape, and erode beaches.
- USING SCIENTIFIC METHODS **Hypothesize** ways in which beaches can be preserved from the erosive forces of wave activity.

Materials

- metric ruler
- milk cartons, empty, small (2)
- pebbles
- plaster of Paris
- plastic container (large) or long wooden box lined with plastic
- rocks, small
- sand, 5 to 10 lb
- wooden block, large

Procedure

1. One day before you begin the investigation, make two plaster blocks. Mix a small amount of water with plaster of Paris until the mixture is smooth. Add five or six small rocks to the mixture for added weight. Pour the plaster mixture into the milk cartons. Let the plaster harden overnight. Carefully peel the milk cartons away from the plaster.
2. Prepare a wooden box lined with plastic or other similar large, shallow container. Make a beach by placing a mixture of sand and small pebbles at one end of the container. The beach should occupy about one-fourth the length of the container. See step 2. In the area in front of the sand, add water to a depth of 2 to 3 cm. Use the large wooden block to generate several waves by moving the block up and down in the water at the end of the container opposite the beach. Continue this wave action until about half the beach has moved. Record your observations.
3. Remove the water, and rebuild the beach. In some places, breakwaters have been built offshore in an attempt to protect beaches from washing away. Build a breakwater by placing two plaster blocks across the middle of the container. Using the metric ruler, leave a 4 cm space between the blocks. See step 3. Use a wooden block to generate waves. Describe the results.
4. Drain the water, and make a new beach along one side of the container for about half its length. See step 4. Using the wooden block, generate a series of waves from the same end of the container as the end of the beach. Record your observations.

▶ **Step 2** Use a wooden block to generate waves at the end of the container opposite the beach.

5. Rebuild the beach along the same side of the container. A jetty or dike can be built out into the ocean to intercept and break up a longshore current. Make a jetty by placing one of the small plaster blocks in the sand. See step 5. As you did in the previous steps, use the wooden block to generate waves. Describe the results.
6. Remove the wet sand, and put it in a container. Dispose of the water. (Note: Follow your teacher's instructions for disposal of the sand and water. Never pour water containing sand into a sink.)

▶ **Step 3** Build a breakwater by placing two plastic blocks across the middle of the container.

Analysis

1. **Describing Events** In step 2 of the procedure, what happened to the beach when water was first poured into the container? What happened to the particles of fine sand? Predict what would happen to the beach if it had no source of additional sand.
2. **Analyzing Results** In step 3 of the procedure, did the breakwater help protect the beach from washing away?
3. **Describing Events** What happened to the beach that you made in step 4 of the procedure? What happened to the shape of the waves along the beach?
4. **Analyzing Results** What effect did the jetty have on the beach that you made in step 5 of the procedure?

▶ **Step 4** Make a beach lengthwise along one side of the container. The length of the beach should equal one-half the length of the container.

Conclusions

5. **Drawing Conclusions** What can be done to preserve a beach area from being washed away as a result of wave action and longshore currents?
6. **Drawing Conclusions** What can be done to preserve a beach area that has been changed as a result of excessive use by people?

