Section 1.1

1 FOCUS

Section Objectives

1.1 **Define** Earth science.
1.2 **Describe** the formation of Earth and the solar system.

Reading Focus

Build Vocabulary L2

Word Parts Ask students to use a dictionary to determine the meanings of the following word parts:
geo- (Earth); *astro-* (outer space); *-ology* (study of); *-ography* (study of); *-onomy* (study of)
Based on this discussion and their prior knowledge, have students predict the meaning of this section's vocabulary words. Then, have students look up the words in the Glossary to check their predictions and make any necessary corrections. *Meteorology* will likely present a problem, with most students predicting that it is the study of meteors, rather than the study of the atmosphere.

Reading Strategy L2

a. Earth, earthquakes, mountains, volcanoes, Earth's history
b. oceanography
c. composition and movements of seawater, coastal processes, seafloor topography, marine life
d. meteorology
e. atmosphere, weather, climate
f. astronomy
g. universe, solar system

2 INSTRUCT

Overview of Earth Science

Build Reading Literacy L1

Refer to **p. 216D** in **Chapter 8,** which provides guidelines for comparing and contrasting.

Compare and Contrast Have students create a table to compare and contrast physical geology and historical geology. They should fill in their table as they read the first part of this section. Areas to consider include the focus of each area and examples of what is studied.
Visual

1.1 What Is Earth Science?

Reading Focus

Key Concepts

- What is the study of Earth science?
- How did Earth and the solar system form?

Vocabulary

- Earth science
- geology
- oceanography
- meteorology
- astronomy

Reading Strategy

Categorizing As you read about the different branches of Earth science, fill in the column with the name of each branch and list some of the things that are studied.

geology	a. ?
b. ?	c. ?
d. ?	e. ?
f. ?	g. ?

The spectacular eruption of a volcano, the magnificent scenery of a rocky coast, and the destruction created by a hurricane are all subjects for Earth science. The study of Earth science deals with many fascinating and practical questions about our environment. What forces produced the mountains shown on page 1? Why does our daily weather change? Is our climate changing? How old is Earth? How is Earth related to the other planets in the solar system? What causes ocean tides? What was the Ice Age like? Will there be another?

Understanding Earth is not an easy task because our planet is always changing. Earth is a dynamic planet with a long and complex history.

Figure 1 Scientists called paleontologists study fossils, which are signs of life in the distant past, to find out how life-forms have changed through time.
Posing Questions ***What questions do you have about this fossil?***

Overview of Earth Science

Earth science is the name for the group of sciences that deals with Earth and its neighbors in space. Earth science includes many subdivisions of geology such as geochemistry, geophysics, geobiology and paleontology, as well as oceanography, meteorology, and astronomy.

Units 1 through 4 focus on the science of **geology,** a word that means "study of Earth." Geology is divided into two broad areas—physical geology and historical geology.

Physical geology includes the examination of the materials that make up Earth and the possible explanations for the many processes that shape our planet. Processes below the surface create earthquakes, build mountains, and produce volcanoes. Processes at the surface break rock apart and create different landforms. Erosion by water, wind, and ice results in different landscapes. You will learn that rocks and minerals form in response to Earth's internal and external processes. Understanding the origin of rocks and minerals is an important part of understanding Earth.

In contrast to physical geology, the aim of historical geology is to understand Earth's long history. Historical geology tries to establish a timeline of the vast number of physical and biological changes that have occurred in the past. See Figure 1. We study physical geology before historical geology because we must first understand how Earth works before we try to unravel its past.

Reading Checkpoint *What are the two main areas of geology?*

Unit 5 is devoted to **oceanography.** Oceanography integrates the sciences of chemistry, physics, geology, and biology. Oceanographers study the composition and movements of seawater, as well as coastal processes, seafloor topography, and marine life. See Figure 2.

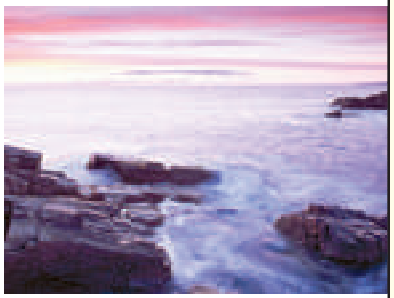


Figure 2 Oceanographers study all aspects of the ocean—the chemistry of its waters, the geology of its seafloor, the physics of its interactions with the atmosphere, and the biology of its organisms.

Unit 6 examines the composition of Earth's atmosphere. The combined effects of Earth's motions and energy from the sun cause the atmosphere to produce different weather conditions. This, in turn, creates the basic pattern of global climates. **Meteorology** is the study of the atmosphere and the processes that produce weather and climate. Like oceanography, meteorology also involves other branches of science.

Unit 7 demonstrates that understanding Earth requires an understanding of Earth's position in the universe. The science of **astronomy,** the study of the universe, is useful in probing the origins of our own environment. All objects in space, including Earth, are subject to the same physical laws. Learning about the other members of our solar system and the universe beyond helps us to understand Earth.

Throughout its long existence, Earth has been changing. In fact, it is changing as you read this page and will continue to do so. Sometimes the changes are rapid and violent, such as when tornados, landslides, or volcanic eruptions occur. Many changes, however, take place so gradually that they go unnoticed during a lifetime.

Formation of Earth

Earth is one of nine planets that revolve around the sun. Our solar system has an orderly nature. Scientists understand that Earth and the other planets formed during the same time span and from the same material as the sun. **The nebular hypothesis suggests that the bodies of our solar system evolved from an enormous rotating cloud called the solar nebula. It was made up mostly of hydrogen and helium, with a small percentage of heavier elements.** Figure 3 on page 4 summarizes some key points of this hypothesis.

Use Community Resources L2

The USGS (United States Geological Survey) has a network of regional offices where geologists study geological phenomena at local, regional, and global levels. Their activities include monitoring earthquake activity, mapping subsurface rock formations, and providing the public with information about geologic events such as floods and landslides. Ask a USGS geologist from a local office to talk to the class about what geologists do at their jobs. Ask students to prepare questions in advance.
Interpersonal

Formation of Earth

Build Reading Literacy L1

Refer to **p. 186D** in **Chapter 7,** which provides guidelines for relating text and visuals.

Relate Text and Visuals Have students turn ahead in the text to Figure 3 on p. 4 for a visual representation of the nebular hypothesis. Have them read the figure caption, then use the figure to describe the major steps in the nebular hypothesis. *(Solar system begins as cloud of dust and gases. Cloud starts to rotate and collapse. Heated center forms the sun. Cooling creates solid particles. Collisions create asteroid-sized bodies. Asteroids form the inner planets. Lighter materials and gases form the outer planets.)*
Visual

Customize for English Language Learners

Students should use the words and word parts they just learned, along with their prior knowledge, to define the following words: *oceanographer, meteorologist, geography, geologist, geological, astronaut, astronomer.* Students should then use a dictionary to check their definitions. Review the correct meanings of these words with students when they are finished.

Answer to . . .

Reading Checkpoint *The two main areas of geology are physical geology and historical geology.*

Section 1.1 (continued)

Use Visuals L1

Figure 3 Have students study the diagram illustrating the nebular hypothesis. Ask: **What do all stages of this hypothesis have in common?** *(In all stages, the system is spinning.)* **What was the first stage in the development of our solar system?** *(Our solar system began as an enormous cloud of gas and dust.)* **Challenge students to make a timeline or flowchart of the key events in the formation of our solar system.** *(Students should make a timeline or flowchart based on steps A through E given in the figure caption.)*
Visual, Logical

Teacher Demo

Separation and Density L2

Purpose Students see how substances separate based on density.

Materials 2 large glass jars with lids, 100 mL sand, 100 mL rock salt, 100 mL sugar, 100 mL water, 100 mL vegetable oil, 100 mL corn syrup

Procedure At the start of the class, place all of the solids in one jar and all the liquids in another jar. Put the lids on both jars and shake them carefully. Let the jars settle during the class. Then, have the students look at them. Ask: **Why did the liquids separate?** *(Differences in density made the liquids rise or fall and separate.)* **Why didn't the solids separate?** *(The solid particles were unable to move past each other.)* **What state was Earth most likely in when it separated into layers?** *(The materials that made up Earth must have been molten or nearly molten.)*

Expected Outcome The liquids will separate into different layers. The solids will remain mixed.
Visual, Logical

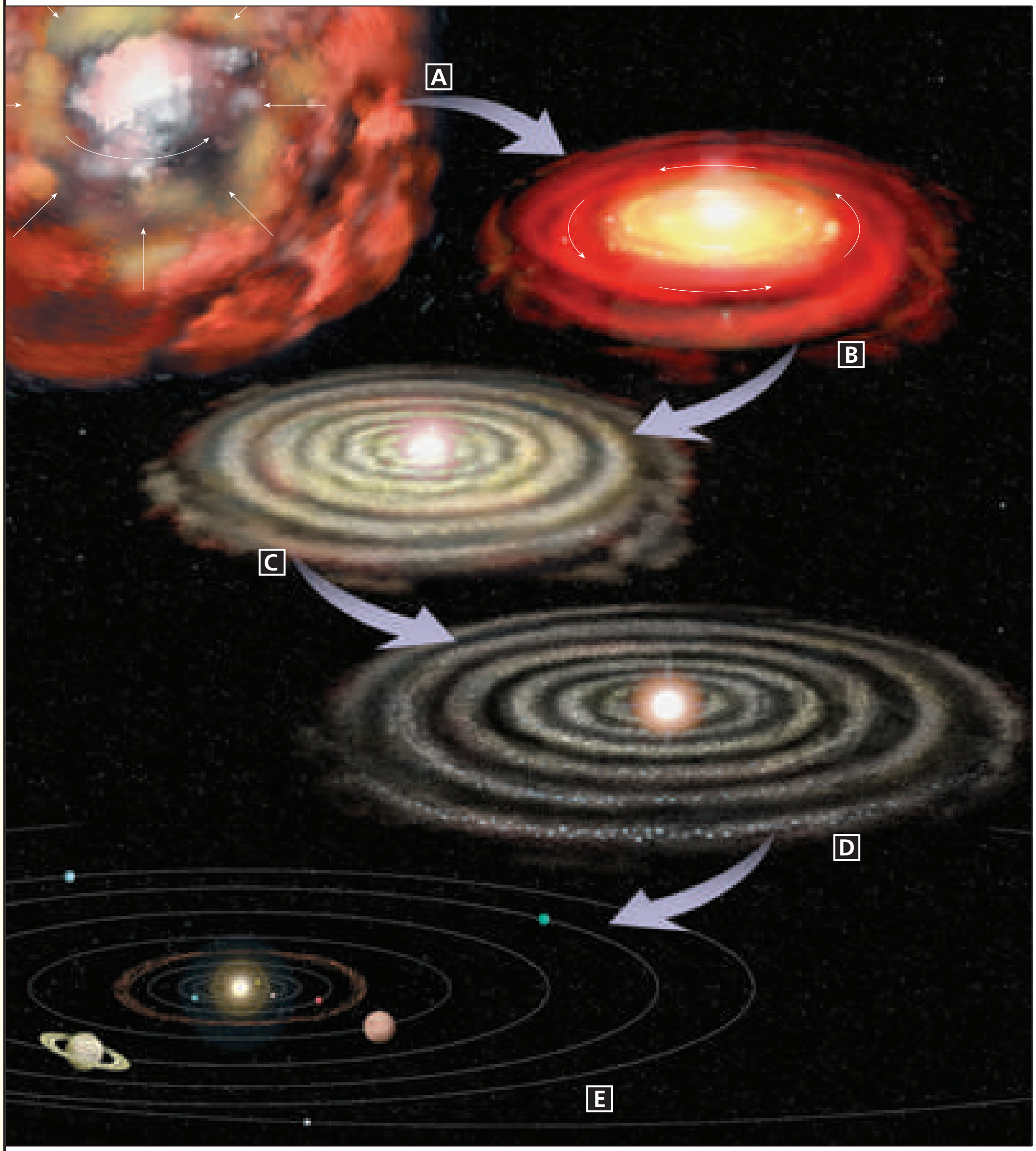


Figure 3 Formation of the Solar System According to the Nebular Hypothesis A Our solar system began as an enormous cloud of dust and gases made up mostly of hydrogen and helium with a small percentage of heavier elements. **B** This cloud, called a nebula, started to rotate and collapse toward the center of the cloud. Heat was generated at the center, which eventually formed the sun. **C** Cooling of the nebula caused rocky and metallic materials to form tiny solid particles. **D** Repeated collisions of these particles resulted in the formation of asteroid-sized bodies. **E** These asteroids eventually combined to form the four inner planets—Mercury, Venus, Earth, and Mars. The lighter materials and gases combined farther away from the center to form the four outer planets—Jupiter, Saturn, Uranus, and Neptune.

Facts and Figures

As Earth was forming, density differences caused denser materials to sink to Earth's core, while less dense materials escaped to the atmosphere. Density differences continue to shape Earth today. Today's volcanic eruptions are generally caused by less dense magma and gases rising up through the mantle until they penetrate the crust, resulting in a volcanic eruption. This is an example of the principle of uniformitarianism, which is essential to the study of geology. This principle states that the processes that exist on Earth today are identical to the processes that existed on Earth in the distant past. This principle allows geologists to make useful inferences based on contemporary observations.

High temperatures and weak fields of gravity characterized the inner planets. As a result, the inner planets were not able to hold onto the lighter gases of the nebular cloud. The lightest gases, hydrogen and helium, were whisked away toward the heavier planets by the solar wind. Earth, Mars, and Venus were able to retain some heavier gases including water vapor and carbon dioxide. The materials that formed by outer planets contained high percentages of water, carbon dioxide, ammonia, and methane. The size and frigid temperatures of the outer planets provided the surface gravity to hold these heavier gases.

Layers Form on Earth Shortly after Earth formed, the decay of radioactive elements, combined with heat released by colliding particles, produced some melting of the interior. This allowed the denser elements, mostly iron and nickel, to sink to Earth's center. The lighter, rocky components floated outward, toward the surface. This sinking and floating is believed to still be occurring, but on a much smaller scale. As a result of this process, Earth's interior is not made of uniform materials. It consists of layers of materials that have different properties.

Reading Checkpoint *Why does Earth have layers?*

An important result of this process is that gaseous materials were allowed to escape from Earth's interior, just as gases escape today during volcanic eruptions. In this way, an atmosphere gradually formed along with the ocean. It was composed mainly of gases that were released from within the planet.

Section 1.1 Assessment

Reviewing Concepts

1. What are the sciences that are included in Earth science?
2. What topics are included in the study of physical geology?
3. Explain how physical geology differs from historical geology.
4. Describe the nebular hypothesis.

Critical Thinking

5. **Forming Conclusions** Explain why Earth is called a dynamic planet.
6. **Inferring** Would meteorology be a useful science to apply to the study of planets such as Mercury and Mars? Explain.
7. **Hypothesizing** Suppose that as Earth formed, all lighter elements were released to surrounding space. How might this affect the structure of Earth today?

Connecting Concepts

Summarizing Earth science is composed of many different areas of study. Why is it important to include all of these areas in the study of Earth and the solar system?

Build Science Skills L2

Inferring Based on the information in this section, ask students to infer which of Earth's layers will be the densest. Have students turn ahead in the text to Figure 6 on p. 8 to see a diagram of Earth's layers.
Logical

3 ASSESS

Evaluate Understanding L2

To assess students' knowledge of section content, ask them to answer the Key Concepts questions at the beginning of this section.

Reteach L1

Have students use Figure 3 to explain in their own words the formation of our solar system.

Connecting Concepts

Because Earth is an ever-changing planet, all the spheres on Earth are interactive and affect one another. To understand Earth's existence and history, it is important to study all aspects of Earth together.

Answer to . . .

Reading Checkpoint *Earth has layers because denser elements sank to Earth's center and less dense elements floated to the surface.*

Section 1.1 Assessment

1. Earth science includes many subdivisions of geology such as geochemistry, geophysics, geobiology, and paleontology, as well as meteorology, oceanography, and astronomy.
2. Physical geology includes processes that operate on and below Earth's surface such as volcanoes, mountain building, erosion, and earthquakes.
3. Historical geology's aim is to understand Earth's history. Physical geology's aim is to understand the processes that shape Earth.
4. This hypothesis suggests that the solar system began as an enormous cloud of dust and gas. The cloud began to rotate, heat was produced, and the cloud began to collapse toward the center. The sun formed at the center from this heat. Cooling of the cloud caused rocky and metallic materials to form the inner planets. The outer planets formed from lighter materials and gases.
5. The surface of Earth is continually changing due to its layered structure.
6. It would not be very useful because these two planets have only very thin atmospheres. Very few meteorological processes are occurring on them.
7. If all the lighter elements were no longer a part of Earth's structure, Earth probably would not have layers defined by their density.

Earth's Place in the Universe **L2**

Background

The Milky Way is a collection of several hundred billion stars, the oldest of which is about 10 billion years. It is one of a cluster of approximately 28 galaxies, called the Local Group, that exists in our region of the universe. Initially, the oldest stars in the Milky Way formed from nearly pure hydrogen. Later, succeeding generations of younger stars, including our Sun, would have heavier, more complex atoms available for their formation.

Teaching Tips

- As students read the feature and look at Figure 4, have them make a timeline of the events shown from the big bang to the present.
- While reading Earth's Place in the Universe feature, have students create a flowchart showing the chain of events starting with the big bang and ending with the formation of our sun and the planets of our solar system. *(Big Bang → Protons and neutrons appear → Hydrogen and helium form → Hydrogen and helium condense into clouds → Galaxies and galaxy clusters form and start spreading apart → Clouds of gas and dust collapse, forming stars → Stars become supernovas → Nebula, enriched from supernovas, contracts, rotates, and flattens → Planets and our sun form)*

Address Misconceptions **L2**

Students may think that the Milky Way is at the center of the universe. They may have inferred this from learning that almost all galaxies are moving away from the Milky Way in all directions. To dispel this misconception, have students mark with a black marker a number of dots on a partially inflated balloon. Blow up the balloon and observe what happens to the dots. They all move away from each other, as do almost all galaxies. All points in the universe can be thought of as being the center of the universe, as everything else is moving away from everything else.
Visual

earth as a SYSTEM

Earth's Place in the Universe

For centuries, people who have gazed at the night sky have wondered about the nature of the universe, Earth's place within it, and whether or not we are alone. Today many exciting discoveries in astronomy are beginning to provide answers about the origin of the universe, the formation and evolution of stars, and how Earth came into existence.

The realization that the universe is immense and orderly began in the early 1900s. Edwin Hubble and other scientists demonstrated that the Milky Way galaxy is one of hundreds of billions of galaxies, each of which contains billions of stars. Evidence supports that Earth, its materials, and all living things are the result of the Big Bang theory. The universe began between 13 and 14 billion years ago as a dense, hot, massive amount of material exploded with violent force. See Figure 4. Within about one second, the temperature of the expanding universe cooled to approximately 10 billion degrees. Basic atomic particles called protons and neutrons began to appear. After a few minutes, atoms of the simplest elements—hydrogen and helium—had formed. The initial conversion of energy to matter in the young universe was completed.

During the first billion years or so, matter (essentially hydrogen and helium) in the expanding universe clumped together to form enormous clouds that eventually collapsed to become galaxies and clusters of galaxies. Inside these collapsing clouds, smaller concentrations of matter formed into stars. One of the billions of galaxies to form was the Milky Way.

During the life of most stars, energy produced as hydrogen nuclei (protons) fuses with other hydrogen nuclei to form helium. During this process, called nuclear fusion, matter is converted to energy. Stars begin to die when their nuclear fuel is used up. Massive stars often have explosive deaths. During these events, called supernovas, nuclear fusion produces atoms such as oxygen, carbon, and iron. These atoms may become the materials that make up future generations of stars. From the debris scattered during the death of a preexisting star, our sun, and the solar system formed

Our star, the sun, is at the very least a second-generation star. Along with the planets in our solar system, the sun began forming nearly 5 billion years ago from a large interstellar cloud called a nebula. This nebula consisted of dust particles and gases enriched in heavy elements from supernova explosions. Gravitational energy caused the nebula to contract, rotate, and flatten. Inside, smaller concentrations of matter began condensing to form the planets. At the center of the nebula there was sufficient pressure and heat to initiate hydrogen nuclear fusion, and our sun was born.

It has been said that all life on Earth is related to the stars. This is true because the atoms in our bodies and the atoms that make up everything on Earth, owe their origin to a supernova event that occurred billions of years ago, trillions of kilometers away.

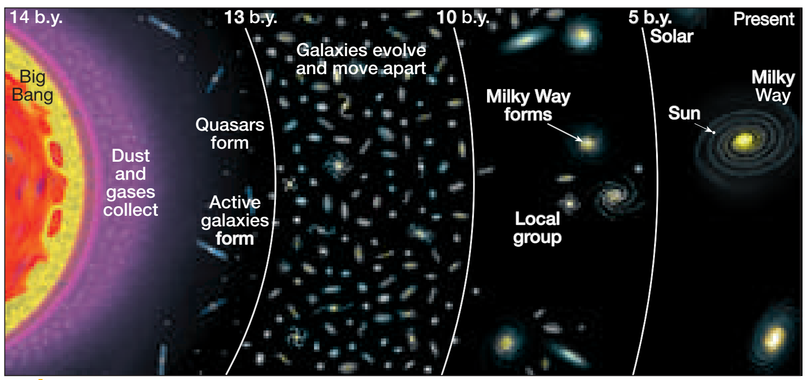


Figure 4 Big Bang Theory Between 13 and 14 billion years ago, a huge explosion sent all of the universe's matter flying outward at great speed. After a few billion years, the material cooled and condensed into the first stars and galaxies. About 5 billion years ago, our solar system began forming in a galaxy that is now called the Milky Way galaxy.

1.2 A View of Earth

Reading Focus

Key Concepts

- What are the four major spheres into which Earth is divided?
- What defines the three main parts of the solid Earth?
- Which model explains the position of continents and the occurrence of volcanoes and earthquakes?

Vocabulary

- hydrosphere
- atmosphere
- geosphere
- biosphere
- core
- mantle
- crust

Reading Strategy

Predicting Before you read, predict the meaning of the vocabulary words. After you read, revise your definition if your prediction was incorrect.

Vocabulary Term	Before You Read	After You Read
hydrosphere	a. ?	b. ?
atmosphere	c. ?	d. ?
geosphere	e. ?	f. ?
biosphere	g. ?	h. ?
core	i. ?	j. ?
mantle	k. ?	l. ?
crust	m. ?	n. ?

A view such as the one in Figure 5A provided the *Apollo 8* astronauts with a unique view of our home. Seen from space, Earth is breathtaking in its beauty. Such an image reminds us that our home is, after all, a planet—small, self-contained, and in some ways even fragile.

If you look closely at Earth from space, you may see that it is much more than rock and soil. The swirling clouds and the vast global ocean emphasize the importance of water on our planet.

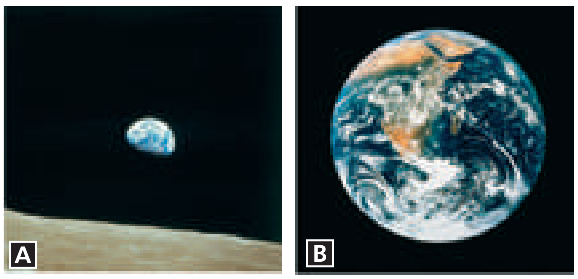


Figure 5 A View that greeted the *Apollo 8* astronauts as their spacecraft emerged from behind th Moon. **B** Africa and Arabia are prominent in this image of Earth taken from *Apollo 17.* The tan areas are desert regions. The bands of clouds over central Africa are associated with rainforests. Antarctica, which is covered by glacial ice, is visible at the south pole. The dark blue oceans and white swirling clouds remind us of the importance of oceans and the atmosphere.

Earth's Major Spheres

The view of Earth shown in Figure 5B should help you see why the physical environment is traditionally divided into three major spheres: the water portion of our planet, the **hydrosphere;** Earth's gaseous envelope, the **atmosphere;** and the **geosphere.**

Our environment is characterized by the continuous interactions of air and rock, rock and water, and water and air. The **biosphere,** which is made up of all the life-forms on Earth, interacts with all three of these physical spheres. **Earth can be thought of as consisting of four major spheres: the hydrosphere, atmosphere, geosphere, and biosphere.**

Section 1.2

1 FOCUS

Section Objectives

1.3 **Describe** Earth's four major spheres.
1.4 **Differentiate** among the three parts of the geosphere.
1.5 **State** the value of the theory of plate tectonics to Earth Science.

Reading Focus

Build Vocabulary L2

Word Parts Explain to students that *hydro-* relates to water and *atmos-* relates to air. Have them use this information, along with prior knowledge, to predict the meaning of the vocabulary words for this section.

Reading Strategy L2

Sample answer:
a. ball of water
b. all water on Earth
c. ball of air
d. gaseous envelope surrounding Earth
e. ball of rock
f. solid part of Earth below the atmosphere and oceans
g. ball of living things
h. all life on Earth
i. center of Earth
j. dense inner sphere
k. ledge
l. less dense middle layer
m. outer envelope
n. light, thin outer layer

2 INSTRUCT

Earth's Major Spheres

Use Visuals L1

Figure 5 This image of Earth was taken by astronauts in space. Ask: **Which of Earth's features are visible from space?** *(oceans, continents, clouds)* **What does the color of the land that is visible tell you about the climate in those regions?** *(Brown indicates a desert climate. Green indicates a wet climate.)* **What other Earth features do you think would be visible from space?** *(smoke from forest fires and city lights at night)* **Who might find images from space useful?** *(meteorologists, geologists, oceanographers)*
Visual, Verbal

Section 1.2 (continued)

Build Reading Literacy L1

Refer to **p. 1D**, which provides guidelines for guided anticipation.

Anticipation Guide Ask students to respond to the following questions in writing before they read this section. Have students check their answers and make changes as needed after they finish reading the section. Students should answer True or False to the following series of statements:

- The atmosphere contains all of the water on Earth. *(F)*
- Groundwater is part of Earth's hydrosphere. *(T)*
- Earth's atmosphere does nothing to protect us from the sun's radiation. *(F)*
- There is no crust under Earth's oceans. *(F)*
- Earth's crust is the same thickness under land as under water. *(F)*
- The only layer of Earth that is solid is the crust. *(F)*
- The biosphere affects all other spheres of Earth. *(T)*

Verbal

Teacher Demo

Earth's Layers L2

Purpose Provide students with a three-dimensional model of Earth's layered structure.

Materials hard-boiled egg, knife

Procedure Show students a hard-boiled egg. Crack the shell in several places so pieces of shell can slide a bit over the white of the egg. Tell students the shell of the egg represents Earth's crust, which is a thin layer, cracked and broken into plates that can move. Cut the egg in half. Show students that the white of the egg represents Earth's mantle, and the yolk of the egg represents Earth's core.

Expected Outcome Students will be able to relate the structure of the egg to the structure of Earth and can use this representation to create a mental model of what Earth's layers look like.

Visual, Logical

Hydrosphere Water is what makes Earth unique. All of the water on Earth makes up the hydrosphere. Continually on the move, water evaporates from the oceans to the atmosphere, falls back to Earth as rain, and runs back to the ocean. The oceans account for approximately 97 percent of the water on Earth. The remaining 3 percent is fresh water and is present in groundwater, streams, lakes, and glaciers.

Although these freshwater sources make up a small fraction of the total amount of water on Earth, they are quite important. Streams, glaciers, and groundwater are responsible for sustaining life and creating many of Earth's varied landforms.

Atmosphere A life-sustaining, thin, gaseous envelope called the atmosphere surrounds Earth. It reaches beyond 100 kilometers above Earth, yet 90 percent occurs within just 16 kilometers of Earth's surface. This thin blanket of air is an important part of Earth. It provides the air that we breathe. It protects us from the sun's intense heat and dangerous radiation. The energy exchanges that continually occur between space, the atmosphere, and Earth's surface produce weather and climate.

If Earth had no atmosphere, life on our planet as we know it could not exist. Many of the processes and interactions that make the surface such a dynamic place would not occur. For example, without weathering and erosion, the face of our planet might more closely resemble the moon.

Geosphere Lying beneath both the atmosphere and the ocean is the geosphere. **Because the geosphere is not uniform, it is divided into three main parts based on differences in composition—the core, the mantle, and the crust.** Figure 6A shows the dense or heavy inner sphere that is the core; the less dense mantle; and the lighter, thin crust. The crust is not uniform in thickness. It is thinnest beneath the oceans and thickest beneath the continents. Figure 6B shows that the crust and uppermost mantle make up a rigid outer layer called the lithosphere. Beneath the lithosphere, the rocks become partially molten, or melted. They are able to slowly flow because of the uneven distribution of heat deep within Earth. This region is called the asthenosphere. Beneath the asthenosphere, the rock becomes more dense. This region of Earth is called the lower mantle.

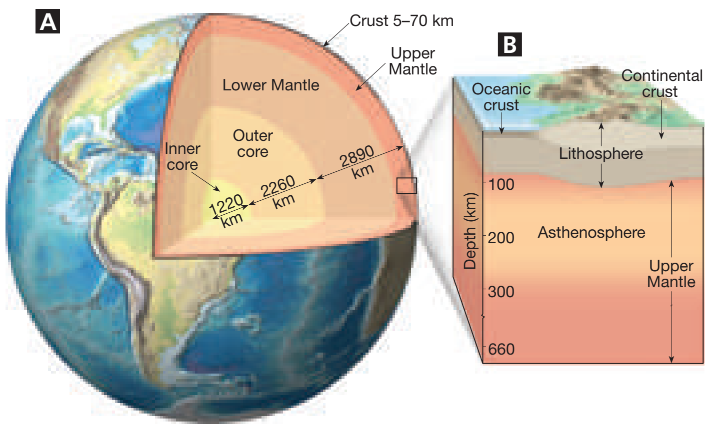


Figure 6 A On this diagram, the inner core, outer core, and mantle are drawn to scale but the thickness of the crust is exaggerated by about 5 times. **B** There are two types of crust—oceanic and continental. The lithosphere is made up of the crust and upper mantle. Below the lithosphere are the asthenosphere and the lower mantle.

Customize for Inclusion Students

Learning Disabled Have learning disabled students draw labeled pictures illustrating each of Earth's four major spheres: hydrosphere, atmosphere, geosphere, and biosphere. Be sure they include Earth's layers in their sketch of the solid Earth. They can use Figure 6 as a guide.

Biosphere The biosphere includes all life on Earth. It is concentrated in a zone that extends from the ocean floor upward for several kilometers into the atmosphere. Plants and animals depend on the physical environment for life. However, organisms do more than just respond to their physical environment. Through countless interactions, organisms help maintain and alter their physical environment. Without life, the makeup and nature of the solid Earth, hydrosphere, and atmosphere would be very different.

Reading Checkpoint *What are Earth's four major spheres?*

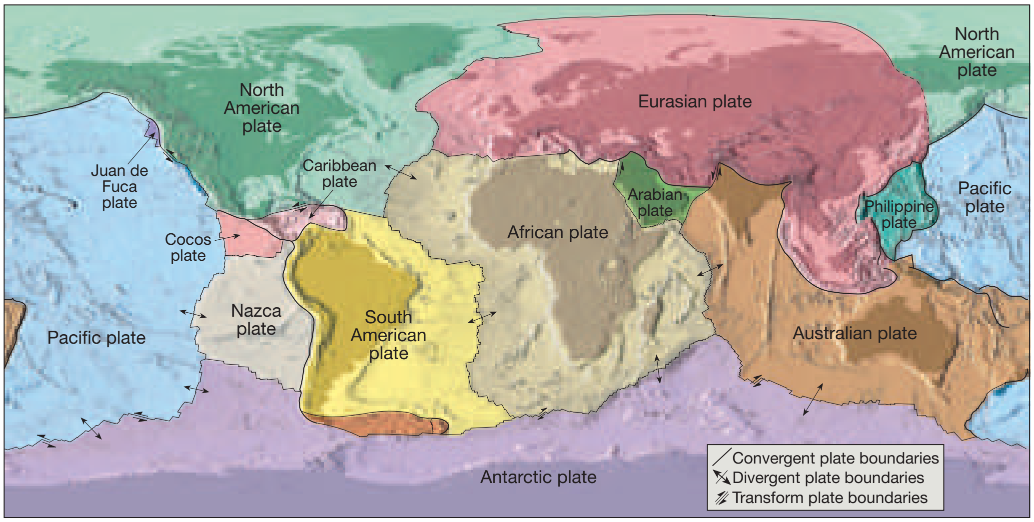


Figure 7 Plate Tectonics There are currently 7 major plates recognized and numerous smaller plates.
Relating Cause and Effect ***What is the relationship between mountain chains and plate boundaries?***

Plate Tectonics

You have read that Earth is a dynamic planet. If we could go back in time a billion years or more, we would find a planet with a surface that was dramatically different from what it is today. Such prominent features as the Grand Canyon, the Rocky Mountains, and the Appalachian Mountains did not exist. We would find that the continents had different shapes and were located in different positions from those of today.

There are two types of forces affecting Earth's surface. *Destructive forces* such as weathering and erosion work to wear away high points and flatten out the surface. *Constructive forces* such as mountain building and volcanism build up the surface by raising the land and depositing new material in the form of lava. These constructive forces depend on Earth's internal heat for their source of energy.

Facts and Figures

It is important to note that the "solid Earth" is not really all solid. The crust, mantle, and inner core are solid, but the outer core is liquid. In addition, a tiny part of Earth's mantle (in the astherosphere) is molten, which gives rise to the lava that flows out of volcanoes. Scientists have inferred the state of matter for each of Earth's layers by studying the paths that seismic waves take through Earth.

Build Science Skills L2

Making Judgments Present groups with the questions below. Challenge them to reach a consensus answer to each question. Once all groups have finished, have one student in each group present the results. Ask: **How does the hydrosphere, atmosphere, and geosphere affect the biosphere?** *(Flooding, tornadoes, hurricanes, volcanoes, and earthquakes have caused loss of life and habitat.)* **How do members of the biosphere affect the geosphere?** *(Humans have dug mines into the crusts. Burrowing animals also affect the solid Earth, though often in more of a temporary way.)* **How do members of the biosphere affect the hydrosphere and atmosphere?** *(Humans have polluted both water and air. Human-made dams and those built by beavers can have a dramatic effect on the flow of rivers.)* **Does the biosphere influence the other spheres more than the other spheres influence the biosphere? Explain your answer.** *(Students can answer either way as long as they have solid reasoning to support their decision. For example, when changes in the other spheres threaten the biosphere, humans usually find a way to adjust to the changes. However, the other spheres are not always able to respond to human efforts.)*
Verbal

Plate Tectonics

Build Reading Literacy L1

Refer to **p. 362D** in **Chapter 13,** which provides guidelines for using prior knowledge.

Use Prior Knowledge Based on their previous experiences with words such as *construction* and *destroy*, have students predict the definitions of the terms *constructive forces* and *destructive forces*. Help students see this connection and then check that they understand both terms by asking them to list some destructive forces and some constructive forces.
Verbal

Answer to . . .

Figure 7 *Mountain chains are often found along plate boundaries.*

Reading Checkpoint *The four major spheres are the hydrosphere, atmosphere, geosphere, and biosphere.*

Section 1.2 (continued)

Teacher Demo

Convection and Plates L2

Purpose Students observe how heat from within Earth can move plates.

Materials hot plate; deep, wide glass container such as a lasagna pan; diluted tomato soup; large, thin sponges; scissors; tongs

Procedure Fill the container about halfway with tomato soup, and put it on the hot plate. Slowly heat it until convection cells form (soup rising in the center and falling at the edges). While the soup is heating, cut various rough plate shapes out of the sponges. Use the tongs to place the sponges on the surface of the soup. Have students observe what happens to the sponges. (If necessary, review the concept of convection.) Ask: **Why is the soup moving?** *(Heat from below creates convection cells.)* **Why do the "plates" move?** *(The moving soup carried the plates along with it.)* **How is the actual movement of Earth's plates different from this demonstration?** *(The molten rock in the mantle is solid, and therefore slower-moving than the soup, and so the actual plates move much more slowly.)*

Safety Caution students not to touch the hot container or soup.

Expected Outcome The heat will create convection cells that move the sponges around.
Visual, Logical

3 ASSESS

Evaluate Understanding L2

Have students make posters showing Earth's layers and spheres. Students should label their drawings with the terms crust, mantle, core, hydrosphere, biosphere, and atmosphere.

Reteach L1

Use Figure 7 to review Earth's plates and the concept of plate tectonics.

Connecting Concepts

Students' answers could include discussions of the hydrosphere (sea level changes), atmosphere (weather and climate changes), geosphere (erosion of topsoil, earthquake occurrence), and biosphere (evolution of living things).

Within the last several decades, a great deal has been learned about the workings of Earth. In fact, this period is called a revolution in our knowledge about Earth. This revolution began in the early part of the twentieth century with the idea that the continents had moved about the face of the Earth. This idea contradicted the accepted view that the continents and ocean basins are stationary features on the face of Earth. Few scientists believed this new idea. More than 50 years passed before enough data were gathered to transform this hypothesis into a widely accepted theory. **The theory that finally emerged, called plate tectonics, provided geologists with a model to explain how earthquakes and volcanic eruptions occur and how continents move.**

Reading Checkpoint *What is the difference between destructive forces and constructive forces?*

According to the plate tectonics model, Earth's lithosphere is broken into several individual sections called plates. Figure 7 on page 9 shows their current position. These plates move slowly and continuously across the surface. This motion is driven by the result of an unequal distribution of heat within Earth. Ultimately, this movement of Earth's lithospheric plates generates earthquakes, volcanic activity, and the deformation of large masses of rock into mountains. You will learn more about the powerful effects of plate tectonics in Chapter 9.

Section 1.2 Assessment

Reviewing Concepts

1. Which of Earth's spheres do each of these features belong: lake, meadow, canyon, cloud?
2. What are the three main parts of the geosphere?
3. Why is the solid Earth layered?
4. The plate tectonics theory explains the existence and occurrence of what features?
5. What sort of energy allows the tectonic plates to move?
6. Describe an example of how water moves through the hydrosphere.

Critical Thinking

7. **Inferring** Using the definitions of spheres as they occur on Earth, what spheres do you think are present on Venus?
8. **Applying Concepts** Describe a situation in which two or more of Earth's spheres are interacting.
9. **Classifying** Choose an Earth science branch. List how some of its studies relate to Earth's spheres.

Connecting Concepts

Earth's Spheres You learned in Section 1.1 that Earth is a dynamic planet. Explain how features in each of Earth's spheres are changing over time.

Section 1.2 Assessment

1. lake: hydrosphere, meadow: geosphere, canyon: geosphere, cloud: atmosphere
2. The three main parts of the geosphere are the core, mantle, and crust.
3. The layers formed because of density differences in the materials that made up early Earth.
4. Plate tectonics explains mountains, continents, ocean basins, earthquakes, and volcanoes.
5. Plate tectonics depends on Earth's internal heat.
6. Sample answer: Water in a lake evaporates into the atmosphere. The water vapor condenses and falls from the clouds into the lake as rain and the cycle begins again.
7. geosphere, atmosphere
8. Sample answer: waves (hydrosphere) crashing onto the shore (geosphere); birds (biosphere) flying in the sky (atmosphere)
9. Sample answer: meteorology: cloud cover—atmosphere; rain storms—hydrosphere and atmosphere

1.3 Representing Earth's Surface

Reading Focus

Key Concepts

- What lines on a globe are used to indicate location?
- What problems do mapmakers face when making maps?
- How do topographic maps differ from other maps?

Vocabulary

- latitude
- longitude
- topographic map
- contour line
- contour interval

Reading Strategy

Monitoring Your Understanding Preview the Key Concepts, topic headings, vocabulary, and figures in this section. List two things you expect to learn. After reading, state what you learned about each item you listed.

What I Expect to Learn	What I Learned
a. ?	b. ?
c. ?	d. ?

Determining Location

Today we use maps and computer programs to help us plan our routes. Long ago, people had to rely on maps that were made using data and information that were collected by travelers and explorers. Today computer technology is available to anyone who wants to use it. Mapmaking has changed a lot throughout recorded history.

After Christopher Columbus and others proved that Earth was not flat, mapmakers began to use a global grid to help determine location.

Global Grid Scientists use two special Earth measurements to describe location. The distance around Earth is measured in degrees. **Latitude is the distance north or south of the equator, measured in degrees. Longitude is the distance east or west of the prime meridian, measured in degrees.** Earth is 360 degrees in circumference. Lines of latitude are east-west circles around the globe. All points on the circle have the same latitude. The line of latitude around the middle of the globe, at 0 degrees (°), is the equator. Lines of longitude run north and south. The prime meridian is the line of longitude that marks ° of longitude as shown in Figure 8.

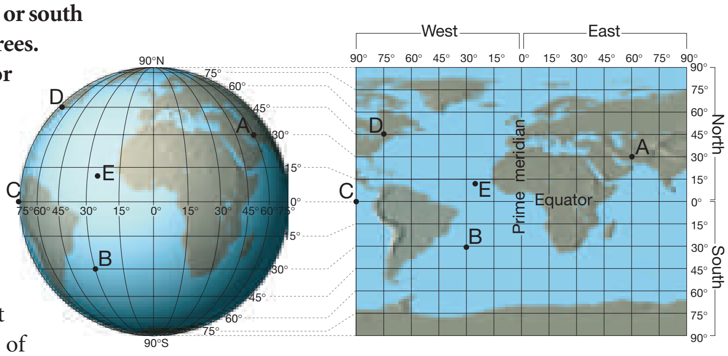


Figure 8 Global Grid

Section 1.3

1 FOCUS

Section Objectives

1.6 **Locate** points on Earth's surface by their latitude and longitude.

1.7 **Describe** the advantages and disadvantages of different types of mass.

1.8 **Explain** what makes topographic maps different from other maps.

Reading Focus

Build Vocabulary L2

Paraphrase Have students look up the vocabulary words for this section in the Glossary and then rewrite the definitions in their own words. Help students remember latitude lines run horizontally across Earth with the mnemonic "Lat lies flat." Similarly, help them see that longitude lines run the "long way" over Earth.

Reading Strategy L2

Sample answer:
a. I expect to learn about latitude and longitude.
b. Latitude lines measure degrees north and south of the equator; longitude lines measure degrees east and west of the prime meridian.
c. I expect to learn about different types of maps.
d. There are many different types of maps. Maps are hard to make accurately. Different map types have different advantages and disadvantages.

2 INSTRUCT

Determining Location

Use Visuals L1

Figure 8 Help students find point D on the global grid in this figure. Ask: **What is the latitude and longitude of point D?** *(45°N, 75°W)* **What major city is near point D?** *(Montreal, Canada)* **If an earthquake occurred near point D, are people at point A likely to feel it? Why or why not?** *(No, point D is in the Western Hemisphere and point A is in the Eastern Hemisphere.)*
Visual, Logical

Maps and Mapping

Use Visuals L1

Figure 9 Use this diagram to explain the concepts of latitude and longitude and how they are measured. Emphasize that although latitude and longitude are usually shown on Earth's surface, they are actually measured inside Earth. Ask: **From which point is latitude measured?** *(the equator)* **From which point is longitude measured?** *(the prime meridian)*
Visual, Logical

Build Reading Literacy L1

Refer to **p. 124D** in **Chapter 5**, which provides guidelines for summarizing.

Summarize Have students write a summary of this section that includes each map type and its advantages and disadvantages. This can be done as a table. Here is an example:

Map Type	Advantages	Disadvantages
Mercator projection	Rectangular; longitude lines are parallel; directions shown accurately	Sizes and distances distorted
Robinson projection	Most distances, sizes, and shapes are accurate	Distortions around the map edges
Conic projection	Great accuracy over small areas; good for road and weather maps	Lots of distortion on most of the map
Gnomonic projection	Reliably shows the shortest distance between two points	Exact distances and directions are distorted

Visual, Verbal

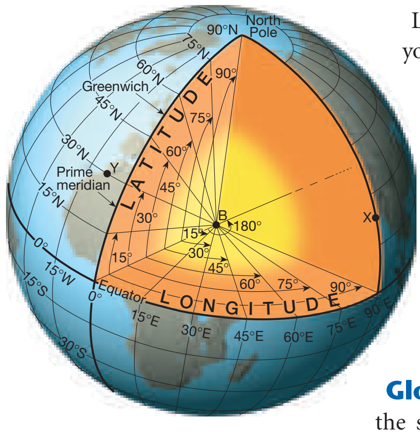


Figure 9 Measuring Latitude and Longitude

Lines of latitude and longitude form a global grid. This grid allows you to state the absolute location of any place on Earth. For example, Savannah, Georgia, is located at 32° north latitude and 81° west longitude.

The equator divides Earth in two. Each half is called a hemisphere. The equator divides Earth into northern and southern hemispheres. The prime meridian and the 180° meridian divide Earth into eastern and western hemispheres.

Reading Checkpoint *How does the global grid divide Earth?*

Globes As people explored Earth, they collected information about the shapes and sizes of islands, continents, and bodies of water. Mapmakers wanted to present this information accurately. The best way was to put the information on a model, or globe, with the same round shape as Earth itself. By using an accurate shape for Earth, mapmakers could show the continents and oceans of Earth much as they really are. The only difference would be the scale, or relative size.

But there is a problem with globes. Try making a globe large enough to show the streets in your community. The globe might have to be larger than your school building! A globe can't be complete enough to be useful for finding directions and at the same time small enough to be convenient for everyday use.

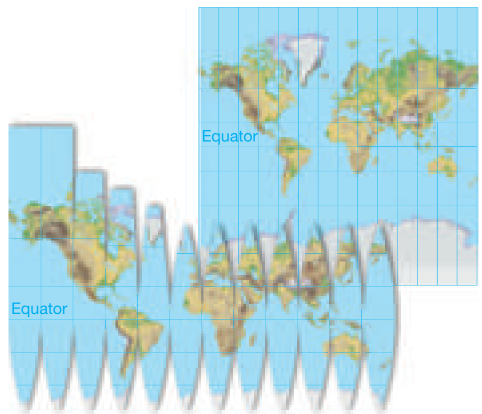


Figure 10 Mercator Map To make a Mercator map, mapmakers have to carve an image of Earth's surface into slices and then stretch the slices into rectangles. Stretching the slices enlarges parts of the map. The enlargement becomes greater toward the north and south poles. **Observing** ***What areas on the map appear larger than they should?***

Maps and Mapping

A map is a flat representation of Earth's surface. But Earth is round. Can all of Earth's features be accurately represented on a flat surface without distorting them? The answer is no. **No matter what kind of map is made, some portion of the surface will always look either too small, too big, or out of place. Mapmakers have, however, found ways to limit the distortion of shape, size, distance, and direction.**

The Mercator Projection In 1569, a mapmaker named Gerardus Mercator created a map to help sailors navigate around Earth. On this map, the lines of longitude are parallel, making this grid rectangular, as shown on the map in Figure 10. The map was useful because, although the sizes and distances were distorted, it showed directions accurately. Today, more than 400 years later, many seagoing navigators still use the Mercator projection map.

Customize for Inclusion Students

Learning Disabled Students can more easily locate positions on a map using latitude and longitude coordinates by using the following procedure. First, help students orient themselves to the map by locating the equator and the prime meridian. Have students go over those two key points using a highlighter and extend the lines out to the edge of the paper. Next, have students write *N* in the left and right margins above the equator, and *S* in the left and right margins below the equator. Students should write *W* in the margins above and below the map west of the prime meridian, and write *E* in the margins above and below the map east of the prime meridian.

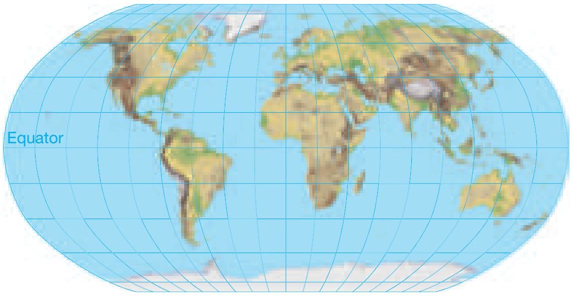


Figure 11 Robinson Projection Map Compare this map to the Mercator projection.
Comparing and Contrasting ***How do the shapes in the continents differ between these maps? Are there any other differences?***

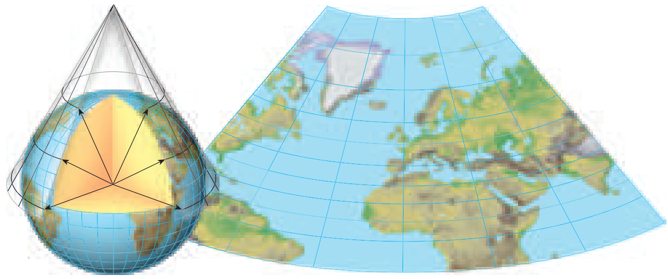


Figure 12 Conic Projection Map Because there is little distortion over small areas, conic projections are used to make road maps and weather maps.

Different Projection Maps for Different Purposes

The best projection is always determined by its intended use. The Robinson projection map is one of the most widely used. Maps that use this projection show most distances, sizes, and shapes accurately. However, even a Robinson projection has distortions, especially in areas around the edges of the map. You can see this in Figure 11. Conic projection maps are made by wrapping a cone of paper around a globe at a particular line of latitude, as shown in Figure 13. Various points and lines are projected onto the paper. There is almost no distortion along the line of latitude that's in contact with the cone, but there can be much distortion in areas away from this latitude. Because accuracy is great over a small area, these maps are used to make road maps and weather maps. Gnomonic projections, as shown in Figure 13, are made by placing a piece of paper on a globe so that it touches a single point on the globe's surface. Various points and lines are then projected onto the paper. Although distances and directions are distorted on these maps, they are useful to sailors and navigators because they show with great accuracy the shortest distance between two points.

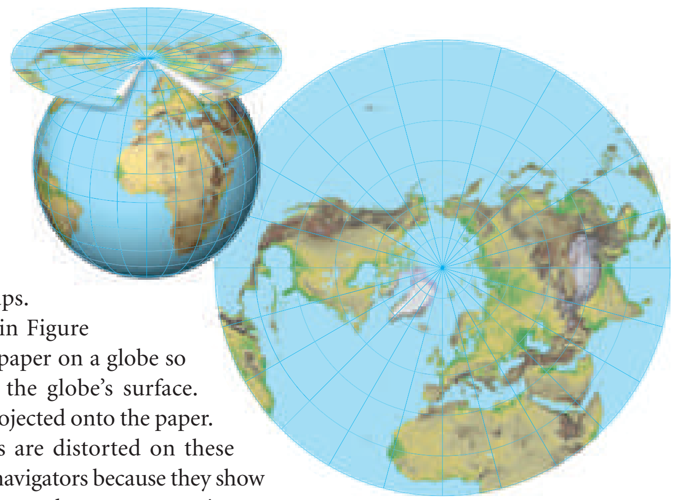


Figure 13 Gnomonic Projection Map Gnomonic projections allow sailors to accurately determine distance and direction across the oceans.

Reading Checkpoint ***What major problem must mapmakers overcome?***

Teacher Demo

Conic and Gnomonic Projections

L2

Purpose Students see how conic and gnomonic projections are made.

Materials small globe, blank transparency sheet

Procedure Use a photocopier to copy the maps in Figures 12 and 13 onto a blank transparency sheet. Make the figures as large as possible. Cut the transparency in half to separate the figures. Wrap the copy of Figure 12 around the globe in a cone shape as shown. Point out how the features of the globe line up with the projection. Hold the copy of Figure 13 flat on top of the North Pole as shown. Ask: **Where was the conic projection most accurate?** *(near the latitude where the cone touches the globe)* **Least accurate?** *(near the top and bottom)* **Where was the gnomonic projection most accurate?** *(near the North Pole)*

Expected Outcome Students will observe how the projections are related to round Earth.
Visual, Logical

Use Visuals

L1

Figures 10–13 Advise students to look carefully at Figures 10–13 to see how each map is created and why this process results in distortion. Ask: **Based on Figure 10, how does the way a Mercator map is created cause distortion?** *(Since the Mercator map is made by slicing a globe, each section is rounded and the sections don't fit together, so each piece must be stretched into a rectangle, causing distortion.)* **Using Figure 11, explain how a conic projection map is created.** *(A cone of paper is put over a globe, and the lines of the globe are projected onto the paper.)*
Visual

Answer to . . .

Figure 10 *the areas near the poles*

Figure 11 *The continents are less distorted near the poles The longitude lines are straight, not curved.*

Reading Checkpoint *into hemispheres*

Reading Checkpoint *Representing round Earth on flat paper causes distortion in shape, size, distance.*

Topographic Maps

Use Community Resources L2

A cartographer is someone who makes maps. While maps were once drawn entirely by hand based on aerial photographs, almost all modern mapmaking is done using computers. Training in GIS (geographic information systems) is usually required for the job. Ask a cartographer from a local college, university, or government office to talk to the class about how maps are made. Have students prepare questions in advance.
Interpersonal

Build Science Skills L2

Applying Concepts Have students answer the following questions by using Figure 15. Ask: **Find an area with a steep slope. Name a feature in this area.** *(the southern part of the map; Sugar Loaf Mountain)* **How do you know that this area has a steep slope?** *(The contour lines are close together.)* **Find an area on the map with a gentle slope. Name a feature in this area.** *(the eastern edge of the map; Turquoise Lake)* **How can you tell that this area has a gentle slope?** *(The contour lines are far apart.)* Discuss students' answers and clarify if needed.
Visual

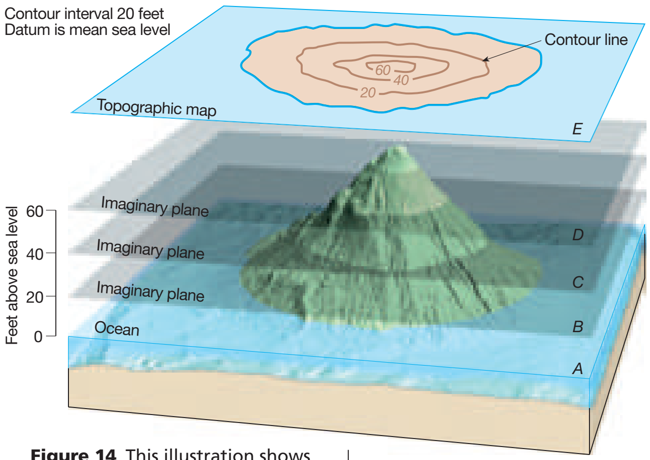


Figure 14 This illustration shows how contour lines are determined when topographic maps are constructed.

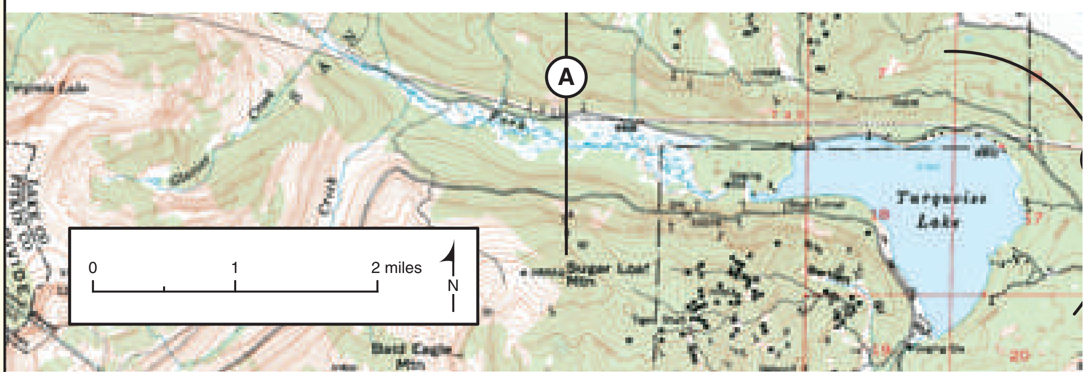
Topographic Maps

A **topographic map,** like the one shown in Figure 15, represents Earth's three-dimensional surface in two dimensions. **Topographic maps differ from the other maps discussed so far because topographic maps show elevation. Topographical maps show elevation of Earth's surface by means of contour lines.** Most also show the presence of bodies of water, roads, government and public buildings, political boundaries, and place names. These maps are important for geologists, hikers, campers and anyone else interested in the three-dimensional lay of the land.

Contour Lines The elevation of the land is indicated by using contour lines. Every position along a single contour line is the same elevation. Adjacent contour lines represent a change in elevation. Every fifth line is bold and labeled with the elevation. It is called an index contour. The **contour interval** tells you the difference in elevation between adjacent lines. The steepness of an area can be determined by examining a map. Lines that are closer together indicate a steeper slope, while lines farther apart indicate a gentler slope. You can see this relationship on the illustration in Figure 14. Contour lines that form a circle represent a hill. A depression is represented by circular contours that have hachure marks, which are small lines on the circle that point to the center. Contour lines never touch or intersect.

Reading Checkpoint *How do topographic maps indicate changes in elevation?*

Figure 15 Topographic Map
This is a portion of the Holy Cross, Colorado, topographic map. Contour lines are shown in brown.



Facts and Figures

Topographic maps contain a great deal of information. Each map has a legend that gives information about the map and the symbols used on it. The legend lists the title of the map (usually a major feature), the dates the map was produced and revised, and the latitude and longitude. There is a small diagram showing the map's location in the state and the names of adjacent maps. A small box contains the contour interval and the scale as a ratio and as scale bars in miles, feet, and kilometers/meters. A magnetic declination diagram shows the differences in degrees among true north, grid north, and magnetic north. A long list explains the symbols shown on the map, which can include contour lines, depressions, ocean depth lines, boundaries, survey markers, forests, fields, built-up areas, buildings, roads, and railways.

Scale A map represents a certain amount of area on Earth's surface. So it is necessary to be able to determine distances on the map and relate them to the real world. Suppose you want to build a scale model of a boat that is 20 feet long. If your model is a 1/5-scale model, then it is 4 feet long.

In a similar way, a map is drawn to scale where a certain distance on the map is equal to a certain distance at the surface. Because maps model Earth's surface, the scale must be larger than that of the model boat. Look at the scale on the map in Figure 16. The ratio reads 1:24,000. This means that 1 unit on the map is equal to 24,000 units on the ground. Because the ratio has no units, it may stand for anything. We usually use inches or centimeters for our units. If the 1 stands for 1 centimeter on the map, how many kilometers does the 24,000 stand for on the ground?

Another scale provided on a map is a bar scale. See Figure 15. This allows you to use a ruler to measure the distance on the map and then line the ruler up to the bar to determine the distance represented.

Geologic Maps It is often desirable to know the type and age of the rocks that are exposed, or crop out, at the surface. This kind of map is shown in Figure 16. **A map that shows this information is called a geologic map.** Once individual rock formations are identified, and mapped out, their distribution and extent are drawn onto the map. Each rock formation is assigned a color and sometimes a pattern. A key provides the information needed to learn what formations are present on the map. Contour lines are often included to provide a more detailed and useful map.

Go Online SCI LINKS NSTA

For: Links on mapping
Visit: www.SciLinks.org
Web Code: cjn-1013

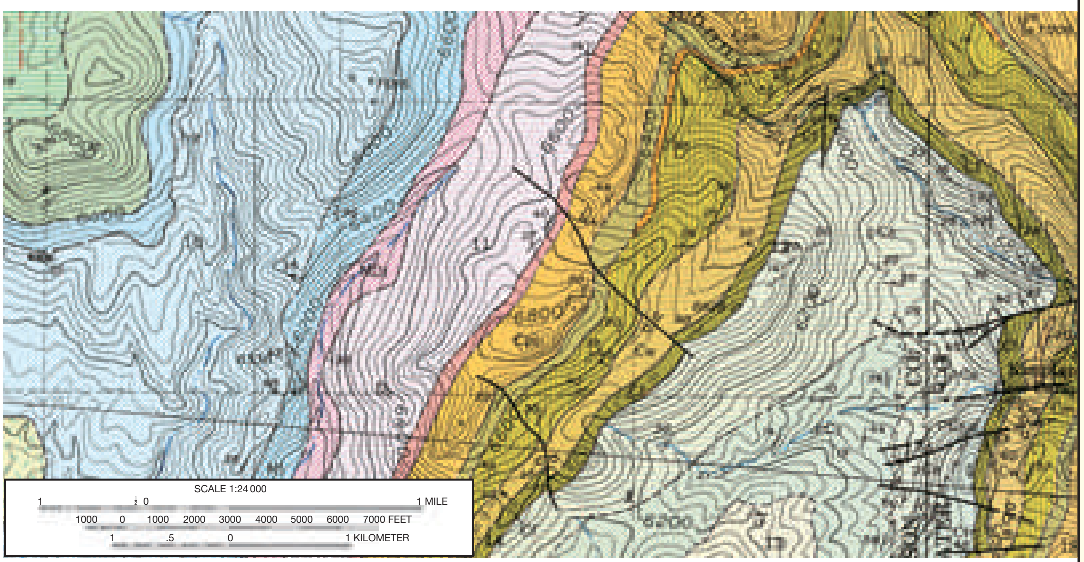


Figure 16 Geologic Map The color coding on the map represents some rock formations in Montana. Each color and pattern represents a different type of rock.

Integrate Math

L2

Working With Ratios Working with a map key to determine actual distances often requires the use of ratios, a topic taught in math class. Explain the following process to your students. If a map legend has 1:24,000, this suggests that 1 unit (centimeters or inches) on the map is equal to 24,000 units (centimeters or inches) on Earth. To determine how many kilometers 1 cm on the map would equal, set up a ratio (using the conversion factor 1 km = 100,000 cm), as follows: 1 km / 100,000 cm = *x*km / 24,000 cm, then solve the ratio by cross-multiplication. The result will be that 1 cm on the map represents 0.24 km on Earth. Because 1:24,000 represents a ratio, it does not matter what unit is used as long as the map's unit matches the unit on Earth. This ratio would allow students to determine how many inches on Earth corresponded to inches on the map.
Logical

Direct students to the **Math Skills** in the **Skills and Reference Handbook** at the end of the student text for additional help.

Use Community Resources

L2

Geologic maps are used by research scientists, government agencies, and mining companies. Ask a geologist from a local college, university, mining company, or government office to talk to the class about how geologic maps are made, what information they show, and how they are used. Ask students to prepare questions in advance.
Interpersonal

Go Online NSTA SCI LINKS

Download a worksheet on mapping for students to complete, and find additional teacher support from NSTA SciLinks.

Answer to . . .

Reading Checkpoint *Topographic maps indicate changes in elevation with contour lines. Lines closer together indicate a steeper slope.*

Advanced Technology

Use Visuals L1

Figure 17 Tell students that the image shown is similar to a photograph, but taken from a satellite orbiting around Earth. Ask: **What are the light blue areas?** *(moving sediment)* **Where is the sediment coming from?** *(It is carried down by the Mississippi River.)* **What is the area at the center right side of the image called and how do you think it was formed?** *(the Mississippi delta was formed from sediments deposited by the river.)*
Visual, Logical

Integrate Social Studies L2

Space Age The successful launch of *Sputnik* by the Soviet Union was a significant event in the Cold War era. It marked the beginning of the Space Age and was the first victory in the space race between the United States and the Soviet Union. In response, the United States accelerated its efforts to launch its own satellite.

Figure 17 Satellite Image of the Mississippi River Delta Moving sediment (light blue) indicates current patterns. Red shows vegetation.

Advanced Technology

Advanced technology is used to make maps that are more accurate than ever before. **Today's technology provides us with the ability to more precisely analyze Earth's physical properties.** Scientists now use satellites and computers to send and receive data. These data are converted into usable forms such as pictures and numerical summaries.

The process of collecting data about Earth from a distance, such as from orbiting satellites, is called remote sensing. Satellites use remote sensing to produce views of Earth that scientists use to study rivers, oceans, fires, pollution, natural resources, and many other topics. How might a scientist use the image shown in Figure 17?

We can use this technology in our daily lives too. For example, Global Positioning Systems (GPS) can provide maps in our cars to help us reach our destinations. GPS consists of an instrument that receives signals to compute the user's latitude and longitude as well as speed, direction, and elevation. GPS is an important tool for navigation by ships and airplanes. Scientists use GPS to track wildlife, study earthquakes, measure erosion, and many other purposes. Table 1 describes some of the technology that is particularly useful in the study of Earth science.

Facts and Figures

The first satellite to orbit Earth was called *Sputnik*. The Soviet Union launched it on October 4, 1957. It was a 23-inch, 184-pound metal ball containing a thermometer, a battery, and a radio transmitter. On its exterior, four whip antennas transmitted short-wave frequencies between 20 and 40 MHz, common frequencies intended to make *Sputnik's* presence obvious to the world, and particularly to the United States. *Sputnik* orbited Earth for 92 days before burning up in Earth's atmosphere.

Table 1 Technology and Earth Science

Type of Equipment	Capabilities
Weather Satelllites	• These monitor atmospheric temperature and humidity, ground and surface seawater temperature, cloud cover, and water-ice boundaries. • They can help locate sources of distress signals. • They are able to scan Earth's surface in one 24-hour period.
Navigation Satellites	• These assist ships and submarines to determine their exact location at any time.
Landsat Satellites	• The first Landsat satellite was launched in 1972. Landsat 7 was launched in 1999. • They provide data on Earth's landmasses, coastal boundaries, and coral reefs. • Pictures taken are transmitted to ground stations around the world. • They orbit Earth every 99 minutes and complete 14 orbits per day. • Total coverage of Earth is achieved in 16 days.
Global Positioning System (GPS)	• This system combines satellite information with computer technology to provide location information in three dimensions: latitude, longitude, and altitude. • Three satellite signals are detected by a receiver. The distance from the satellites to the receiver is calculated, and the location is determined using the triangulation method. A fourth signal is then used to mathematically determine exact position.
Very Long Baseline Interferometry (VLBI)	• VLBI utilizes a large network of antennas around the world to receive radio waves from space objects such as quasars. • In Earth science, VLBI is used in geodesy, or the measurement of the geosphere. • Using the arrival times of radio waves from quasars, the position of radio telescopes on Earth are determined to within millimeters of their position. • Small changes in the telescope positions allow scientists to study tectonic plate motions and other movements of Earth's crust with great precision and accuracy.

Section 1.3 Assessment

Reviewing Concepts

1. Describe the two sets of lines that are used on globes and some maps.
2. What happens to the images on the globe when they are transferred to a flat surface?
3. What is the purpose of contour lines on topographic maps?
4. What two lines mark zero degrees on the globe? In which directions do these lines run?
5. Why is the Mercator projection map still in use today?
6. What types of advanced technology are used in mapmaking today?

Critical Thinking

7. **Applying Concepts** Why are there so many different types of maps?
8. **Drawing Conclusions** How can data from VLBI be used in mapmaking today?
9. **Conceptualizing** An area on a topographic map has the following contour line configuration: First, the lines are fairly widely spaced. Then they are closely spaced. Finally, they are circular. Describe the topography represented by these lines.

Math Practice

Use the bar scale on Figure 15 to answer the following question.

10. Determine the distance along the shoreline of Turquoise Lake from the gaging station on the west shore to the gaging station on the south shore. Record your answer in kilometers.

Build Science Skills L2

Posing Questions Have students select one type of equipment described in Table 1 to research. Encourage students to make a list of questions about the equipment, such as when and where it was invented and by whom. Then have them research how the technology works and close with some applications of the technology they selected. Students can present their work as a written report, an oral report, or a poster to share with the class.
Verbal, Visual

3 ASSESS

Evaluate Understanding L2

Give students a topographic map that includes latitude and longitude. Have them locate specific features on the map, such as hills and depressions, based on the shapes of the contour lines. Have students determine the latitude and longitude of these features. Give students the latitude and longitude of a few sites of interest on the map and have them tell you what they find at each of those locations.

Reteach L1

Have students answer the Assessment questions in small groups. Assign the lower ability students to answer the Reviewing Concepts questions and the higher ability students to answer the Critical Thinking questions. Have partners then share and discuss their answers. Once all groups are finished, have students report their answers to the class. Clarify concepts as needed.

Math Practice

Solution
10. The distance in centimeters on the map is approximately 5.5 cm. The distance on the ground is approximately 3.43 km.

Section 1.3 Assessment

1. Lines of latitude are east-west circles around the globe. Lines of longitude run north and south.
2. They become distorted.
3. Contour lines indicate elevation.
4. The lines are the equator, which runs east and west, and the prime meridian, which runs north and south.
5. It is useful to sailors because although size and shape are distorted, it shows directions accurately.
6. Sample answer: satellites, computers, high-powered telescopes, sonar, GPS, VLBI
7. Each type of map is particularly useful in some capacity. Conic projections are good for small-scale maps such as road maps. Topographic maps help geologists and hikers. Mercator projections help sailors to navigate.
8. Because small-scale changes in position can be detected by VLBI technology, movements of Earth's crust can be measured precisely.
9. The land starts out relatively flat and rises steeply to the top of a hill.

Section 1.4

1 FOCUS

Section Objectives

1.9 **Describe** the primary goal of Earth system science and **define** the term *system*.

1.10 **Describe** Earth's two major sources of energy.

1.11 **Explain** how humans affect Earth's systems.

1.12 **Distinguish** between renewable and nonrenewable resources.

Reading Focus

Build Vocabulary L2

Word Forms Have students predict the meanings of *open system* and *closed system* based on their prior knowledge of the words *open*, *closed*, and *system*. Have students verify their predictions by reading the section.

Reading Strategy L2

Earth System Science

A. What is a System?

1. System—any size group of interacting parts forming a whole
2. Types of Systems—closed and open

B. Earth as a System

1. Earth has two energy sources—the sun and Earth's interior.
2. The parts of the Earth system are linked so a change in one part can cause changes in all the other parts.

2 INSTRUCT

What Is a System?

Build Science Skills L2

Using Analogies The text gives an analogy of a car's cooling system to a natural system. Challenge students to think of other analogies between human-made and natural systems. They should write a description of the analogy they choose, including diagrams if appropriate. The descriptions should explain how the analogies are similar to the actual process and different from it.
Verbal, Logical

1.4 Earth System Science

Reading Focus

Key Concepts

- How is Earth a system?
- What is a system?
- Where does the energy come from that powers Earth's systems?
- How do humans affect Earth's systems?
- What makes a resource renewable or nonrenewable?

Vocabulary

- system

Reading Strategy

Outlining As you read, make an outline of the most important ideas in this section. Begin with the section title, then list the green headings as the next step of the outline. Outline further as needed.

I. Earth System Science
  A. What is a System?
    1. ___?___
    2. ___?___
  B. ___?___

As we study Earth, we see that it is a dynamic planet with many separate but interactive parts or spheres. Earth scientists are studying how these spheres are interconnected. **This way of looking at Earth is called Earth system science. Its aim is to understand Earth as a system made up of numerous interacting parts, or subsystems.** Instead of studying only one branch of science, such as geology, chemistry, or biology, Earth system science tries to put together what we know from our study of all of these branches. Using this type of approach, we hope to eventually understand and solve many of our global environmental problems.

Reading Checkpoint *What Is Earth system science?*

What Is a System?

Most of us hear and use the term system frequently. You might use your city's transportation system to get to school. A news report might inform us of an approaching weather system. We know that Earth is just a small part of the much larger solar system.

A system can be any size group of interacting parts that form a complex whole. Most natural systems are driven by sources of energy that move matter and/or energy from one place to another. A simple analogy is a car's cooling system. It contains a liquid (usually water and antifreeze) that is driven from the engine to the radiator and back again. The role of this system is to transfer the heat generated by combustion in the engine to the radiator, where moving air removes the heat from the system.

This kind of system is called a closed system. Here energy moves freely in and out of the system, but no matter enters or leaves the system. In the case of the car's cooling system, the matter is the liquid. By contrast, most natural systems are open systems. Here both energy and matter flow into and out of the system. In a river system, for example, the amount of water flowing in the channel can vary a great deal. At one time or place, the river may be fuller than it is at another time or place.

Earth as a System

The Earth system is powered by energy from two sources. **One source is the sun, which drives external processes that occur in the atmosphere, hydrosphere, and at Earth's surface.** Weather and climate, ocean circulation, and erosional processes are driven by energy from the sun. **Earth's interior is the second source of energy.** There is heat that remains from the time Earth formed. There is also heat continuously generated by the decay of radioactive elements. These sources power the internal processes that produce volcanoes, earthquakes, and mountains.

The parts of the Earth system are linked so that a change in one part can produce changes in any or all of the other parts. For example, when a volcano erupts, lava may flow out at the surface and block a nearby valley. This new obstruction influences the region's drainage system by creating a lake or causing streams to change course. Volcanic ash and gases that can be discharged during an eruption might be blown high into the atmosphere and influence the amount of solar energy that can reach Earth's surface. The result could be a drop in air temperatures over the entire hemisphere.

Figure 18 When Mount St. Helens erupted in May 1980, the area shown here was buried by a volcanic mudflow. Now, plants are reestablished and new soil is forming.

Reading Checkpoint *How do we know that Earth's systems are connected?*

Over time, soil will develop on the lava or ash-covered surface and, as shown in Figure 18, plants and animals will reestablish themselves. This soil will reflect the interactions among many parts of the Earth system—the original volcanic material, the type and rate of weathering, and the impact of biological activity. Of course, there would also

Build Reading Literacy L1

Refer to **p. 216D** in **Chapter 8,** which provides guidelines for comparing and contrasting.

Compare and Contrast Help students understand the difference between an open system and a closed system. Have students make a comparison chart, starting with the definition of each type of system. Have students classify each system listed during the brainstorming session as either an open system or a closed system. Example:

	Open System	Closed System
Definition	Energy and matter move in and out of the system.	Energy moves in and out of the system, but matter cannot enter or leave.
Examples	weather system river system	cooling system

Have students research a list of systems. Then have students put each system in the correct column on their comparison chart.
Verbal, Logical

Earth as a System

Build Science Skills L2

Relating Cause and Effect Using this section of the textbook, have students make a concept map showing how a volcanic eruption (an event of the geosphere) can causes changes in all the other spheres (hydrosphere, atmosphere, and biosphere). Have students use the concept map to make a poster to be displayed in the classroom. Challenge students to create a product that is both visually appealing and scientifically accurate. Ask students to think of another event on Earth and predict how it would affect all the other spheres. Have students make another concept map poster on this event.
Visual, Group

Customize for English Language Learners

Review with English language learners the meanings of the words *open* and *closed.* Help students relate the meanings of *open* and *closed* to *open system* and *closed system.* Before teaching the terms *renewable resources* and *nonrenewable resources,* explain what it means to renew a library book (take it out again before you return it). Help students relate this use of the word *renew* to the terms *renewable resources* and *nonrenewable resources.* Tell students that if they are not allowed to renew a library book (nonrenewable) it is often because the library does not have enough books on that topic to meet the needs of their patrons. Explain that a renewable resource can be used as often as we like because there is always more of it being made.

Answer to . . .

Reading Checkpoint *Earth system science is a way of looking at Earth as a system made up of several interacting subsystems.*

Reading Checkpoint *Events taking place in one part can produce changes in all the other parts.*

Address Misconceptions L2

Students may think that only human actions can seriously affect the environment. Use the example of the eruption of Mount St. Helens to emphasize that natural events can have widespread and negative effects on the environment. The 1980 eruptions spread ash over much of eastern Washington. About 500 square kilometers of forest were destroyed or damaged. Most large animals in the area were killed by the blast, but some small animals survived. More than 20 years later, the area is still fairly barren. It may take at least 200 years for the forest to be restored to its previous state. Large mammals such as elk have already repopulated the area, along with birds, insects, and small mammals.

People and the Environment

Use Visuals L1

Figure 19 This flood was caused by the action of humans. Ask: **What was the actual cause of this flood?** *(building the Aswan Dam)* **What are some ways humans can cause floods or make them worse?** *(by clearing forests, building cities, and constructing dams)* **Visual, Logical**

be significant changes in the biosphere. Some organisms and their habitats would be eliminated by the lava and ash, while new settings for life, such as the lake, would be created. The potential climate change could also have an effect on some life-forms.

The Earth system is characterized by processes that occur over areas that range in size from millimeters to thousands of kilometers. Time scales for Earth's processes range from milliseconds to billions of years. Despite this great range in distance and time, many processes are connected. A change in one component can influence the entire system.

Humans are also part of the Earth system. **Our actions produce changes in all of the other parts of the Earth system.** When we burn gasoline and coal, build breakwaters along a shoreline, dispose of our wastes, and clear the land, we cause other parts of the Earth system to respond, often in unforeseen ways. Throughout this book, you will learn about many of Earth's subsystems, such as the hydrologic (water) system, the tectonic (mountain-building) system, and the climate system. Remember that these components and we humans are all part of the complex interacting whole we call the Earth system.

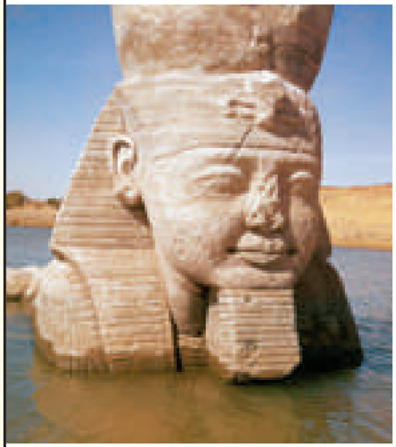


Figure 19 The benefit that was intended by the construction of the Aswan Dam in Egypt was not achieved.
Drawing Conclusions ***How might the flooding here have been avoided?***

People and the Environment

Environment refers to everything that surrounds and influences an organism. Some of these things are biological and social. Others are nonliving such as water, air, soil and rock as well as conditions such as temperature, humidity, and sunlight. These nonliving factors make up our physical environment. Because studying the Earth sciences leads to an understanding of the physical environment, most of Earth science can be characterized as environmental science.

Reading Checkpoint ***What are examples of nonliving factors?***

Today the term *environmental science* is usually used for things that focus on the relationships between people and the natural environment. For example, we can dramatically influence natural processes. A river flooding is natural, but the size and frequency of flooding can be changed by human activities such as clearing forests, building cities, and constructing dams. Unfortunately, natural systems do not always adjust to artificial changes in ways we can anticipate. An alteration to the environment that was intended to benefit society may have the opposite effect, as shown in Figure 19.

Resources Resources are an important focus of the Earth sciences. They include water and soil, metallic and nonmetallic minerals, and energy. Together they form the foundation of modern civilization. The Earth sciences deal not only with the formation and occurrence of

Facts and Figures

One of the reasons it is often difficult to predict how natural systems will respond to unexpected changes is the prevalence of positive and negative feedback mechanisms. Processes that feed into changes, making them more severe, are considered positive feedback. As humans put more carbon dioxide into the air, Earth may hold more of the sun's heat and begin to warm. This warming may cause snow and ice near the poles to melt. This melting may make Earth absorb more of the sun's rays, thus increasing Earth's temperature further. This is an example of positive feedback. Negative feedback mechanisms work to return the system to the way it was before the change. For example, an increase in Earth's temperature may result in an increase in evaporation, and then an increase in clouds. Clouds cause Earth to reflect more of the sun's rays back into space, cooling Earth back down.

these vital resources but also with maintaining supplies and the environmental impact of their mining and use.

Resources are commonly divided into two broad categories—renewable resources and nonrenewable resources. **Renewable resources can be replenished over relatively short time spans.** Common examples are plants and animals for food, natural fibers for clothing, and forest products for lumber and paper. Energy from flowing water, wind, and the sun are also considered renewable resources.

Important metals such as iron, aluminum, and copper plus our most important fuels of oil, natural gas, and coal are classified as nonrenewable resources. **Although these and other resources continue to form, the processes that create them are so slow that it takes millions of years for significant deposits to accumulate.** Earth contains limited quantities of these materials. Although some nonrenewable resources, such as aluminum, can be used over and over again, others, such as oil, cannot. When the present supplies are exhausted, there will be no more.

Reading Checkpoint *How do renewable and nonrenewable resources differ?*

Go Online SCiLINKS NSTA

For: Links on environmental decision-making
Visit: www.SciLinks.org
Web Code: cjn-1014

Population Figure 20 shows that the population of Earth is growing rapidly. Although it took until the beginning of the nineteenth century for the population to reach 1 billion, just 130 years were needed for the population to double to 2 billion. Between 1930 and 1975, the figure doubled again to 4 billion, and by about 2010, as many as 7 billion people may inhabit Earth. Clearly, as population grows, so does the demand for resources. However, the rate of mineral and energy resource usage has increased more rapidly than the overall growth of the population.

How long will the remaining supplies of basic resources last? How long can we sustain the rising standard of living in today's industrialized countries and still provide for the growing needs of developing regions? How much environmental deterioration are we willing to accept to obtain basic resources? Can alternatives be found? If we are to cope with the increasing demand on resources and a growing world population, it is important that we have some understanding of our present and potential resources.

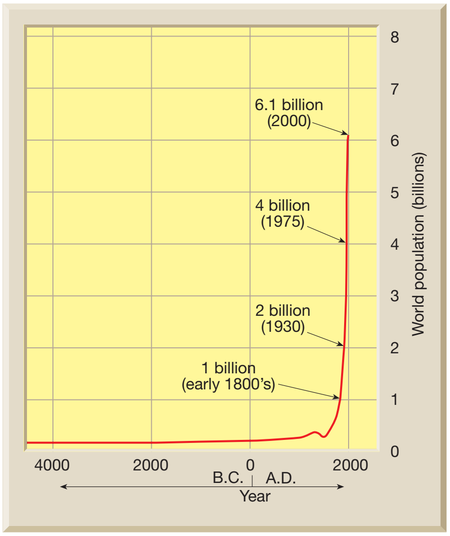


Figure 20 Growth of World Population

Environmental Problems

In addition to the search for mineral and energy resources, the Earth sciences must also deal with environmental problems. Some of these problems are local, some are regional, and still others are global. Humans can cause problems, such as the one shown in Figure 21. **Significant**

Build Science Skills L2

Problem Solving Explain that when supplies of a nonrenewable resource start running low, it is often possible to substitute some other resource. Have students work in small groups to brainstorm and research alternatives to oil that can be used when all of our oil has been used up. If students are having trouble getting started, suggest that they focus on transportation and power generation. Areas students can investigate include natural gas, coal, biodiesel, nuclear power, wind power, and solar power. Have each group present their results to the class.
Interpersonal, Logical

Address Misconceptions L2

Students may think that the world population is expected to continue to increase indefinitely. Tell students that many demographers (scientists who study changes in human populations) expect population growth to slow down over the next 100 years. In fact, some predict that the total population may even decrease. The reason for this is that in many developed countries, people are not having enough children to replace themselves. Most current population growth is occurring in developing countries. However, as those countries develop, their birth rates are also expected to fall.

Go Online NSTA SCiLINKS

Download a worksheet on environmental decision-making for students to complete, and find additional teacher support from NSTA SciLinks.

Answer to . . .

Figure 19 *The flooding could have been avoided by not building the dam.*

Reading Checkpoint *Nonliving factors include water, air, soil, rock, temperature, humidity, and sunlight.*

Reading Checkpoint *Renewable resources can be replenished over a relatively short time span. Nonrenewable resources take millions of years to accumulate.*

Section 1.4 (continued)

Environmental Problems

Build Science Skills L2

Inferring Discuss with students that events such as earthquakes, landslides, floods, hurricanes, beach erosion from coastal storms, and drought are natural processes. Help students understand that these natural processes become hazards "only when people try to live where these processes occur." Provide small groups of students with one or more pictures of damage from natural disasters. Some examples to use would be flooded homes, a coastal home about to be carried out to sea, buildings damaged by an earthquake, or urban flooding due to too much paved land. Ask: **What happened here? How could this disaster have been prevented?** *(Sample answer: This home is being carried out to sea because it was built too close to the ocean. These homes were flooded because they were built on a flood plain. This building was destroyed because it was built too close to a fault line.)* Have students infer the answers to these two questions, and then share their ideas with the class. Use this as an opportunity to introduce students to various Earth events and processes that will be studied later in the year.
Visual

3 ASSESS

Evaluate Understanding L2

Ask students to write a five-question quiz on this section along with an answer key. Then have students ask one another the questions.

Reteach L1

Use the outlines students created for this chapter's reading strategy to review the main ideas from this section.

Connecting Concepts

Images can show scars of landslides, suggesting that the area may not be stable.

Answer to . . .

Figure 21 *Sample answer: home heating, motor vehicles, industry, power plants*

Figure 21 Air pollution in the Chinese city of Guangzhou. Air quality problems affect many cities. **Interpreting Photographs** ***What may have contributed to this air pollution problem?***

threats to the environment include air pollution, acid rain, ozone depletion, and global warming. The loss of fertile soils to erosion, the disposal of toxic wastes, and the contamination and depletion of water resources are also of considerable concern. The list continues to grow.

People must cope with the many natural hazards that exist such as the one shown in Figure 22. Earthquakes, landslides, floods, hurricanes, and drought are some of the many risks. Of course, environmental hazards are simply natural processes. They become hazards only when people try to live where these processes occur.

It is clear that as world population continues to grow, pressures on the environment will increase as well. Therefore, an understanding of Earth is essential for the location and recovery of basic resources. It is also essential for dealing with the human impact on the environment and minimizing the effects of natural hazards. Knowledge about Earth and how it works is necessary to our survival and well being. Earth is the only suitable habitat we have, and its resources are limited.

Figure 22 The damage here was caused by a landslide that was triggered by an earthquake.

Section 1.4 Assessment

Reviewing Concepts

1. Why do scientists study Earth as a system?
2. If a system is a collection of interacting parts, what happens when one of the parts is changed?
3. What are the two sources of energy that power Earth's systems?
4. List three ways that humans affect Earth's systems.
5. Large numbers of tiny ocean organisms die every day, fall to the ocean floor, are buried, and are eventually converted to oil and natural gas. Why are these two fuels considered nonrenewable?

Critical Thinking

6. **Applying Concepts** Describe the parts of a tree in terms of it being a system.
7. **Evaluating** Is it possible for humans to have no effect on any of Earth's systems? Explain.
8. **Applying Concepts** How can scientists help to prevent a natural process from becoming an environmental hazard?

Connecting Concepts

City Planning In Section 1.3, you learned about Landsat satellite imaging. How can data from Landsat help city planners determine where and where not to build?

Section 1.4 Assessment

1. Earth is a system made up of numerous interacting parts, or subsystems.
2. Other parts may also change.
3. The sources are the sun and reactions in Earth's interior.
4. Sample answer: contaminating water, polluting air, disposing of toxic waste
5. It takes too long (millions of years) for the organisms to be converted into oil.
6. Roots transport food and water up through the trunk, which holds the tree upright. The trunk transports food and serves as support for branches and leaves. Leaves help keep the tree moist and shaded and release excess water through pores.
7. No, every day you affect at least one of Earth's systems, even on the smallest scale. Simply breathing changes the atmosphere around you or stepping on the grass may affect the biosphere beneath your foot.
8. Sample answer: They can analyze an area to see if it is safe to live there. If the land is unstable or subject to flooding, they may make recommendations that people not choose to live there.

1.5 What Is Scientific Inquiry?

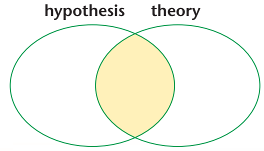
Reading Focus

Key Concepts
- What is a hypothesis?
- What is a theory?

Vocabulary
- hypothesis
- theory

Reading Strategy

Comparing and Contrasting Complete the Venn diagram by listing the ways hypothesis and theory are alike and how they differ.



All science is based on two assumptions. First, the natural world behaves in a consistent and predictable manner. Second, through careful, systematic study, we can understand and explain the natural world's behavior. We can use this knowledge to make predictions about what should or should not be expected. For example, by knowing how oil deposits form, geologists are able to predict the most likely sites for exploration.

The development of new scientific knowledge involves some basic steps. First, scientists collect data through observation and measurement. These data are essential to science and serve as the starting point for the development of scientific theories.

Hypothesis

Once data have been gathered, scientists try to explain how or why things happen in the manner observed. Scientists do this by stating a possible explanation called a scientific hypothesis. Sometimes more than one hypothesis is developed to explain a given set of observations. Just because a hypothesis is stated doesn't mean that it is correct or that the scientific community will automatically accept it.

Before a hypothesis can become an accepted part of scientific knowledge, it must be tested and analyzed. If a hypothesis can't be tested, it is not scientifically useful, no matter how interesting it might seem. Hypotheses that fail rigorous testing are discarded. The history of science is filled with discarded hypotheses. One of the best known is the Earth-centered model of the universe. This hypothesis was based on the apparent movement of the sun, moon, and stars around Earth.

Go Online SCI LINKS NSTA

For: Links on scientific methods
Visit: www.SciLinks.org
Web Code: cjn-1015

Section 1.5

1 FOCUS

Section Objectives

1.13 **Define** the terms *hypothesis* and *theory*.

Reading Focus

Build Vocabulary L2

Word Meanings Before they read the section, have students write down definitions for *hypothesis* and *theory*. As they read the section, have them note the scientific definitions of these terms and compare them to their definitions.

Reading Strategy L2

Hypothesis: an idea someone wants to test; Theory: an explanation that is supported by evidence and widely accepted; Similarities: could be proven wrong, can be tested

2 INSTRUCT

Hypothesis

Build Reading Literacy L1

Refer to **p. 446D** in **Chapter 16**, which provides guidelines for sequencing.

Sequence Tell students to create a flowchart showing the steps toward the development of a scientific theory. They should begin the flowchart as they are reading the introduction to this section and should end it at Scientific Methods. *(Sample response: Collect data → Develop hypotheses or models → Test hypothesis (experiment) → Accept, modify, or reject hypothesis → If well tested, the hypothesis becomes a theory.)* Have students check their flowchart against the sequence of steps provided in the Scientific Methods section of the text.
Visual, Verbal

Go Online NSTA SCI LINKS

Download a worksheet on scientific methods for students to complete, and find additional teacher support from NSTA SciLinks.

Section 1.5 (continued)

Theory

Address Misconceptions L2

Students often think that a scientific theory is an ultimate truth, and therefore can never be changed. This is not true. A theory is only accepted if a multitude of tests support the theory. However, if even one scientist finds a situation where the theory fails, that theory is again called into question and must be revised or replaced. For this reason, science is constantly changing. One example is medicines or supplements that have been promoted and used for years suddenly being pulled off the shelves after the discovery of unexpected and dangerous side effects.
Verbal

Scientific Methods

Integrate Language Arts L2

Representing Definitions There are many definitions for the word *model*. Have students use a dictionary to write down as many definitions of the word as possible. Then have them draw or cut out pictures representing these definitions. Help students determine which definition is most appropriate in this section.
Visual, Verbal

3 ASSESS

Evaluate Understanding L2

Give students the steps of the scientific method in random order, and have them put the steps in the correct order.

Reteach L1

Have students illustrate each step of the scientific method on the flowchart they created earlier. Help students understand that scientists regularly go back a few steps in the method as they attempt to arrive at a theory.
Visual

Writing in Science

Many scientists repeated the same observations and recorded similar results. These observations were made in many places around the world, yet all had the same basic principles. Advise students that they can find out more about the theory of plate tectonics in Chapter 9.

As the mathematician Jacob Bronowski stated, "Science is a great many things, but in the end they all return to this: Science is the acceptance of what works and the rejection of what does not."

Theory

When a hypothesis has survived extensive testing and when competing hypotheses have been eliminated, a hypothesis may become a scientific **theory.** **A scientific theory is well tested and widely accepted by the scientific community and best explains certain observable facts.** For example, the theory of plate tectonics provides the framework for understanding the origin of continents and ocean basins, plus the occurrence of mountains, earthquakes, and volcanoes.

Scientific Methods

The process of gathering facts through observations and formulating scientific hypotheses and theories is called the scientific method. There is no set path that scientists must follow in order to gain scientific knowledge. However, many scientific investigations involve the following steps: (1) the collection of scientific facts through observation and measurement, (2) the development of one or more working hypotheses or models to explain these facts, (3) development of observations and experiments to test the hypotheses, and (4) the acceptance, modification, or rejection of the hypothesis based on extensive testing.

Section 1.5 Assessment

Reviewing Concepts

1. You have just come up with an explanation to a question that has bothered you for some time. What must you do to have your explanation become a hypothesis?
2. Explain how a hypothesis can become a theory.
3. According to the scientific community, how does the natural world behave?
4. What happens if more than one hypothesis is put forward to explain the same observations?
5. When is a model useful in scientific investigations?

Thinking Critically

6. **Applying Concepts** Why do most scientists follow a set order of steps when carrying out a scientific investigation?
7. **Designing Experiments** While carrying out an investigation, a scientist observes some unexpected results. What are the scientist's next steps?
8. **Understanding Concepts** Why is it necessary to use careful and systematic methods when carrying out scientific investigations?

Writing in Science

Explanatory Paragraph It took a long time for the scientific community to accept the theory of plate tectonics. Write a paragraph suggesting how the use of proper scientific methods helped the theory gain acceptance.

Section 1.5 Assessment

1. Test and analyze the hypothesis.
2. A hypothesis can become a theory once it has survived extensive testing and when competing hypotheses have been eliminated.
3. in a consistent and predictable manner
4. They are all tested and analyzed.
5. A model can be used at any point in the process such as testing a hypothesis or explaining a theory.
6. If an orderly set of steps is followed, the observations and results are more reliable. The experiment can be conducted again using the same procedure.
7. Sample answer: The scientist should record his or her observations and any numerical results that can be recorded. The scientist should continue carrying out the experiment and reanalyze the hypothesis to see if it can be adjusted to accommodate the new results.
8. To be accepted by the scientific community, all experiments must be able to be conducted repeatedly with the same results obtained and with a minimal amount of error. By using systematic methods, this can be done.

understanding EARTH

Studying Earth From Space

Scientific facts are gathered in many ways, such as laboratory studies, field observations, and field measurements. Satellite images like the one in Figure 23 are another useful source of data. Such images provide perspectives that are difficult to get from more traditional sources. The high-tech instruments aboard many satellites enable scientists to gather information from remote regions where data are otherwise scarce.

The image in Figure 23 makes use of the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER). Because different materials reflect and give off energy in different ways, ASTER can provide detailed information about the composition of Earth's surface. Figure 23 is a three-dimensional view looking north over Death Valley, California. The data have been computer enhanced to exaggerate the color variations that highlight differences in types of surface materials.

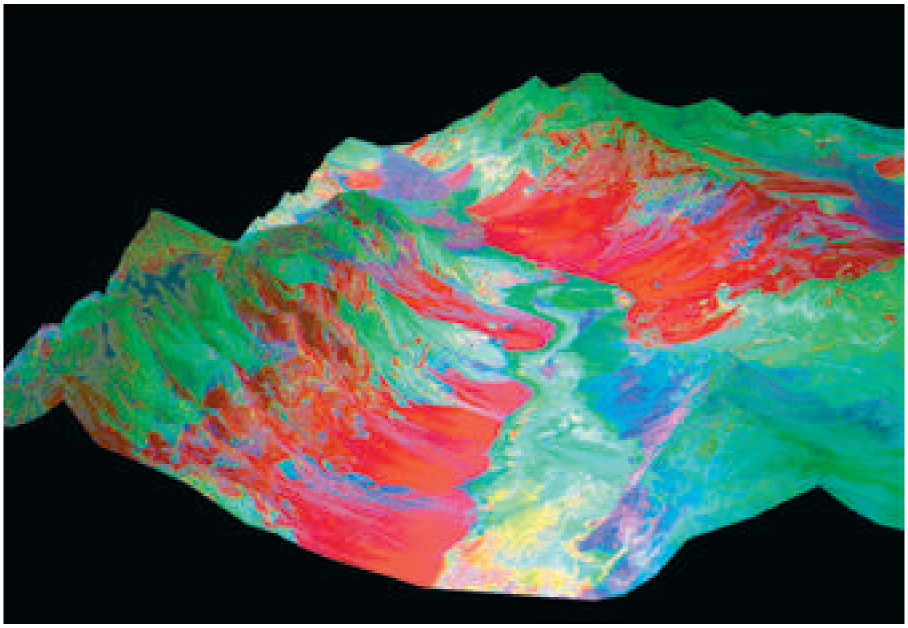


Figure 23 This satellite shows detailed information about the composition of surface materials in Death Valley, California. It was produced by superimposing nighttime thermal infrared data, acquired on April 7, 2000, over topographic data from the U.S. Geological survey. (Image courtesy of NASA)

Salt deposits on the floor of Death Valley appear in shades of yellow, green, purple, and pink. These indicate the presence of carbonate, sulfate, and chloride minerals. The Panamint Mountains to the west and the Black Mountains to the east are made up of sedimentary limestones, sandstones, shales, and metamorphic rocks. The bright red areas are dominated by the mineral quartz, found in sandstone; the green areas are limestone. In the lower center of the image is Badwater, the lowest point in North America.

understanding EARTH

Studying Earth From Space

L2

Background ASTER is an imaging instrument that obtains detailed maps of land surface temperature. It flies on a satellite called Terra, which was launched in 1999. ASTER is part of NASA's Earth Observing System (EOS), which is a series of satellites, a science component, and a data system. EOS will help scientists develop a deeper understanding of Earth as an integrated system—the interactions among the biosphere, hydrosphere, lithosphere, and atmosphere.