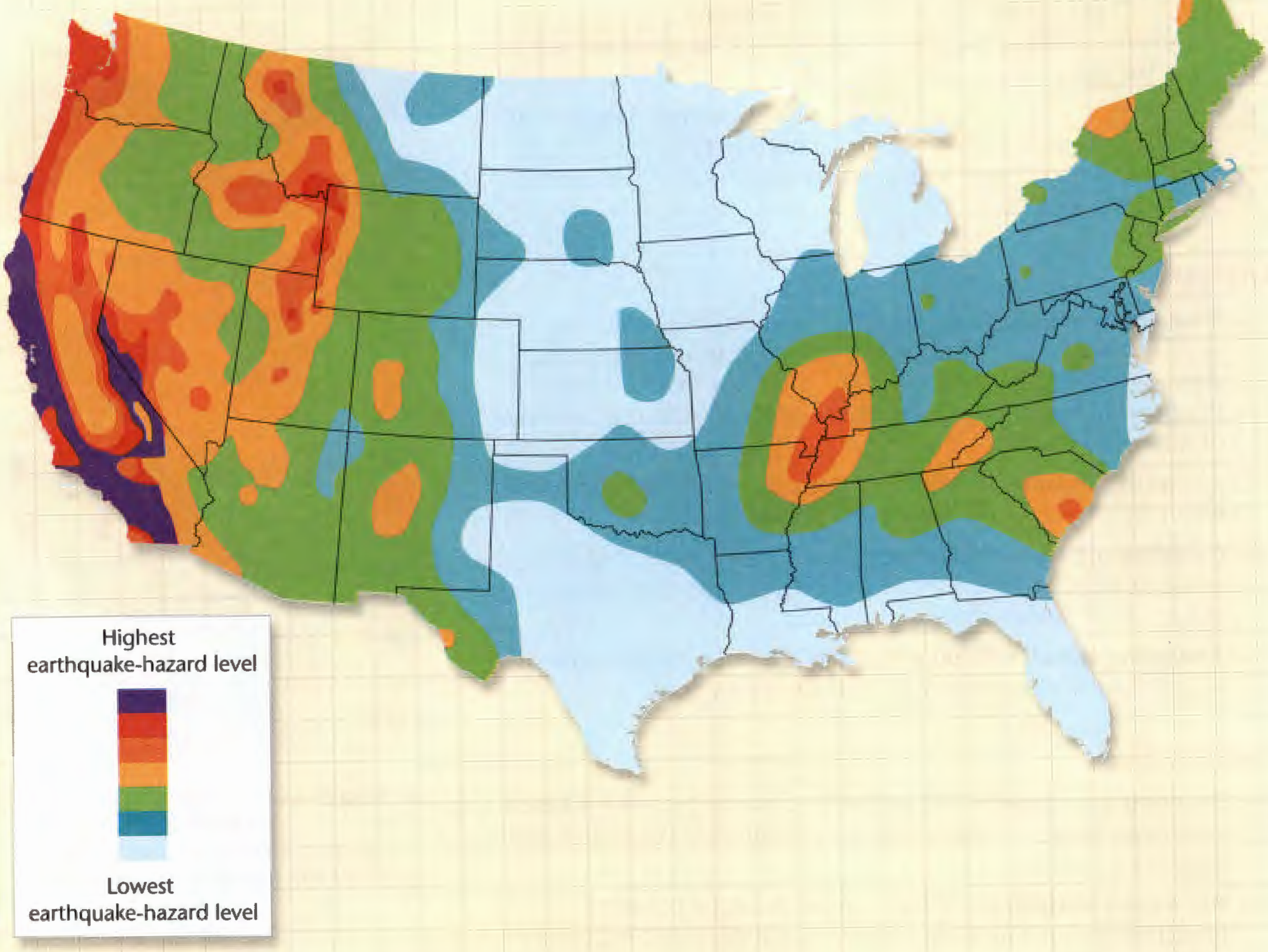
Extension

1. **Building Models** Make a beach that would be in danger of being washed away by a longshore current. Based on what you have learned, build a model in which the beach would be preserved by a breakwater or jetties. Explain how your model illustrates ways in which longshore currents can be intercepted and broken up.

▶ **Step 5** Place one of the small plaster blocks in the sand to make a jetty.

MAPS *in action*

EARTHQUAKE HAZARD MAP OF THE CONTIGUOUS UNITED STATES



MAP SKILLS

Use the earthquake-hazard map of the contiguous United States to answer the questions below.

1. **Using a Key** Which area of the contiguous United States has a very high earthquake-hazard level?
2. **Using a Key** Determine which areas of the contiguous United States have very low earthquake-hazard levels.
3. **Analyzing Relationships** In which areas of the contiguous United States would scientists most likely set up earthquake-sensing devices?
4. **Inferring Relationships** Most earthquakes take place near tectonic plate boundaries. Based on the hazard levels, where do you think a boundary between two tectonic plates is located in the United States?
5. **Forming a Hypothesis** The New Madrid earthquake zone passes through southeastern Missouri and western Tennessee and has experienced some of the most widely felt earthquakes in U.S. history. Yet this earthquake zone lies far from any tectonic plate boundary. Propose a hypothesis that would explain these earthquakes.

SCIENCE & TECHNOLOGY

TRACKING OCEAN CURRENTS WITH TOY DUCKS

Scientists usually study ocean currents by releasing labeled drift bottles from various points and recording where they are found. However, only about 2 percent of drift bottles are recovered, so this type of research takes a long time. A large toy spill is helping scientists track surface currents in the Pacific Ocean.