Teaching Tips

- As students read the feature and look at Figure 23, have them identify on the image the various regions described in the text.
- Explain to students that this image does not show the true colors of Death Valley as seen from space. Instead, the colors were inserted by scientists to indicate differences in surface composition. Ask: **What do you think this image would look like in true color?** *(Since Death Valley is a desert, it would be mostly tan in color.)* **Based on the information given on what the colors indicate, what is the composition of the most distant mountains in the image?** *(mostly limestone, with some sandstone and a little bit of salt)*
- Have students research ASTER and EOS on NASA's web site and prepare a report to the class.

Visual, Logical

Section 2.1

1 FOCUS

Section Objectives

2.1 **Explain** how elements are related to minerals.
2.2 **Identify** the kinds of particles that make up atoms.
2.3 **Explain** the differences between ions and isotopes.
2.4 **Explain** what compounds are and **describe** why they form.
2.5 **Compare and contrast** the three major types of chemical bonds.

Reading Focus

Build Vocabulary L2

Concept Map Have students construct a concept map using the terms *chemical bond*, *ionic bond*, *covalent bond*, and *metallic bond*. The main concept (*chemical bond*) should be at the top. Tell students to place the terms in ovals and list the characteristics of each type of bond underneath the oval. For each type of bond, students should include some examples and their properties.

Reading Strategy L2

Differences: Electron is much less massive than proton and neutron; electron is negatively charged, proton is positively charged, neutron is not charged.
Similarities: All are subatomic particles.

2 INSTRUCT

Elements and the Periodic Table

Build Reading Literacy L1

Refer to **p. 392D** in **Chapter 14**, which provides guidelines for this strategy.

Preview Have students preview the section (pp. 34–43), focusing their attention on headings, visuals, and boldfaced material. Ask: **Based on your preview, which figure in the section do you think contains the most information?** *(Figure 1 on pp. 36–37)* **Based on your preview, name three classes of elements.** *(metals, nonmetals, and metalloids)*
Visual, Verbal

2.1 Matter

Reading Focus

Key Concepts

- What is an element?
- What particles make up atoms?
- What are isotopes?
- What are compounds and why do they form?
- How do chemical bonds differ?

Vocabulary

- element
- atomic number
- energy level
- isotope
- mass number
- compound
- chemical bond
- ion
- ionic bond
- covalent bond
- metallic bond

Reading Strategy

Comparing and Contrasting Copy the graphic organizer. As you read, complete the organizer to compare and contrast protons, neutrons, and electrons.

Protons	Electrons	Neutrons
Differences		
Similarities		

You and everything else in the universe are made of matter. Matter is anything that has volume and mass. On Earth, matter usually exists in one of three states—solid, liquid, or gas. A solid is a type of matter that has a definite shape and a definite volume. Rocks and minerals are solids. A liquid is matter that has a definite volume, but not a definite shape. Earth's oceans, rivers, and lakes are liquids. A gas is matter that has neither a definite shape nor a definite volume. Most of Earth's atmosphere is composed of the gases nitrogen and oxygen. Though matter can be classified by its physical state: solid, liquid, or gas, it is more useful to look at its chemical composition and structure. Each of Earth's nearly 4000 minerals is a unique substance. The building blocks of minerals are **elements.**

Elements and the Periodic Table

The names of many elements are probably very familiar to you. Many common metals are elements, such as copper, iron, silver, and gold. **An element is a substance that cannot be broken down into simpler substances by chemical or physical means.** There are more than 112 known elements, and new elements continue to be discovered. Of these, 92 occur naturally, the others are produced in laboratories.

The elements have been organized by their properties in a document called the periodic table, which is shown in Figure 1 on pages 36 and 37. You see from the table that the name of each element is represented by a symbol consisting of one, two, or three letters. Symbols provide a shorthand way of representing an element. Each element is

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also known by its atomic number, which is shown above each symbol on the table. Look at the block for sulfur, element 16, and gold, element 79. Sulfur and gold are minerals made of one element. Most elements are not stable enough to exist in pure form in nature. Thus, most minerals are combinations of elements.

The rows in the periodic table are called periods. The number of elements in a period varies. Period 1, for example, contains only two elements. These elements are hydrogen (H) and helium (He). Period 2 contains the elements lithium (Li) through neon (Ne). Periods 4 and 5 each contain 18 elements while Period 6 includes 32 elements.

The columns in the periodic table are called groups. Note that there are 18 groups in the periodic table shown on pages 36 and 37. Elements within a group have similar properties.

Of the known elements, only eight make up most of Earth's continental crust. These eight elements are listed in Table 1. Notice that six of the eight elements in Table 1 are classified as metals. Metals have specific properties such as the ability to be shaped and drawn into wire. Metals are also good conductors of heat and electricity. They combine in thousands of ways to form compounds, the building blocks of most Earth materials. To understand how elements form compounds we need to review their building blocks which are atoms.

Table 1 Relative Abundance of the Most Common Elements in Earth's Continental Crust

Element	Approximate Percentage by Weight
Oxygen (O)	46.6
Silicon (Si)	27.7
Aluminum (Al)	8.1
Iron (Fe)	5.0
Calcium (Ca)	3.6
Sodium (Na)	2.8
Potassium (K)	2.6
Magnesium (Mg)	2.1
All others	1.7

Source: Data from Brian Mason.

Atoms

As you might already know, all elements are made of atoms. **An atom is the smallest particle of matter that contains the characteristics of an element.**

The central region of an atom is called the nucleus. The nucleus contains protons and neutrons. Protons are dense particles with positive electrical charges. Neutrons are equally dense particles that have no electrical charge. Electrons, which are small particles with little mass and negative electrical charges, surround an atom's nucleus.

Protons and Neutrons

A proton has about the same mass as a neutron. Hydrogen atoms have only a single proton in their nuclei. Other atoms contain more than 100 protons. The number of protons in the nucleus of an atom is called the **atomic number.** All atoms with six protons, for example, are carbon atoms. The atomic number of carbon is 6. Likewise, every atom with eight protons is an oxygen atom. The atomic number of oxygen is 8.

Atoms have the same number of protons and electrons. Carbon atoms have six protons and therefore six electrons. Oxygen atoms have eight protons in their nuclei and have eight electrons surrounding the nucleus.

Build Math Skills L2

Using Tables and Graphs Have students convert Table 1 into a circle graph. Ask: **Why would a circle graph be a good alternative way to show the information in Table 1?** *(A circle graph shows the parts that make up a whole, just as the elements listed in the table make up a whole—100 percent of the elements in the continental crust.)* Suggest that students first estimate the size of each wedge of the circle graph and draw the graph accordingly. Then have them precisely draw the graph by first multiplying each percent by 360° to find the central angle of each wedge. They can then use a protractor to draw each central angle on a circle. Students can compare their estimates with their precise graphs. Some students may wish to create their graphs using software. Ask: **What advantage does a circle graph have over a table of percentages?** *(The sizes of the wedges of the graph often make it easier to compare different quantities.)*
Visual, Logical

Atoms

Integrate Biology L2

Cell Nucleus Students may know that most cells in living organisms also have a structure called a nucleus. Inform students that the cell's nucleus contains the cell's genetic, or hereditary, material. Ask: **How are an atom's nucleus and a cell's nucleus similar?** *(They are both central structures of a basic unit.)* **How are the two nuclei different?** *(The cell nucleus controls the activities of the cell. The atomic nucleus does not have a similar function.)*
Logical

Address Misconceptions L2

Although the text says that all matter is made of atoms, this is not strictly true everywhere in the universe. For example, the solar wind produced by the sun consists of a stream of protons and electrons. Also, in a neutron star, enormous pressure forces electrons and protons in the atoms in a star to combine with each other, leaving only a very dense ball of neutrons.
Logical

Customize for English Language Learners

To help students understand the idea of energy levels, have them work in pairs to think of everyday situations that involve different levels. Examples might include dresser drawers, shelves in a bookshelf, and bleachers ins a gym. Ask students how these analogies are different from energy levels in atoms. *(Energy levels are not physical objects and are not evenly spaced.)* If you have a bookshelf in the class, have students place marbles on different levels to represent electrons.

Use Visuals L1

Figure 1 Use this figure to discuss how information is shown on a periodic table. Ask: **What are the boldfaced single or double letters, such as *H* and *Li*?** *(symbols for each element)* **What is the number above each symbol?** *(the element's atomic number)* **What is the number below each symbol?** *(the element's atomic mass)* **What do the colors of the boxes indicate?** *(They show whether an element is a metal, transition metal, nonmetal, noble gas, lanthanide, or actinide.)*
Visual, Logical

Build Science Skills L2

Using Tables and Graphs Use the data in Figure 1 to show the advantage of arranging elements by atomic number instead of atomic mass. Make a large graph with atomic number on the horizontal axis and atomic mass on the vertical axis for elements 1 through 20. Draw straight lines between the points. Ask: **What does the graph show about the general relationship between atomic number and atomic mass?** *(As the atomic number increases, so does the atomic mass.)* **Are there any points on the graph that do not follow the pattern?** *(Yes, the atomic mass of element 18, argon, is greater than the atomic mass of element 19, potassium.)* Point out that arranging the elements strictly by increasing atomic mass would result in some elements with unlike properties being grouped together.
Visual, Logical

Periodic Table of the Elements

Figure 1

	Nonmetals	Metals	Metalloids
Solid	C	Li	B
Liquid	Br	Hg	
Gas	H		
Not found in nature		Tc	

1 1A	2 2A	3 3B	4 4B	5 5B	6 6B	7 7B	8 8B	9 8B
1 **H** Hydrogen 1.0079								
3 **Li** Lithium 6.941	4 **Be** Beryllium 9.0122							
11 **Na** Sodium 22.990	12 **Mg** Magnesium 24.305							
19 **K** Potassium 39.098	20 **Ca** Calcium 40.08	21 **Sc** Scandium 44.956	22 **Ti** Titanium 47.90	23 **V** Vanadium 50.941	24 **Cr** Chromium 51.996	25 **Mn** Manganese 54.938	26 **Fe** Iron 55.847	27 **Co** Cobalt 58.933
37 **Rb** Rubidium 85.468	38 **Sr** Strontium 87.62	39 **Y** Yttrium 88.906	40 **Zr** Zirconium 91.22	41 **Nb** Niobium 92.906	42 **Mo** Molybdenum 95.94	43 **Tc** Technetium (98)	44 **Ru** Ruthenium 101.07	45 **Rh** Rhodium 102.91
55 **Cs** Cesium 132.91	56 **Ba** Barium 137.33	71 **Lu** Lutetium 174.97	72 **Hf** Hafnium 178.49	73 **Ta** Tantalum 180.95	74 **W** Tungsten 183.85	75 **Re** Rhenium 186.21	76 **Os** Osmium 190.2	77 **Ir** Iridium 192.22
87 **Fr** Francium (223)	88 **Ra** Radium (226)	103 **Lr** Lawrencium (262)	104 **Rf** Rutherfordium (261)	105 **Db** Dubnium (262)	106 **Sg** Seaborgium (263)	107 **Bh** Bohrium (264)	108 **Hs** Hassium (265)	109 **Mt** Meitnerium (268)

Lanthanide Series

57 **La** Lanthanum 138.91	58 **Ce** Cerium 140.12	59 **Pr** Praseodymium 140.91	60 **Nd** Neodymium 144.24	61 **Pm** Promethium (145)	62 **Sm** Samarium 150.4

Actinide Series

89 **Ac** Actinium (227)	90 **Th** Thorium 232.04	91 **Pa** Protactinium 231.04	92 **U** Uranium 238.03	93 **Np** Neptunium (237)	94 **Pu** Plutonium (244)

Metals—elements that are good conductors of heat and electric current

Nonmetals—elements that are poor conductors of heat and electric current

Metalloids—elements with properties that are somewhat similar to metals and nonmetals

36 *Chapter 2*

Facts and Figures

Although plutonium is classified as a synthetic element, traces of plutonium isotopes Pu-238 and Pu-239 appear at low concentrations (about one part per 1011) in pitchblende, a uranium ore. In 1971, Darlene Hoffman, a scientist at Los Alamos National Laboratory, discovered traces of Pu-244 in Precambrian rocks. Because this isotope has a half-life of about 82 million years, it probably existed when Earth formed.

Atomic number	6
Element symbol	C
Element name	Carbon
Atomic mass	12.011

10	11 1B	12 2B	13 3A	14 4A	15 5A	16 6A	17 7A	18 8A
								2 He Helium 4.0026
			5 B Boron 10.81	6 C Carbon 12.011	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998	10 Ne Neon 20.179
			13 Al Aluminum 26.982	14 Si Silicon 28.086	15 P Phosphorus 30.974	16 S Sulfur 32.06	17 Cl Chlorine 35.453	18 Ar Argon 39.948
28 Ni Nickel 58.71	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.72	32 Ge Germanium 72.59	33 As Arsenic 74.922	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.80
46 Pd Palladium 106.4	47 Ag Silver 107.87	48 Cd Cadmium 112.41	49 In Indium 114.82	50 Sn Tin 118.69	51 Sb Antimony 121.75	52 Te Tellurium 127.60	53 I Iodine 126.90	54 Xe Xenon 131.30
78 Pt Platinum 195.09	79 Au Gold 196.97	80 Hg Mercury 200.59	81 Tl Thallium 204.37	82 Pb Lead 207.2	83 Bi Bismuth 208.98	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)
110 *Uun Ununnilium (269)	111 *Uuu Unununium (272)	112 *Uub Ununbium (277)		114 *Uuq Ununquadium				

*Name not officially assigned.

63 Eu Europium 151.96	64 Gd Gadolinium 157.25	65 Tb Terbium 158.93	66 Dy Dysprosium 162.50	67 Ho Holmium 164.93	68 Er Erbium 167.26	69 Tm Thulium 168.93	70 Yb Ytterbium 173.04
95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)

Integrate Language Arts L2

Elements 110, 111, 112, and 114 have not been named yet. Scientists can propose names for new elements, but the International Union of Pure and Applied Chemistry has final approval. Until new elements receive official names, chemists refer to them by their Latin-based atomic numbers. For example, element 114 is called ununquadium, Latin for one-one-four. Increase students' familiarity with the periodic table by discussing some of the strategies used to name elements (scientists, geographic locations, mythological characters).
Verbal, Portfolio

Build Science Skills L2

Comparing and Contrasting For this activity, use a periodic table that is several years old to display or distribute to students. You might use one from an older textbook. To illustrate the dynamic nature of science, have students compare Figure 1 to the older periodic table. Ask: **What differences do you notice between the two periodic tables?** *(Depending on when the older table was printed, the number of elements may vary and some elements in Period 7 may not have assigned names. Some values for atomic mass are likely to vary.)* Make a list of responses on the board. Then ask: **How will the periodic table change in the future?** *(Unnamed elements will be assigned official names and more elements may be discovered.)*
Visual, Verbal

Section 2.1 (continued)

Use Visuals **L1**

Figure 2 Use this diagram to show a model of the atom. Explain to students that each energy level contains a certain number of electrons.
Visual

Build Math Skills **L2**

Calculating An electron has a mass of 9.11×10^{-28} g. Have students calculate a more exact ratio between the mass of a proton and the mass of an electron. If necessary, review the idea of a ratio: a dimensionless number used to compare two values. *(The mass of a proton is* 1.674×10^{-24} *g.* 1.674×10^{-24} *g/*9.11×10^{-28} *g = 1838)* The ratio is actually 1836:1. The error is due to rounding.
Logical

Build Science Skills **L2**

Using Models Have students build models of atoms similar to Figure 2 using materials found at home or in the classroom. Models do not have to be exactly to scale but should show the relationships among the particles clearly. ACTIVITY
Visual, Logical

Isotopes

Build Science Skills **L2**

Calculating Oxygen-18 has a mass number of 18 and 10 neutrons in its nucleus. Oxygen-17 has a mass number of 17 and 9 neutrons in its nucleus. Ask: **What is the atomic number of oxygen?** *(8)*
Logical

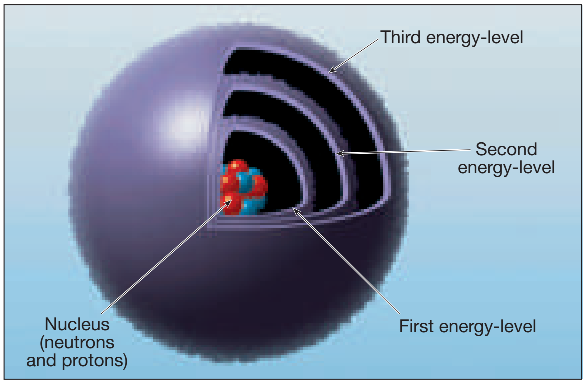


Figure 2 Model of an Atom The electrons that move about an atom's nucleus occupy distinct regions called energy levels.

Electrons An electron is the smallest of the three fundamental particles in an atom. An electron has a mass of about 1/1836 the mass of a proton or a neutron. Electrons move about the nucleus so rapidly that they create a sphere-shaped negative zone. You can picture moving electrons by imagining a cloud of negative charges surrounding the nucleus, as shown in Figure 2.

Electrons are located in regions called **energy levels.** Each energy level contains a certain number of electrons. Interactions among electrons in the outermost energy levels explains how atoms form compounds, as you will find out later in the chapter.

Reading Checkpoint *How are electrons, protons, and neutrons alike and how are they different?*

Q & A

Q *Are the minerals in this chapter the same as those in dietary supplements?*

A Not ordinarily. Most minerals found in dietary supplements are compounds made in the laboratory. These dietary minerals often contain elements that are metals, such as calcium, potassium, magnesium, and iron. From the geologist's point of view, a mineral must be a naturally occurring crystalline solid.

Isotopes

Atoms of the same element always have the same number of protons. For example, every carbon atom has 6 protons. Carbon is element number 6 on the periodic table. But the number of neutrons for atoms of the same element can vary. **Atoms with the same number of protons but different numbers of neutrons are isotopes of an element.** Isotopes of the same element are labeled using a convention called the mass number and with the element's name or symbol. The **mass number** of an atom is the total mass of the atom (protons plus neutrons) expressed in atomic mass units. The proton and the neutron each have a mass that is slightly larger than the atomic mass unit. Recall that the mass of an electron is so small that the number of electrons has no effect on the mass number of an atom.

Carbon has 15 different isotopes. Models for three of these are shown in Figure 3. Carbon-12 makes up almost 99 percent of all carbon on Earth. Carbon-12 has 6 protons and 6 neutrons. Carbon-13 makes up much of the remaining naturally occurring carbon atoms on Earth. Carbon-13 has 6 protons and 7 neutrons.Though only traces of carbon-14 are found in nature, the presence of this isotope is often used to determine the age of once-living things. Carbon-14 has 6 protons and 8 neutrons

The nuclei of most atoms are stable. However, many elements have atoms whose nuclei are unstable. Such atoms disintegrate through a process called radioactive decay. Radioactive decay occurs because the forces that hold the nucleus together are not strong enough.

Facts and Figures

Carbon-14 can be used to find the ages of some objects. Carbon-14 is formed continuously by natural processes in the atmosphere. Carbon in the atmosphere reacts with oxygen to form carbon dioxide. Plants take in carbon dioxide during photosynthesis, the process by which they use energy in sunlight to make food. Initially, the ratio of carbon-14 to carbon-12 is the same in plants as it is in the atmosphere. The same is true for an animal that eats a plant. After a plant or animal dies, though, it no longer takes in carbon. The carbon-14 gradually undergoes radioactive decay to form nitrogen-14 with a half-life of 5730 years. The age of an object containing plant or animal material can be determined by comparing the ratio of carbon-14 to carbon-12 in the object to the ratio of these isotopes in the atmosphere. If the ratio of carbon-14 to carbon-12 in the object is one-quarter the ratio of carbon-14 to carbon-12 in the atmosphere, for example, then two half-lives, or 11,460 years, have passed since the plant or animal was alive.

During radioactive decay, unstable atoms radiate energy and particles. Some of this energy powers the movements of Earth's crust and upper mantle. The rates at which unstable atoms decay are measurable. Therefore certain radioactive atoms can be used to determine the ages of fossils, rocks, and minerals.

Reading Checkpoint *What are isotopes?*

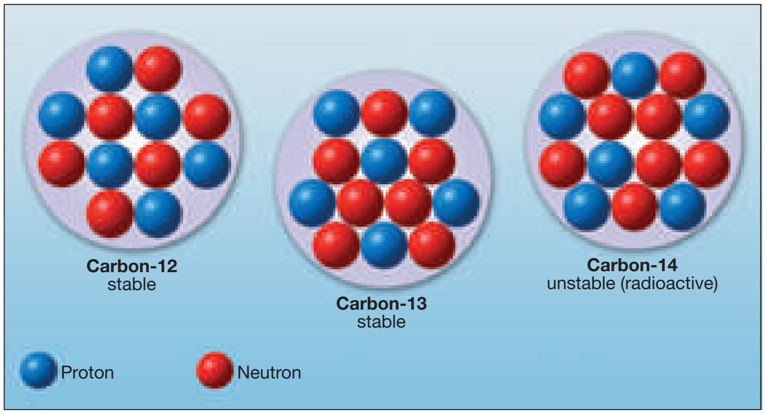


Figure 3 Nuclei of Isotopes of Carbon Carbon has many isotopes. Of these, three occur in nature. **Comparing and Contrasting** ***How are the nuclei of these isotopes the same, and how do they differ?***

Why Atoms Bond

Most elements exist combined with other elements to form substances with properties that are different from the elements themselves. Sodium is often found combined with the element chlorine as the mineral halite. Lead ore is really the mineral galena, which is the element, lead, combined with the element, sulfur. Chemical combinations of the atoms of elements are called **compounds.** **A compound is a substance that consists of two or more elements that are chemically combined in specific proportions.** Compounds form when atoms are more stable (exist at a lower energy state) in a combined form. The chemical process, called bonding, centers around the electron arrangements of atoms. Thus, when atoms combine with others to form compounds, they gain, lose, or share electrons.

Scientists have discovered that the most stable elements are found on the right side of the periodic table in Group 8A (18). These elements have a very low reactivity and exist in nature as single atoms. Scientists explain why atoms form compounds by considering how an atom undergoes changes to its electron structure to be more like atoms in Group 8A.

Teacher Demo

Isotopes and Numbers L2

Purpose Students will observe the relationships among number of protons, number of neutrons, atomic number, and mass number for different isotopes.

Materials overhead projector, red and green gummy candies

Procedure Explain that the green candies represent neutrons and the red candies represent protons. Model a carbon-12 nucleus by placing a group of 6 red candies and 6 green candies on the overhead. Ask students to count the number of candies (particles) to determine the mass number of the carbon atom *(12)*. Then ask students what the atomic number is for carbon *(6)*. Then remove a red candy (proton) and ask if the atom is still carbon *(no)*. Replace the red candy and add a green candy (neutron). Ask students if the atom is still carbon *(yes)*. Then ask: **How is this atom different from the original one?** *(The atom has a different isotope, carbon-13.)* Show students the appropriate notation to represent isotopes: element name with mass number or element symbol with mass number and atomic number.

carbon-13 or $^{13}_{6}C$

Expected Outcome Students should gain a familiarity with mass numbers, atomic numbers, and isotopes.
Visual

Answer to . . .

Figure 3 *The isotopes all have the same number of protons, and thus, the same atomic number, but each has a different number of neutrons.*

Reading Checkpoint *They all are subatomic particles that make up atoms. Protons have positive electrical charges, neutrons have no charge, and electrons have negative charges. Protons and neutrons are found in an atom's nucleus. Electrons move about the nucleus.*

Reading Checkpoint *Isotopes are atoms of the same element with the same number of protons but different numbers of neutrons.*

Minerals 39

Section 2.1 (continued)

Build Science Skills L2

Predicting Emphasize that, except for hydrogen and helium, the dots in an electron dot diagram do not represent all of the electrons in an atom, just the valence electrons.

Have students look at Figure 4. Ask them to predict the electron dot diagrams for rubidium, strontium, indium, tin, antimony, tellurium, iodine, and xenon. *(These elements—Rb, Sr, In, Sn, Sb, Te, I, and Xe—have the same valence electron configurations as the elements directly above them in the periodic table.)*
Logical, Visual

Types of Chemical Bonds

Address Misconceptions

Many students think that atoms become positively charged as a result of gaining protons. Challenge this misconception by explaining that electrons are the only subatomic particles that can be removed from or added to an atom during a chemical reaction. Remind students that protons are bound into the nuclei of atoms and cannot be removed or added during chemical reactions.
Logical

Integrate Chemistry L2

Ionic Compounds and Conduction
Why are solid ionic compounds poor conductors of electricity whereas melted ionic compounds are good conductors? Tell students that for an electric current to flow through a substance, charged particles must be able to move from one place to another. In a solid ionic crystal, the ions are fixed in a lattice. Ask: **Why can't ionic solids conduct electricity?** *(Since the ions are in fixed positions, they cannot conduct current.)* **What happens if the solid is melted?** *(The ions are freed from the lattice.)* **Why is the melted solid a good conductor of electricity?** *(The ions can move around and conduct a current.)*
Logical

Look at Figure 4. It shows the shorthand way of representing the number of electrons in the outer energy level. Recall that electrons move about the nucleus of an atom in a region called an electron cloud. Within this cloud, only a certain number of electrons can occupy each energy level. For example, a maximum of two electrons can occupy the first energy level. From Figure 4, you see that helium (He) is shown with two electrons. A maximum of eight electrons can be found in the second energy level. You also see from the figure that neon (Ne) is shown with eight electrons. **When an atom's outermost energy level does not contain the maximum number of electrons, the atom is likely to form a chemical bond with one or more other atoms. Chemical bonds** can be thought of as the forces that hold atoms together in a compound. The principal types of chemical bonds are ionic bonds, covalent bonds, or metallic bonds.

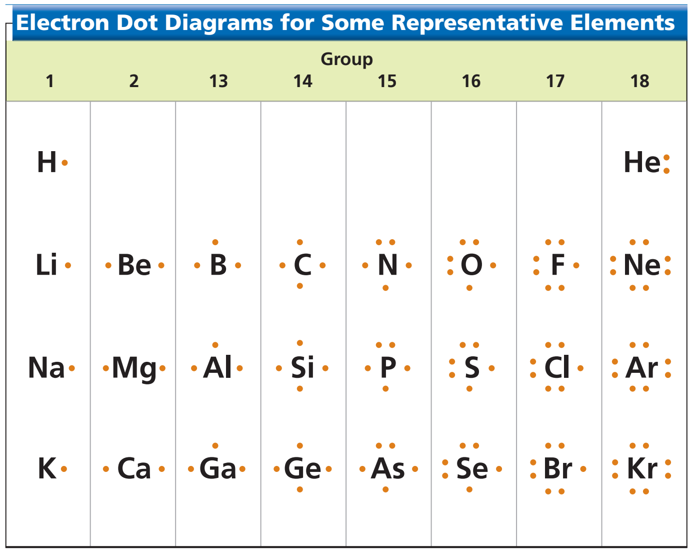


Figure 4 In an electron dot diagram, each dot represents an electron in the atom's outer energy level. These electrons are sometimes called valence electrons.
Observing ***How many electrons do sodium and chlorine have in their outer energy levels?***

Types of Chemical Bonds

Ionic Bonds An atom that gains electrons becomes negatively charged. This happens because the atom now has more electrons than protons. An atom that loses electrons becomes positively charged. This happens because the atom now has more protons than electrons. An atom that has an electrical charge because of a gain or loss of one or more electrons is called an **ion.** Oppositely charged ions attract each other to form crystalline compounds. **Ionic bonds form between positive and negative ions.**

Some common compounds on Earth have both a chemical name and a mineral name. For example, table salt has a chemical name, sodium chloride, and a mineral name, halite. Salt forms when sodium (Na) reacts with chlorine (Cl) as shown in Figure 5A. Sodium is very unstable and reactive. Sodium atoms lose one electron and become positive ions. Chlorine atoms gain one electron and become negative ions. These oppositely charged ions are attracted to each other and form the compound called sodium chloride.

The properties of a compound are different from the properties of the elements in the compound. Sodium is a soft, silvery metal that reacts vigorously with water. If you held it in your hand, sodium could burn your skin. Chlorine is a green poisonous gas. Chemically combined these atoms produce table salt, the familiar crystalline solid that is essential to health.

Reading Checkpoint *What happens when two or more atoms react?*

Formation of Sodium Chloride

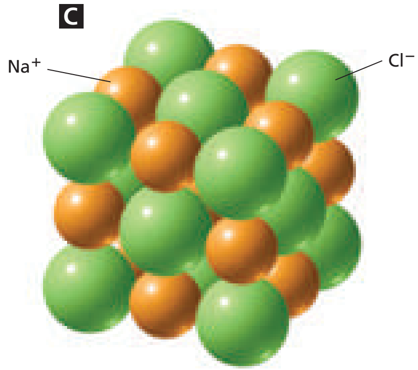
Figure 5 **A** When sodium metal comes in contact with chlorine gas, a violent reaction occurs. **B** Sodium atoms transfer one electron to the outer energy levels of chlorine atoms. Both ions now have filled outer energy levels **C** The positive and negative ions formed attract each other to form a crystalline solid with a rigid structure.

A

B

$$Na\cdot + \cdot\ddot{\underset{\cdot\cdot}{Cl}}: \rightarrow Na^{+}\ :\ddot{\underset{\cdot\cdot}{Cl}}:^{-}$$

C



Use Visuals L1

Figure 5 Use this diagram to explain how an ionic compound forms. Ask: **What happens to the sodium atom when it loses an electron?** *(It becomes a positive ion.)* **What happens to a chlorine atom when it gains an electron?** *(It becomes a negative ion.)* **What happens to the two ions?** *(They are attracted to each other and form a compound.)*
Visual, Logical

Integrate Health L2

Sodium and Chlorine in the Body Sodium chloride, or table salt, is an essential nutrient for human beings. Tell students that sodium and chlorine both help maintain the acid-base balance in the body. Sodium is also involved in maintaining the water balance of the body and in nerve function. Chlorine is needed for the formation of gastric juice for digestion of food. The average American gets about 20 times the required intake of sodium.
Logical

Answer to . . .

Figure 4 *Sodium has one electron in its outer energy level (valence electron) and chlorine has seven.*

Reading Checkpoint *Electrons are gained, lost, or shared when two or more atoms react to form a compound.*

Section 2.1 (continued)

Build Reading Literacy L1

Refer to **p. 502** in **Chapter 18,** which provides guidelines for this strategy.

Visualize Tell students that forming a mental image of concepts they are learning helps them remember new concepts. After students have read about ionic, covalent, and metallic bonds, have them visualize models for each type of bond. Then encourage students to draw diagrams that demonstrate the differences among these three types of bonds.
Visual

Teacher Demo

Comparing Bonds L2

Purpose Students observe differences in the properties of substances with different bonds.

Materials rock salt, chalk, copper wire, hammer, goggles

Procedure Take students outside to an open area. Allow them to examine the samples of rock salt, chalk, and copper wire. Have students stand back a safe distance. Put on goggles, then place each sample on a hard surface and hit it with a hammer. Invite students to observe how each sample looks after being pounded with the hammer.

Expected Outcome The rock salt and chalk shatter because they are ionic and covalent substances, respectively. The copper wire changes shape instead of shattering because metals are malleable.
Visual

Address Misconceptions L2

Many students do not differentiate among atoms, molecules, and ions in their perceptions of particles. Challenge this misconception by having students make drawings to represent an atom, a molecule, and an ion. Students should draw a single sphere for an atom, at least two spheres joined in some way for a molecule, and one sphere with either a plus or a minus sign for an ion.
Visual

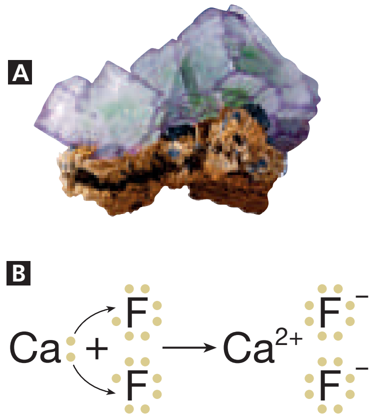


Figure 6 Ionic Compound A Fluorite is an ionic compound that forms when calcium reacts with fluorine. **B** The dots shown with the element's symbol represent the electrons in the outermost levels of the ions.
Explaining *Explain what happens to the electrons in calcium atoms and fluorine atoms when fluorite forms.*

Compounds that contain ionic bonds are called ionic compounds. Figure 6 shows calcium fluoride, a common ionic compound. Our model for ionic bonding suggests that one calcium atom transfers two electrons from its outermost energy level to two atoms of fluorine. This transfer gives all atoms the right numbers of electrons in their outer energy levels. The compound that forms is known as the mineral fluorite.

Ionic compounds are rigid solids with high melting and boiling points. These compounds are poor conductors of electricity in their solid states. When melted, however, many ionic compounds are good conductors of electricity. Most ionic compounds consist of elements from groups 1 and 2 on the periodic table reacting with elements from groups 16 and 17 of the table.

Reading Checkpoint *How do ionic bonds form, and what are some properties of ionic compounds?*

Covalent Bonds

Covalent bonds form when atoms share electrons. Compounds with covalent bonds are called covalent compounds. Figure 7 shows silicon dioxide, one of the most common covalent compounds on Earth. Silicon dioxide forms when one silicon atom and two oxygen atoms share electrons in their outermost energy levels. Silicon dioxide is also known as the mineral quartz.

The bonding in covalent compounds results in properties that differ from those of ionic compounds. Unlike ionic compounds, many covalent compounds have low melting and boiling points. For example, water, a covalent compound, boils at 100°C at standard pressure. Sodium chloride, an ionic compound, boils at 1413°C at standard pressure. Covalent compounds also are poor conductors of electricity, even when melted.

The smallest particle of a covalent compound that shows the properties of that compound is a molecule. A molecule is a neutral group of atoms joined by one or more covalent bonds. Water, for example, consists of molecules. These molecules are made of two hydrogen atoms covalently-bonded to one oxygen atom. The many gases that make up Earth's atmosphere, including hydrogen, oxygen, nitrogen, and carbon dioxide, also consist of molecules.

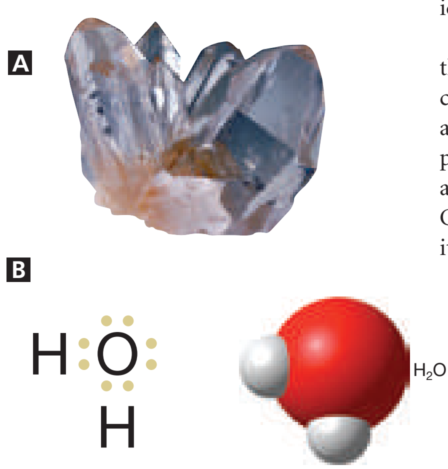


Figure 7 Covalent Compounds A Quartz is a covalent compound that forms when silicon and oxygen atoms bond. **B** Water consists of molecules formed when hydrogen and oxygen share electrons.

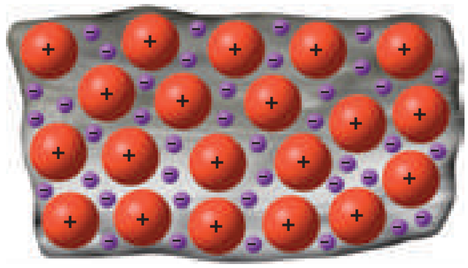
Facts and Figures

Unlike ionic and covalent compounds, metals are malleable and ductile. Instead, metal ions are held together in a "sea of electrons" referred to as the metallic bond. When a piece of metal is deformed, the ions move to new positions. The piece of metal does not break because the ions are still held attracted to the electrons.

Metallic Bonds Metals are malleable, which means that they can be easily shaped. You've observed this property when you wrapped aluminum foil around food or crushed an aluminum can. Metals are also ductile, meaning that they can be drawn into thin wires without breaking. The wiring in your school or home is probably made of the metal copper. Metals are excellent conductors of electricity.

Metallic bonds form when electrons are shared by metal ions. Figure 8 shows a model for this kind of bond. The sharing of an electron pool gives metals their characteristic properties. Using the model you can see how an electrical current is easily carried through the pool of electrons. Later in this chapter, you will learn about some metals that are classified as minerals.

A



B

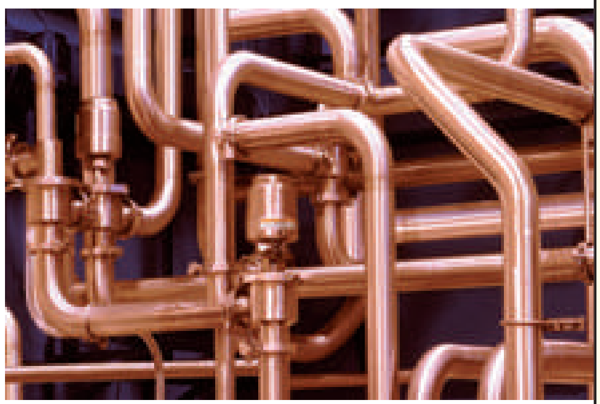


Figure 8 Metallic Bonds A Metals form bonds with one another by sharing electrons. **B** Such bonds give metals, such as this copper, their characteristic properties. Metals can be easily formed and shaped.

Section 2.1 Assessment

Reviewing Concepts

1. What is an element?
2. What kinds of particles make up atoms?
3. What are isotopes?
4. What are compounds and why do they form?
5. Contrast ionic, covalent, and metallic bonds.

Critical Thinking

6. **Comparing and Contrasting** Compare and contrast solids, liquids, and gases.
7. **Applying Concepts** What elements in Table 1 are metals?
8. **Applying Concepts** A magnesium atom needs two electrons to fill its outermost energy level. A chlorine atom needs one electron to fill its outermost shell. If magnesium reacts with chlorine, what type of bond will most likely form? Explain.
9. **Applying Concepts** Which elements in the periodic table might combine with oxygen to form compounds similar to magnesium dioxide (MgO_2)?

Math Practice

10. The isotopes of carbon have from 2 to 16 neutrons. Use this information to make a table that shows the 15 isotopes of carbon and the atomic number and mass number of each.

3 ASSESS

Evaluate Understanding L2

Have students describe why substances form ionic, covalent, and metallic bonds.

Reteach L1

Use Figures 5 and 6 to review the formation of ions and ionic bonds. Be sure students understand that the ionic bond is the electrostatic attraction between ions of opposite charge. Ionic compounds do not exist as discrete pairs of ions, but as aggregates of ions.

Math Practice

Solutions

10. The atomic number, which is the number of protons in an element, is the same for each isotope of carbon. The mass number varies from 8 (6 protons + 2 neutrons) to 24 (6 protons + 18 neutrons).

Answer to . . .

Figure 6 *Calcium transfers its two electrons to two fluorine atoms, forming two fluoride ions.*

Reading Checkpoint *Ionic bonds form when electrons are transferred from one atom to another. Ionic compounds are rigid solids with high melting and boiling points and are poor conductors of electricity in their solid states. When melted, many ionic compounds are good conductors of electricity.*

Section 2.1 Assessment

1. An element is a class of matter that contains only one type of atom. An element cannot be broken down, chemically or physically, into a simpler substance with the same properties.
2. Protons and neutrons are found in an atom's nucleus, while electrons move about this central core.
3. Isotopes are atoms of the same element that have the same number of protons but different numbers of neutrons.
4. A compound is a substance that consists of two or more elements. Compounds form as the result of changes in the arrangement of electrons in the outermost shells of the bonded atoms.
5. Ionic bonds are those that form when electrons are transferred. Covalent bonds involve the sharing of electrons. Metallic bonds exist when electrons are shared by metallic ions.
6. All are forms of matter, and thus all are made of atoms. A solid has a definite shape and definite volume. A liquid has a definite volume, but not a definite shape. A gas has neither a definite volume nor a definite shape.
7. aluminum, iron, calcium, sodium, potassium, magnesium
8. An ionic bond forms because magnesium will give up or transfer its two electrons to two chlorine ions.
9. Elements in groups 1 and 2 have similar properties to those of magnesium and often combine with oxygen to form compounds.

Section 2.2

1 FOCUS

Section Objectives

2.6 **List** five characteristics of minerals.
2.7 **Describe** the processes that result in mineral formation.
2.8 **Explain** how minerals can be classified.
2.9 **List** some of the major groups of minerals.

Reading Focus

Build Vocabulary L2

Word Parts Help students understand the meaning of the word *tetrahedron* by breaking the word down into parts. The part *tetra* comes from the Greek word for "four." The part *hedron* comes from the Greek word for "face." So a tetrahedron is a shape that has four faces.

Reading Strategy L2

Silicates: made of tetrahedra; quartz; feldspar
Carbonates: contain carbon, oxygen, and one or more other metallic elements; calcite; dolomite
Oxides: contain oxygen, and one or more other elements; rutile; corundum
Sulfate and sulfides: contain sulfur; gypsum; galena
Halides: contain a halogen ion plus one or more other elements; halite; fluorite
Native elements: substances that exist as free elements; gold; silver

2 INSTRUCT

Address Misconceptions L2

Students may think that the minerals discussed in this chapter are the same as the minerals found in vitamin pills. They are related, but not the same. Remind students of the Q&A on p. 38. In earth science, a mineral is a naturally occurring inorganic crystalline solid. In contrast, minerals found in vitamin pills are inorganic compounds made in the laboratory that contain elements needed by the body. Many elements needed by the body are metals such as calcium, potassium, phosphorus, magnesium, and iron.
Logical

2.2 Minerals

Reading Focus

Key Concepts

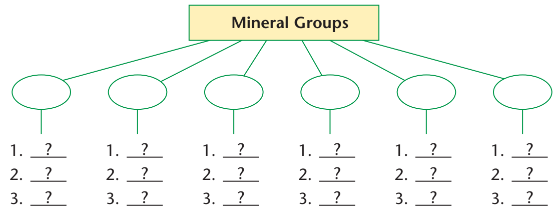
- What are five characteristics of a mineral?
- What processes result in the formation of minerals?
- How can minerals be classified?
- What are some of the major groups of minerals?

Vocabulary

- mineral
- silicate
- silicon-oxygen tetrahedron

Reading Strategy

Previewing Copy the organizer below. Skim the material on mineral groups on pages 47 to 49. Place each group name into one of the ovals in the organizer. As you read this section, complete the organizer with characteristics and examples of each major mineral group.



Look at the salt shaker in Figure 9B. This system is made up of the metal cap, glass container, and salt grains. Each component is made of elements or compounds that either are minerals or that are obtained from minerals. In fact, practically every manufactured product that you might use in a typical day contains materials obtained from minerals. What other minerals do you probably use regularly? The lead in your pencils actually contains a soft black mineral called graphite. Most body powders and many kinds of make-up contain finely ground bits of the mineral talc. Your dentist's drill bits contain tiny pieces of the mineral diamond. It is hard enough to drill through your tooth enamel. The mineral quartz is the main ingredient in the windows in your school and the drinking glasses in your family's kitchen. What do all of these minerals have in common? How do they differ?

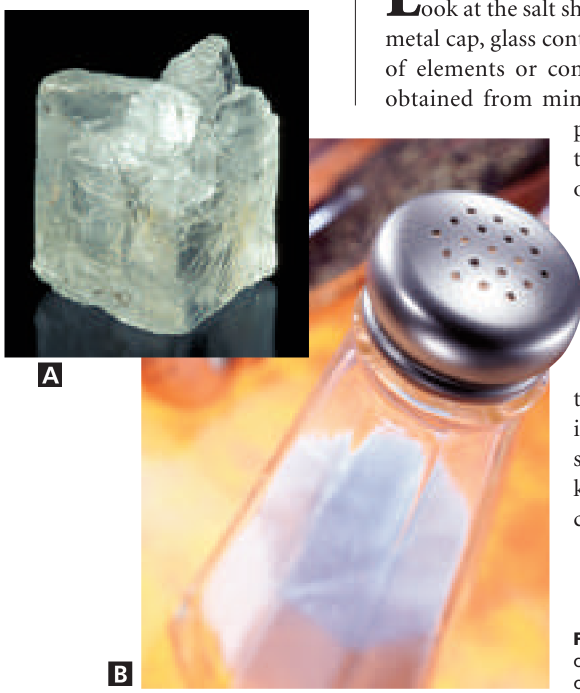


Figure 9 **A** Table salt is the mineral halite. **B** The glass container is made from the mineral quartz. Bauxite is one of the minerals that provides aluminum for the cap.

Minerals

A mineral in Earth science is different from the minerals in foods. **A mineral is a naturally occurring, inorganic solid with an orderly crystalline structure and a definite chemical composition.** For an Earth material to be considered a mineral, it must have the following characteristics:

1. **Naturally occurring** A mineral forms by natural geologic processes. Therefore, synthetic gems, such as synthetic diamonds and rubies, are not considered minerals.
2. **Solid substance** Minerals are solids within the temperature ranges that are normal for Earth's surface.
3. **Orderly crystalline structure** Minerals are crystalline substances which means that their atoms or ions are arranged in an orderly and repetitive manner. You saw this orderly type of packing in Figure 5 for halite (NaCl). The gemstone opal is not a mineral even though it contains the same elements as quartz. Opal does not have an orderly internal structure.
4. **Definite chemical composition** Most minerals are chemical compounds made of two or more elements. A few, such as gold and silver, consist of only a single element (native form). The common mineral quartz consists of two oxygen atoms for every silicon atom. Thus the chemical formula for quartz would be SiO_2.
5. **Generally considered inorganic** Most minerals are inorganic crystalline solids found in nature. Table salt (halite) is one such mineral. However, sugar, another crystalline solid is not considered a mineral because it is classified as an organic compound. Sugar comes from sugar beets or sugar cane. We say "generally inorganic" because many marine animals secrete inorganic compounds, such as calcium carbonate (calcite). This compound is found in their shells and in coral reefs. Most geologists consider this form of calcium carbonate a mineral.

How Minerals Form

Minerals form nearly everywhere on Earth under different conditions. For example, minerals called silicates often form deep in the crust or mantle where temperatures and pressures are very high. Most of the minerals known as carbonates form in warm, shallow ocean waters. Most clay minerals form at or near Earth's surface when existing minerals are exposed to weathering. Still other minerals form when rocks are subjected to changes in pressure or temperature. **There are four major processes by which minerals form: crystallization from magma, precipitation, changes in pressure and temperature, and formation from hydrothermal solutions.**

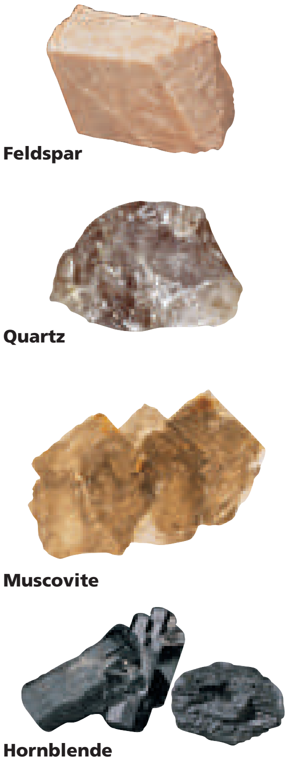


Figure 10 These minerals often form as the result of crystallization from magma.

Minerals

Build Reading Literacy

L1

Refer to **p. 334D** in **Chapter 12**, which provides guidelines for this strategy.

Outline Have students read the text on pp. 45–49 about how minerals form and mineral groups. Encourage students to use the headings as major divisions in an outline. Have students refer to their outlines when answering the questions in the Section 2.2 Assessment.
Verbal, Logical

How Minerals Form

Teacher Demo

Crystallization of Sulfur

L2

Purpose Students observe how the rate of cooling of a mineral affects crystal size.

Materials two crucibles, 50-mL beaker, water, teaspoon, sulfur powder, tongs, Bunsen burner, magnifying glass

Procedure Put a teaspoon of powdered sulfur into one of the crucibles. Using tongs, hold the crucible near the burner flame until the sulfur melts. Set the crucible aside to cool. Put a teaspoon of powdered sulfur into the second crucible. Put about 200 mL of water in the beaker. Melt the sulfur in the second crucible and carefully pour the molten sulfur into the beaker. Pour off the water. As soon as the first crucible has cooled, allow students to look at both sets of crystals using the magnifying glass.

Safety Wear goggles, apron, and heat-resistant mitts while melting the sulfur. Make sure students are at a safe distance from the crucible and flame and that the room is well ventilated.

Expected Outcome The sulfur in the first crucible, which cooled slowly, will have bigger crystals than the sulfur that cooled quickly.
Visual, Logical

Customize for English Language Learners

To help students learn and understand the names of the different mineral groups, have them focus on the roots of the names and ignore the endings. The beginning of *silicates*, for example, is *silic-*. This is similar to *silicon* and indicates that silicates contain silicon. Have students go though all the other names, isolate the beginnings of the names, and figure out what the name indicates about what elements the minerals contain *(carbonates: carbon-, carbon; oxides: ox-, oxygen; sulfates and sulfides: sulf-, sulfur; halides: hal-, halogens)*.

Teacher Demo

Precipitation of a Mineral L2

Purpose Students observe how a mineral can form by precipitation.

Materials rock salt, spoon warm water, 400-mL beaker, shallow pan or tray

Procedure Out of view of students, add rock salt spoon by spoon to a beaker of warm water, stirring as you go. Stop when no more salt will dissolve. Show the beaker to students and ask them if there is a mineral in it. Most will say no. Then pour the liquid into the pan and leave it in a warm and/or sunny spot. (If you don't have a suitable warm and/or sunny spot or want to save time, pour some of the solution into an evaporation dish and heat it on a hot plate.) When the water has evaporated, show the pan to students and ask them to identify the substance in it *(halite crystals).*

Expected Outcome As the water evaporates, the salt will precipitate out of the solution and form crystals.
Visual, Logical

Build Science Skills L2

Inferring Sometimes rocks are buried deep under Earth's surface. When they reach the surface again they are often changed into a different type of rock. Ask students why this happens. *(The rocks are subjected to great heat and pressure deep below Earth's surface. The heat and pressure cause reactions that change the minerals and thus produces new types of rocks.)*
Logical

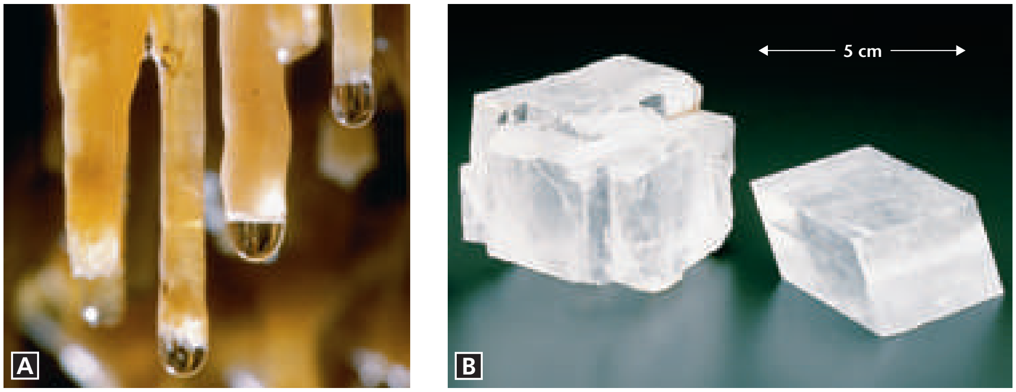


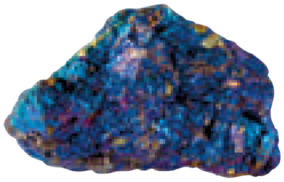
Figure 11 **A** This limestone cave formation is an obvious example of precipitation. **B** Halite and calcite are also formed by precipitation.

Crystallization from Magma Magma is molten rock. It forms deep within Earth. As magma cools, elements combine to form minerals such as those shown in Figure 10 on page 45. The first minerals to crystallize from magma are usually those rich in iron, calcium, and magnesium. As minerals continue to form, the composition of the magma changes. Minerals rich in sodium, potassium, and aluminum then form.

Precipitation The water in Earth's lakes, rivers, ponds, oceans, and beneath its surface contains many dissolved substances. If this water evaporates, some of the dissolved substances can react to form minerals. Changes in water temperature may also cause dissolved material to precipitate out of a body of water. The minerals are left behind, or precipitated, out of the water. Two common minerals that form in this way are shown in Figure 11.

Pressure and Temperature Some minerals, including talc and muscovite, form when existing minerals are subjected to changes in pressure and temperature. An increase in pressure can cause a mineral to recrystallize while still solid. The atoms are simply rearranged to form more compact minerals. Changes in temperature can also cause certain minerals to become unstable. Under these conditions, new minerals form, which are stable at the new temperature.

Figure 12 Bornite (blue and purple) and chalcopyrite (gold) are sulfur minerals that form from thermal solutions.



Hydrothermal Solutions A hydrothermal solution is a very hot mixture of water and dissolved substances. Hydrothermal solutions have temperatures between about 100°C and 300°C. When these solutions come into contact with existing minerals, chemical reactions take place to form new minerals. Also, when such solutions cool, some of the elements in them combine to form minerals such as quartz and pyrite. The sulfur minerals in the sample shown in Figure 12 formed from thermal solutions.

Reading Checkpoint *Describe what happens when a mineral is subjected to changes in pressure or temperature.*

Mineral Groups

Over 3800 minerals have been named, and several new ones are identified each year. You will be studying only the most abundant minerals. **Common minerals, together with the thousands of others that form on Earth, can be classified into groups based on their composition.** Some of the more common mineral groups include the silicates, the carbonates, the oxides, the sulfates and sulfides, the halides, and the native elements. First, you will learn about the most common groups of minerals on Earth—the **silicates.**

Silicates If you look again at Table 1, you can see that the two most abundant elements in Earth's crust are silicon and oxygen. **Silicon and oxygen combine to form a structure called the silicon-oxygen tetrahedron.** This structure is shown in Figure 13. The tetrahedron, which consists of one silicon atom and four oxygen atoms, provides the framework of every silicate mineral. Except for a few silicate minerals, such as pure quartz (SiO_2), most silicates also contain one or more other elements.

Silicon-oxygen tetrahedra can join in a variety of ways, as you can see in Figure 14 on the next page. The silicon-oxygen bonds are very strong. Some minerals, such as olivine, are made of millions of single tetrahedra. In minerals such as augite, the tetrahedra join to form single chains. Double chains are formed in minerals such as hornblende. Micas are silicates in which the tetrahedra join to form sheets. Three-dimensional network structures are found in silicates such as quartz and feldspar. As you will see, the internal structure of a mineral affects its properties.

Reading Checkpoint *What is the silicon-oxygen tetrahedron, and in how many ways can it combine?*

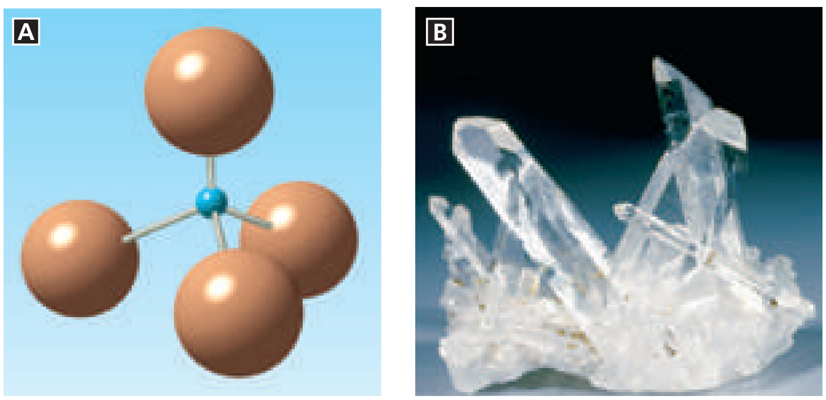


Figure 13 A The silicon-oxygen tetrahedron is made of one silicon atom and four oxygen atoms. The rods represent chemical bonds between silicon and the oxygen atoms. **B** Quartz is the most common silicate mineral. A typical piece of quartz like this contains millions of silicon-oxygen tetrahedra.

Mineral Groups

Address Misconceptions

L2

Students may think that the silicates described in this section are the same materials as those in silicon computer chips or silicone sealant. They are different materials, although all three contain silicon. Silicon chips are made from pure silicon, which does not contain the oxygen found in silicates. Silicone is an artificially-made silicon-oxygen polymer gel that feels rubbery and is water repellent, chemically inert, and stable at extreme temperatures.
Verbal

Use Visuals

L1

Figure 13 Use this diagram to explain the basic structure of silicates. Ask: **What is the atom at the center of the tetrahedron?** *(a silicon atom)* **What are the four atoms at the corners of the tetrahedron?** *(oxygen atoms)* **What do the rods represent?** *(chemical bonds between the atoms)* **Why is this structure called a tetrahedron?** *(it has four sides, or faces)*
Visual

Facts and Figures

Judging from the enormous number of known minerals, one might think that a large number of elements are needed to make them. Surprisingly, the bulk of these minerals are made up of only eight elements. These elements, in order of abundance, are oxygen (O), silicon (Si), aluminum (Al), iron (Fe), calcium (Ca), sodium (Na), potassium (K), and magnesium (Mg). These eight elements represent over 98 percent by weight of the continental crust. The two most abundant elements, oxygen and silicon, comprise nearly three-fourths of Earth's continental crust. These elements are the main building blocks of silicates. The most common group of silicates, the feldspars, compose over 50 percent of Earth's crust. Quartz is the second most abundant mineral in the continental crust. It is a silicate made mostly of oxygen and silicon.

Answer to . . .

Reading Checkpoint *The mineral often becomes unstable, and its atoms react to form a new mineral.*

Reading Checkpoint *The silicon-oxygen tetrahedron consists of one silicon atom and four oxygen atoms and provides the framework of every silicate mineral. These tetrahedra can join to form single chains, double chains, sheets, and three-dimensional networks. In these arrangements the corner oxygen atoms are shared between silicon atoms so the ratio is not necessarily 1 to 4.*

Section 2.2 (continued)

Build Science Skills

L2

Using Models ACTIVITY Have students use Figures 13 and 14 to build models of the various silicate structures. They can use balls of modeling clay or gumdrops to represent silicon and oxygen atoms and toothpicks to represent chemical bonds. First have each student build several silicon-oxygen tetrahedra as shown in Figure 13. Then have students work in groups to combine their tetrahedra into chains and other structures as shown in Figure 14.
Kinesthetic, Visual, Logical

Use Visuals

L1

Figure 14 Use this diagram to explain the different structures that silicate tetrahedra can form. Ask: **How does a single chain form?** *(A series of tetrahedra are joined together end-to-end.)* **How are double chains formed?** *(Two single chains are joined together side-by-side.)* **How are sheets formed?** *(Many single chains are joined together side-by-side.)*
Visual

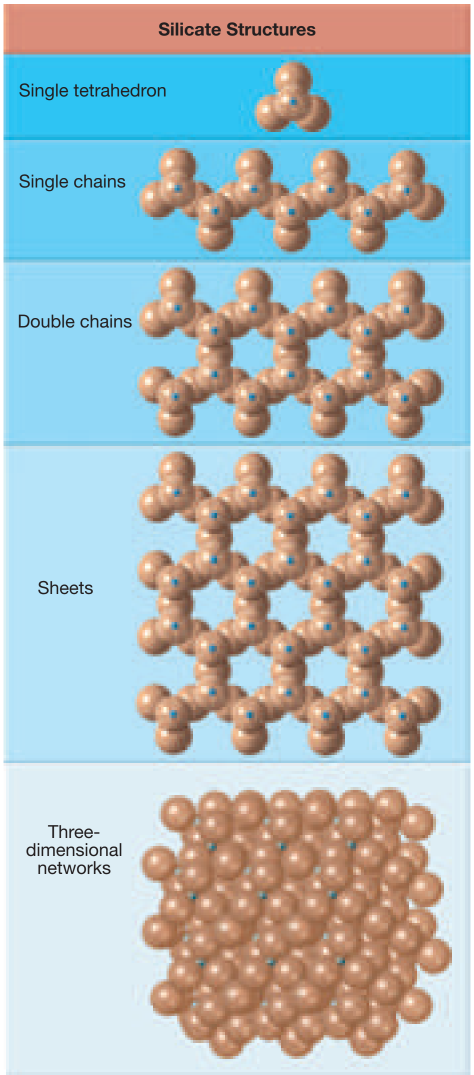


Figure 14 Silicon-oxygen tetrahedra can form chains, sheets, and three-dimensional networks.
Formulating Hypotheses ***What type of chemical bond is formed by silicon atoms in an SiO_4 tetrahedron?***

Recall that most silicate minerals crystallize from magma as it cools. This cooling can occur at or near Earth's surface, where temperatures and pressures are relatively low. The formation of silicates can also occur at great depths, where temperatures and pressures are high. The place of formation and the chemical composition of the magma determine which silicate minerals will form. For example, the silicate olivine crystallizes at temperatures of about 1200°C. Quartz crystallizes at about 700°C.

Some silicate minerals form at Earth's surface when existing minerals are exposed to weathering. Clay minerals, which are silicates, form this way. Other silicate minerals form under the extreme pressures that occur with mountain building. Therefore, silicate minerals can often provide scientists with clues about the conditions in which the minerals formed.

Carbonates Carbonates are the second most common mineral group. **Carbonates are minerals that contain the elements carbon, oxygen, and one or more other metallic elements.** Calcite ($CaCO_3$) is the most common carbonate mineral. Dolomite is another carbonate mineral that contains magnesium and calcium. Both limestone and marble are rocks composed of carbonate minerals. Both types of rock are used in building and construction.

Oxides **Oxides are minerals that contain oxygen and one or more other elements, which are usually metals.** Some oxides, including the mineral called rutile (TiO_2), form as magma cools deep beneath Earth's surface. Rutile is titanium oxide. Other oxides, such as corundum (Al_2O_3), form when existing minerals are subjected to changes in temperature and pressure. Corundum is aluminum oxide. Still other oxides, such as hematite (Fe_2O_3), form when existing minerals are exposed to liquid water or to moisture in the air. Hematite is one form of iron oxide.

Sulfates and Sulfides **Sulfates and sulfides are minerals that contain the element sulfur.** Sulfates, including anhydrite ($CaSO_4$) and gypsum ($CaSO_4 \cdot 2H_2O$), form when mineral-rich waters evaporate. Sulfides, which include the minerals galena (PbS), sphalerite (ZnS), and pyrite (FeS_2), often form from thermal, or hot-water, solutions. Figure 15 shows two of these sulfides.

Halides **Halides are minerals that contain a halogen ion plus one or more other elements.** Halogens are elements from Group 7A of the periodic table. This group includes the elements fluorine (F) and chlorine (Cl). The mineral halite (NaCl), table salt, is a common halide. Fluorite (CaF_2) is also a common halide and is used in making steel. It forms when salt water evaporates.

Native Elements **Native elements are a group of minerals that exist in relatively pure form.** You are probably familiar with many native elements, such as gold (Au), silver (Ag), copper (Cu), sulfur (S), and carbon (C). Native forms of carbon are diamond and graphite. Some native elements form from hydrothermal solutions.

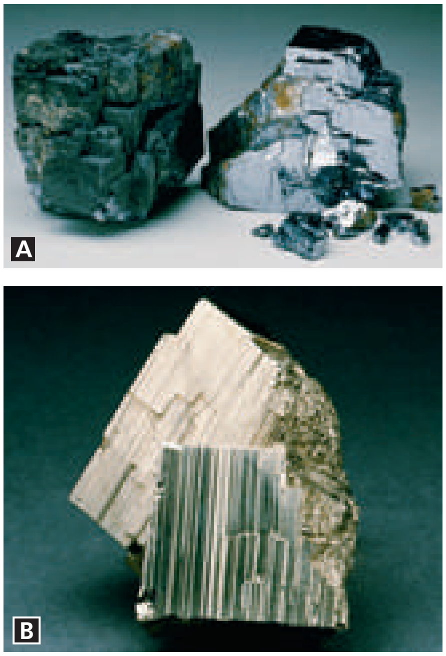


Figure 15 Sulfides A Galena is a sulfide mineral that can be mined for its lead. **B** Pyrite is another sulfide that is often called fool's gold.
Inferring ***What element do you think pyrite is generally mined for?***

Section 2.2 Assessment

Reviewing Concepts

1. What are five characteristics of a mineral?
2. Describe four processes that result in the formation of minerals.
3. How can minerals be classified?
4. Name the major groups of minerals, and give at least two examples of minerals in each group.

Critical Thinking

5. **Comparing and Contrasting** Compare and contrast sulfates and sulfides.
6. **Formulating Conclusions** When hit with a hammer, quartz shows an uneven breakage pattern. Using Figure 14, what can you suggest about its structure?
7. **Applying Concepts** To which mineral group do each of the following minerals belong: bornite (Cu_5FeS_4), cuprite (Cu_2O), magnesite ($MgCO_3$), and barite ($BaSO_4$)?

Writing in Science

Explanatory Paragraph Coal forms from ancient plant matter that has been compressed over time. Do you think coal is a mineral? Write a paragraph that explains your reasoning.

Use Community Resources **L2**

Invite a geologist from a local college or company to visit the classroom and discuss different groups of minerals with students. Ask the geologist to bring in samples from each group of minerals to show to students.
Visual, Interpersonal

3 ASSESS

Evaluate Understanding **L2**

Have students describe the four major processes by which minerals can form.

Reteach **L1**

Review the five characteristics that a material must have to be considered a mineral. Have students list and define all of the science terms used in the description of the five characteristics. Then review each of the five points again to be sure students understand them.

Writing in Science

Students should explain that because coal is formed from once-living things, it is not considered a mineral. Also, coal is a carbon-based material that falls into the class of organic compounds.

Answer to . . .

Figure 14 *covalent*

Figure 15 *Iron (Fe)*

Section 2.2 Assessment

1. A mineral is a natural, inorganic solid with an orderly internal structure and a definite chemical composition.
2. Crystallization occurs when minerals form as magma cools. Precipitation is a process whereby minerals form as waters rich in dissolved substances evaporate. Changes in pressure and temperature can cause the atoms in a mineral to change places to form a new mineral. Precipitation from hydrothermal solutions is another way in which minerals form.
3. Minerals can be classified according to their compositions.
4. silicates (quartz, feldspar, olivine, and mica); carbonates (calcite, dolomite); oxides (rutile, corundum, hematite); sulfates (anhydrite, gypsum); sulfides (galena, pyrite, sphalerite); halides (fluorite, halite); native elements (gold, silver, copper, iron, sulfur, diamond)
5. Both contain the element sulfur. Sulfates also contain oxygen and a metallic element. Sulfides contain only sulfur and one or more other metallic elements.
6. The tetrahedra that combine to form quartz share very strong bonds, resulting in an uneven breakage.
7. Bornite is a sulfide mineral, cuprite is an oxide, magnesite is a carbonate mineral, and barite is a sulfate.

Section 2.3

1 FOCUS

Section Objectives

2.10 **Explain** why color is often not a useful property in identifying minerals.

2.11 **Define** the terms *luster, crystal form, streak,* and Mohs scale.

2.12 **Distinguish** between cleavage and fracture.

2.13 **Explain** density and how it can be used to identify substances.

2.14 **Describe** some other properties that can be used to identify minerals.

Reading Focus

Build Vocabulary L2

Paraphrase As students read the section, have them look for the vocabulary terms that describe properties of minerals. For each term, have students write a definition in their own words. If students are having trouble, use mineral samples to demonstrate each of the properties.

Reading Strategy L2

A.1 Often not used to identify minerals
A.2 Small amounts of different elements can give the same mineral different colors.
B.1 Describes how light is reflected from surface
B.2 Metallic and nonmetallic lusters

2 INSTRUCT

Color

Build Reading Literacy L1

Refer to **p. 32D** in this chapter, which provides guidelines for this strategy.

Preview Before they read the section, have students skim the headings, visuals, and boldfaced sentences and terms to preview how the text is organized. Have students note any unfamiliar terms and concepts and make notes about these as they read the section.
Verbal

2.3 Properties of Minerals

Reading Focus

Key Concepts

- What properties can be used to identify minerals?
- What is the Mohs scale?
- What are some distinctive properties of minerals?

Vocabulary

- streak
- luster
- crystal form
- hardness
- Mohs scale
- cleavage
- fracture
- density

Reading Strategy

Outlining Before you read, make an outline of this section, following the format below. Use the green headings as the main topics. As you read, add supporting details.

I. Properties of Minerals
  A. Color
    1. ________
    2. ________
  B. Luster
    1. ________
    2. ________

As you can see from the photographs in this chapter, minerals occur in different colors and shapes. Now you will learn that minerals vary in the way they reflect light and in the way in which they break. You will also find out that some minerals are harder than others and that some minerals smell like rotten eggs. All of these characteristics, or properties, of minerals can be used to identify them.

Color

One of the first things you might notice about a mineral is its color. While color is unique to some minerals, this property is often not useful in identifying many minerals. **Small amounts of different elements can give the same mineral different colors.** You can see examples of this in Figure 16.

Figure 16 Small amounts of different elements give these sapphires their distinct colors. **Observing** ***Why is color often not a useful property in mineral identification?***

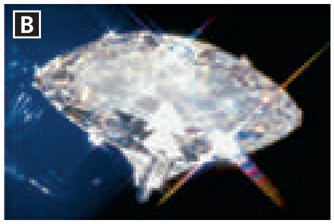


Figure 17 **A** The mineral copper has a metallic luster. **B** The brilliant luster of diamond is also known as an adamantine luster.

Streak

Streak is the color of a mineral in its powdered form. Streak is obtained by rubbing a mineral across a streak plate, a piece of unglazed porcelain. While the color of a mineral may vary from sample to sample, the streak usually doesn't. Therefore, streak can be a good indicator. Streak can also help to see the difference between minerals with metallic lusters and minerals with nonmetallic lusters. Metallic minerals generally have a dense, dark streak. Minerals with nonmetallic lusters do not have such streaks.

Figure 18 Crystal Form
A This quartz sample shows hexagonal (six-sided) crystals. The ends of the crystals have a pyramid shape. **B** Fluorite often forms cubic crystals.

Luster

Luster is used to describe how light is reflected from the surface of a mineral. Minerals that have the appearance of metals, regardless of their color, are said to have a metallic luster. The piece of copper shown in Figure 17A has a metallic luster. Minerals with a nonmetallic luster are described by many adjectives. These include vitreous or glassy, like the quartz crystals in Figure 5. Other lusters include pearly, silky, and earthy. Diamond has an adamantine, or brilliant luster. Some minerals appear *somewhat* metallic and are said to have a sub-metallic luster.

Crystal Form

Crystal form is the visible expression of a mineral's internal arrangement of atoms. Every mineral has a distinct crystal form.

Usually, when a mineral forms slowly and without space restrictions, it will develop into a crystal with well-formed faces—sides, top, and bottom—as shown in Figure 18. Most of the time, however, minerals compete for space. This crowding results in an intergrown mass of small crystals. None of these crystals shows its crystal form.

Reading Checkpoint *What two conditions produce crystals with well-defined faces?*

Streak

Integrate Chemistry L2

Streak Color There are several reasons why a mineral's streak color may differ from the color of the mineral itself. Some translucent minerals are colored by trace impurities of other elements. These colors are visible in a large sample because light passes through the impurities before reaching the eye. A streak will often not show this coloring effect and will appear white instead. Also, the structure and surface coatings of a sample may affect its color. Again, the streak will not show these effects and will instead show the true color of the mineral. Have students research how streak can be used to distinguish gold from iron pyrite. *(Samples of both have a gold color. Gold has a golden streak but iron pyrite has a black streak.)*
Logical

Luster

Integrate Physics L2

Causes of Luster The type of luster a mineral displays depends on how light interacts with the surface of the sample. If most of the light is reflected or absorbed, the mineral will have a metallic luster. A few minerals allow a small amount of light to penetrate, and have submetallic luster. Nonmetallic luster occurs when light can pass through the sample. If the mineral has a high index of refraction (the amount that light bends when it is passing through the mineral), such as diamond, the luster is described as adamantine. Minerals with lower indices of refraction have glassy or vitreous luster.
Logical, Visual

Crystal Form

Use Visuals L1

Figure 18 Show students a sample of granite with coarse texture. Point out the quartz crystals in the rock. Have students compare these crystals with the quartz crystals in Figure 18A. Ask: **Why do the crystals look so different if they are both quartz?** *(The crystals in the granite did not have adequate space in which to develop the full crystal form shown in the photograph.)*
Visual

Answer to . . .

Figure 16 *The same mineral can be different colors.*

Reading Checkpoint *unrestricted space and a slow rate of formation*

Customize for Inclusion Students

Behaviorally Disordered For students who have difficulty concentrating on reading or class lectures, have them explore mineral samples on their own to learn about the properties of minerals. Students can work on their own or in small groups to explore three to five minerals. Encourage students to take notes about each mineral's color, luster, crystal form, streak, hardness, cleavage, fracture, and density.

Section 2.3 (continued)

Hardness

Use Visuals L1

Figure 19 Have students use the Mohs scale of hardness to give the hardness ranges for the following descriptions: a mineral that can be scratched by your fingernail *(less than 2.5)*, a mineral that cannot be scratched by your fingernail and cannot scratch glass *(2.5 to 5.5)*, a mineral that scratches glass *(greater than 5.5)*.
Visual

Build Science Skills L1

Inferring Ask: **What does the use of a pencil tell you about the hardness of graphite?** *(Graphite, or pencil "lead," is a very soft mineral because it leaves a mark, or streak, when rubbed against paper or most surfaces.)* **What can you say about the hardness of chalk versus the hardness of a chalkboard?** *(Chalk is softer than the board.)* **What kind of minerals could you not test for streak when using a streak plate?** *(Minerals that are harder than the streak plate will not leave a streak; instead they will scratch the plate.)*
Logical

Cleavage

Integrate Language Arts L2

Origin of the Names Mica and Muscovite Tell students that the name "mica" probably came from the Latin word *micare*, which means "to shine" and refers to mica's appearance. Muscovite, a common type of mica, was named after the old Russian state of Muscovy. In the 1300s, it was common in Muscovy to use mica as a substitute for glass, so it was called muscovy glass. Biotite is another common type of mica. Have students research the origin of that name. *(It was named for J. B. Biot, a French physicist.)*
Verbal

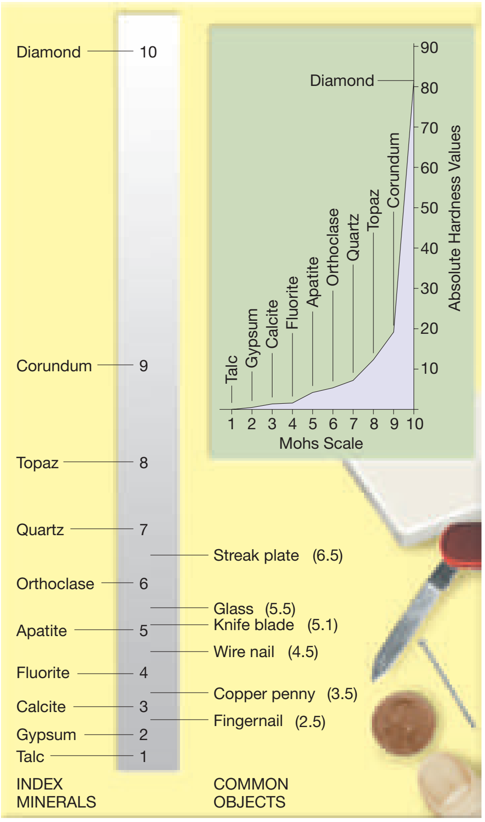


Figure 19 Mohs Scale to Hardness Common objects can be used with the Mohs scale to determine mineral hardness. **Using Tables and Graphs** ***A mineral has a hardness of 4.2. Which common items on the chart will that mineral scratch?***

Hardness

One of the most useful properties to identify a mineral is hardness. **Hardness** is a measure of the resistance of a mineral to being scratched. You can find this property by rubbing the mineral against another mineral of known hardness. One will scratch the other, unless they have the same hardness.

Geologists use a standard hardness scale called the Mohs scale. **The Mohs scale consists of 10 minerals arranged from 10 (hardest) to 1 (softest).** See Figure 19. Any mineral of unknown hardness can be rubbed against these to determine its hardness. Other objects can also be used to determine hardness. Your fingernail, for example, has a hardness of 2.5. A copper penny has a hardness of 3.5. A piece of glass has a hardness of about 5.5. Look again at Figure 19. The mineral gypsum, which has a Mohs hardness of 2, can be easily scratched by your fingernail. The mineral calcite, which resembles gypsum, has a hardness of 3. Calcite cannot be scratched by your fingernail. Calcite, which can resemble the mineral quartz, cannot scratch glass, because its hardness is less than 5.5. Quartz, the hardest of the common minerals with a Mohs hardness of 7, will scratch a glass plate. Diamond, the hardest mineral on Earth, can scratch anything.

Reading Checkpoint *Describe three or four of the most useful properties for identifying unknown minerals.*

Cleavage

In the atomic structure of a mineral, some bonds are weaker than others. These weak bonds are places where a mineral will break when it is stressed. **Cleavage is the tendency of a mineral to cleave, or break, along flat, even surfaces.**

Minerals called micas show the simplest type of cleavage. Because the micas have weak bonds in one direction, they cleave to form thin, flat sheets, as shown in Figure 20A. Look again at Figure 14. Can you see the relationship between mica's internal structure and the cleavage it shows? Mica, and all other silicates, tend to cleave between the silicon-oxygen structures rather than across them. This is because the silicon-oxygen bonds are strong. The micas' sheet structure causes them to cleave into flat plates. Quartz has equally strong silicon-oxygen bonds in all directions. Therefore, quartz has no cleavage but fractures instead.

Some minerals have cleavage in more than one direction. Look again at Figure 11. Halite (11A) has three directions of cleavage. The cleavage planes of halite meet at 90-degree angles. Calcite (11B) also has three directions of cleavage. The cleavage planes of calcite, however, meet at 75-degree angles.

Fracture

Minerals that do not show cleavage when broken are said to fracture. Fracture is the uneven breakage of a mineral. For example, quartz shows a curvy and glassy fracture. Like cleavage, there are different kinds of fracture. Minerals that break into smooth, curved surfaces like the quartz in Figure 20B have a conchoidal fracture. Other minerals, such as asbestos, break into splinters or fibers. Many minerals have an irregular fracture.

Reading Checkpoint *How are cleavage and fracture different?*

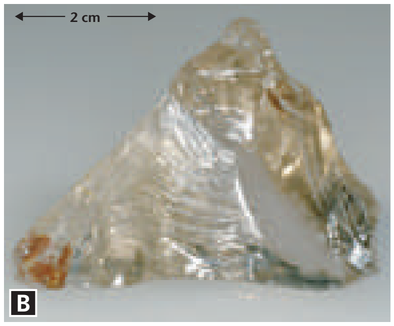


Figure 20 **A** Mica has cleavage in one direction and therefore cleaves into thin sheets. **B** The bonds in quartz are very strong in all directions, causing quartz to display conchoidal fracture.

Density

Density is a property of all matter that is the ratio of an object's mass to its volume. Density is a ratio and can be expressed using the following equation.

$$Density\ (D) = \frac{mass\ (m)}{Volume\ (V)}$$

Density is expressed using derived units with a unit of mass over a unit of volume. For example, the density of copper is 8.96 g/cm^3 (grams per cubic centimeter). Therefore, any sample of pure copper with a volume of one cubic centimeter will have a mass of 8.96 grams.

Many common minerals have densities between 2 and 5 g/cm^3. Some metallic minerals have densities that are often greater than rock-forming minerals. Galena, the ore of lead, has a density around 7.5 g/cm^3. The density of gold is 19.3 g/cm^3. The density of a pure mineral is a constant value. Thus, density can be used to determine the purity or identity of some minerals.

Go Online SCI LINKS NSTA

For: Links on mineral identification
Visit: www.SciLinks.org
Web Code: cjn-1023

Fracture

Use Visuals L1

Figure 20 Use these photographs to explain fracture and cleavage. Ask: **What is cleavage?** *(the tendency of a mineral to break along flat, even surfaces)* **Which mineral shows cleavage?** *(mica)* **What is fracture?** *(the uneven breakage of a mineral)* **Which mineral shows fracture?** *(quartz)*
Visual

Density

Integrate Chemistry L2

Density and Atomic Mass Specific gravity was once used to distinguish minerals. However, today geologists use density. The specific gravity of a mineral depends on its density. (Density is mass per unit of volume and is expressed in grams per cubic centimeter.) Density in turn depends mainly on the chemical composition of a mineral. Minerals made of elements with high atomic masses generally have higher densities than minerals made of atoms with low atomic masses. Tell students that the mineral galena contains large amounts of lead, which has a high atomic mass. Ask: **Would you expect the density of galena to be relatively low or high?** *(high)* Tell students that the mineral quartz is made up of silicon and oxygen, which have low atomic masses. **Would you expect the density of quartz to be relatively low or high?** *(low)*
Logical

Go Online NSTA SCI LINKS

Download a worksheet on mineral identification for students to complete, and find additional teacher support from NSTA SciLinks.

Facts and Figures

Like mica, asbestos is a sheet-forming mineral. However, unlike flat sheets of mica, sheets of asbestos roll up in a tight needle-like formation. These needles can cause serious damage to lungs if inhaled. Before people realized that asbestos caused a health risk, it was a popular insulation material. Now, many older buildings must undergo expensive asbestos removal in order to be safe.

Answer to . .

Figure 19 *copper penny and fingernail*

Reading Checkpoint *Hardness, streak, luster, and density are the most definitive properties that can be used to identify minerals*

Reading Checkpoint *Cleavage is the tendency for a mineral to break along flat, even surfaces. Fracture is the uneven breakage of a mineral.*

Distinctive Properties of Minerals

Use Community Resources L2

As noted on p. 49, invite a geologist from a local college or company to visit the classroom and discuss properties of minerals with students. Ask the geologist to bring in samples of unusual minerals and demonstrate their properties to students.
Visual, Interpersonal

Build Science Skills L2

Designing Experiments ACTIVITY Give each student or group of students two mineral samples. Tell them only that one is calcite and the other is dolomite. Have students design an activity they could do without any additional materials or equipment to determine the identities of the two samples. *(Try to scratch the samples with each other. The one that is scratched is softer and is calcite.)* Then ask students how they might identify the samples using additional materials. *(Place dilute hydrochloric acid on each sample to see if it fizzes.)* Have them carry out their experiment. Be sure students wear safety goggles and gloves when using the hydrochloric acid. Dispense the acid in small dropper bottles and be sure it is diluted.
Logical

Table 2 Some Common Minerals and Their Properties

Name	Chemical Formula and Mineral Group	Common Color(s)	Density (g/cm^3)	Hardness	Comments
Quartz	SiO_2 silicates	colorless, milky white, pink, brown	2.65	7	glassy luster; conchoidal fractures
Orthoclase feldspar	$KAlSi_3O_8$ silicates	white to pink	2.57	6	cleaves in two directions at 90°
Plagioclase feldspar	$(Na,Ca)AlSi_3O_8$ silicates	white to gray	2.69*	6	cleaves in two directions at 90°; striations common
Galena	PbS sulfides	metallic silver	7.5*	2.5	cleaves in three directions at 90°; lead gray streak
Pyrite	FeS_2 sulfides	brassy yellow	5.02	6–6.5	fractures; forms cubic crystals; greenish-black streak
Sulfur	S native elements	yellow	2.07*	1.5–2.5	fractures; yellow streak smells like rotten eggs
Fluorite	CaF_2 halides	colorless, purple	3.18	4	perfect cleavage in three directions; glassy luster
Olivine	$(Mg,Fe)_2SiO_4$ silicates	green, yellowish-green	3.82*	6.5–7	fractures; glassy luster; often has granular texture
Calcite	$CaCO_3$ carbonates	colorless, gray	2.71	3	bubbles with HCl; cleaves in three directions
Talc	$Mg_3Si_4O_{10}(OH)_2$ silicates	pale green, gray, white	2.75*	1	pearly luster; feels greasy; cleaves in one direction
Gypsum	$CaSO_4 \bullet 2H_2O$ sulfates	colorless, white, gray	2.32	2	glassy or pearly luster; cleaves in three directions
Muscovite mica	$Kal_3Si_3O_{10}(OH)_2$ silicates	colorless in thin sheets to brown	2.82*	2–2.5	silky to pearly luster; cleaves in one direction to form flexible sheets

* Average density of the mineral

Figure 21 Calcite shows the property of double refraction.

Distinctive Properties of Minerals

Some minerals can be recognized by other distinctive properties. Talc and graphite, for example, both have distinctive feels. Talc feels soapy. Graphite feels greasy. Metallic minerals, such as gold, silver, and copper, are easily shaped. Some types of magnetite are magnetic and can be used to pick up paper clips and small nails. When a piece of transparent calcite is placed over printed material, the letters appear doubled as Figure 21 shows. This property is called double refraction. Streaks of a few minerals that contain sulfur smell like rotten eggs. Carbonate minerals, such as calcite, will fizz when they come into contact with hydrochloric acid.

A mineral's properties depend on the elements that compose the mineral (its composition) and its structure (how its atoms are arranged). Table 2 lists some of the more common minerals and their properties. You will use this table to identify minerals in the lab on pages 58 and 59.

Table 2 Some Common Minerals and Their Properties, *continued*

Name	Chemical Formula and Mineral Group	Common Color(s)	Density (g/cm^3)	Hardness	Comments
Biotite mica	$K(Mg,Fe)_3(AlSi_3O_{10})(OH)_2$ silicates	dark green to brown to black	3.0*	2.5–3	perfect cleavage in one direction to form flexible sheets
Halite	$NaCl$ halides	colorless, white	2.16	2.5	has a salty taste; dissolves in water; cleaves in three directions
Augite	$(Ca, Na)(Mg, Fe, Al)(Si, Al)_2O_6$ silicates	dark green to black	3.3*	5–6	glassy luster; cleaves in two directions; crystals have 8-sided cross section
Hornblende	$(Ca, Na)_{2\text{-}3}(MgFeAl)_5Si_6(SiAl)_2O_{22}(OH)_2$ silicates	dark green to black	3.2*	5–6	glassy luster; cleaves in two directions; crystals have 6-sided cross section
Hematite	Fe_2O_3 oxides	reddish brown to black	5.26	5.5–6.5	metallic luster in crystals; dull luster in earthy variety; dark red streak
Dolomite	$CaMg(CO_3)_2$ carbonates	pink, colorless, white, gray	2.85	3.5–4	does not react to HCl as quickly as calcite; cleaves in three directions
Magnetite	Fe_3O_4 oxides	black	5.18	6	metallic luster; black streak; strongly magnetic
Copper	Cu native elements	copper-red on fresh surface	8.9	2.5–3	metallic luster; fractures; can be easily shaped
Graphite	C native elements	black to gray	2.3	1–2	black to gray streak; marks paper; feels slippery

Section 2.3 Assessment

Reviewing Concepts

1. Describe five common properties of minerals that can be used to identify them.
2. How is the Mohs scale used?
3. What are some unique properties that can be used to identify minerals?

Critical Thinking

4. **Applying Concepts** What kind of luster do the minerals shown in Figure 15 have? Explain your choice.
5. **Applying Concepts** Hornblende is a double-chain silicate. How many planes of cleavage do you think hornblende has when it breaks? Explain your answer.
6. **Applying Concepts** A mineral scratches a piece of fluorite but cannot be scratched by a piece of glass. What is this mineral's hardness?

Connecting Concepts

Mineral Properties Choose one of the minerals pictured in this chapter. Find out to which mineral system it belongs as well as its luster, streak, hardness, specific gravity, and whether it cleaves or fractures. Also note any unique properties of the mineral.

Integrate Social Studies L2

Mining Economics Mineral resources are Earth's storehouse of minerals that can be recovered for use. The term *ore* refers to useful metallic minerals that can be mined at a profit. For pure elements, the element must be concentrated well above the level of its average crustal abundance to be worth mining. Copper must be present at about 100 times its average concentration, whereas for aluminum the ratio is only 4. Have students research the history of the copper mine at Bingham Canyon, Utah. *(It is one of the largest open-pit mines on Earth. Mining was halted in 1985 because it was uneconomic but later restarted with new equipment that made it profitable.)*
Verbal, Logical

3 ASSESS

Evaluate Understanding L2

Provide students with 4 or 5 unidentified minerals. Challenge students to place the minerals in order of hardness from softest to hardest. They should rub any two of the minerals together and repeat this process until they can determine the order of hardness. Remind students that a harder mineral will scratch a softer mineral and a softer mineral may leave a streak on a harder mineral. After rubbing two minerals together, students may need to rub the mark with their finger to tell if it is a scratch or a streak.

Connecting Concepts

Answers will vary. Most of the minerals pictured in this chapter are described in Table 4. Many are shown on the GEODe CD-ROM as well.

Section 2.3 Assessment

1. Sample answers: luster, crystal form, streak, Mohs hardness, magnetism, density, odor, double refraction, cleavage, and fracture.
2. The Mohs scale is an ordering of minerals according to hardness.
3. Feel, magnetism, double refraction, odor, and reaction to HCl are a few properties unique to only some minerals.
4. Both minerals have metallic luster because they appear to shine like metals.
5. Hornblende cleaves in two directions when the two sets of bonds in the double chain structure break.
6. The mineral's hardness is greater than 4 but less than 5.5 on the Mohs hardness scale.

understanding EARTH

Gemstones

L2

Background

- Why can diamond and graphite be made of the same material (carbon) but form such different minerals? You could make a diamond out of your pencil if you could squeeze it hard enough. The pressure would compress the carbon atoms of the graphite together until they eventually formed the strong covalent bonds of diamond. In fact, this is roughly how synthetic diamonds are made: by squeezing carbon very tightly. Natural diamonds are thought to form more than 150 km beneath the surface, where the pressures are very high. The diamonds that we find at the surface have been brought up from deep within Earth by geologic processes.
- Pure quartz, containing only SiO_2, is clear and colorless. However, natural quartz comes in many color varieties that form when different elements are contained in the crystal structure. If small amounts of titanium and iron are included, the result is rose quartz. The inclusion of manganese produces purple amethyst. The inclusion of aluminum produces smoky quartz.
- A precious gemstone that has gained in popularity in recent years is tanzanite. Mined only in the east-African country of Tanzania, tanzanite was discovered in 1967. Its color ranges from a light purplish blue to the more prized deep blues. The most prized stones are deep blue rimmed in a purplish hue. This hydrated calcium aluminum silicate is actually the blue variety of the gemstone called zoisite. But the jeweler Louis Comfort Tiffany, who popularized the gem after its discovery, thought that the correct name of *blue zoisite* was too reminiscent of the word *suicide*. So he suggested *tanzanite* instead.

understanding EARTH

Gemstones

Precious stones have been prized by people since ancient times. Unfortunately, much misinformation exists about the nature of gems and the minerals of which they are composed. Part of the misinformation stems from the ancient practice of grouping precious stones by color rather than mineral makeup. For example, the more common red spinels were often passed off to royalty as rubies, which are more valuable gems. Even today, when modern techniques of mineral identification are commonplace, yellow quartz is frequently sold as topaz.

What's In a Name?

Compounding the confusion is the fact that many gems have names that are different from their mineral names. For example, diamond is composed of the mineral of the same name, whereas sapphire is a form of corundum, an aluminum oxide-rich mineral. Although pure aluminum oxide is colorless, a tiny amount of a foreign element can produce a vividly colored gemstone. Therefore, depending on the impurity, sapphires of nearly every color exist. Pure aluminum oxide with trace amounts of titanium and iron produce the most prized blue sapphires. If the mineral corundum contains enough chromium, it exhibits a brilliant red color, and the gem is called ruby. Large gem-quality rubies are much rarer than diamonds and thus command a very high price.

If the specimen is not suitable as a gem, it simply goes by the mineral name corundum. Although common corundum is not a gemstone, it does have value as an abrasive material. Whereas two gems—rubies and sapphires—are composed of the mineral corundum, quartz is the parent mineral of more than a dozen gems. Table 3 lists some well-known gemstones and their mineral names.

Figure 22 Emerald is the dark green variety of the mineral beryl. More common blue-green beryl is aquamarine.

Precious or Semiprecious?

What makes a gem a gem instead of just another mineral? Basically, certain mineral specimens, when cut and polished, possess beauty of such quality that they can command a price that makes the process of producing the gem profitable. Gemstones can be divided into two categories: precious and semiprecious. A *precious* gem has beauty, durability, size, and rarity, whereas a *semiprecious* gem usually has only one or two of these qualities. The gems that have traditionally enjoyed the highest esteem are diamonds, rubies, sapphires, emeralds, and some varieties of opal. All other gemstones are classified as semiprecious. It should be noted, however, that large, high-quality specimens of semiprecious stones can often command a very high price.

Obviously, beauty is the most important quality that a gem can possess. Today we prefer translucent stones with evenly tinted colors. The most favored hues appear to be red, blue, green, purple, rose,

56 *Chapter 2*

Figure 23 A diamond in the rough looks very different from the brilliant, multi-faceted gem it can become.

and yellow. The most prized stones are deep red rubies, blue sapphires, grass-green emeralds, and canary-yellow diamonds. Colorless gems are generally less than desirable except in the case of diamonds that display "flashes of color" known as brilliance.

Notice in figure 23 that gemstones in the "rough" are dull and would be passed over by most people as "just another mineral." Gemstones must be cut and polished by experienced artisans before their true beauty can be displayed.

The durability of a gem depends on its hardness—that is, its resistance to abrasion by objects normally encountered in everyday living. For good durability, gems should be as hard or harder than quartz, as defined by the Mohs scale of hardness. One notable exception is opal, which is comparatively soft (hardness 5 to 6.5) and brittle. Opal's esteem comes from its fire, which is a display of a variety of brilliant colors including greens, blues, and reds.

It seems to be human nature to treasure that which is rare. In the case of gemstones, large, high-quality specimens are much rarer than smaller stones. Thus, large rubies, diamonds, and emeralds, which are rare in addition to being beautiful and durable, command the very highest prices.

Table 3 Some Important Gemstones

Gem	Mineral Name	Prized Hues
Precious		
Diamond	Diamond	Colorless, yellows
Emerald	Beryl	Greens
Opal	Opal	Brilliant hues
Ruby	Corundum	Reds
Sapphire	Corundum	Blues
Semiprecious		
Alexandrite	Chrysoberyl	Variable
Amethyst	Quartz	Purples
Aquamarine	Beryl	Blue-greens
Cat's-eye	Chrysoberyl	Yellows
Chalcedony	Quartz (agate)	Banded
Citrine	Quartz	Yellows
Garnet	Garnet	Reds, greens
Jade	Jadeite or nephrite	Greens
Moonstone	Feldspar	Transparent blues
Peridot	Olivine	Olive greens
Smoky quartz	Quartz	Browns
Spinel	Spinel	Reds
Topaz	Topaz	Purples, reds
Tourmaline	Tourmaline	Reds, blue-greens
Turquoise	Turquoise	Blues
Zircon	Zircon	Reds

Teaching Tips

- Stories of mystery, adventure, and intrigue surround some of the more famous gemstones, such as the Hope Diamond. Invite students to research some of these stories and share them with the class. You might suggest some students create a booklet for distribution among the class.
- Invite a jeweler, gem cutter, or gemologist to the class to discuss how a rough stone is turned into a beautifully cut gem. Note how hardness, cleavage, and refraction are taken into account when cutting gems.

Verbal, Interpersonal

Section 3.1

1 FOCUS

Section Objectives

3.1 **Define** the term *rock*.
3.2 **Identify** the three major types of rocks and **explain** how they differ.
3.3 **Describe** the rock cycle.
3.4 **List** the forces that power Earth's rock cycle.

Reading Focus

Build Vocabulary L2

Cycle Diagram Have students construct a cycle diagram of the rock cycle. Students should use the terms *igneous rock, sedimentary rock, metamorphic rock, sediments, magma,* and *lava* to indicate the materials involved in the rock cycle. The processes of the rock cycle are shown in Figure 2 on p. 67. Tell students to place the terms in ovals and use labeled arrows to indicate how one process leads to another.

Reading Strategy L2

a. a solid mixture of one or more minerals
b. rock that forms when magma or lava cools and hardens
c. rock that forms when sediments become compacted and cemented
d. bits of earth materials

2 INSTRUCT

Rocks

Use Visuals L1

Figure 1 Ask: **How does the texture of obsidian compare with that of pumice?** *(Obsidian is smooth; pumice is rough.)* **What other differences do you see?** *(Sample answer: The color and shape of the samples are different.)*
Visual

3.1 The Rock Cycle

Reading Focus

Key Concepts

- What is a rock?
- What are the three major types of rocks?
- How do igneous, sedimentary, and metamorphic rocks differ?
- What is the rock cycle?
- What powers Earth's rock cycle?

Vocabulary

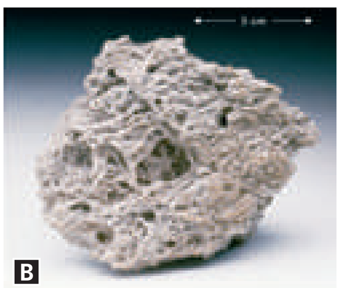
- rock
- igneous rock
- sedimentary rock
- metamorphic rock
- rock cycle
- magma
- lava
- weathering
- sediments

Reading Strategy

Building Vocabulary Copy and expand the table to include each vocabulary term. As you read, write down the definition for each term.