Toys Ahoy!

In 1993, thousands of bathtub toys were found on Alaskan beaches. When oceanographers heard about this, they placed advertisements in newspapers up and down the Alaskan coast asking people who found the toys to call them. They discovered that in 1992 a container ship that was traveling northwest of Hawaii ran into a storm. Several containers were washed overboard and burst open. One of these held 29,000 plastic toys. Ten months later, the toys—blue turtles, yellow ducks, red beavers, and green frogs—began washing up near Sitka, Alaska. In the following years, toys began to be found farther north, in the Bering Sea. The map below shows where the containers went overboard and where the toys were found.

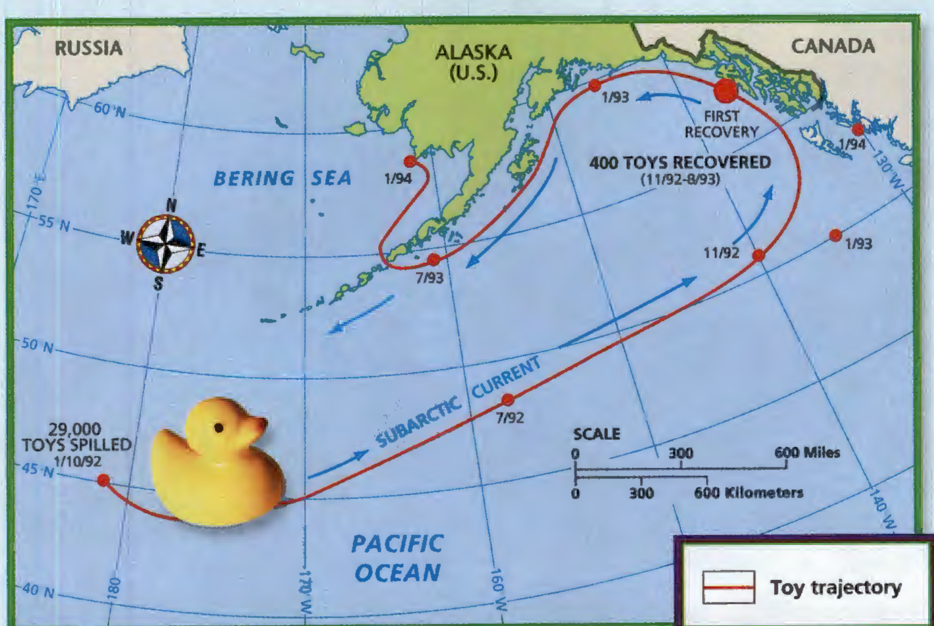
The Data in the Deep Blue Sea

Obviously, the toys had traveled east from where they were spilled. But what did this reveal about the currents in the North Pacific? The answer is not as obvious as it might seem. First, floating objects are moved by wind as well as by currents. The floating toys stuck up about 4 cm above the water, which may have caused them to be moved by the wind as well as by currents. The toys started out in cardboard and plastic packages. Did the packages make them sink when they were first released? To find the answer, scientists obtained some of the packaged toys from the manufacturer in China and dropped them in buckets of sea water. The glue in the packaging dissolved within a day and released the toys. So it was obvious that the toys had floated most of the way to where they were found.

Experiments showed how fast they moved under the influence of wind without any current. The toys had floated past a weather station where many drift bottles had been released and also past the place where 61,000 shoes had fallen off a ship in 1990. About two percent of the shoes were recovered in Alaska. Comparing data from the toys and the shoes with other data from as far back as 1946, the researchers concluded that the current across the northeast Pacific Ocean moves little from year to year. But the data showed that in 1990 and 1992 the current was unusually far north.

Data that help us understand ocean currents and many other natural processes come not just from scientific experiments. Data sometimes come from the most unusual sources.

▶ This map is a computer simulation that shows the possible trajectory of the toys and their estimated locations on certain dates as they floated across the Pacific Ocean from the point of the spill to recovery points in Alaska.



What Do You Think?

Take a look at Figure 22. If the toys continue to be carried by surface currents, where might they be found in the future? How might the height of the toys above the water's surface have influenced the speed at which they traveled?