Term	Definition
rock	a. ___?___
igneous rock	b. ___?___
sedimentary rock	c. ___?___
sediments	d. ___?___

Figure 1 **A** Obsidian and **B** pumice are two examples of rocks that do not have a crystalline structure.



Why do we study rocks? All Earth processes such as volcanic eruptions, mountain building, weathering, erosion, and even earthquakes involve rocks and minerals. Rocks contain clues about the environments in which they were formed. For example, if a rock contains shell fragments, it was probably formed in a shallow ocean environment. The locations of volcanic rocks tell a story of volcanic activity on Earth through time. Thus, you can see that a basic knowledge of rocks is essential to understanding the Earth.

Rocks

A rock is any solid mass of mineral or mineral-like matter that occurs naturally as part of our planet. A few rocks are composed of just one mineral. However, most rocks, like granite, occur as solid mixtures of minerals. A characteristic of rock is that each of the component minerals retains their properties in the mixture. A few rocks are composed of nonmineral matter. Coal is considered a rock even though it consists of organic material. Obsidian and pumice, shown in Figure 1, are volcanic rocks that do not have a crystalline structure.

Rocks are classified into three groups based on how they were formed. **The three major types of rocks are igneous rocks, sedimentary rocks, and metamorphic rocks.** Before examining each group, you will look at a model for the rock cycle, which is the process that shows the relationships between the rock groups.

Reading Checkpoint *What are the three types of rocks?*

The Rock Cycle

Earth is a system. It consists of many interacting parts that form a complex whole. **Interactions among Earth's water, air, and land can cause rocks to change from one type to another. The continuous processes that cause rocks to change make up the rock cycle.** Most changes in the rock cycle take place over long periods of time.

Figure 2 shows some key events in the rock cycle. Refer to the figure throughout this section as you examine how rock might change over time. Look at Figures 2A and 2B. **Magma** is molten material that forms deep beneath Earth's surface. **When magma cools and hardens beneath the surface or as the result of a volcanic eruption, igneous rock forms.** Magma that reaches the surface is called **lava.**

Rock Cycle

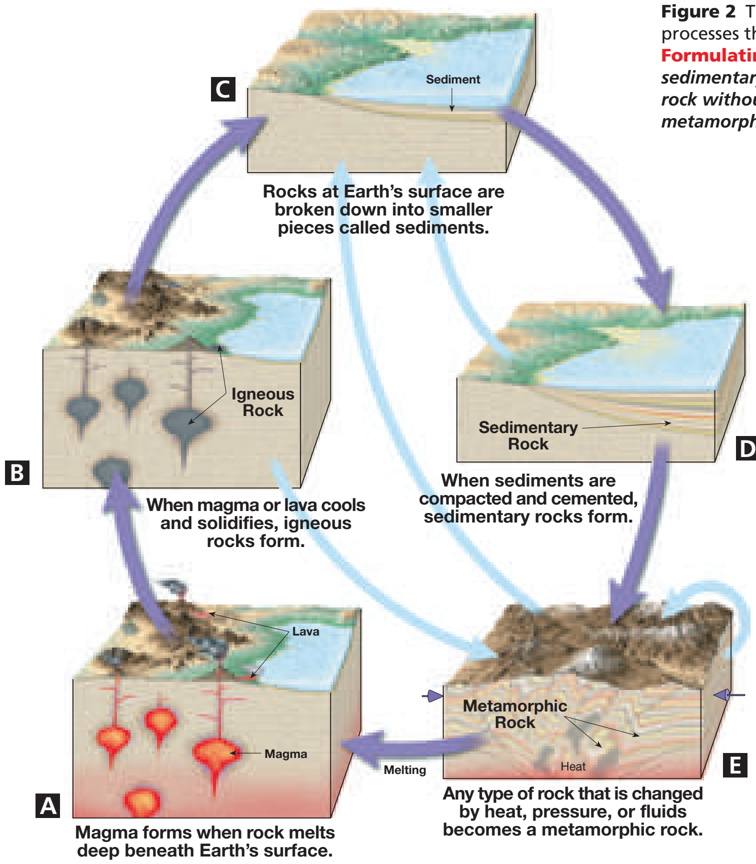


Figure 2 The rock cycle consists of many processes that change Earth's rocks. **Formulating Hypotheses** ***Can a sedimentary rock become an igneous rock without changing first to a metamorphic rock? Explain.***

Customize for English Language Learners

Encourage students to compile vocabulary terms into a science glossary. Have students consult dictionaries to obtain the pronunciation and definition of each term and then write these items in their glossaries. Model how to use the dictionary to determine the proper pronunciation of difficult words, such as *igneous* or *metamorphic*. Students may also want to draw simple diagrams next to the terms to further help them to remember each word's meaning. To reinforce language skills, have students arrange the terms in alphabetical order.

The Rock Cycle

Use Visuals L1

Figure 2 Point out that the arrows represent the processes that link each group to the others. Ask: **What processes form sedimentary rocks?** *(compaction and cementation)* **What possible changes might a sedimentary rock undergo?** *(A sedimentary rock might be broken back down into sediments. Heat and pressure could change it into a metamorphic rock.)* **What type of rock is formed by cooling magma or lava?** *(igneous rock)* **What happens to igneous rock that is weathered?** *(It is broken down into sediments.)*
Visual

Build Reading Literacy L1

Refer to **p. 186D** in **Chapter 7**, which provides the guidelines for relating text and visuals.

Relate Text and Visuals Tell students to read the text on pp. 67–68. Have them list any concepts about the rock cycle that are unclear or difficult to understand. Write a few of these concepts on the board. Then have students carefully study Figure 2. Using the list on the board, have volunteers explain how the visual helped them to better understand the rock cycle.
Verbal, Visual

Answer to . . .

Figure 2 *No, because any change in temperature and/or pressure will cause the sedimentary rock to become a metamorphic rock. If the temperatures and/or pressures are great enough, the metamorphic rock will melt to form magma, which will crystallize to form an igneous rock.*

Reading Checkpoint *Igneous rocks, sedimentary rocks, and metamorphic rocks are the three major types of rocks. Igneous rocks form when magma or lava cools. Sedimentary rocks form when sediments become compacted and cemented. Metamorphic rocks form when existing rocks are changed by heat, pressure, or solutions.*

Teacher Demo

Weathering

L2

Purpose Students will observe how ice can be an agent of weathering.

Materials 2-L plastic bottle with cap, water

Procedure Fill the plastic bottle nearly full with water and put on the cap. Have students note the level of the water. Place the bottle in the freezer for several hours, then have students observe the frozen water.

Expected Outcome Students will observe how the ice expanded and distorted the bottle. Tell them that in a similar way, water can seep through cracks and pores in rocks, then freeze and expand to break apart the rocks.
Visual

Build Science Skills

L2

ACTIVITY

Using Models Have students work with a partner to design simple models that show how pressure affects rocks. For example, students can place a heavy textbook on a sandwich or squeeze a piece of modeling clay between their hands.
Kinesthetic, Interpersonal

Figure 3 El Capitan in Yosemite National Park This granite was once buried deep beneath Earth's surface. Now that it is exposed, it will eventually weather and form sediments.

What will happen if an igneous rock that formed deep within Earth is exposed at the surface? Any rock at Earth's surface, including the granite shown in Figure 3, will undergo weathering. **Weathering** is a process in which rocks are physically and chemically broken down by water, air, and living things. These weathered pieces of earth materials are **sediments.** Sediments are often moved by water, gravity, glaciers, or wind. **Eventually, sediments are compacted and cemented to form sedimentary rock, as shown in Figure 2C and 2D.**

If the sedimentary rocks become buried deep within Earth, they will be subjected to increases in pressure and/or temperature. **Under extreme pressure and temperature conditions, sedimentary rock will change into metamorphic rock, as shown in Figure 2E.** If the metamorphic rocks are subjected to additional pressure changes or to still higher temperatures, they may melt to form magma. The magma will eventually crystallize to form igneous rock once again.

Facts and Figures

Some of the most important accumulations of metals, such as gold, silver, copper, mercury, lead, platinum, and nickel, are produced by igneous and metamorphic processes. For example, as a large magma body cools, the heavy minerals that crystallize early tend to settle to the lower portion of the magma chamber. This type of process is particularly active in large basaltic magmas where chromite, magnetite, and platinum are occasionally generated. Layers of chromite, an ore of chromium, are mined from such deposits in the Bushveld Complex in South Africa, which contains more than 70 percent of the world's known platinum reserves.

Alternate Paths

The purple arrows in Figure 2 show only one way in which an igneous rock might form and change. Other paths are just as likely to be taken as an igneous rock goes through the rock cycle. The blue arrows show a few of these alternate paths.

Suppose, for example, that an igneous rock remained deeply buried. Eventually, the rock could be subjected to strong forces and high temperatures such as those associated with mountain building. Then, the igneous rock could change into one or more kinds of metamorphic rock. If the temperatures and pressures were high enough, the igneous rock could melt and recrystallize to form new igneous rock.

Metamorphic and sedimentary rocks, as well as sediment, do not always remain buried. Often, overlying rocks are stripped away, exposing the rock that was once buried. When this happens, the rocks weather to form sediments that eventually become sedimentary rocks. However, if the sedimentary rocks become buried again, metamorphic rocks, like those used for the roof tiles in Figure 4, will form.

Where does the energy that drives Earth's rock cycle come from? **Processes driven by heat from Earth's interior are responsible for forming both igneous and metamorphic rocks. Weathering and the movement of weathered materials are external processes powered by energy from the sun. External processes produce sedimentary rocks.**

Figure 4 The roof on this house is made of slate. Slate is a metamorphic rock that forms from the sedimentary rock shale. **Explaining** ***How can shale become slate?***

Section 3.1 Assessment

Reviewing Concepts

1. What is a rock?
2. What are the three major types of rocks?
3. How do igneous, sedimentary, and metamorphic rocks differ?
4. What is the rock cycle?
5. What powers Earth's rock cycle?

Critical Thinking

6. **Comparing and Contrasting** Compare and contrast igneous and metamorphic rocks.
7. **Applying Concepts** How might a sedimentary rock become an igneous rock?
8. **Applying Concepts** List in order the processes that could change one sedimentary rock into another sedimentary rock.

Writing in Science

Writing to Persuade Coral reefs are made of calcite that is secreted by the corals and algae that make up the reefs. Over time, this calcite accumulates to form limestone. Use what you know about minerals and rocks to write a paragraph explaining whether or not you think that this limestone is a rock.

Alternate Paths

Use Community Resources L2

Invite a construction contractor to discuss with the class how various rocks are used as building materials. Ask the contractor to bring in sample supplies for students to examine. Have students prepare by brainstorming questions to ask the contractor about the different qualities of rocks, such as durability and strength.
Verbal

3 ASSESS

Evaluate Understanding L2

Have students draw sketches illustrating the source of the energy that drives the rock cycle. For example, to represent the interior processes that form igneous rocks, a sketch might show molten material deep inside Earth.

Reteach L1

Use Figure 2 to draw a diagram of the rock cycle that does not include arrows. Make copies of the diagram and distribute it to students. Have students add arrows showing the relationships among the processes of the rock cycle.

Writing in Science

Students should recall that most limestones are made from organic sediments such as shells and the secretions of corals. This limestone is a biochemical sedimentary rock.

Answer to . . .

Figure 4 *If shale is subjected to an increase in pressure and/or temperature, it can become the metamorphic rock called slate.*

Section 3.1 Assessment

1. Most rocks are mixtures of one or more minerals. Some rocks, however, are not made of minerals.
2. igneous rocks, sedimentary rocks, and metamorphic rocks
3. Rocks differ in the way they form. Igneous rocks form when magma or lava cools and solidifies. Sedimentary rocks form when sediments become compacted and cemented. Metamorphic rocks form when existing rocks are changed by heat, pressure, or solutions.
4. interactions among Earth's water, air, and land which cause rocks to change
5. processes deep within Earth and energy from the sun
6. Both form as the result of increases in pressure or temperature. Igneous rock formation involves melting, while the formation of metamorphic rocks does not.
7. The sedimentary rock could become buried at depths where temperatures and pressures were great enough to cause melting. When the melted material (magma) cooled and hardened, an igneous rock would form.
8. weathering, transportation, deposition, compaction, and cementation

Section 3.2

1 FOCUS

Section Objectives

3.5 Compare and contrast intrusive and extrusive igneous rocks.

3.6 **Demonstrate** how the rate of cooling affects an igneous rock's texture.

3.7 **Classify** igneous rocks according to texture and composition.

Reading Focus

Build Vocabulary L2

Word Parts To help students distinguish between intrusive and extrusive rocks, have them look up the meanings of the prefixes *in-* and *ex-*. Students will find that both prefixes stem from Latin terms. *In-* means "within or into"; *ex-* means "out of" or "outside." Point out that by knowing the meaning of these prefixes, students can better remember which igneous rocks form "within" Earth and which form "outside," or on, Earth's surface.

Reading Strategy L2

A.1. rock that forms when magma hardens beneath Earth's surface
A.2. Common example of igneous intrusive rock is granite.
B.1. rock that forms when lava hardens
B.2. Common example of igneous extrusive rock is rhyolite.

2 INSTRUCT

Build Science Skills L2

Inferring Reiterate that magma, which occurs beneath Earth's surface, often cools more slowly than lava, which occurs at Earth's surface. Then have students examine Figure 5. Ask them to use the photograph to infer why lava often cools more quickly than magma. *(Lava is exposed to air and water, which speeds up its cooling rate.)*
Logical

3.2 Igneous Rocks

Reading Focus

Key Concepts

- How are intrusive and extrusive igneous rocks alike and different?
- How does the rate of cooling affect an igneous rock's texture?
- How are igneous rocks classified according to composition?

Vocabulary

- intrusive igneous rock
- extrusive igneous rock
- porphyritic texture
- granitic composition
- basaltic composition
- andesitic composition
- ultramafic

Reading Strategy

Outlining Copy the outline and complete it as you read. Include points about how each of these rocks form, some of the characteristics of these rock types, and some examples of each.

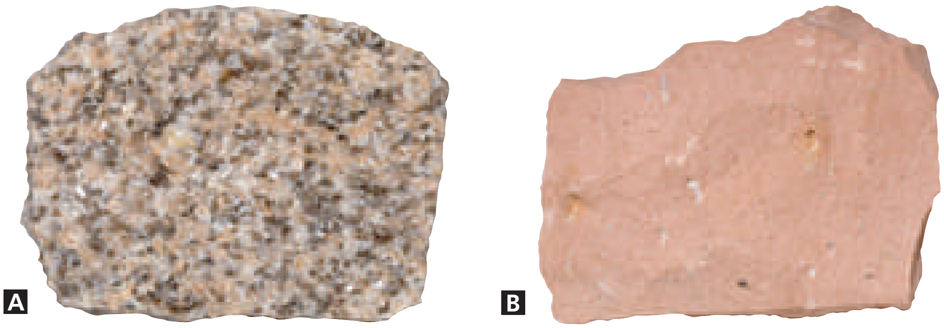
I. Igneous Rocks
  A. Intrusive Rocks
    1. ___?___
    2. ___?___
  B. Extrusive Rocks
    1. ___?___
    2. ___?___

Recall from the discussion of the rock cycle that igneous rocks form when magma or lava cools and hardens. When the red hot lava shown in Figure 5 cools, a dark-colored igneous rock called basalt will form. If this melted material had stayed deep beneath Earth's surface, a very different kind of igneous rock would have been produced as the material cooled. Different kinds of igneous rocks form when magma and lava cool and harden.

Figure 5 Basaltic Lava Lava from this Hawaiian volcano flows easily over Earth's surface. When this lava cools and hardens, the igneous rock called basalt will form.

Formation of Igneous Rocks

The word *igneous* comes from the Latin word *ignis,* which means "fire." Perhaps that is why people often associate igneous rock with fiery volcanic eruptions like the one shown in Figure 5. Igneous rock also forms deep beneath Earth's surface.



A

B

Figure 6 **A** Granite is an intrusive igneous rock that forms when magma cools slowly beneath Earth's surface. **B** Rhyolite is an extrusive igneous rock that forms when lava cools quickly at Earth's surface.

Intrusive Igneous Rocks **Rocks that form when magma hardens beneath Earth's surface are called intrusive igneous rocks.** That is because they *intrude* into the existing rocks. We would never see these deep rocks were it not for erosion stripping away the overlying rock.

Magma consists mainly of the elements silicon and oxygen, plus aluminum, iron, calcium, sodium, potassium, and magnesium. Magma also contains some gases, including water vapor. These gases are kept within the magma by the pressure of the surrounding rocks. Because magma is less dense than the surrounding rocks, it slowly works its way toward the surface. As magma rises, it cools, allowing elements to combine and form minerals. Gradually, the minerals grow in size, forming a solid mass of interlocking crystals. Granite, shown in Figure 6A, is a common intrusive igneous rock.

Extrusive Igneous Rocks You know that when magma reaches Earth's surface, it is called lava. Lava is similar to magma, except that in lava, most of the gases have escaped. **When lava hardens, the rocks that form are called extrusive igneous rocks.** That is because they are *extruded* onto the surface The rhyolite shown in Figure 6B is an extrusive igneous rock.

Q&A

Q *How are magma and lava the same, and how are they different?*

A Magma and lava are both terms used to describe melted rock. The composition of magma and lava can be the same. However, magma is melted material beneath Earth's surface. Lava is melted material at Earth's surface.

Formation of Igneous Rocks

Use Visuals **L1**

Figure 6 Ask: **In what ways are the two rocks similar?** *(Sample answer: Both are solids. Both are light-colored igneous rocks.)* **In what ways are the two rocks different?** *(Sample answer: The granite is multicolored and has a rough surface. The rhyolite is more uniformly colored and has a smoother surface.)*
Visual

Address Misconceptions **L2**

Ask students to describe the mass of rocks in relation to other solid objects. Some may mistakenly think that all rocks are heavy. Bring a sample of pumice into class. Pass around the rock, giving all students an opportunity to feel its heft. Many pumice samples will float in water. Place your sample in a pan of water to demonstrate this. Explain that some rocks, such as pumice, form when lava cools very quickly, leaving numerous air bubbles in the rock. The air bubbles cause pumice to be light.
Kinesthetic

Customize for Inclusion Students

Learning Disabled Have samples of igneous rocks available for students to examine. As they read the section, have them arrange the samples on a posterboard and write details about the texture and composition of the rocks under each sample. For example, students can write "coarse-grained, granitic" under a sample of granite.

Section 3.2 (continued)

Classification of Igneous Rocks

Teacher Demo

Crystal Formation L2

Purpose Students will observe how the rate of cooling affects crystal size.

Materials 2 shallow pans, 250-mL beaker, water, teaspoon, sulfur powder, thermal mitt, hot plate, magnifying glass

Procedure Put a teaspoon of sulfur powder into a shallow pan. Heat the pan until the sulfur melts, then place it aside to slowly cool. Heat another teaspoon of sulfur powder in a second shallow pan. Pour the melted sulfur into a beaker half-filled with water so that the sulfur cools quickly. Allow students to view the resulting crystals from both trials with a magnifying glass.

Expected Outcome Students will observe that cooling rates affect the size of crystals—the sulfur that cooled slowly formed larger crystals than the sulfur that cooled quickly.
Visual

Build Reading Literacy L1

Refer to **p. 362D** in **Chapter 13**, which provides the guidelines for using prior knowledge.

Use Prior Knowledge Ask students what they think of when they hear the word *texture*. Students will likely say that texture refers to the way an object feels to the touch. Ask them to describe some textures they have felt. *(Sample answers: rough, smooth, sticky, powdery)* Explain that the scientific meaning of *texture* in this section refers to the overall appearance of a rock based on the size, shape, and arrangement of its crystals.
Intrapersonal, Verbal

Q & A

Q *Native Americans used obsidian for making arrowheads and cutting tools. Is this the only material they used?*

A No. Native Americans used whatever materials were locally available to make tools, including any hard dense rock material that could be shaped. This includes materials such as the metamorphic rocks slate and quartzite, sedimentary deposits made of silica called jasper, chert, opal, flint, and even jade. Some of these deposits occur in only a few areas. That helps anthropologists reconstruct trade routes between different Native Americans groups.

Classification of Igneous Rocks

A quick glance at the two rocks in Figure 6 tells you that they are different. The granite contains large mineral grains. Only a few of the mineral grains in the sample of rhyolite can be seen with the unaided eye. **Texture and composition are two characteristics used to classify igneous rocks.** Texture describes the appearance of an igneous rock based on its size, shape, and the arrangement of its interlocking crystals. The composition classes of igneous rocks are based on the proportions of light and dark minerals in the rock.

Coarse-Grained Texture The rate of cooling strongly affects the textures of igneous rocks. If magma cools very slowly, few centers of crystal growth develop. Slow cooling also allows charged atoms, or ions, to move large distances within the magma. **Slow cooling results in the formation of large crystals.** Igneous rocks with large crystals exhibit a coarse-grained texture.

Fine-Grained Texture If cooling of magma or lava occurs rapidly, the ions in the melted material lose their motion and quickly combine. This results in a large number of tiny crystals that all compete for the available ions. **Rapid cooling of magma or lava results in rocks with small, interconnected mineral grains.** Igneous rocks with small grains are said to have a fine-grained texture.

Glassy Texture When lava spews onto Earth's surface, there may not be enough time for the ions in the lava to arrange themselves into a network of crystals. So the solids produced this way are made of randomly distributed ions. Such rocks have a glassy texture. The obsidian and pumice shown in Figure 1 on page 66 are igneous rocks with glassy textures.

Porphyritic Texture A large body of magma located deep within Earth may take tens of thousands of years to harden. Minerals that crystallize from the magma do not form at the same rate or at the same time. It is possible for some crystals to become quite large before others even start to form. The resulting rock can have large crystals, called phenocrysts, surrounded by fine-grained minerals. Rocks with very different-size minerals experience different rates of cooling. These rocks have a **porphyritic texture.** The igneous rock shown in Figure 7 has a porphyritic texture.

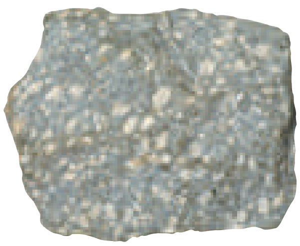


Figure 7 This sample of andesite displays igneous rock with a porphyritic texture.
Describing ***Describe how this rock probably formed.***

Reading Checkpoint ***How does the rate of cooling of magma or lava affect the texture of igneous rocks?***

Granitic Composition One group of igneous rocks includes those that are made almost entirely of the light-colored silicate minerals quartz and feldspar. Igneous rocks in which these are the main minerals are said to have a **granitic composition.** In addition to quartz and feldspar, most granitic rocks contain about 10 percent dark silicate minerals. These dark minerals are often biotite mica and amphibole. Granitic rocks contain about 70 percent silica and are the major rocks of the continental crust. Rhyolite is an extrusive granitic rock. Compare granite and rhyolite again in Figure 6 on page 71.

Go Online SCILINKS NSTA

For: Links on igneous rocks
Visit: www.SciLinks.org
Web Code: cjn-1032

Basaltic Composition Rocks that contain many dark silicate minerals and plagioclase feldspar have a **basaltic composition.** Basaltic rocks are rich in the elements magnesium and iron. Because of their iron content, basaltic rocks are typically darker and denser than granitic rocks. The most common basaltic rock is basalt, shown in Figure 8. Gabbro is an intrusive igneous rock with a basaltic composition.

Figure 8 Basalt is an igneous rock made mostly of dark-colored silicate minerals.
Describing ***Describe the texture of this igneous rock.***

Other Compositional Groups Rocks with a composition between granitic and basaltic rocks have an **andesitic composition.** This group of igneous rocks is named after the common volcanic rock andesite. Andesitic rocks contain at least 25 percent dark silicate minerals—mainly amphibole, pyroxene, and biotite mica. The other dominant mineral in andesitic rocks is plagioclase feldspar.

Another important igneous rock is peridotite. This rock contains mostly the minerals olivine and pyroxene. Because peridotite is composed almost entirely of dark silicate minerals, its chemical composition is referred to as **ultramafic.** Although ultramafic rocks are rare at Earth's surface, much of the upper mantle is thought to be made of peridotite.

Reading Checkpoint ***Describe the main differences between granitic and basaltic rocks.***

Integrate Chemistry

L2

In the early twentieth century, N. L. Bowen, a geologist, discovered that as magma cools, certain minerals crystallize first at very high temperatures. At successively lower temperatures, other minerals form. Bowen also demonstrated that if a mineral remains in the molten solution after crystallization, it will react with the remaining liquid to produce the next mineral, in a sequence known as Bowen's reaction series. Allow students to study Bowen's reaction series, Transparency 15. Tell them to compare the chart with Table 1 on p. 74. Ask: **What do you notice about the minerals that make up the rocks?** *(Each rock group consists of minerals that crystallize in the same temperature range.)*
Logical, Visual

Go Online NSTA SCILINKS

Download a worksheet on igneous rocks for students to complete, and find additional teacher support from NSTA SciLinks.

Facts and Figures

Magma is basically a very hot, thick fluid, but it also contains solids and gases. The solids are mineral crystals. The liquid portion of the magma body is composed of ions that move about freely. However, as magma cools, the random movements of the ions slow, and the ions begin to arrange themselves into orderly patterns. This process is called crystallization. Usually not all of the molten material solidifies at the same time. Rather, as it cools, numerous small crystals develop. In a systematic fashion, ions are added to these centers of crystal growth. When the crystals grow large enough for their edges to meet, their growth ceases for lack of space, and crystallization continues elsewhere. Eventually, all of the liquid is transformed into a solid mass of interlocking crystals.

Answer to . . .

Figure 7 *The rock experienced at least two episodes of cooling. Slow cooling resulted in the larger mineral grains. Rapid cooling produced the fine-grained minerals.*

Figure 8 *The rock is a fine-grained igneous rock.*

Reading Checkpoint *A slowly cooling magma or lava will produce rocks in which the mineral grains are relatively large. Quickly cooling molten material will result in rocks with small mineral grains. Lava that is cools extremely rapidly will produce a glassy rock. Rocks that form as the result of different cooling rates will have both large and small mineral grains.*

Reading Checkpoint *Granitic rocks contain mostly quartz and feldspar and thus are light-colored. Basaltic rocks are rich in iron and thus are dark-colored and more dense.*

Section 3.2 (continued)

Use Visuals L1

Table 1 Make sure all students can clearly read the table. If necessary, make enlarged copies of the table for students. Ask: **Which rocks have the highest percentage of dark minerals?** *(ultramafic rocks)* **Identify a coarse-grained basaltic rock.** *(gabbro)* **What minerals are in granite?** *(quartz, potassium feldspar, sodium-rich plagioclase feldspar)*
Visual

3 ASSESS

Evaluate Understanding L2

Using Table 1 as a guide, have each student make two tables. One table should show the different textures of igneous rocks. The second table should show the composition of igneous rocks.

Reteach L1

Use a simple graphic to help summarize the relationship between cooling rate and crystal size in igneous rocks. For example, draw an arrow pointing upward on the board. Label the arrow "Cooling rate." Ask: **As the rate of cooling increases, what happens to crystal size?** *(It decreases.)* To illustrate the answer, draw a downward-pointing arrow next to the first arrow. Label this second arrow "Crystal size."

Writing in Science

Sample answer: Obsidian likely formed when lava reached Earth's surface and cooled very rapidly. Refer to the text and Table 1 to evaluate students' answers.

To summarize, igneous rocks form when magma or lava cools and hardens. Intrusive rocks form when magma cools and hardens deep within Earth. Extrusive rocks form when lava cools and hardens on Earth's surface. Igneous rocks can be classified according to texture and composition. A general classification scheme based on texture and mineral composition is shown in Table 1.

Table 1 Classification of Major Igneous Rocks

	Chemical Composition	Granitic	Andesitic	Basaltic	Ultramafic
	Dominant Minerals	Quartz Potassium feldspar Sodium-rich plagioclase feldspar	Amphibole Sodium- and calcium-rich plagioclase feldspar	Pyroxene Calcium-rich plagioclase feldspar	Olivine Pyroxene
TEXTURE	Coarse-grained	**Granite**	**Diorite**	**Gabbro**	**Peridotite**
	Fine-grained	**Rhyolite**	**Andesite**	**Basalt**	**Komatiite** (rare)
	Porphyritic	"Porphyritic" precedes any of the above names whenever there are appreciable phenocrysts.			Uncommon
	Glassy	**Obsidian** (compact glass) **Pumice** (frothy glass)			
	Rock Color (based on % of dark minerals)	0% to 25%	25% to 45%	45% to 85%	85% to 100%

Section 3.2 Assessment

Reviewing Concepts

1. Compare and contrast the formation of intrusive and extrusive igneous rocks.
2. How do coarse-grained igneous rocks form?
3. How are igneous rocks classified according to composition?
4. How do fine-grained igneous rocks form?
5. How do igneous rocks with glassy textures form?

Critical Thinking

6. **Contrasting** Contrast basalt and granite in terms of how each forms, the texture of each rock, the color of each rock, and each rock's composition.
7. **Formulating Hypotheses** The extrusive igneous rock pumice contains many small holes. Hypothesize how these holes might form.

Writing in Science

Explanatory Paragraph Write a paragraph to explain how one of the igneous rocks pictured in this chapter may have formed.

Section 3.2 Assessment

1. Both types of rocks form when molten material cools and solidifies. Intrusive igneous rocks form when magma cools and solidifies within Earth. Extrusive igneous rocks form when lava cools and hardens at the surface.
2. Coarse-grained igneous rocks form when magma cools slowly within Earth.
3. Igneous rocks can be classified by composition based on the major minerals in the rocks. Light-colored rocks have granitic compositions. Dark-colored rocks have basaltic compositions. Dark-colored rocks that contain only olivine and pyroxene are ultramafic rocks.
4. Fine-grained igneous rocks form when lava cools quickly at Earth's surface.
5. Igneous rocks with glassy textures form when lava cools very quickly.
6. Granite forms as magma slowly cools below the surface. This slow rate of cooling produces large mineral grains. Most of these minerals are quartz and feldspar, thus granite is light-colored, with a granitic composition. Basalt forms when lava cools quickly at the surface. This quick cooling rate results in very small mineral grains. The major minerals in basalt are dark-colored silicates that give basalt its dark color. A basalt has a basaltic composition.
7. Lava is magma that reaches the surface. As it rises, reduced pressure on the magma causes some of its gases to come out of solution. These gases form bubbles or holes as the molten material cools.

3.3 Sedimentary Rocks

Reading Focus

Key Concepts

- Describe the major processes involved in the formation of sedimentary rocks.
- What are clastic sedimentary rocks?
- What are chemical sedimentary rocks?
- What features are unique to some sedimentary rocks?

Vocabulary

- erosion
- deposition
- compaction
- cementation
- clastic sedimentary rock
- chemical sedimentary rock

Reading Strategy

Outlining Copy this outline beneath the outline you made for Section 3.2. Complete this outline as you read. Include points about how each of these rocks form, some of the characteristics of each rock type, and some examples of each.

II. Sedimentary Rocks
  A. Clastic Rocks
    1. ___?___
    2. ___?___
  B. Chemical Rocks
    1. ___?___
    2. ___?___

All sedimentary rocks begin to form when existing rocks are broken down into sediments. Sediments, which consist mainly of weathered rock debris, are often transported to other places. When sediments are dropped, they eventually become compacted and cemented to form sedimentary rocks. The structures shown in Figure 9 are made of the sedimentary rock called sandstone. It is only one of many types of sedimentary rocks.

Figure 9 Sedimentary Rocks in Canyonlands National Park, Utah The rocks shown here formed when sand and other sediments were deposited and cemented. Weathering processes created this arch.

Section 3.3

1 FOCUS

Section Objectives

3.8 **Describe** the major processes involved in the formation of sedimentary rocks.

3.9 **Distinguish** between clastic sedimentary rocks and chemical sedimentary rocks.

3.10 **Identify** the features that are unique to some sedimentary rocks.

Reading Focus

Build Vocabulary L2

LINCS Have students **L**ist the parts of the vocabulary words that they know. For example, *cement* is part of *cementation*. Next, they should **I**magine a mental picture of the term's meaning and describe the image in their own words. Sediments held together by cement might be an image for cementation. Students should then make a **N**ote of a familiar "sound-alike" word. They can **C**onnect the terms by making up a short story about the meaning of the term that incorporates the sound-alike word. Lastly, students should conduct a **S**elf-test by quizzing themselves on the vocabulary terms.

Reading Strategy L2

A.1. rock made up of weathered bits of rocks and minerals
A.2. Common example of clastic sedimentary rock is shale.
B.1. rock that forms when dissolved minerals precipitate from water
B.2. Common example of chemical sedimentary rock is limestone.

Section 3.3 (continued)

2 INSTRUCT

Build Reading Literacy L1

Refer to **p. 64D** in **Chapter 3**, which provides the guidelines for directed reading/thinking activity (DRTA).

DRTA Before students read this section, have them preview the key concepts, vocabulary terms, and headings. Ask: **What do you think you will learn in this section?** *(Sample answer: about sedimentary rock formation, clastic sedimentary rocks, and chemical sedimentary rocks)* **What type of questions might a teacher ask about this topic?** *(Sample answer: How do sedimentary rocks form? How are sedimentary rocks classified?)* List these questions on the board. As students read the section, pause to discuss the answers to the questions.
Verbal

Formation of Sedimentary Rocks

Address Misconceptions L2

Some students may think that rocks are stronger than the agents of mechanical and chemical weathering. To help dispel this misconception, place a few drops of vinegar on a sample of limestone. Have students observe the resulting chemical reaction. Ask: **What do you think would happen if the acid continued to drip on the rock over a long period?** (*The rock would eventually break down or be chemically weathered.)*
Visual, Logical

Build Science Skills L2

Observing Provide small groups of students with 250-mL beakers, stirrers, sand, water, gravel, and soil. Tell students to half-fill the beakers with water. They should then pour about a handful of each material into the water. Have them stir the mixture, then observe what happens to the materials. Ask: **Which materials settled on the bottom? Which settled on the top?** *(The heavier materials settled on the bottom; the smaller, lighter materials settled on the top.)* **What does this activity model?** *(the settling out of sediments from a fluid, such as water or air)*
Kinesthetic, Visual

Formation of Sedimentary Rocks

The word *sedimentary* comes from the Latin word *sedimentum*, which means "settling." Sedimentary rocks form when solids settle out of a fluid such as water or air. The rocks shown in Figure 10 formed when sediments were dropped by moving water. The sediments eventually became cemented to form rocks. Several major processes contribute to the formation of sedimentary rocks.

Weathering, Erosion, and Deposition Recall that weathering is any process that breaks rocks into sediments. Weathering is often the first step in the formation of sedimentary rocks. Chemical weathering takes place when the minerals in rocks change into new substances. Weathering also takes place when physical forces break rocks into smaller pieces. Living things, too, can cause chemical and physical weathering.

Weathered sediments don't usually remain in place. Instead, water, wind, ice, or gravity carries them away. **Erosion involves weathering and the removal of rock. When an agent of erosion—water, wind, ice, or gravity—loses energy, it drops the sediments. This process is called deposition.** Sediments are deposited according to size. The largest sediments, such as the rounded pebbles in the conglomerate in Figure 10A, are deposited first. Smaller sediments, like the pieces of sand that make up the sandstone in Figure 10B, are dropped later. Some sediments are so small that they are carried great distances before being deposited.

A
B

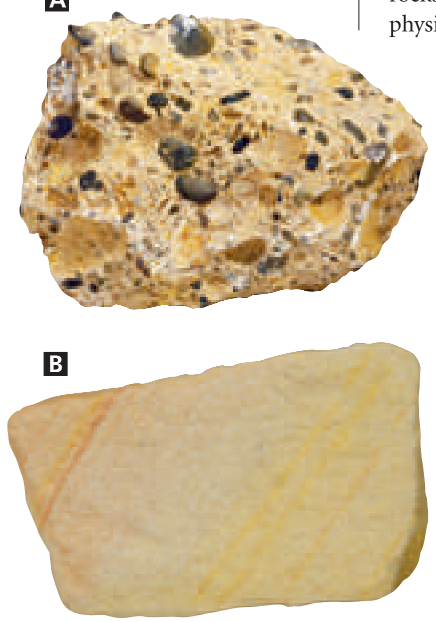


Figure 10 Although these two rocks appear quite different, both formed when sediments were dropped by moving water. **A** Conglomerate is made of rounded pebbles cemented together. **B** Sandstone is made of sand grains cemented together.

Compaction and Cementation After sediments are deposited, they often become lithified, or turned to rock. **Compaction** and **cementation** change sediments into sedimentary rock. **Compaction is a process that squeezes, or compacts, sediments.** Compaction is caused by the weight of sediments. During compaction, much of the water in the sediments is driven out.

Cementation takes place when dissolved minerals are deposited in the tiny spaces among the sediments. Much of the cement in the conglomerate shown in Figure 10A can be seen with the unaided eye. The cement holding the sand grains together in the sandstone in Figure 10B, however, is microscopic.

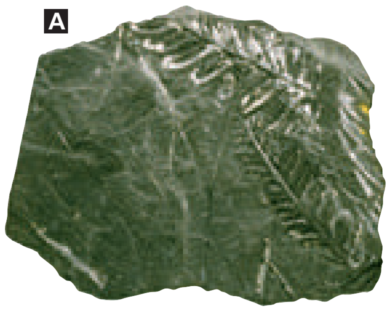
Reading Checkpoint ***Briefly describe the five major processes involved in the formation of sedimentary rocks.***

Customize for English Language Learners

Compile a classroom library using up-to-date magazines and newspaper articles. Select reading materials that correspond to chapter content. For example, try to find articles that discuss different types of rocks. Avoid academic journals and reference materials with high reading levels. Provide opportunities for ELL students to read the articles in class. This will give them a broader context in which to place this chapter's vocabulary terms and key concepts.

Classification of Sedimentary Rocks

Just like igneous rocks, sedimentary rocks can be classified into two main groups according to the way they form. The first group includes rocks that are made of weathered bits of rocks and minerals. These rocks are called **clastic sedimentary rocks.** The second group forms when dissolved minerals precipitate from water solutions. These rocks are called **chemical sedimentary rocks.**



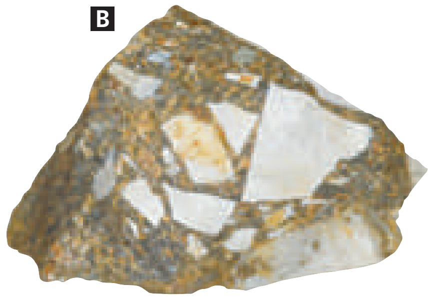


Figure 11 A Shale and **B** breccia are common clastic sedimentary rocks. This sample of shale contains plant fossils. **Formulating Hypotheses** ***How do you think this breccia might have formed?***

Clastic Sedimentary Rocks Many different minerals are found in clastic rocks. The most common are the clay minerals and quartz. This is because clay minerals, like those that make up much of the shale in Figure 11A, are the most abundant products of chemical weathering. Quartz, which is a major mineral in the breccia shown in Figure 11B, is a common sedimentary mineral for a different reason. It is very durable and resistant to chemical weathering.

Clastic sedimentary rocks can be grouped according to the size of the sediments in the rocks. When rounded, gravel-size or larger particles make up most of the rock, the rock is called conglomerate. If the particles are angular, the rock is called breccia. Sandstone is the name given to rocks when most of the sediments are sand-size grains. Shale, the most common sedimentary rock, is made of very fine-grained sediment. Siltstone is another fine-grained rock.

Reading Checkpoint *Describe the major types of clastic sedimentary rocks.*

Chemical and Biochemical Sedimentary Rocks Chemical sedimentary rocks form when dissolved substances precipitate, or separate, from water solution. This precipitation generally occurs when the water evaporates or boils off leaving a solid product. Examples of this type of chemical rock are some limestones, rock salt, chert, flint, and rock gypsum.

Go Online NSTA SCILINKS

For: Links on sedimentary rocks
Visit: www.SciLinks.org
Web Code: cjn-1034

Classification of Sedimentary Rocks

Teacher Demo

Chemical Weathering L2

Purpose Students will observe how chemical weathering can change the minerals in rocks.

Materials calcium tablet, 250-mL beaker, vinegar

Procedure Half-fill the beaker with vinegar. Place the calcium tablet into the vinegar. Allow students to observe the reaction.

Expected Outcome Students will observe that the calcium fizzes, foams, and eventually dissolves in the vinegar. Explain that chemical weathering breaks down rocks in a similar, though slower, fashion.

Visual

Go Online NSTA SCILINKS

Download a worksheet on sedimentary rocks for students to complete, and find additional teacher support from NSTA SciLinks.

Answer to . . .

Figure 11 *Rocks were weathered. The larger fragments were deposited. Fine-grained sediments were deposited later. Little compaction occurred because of the size of the angular sediments. Dissolved minerals entered the spaces among the sediments and held them together to form the breccia.*

Reading Checkpoint *Weathering breaks existing rocks into smaller pieces. Erosion is the process whereby sediments are moved from place to place. Deposition occurs when sediments are dropped by erosional agents. Compaction is the process of squeezing sediments. Cementation is a process that "glues" sediments together to form sedimentary rocks.*

Reading Checkpoint *Conglomerates and breccias are made mostly of gravel-sized sediments. Sandstone is made mostly of sand-size grains. Shale and siltstone are fine-grained rocks in which clay-size or smaller particles are the major components.*

Section 3.3 (continued)

Build Science Skills

L2

Designing Experiments

ACTIVITY

Have students work in small groups to design an experiment to show how sedimentary rocks form when dissolved minerals precipitate from water. Students should develop a hypothesis and procedure, listing controls, safety measures, and materials to be used. A sample experiment might involve placing table salt in water, then heating the water until it evaporates. If time permits, allow students to carry out their experiments. **Logical, Interpersonal**

Features of Some Sedimentary Rocks

Use Visuals

L1

Figure 13 Ask: **Based on its appearance, what can you infer about the rock labeled A?** *(It may have formed along a beach or stream bed.)* **What can you infer about the rock labeled B?** *(It may have formed when wet mud or clay dried and shrank.)* **Visual**

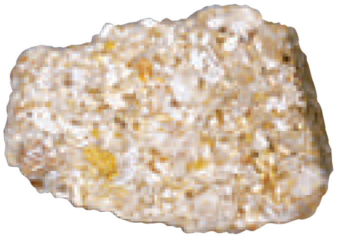


Figure 12 This biochemical rock, called coquina, is a type of limestone that is made of hundreds of shell fragments.

About 90 percent of limestones are formed from biochemical sediments. Such sediments are the shells and skeletal remains of organisms that settle to the ocean floor. The coquina in Figure 12 is one obvious example. You can actually see the shells cemented together. Another biochemical rock is chalk, the material used to write on a chalkboard.

Features of Some Sedimentary Rocks

Sedimentary rocks, like other types of rocks, are used to unravel what may have happened in Earth's long history. **The many unique features of sedimentary rocks are clues to how, when, and where the rocks formed.** Each layer of a sedimentary rock, for example, records a period of sediment deposition. In undisturbed rocks, the oldest layers are found at the bottom. The youngest layers are found at the top of the rocks. Ripple marks like the ones shown in Figure 13A may indicate that the rock formed along a beach or stream bed. The mud cracks in Figure 13B formed when wet mud or clay dried and shrank, leaving a rock record of a dry environment.

Fossils, which are the traces or remains of ancient life, are unique to some sedimentary rocks. Fossils can be used to help answer many questions about the rocks that contain them. For example, did the rock form on land or in the ocean? Was the climate hot or cold, rainy or dry? Did the rock form hundreds, thousands, millions, or billions of years ago? Fossils also play a key role in matching up rocks from different places that are the same age.

To summarize, sedimentary rocks are rocks that form as the result of four major processes. *Weathering* produces particles called sediments. Wind, water, ice, and gravity *erode* and *deposit* these sediments. Over time, the sediments are *compacted and cemented* to form rocks. Sedimentary rocks can be classified according to how they form. A general classification scheme based on a rock's formation, texture, and composition is shown in Table 2.

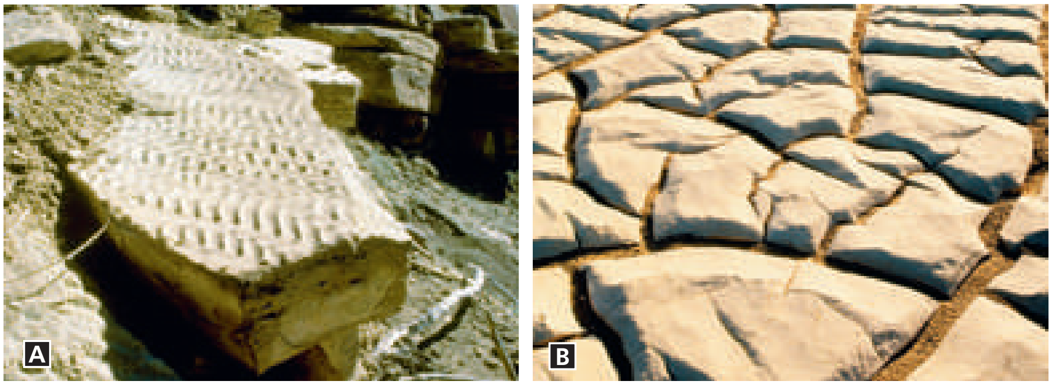


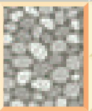
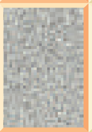
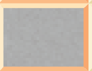
Figure 13 **A** Ripple marks and **B** mud cracks are features of sedimentary rocks that can be used to learn about the environments in which the rocks formed.

Facts and Figures

Unlike other chemical sedimentary rocks, which are rich in calcite or silica, coal is made mostly of organic matter. When coal is viewed under a magnifying glass, chemically altered leaves, bark, and wood are visible. The materials provide evidence that coal is the end product of the burial of large amounts of plant materials over long periods of time. The initial stage of coal formation is the accumulation of large quantities of plant remains in a swampy environment. Coal then undergoes successive stages of formation. With each stage, higher temperatures and pressures drive off impurities and volatiles.

Table 2 Classification of Major Sedimentary Rocks

Clastic Sedimentary Rocks

Texture (grain size)		Sediment Name	Rock Name
Coarse (over 2 mm)		Gravel (rounded fragments)	**Conglomerate**
		Gravel (angular fragments)	**Breccia**
Medium (1/16 to 2 mm)		Sand	**Sandstone**
Fine (1/16 to 1/256 mm)		Mud	**Siltstone**
Very fine (less than 1/256 mm)		Mud	**Shale**

Chemical Sedimentary Rocks

Composition	Texture (grain size)	Rock Name	
Calcite, $CaCO_3$	Fine to coarse crystalline	**Crystalline Limestone**	
		Travertine	
	Visible shells and shell fragments loosely cemented	**Coquina**	**Biochemical Limestone**
	Various size shells and shell fragments cemented with calcite cement	**Fossiliferous Limestone**	
	Microscopic shells and clay	**Chalk**	
Quartz, SiO_2	Very fine crystalline	**Chert (light colored) Flint (dark colored)**	
Gypsum $CaSO_4 \cdot 2H_2O$	Fine to coarse crystalline	**Rock Gypsum**	
Halite, NaCl	Fine to coarse crystalline	**Rock Salt**	
Altered plant fragments	Fine-grained organic matter	**Bituminous Coal**	

Section 3.3 Assessment

Reviewing Concepts

1. Contrast weathering, erosion, and deposition.
2. Name four clastic sedimentary rocks and explain how these rocks form.
3. Name four chemical sedimentary rocks and explain how these rocks form.
4. Explain how three different features of sedimentary rocks can be used to determine how, where, or when the rocks formed.
5. What is compaction?
6. Where do the cements that hold sediments together come from?

Critical Thinking

7. **Applying Concepts** Briefly describe how the rock shown in Figure 12 may have formed.
8. **Predicting** Which type of sediments do you think would undergo more compaction—grains of sand or grains of clay? Explain your choice.
9. **Formulating Conclusions** Suppose you found a sedimentary rock in which ripple marks were pointing toward the ground. What could you conclude about the rock?

Connecting Concepts

Sedimentary Rocks Choose one of the sedimentary rocks pictured in this section. Find out how the rock is useful to people.

Use Visuals L1

Table 2 Ask: **How does the texture of gravel compare with that of sand?** *(Gravel has a coarse texture; grain size is more than 2 mm. Sand has a medium texture; grain size is 1/16 to 2 mm.)* **What type of detrital sedimentary rock has a very fine texture?** *(shale)* **What is the chemical composition of chalk?** *(calcite)* **Which chemical sedimentary rock is made up of halite?** *(rock salt)*
Visual

3 ASSESS

Evaluate Understanding L2

Give students samples of sandstone, siltstone, shale, breccia, and conglomerate. Have them use magnifying glasses to classify the rocks according to grain size.

Reteach L1

Review Table 2. As you discuss the different types of textures and chemical compositions, explain how each sedimentary rock likely formed.

Connecting Concepts

Sample answer: Shale is used in construction. Coal is used as an energy resource.

Section 3.3 Assessment

1. Weathering is any process in which rocks are broken down into smaller pieces. Erosion involves the weathering and removal of sediments. Deposition is the dropping of sediments by agents of erosion.
2. Conglomerate, breccia, sandstone, shale, and siltstone are clastic rocks. Clastic rocks form when bits of weathered materials are compacted and cemented together.
3. Most limestones, rock salt, rock gypsum, flint, and chert are chemical sedimentary rocks that form when dissolved minerals precipitate from water.
4. Each layer of a sedimentary rock records a period of deposition. Ripple marks indicate that a rock bed formed in water. Mud cracks are indicative of unusually dry periods. Fossils can be used to determine if a rock formed on land or in the ocean, if the climate was hot or cold, or rainy or dry, and when the rock containing them formed.
5. Compaction is the process that squeezes, or compacts, sediments.
6. Cements are dissolved minerals that are deposited in the tiny places among the sediments.
7. Animals with shells died. The shells accumulated and became cemented to form a sedimentary rock.
8. Because they are smaller, clay particles undergo more compaction than sand-size particles.
9. Ripple marks indicate that a rock formed in water. And, because the ripple marks were pointing down, one can infer that the rock has been overturned from its original position.

Section 3.4

1 FOCUS

Section Objectives

3.11 **Predict** where most metamorphism takes place.
3.12 **Distinguish** contact metamorphism from regional metamorphism.
3.13 **Identify** the three agents of metamorphism and **explain** what changes they cause.
3.14 **Recognize** foliated metamorphic rocks and **describe** how they form.
3.15 **Classify** metamorphic rocks.

Reading Focus

Build Vocabulary L2

Paraphrase Explain vocabulary terms using words students know. For example, *contact metamorphism* occurs when two rocks come into contact with one another. *Regional metamorphism* takes place over a large region. *Foliated metamorphic rocks* have distinct layers. *Nonfoliated metamorphic rocks* do not. Once students are able to distinguish among the vocabulary terms, focus on the processes that cause the different types of metamorphism and the different types of metamorphic rock.

Reading Strategy L2

A.1. rock that forms when minerals recrystallize at right angles to the direction of pressure
A.2. Common example of foliated metamorphic rock is slate.
B.1. rock that does not have a banded texture
B.2. Common example of nonfoliated metamorphic rock is marble.

2 INSTRUCT

Formation of Metamorphic Rocks

Use Visuals L1

Figure 14 Ask students to describe the rocks. *(Sample answer: The rocks are folded and multicolored.)* **What force could cause the rocks to fold?** *(intense pressure)*
Visual

3.4 Metamorphic Rocks

Reading Focus

Key Concepts

- Where does most metamorphism take place?
- How is contact metamorphism different from regional metamorphism?
- What are three agents of metamorphism, and what kinds of changes does each cause?
- What are foliated metamorphic rocks, and how do they form?
- How are metamorphic rocks classified?

Vocabulary

- metamorphism
- contact metamorphism
- regional metamorphism
- hydrothermal solution
- foliated metamorphic rock
- nonfoliated metamorphic rock

Reading Strategy

Outlining Copy this outline beneath the outline you made for Section 3.3. Complete it as you read. Include points about how each of these rocks form, some of the characteristics of each rock type, and some examples of each.

III. Metamorphic Rocks
  A. Foliated Rocks
    1. ___?___
    2. ___?___
  B. Nonfoliated Rocks
    1. ___?___
    2. ___?___

Figure 14 Deformed Rock Intense pressures metamorphosed these rocks by causing them to fold as well as change composition.

Recall that metamorphic rocks form when existing rocks are changed by heat and pressure. **Metamorphism** is a very appropriate name for this process because it means *to change form.* Rocks produced during metamorphism often look much different from the original rocks, or parent rocks. The folds in the rocks shown in Figure 14 formed when the parent rocks were subjected to intense forces. These highly folded metamorphic rocks may also develop a different composition than the parent rocks had.

Formation of Metamorphic Rocks

Most metamorphic changes occur at elevated temperatures and pressures. These conditions are found a few kilometers below Earth's surface and extend into the upper mantle. Most metamorphism occurs in one of two settings—contact metamorphism or regional metamorphism.

Contact Metamorphism When magma intrudes—forces its way into—rock, contact metamorphism may take place. **During contact metamorphism, hot magma moves into rock.** Contact metamorphism often produces what is described as low-grade metamorphism. Such changes in rocks are minor. Marble, like that used to make the statue in Figure 15, is a common contact metamorphic rock. Marble often forms when magma intrudes a limestone body.

Figure 15 Statue Carved from Marble Marble is a common metamorphic rock that forms as the result of contact metamorphism of limestone.

Regional Metamorphism During mountain building, large areas of rocks are subjected to extreme pressures and temperatures. The intense changes produced during this process are described as high-grade metamorphism. **Regional metamorphism results in large-scale deformation and high-grade metamorphism.** The rocks shown in Figure 14 on page 80 were changed as the result of regional metamorphism.

Agents of Metamorphism

The agents of metamorphism are heat, pressure, and hydrothermal solutions. During metamorphism, rocks are usually subjected to all three of these agents at the same time. However, the effect of each agent varies greatly from one situation to another.

Heat The most important agent of metamorphism is heat. Heat provides the energy needed to drive chemical reactions. Some of these reactions cause existing minerals to recrystallize. Other reactions cause new minerals to form. The heat for metamorphism comes mainly from two sources—magma and the change in temperature with depth. Magma essentially "bakes" any rocks that are in contact with it. Heat also comes from the gradual increase in temperature with depth. In the upper crust, this increase averages between 20°C and 30°C per kilometer.

When buried to a depth of about 8 kilometers, clay minerals are exposed to temperatures of 150°C to 200°C. These minerals become unstable and recrystallize to form new minerals that are stable at these temperatures, such as chlorite and muscovite. In contrast, silicate minerals are stable at these temperatures. Therefore, it takes higher temperatures to change silicate minerals.

Reading Checkpoint *Compare and contrast contact and regional metamorphism.*

Q & A

Q *How hot is it deep in the crust?*

A The deeper a person goes beneath Earth's surface, the hotter it gets. The deepest mine in the world is the Western Deep Levels mine in South Africa, which is about 4 kilometers deep. Here, the temperature of the surrounding rock is so hot that it can scorch human skin. In fact, miners in this mine often work in groups of two. One miner mines the rock, and the other operates a large fan that keeps the worker cool.

Build Science Skills L2

Posing Questions Have students read the text about contact metamorphism and regional metamorphism. Then have them pose questions about the concepts that can be answered through experimentation, observation, or research. A sample question might be: During contact metamorphism, what causes the magma to move into the rock? *(Magma is less dense than surrounding rock so pressure forces it toward the surface. As it moves, it can come into contact with and alter surrounding rock.)*
Logical

Agents of Metamorphism

Integrate Physics L2

Buried rocks are subject to a force known as *confining pressure*, wherein pressure is applied equally in all directions. In contrast, *differential stress* is unequal force applied in different directions. Differential stress, which occurs during mountain-building, acts mainly along one plane. Rocks subjected to differential stress are shortened in the direction in which pressure is applied and lengthened in the direction perpendicular to the pressure. Have students observe while you squeeze a ball of clay between your palms. Ask: **Is this an example of confining pressure or differential stress?** *(differential stress)*
Kinesthetic, Visual

Customize for Inclusion Students

Behaviorally Disordered Minimize distractions for students with behavioral disorders. For example, have students sit near the front of the class so that they are focused on you, rather than their classmates. Before conducting any activities, make sure students clear off their desks. If necessary, provide storage space in the classroom for students' books and other materials.

Answer to . . .

Reading Checkpoint *Both processes change existing rocks into metamorphic rocks. Contact metamorphism is caused by magma and often produces slight changes in rocks. Regional metamorphism is large-scale deformation that can result in drastic changes to the rocks involved.*

Quick Lab

Observing Some of the Effects of Pressure on Mineral Grains L2

Objective
After completing this activity, students will be able to observe the effect of pressure on the rearrangement of mineral grains in a model rock.

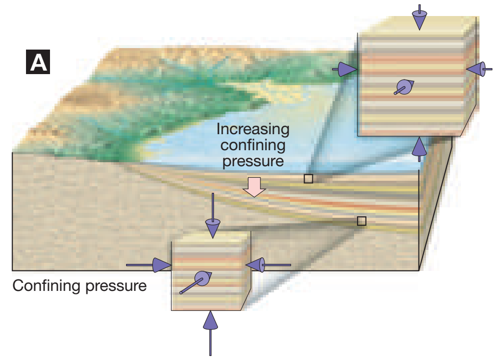
Skills Focus **Modeling, Observing, Inferring**

Prep Time 10 minutes to organize materials

Class Time 15 minutes

Expected Outcome Students will observe that the pressure from opposite directions—from above (their pushing down on the "rock") and below (the table's pushing up on the "rock")—will cause "minerals" to align at right angles to the direction of stress.

Analyze and Conclude
1. The model minerals were randomly distributed throughout the rock before pressure was applied. The minerals aligned themselves at right angles to the direction of stress.
2. Pressure causes the minerals to reorient themselves in the rock.
3. No, heat from the hand and contact with the table also affected the model rock.
Kinesthetic, Visual



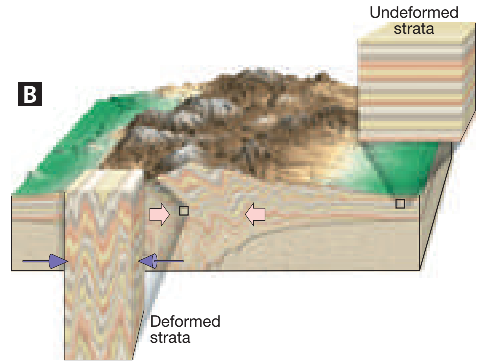


Figure 16 Pressure (Stress) As a Metamorphic Agent
A Forces in all directions are applied equally to buried rocks.
B During mountain building, rocks subjected to differential stress are shortened in the direction that pressure is applied.

Figure 17 Imagine the tremendous amounts of pressure that caused these rocks to fold.

Pressure (Stress) Pressure, like temperature, also increases with depth. Like the water pressure you might have experienced at the bottom of a swimming pool, pressure on rocks within Earth is applied in all directions. See Figure 16. Pressure on rocks causes the spaces between mineral grains to close. The result is a more compact rock with a greater density. This pressure also may cause minerals to recrystallize into new minerals.

Increases in temperature and pressure cause rocks to flow rather than fracture. Under these conditions, mineral grains tend to flatten and elongate.

Quick Lab

Observing Some of the Effects of Pressure on Mineral Grains

Materials

soft modeling clay; 2 pieces of waxed paper (each 20 cm × 20 cm); 20–30 small, round, elongated plastic beads; small plastic knife

Procedure

1. Use the clay to form a ball about the size of a golf ball. Randomly place all of the beads into this model rock.
2. Make a sketch of the rock. Label the sketch *Before*.
3. Sandwich the model rock between the two pieces of waxed paper. Use your weight to apply pressure to the model rock.
4. Remove the waxed paper and observe your "metamorphosed" rock.
5. Draw a top view of your rock and label it *After*. Include arrows to show the directions from which you applied pressure.
6. Make a cut through your model rock. Sketch this view of the rock.

Analyze and Conclude

1. **Comparing and Contrasting** How did the *Before* sketch compare with the *After* sketch of your model rock?
2. **Drawing Conclusions** How does pressure affect the mineral grains in a rock?
3. **Inferring** Was pressure the only agent of change that affected your rock? Explain.

During mountain building, horizontal forces metamorphose large segments of Earth's crust. This often produces intricately folded rocks like those shown in Figure 17.

Reactions in Solution Water solutions containing other substances that readily change to gases at the surface play an important role in some types of metamorphism. Solutions that surround mineral grains aid in recrystallization by making it easier for ions to move. When solutions increase in temperature reactions among substances can occur at a faster rate. When these hot, water-based solutions escape from a mass of magma, they are called **hydrothermal solutions.** These hot fluids also promote recrystallization by dissolving original minerals and then depositing new ones. As a result of contact with hydrothermal solutions, a change in a rock's overall composition may occur.

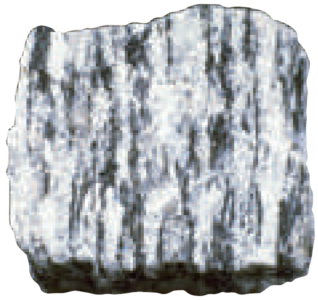


Figure 18 Gneiss is a foliated metamorphic rock. **Inferring** ***In which directions was pressure exerted on this rock?***

Classification of Metamorphic Rocks

Like igneous rocks, metamorphic rocks can be classified by texture and composition. **The texture of metamorphic rocks can be foliated or nonfoliated.**

Foliated Metamorphic Rocks When rocks undergo contact metamorphism, they become more compact and thus more dense. A common example is the metamorphic rock slate. Slate forms when shale is subjected to temperatures and pressures only slightly greater than those at which the shale formed. The pressure on the shale causes the microscopic clay minerals to become more compact. The increase in pressure also causes the clay minerals to align in a similar direction.

Under more extreme conditions, certain minerals will recrystallize. Some minerals recrystallize with a preferred orientation, which is at right angles to the direction of the force. The resulting alignment usually gives the rock a layered or banded appearance. This rock is called a **foliated metamorphic rock.** Gneiss, the metamorphic rock shown in Figure 18, is a foliated rock. Another foliated metamorphic rock is schist.

Go Online SciLinks NSTA

For: Links on metamorphic rocks
Visit: www.SciLinks.org
Web Code: cjn-1033

Nonfoliated Metamorphic Rocks A metamorphic rock that does not have a banded texture is called a **nonfoliated metamorphic rock.** Most nonfoliated rocks contain only one mineral. Marble, for example, is a nonfoliated rock made of calcite. When its parent rock, limestone, is metamorphosed, the calcite crystals combine to form the larger interlocking crystals seen in marble. A sample of marble is shown in Figure 19. Quartzite and anthracite are other nonfoliated metamorphic rocks.

Figure 19 Marble is a nonfoliated metamorphic rock.

Reading Checkpoint *Contrast foliated and nonfoliated metamorphic rocks.*

Classification of Metamorphic Rocks

Build Reading Literacy L1

Refer to **p.124D** in **Chapter 5**, which provides the guidelines for summarizing.

Summarize Have students read the text on page 83. In their own words, have them summarize how metamorphic rocks are classified. *(Sample answer: Metamorphic rocks are classified by texture. There are two kinds of textures—foliated and nonfoliated. Foliated metamorphic rocks have a layered look; nonfoliated metamorphic rocks do not have a layered appearance.)*

Verbal

Go Online NSTA SciLinks

Download a worksheet on metamorphic rocks for students to complete, and find additional teacher support from NSTA SciLinks.

Facts and Figures

Slate is a very fine-grained foliated rock composed of minute mica flakes. The most noteworthy characteristic of slate is its excellent rock cleavage, meaning that it splits easily into flat slabs. This property has made slate a most useful rock for roof and floor tiles, chalkboards, and billiard tables. Slate is most often generated by the low-grade metamorphism of shale, though less frequently it forms from the metamorphism of volcanic ash. Slate can be almost any color, depending on its mineral constituents. Black slate contains organic material; red slate gets it color from iron oxide; and green slate is usually composed of chlorite, a micalike mineral.

Answer to . . .

Figure 18 *Pressure was exerted from the sides.*

Reading Checkpoint *Foliated metamorphic rocks have a layered or banded appearance. Nonfoliated metamorphic rocks do not have a banded texture.*

Section 3.4 (continued)

Use Visuals L1

Table 3 Ask: **What is the parent rock of schist?** *(phyllite)* **Which has undergone more intense metamorphism, slate or gneiss? Explain your answer.** *(Gneiss has undergone more intense metamorphism, as indicated by the arrow in the table.)* **Which nonfoliated rock has the finest grains?** *(anthracite)*
Visual

3 ASSESS

Evaluate Understanding L2

Have students examine Table 3. Ask: **Generally, what can you say about the relationship between texture and increasing metamorphism that results in foliated rocks?** *(The more intense the metamorphism, the courser the texture, or larger the grain size.)*

Reteach L1

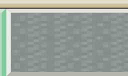
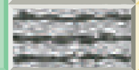
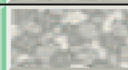
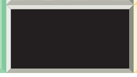
Have students make tables that compare and contrast contact metamorphism and regional metamorphism.

Writing in Science

Sample answer: All are solids that form and change because of Earth processes. All can be classified according to texture and/or composition. The major difference among the three rock types is that each forms at different temperatures and pressures.

To summarize, metamorphic rocks form when existing rocks are changed by heat, pressure, or hydrothermal solution. Contact metamorphism is often caused when hot magma intrudes a body of rock. Changes during this type of metamorphism are minor. Regional metamorphism is associated with mountain building. Such metamorphic changes can be extreme. Metamorphic rocks can be classified by texture as foliated or nonfoliated, as shown in Table 3.

Table 3 Classification of Major Metamorphic Rocks

Rock Name		Texture		Grain Size	Comments	Parent Rock
Slate	Increasing Metamorphism	Foliated		Very fine	Smooth dull surfaces	Shale, mudstone, or siltstone
Phyllite				Fine	Breaks along wavy surfaces, glossy sheen	Slate
Schist				Medium to Coarse	Micaceous minerals dominate	Phyllite
Gneiss				Medium to Coarse	Banding of minerals	Schist, granite, or volcanic rocks
Marble		Nonfoliated		Medium to coarse	Interlocking calcite or dolomite grains	Limestone, dolostone
Quartzite				Medium to coarse	Fused quartz grains, massive, very hard	Quartz sandstone
Anthracite				Fine	Shiny black organic rock that fractures	Bituminous coal

Section 3.4 Assessment

Reviewing Concepts

1. Where does most metamorphism take place?
2. Compare and contrast contact metamorphism and regional metamorphism?
3. Name the agents of metamorphism and explain how each changes a rock.
4. What are foliated rocks, and how do they form?
5. How are metamorphic rocks classified?

Critical Thinking

6. **Applying Concepts** What is the major difference between igneous and metamorphic rocks?
7. **Predicting** What type of metamorphism—contact or regional—would result in a schist? Explain your choice.
8. **Formulating Conclusions** Why can the composition of gneiss vary but overall texture cannot?

Writing in Science

Explanatory Paragraph Write a short paragraph that explains the major differences and similarities among the three major rock groups.

Section 3.4 Assessment

1. Most metamorphism takes place in a zone that begins several kilometers below the surface and extends into the upper mantle.
2. Contact metamorphism is a process whereby slight changes occur in rocks as the result of an increase in temperature resulting from a magma body. Regional metamorphism, which is associated with mountain-building, can result in high-grade changes in both composition and structure.
3. Heat can cause existing minerals to recrystallize or it can cause new minerals to form. Pressure produces a more compact rock with a greater density. Pressure also causes minerals to recrystallize. Fluids aid in recrystallization by making it easier for ions to move and by dissolving original minerals and depositing new ones.
4. Foliated rocks are banded metamorphic rocks that form when minerals realign as the result of pressure from opposing sides.
5. Metamorphic rocks can be classified according to composition and texture.
6. While both types of rocks form as the result of changes in temperature and pressure, metamorphism does not involve melting.
7. Schists, as indicated in Table 3, are the result of high-grade metamorphism that is generally associated with mountain-building.
8. Gneiss is a banded rock that forms as the result of pressure from opposing sides. This directional pressure results in foliation. However, because the parent rocks of gneisses can vary, so can the compositions of these metamorphic rocks.

earth as a SYSTEM

The Carbon Cycle

To illustrate the movement of material and energy in the Earth system, we can take a brief look at the carbon cycle, shown in Figure 20. Pure carbon is rare in nature. It is found mainly as two minerals—diamond and graphite. Most carbon is bonded to other elements to form compounds. Carbon dioxide (CO_2), for example, is an important gas in Earth's atmosphere. Calcite ($CaCO_3$) is a mineral found in many sedimentary and metamorphic rocks. Hydrocarbons, such as coal, oil, and natural gas, are compounds made of carbon and hydrogen. Carbon also combines with hydrogen and oxygen to form the basic compounds that make up living things. This important element moves continually among Earth's major spheres by way of the carbon cycle.

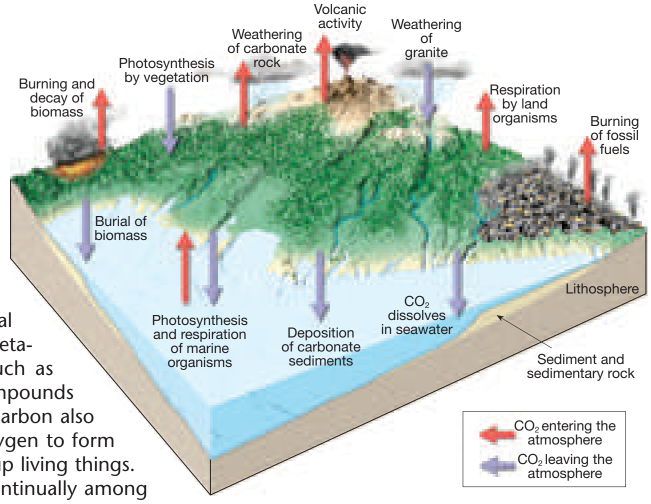


Figure 20 The Carbon Cycle

Carbon Dioxide on the Move

In the atmosphere, carbon is found mainly as carbon dioxide. This gas absorbs much of the energy given off by Earth. Therefore, carbon dioxide influences the heating of the atmosphere. Carbon dioxide constantly moves into and out of the atmosphere by way of four major processes: photosynthesis, respiration, organic decay, and combustion of organic material.

Carbon and Fossil Fuels

Some carbon from decayed organic matter is deposited as sediment. Over long periods of time, this carbon becomes buried. Under the right conditions, some of these carbon-rich deposits are changed to fossil fuels, such as coal. When fossil fuels are burned, huge quantities of carbon dioxide enter into the air.

The Role of Marine Animals

Chemical weathering of certain rocks produce bicarbonate ions that dissolve water. Groundwater, rivers, and streams carry these ions to the ocean. Here, some organisms extract this substance to produce body parts—shells, skeletons, and spines—made of calcite. When the organisms die, these hard parts settle to the ocean floor and become the sedimentary rock called limestone.

The Complete Cycle

The source of most CO_2 in the atmosphere is thought to be from volcanic activity early in Earth's history. When CO_2 combines with water, it forms carbonic acid. This substance reacts with rock through chemical weathering to form bicarbonate ions that are carried by groundwater and streams to the ocean. Here, marine organisms take over and sedimentary rock is eventually produced. If this rock is then exposed at the surface and subjected to chemical weathering, CO_2 is also produced. Use Figure 20 to trace the path of carbon from the atmosphere to the hydrosphere, the geosphere, the biosphere, and back to the atmosphere.

earth as a SYSTEM

The Carbon Cycle L2

Background

- During photosynthesis, plants absorb carbon dioxide from the atmosphere and use it to produce the essential organic compounds—complex sugars—that they need for growth. When animals consume plants or other animals that eat plants, the animals use these organic compounds as a source of energy. Then, through the process of respiration, the animals return carbon dioxide to the atmosphere. Plants also return some carbon dioxide to the atmosphere by way of respiration.
- When plants die and decay or are burned, this biomass is oxidized and carbon dioxide is returned to the atmosphere.
- The lithosphere is by far Earth's largest depository of carbon. A variety of rocks contain carbon. The most abundant is limestone. When limestone undergoes chemical weathering, the stored carbon is released into the atmosphere.

Teaching Tips

- Have students contrast different solids that contain carbon, such as coal, diamond, graphite, calcite, and limestone. Have students explain how the carbon is released from each of these components of the lithosphere into Earth's other spheres.
- Write the chemical equations for photosynthesis and respiration on the board or on an overhead transparency to reinforce the fact that the products of one reaction are the reactants of the other reaction.
- Use a clean, empty 2-L bottle, plants, soil, and a thermometer to make a mini-greenhouse to demonstrate how gases in the air, including carbon dioxide, can absorb solar energy. Refer to the following Web site for tips on such a demonstration: http://www.bigelow.org/virtual/handson/greenhouse_make.html

Section 4.1

1 FOCUS

Section Objectives

4.1 **Distinguish** between renewable and nonrenewable resources.
4.2 **Identify** which energy resources are fossil fuels.
4.3 **Predict** which energy resources might replace dwindling petroleum supplies in the future.
4.4 **Describe** the processes that concentrate minerals into large deposits as they form.
4.5 **Recognize** how nonmetallic mineral resources are used.

Reading Focus

Build Vocabulary L2

Word Forms Ask students to write a short paragraph explaining how a renewable library book is similar to a renewable resource. After students read the section, ask them if their paragraphs must be changed. If so, what changes would they make?

Reading Strategy L2

Answers will vary depending on students' prior knowledge and what they learn from the section.

2 INSTRUCT

Renewable and Nonrenewable Resources

Use Visuals L1

Figure 1 Point out some of the features of the New York skyline. Ask: **What mineral resources can be found in the scene in the photo?** *(stone facings on buildings, iron ore in the steel structures, petroleum in the asphalt streets)* **What energy resources probably power the lights in the photo?** *(probably coal, possibly nuclear fuel)*
Visual

4.1 Energy and Mineral Resources

Reading Focus

Key Concepts

- What is the difference between renewable and nonrenewable resources?
- Which energy resources are fossil fuels?
- Which energy resources might replace dwindling petroleum supplies in the future?
- What processes concentrate minerals into deposits sufficiently large enough to mine?
- How are nonmetallic mineral resources used?

Vocabulary

- renewable resource
- nonrenewable resource
- fossil fuel
- ore

Reading Strategy

Monitoring Your Understanding Copy this table onto a separate piece of paper before you read this section. List what you know about energy and mineral resources in the first column and what you'd like to know in the second column. After you read, list what you have learned in the last column.

Energy and Mineral Resources		
What I Know	What I Would Like to Know	What I Learned
a. ?	c. ?	e. ?
b. ?	d. ?	f. ?

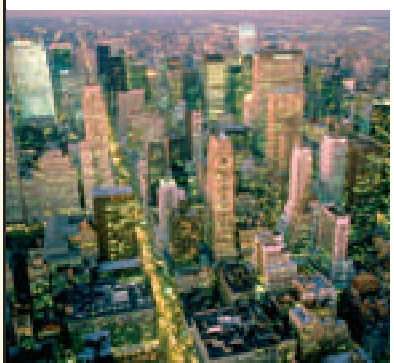


Figure 1 Mineral resources went into the construction of every building in this New York skyline. Energy resources keep the lights on, too.

Mineral and energy resources are the raw materials for most of the things we use. Mineral resources are used to produce everything from cars to computers to basketballs. Energy resources warm your home, fuel the family car, and light the skyline in Figure 1.

Renewable and Nonrenewable Resources

There are two categories of resources—renewable and nonrenewable. **A renewable resource can be replenished over fairly short time spans such as months, years, or decades.** Common examples are plants and animals for food, natural fibers for clothing, and trees for lumber and paper. Energy from flowing water, wind, and the sun are also renewable resources.

By contrast, a nonrenewable resource takes millions of years to form and accumulate. When the present supply of nonrenewable resources run out, there won't be any more. Fuels such as coal, oil, and natural gas are nonrenewable. So are important metals such as iron, copper, uranium, and gold.

Earth's population is growing fast which increases the demand for resources. Because of a rising standard of living, the rate of mineral and energy resource use has climbed faster than population growth. For example, 6 percent of the world's population lives in the United States, yet we use 30 percent of the world's annual production

U.S. Coal Fields

MAP MASTER Skills Activity

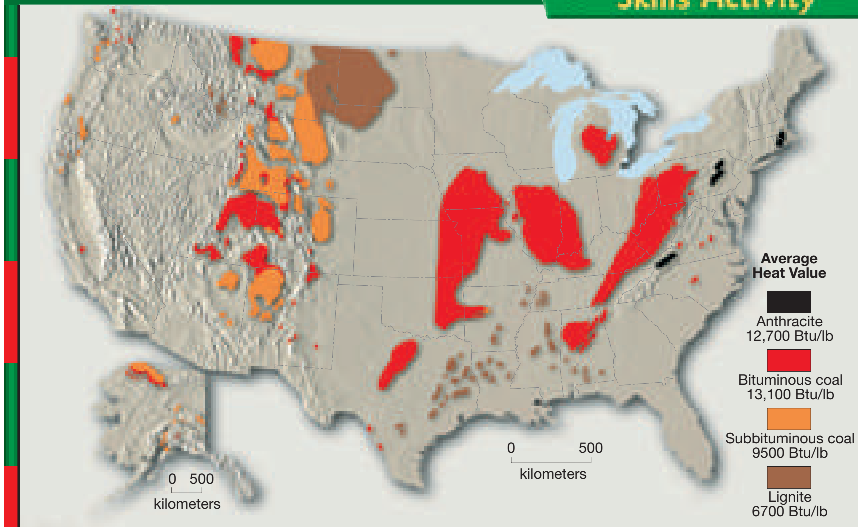


Figure 2
Location This map shows the location of major coal deposits in the United States. **Identify** Which type of coal is most plentiful? **Locate** Where are the anthracite deposits in the U.S. located?

of mineral and energy resources. How long can existing resources provide for the needs of a growing population?

Fossil Fuels

Nearly 90 percent of the energy used in the United States comes from fossil fuels. A **fossil fuel** is any hydrocarbon that may be used as a source of energy. **Fossil fuels include coal, oil, and natural gas.**

Coal Coal forms when heat and pressure transform plant material over millions of years. Coal passes through four stages of development. The first stage, peat, is partially decayed plant material that sometimes look like soil. Peat then becomes lignite, which is a sedimentary rock that is often called brown coal. Continued heat and pressure transforms lignite into bituminous coal, or soft coal. Bituminous coal is another sedimentary rock. Coal's last stage of development is a metamorphic rock called anthracite or hard coal. As coal develops from peat to bituminous, it becomes harder and releases more heat when burned.

Power plants primarily use coal to generate electricity. In fact, electric power plants use more than 70 percent of the coal mined today. The world has enormous coal reserves. Figure 2 shows coal fields in the United States.

Go Online SCI LINKS NSTA

For: Links on fossil fuels
Visit: www.SciLinks.org
Web Code: cjn-1041

Fossil Fuels

Integrate Economics L2

Resource Dependence Tell students that modern industries require many different mineral resources. Although some countries have substantial mineral deposits, no nation is self-sufficient. Because deposits are limited in number and location, all countries use trade to fulfill some of their needs. Students can research which countries are major suppliers of various resources and color a world map to show these sources of resources such as aluminum, iron, gold, and copper.
Visual, Kinesthetic

MAP MASTER Skills Activity

Answers
Identify bituminous coal
Locate in Pennsylvania, Virginia, Rhode Island, and Massachusetts

Build Reading Literacy L1

Refer to **p. 92D**, which provides the guidelines for using context clues.

Using Context Clues Have students explain the meaning of the term *fossil fuels*. The text discussion on how fossil fuels were formed should allow students to infer the meaning of the term. *(Coal, oil, and natural gas are fuels that formed from the remains, or fossils, of once-living plants and animals.)*
Verbal, Logical

Customize for Inclusion Students

Gifted Have students research the hydrocarbons that are found in petroleum. They might enjoy drawing structures or making models (using model-building kits or gumdrops and toothpicks) of straight-chain hydrocarbons and some of the simpler ring hydrocarbons. Students can also investigate the process of fractional distillation, in which crude petroleum is separated into different components or fractions according to their boiling points. The various fractions produced range from fuel gasoline to thick asphalts and lubricating grease.

Go Online NSTA SCI LINKS

Download a worksheet on fossil fuels for students to complete, and find additional teacher support from NSTA SciLinks.

Teacher Demo

Observing Coal L2

Purpose Students compare various stages of coal.

Materials samples of lignite, bituminous, and anthracite (Coal samples are often available from fuel companies, which are listed under *Coal* in the Yellow Pages of the phone book.)

Procedure Obtain samples of various coals. Pass samples around so students can compare them.

Expected Outcomes Anthracite will likely be a shiny dark grey or black. Bituminous and lignite will not be shiny, and lignite will likely be more brown in color than the other samples. Students will be able to break off pieces of lignite and possibly bituminous, but anthracite is too hard to break easily.
Visual

Use Visuals L1

Figure 3 Have students examine the diagram of an oil trap. Ask: **What prevents the gas and oil from rising to the surface and evaporating?** *(a cap rock)* **Why does the natural gas collect above the petroleum?** *(The gas is less dense than the oil.)* **What might happen if tremendous pressure builds up in the oil trap?** *(The pressure might force the petroleum up to the surface and cause a "gusher" or oil fountain.)*
Visual, Logical

Build Science Skills L2

ACTIVITY

Using Models Have students make a model of an oil trap and observe the difference in densities of rock, oil, and water. In a graduated cylinder or tall jar, have students mix equal quantities of vegetable oil, gravel, and water. Let stand for 10 minutes and observe the layers that form. Students will find that the gravel sinks to the bottom of the container and the oil floats on top of the water layer. Ask: **What would happen if an antacid tablet were dropped into the graduated cylinder?** *(Bubbles of carbon dioxide would be produced. The bubbles would rise to the top and dissipate into the air.)* **What do the bubbles of carbon dioxide represent?** *(natural gas deposits)*
Kinesthetic, Visual

Although coal is plentiful, its recovery and use present problems. Surface mining scars the land. Today, all U.S. surface mines must restore the land surface when mining ends. Underground mining doesn't scar as much. However, it has been costly in terms of human life and health. Mining is safer today because of federal safety regulations. Yet, the hazards of collapsing roofs and gas explosions remain.

Burning coal—much of which is high in sulfur—also creates air pollution problems. When coal burns, the sulfur becomes sulfur oxides in the air. A series of chemical reactions turns the sulfur oxides into sulfuric acid, which falls to Earth as acid precipitation—rain or snow that is more acidic than normal. Acid precipitation can have harmful effects on forests and aquatic ecosystems, as well as metal and stone structures.

Petroleum and Natural Gas Petroleum (oil) and natural gas form from the remains of plants and animals that were buried in ancient seas. Petroleum formation begins when large quantities of plant and animal remains become buried in ocean-floor sediments. The sediment protects these organic remains from oxidation and decay. Over millions of years and continual sediment build up, chemical reactions slowly transform some of the organic remains into the liquid and gaseous hydrocarbons we call petroleum and natural gas.

These materials are gradually squeezed from the compacting, mud-rich sediment layers. The oil and gas then move into nearby permeable beds such as sandstone. Because this happens underwater, the rock layers containing the oil and gas are saturated with water. However, oil and natural gas are less dense than water, so they migrate upward through the water-filled spaces of the enclosing rocks. If nothing stops this migration, the fluids will eventually reach the surface.

Sometimes an oil trap—a geologic structure that allows large amounts of fluids to accumulate—stops upward movement of oil and gas. Several geologic structures may act as oil traps, but all have two things in common. First, an oil trap has a permeable reservoir rock that allows oil and gas to collect in large quantities. Second, an oil trap has a cap rock that is nearly impenetrable and so keeps the oil and gas from escaping to the surface. One structure that acts as an oil trap is an anticline. An anticline is an uparched series of sedimentary rock layers, as shown in Figure 3.

When a drill punctures the cap rock, pressure is released, and the oil and gas move toward the drill hole. Then a pump lifts the petroleum out.

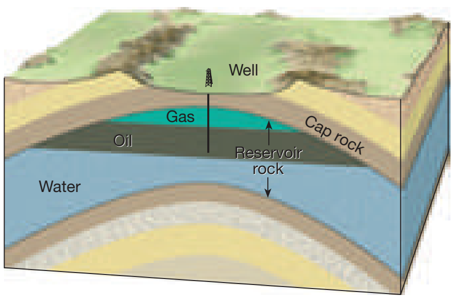


Figure 3 Anticlines are common oil traps. The reservoir rock contains water, oil, and gas. The fluids collect at the top of the arch with less dense oil and gas on top.
Interpreting Diagrams ***Why is the water located beneath the oil and gas?***

Reading Checkpoint ***What two features must an oil trap have?***

Facts and Figures

Different stages of coal have different moisture and heat contents. In general, the lower the moisture content of a coal, the higher the heat content will be. Lignite has a high inherent moisture content, sometimes as high as 45 percent. The heat content of lignite ranges from 9 to 17 million Btu per ton. Bituminous coal has a moisture content that is usually less then 20 percent. The heat content of bituminous coal ranges from 21 to 30 million Btu per ton. Anthracite coal has the lowest moisture content, generally less than 15 percent. The heat content of anthracite ranges from 22 to 28 million Btu per ton.

Tar Sands and Oil Shale

In the years to come, world petroleum supplies will dwindle. **Some energy experts believe that fuels derived from tar sands and oil shales could become good substitutes for dwindling petroleum supplies.**

Figure 4 Tar Sand Deposits In North America, the largest tar sand deposits occur in the Canadian province of Alberta. They contain an estimated reserve of 35 billion barrels of oil.

Tar Sands Tar sands are usually mixtures of clay and sand combined with water and varying amounts of a black, thick tar called bitumen. Deposits occur in sands and sandstones, as the name suggests, but also in shales and limestones. The oil in these deposits is similar to heavy crude oils pumped from wells. The oil in tar sands, however, is much more resistant to flow and cannot be pumped out easily. The Canadian province of Alberta (Figure 4) has the largest tar sand deposits, which accounts for about 15 percent of Canada's oil production.

Currently, tar sands are mined at the surface, much like the strip mining of coal. The excavated material is then heated with pressurized steam until the bitumen softens and rises. The material is processed to remove impurities, add hydrogen, and refine into oil. However, extracting and refining tar sand requires a lot of energy—nearly half as much as the end product yields.

Obtaining oil from tar sand has significant environmental drawbacks. Mining tar sand causes substantial land disturbance. Processing also requires large amounts of water. When processing is completed, contaminated water and sediment accumulate in toxic disposal ponds.

Only about 10 percent of Alberta's tar sands can be economically recovered by surface mining. In the future, other methods may be used to obtain the more deeply buried material, reduce the environmental impacts, and make mining tar sands more economical.

Reading Checkpoint *What are some environmental drawbacks to mining tar sands?*

Oil Shale Oil shale is a rock that contains a waxy mixture of hydrocarbons called kerogen. Oil shale can be mined and heated to vaporize the kerogen. The kerogen vapor is processed to remove impurities, and then refined.

Roughly half of the world's oil shale supply is in the Green River Formation of Colorado, Utah, and Wyoming. See Figure 5 on page 98. The oil shales are part of sedimentary layers that accumulated at the bottom of two extremely large, shallow lakes 57 to 36 million years ago.

Tar Sands and Oil Shale

Build Reading Literacy **L1**

Refer to **p. 124D** in **Chapter 5,** which provides the guidelines for summarizing.

Summarize Have students summarize the process by which tar sands are extracted from their deposits by making a flow diagram. Diagrams should have the various steps of the process labeled. Ask: **Why are tar sands so much more difficult to extract than petroleum?** *(Tar sands are so thick that they do not flow. Thus, they cannot be pumped out of the ground the way crude oil can. Hot fluids are injected into the tar sands to reduce the material's resistance to flow. The material can then be pumped out.)*
Logical

Facts and Figures

Oil shales contain an enormous amount of oil. Worldwide, the U.S. Geological Survey estimates that there are more than 3000 billion barrels of oil in shales that could yield more than 38 liters of oil per ton of shale. However, present technology is only able to recover less than 200 billion barrels. Still, estimated U.S. resources are about 14 times greater than those of conventionally recoverable oil.

Answer to . . .

Figure 3 *The density of water is greater than the densities of oil and gas, so water is located beneath oil and gas.*

Reading Checkpoint *permeable reservoir rock to allow oil and gas to collect and a cap rock that keeps oil and gas from escaping*

Reading Checkpoint *Processing requires a lot of energy and water and causes the accumulation of contaminated water and sediment in toxic disposal ponds. Mining causes substantial land disturbance.*

Use Visuals L1

Figure 5 Have students examine the map. Ask: **Where is the Green River Formation located?** *(Northern Colorado, Wyoming, and Utah)* **Does this area have abundant water supplies?** *(No, the area is semi-arid.)*
Visual, Logical

Formation of Mineral Deposits

Build Science Skills L2

Using Tables and Graphs Have students choose three ores and make a table listing the metal present in each, where in the United States each is mined, and what each is used for. Students can list other information about the chosen ores as well.
Intrapersonal, Verbal

Integrate Chemistry L2

Crystal Size Tell students that the crystal size of minerals that form from magma is determined by how quickly the magma cools. If the rate of cooling is slow, the atoms of the mineral have time to arrange themselves into a large crystal lattice. If cooling is rapid, the atoms have time to arrange themselves only into small crystals. The Teacher Demo on the next page can be done as part of this discussion.
Visual, Kinesthetic

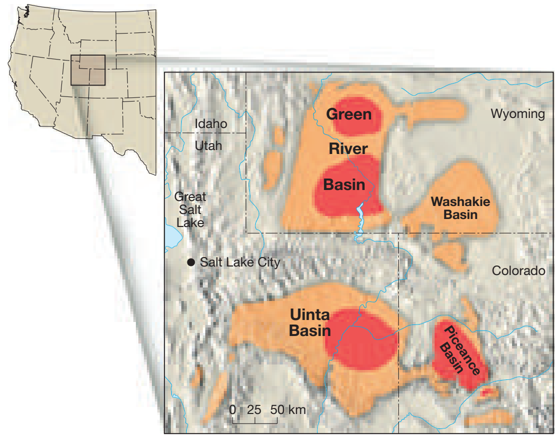


Figure 5 Distribution of Oil Shale in the Green River Formation The areas in red are the richest deposits.
Posing Questions ***How might the mining and processing of oil shale become more economically attractive?***

Some people see oil shale as a partial solution to dwindling fuel supplies. However, the heat energy in oil shale is only about one-eighth that in crude oil because oil shale contains large amounts of minerals. This mineral material adds costs to the mining, processing, and waste disposal of oil shale. The processing of it requires large amounts of water, which is scarce in the semi-arid region where the shales are found. Current technology makes mining oil shale an unprofitable solution.

Formation of Mineral Deposits

Practically every manufactured product contains substances that come from minerals. Mineral resources are deposits of useful minerals that can be extracted. Mineral reserves are deposits from which minerals can be extracted profitably. **Ore** is a useful metallic mineral that can be mined at a profit.

There are also known deposits that are not yet economically or technologically recoverable. These deposits, as well as deposits that are believed to exist, are also considered mineral resources.

The natural concentration of many minerals is rather small. A deposit containing a valuable mineral is worthless if the cost of extracting it exceeds the value of the material that is recovered. For example, copper makes up about 0.0135 percent of Earth's crust. However, for a material to be considered a copper ore, it must contain a concentration of about 50 times this amount.

Geologists have established that the occurrences of valuable mineral resources are closely related to Earth's rock cycle. The rock cycle includes the formation of igneous, sedimentary, and metamorphic rock as well as the processes of weathering and erosion. **Some of the most important mineral deposits form through igneous processes and from hydrothermal solutions.**

Mineral Resources and Igneous Processes Igneous processes produce important deposits of metallic minerals, such as gold, silver, copper, mercury, lead, platinum, and nickel. For example, as a large body of magma cools, heavy minerals crystallize early and settle to the bottom of the magma chamber. Chromite (chromium ore), magnetite, and platinum sometimes form this way. Such deposits produced layers of chromite at Montana's Stillwater Complex. Another deposit is found in the Bushveld Complex in South Africa. This deposit contains over 70 percent of the world's known platinum reserves.

Hydrothermal Solutions Hydrothermal (hot-water) solutions generate some of the best-known and most important ore deposits. Examples of hydrothermal deposits include the gold deposits of the Homestake Mine in South Dakota; the lead, zinc, and silver ores near Coeur D'Alene, Idaho; the silver deposits of the Comstock Lode in Nevada; and the copper ores of Michigan's Keweenaw Peninsula.

Most hydrothermal deposits form from hot, metal-rich fluids that are left during the late stages of the movement and cooling of magma. Figure 6 shows how these deposits form. As the magma cools and becomes solid, liquids and various metal ions collect near the top of the magma chamber. These ion-rich solutions can move great distances through the surrounding rock. Some of this fluid moves along openings such as fractures or bedding planes. The fluid cools in these openings and the metallic ions separate out of the solution to produce vein deposits, like those shown in Figure 7. Many of the most productive gold, silver, and mercury deposits occur as hydrothermal vein deposits.

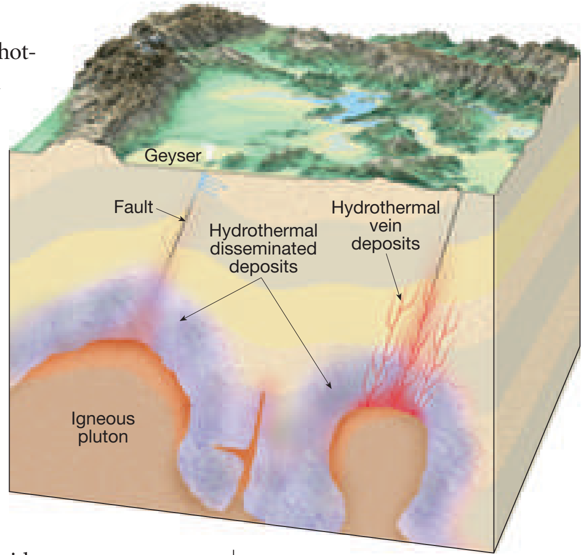


Figure 6 Mineral-rich hot water seeps into rock fractures, cools, and leaves behind vein deposits.

Placer Deposits Placer deposits are formed when eroded heavy minerals settle quickly from moving water while less dense particles remain suspended and continue to move. This settling is a means of sorting in which like-size grains are deposited together due to the density of the particles. Placer deposits usually involve minerals that are not only heavy but also durable and chemically resistant. Common sites of accumulation include point bars on the inside of bends in streams, as well as cracks, depressions, and other streambed irregularities.

Figure 7 Light veins of quartz lace a body of darker gneiss in Washington's North Cascades National Park.

Use Visuals

L1

Figure 6 Have students examine the diagram of hydrothermal deposition. Ask: **Where are minerals likely to be deposited as veins?** *(in rock fractures)* **What is the source of the hot mineral-laden water in the diagram?** *(the geyser)*
Visual, Logical

Teacher Demo

Varying the Size of Crystals

L2

Purpose Students observe how sulfur crystals form in relation to their rate of cooling.

CAUTION: This demonstration should be done in a fume hood or area with very good ventilation. Sulfur fumes can adversely affect students with respiratory problems.

Materials 2 crucibles, beaker, water, teaspoon, sulfur powder, clamp, Bunsen burner, magnifying glass

Procedure Place 1 teaspoon of powdered sulfur in one of the crucibles. Heat the crucible until the sulfur melts, then allow it to cool slowly. Place 1 teaspoon of sulfur in the second crucible. Melt the sulfur, and slowly pour it into a beaker that has been half-filled with water.

Expected Outcome Students should notice that the sulfur that cooled slowly developed larger crystals than the sulfur that cooled rapidly in water.
Visual, Logical

Facts and Figures

The term *placer* is probably of Spanish derivation and was used by the early Spanish miners in both North and South America as a name for gold deposits found in the sands and gravels of streams. Originally, the term seems to have meant "sand bank" or "a place in a stream where gold was deposited."

Answer to . . .

Figure 5 *Oil shale may become more economically attractive if the prices of petroleum and other competing fuels rise.*

Use Visuals

L1

Figure 8 Have students think about prospecting for gold. Ask: **Why does the gold dust settle to the bottom of the pan?** *(The gold dust is heavier than the other material suspended in the water.)* **Why doesn't the gold dissolve in water?** *(Gold is not soluble in water.)*
Visual, Logical

Nonmetallic Mineral Resources

Build Science Skills

L2

Designing Experiments

ACTIVITY

When a drop of dilute hydrochloric acid is placed on limestone, it effervesces—bubbles of carbon dioxide are produced. Have students make a hypothesis about whether cement, concrete, and garden lime will effervesce when dilute hydrochloric acid is applied. Encourage students to design an experiment to test their hypothesis. Supply samples of limestone, cement, and concrete.
Intrapersonal, Logical

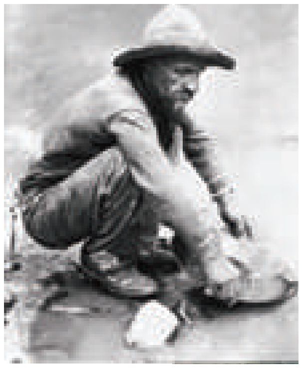


Figure 8 Placer deposits led to the California gold rush. Here, a prospector in 1850 swirls his gold pan, separating sand and mud from flecks of gold.

Gold is the best-known placer deposit. In 1848, placer deposits of gold were discovered in California, sparking the famous California gold rush. Early prospectors searched rivers by using a flat pan to wash away the sand and gravel and concentrate the gold "dust" at the bottom. Figure 8 shows this common method. Years later, similar deposits created a gold rush to Alaska. Sometimes prospectors follow the placer deposits upstream. This method may lead prospectors to the original mineral deposit. Miners found the gold-bearing veins of the Mother Lode in California's Sierra Nevadas by following placer deposits.

Reading Checkpoint *What are mineral resources?*

Nonmetallic Mineral Resources

Nonmetallic mineral resources are extracted and processed either for the nonmetallic elements they contain or for their physical and chemical properties. People often do not realize the importance of nonmetallic minerals because they see only the products that resulted from their use and not the minerals used to make the products.

Examples of nonmetallic minerals include the fluorite and limestone that are part of the steelmaking process and the fertilizers needed to grow food, as shown in Table 1.

Nonmetallic mineral resources are divided into two broad groups—building materials and industrial minerals. For example, natural aggregate (crushed stone, sand, and gravel), is an important material used in nearly all building construction.

Some substances, however, have many uses in both construction and industry. Limestone is a good example. As a building material, it is used as crushed rock and building stone. It is also an ingredient in cement. As an industrial mineral, limestone is an ingredient in the manufacture of steel. Farmers also use it to neutralize acidic soils.

Many nonmetallic resources are used for their specific chemical elements or compounds. These resources are important in the manufacture of chemicals and fertilizers. In other cases, their importance is related to their physical properties. Examples include abrasive minerals such as corundum and garnet.

Although industrial minerals are useful, they have drawbacks. Most industrial minerals are not nearly as abundant as building materials. Manufacturers must also transport nonmetallic minerals long distances, adding to their cost. Unlike most building materials, which need a minimum of processing before use, many industrial minerals require considerable processing to extract the desired substance at the proper degree of purity.

Q & A

Q *How big was the largest gold nugget ever discovered?*

A The largest gold nugget ever discovered was the Welcome Stranger Nugget found in 1869 as a placer deposit in the gold-mining region of Victoria, Australia. It weighed a massive 2520 troy ounces (210 pounds, or 95 kilograms) and, at today's gold prices, was worth over $700,000. The largest gold nugget known to remain in existence today is the Hand of Faith Nugget, which was found in 1975 near Wedderburn, Victoria, Australia. It was found with a metal detector and weighs 875 troy ounces (73 pounds, or 33 kilograms). Sold in 1982, it is now on display in the Golden Nugget Casino in Las Vegas, Nevada.

Facts and Figures

Our society uses enormous quantities of nonmetallic minerals each year. The per-person consumption of non-fuel resources in the United States totals more than 11 metric tons. About 94 percent of these resources are nonmetallics.

Table 1 Occurrences and Uses of Nonmetallic Minerals

Mineral	Uses	Geological Occurrences
Apatite	Phosphorus fertilizers	Sedimentary deposits
Asbestos (chrysotile)	Incombustible fibers	Metamorphic alteration
Calcite	Aggregate; steelmaking; soil conditioning; chemicals; cement; building stone	Sedimentary deposits
Clay minerals (kaolinite)	Ceramics; china	Residual product of weathering
Corundum	Gemstones; abrasives	Metamorphic deposits
Diamond	Gemstones; abrasives	Kimberlite pipes; placers
Fluorite	Steelmaking; aluminum refining; glass; chemicals	Hydrothermal deposits
Garnet	Abrasives; gemstones	Metamorphic deposits
Graphite	Pencil lead; lubricant; refractories	Metamorphic deposits
Gypsum	Plaster of Paris	Evaporite deposits
Halite	Table salt; chemicals; ice control	Evaporite deposits, salt domes
Muscovite	Insulator in electrical applications	Pegmatites
Quartz	Primary ingredient in glass	Igneous intrusions, sedimentary deposits
Sulfur	Chemicals; fertilizer manufacture	Sedimentary deposits, hydrothermal deposits
Sylvite	Potassium fertilizers	Evaporite deposits
Talc	Powder used in paints, cosmetics, etc.	Metamorphic deposits

Section 4.1 Assessment

Reviewing Concepts

1. What is the difference between a renewable and a nonrenewable resource?
2. What are the three major fossil fuels?
3. What are tar sands and oil shale?
4. How do hydrothermal deposits form?
5. What are the two broad categories of nonmetallic mineral resources?
6. Compare and contrast the formation of coal with that of petroleum and natural gas.

Critical Thinking

7. **Drawing Conclusions** Why isn't the use of tar sands more widespread in the United States?
8. **Applying Concepts** Explain how following placer deposits upstream would help prospectors find the original deposit.

Writing in Science

Compare-Contrast Paragraph Write a paragraph describing the difference in the use of nonmetallic building minerals and nonmetallic industrial minerals.

Use Visuals L1

Table 1 Have students study the table. Ask: **What is halite, and what are its uses?** *(Halite is table salt. In addition to seasoning food, it is used in chemical processes and to melt ice.)* **Which mineral listed occurs in Kimberlite pipes?** *(diamond)* **Which mineral listed occurs as hydrothermal deposits?** *(fluorite)*
Visual, Logical

3 ASSESS

Evaluate Understanding L2

To assess students' knowledge of section content, have them list two renewable resources and two nonrenewable resources. Students should explain why each resource listed is renewable or nonrenewable.

Reteach L1

Have students make a poster diagramming the process by which coal is formed. The type of vegetation depicted should be appropriate for the time. *(Large tree ferns and other swamp vegetation were predominant in coal swamps during the Pennsylvanian and Permian periods.)*

Writing in Science

Building materials are abundant, need little processing, need not be pure, and are usually found close to where they are used. Industrial minerals are used for their chemical or physical properties, are relatively scarce, must be extracted and purified, and must be transported.

Answer to . . .

Reading Checkpoint *Mineral resources are Earth materials that are extracted and processed for either the metals or the elements they contain.*

Section 4.1 Assessment

1. Renewable resources have unlimited supplies and can be replaced; nonrenewable resources have limited supplies and cannot be replaced.
2. coal, petroleum, natural gas
3. geologic structures that contain low grade hydrocarbons mixed with clay, sand, or shale
4. Hydrothermal deposits form from hot, metal-rich fluids that are left when magma cools. The metal ions collect as mineral deposits in small openings such as rock fractures.
5. building materials and industrial minerals
6. Coal was formed from plant material that collected in swamps. Petroleum and natural gas were formed from plant and animal material that collected and were buried in ancient seas.
7. Most of the world's tar-sand deposits are in Canada. The few deposits in the United States are in California. In addition, mining tar sands has serious environmental drawbacks and is expensive.
8. Placer deposits are minerals that are carried by moving water from a source upstream. By following the deposits upstream, it is possible to find the original deposit.

Section 4.2

1 FOCUS

Section Objectives

4.6 **Evaluate** the advantages of solar energy.

4.7 **Explain** how nuclear power plants use nuclear fission to produce energy.

4.8 **Evaluate** wind power's potential for providing energy in the future.

4.9 **Relate** how hydroelectric power, geothermal energy, and tidal power contribute to our energy resources.

Reading Focus

Build Vocabulary L2

Word Parts Have students break the word *geothermal* into its parts. They should use a dictionary to find the meaning and derivation of each part. (Geo- *or* ge- *is a Greek combination form meaning "earth or ground."* Thermal *comes from the Greek word* therme *meaning "coming from heat." Geothermal energy is heat that comes from within Earth.)*

Reading Strategy L2

a. solar energy
b. nuclear energy
c. wind energy
d. hydroelectric power
e. geothermal energy
f. tidal power

2 INSTRUCT

Solar Energy

Use Visuals L1

Figure 9 Have students examine the photo. Tell them that the structures on the ground are tracking mirrors that reflect the solar energy onto a receiver mounted on the tower. Ask: **What do you think happens to the solar energy once it enters the receiver?** *(The solar energy is absorbed by a fluid, typically molten salt or air, and used to generate steam to power a conventional turbine.)* **Can electricity be generated at night?** *(No; energy can be stored at night, but not generated at night.)*
Visual, Logical

4.2 Alternate Energy Sources

Reading Focus

Key Concepts

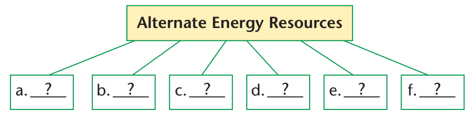
- What are the advantages of using solar energy?
- How do nuclear power plants use nuclear fission to produce energy?
- What is wind power's potential for providing energy in the future?
- How do hydroelectric power, geothermal energy, and tidal power contribute to our energy resources?

Vocabulary

- hydroelectric power
- geothermal energy

Reading Strategy

Previewing Skim the section and start a concept map for the various alternate energy resources.



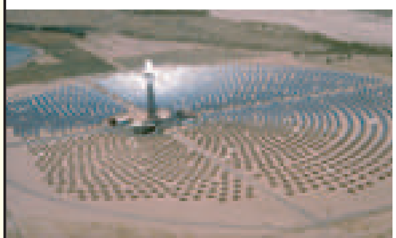


Figure 9 Solar One is a solar installation used to generate electricity in the Mojave Desert near Barstow, California.

There's no doubt that we live in the age of fossils fuels. These non-renewable resources supply nearly 90 percent of the world's energy. But that can't last forever. At the present rates of consumption, the amount of recoverable fossil fuels may last only another 170 years. As the world population soars, the rate of consumption will climb as well. This will leave fossil fuel reserves in even shorter supply. In the mean-time, the burning of huge quantities of fossil fuels will continue to damage the environment. Our growing demand for energy along with our need for a healthy environment will likely lead to a greater reliance on alternate energy sources.

Solar Energy

Solar energy is the direct use of the sun's rays to supply heat or electricity. **Solar energy has two advantages: the "fuel" is free, and it's non-polluting.** The simplest and perhaps most widely used solar energy systems are passive solar collectors such as south-facing windows. As sunlight passes through the glass, objects in the room absorb its heat. These objects radiate the heat, which warms the air.

More elaborate systems for home heating use an active solar collector. These roof-mounted devices are usually large, blackened boxes covered with glass or plastic. The heat they collect can be transferred to areas where it is needed by circulating air or liquids through piping. Solar collectors are also used to heat water for domestic and commercial needs. For example, solar collectors provide hot water for more than 80 percent of Israel's homes.

There are a few drawbacks to solar energy. While the energy collected is free, the necessary equipment and installation is not. A supplemental heating unit is also needed when there is less solar energy—on cloudy days or in the winter—or at night when solar energy is unavailable. However, over the long term, solar energy is economical in many parts of the United States. It will become even more cost effective as the prices of other fuels increase.

Research is currently underway to improve the technologies for concentrating sunlight. Scientists are examining a way to use mirrors to track the sun and keep its rays focused on a receiving tower. Figure 9 shows a solar collection facility with 2000 mirrors that was built near Barstow, California. This facility heats water in pressurized panels to over 500°C by focusing solar energy on a central tower. The superheated water is then transferred to turbines, which turn electrical generators.

Another type of collector, shown in Figure 10, uses photovoltaic (solar) cells. They convert the sun's energy directly into electricity.

Figure 10 Solar cells convert sunlight directly into electricity. This array of solar panels is near Sacramento, California. **Applying Concepts** ***What characteristics would you look for if you were searching for a location for a new solar plant?***

Reading Checkpoint *What are the two main advantages of using solar energy?*

Nuclear Energy

Nuclear power meets about 7 percent of the energy demand of the United States. The fuel for nuclear plants, like the one in Figure 11, comes from radioactive materials that release energy through nuclear fission. **In nuclear fission, the nuclei of heavy atoms such as uranium-235 are bombarded with neutrons. The uranium nuclei then split into smaller nuclei and emit neutrons and heat energy.** The neutrons that are emitted then bombard the nuclei of adjacent uranium atoms, producing a chain reaction. If there is enough fissionable material and if the reaction continues in an uncontrolled manner, fission releases an enormous amount of energy as an atomic explosion.

In a nuclear power plant, however, the fission reaction is controlled by moving neutron-absorbing rods into or out of the nuclear reactor. The result is a controlled nuclear chain reaction that releases great amounts of heat. The energy drives steam turbines that turn electrical generators. This is similar to what occurs in most conventional power plants.

Figure 11 Diablo Canyon Nuclear Plant Near San Luis Obispo, California Reactors are in the dome-shaped buildings. You can see cooling water being released to the ocean. **Analyzing** ***The siting of this plant was controversial because it is close to faults. Why would that be a cause for concern?***

Customize for English Language Learners

Encourage students who are new to the United States to describe any differences in the use or production of energy they may have observed. For example, cooking and heating fuels may be different from those used in the United States.

Many European and Asian countries rely more heavily on nuclear power than Americans do. For example, 75 percent of France's power comes from nuclear energy.

Build Science Skills L2

Using Models ACTIVITY

Have students make a model solar oven. Each student will need a long, narrow potato chip can; scissors; a long wooden skewer; tape; a 20- × 30-cm piece of transparency film; and a hot dog. The can should be cut as follows: make two 8-cm cuts around the can connected by an 18-cm cut to form an *H*. Bend back the flaps but do not remove them from the can. They will be used to reflect solar energy onto the hot dog. Cover the opening on the inside of the can with the transparency film and tape the film into place. Make small holes in the metal end of the can and in the plastic lid. Remove the lid. Put a hot dog lengthwise onto the skewer and slide the skewer into the can, inserting the end into the hole in the metal end. Put the plastic lid on the can and insert the other end of the skewer into the hole in the lid. The hot dog will be suspended inside the can. Place the solar oven into direct sunlight and adjust the flaps so that they reflect solar energy onto the hot dog. Ask students what they can do to make the hot dog cook faster. *(Answers will vary. Students may suggest that they can insulate the can or enlarge the flaps with aluminum foil.)*
Kinesthetic, Logical

Nuclear Energy

Build Reading Literacy L1

Refer to **p. 362D** in **Chapter 13,** which provides the guidelines for using prior knowledge.

Use Prior Knowledge Have students use their knowledge of the structure of an atom to make a model of an atom having 6 protons and 6 neutrons. Ask: **How many electrons will this atom have?** *(6)* **What element is represented by this atom?** *(carbon)* **Is this atom radioactive? Explain.** *(It is not radioactive because its nucleus is stable.)*
Kinesthetic, Logical

Answer to . . .

Figure 10 *abundant sunlight, long summers, abundant space*

Figure 11 *Faults are prone to earthquakes which could damage the reactor.*

Reading Checkpoint *The fuel is free and it's non-polluting.*

Address Misconceptions L2

Students may have many misconceptions about nuclear energy. They may think that a nuclear power plant may explode. Others fear that the electricity might be radioactive or that nuclear wastes release radioactivity into the air. Some students may think nuclear power plants produce power through nuclear explosions. Explain to students that nothing is exploded or burned. The uranium that is brought to Earth's surface during coal mining can have a greater effect on the environment than nuclear waste. Nuclear power plants are not that different from coal-burning plants. The heat needed to boil water into steam is produced by burning fossil fuels in a coal-burning power plant. Ask: **Where does the heat needed to produce steam come from in a nuclear power plant?** *(from splitting certain atoms of uranium)* Once the steam is produced, it turns the blades of a turbine, which causes a generator to produce electricity. Ask: **Is the process of producing electricity from steam in a nuclear plant the same or different from the process in a coal-burning plant?** *(the same; only the method of producing steam is different.)*
Logical

Wind Energy

Build Science Skills L2

Applying Concepts Ask: **Why are mountain passes good locations for wind farms?** *(Most mountain passes have strong, steady winds that sweep through the area.)* **What other locations would make good locations for wind farms?** *(along a seacoast)*
Intrapersonal, Logical

Go Online NSTA SciLinks

Download a worksheet on wind for students to complete, and find additional teacher support from NSTA SciLinks.

At one time, energy experts thought nuclear power would be the cheap, clean energy source that would replace fossil fuels. But several obstacles have slowed its development. First, the cost of building safe nuclear facilities has increased. Second, there are hazards associated with the disposal of nuclear wastes. Third, there is concern over the possibility of a serious accident that could allow radioactive materials to escape. The 1979 accident at Three Mile Island in Pennsylvania made this concern a reality. A malfunction in the equipment led the plant operators to think there was too much water in the primary system. Instead there was not enough water. This confusion allowed the reactor core to lie uncovered for hours. Although there was little danger to the public, the malfunction resulted in substantial damage to the reactor.

Unfortunately, the 1986 accident at Chernobyl in Ukraine was far more serious. In this case, the reactor went out of control. Two small explosions lifted the roof of the structure, and pieces of uranium spread over the surrounding area. A fire followed the explosion. During the 10 days that it took to put out the fire, the atmosphere carried high levels of radioactive material as far away as Norway. Eighteen people died within six weeks of the accident. Thousands more faced an increased risk of death from cancers associated with the fallout.

Reading Checkpoint *What is nuclear fission?*

Go Online NSTA SciLinks
For: Links on wind
Visit: www.SciLinks.org
Web Code: cjn-1042

Figure 12 These wind turbines are operating near Palm Springs, California.

Wind Energy

According to one estimate, if just the winds of North and South Dakota could be harnessed, they would provide 80 percent of the electrical energy used in the United States. Wind is not a new energy source. People have used it for centuries to power sailing ships and windmills for grinding grains.

Following the "energy crisis" brought about by the oil embargo of the 1970s, interest in wind power and other alternative forms of energy grew. In 1980, the federal government started a program to develop wind-power systems, such as the one shown in Figure 12. The U.S. Department of Energy set up experimental wind farms in mountain passes with strong, steady winds. One of these facilities, at Altamont Pass near San Francisco, now operates more than 7000 wind turbines. In the year 2000, wind supplied a little less than one percent of California's electricity.

Some experts estimate that in the next 50 to 60 years, wind power could meet between 5 to 10 percent of the country's demand for electricity. Islands and other isolated regions that must import fuel for generating power are major candidates for wind energy expansion.

The future for wind power looks promising, but there are difficulties. The need for technical advances, noise pollution, and the cost of large tracts of land in populated areas are obstacles to development.

Facts and Figures

Although many people think wind power is a new development, the use of multiple wind turbines to perform a task is nothing new. Dutch engineers used multiple windmills to drain water from their countryside. The Dutch called these early wind farms *gangs* of windmills, and a group can still be seen southeast of Rotterdam at Kinderdijk. Windmills may also have been the driving force of the industrial revolution in the Netherlands during the eighteenth century. Dutch millers constructed an amazing assembly of more than 700 industrial windmills in a region northwest of Amsterdam. These windmills powered Dutch industry before the use of coal became widespread in the rest of Europe.

Figure 13 Glen Canyon Dam and Lake Powell on the Colorado River As dam operators release water in the reservoir, it passes through machinery that drives turbines and produces electricity.

Hydroelectric Power

Like wind, moving water has been an energy source for centuries. The mechanical energy that waterwheels produce has powered mills and other machinery. Today, the power that falling water generates, known as **hydroelectric power,** drives turbines that produce electricity. In the United States, hydroelectric power plants produce about 5 percent of the country's electricity. Large dams, like the one in Figure 13, are responsible for most of it. The dams allow for a controlled flow of water. **The water held in a reservoir behind a dam is a form of stored energy that can be released through the dam to produce electric power.**

Although water power is a renewable resource, hydroelectric dams have finite lifetimes. Rivers deposit sediment behind the dam. Eventually, the sediment fills the reservoir. When this happens, the dam can no longer produce power. This process takes 50 to 300 years, depending on the amount of material the river carries. An example is Egypt's Aswan High Dam on the Nile River, which was completed in the 1960s. It is estimated that half the reservoir will be filled with sediment by 2025.

The availability of suitable sites is an important limiting factor in the development of hydroelectric power plants. A good site must provide a significant height for the water to fall. It also must have a high rate of flow. There are hydroelectric dams in many parts of the United States, with the greatest concentration in the Southeast and the Pacific Northwest. Most of the best U.S. sites have already been developed. This limits future expansion of hydroelectric power.

Geothermal Energy

Geothermal energy is harnessed by tapping natural underground reservoirs of steam and hot water. **Hot water is used directly for heating and to turn turbines to generate electric power.** The reservoirs of steam and hot water occur where subsurface temperatures are high due to relatively recent volcanic activity.

Hydroelectric Power

Teacher Demo

Modeling Hydroelectric Power **L2**

Purpose Students determine how the amount of energy from falling water increases with increasing height.

Materials piece of plastic or transparency film, scissors, plastic straw, straight pin, jar, water, metric ruler

Procedure Make a pinwheel by cutting a square piece of plastic or transparency film. Attach the pinwheel to a plastic straw by placing a straight pin through the center of the pinwheel and through the straw. Hold the pinwheel over a sink while a student pours a full jar of water on the pinwheel from a measured height. Have students count the number of turns the pinwheel makes. Repeat the procedure several times using the same amount of water and the same rate of flow. Vary only the height of the water jar above the pinwheel.

Expected Outcome The pinwheel should turn faster and make more turns as the water is poured from increasing height.
Visual, Kinesthetic

Geothermal Energy

Integrate Geography **L2**

Iceland Inform students that geothermal energy is one of Iceland's greatest natural resources. The capital of Iceland has enjoyed this valuable source of power for more than 60 years. Geothermal heat is used mostly to heat fresh water, which is utilized directly for central heating. Over 89 percent of all the houses in Iceland are heated this way. Geothermal water is also used in swimming pools, for melting snow, farm fishing, drying timber and wool, and heating greenhouses. Ask: **What can you tell about volcanic activity in Iceland?** *(Iceland is volcanically active.)* **Do you think Iceland's energy source is renewable or nonrenewable?** *(renewable)*
Intrapersonal, Logical

Answer to . . .

Reading Checkpoint *Nuclear fission is the splitting of an unstable nucleus of an atom into smaller parts, releasing large amounts of energy.*

Teacher Demo

Making a Geyser

L2

Purpose Students model a geyser and observe how it works.

Materials water; 250- or 500-mL Pyrex flask with tight-fitting, one-hole rubber stopper; glass tube 33–45 cm long; hot plate or Bunsen burner; ring stand; strong, small plastic bowl or container; ice pick or drill; plumber's putty

Safety Use caution when inserting the glass tube into the stopper. Perform this demo behind a safety shield. Have everyone in the room wear goggles.

Procedure Fill the flask with water about 3/4 full. Carefully insert the glass tube in the rubber stopper. Place the stopper in the flask and adjust the tube so that it goes down into the flask about 3/4 of the way to the bottom. Place the flask on the hot plate or on a ring stand just above a Bunsen burner. Drill a hole in a strong, small plastic bowl or container. Work the top of the glass tube into the hole in the bowl and position the bowl on a ring stand above the flask. Plumber's putty can be applied to the bottom of the bowl around the glass tube to keep the bottom of the bowl from leaking. The glass tube should extend up an inch or so into the bowl. The bowl will catch the water from an eruption and also allow the water to flow back into the model. Fill the bowl until water runs down the tube into the flask. Keep adding water until the flask and tube are full. Do not fill the bowl above the top of the glass tube. Turn the hot plate on and allow the water to heat up. Observe how long it takes for an eruption to occur.

Expected Outcomes As the water in the flask turns to steam, pressure builds up inside the flask. Water erupts into the air inside the bowl. After the eruption, water from the bowl should run back down the tube into the flask.
Visual, Kinesthetic

Figure 14 The Geysers is the world's largest electricity-generating geothermal facility. Most of the steam wells are about 3,000 meters deep.

In the United States, areas in several western states use hot water from geothermal sources for heat. The first commercial geothermal power plant in the United States was built in 1960 at The Geysers, shown in Figure 14. The Geysers is an important source of electrical power for nearby San Francisco and Oakland. Although production in the plant has declined, it remains the world's premier geothermal field. It continues to provide electrical power with little environmental impact. Geothermal development is now also occurring in Nevada, Utah, and the Imperial Valley of California.

Geothermal power is clean but not inexhaustible. When hot fluids are pumped from volcanically heated reservoirs, the reservoir often cannot be recharged. The steam and hot water from individual wells usually lasts no more than 10 to 15 years. Engineers must drill more wells to maintain power production. Eventually, the field is depleted.

As with other alternative methods of power production, geothermal sources are not expected to provide a high percentage of the world's growing energy needs. Nevertheless, in regions where people can develop its potential, its use will no doubt grow.

Reading Checkpoint *In what two ways is geothermal energy used?*

Tidal Power

Several methods of generating electrical energy from the oceans have been proposed, yet the ocean's energy potential still remains largely untapped. The development of tidal power is one example of energy production from the ocean.

Tides have been a power source for hundreds of years. Beginning in the 12th century, tides drove water wheels that powered gristmills

Q & A

Q *Is power from ocean waves a practical alternative energy source?*

A It's being seriously explored now. In November 2000, the world's first commercial wave power station opened on the Scottish island of Islay. It provides power for the United Kingdom. The 500-kilowatt power station uses an oscillating water column, in which incoming waves push air up and down inside a concrete tube that is partly under the ocean's surface. Air rushing in and out of the top of the tube drives a turbine to produce electricity. If the facility succeeds, it could open the door for wave power to become a significant contributor of renewable energy in some coastal areas.

Facts and Figures

There are 600 to 700 geysers in the world today. Between 400 and 500 of these are found in Yellowstone National Park. Geysers form in areas where groundwater can circulate several thousand feet deep in Earth's crust and be heated by a volcanic heat source. Geysers exist only when certain conditions are present: a volcanic heat source, molten rock (magma) near the surface, water that can circulate near the heat source and become superheated, a "plumbing" system, and silica-rich rocks that can sustain the force that is needed for an eruption.

and sawmills. During the seventeenth and eighteenth centuries, a tidal mill produced much of Boston's flour. But today's energy demands require more sophisticated ways of using the force created by the continual rise and fall of the ocean.

Tidal power is harnessed by constructing a dam across the mouth of a bay or an estuary in coastal areas with a large tidal range. The strong in-and-out flow that results drives turbines and electric generators. An example of this type of dam is shown in Figure 15.

The largest tidal power plant ever constructed is at the mouth of France's Rance River. This tidal plant went into operation in 1966. It produces enough power to satisfy the needs of Brittany—a region of 27,000 square kilometers—and parts of other regions. Much smaller experimental facilities have been built near Murmansk in Russia, near Taliang in China, and on an arm of the Bay of Fundy in Canada.

Tidal power development isn't economical if the tidal range is less than eight meters or if a narrow, enclosed bay isn't available. Although the tides will never provide a high portion of the world's ever-increasing energy needs, it is an important source at certain sites.

Tidal Dam

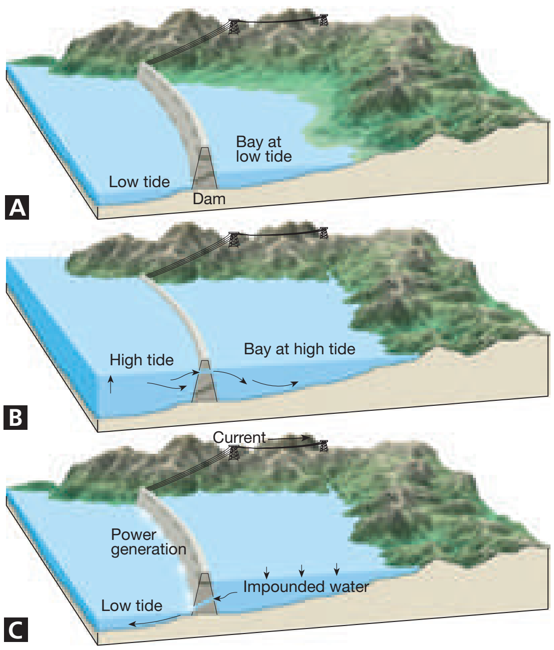


Figure 15 **A** At low tide, water is at its lowest level on either side of the dam. **B** At high tide, water flows through a high tunnel. **C** At low tide, water drives turbines as it flows back to sea through a low tunnel.
Analyzing Concepts ***Why is a large tidal range (difference in water level between high and low tide) needed to produce power?***

Section 4.2 Assessment

Reviewing Concepts

1. What are the advantages and drawbacks of using solar energy?
2. How do nuclear power plants produce energy?
3. What percentage of our energy might be met by wind power over the next 60 years?
4. What are the advantages and drawbacks of hydroelectric power, geothermal energy, and tidal power?

Critical Thinking

5. **Predicting** Why will the interest in alternate energy sources probably grow in the future?
6. **Classifying** Identify solar, nuclear, and wind power as renewable or nonrenewable energy sources. Explain your answers.

Writing in Science

Explain a Concept Write a letter to a family member explaining how tidal power works.

Tidal Power

Use Visuals L1

Figure 15 Have students study the diagram. Ask: **What might be a biological disadvantage of a tidal dam?** *(The dam probably disrupts marine or coastal ecosystems.)* **Which way does water flow through the dam at high tide?** *(toward land)* **Which way does water flow through the dam at low tide?** *(toward the sea)*
Visual, Logical

3 ASSESS

Evaluate Understanding L2

To assess students' knowledge of section content, have each student write three review questions. Invite students to read their review questions to the class. Have the class answer the questions. Continue until everyone has had a turn to read their questions or until unique questions have all been answered.

Reteach L1

Have students make a table of alternate energy sources, the advantages and disadvantages of each, and whether each source is renewable or nonrenewable.

Writing in Science

Students' letters will vary but they should mention that both a large tidal range and a narrow, enclosed bay are requirements for harnessing tidal energy. Letters should also describe how a tidal dam operates and the direction of water flow at high and low tides.

Section 4.2 Assessment

1. advantages: free and unlimited supply of energy; drawbacks: expensive equipment, supplemental heating unit needed when solar energy is not available
2. Heat produced by the nuclear fission of uranium atoms is used to heat water. The steam drives a turbine that turns an electrical generator, producing electric power.
3. between 5 and 10 percent
4. Hydroelectric—advantages: renewable; drawbacks: dams have finite lifetimes, high water levels needed. Geothermal—advantages: clean; drawbacks: nonrenewable, suitable sites are rare. Tidal—advantages: renewable; drawbacks: limited sites available with enclosed bays and large tidal range
5. Fossil fuel reserves will be in very short supply due to growing demand for energy and for a healthy environment.
6. Solar and wind power are renewable energy sources because the supplies of sunlight and wind are unlimited. Nuclear energy is nonrenewable because the supply of uranium is limited.

Answer to . . .

Figure 15 *The greater the tidal range, the more potential energy the water will have. This energy is converted to mechanical energy when the turbine's blades turn, then to electrical energy by the generator.*

Reading Checkpoint *directly for heating and to turn turbines to generate electricity*

Section 4.3

1 FOCUS

Section Objectives

4.10 **Explain** why fresh water is a vital resource.

4.11 **Recognize** why the chemical composition of the atmosphere is important.

4.12 **Identify** Earth's important land resources.

Reading Focus

Build Vocabulary L2

Paraphrase Before students read the section, have them explain what they think *point source* and *nonpoint source* mean. After they have read the section, ask students to explain the meanings of the terms in their own words, noting how their definitions have changed, if at all.

Reading Strategy L2

a. pollution that does not have a specific point of origin
b. runoff, water filtering through piles of waste rock
c. water that flows over the land rather than seeping into the ground
d. waste oil from streets, pesticides off farm fields
e. gases that help maintain a warm temperature near Earth's surface
f. carbon dioxide, methane, water vapor

2 INSTRUCT

The Water Planet

Use Community Resources L2

Have students research the water supply in their community. They should find out where their water comes from and how it is treated to make it safe for human use. The Department of Public Works or the water department will have this information. Students may be able to tour the municipal water treatment plant.
Verbal, Interpersonal

4.3 Water, Air, and Land Resources

Reading Focus

Key Concepts

- Why is fresh water a vital resource?
- Why is the chemical composition of the atmosphere important?
- What are Earth's important land resources?

Vocabulary

- point source pollution
- nonpoint source pollution
- runoff
- acid precipitation
- global warming

Reading Strategy

Building Vocabulary Copy the table below. As you read, add definitions and examples to complete the table.

Definitions	Examples
point source pollution: Pollution that can be traced to a location	factory pipes, sewer pipes
nonpoint source pollution: a. ?	b. ?
runoff: c. ?	d. ?
greenhouse gas: e. ?	f. ?

Figure 16 Oceans cover almost three fourths of Earth surface, making Earth a unique planet.

Water, air, and land resources are essential for life. You need clean air and water every day. What's more, soil provides nutrients that allow plants—the basis of our own food supply—to grow. How do people use—and sometimes misuse—these vital resources?

The Water Planet

Figure 16 shows Earth's most prominent feature—water. Water covers nearly 71 percent of Earth's surface. However, most of this water is saltwater, not fresh water. Oceans have important functions. Their currents help regulate and moderate Earth's climate. They are also a vital part of the water cycle, and a habitat for marine organisms. Fresh water, however, is what people need in order to live. **Each day, people use fresh water for drinking, cooking, bathing, and growing food.** While fresh water is extremely important, Earth's reserves are relatively small. Less than one percent of the water on the planet is usable fresh water.

Freshwater Pollution Pollution has contaminated many freshwater supplies. In general, there are two types of water pollution sources—point sources and nonpoint sources. **Point source pollution** is pollution that comes from a known and specific location, such as the factory pipes in Figure 17. Other examples include a leaking landfill or storage tank.

Nonpoint source pollution is pollution that does not have a specific point of origin. **Runoff,** the water that flows over the land rather than seeping into the ground, often carries nonpoint source pollution. Runoff can carry waste oil from streets. It can wash sediment from construction sites or pesticides off farm fields and lawns. Water filtering through piles of waste rock from coal mines can carry sulfuric acid into rivers or lakes. This contaminated water can kill fish and other aquatic life.

As you can see in Table 2, water pollution has adverse health effects. Pollutants can damage the body's major organs and systems, cause birth defects, lead to infectious diseases, and cause certain types of cancers. Contaminated fresh water can sicken or kill aquatic organisms and disrupt ecosystems. What's more, fish and other aquatic life that live in contaminated waters often concentrate poisons in their flesh. As a result, it is dangerous to eat fish taken from some polluted waters.

Reading Checkpoint *What is the difference between a point and nonpoint water pollution source?*

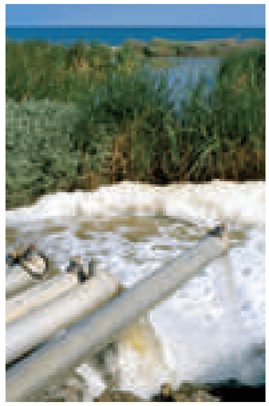


Figure 17 Pollution from point sources, such as these factory pipes, is easy to locate and control.

Table 2 Major Types of Water Pollution

Type	Examples	Sources	Effects
Disease organisms	Bacteria, viruses	Wastes from people and animals	Typhoid, cholera, dysentery, infectious hepatitis
Wastes that remove oxygen from water	Animal manure and plant debris that bacteria decompose	Sewage, animal feedlots	Great amounts of bacteria can remove oxygen from water, killing fish
Inorganic chemicals	Acids, toxic metals	Industrial effluent, urban runoff, household cleaners	Poisons fresh water and can sicken those who drink it
Organic chemicals	Oil, gasoline, plastic, pesticides, detergent	Farm and yard runoff, industrial waste, household cleaners	Some cancers, disorders of nervous and reproductive systems
Plant fertilizer	Water soluble compounds with nitrate, phosphorus ions	Sewage, manure, farm and garden runoff	Spurs rapid growth of algae that decay and deplete water's oxygen; fish die
Sediment	Soil	Erosion	Disrupts aquatic food webs, clogs lakes and reservoirs, reduces photosynthesis of aquatic plants
Radioactive substances	Radon, uranium, radioactive iodine	Nuclear power plants, uranium ore mining and processing	Some cancers, birth defects, genetic mutations

Use Visuals L1

Table 2 Have students study the table. Ask: **Why is fertilizer considered a pollutant if it is needed by plants?** *(It causes rapid growth of algae that decay and deplete water's oxygen.)* **What are some sources of water pollution from organic chemicals?** *(farm and yard runoff, industrial waste, and household cleaners)* **Where do disease organisms that pollute water come from?** *(wastes from people and animals)* **What two types of water pollution can cause cancers in humans?** *(organic chemicals and radioactive substances)*
Visual

Build Science Skills L2

Applying Concepts Have students explain how fish and other aquatic life that live in polluted water can concentrate poisons in their flesh. *(Fish and other aquatic organisms pass large amounts of water through their bodies as they extract oxygen from the water. If pollutants are also extracted from the water, they will accumulate in the fish's flesh in increasing concentration. This process is similar to that of a strainer concentrating material from the water that is poured through it.)*
Verbal

Customize for English Language Learners

Have students use a dictionary to look up the meaning of *acid precipitation*. Ask them to list the different forms that acid precipitation can take. *(acid snow, rain, fog)* Ask students why acid precipitation can take many forms. *(Precipitation occurs when water vapor condenses in the atmosphere. The form of precipitation depends on temperature, altitude, and other physical conditions.)*

Answer to . . .

Reading Checkpoint *Point source pollution is pollution that comes from a known and specific location. Nonpoint source pollution is pollution that does not have a specific point of origin.*

Earth's Blanket of Air

Use Visuals

L1

Figure 19 Have students examine the graphs. Ask: **What makes up almost half of all air pollution?** *(carbon monoxide)* **What fraction of pollution sources are industrial processes?** *(about 15 percent)* **What do you think is the source of most carbon monoxide pollution?** *(vehicle exhaust and fuel combustion)*
Visual, Logical

Address Misconceptions

L2

Ask students if there is a hole in the ozone layer high above Earth. If they say yes, they may hold the misconception that there is an actual hole in the sky that lets UV radiation through. Show students NASA satellite photos of ozone distribution so they can read the ozone concentration in the "hole." Explain that ozone is being depleted around the globe but is particularly severe in certain areas, notably above Antarctica. This depletion is actually a temporary depletion of ozone in September and October of each year. In December and January, the "hole" is repaired. The reason for concern is the fact that each year, more ozone is being depleted and less is being repaired. Ask: **What happens during periods of ozone depletion?** *(More UV radiation reaches Earth's surface.)* **Why are scientists concerned if the "hole" is repaired each year?** *(The hole is not completely repaired, and increasing amounts of ozone are being destroyed.)*
Logical

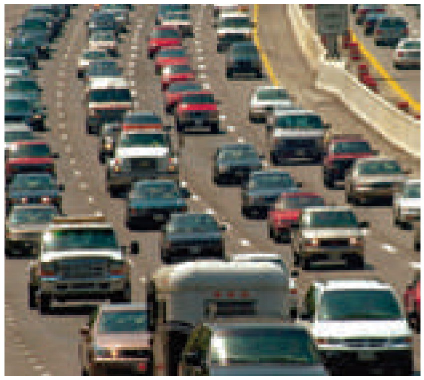


Figure 18 Cars, trucks, and buses are the biggest source of air pollution. Laws that control motor vehicle emissions have helped make the air cleaner in many areas.

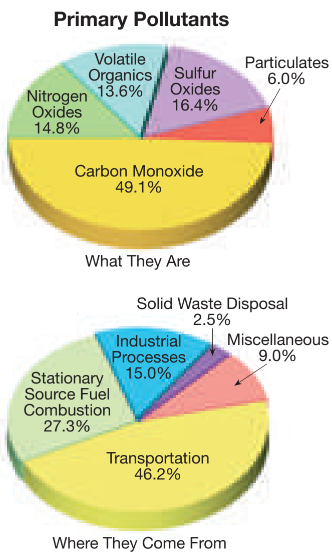


Figure 19 Major Primary Pollutants and Their Sources Percentages are calculated on the basis of weight.
Using Graphs ***What are the three major primary pollutants? What is the major source of air pollution?***

Earth's Blanket of Air

Earth's atmosphere is a blanket of nitrogen, oxygen, water vapor and other gases. **The chemical composition of the atmosphere helps maintain life on Earth.** First and foremost, people and other animals could not live without the oxygen in Earth's atmosphere. But the atmosphere is also part of several other cycles, such as the carbon cycle, that make vital nutrients available to living things.

The atmosphere also makes life on land possible by shielding Earth from harmful solar radiation. There is a layer of protective ozone high in the air. Ozone is a three-atom form of oxygen that protects Earth from 95 percent of the sun's harmful ultraviolet (UV) radiation.

Certain greenhouse gases in the atmosphere—such as carbon dioxide, methane, and water vapor—help maintain a warm temperature near Earth's surface. When solar energy hits Earth, the Earth gives off some of this energy as heat. The gases absorb the heat Earth emits, keeping the atmosphere warm enough for life as we know it.

Reading Checkpoint *What is the role of ozone in the atmosphere?*

Pollution in the Air Pollution can change the chemical composition of the atmosphere and disrupt its natural cycles and functions. Fossil-fuel combustion is the major source of air pollution. Most of this pollution comes from motor vehicles and coal or oil-burning power plants. Motor vehicles, like those in Figure 18, release carbon monoxide, nitrogen oxide, soot, and other pollutants. Some of the pollutants react to form smog. Power plants release sulfur dioxide and nitrogen oxides. These pollutants combine with water vapor in the air to create acid precipitation. Figure 19 shows the primary air pollutants and the sources of those pollutants.

The burning of fossil fuels also produces carbon dioxide, an important greenhouse gas. The amount of carbon dioxide in the atmosphere has increased since industrialization began in the nineteenth century. This increase has altered the carbon cycle and contributed to the unnatural warming of the lower atmosphere, known as **global warming.** Global warming could lead to enormous changes in Earth's environment. These changes could include the melting of glaciers, which would contribute to a rise in sea level and in the flooding of coastal areas.

Chlorofluorocarbons (CFCs) once used in air conditioners and plastic foam production destroy ozone in the stratosphere layer of the atmosphere. Researchers say that a significant loss of ozone could result in an increased incidence of health problems like cataracts and skin cancers because more of the sun's UV radiation would reach Earth's surface.

Facts and Figures

Primary pollutants are those emitted by identifiable sources. They immediately pollute the air when they are emitted. Primary pollutants are also dangerous because they form secondary pollutants when chemical reactions take place among the primary pollutants. The mixture of gases and particles that make up urban smog is a good example of a secondary pollutant. Smog forms when unstable organic compounds and nitrogen oxides from vehicle exhaust react in the presence of sunlight.

Air pollution is a major public health problem. It can cause coughing, wheezing, headaches, as well as lung, eye, and throat irritation. Long-term health effects include asthma, bronchitis, emphysema, and lung cancer. The U.S. Environmental Protection Agency estimates that as many as 200,000 deaths each year are associated with outdoor air pollution.

Land Resources

Earth's land provides soil and forests, as well as mineral and energy resources. How do land resources impact your daily life? Soil is needed to grow the food you eat. Forests provide lumber for your home, wood for furniture, and pulp for paper. Petroleum provides energy and is in the plastic of your computer and CD boxes. Minerals such as zinc, copper, and nickel make up the coins in your pocket. Removing and using resources from Earth's crust can take a heavy environmental toll.

Damage to Land Resources There are an estimated 500,000 mines in the United States. Mines are essential because they produce many of the mineral resources we need. But mining tears up Earth's surface and destroys vegetation, as you can see in Figure 20. It can also cause soil erosion and create pollution that contaminates surrounding soil and water and destroys ecosystems.

Agriculture has many impacts on the land as well. Today, farmers can produce more food per hectare from their land. Extensive irrigation also has allowed many dry areas to be farmed for the first time. But heavy pumping for irrigation of dry areas is depleting the groundwater. And over time, irrigation causes salinization, or the build-up of salts in soil. When irrigation water on the soil evaporates, it leaves behind a salty crust. Eventually, the soil becomes useless for plant growth.

Go Online SCI LINKS NSTA

For: Links on environmental toxins
Visit: www.SciLinks.org
Web Code: cjn-1043

Figure 20 Surface mining destroys vegetation, soil, and the contours of Earth's surface. However, laws now require mine owners to restore the surface after mining operations cease.

Land Resources

Teacher Demo

Motion Accelerates Erosion

L2

Purpose Students demonstrate how the motion of water increases the long-term effects of erosion.

Materials 2 identical clean 1-L jars with lids, marking pen, water, 2 identical pieces of hard candy, measuring cup

Procedure Label the jars A and B. Place a piece of candy in each jar. Pour 500 mL of water into each jar. Cover both jars. Place them in a location where both can be seen. Shake jar A once or twice a day. Do not disturb jar B.

Expected Outcome After only 2 days, students should be able to see that the disturbed candy has dissolved much more than the undisturbed candy.
Kinesthetic, Visual

Build Reading Literacy

L1

Refer to **p. 246D** in **Chapter 9,** which provides the guidelines for relating cause and effect.

Relate Cause and Effect Have students think about the build-up of salts in soil. Ask: **Why can salts build up in soil used for intensive farming?** *(In order to grow large amounts of crops in an area, farmers add heavy applications of fertilizers to support the additional plants. Salts from the fertilizer eventually build up in the soil.)*
Logical

Go Online NSTA SCI LINKS

Download a worksheet on environmental toxins for students to complete, and find additional teacher support from NSTA SciLinks.

Answer to . . .

Figure 19 *The major primary pollutants are carbon monoxide, sulfur and nitrogen oxides, and volatile organics. The major source of air pollution is fossil-fuel combustion.*

Reading Checkpoint *Ozone absorbs harmful ultraviolet radiation from the sun, thus protecting life.*

Section 4.3 (continued)

MAP MASTER™ Skills Activity

Answers

Identifying Effects The amount of virgin forest was much greater in 1620. The eastern half of the United States has lost almost all of its virgin forest. There are now more virgin forests in the western half of the country than in the eastern half.

3 ASSESS

Evaluate Understanding L2

To assess students' knowledge of section content, have them write a short paragraph explaining how ozone can be essential to life when it is in the upper stratosphere, yet a serious pollutant when it is closer to Earth's surface.

Reteach L1

Have students summarize their knowledge of water, land, and air resources by making an outline of the section. They can use the heads as a guide and add information under each head.

Connecting Concepts

Student paragraphs should suggest that wasting paper causes more trees to be cut down, resulting in a loss of species due to elimination of their habitat. When trees are clear-cut, the forest eventually will be replaced by a second-growth forest that has greater area but less diversity than the original forest.

MAP MASTER™ Skills Activity

Virgin Forests 1620–1998

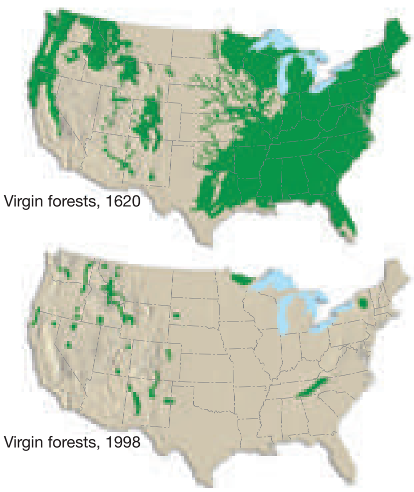


Figure 21

Location These maps compare the location of virgin forests in the contiguous 48 states of the U.S. in 1620 and in 1998. **Identifying Effects** How has the amount of virgin forest changed? How has the location of virgin forest changed?

Trees must be cut to supply our need for paper and lumber. But the removal of forests, especially through clear-cutting, can damage land. Clear-cutting is the removal of all trees in an area of forest. Cleared areas are susceptible to soil erosion. Forest removal also destroys ecosystems and wildlife habitat. The United States actually has more hectares of forest today than it did a century ago. That's because much of the virgin forest (forest that had never been cut down) that was cut long ago has regrown as second-growth forest. The forest is not as diverse as the virgin forest—it does not contain as much variety of plant species. Some forestland has also become tree plantations, with even fewer species. As you see in Figure 21, the United States has lost most of its virgin forest during the last few centuries.

Finally, land serves as a disposal site. You may have seen landfills and other waste facilities. When disposal is done correctly, there is minimal impact on land. But many old landfills leak harmful wastes that get into soil and underground water. The same is true of buried drums of chemicals, which were often disposed of illegally. Waste is inevitable. But there is a need for ways to reduce it and make the disposal safer.

Section 4.3 Assessment

Reviewing Concepts

1. Why is fresh water a vital resource?
2. Why is the chemical composition of Earth's atmosphere important?
3. What is the difference between point source pollution and nonpoint source pollution?
4. What do Earth's land resources provide?

Critical Thinking

5. **Applying Concepts** How would Earth be different if there were no greenhouse gases?
6. **Classifying** Which of the following is a nonpoint source pollution of water: rainwater pouring from an eroded bank into a river, a boat emptying a waste tank into a lake, or a sewage plant sending sewage into a river through a pipe?
7. **Relating Cause and Effect** How would the removal of sulfur from coal affect the type of air pollution in a local area? Explain your answer.

Connecting Concepts

Write a brief paragraph that connects the following: waste of paper, loss of species diversity of forests, and the increase in second-growth forest area.

112 *Chapter 4*

Section 4.3 Assessment

1. People need fresh water for drinking, cooking, bathing, and growing food.
2. The chemical composition of Earth's atmosphere helps to maintain life on Earth.
3. Point source pollution has a known and specific location. Nonpoint source pollution does not have a specific point of origin.
4. soil, forests, mineral and energy resources
5. Earth would be too cold to sustain life.
6. rainwater pouring from an eroded bank into a river
7. Removing sulfur from coal would decrease the amount of sulfur oxides in the air. Sulfur oxides combine with water vapor to form acid precipitation, so the acidity of the precipitation both locally and in more distant areas would decrease.

4.4 Protecting Resources

Reading Focus

Key Concepts

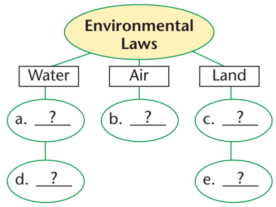
- When were the first laws passed to deal with water pollution?
- What was the most important law passed to deal with air pollution?
- What is involved in protecting land resources?

Vocabulary

- conservation
- compost
- recycling

Reading Strategy

Summarizing After reading this section, complete the concept map below to organize what you know about the major laws that help keep water, air, and land resources clean.



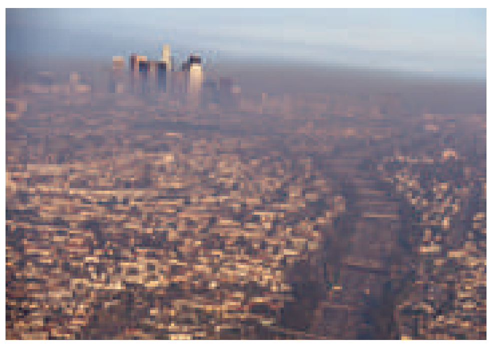
Each year, Americans throw out about 30 million cell phones, 18 million computers, 8 million TV sets, and enough tires to circle the Earth about three times. With just 6 percent of the world's population, Americans use about one third of the world's resources—and produce about one third of the world's garbage.

This high rate of consumption squanders resources, many of which are nonrenewable. The manufacture and disposal of these products uses enormous amounts of energy and creates pollution, as shown in Figure 22. Is there a way to have the products and services we want and still protect resources and create less pollution?

Many people think conservation and pollution prevention are the answer. **Conservation** is the careful use of resources. Pollution prevention means stopping pollution from entering the environment.

Between the late 1940s and 1970, a number of serious pollution problems got the public's attention. Severe air pollution events killed hundreds and sickened thousands in the United States and elsewhere. In the late 1960s, many beaches closed due to pollution. An oil spill off the California coast killed wildlife. Then in 1969, Americans watched news reports of Ohio's polluted Cuyahoga River catching fire and burning for days.

Figure 22 Strict laws have helped curb air pollution, though it remains a problem.



Section 4.4

1 FOCUS

Section Objectives

4.13 **Identify** the first laws passed to deal with water pollution.
4.14 **Name** the most important law passed to deal with air pollution.
4.15 **Explain** what is involved in protecting land resources.

Reading Focus

Build Vocabulary L2

Word Forms Have students use a dictionary to find words that are related to the vocabulary term *conservation*. Each word should be used in a sentence. Knowing the meaning of words such as *conservative* and *conserve* will help students understand the concept of conservation.

Reading Strategy L2

a. Clean Water Act
b. Clean Air Act
c. Resource Conservation and Recovery Act
d. Safe Drinking Water Act
e. Comprehensive Environmental Response, Compensation, and Liability Act

2 INSTRUCT

Integrate Biology L2

Oil Spills and Marine Life Ask students if they know why oil spills are dangerous to wildlife. Tell them that oil destroys the insulating ability of fur-bearing mammals, such as sea otters, and the water-repelling abilities of a bird's feathers, thus exposing these animals to cold water and air temperatures. Many marine birds and animals also swallow oil when they try to clean themselves, which can poison them. Ask: **What is the function of bird feathers?** *(They keep the bird warm and waterproofed, and help the bird fly.)* **What happens to feathers when they get oiled?** *(They become heavy, matted, and soggy.)*
Verbal, Logical

Section 4.4 (continued)

Keeping Water Clean and Safe

Use Visuals

L1

Table 3 Have students read the information in the table. Ask: **How should you dispose of old batteries?** *(Use a hazardous waste site or collection to dispose of them.)* **What happens to household chemicals when they are dumped down a drain?** *(They move through sewers into rivers, lakes, or streams.)*
Visual, Logical

Teacher Demo

Making an Oil Slick

L2

Purpose Students examine the way oil reacts when it mixes with water.

Materials large, clear, glass bowl; vegetable oil; water; cocoa powder

Procedure Mix a little cocoa powder with the oil so it will resemble crude oil. This mixture will make it easier for students to observe the oil. Fill the bowl with water to about 5 cm from the top. Pour some of the oil–cocoa mixture onto the water.

Expected Outcomes Oil and water do not mix, but form two separate layers. The oil, even a little drop, will quickly spread out over the water surface and break up into many little blobs. When oil is spilled onto the ocean, it can be pushed and transported by the wind, currents, and tides because it stays on the top of the water.
Kinesthetic, Visual

Protecting the Air

Use Visuals

L1

Table 4 Have students read the information in the table. Ask: **How can you use solar energy in your home?** *(Allow sunshine in through the windows.)* **Name one way you can use your own physical energy instead of fossil fuel energy.** *(I can walk or ride a bike instead of using a car.)*

Table 3 How You Can Prevent Water Pollution
• Never pour household chemicals (paints, thinners, cleaners, pesticides, waste oil) down the drain or into the toilet.
• Never dump toxic chemicals in the gutter or onto the ground.
• Don't put items that contain hazardous substances, such as batteries or old computer monitors, into the trash.
• Find out about hazardous waste collection sites and times from your local sanitation or public works department.
• Avoid using hazardous substances in the first place.

Keeping Water Clean and Safe

Both the public and government officials became increasingly concerned about pollution. **Starting in the 1970s, the federal government passed several laws to prevent or decrease pollution and protect resources.**

America's polluted rivers and lakes got early attention. In 1972, the U.S. Congress passed the Clean Water Act (CWA). Among other provisions, the law requires industries to reduce or eliminate point source pollution into surface waters. It also led to a huge increase in the number of sewage treatment plants, which eliminated the discharge of raw sewage into many lakes, rivers, and bays. There are still water pollution problems. But because of the CWA, the percentage of U.S. surface waters safe for fishing and swimming increased from 36 percent to 62 percent between 1972 and the end of the 1990s.

The Safe Drinking Water Act of 1974 helped protect drinking resources. It set maximum contaminant levels for a number of pollutants that could harm the health of people. Public water resources are cleaner today because of this law. See Table 3 for ways that individuals can help conserve water and keep it clean.

Reading Checkpoint *What did the Clean Water Act do?*

Protecting the Air

As lawmakers were tackling water pollution in the 1970s, air pollution was also on the agenda. **In 1970, Congress passed the Clean Air Act, the nation's most important air pollution law.** It established National Ambient Air Quality Standards (NAAQS) for six "criteria" pollutants known to cause health problems—carbon monoxide, ozone, lead, sulfur dioxide, nitrogen oxides, and particulates (fine particles). Air monitors, such as the one in Figure 23, sample the air. If the maximum permissible level of pollutants in the air is exceeded, local authorities must come up with plans to bring these levels down. Between 1970 and 2001, the emissions of the six criteria pollutants regulated under the Clean Air Act decreased 24 percent. Over the same time span, energy consumption increased 42 percent and the U.S. population grew by 39 percent.

Today, power plants and motor vehicles use pollution control devices to reduce or eliminate certain byproducts of fossil fuel combustion. Power plants are also more likely to use low-sulfur coal. These controls cut down on emissions of sulfur and nitrogen oxides that often produce acid rain.

Figure 23 Air Sampler

Customize for Inclusion Students

Learning Disabled Have students cut out photos from magazines and newspapers that show water usage and conservation. Students can make a poster with these photos, writing a description next to each photo. If enough photos are collected, two posters can be made, one for water usage and the other for conservation methods. Posters can be hung in a school hallway during Conservation Awareness Week or as part of a conservation program.

Increased use of clean, alternate energy sources such as solar, wind, and hydroelectric power, can also help clear the air. These energy sources don't create air or water pollution, and they're based on renewable resources.

Cars with electric and hybrid (combination of electric and either natural gas, gasoline, or diesel) motors produce fewer or no tailpipe emissions. Several of these lower-emissions models are now available. Some of the hybrid models are also very efficient and get high gas mileage. When a car can go farther on a tank of gas, it uses less fuel and creates less pollution.

Energy conservation is an important air pollution control strategy. Fossil-fuel combustion produces most of the electricity in the United States. If we can use less electricity we would have to burn less fossil fuel. Less fossil-fuel combustion means less air pollution. You can see several energy conservation tips in Table 4.

Table 4 How You Can Save Energy

• Recycle when possible.
• Let the sun in on bright winter days using solar energy to warm rooms.
• Use energy-saving fluorescent bulbs instead of incandescent bulbs where you can.
• Turn off lights when you leave a room. Turn off the radio, TV, or computer when you're not using them.
• Walk or ride a bike when you can.
• When buying electric products, look for the Energy Star sticker which denotes energy-saving products.

Reading Checkpoint *What did the Clean Air Act do?*

Caring for Land Resources

Protecting land resources involves preventing pollution and managing land resources wisely. Farmers, loggers, manufacturers, and individuals can all take steps to care for land resources.

Farmers now use many soil conservation practices to prevent the loss of topsoil and preserve soil fertility. In contour plowing, farmers plow across the contour of hillsides. This method of farming decreases water runoff that washes away topsoil. Another conservation method is strip cropping—crops with different nutrient requirements are planted in adjacent rows. Strip cropping helps preserve the fertility of soil.

Selective cutting conserves forest resources. In this method of logging, some trees in an area of a forest are cut, while other trees remain. This practice preserves topsoil as well as the forest habitat. Clear-cutting, on the other hand, removes whole areas of forest and destroys habitats and contributes to the erosion of topsoil.

Some farmers and gardeners now use less pesticides and inorganic fertilizers to decrease chemicals in soil and on crops. Natural fertilizers such as compost or animal manure have replaced inorganic commercial fertilizers on some fields. **Compost** is partly decomposed organic material that is used as fertilizer. Integrated Pest Management (IPM) uses natural predators or mechanical processes (such as vacuuming pests off leaves) to decrease the number of pests. Pesticide use is a last resort.

Go Online SciLinks NSTA

For: Links on emerging technologies
Visit: www.SciLinks.org
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Caring for Land Resources

Build Reading Literacy L1

Refer to p. **216D** in **Chapter 8,** which provides the guidelines for comparing and contrasting.

Compare and Contrast Tell students that there are two major methods of forestry. Clear-cutting involves the complete removal of all the trees in an area. In selective logging, only certain trees are removed. Trees left standing form a buffer zone. Ask: **Compare the amount of erosion that would take place with both kinds of forestry practices.** *(Clear-cutting exposes bare soil, which is subject to erosion. Selective logging creates buffer zones of trees that slow runoff and prevent any eroded soil from being washed away.)* **Do you think forests are a renewable resource?** *(Answers will vary. The trees will grow back as a second-growth forest, but it will be less diverse than the virgin forest.)* **Logical**

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Download a worksheet on emerging technologies for students to complete, and find additional teacher support from NSTA SciLinks.

Facts and Figures

Integrated Pest Management (IPM) practices began in the 1920s. Progress was slow, however, due to the abundance of inexpensive and effective synthetic pesticides and limited knowledge of their long-term effects on organisms and the environment. Rachel Carson's book, *Silent Spring,* brought the effects of chemical pesticides to the public eye in 1962, and IPM practices became more popular. There are several lines of IPM: chemical controls (the use of pheromones to attract and capture pests), cultural controls (crop rotations, sanitation, and pruning), biological controls (introducing predators, parasites, or pest disease organisms), and genetic controls (breeding pest-resistant crops and tolerant plant varieties).

Answer to . . .

Reading Checkpoint *The Clean Water Act led to an increase in sewage treatment plants; it requires industries to reduce or eliminate point source pollution into surface waters.*

Reading Checkpoint *The Clean Air Act established six criteria pollutants and required communities to not exceed certain levels of pollution for these pollutants.*

Section 4.4 (continued)

Use Community Resources **L2**

Have students investigate recycling programs in their community. If none are available, students may be interested in starting a limited one. If a program exists, students may want to volunteer in some way. Alternatively, students may be interested in participating in a community-wide composting project. **Kinesthetic, Intrapersonal**

3 ASSESS

Evaluate Understanding **L2**

To assess students' knowledge of section content, have them explain the difference between conservation and pollution prevention. *(Conservation is the careful use of resources. Pollution prevention involves ways to prevent pollution from occurring or stopping pollution from entering the environment.)*

Reteach **L1**

Have students make a table listing the laws discussed in this section. For each law, students should write what it does and what it accomplished.

Writing in Science

Student paragraphs should include the ideas that the recycling of aluminum soda cans conserves aluminum and produces less waste.

Answer to . . .

Reading Checkpoint *The Resource Conservation and Recovery Act requires companies to store, transport, and dispose of hazardous waste according to strict guidelines.*

Figure 24 Recycling saves resources, reduces energy consumption, and prevents pollution.

Some laws reduce the possibility of toxic substances getting into the soil. Since 1977, sanitary landfills have largely replaced open dumps and old-style landfills. Sanitary landfills have plastic or clay liners that prevent wastes from leaking into the surrounding soil or groundwater. The Resource Conservation and Recovery Act (RCRA) of 1976 has decreased the illegal and unsafe dumping of hazardous waste. The law requires companies to store, transport, and dispose of hazardous waste according to strict guidelines. The 1980 Comprehensive Environmental Response, Compensation, and Liability Act (Superfund) mandates the cleaning up of abandoned hazardous waste sites that are a danger to the public or the environment.

Reading Checkpoint *What is the RCRA and what does it do?*

Creating less waste by using fewer products and recycling products also helps preserve land resources. **Recycling** is the collecting and processing of used items so they can be made into new products, as Figure 24 shows. By conserving resources and producing less waste, everyone can contribute to a cleaner, healthier future.

Section 4.4 Assessment

Reviewing Concepts

1. When were the first laws passed to deal with water pollution?
2. Identify the most important air pollution control law.
3. What are National Ambient Air Quality Standards?
4. How does selective cutting of forests conserve topsoil?
5. How can gardeners care for land resources?

Critical Thinking

6. **Applying Concepts** How can turning off lights when you're not using them help decrease air pollution?
7. **Relating Cause and Effect** Explain how the Superfund law helps prevent pollution from entering underground water sources.

Writing in Science

Explanatory Paragraph Write a brief paragraph explaining how recycling your aluminum soda cans helps conserve resources and energy.

Section 4.4 Assessment

1. The first laws were passed in the 1970s. The Clean Water Act was passed in 1972.
2. The Clean Air Act, the most important air pollution law, was passed in 1970.
3. NAAQS are maximum permissible levels of six pollutants known to cause health problems.
4. The trees that are left standing keep topsoil from eroding and washing away.
5. by using less pesticides and inorganic fertilizers; by using compost and Integrated Pest Management
6. When you turn off lights, you use less electricity. Since the fuels that produce electricity cause air pollution, less electricity needed means less fuel used and less pollution produced.
7. The Superfund law mandates the cleaning up of dangerous abandoned hazardous waste sites. This prevents the toxic wastes from leaching out of the site and entering underground water sources.

understanding **EARTH**

Bingham Canyon, Utah: The Largest Open-Pit Mine

This huge pit was once where a mountain stood. It's Bingham Canyon copper mine, the largest open-pit mine in the world. The mine, southwest of Salt Lake City, Utah, is 4 kilometers across and covers almost 8 square kilometers. It's so deep—900 meters—that if a steel tower were built at the bottom, it would have to be five times taller than France's Eiffel Tower to reach the pit's rim.

Figure 25 Aerial view of Utah's Bingham Canyon copper mine, the largest open-pit copper mine on Earth.

The pit began in the late 1800s as an underground silver and lead mine. Miners later discovered copper. There are similar deposits at several sites in the American Southwest and in a belt from southern Alaska to northern Chile.

The ore at Bingham Canyon formed after magma was intruded to shallow depths. After this, shattering created extensive fractures in the rock. Hydrothermal solutions penetrated these cracks, and ore minerals formed from the solutions.

Although the percentage of copper in the rock is small, the total volume of copper is huge. Ever since open-pit operations started in 1906, some 5 billion tons of material have been removed, yielding more than 1.2 million tons of copper. Miners have also recovered significant amounts of gold, silver, and molybdenum.

The ore body is far from exhausted. Over the next 25 years, the mine's owners plan to remove and process an additional 3 billion tons of material. This mining operation has generated most of Utah's mineral production for more than 80 years. People have called it the "richest hole on Earth."

Like many older mines, the Bingham pit was unregulated during most of its history. Development occurred before today's awareness of the environmental impacts of mining and prior to effective environmental laws. Today, problems of groundwater and surface water contamination, air pollution, and land reclamation are receiving long overdue attention at Bingham Canyon.

understanding **EARTH**

Bingham Canyon, Utah: The Largest Open-Pit Mine L2

Background

For much of its hundred-year history, Bingham Canyon was owned by Kennecott Copper Corp. However, during the post-1973 oil crisis shake-out, the company was acquired by British Petroleum. It was then sold to Rio Tinto, which operates Bingham Canyon through its subsidiary, Kennecott Utah Copper Corp. The mine employs about 1,400 people and produces about 15 percent of the nation's copper.

Teaching Tips

- Have students research chalcopyrite, the major ore at Bingham Canyon. The formula for chalcopyrite is $CuFeS_2$. The ore is 0.56 percent copper. Chalcopyrite crystals have unevenly faced tetrahedrons that are striated in different directions. The mineral has a metallic luster and a brassy-gold color somewhat less yellow than pyrite.
- Have students make posters showing the processing of copper from mining to grinding and flotation to roasting and smelting to purification by electrolysis.
- Have students make lists of some of the many uses of copper.
- Discuss the importance of copper throughout history, especially in the Bronze Age (bronze is an alloy of tin and copper). Mention the use of copper in brass (an alloy of copper and zinc).
- Tell students that the mine's open pit is one of only a few human-made objects that can be seen from space.
- Have students examine a penny. The composition of the penny has changed several times through the years. During World War II, pennies looked silvery because they were made of zinc-coated steel, due to a shortage of copper. After the war, the composition went back to the traditional copper until 1982. After 1982, the composition was changed again, using cheaper zinc for the core and coating the outside with the traditional copper.

Logical

Section 7.1

1 FOCUS

Section Objectives

7.1 **Describe** the different types of glaciers and where each type is found.

7.2 **Explain** how glaciers move and **describe** the different types of glacial drift.

7.3 **Identify** the landscape features that glaciers form.

7.4 **Explain** the causes of the most recent ice age.

Reading Focus

Build Vocabulary L2

Concept Map Have students construct a concept map using as many vocabulary terms as possible and the following landform features: hanging valleys, cirques arêtes, and horns. Students should place the main concept (Glaciers) in the center oval and use descriptive linking phrases to connect the terms. Instruct students to place the terms in ovals and connect the ovals with lines on which linking words are placed.

Reading Strategy L2

a. Glacier—a thick ice mass that forms over hundreds or thousands of years
b. Ice sheet—an enormous ice mass that flows in all directions from one or more centers and covers everything but the highest land
c. Moraine—layers or ridges of till left behind when glaciers melt
d. Till—material deposited directly by a glacier

7.1 Glaciers

Reading Focus

Key Concepts

- What types of glaciers exist, and where is each type found?
- How do glaciers move?
- What distinguishes the various types of glacial drift?
- What landscape features do glaciers form?

Vocabulary

- ice age
- glacier
- snowline
- valley glacier
- ice sheet
- glacial trough
- till
- stratified drift
- moraine

Reading Strategy

Building Vocabulary Draw a table similar to the one below that includes all the vocabulary terms listed for the section. As you read the section, define each vocabulary term in your own words.

Vocabulary Term	Definition
Glacier	a. ___?___
Ice Sheet	b. ___?___
Moraine	c. ___?___
Till	d. ___?___

Figure 1 Valley Glacier Barry Glacier, in Alaska's Chugach Mountains, slowly advances down this valley.

Earth's climate strongly influences the processes that shape its surface. In this section, you will see the strong link between climate and geology in studying how glaciers shape the land.

Types of Glaciers

As recently as 15,000 years ago—the blink of an eye in geologic history—up to 30 percent of Earth was covered by glacial ice. At that time, Earth was coming out of an **ice age**—a period of time when much of Earth's land is covered in glaciers. Sheets of ice that were thousands of meters thick shaped places like the Alps, Cape Cod, and Yosemite Valley. Long Island, the Great Lakes, and the fjords of Norway were all formed by glaciers. A **glacier** is a thick ice mass that forms over hundreds or thousands of years. Today glaciers still cover nearly 10 percent of Earth's land area. In these regions they continue to sculpt the landscape.

Customize for English Language Learners

Have students create an illustrated science glossary using the vocabulary terms and additional terms that are unfamiliar. Students should write the definition of the term in their own words. Then, students should draw a diagram illustrating the meaning of the term.

Glaciers originate on land in places where more snow falls each winter than melts each summer. The **snowline** is the lowest elevation in a particular area that remains covered in snow all year. At the poles, the snowline occurs at sea level. Closer to the equator, the snowline is near the top of tall mountains. Instead of completely melting away, snow above the snowline accumulates and compacts. The compressed snow first recrystallizes into coarse grains of ice. Further pressure from added snow above changes the coarse grains into interlocking crystals of glacial ice.

A glacier appears to be motionless, but it's not. Sit beside a glacier for an hour and you may hear a sporadic chorus of creaks, cracks, and groans as the mass of ice slowly moves downhill. Just like running water, groundwater, wind, and waves, glaciers are dynamic agents of erosion. They accumulate, transport, and deposit sediment. Thus, glaciers are an important part of the rock cycle.

Valley Glaciers Thousands of small glaciers exist in high mountains worldwide. Unlike fast-flowing mountain streams, glaciers advance only a few centimeters to meters each day. **Valley glaciers** are ice masses that slowly advance down valleys that were originally occupied by streams. **A valley glacier is a stream of ice that flows between steep rock walls from a place near the top of the mountain valley.** Like rivers, valley glaciers can be long or short, wide or narrow, single or with branching tributaries. Figure 1 shows a valley glacier in Alaska.

Ice Sheets **Ice sheets** are enormous ice masses that flow in all directions from one or more centers and cover everything but the highest land. **Ice sheets are sometimes called continental ice sheets because they cover large regions where the climate is extremely cold. They are huge compared to valley glaciers.** Ice sheets covered much of North America during the recent ice age. Figure 2 shows the two remaining ice sheets, which combined cover almost 10 percent of Earth's land area. One ice sheet covers about 80 percent of Greenland. It averages nearly 1500 meters thick, and in places it rises to 3000 meters above the island's surface.

The huge Antarctic Ice Sheet in the Southern Hemisphere is nearly 4300 meters thick in places. This glacier accounts for 80 percent of the world's ice, and it holds nearly two-thirds of Earth's fresh water. If it melted, sea level could rise 60 to 70 meters and many coastal cities would flood.

Reading Checkpoint *Where do ice sheets exist on Earth today?*

Go Online SCI LINKS NSTA

For: Links on glaciers
Visit: www.SciLinks.org
Web Code: cjn-2071

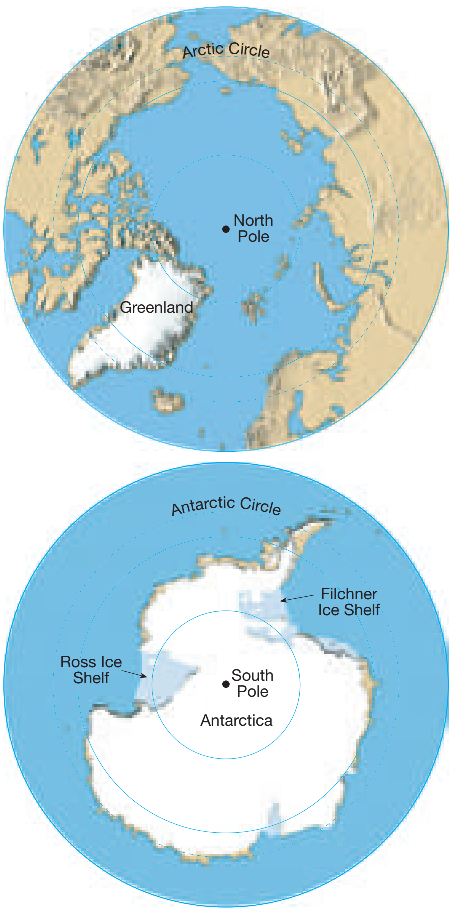


Figure 2 The only present-day ice sheets are those covering Greenland and Antarctica.

2 INSTRUCT

Types of Glaciers

Build Reading Literacy L1

Refer to **p. 186D**, which provides the guidelines for relating text and visuals.

Relate Text and Visuals Have students read pp. 188–189. Have students use Figures 1 and 2 to distinguish between valley glaciers and ice sheets. *(Valley glaciers are ice masses that slowly advance down valleys originally occupied by streams. Ice sheets are enormous ice masses that cover large regions.)*
Visual, Logical

Address Misconceptions L2

Students may have the misconception that glaciers cannot form in the tropics. Glaciers form whenever there are low temperatures and adequate supplies of snow. Because temperatures drop with an increase in altitude, glaciers can occur in the tropics at high elevations. Even near the equator, glaciers form at elevations above 5000 m. Examples of equatorial glaciers include those atop Mt. Kenya and Mt. Kilimanjaro in East Africa. Have students use a map or an atlas to find these mountains and the distance to the equator.
Verbal, Visual

Build Science Skills L2

Comparing and Contrasting Have students read the text on valley glaciers and ice sheets. Ask: **How are these two types of glaciers similar?** *(Both types of glaciers are composed of ice.)* **How do they differ?** *(Valley glaciers are smaller and advance slowly down valleys. Ice sheets cover everything except the highest land in a large region.)*
Verbal

Go Online NSTA SCI LINKS

Download a worksheet on glaciers for students to complete, and find additional teacher support from NSTA SciLinks.

Answer to . . .

Reading Checkpoint *Greenland, Antarctica*

How Glaciers Move

Use Visuals L1

Figure 4 Have students look at the illustration. Ask: **What is the zone of accumulation?** *(the region of the glacier where snow accumulates and ice forms)* **What is the zone of wastage?** *(the foot of the glacier where it loses ice and snow)* **What must happen for a glacier to advance?** *(The glacier must accumulate more ice and snow than is lost at the foot.)* **What must happen for a glacier to retreat?** *(The amount of accumulation must be less than the amount of waste.)*
Verbal

Integrate Physics L2

Most glaciers are blue, unless they contain a large amount of eroded sediment at the surface. Invite students to search the Internet or printed reference sources to find photographs of blue glaciers. Explain that glacial ice absorbs the longer red wavelengths of visible white light while reflecting and scattering shorter blue wavelengths. Ask: **What is another real-world example of something that reflects short wavelengths to cause a blue appearance?** *(the sky)*
Verbal, Logical

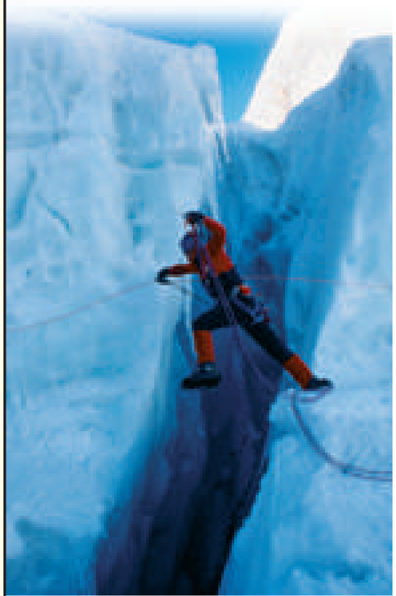


Figure 3 Crevasses like this one in Pakistan can extend 50 meters into a glacier's brittle surface ice.

How Glaciers Move

You might wonder how a glacier, which is solid, can move. **The movement of glaciers is referred to as flow. Glacial flow happens two ways: plastic flow and basal slip.** Plastic flow involves movement within the ice. Under high enough pressure, the normally brittle ice begins to distort and change shape—a property known as plasticity. The weight of overlying ice exerts this pressure on the ice below, causing it to flow. Plastic flow begins at about 50 meters below the glacier surface.

Basal slip is the second cause of glacial movement. Due to gravity, the entire ice mass actually slips and slides downhill along the ground. The upper 50 meters of a glacier is not under enough pressure to have plastic flow. The surface of the glacier behaves differently than the ice below. This uppermost zone of a glacier is brittle, and it is referred to as the zone of fracture. This brittle topmost ice piggybacks a ride on the flowing ice below. The zone of fracture experiences tension when the glacier moves over irregular terrain. This tension results in gaping cracks called crevasses. Crevasses can be 50 meters deep. They are often hidden by snow and make travel across glaciers dangerous, as shown in Figure 3.

Rates of Glacial Movement Different glaciers move at different speeds. Some flow so slowly that trees and other vegetation grow in the debris on their surface. Other glaciers can advance several meters per day. Some glaciers alternate between periods of rapid movement and periods of no movement whatsoever.

Budget of a Glacier Glaciers form where more snow falls in winter than can melt during the summer. They constantly gain and lose ice. Snow accumulates, and ice forms at the head of the glacier in the zone of accumulation, shown in Figure 4. Here new snowfall thickens the glacier and promotes movement. The area of the glacier beyond the snowline is called the zone of wastage. Here the glacier loses ice—and any new snow—to melting.

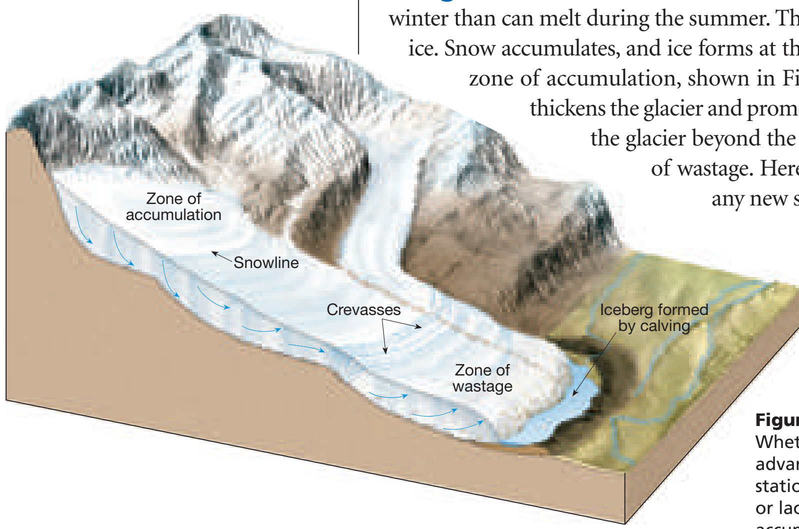


Figure 4 How a Glacier Moves Whether the margin of a glacier advances, retreats, or remains stationary depends on the balance or lack of balance between accumulation and wastage.

Facts and Figures

Glaciers are a part of a fundamental cycle in the Earth system—the water cycle. Water is constantly cycled through the atmosphere, biosphere, and geosphere. Time and time again, the same water is evaporated from the oceans into the atmosphere, precipitated upon the land, and carried by rivers and underground streams back to the sea. However, when precipitation falls at high elevations or high latitudes, the water may not immediately make its way toward the sea. Instead, it may become part of a glacier. Although the ice will eventually melt and make its way to the sea, it may be stored as glacial ice for tens, hundreds, or even thousands of years.

Glaciers also lose ice when large pieces break off their fronts in a process called calving. Calving creates icebergs where glaciers meet the ocean. Because icebergs are just slightly less dense than seawater, they float low in the water. Only about 10 percent of their mass is visible above the surface, as shown in Figure 5. The Greenland Ice Sheet calves thousands of icebergs each year. Many drift southward into the North Atlantic where they are navigational hazards.

The foot of a glacier can advance, retreat, or remain in place. Which course it follows depends on the glacier's budget. **The glacial budget is the balance or lack of balance between accumulation at the upper end of a glacier and loss, or wastage, at the lower end.** If more ice accumulates at the glacier head than melts or calves at the glacier foot, then the glacier advances. The glacier retreats when it loses ice faster than it gains ice. If a glacier gains ice at the same rate as ice melts or calves off, the front or terminus of the glacier remains stationary. Whether the front of a glacier advances, retreats, or remains stationary, the ice within the glacier continues to flow forward. In the case of a receding glacier, the ice still flows forward, but not rapidly enough to offset wastage.

Figure 5 Calving A Ice calves from the front of the Hubbard glacier in Alaska's Wrangell-St. Elias National Park. Once it lands in the water the ice is called an iceberg. Icebergs float on their sides. **B** Just 10 percent of their mass is visible above the surface.

Reading Checkpoint *What causes a glacier to retreat?*

Integrate Social Studies L2

Glaciers in North America Have students research glaciers that are or have been in North America. Have students prepare a computer presentation showing pictures of different elements of glaciers, such as types of glaciers, physical landforms left by glaciers, and glacial erosion.
Verbal, Visual

Build Science Skills L2

Applying Concepts Remind students that a glacier advances when it accumulates more ice than it loses. Tell students about Hubbard Glacier in Alaska, which is pictured in Figure 5. Several other smaller glaciers feed Hubbard Glacier, and the bulk of it is advancing at a rate of about 6 m per year (although one part is advancing at a rate of about 11 m per day and is threatening to close off the Russell Fiord from the sea). Unlike Hubbard Glacier, most glaciers have actually thinned and retreated in the last century. Instruct students to find an example of a retreating glacier. *(Sample answers: Aletsch Glacier in Switzerland, Bering Glacier in Alaska)*
Verbal

Answer to . . .

Reading Checkpoint *A glacier retreats when it loses ice faster than it gains ice.*

Section 7.1 (continued)

Glacial Erosion

Teacher Demo

Glacial Erosion

L2

Purpose Students will observe how rocks and sand incorporated into glaciers form striations.

Materials sand, soap, ice cube

Procedure Place the ice cube in the sand. Sand will stick to the ice cube. The sand represents the rocks and debris that glaciers pick up as they move. Then, scrape the ice cube across the bar of soap. The scratches in the soap represent the striations carved into the surrounding rock by a moving glacier.

Expected Outcome Students will see how easily the sand carves grooves into the soap. The same process occurs between glaciers and surfaces such as bedrock and valley walls that surround a glacier.
Visual, Logical

Figure 6 Glacial Abrasion A glacier smoothed and polished this rock surface in Alaska's Glacier Bay. Rock fragments embedded in the glacier carved the scratches and grooves.

Glacial Erosion

Glaciers are nature's bulldozers. Their ice scrapes, scours, and tears rock from valley floors and walls. Glaciers then carry the rocks down the valley. The rock fragments that are eroded by the glacier drop at the glacier's foot where the ice melts. Unlike streams, which drop sediments while they flow, glaciers hold everything until they melt. They can carry rocks as big as buses over long distances. **Many landscapes were changed by the widespread glaciers of the recent ice age.**

How Glaciers Erode Glaciers mainly erode the land in two ways: plucking and abrasion. Rock surfaces beneath glaciers break up as melted water from the glacier penetrates the cracks. When the water refreezes it expands and pries the rock apart. As a glacier flows over the fractured bedrock surface, it loosens and lifts blocks of rock and incorporates them into the ice. This type of glacial erosion is called plucking.

A second form of glacial erosion is called abrasion. As the glacial ice and its load of rock fragments slide over bedrock, they work like sandpaper to smooth and polish the surface below. The pulverized rock produced by this glacial gristmill is appropriately called rock flour. So much rock flour may be produced that streams of meltwater leaving the glacier often have the grayish appearance of skim milk—visible evidence of the grinding power of the ice. When the ice at the bottom of a glacier contains large rock fragments, long scratches and grooves may be gouged in the bedrock, shown in Figure 6. These glacial striations provide valuable clues to the direction of past glacial movement. By mapping the striations over large areas, geologists often can reconstruct the direction the ice flowed.

As with other agents of erosion, the rate of glacial erosion is highly variable. These differences are mainly controlled by four factors: 1) rate of glacial movement; 2) thickness of the ice; 3) shape, abundance, and hardness of the rock fragments in the ice at the base of the glacier; and 4) the type of surface below the glacier.

Reading Checkpoint *How do glaciers cause erosion?*

Facts and Figures

In addition to valley and continental glaciers, other types of glaciers also exist. Covering some uplands and plateaus are masses of glacial ice called ice caps. Like ice sheets, ice caps completely bury the underlying landscape but are much smaller. Ice caps occur in Iceland and many other places. Another type of glacier, known as piedmont glaciers, occupies broad lowlands at the bases of steep mountains and forms when one or more valley glaciers emerge. The advancing ice spreads out to form a large sheet. The size of individual piedmont glaciers varies greatly. The largest piedmont glacier in North America is the Malaspina Glacier in southeastern Alaska.

Landforms Created by Glacial Erosion

Erosion by valley glaciers produces many spectacular features in mountainous areas. **Glaciers are responsible for a variety of erosional landscape features, such as glacial troughs, hanging valleys, cirques, arêtes, and horns.** Compare and contrast the mountain setting before, during, and after glaciation as shown is Figure 7.

Glaciated Valleys Before glaciation, alpine valleys are usually V-shaped because streams are well above base level and are downcutting. However, in mountain regions that have been glaciated, the valleys are no longer narrow. As a glacier moves down a valley once occupied by a stream, the glacier widens, deepens, and straightens the valley. The once narrow V-shaped valley is changed into a U-shaped **glacial trough.**

The amount of glacial erosion depends in part on the thickness of the ice. Main glaciers cut U-shaped valleys that are deeper than those carved by smaller side glaciers. When the ice recedes, the valleys of the smaller side glaciers are left standing higher than the main glacial trough. These higher valleys are called hanging valleys. Rivers flowing from hanging valleys sometimes produce spectacular waterfalls, such as those in Yosemite National Park, California.

Reading Checkpoint *What is a glacial trough?*

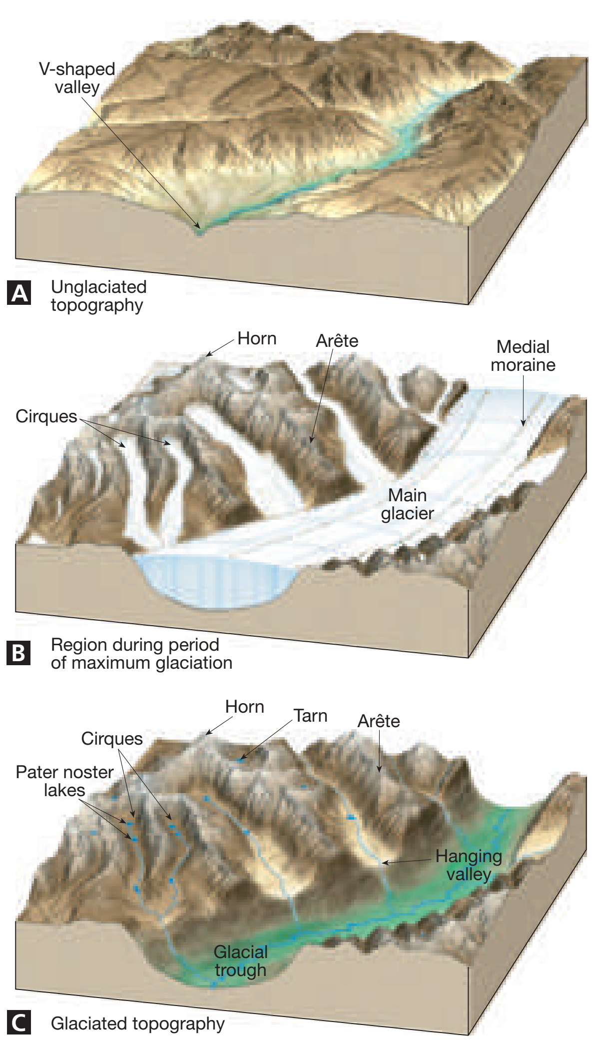


Figure 7 Erosional Landforms Caused by Valley Glaciers **A** shows what the valley glaciers looked like in this mountainous region. **B** reveals the modified landscape and its features. **Inferring** ***What direction did the main valley glacier flow? How do you know?***

Landforms Created by Glacial Erosion

Use Visuals L1

Figure 7 Have students look carefully at Figures 7A and 7B. Ask: **How would you describe a cirque?** *(a bowl-shaped depression that is surrounded on three sides by steep rock walls)* **How did the arête form?** *(The rock walls surrounding the cirques eroded, cirques on opposite sides of the divide grew and formed a sharp ridge.)* **How did the horn form?** (*Several cirques surrounded a single high mountain. As the cirques grew, a single horn emerged.)*
Visual, Verbal

Build Science Skills L2

Using Analogies Ask students if they have ever taken a bath when they were dirty. Ask: **What does the bottom of the tub look like if you let the water drain out?** *(All of the dirt settles to the bottom of the tub.)* Explain that this is similar to the way a glacier deposits its load of debris. As the ice melts from the glacier, the debris falls to the terrain just as the suspended dirt falls to the bottom of the tub.
Verbal

Answer to . . .

Figure 7 *from lower left to upper right; because the glacial trough forms at the beginning of the glacier*

Reading Checkpoint *Glaciers erode by plucking and abrasion.*

Reading Checkpoint *a once narrow V-shaped valley that changes into a U-shape after a glacier moves down the valley*

Glacial Deposits

Use Visuals L1

Figure 9 Have students look carefully at Figure 9. Ask: **Why is glacial till an unsorted mixture of debris?** *(Glacial till is debris that drops out of the glacier as it melts. The till consists of a random assortment of whatever the glacier has picked up as it moved along.)* **What is the difference between till and stratified drift?** *(Till is material deposited directly by a glacier. Stratified drift is deposited by glacial meltwater. Till consists of random-sized objects that are picked up by the glacier. Stratified drift is deposited by size and weight.)*
Verbal

Use Community Resources L2

Invite an Earth science specialist from a local college that is familiar with glaciers to speak to the class. Ask the person to bring pictures or slides that he or she can share with the class.
Interpersonal, Visual

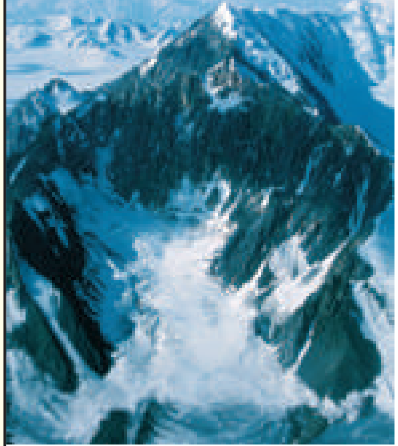


Figure 8 Cirque Natural amphitheaters like this one in Canada's Yukon Territory result from the plucking action of ice in a glacier's zone of accumulation.

Figure 9 Glacial till is an unsorted mixture of many different sediment sizes. A close look often reveals cobbles that have been scratched as they were dragged along by the glacier.

Cirques A cirque is a bowl-shaped depression at the head of a glacial valley that is surrounded on three sides by steep rock walls, as shown in Figure 8. These impressive features are the focal point of the glacier's growth because they form where snow and ice accumulate at the head of a valley glacier. Cirques begin as irregularities in the mountainside. Glaciers carve cirques by plucking rock from along the sides and the bottom. The glaciers then act as conveyor belts that carry away the debris. Sometimes the melting glacier leaves a small lake in the cirque basin.

Arêtes and Horns Other mountain landscapes carved by valley glaciers reveal more than glacial troughs and cirques. Snaking, sharp-edged ridges called arêtes and sharp pyramid-like peaks called horns project above the surroundings. You can see these features in the Alps and the northern Rockies. Horns like the Matterhorn in Switzerland form where several cirques surround a single high mountain. The converging cirques create one distinctive horn. Arêtes form where cirques occur on opposite sides of a divide. As these cirques grow, the divide separating them is reduced to a narrow, sharp ridge.

Glacial Deposits

Glaciers transport huge loads of debris as they slowly advance across the land. When a glacier melts it deposits its sediment. For example, in many areas once covered by the ice sheets of the recent ice age, the bedrock is rarely exposed because glacial deposits that are dozens—or even hundreds—of meters thick completely cover the terrain. Rocky pastures in New England, wheat fields in the Dakota plains, and rolling Midwest farmland are all landscapes resulting from glacial deposition.

Types of Glacial Drift **Glacial drift applies to all sediments of glacial origin, no matter how, where, or in what form they were deposited. There are two types of glacial drift: till and stratified drift.** **Till** is material deposited directly by the glacier. It is deposited as the glacier melts and drops its load of rock debris. Unlike moving water and wind, ice cannot sort the sediment it carries. Therefore, till deposits are usually unsorted mixtures made up of many particle sizes. Notice the unsorted till in Figure 9.

Stratified drift is sediment laid down by glacial meltwater. Stratified drift contains particles that are sorted according to size and weight of the debris. Some deposits of drift are made by streams coming directly from the glacier. Stratified drift often consists of sand and gravel, because the meltwater cannot move large boulders and finer sediments remain suspended and are carried far from the glacier.

Boulders found in till or lying free on the ground are glacial erratics. Their mineral content is different from the underlying bedrock, which shows they were carried there by some means. In parts of New England and other glaciated areas, glacial erratics are scattered throughout pastures and farm fields. Early settlers cleared the smaller ones from their fields and piled them into stone fences that remain today. Geologists can sometimes determine the path of a long-gone glacier by studying the minerals in glacial erratics.

Reading Checkpoint *What is glacial drift?*

Moraines, Outwash Plains, and Kettles

Glaciers are responsible for a variety of depositional features, including moraines, outwash plains, kettles, drumlins, and eskers.

When glaciers melt, they leave layers or ridges of till called **moraines.** These widespread glacial features come in several varieties.

Figure 10 The dark stripe running down the middle of this glacier is a medial moraine. It formed from the lateral moraines of these two merging valley glaciers.

Lateral Moraines The sides of a valley glacier gather large amounts of debris from the valley walls. Lateral moraines are ridges that form along the sides of glacial valleys when the glacier melts and leaves the material it has gathered. Medial moraines are formed when two valley glaciers join to form a single ice stream. Observe the medial and lateral moraines in Figure 10. The till that was once carried along the edges of each glacier joins to form a dark stripe of debris within the newly enlarged glacier.

End Moraines and Ground Moraines Glaciers can remain stationary for long periods of time. When a glacier is stationary it means snow and ice accumulate at the head of the glacier at the same rate snow and ice melt at the foot of the glacier. Within the glacier, the ice still flows. It acts as a conveyor belt to carry rock debris to the end of the glacier. When the ice there melts, it deposits the debris and forms a ridge called an end moraine. The longer the glacier remains stationary, the larger the end moraine grows.

Ground moraines form when glaciers begin to recede. The glacier front continues to deliver debris. The glacier deposits sediment as the ice melts away. However, instead of forming a ridge, the retreating glacier creates a rock-strewn, gently rolling plain. This ground moraine fills in low spots and clogs old stream channels. Ground moraine can thus result in poorly drained swamp lands.

Moraines, Outwash Plains, and Kettles

Build Science Skills L2

Comparing and Contrasting Have students read the text on moraines. Ask: **What do all moraines have in common?** (*All moraines are glacial deposits of till.*) Ask: **How do the various types of moraines differ?** *(Moraines are categorized by how and where the till is deposited. The till of lateral moraines forms on the side of the glacier. The till of a stationary glacier forms at the end of the glacier, forming an end moraine. Receding glaciers scatter till across the width of the glacier as it retreats. Terminal and recessional moraines form when a glacier forms an end moraine and ground moraines many times before it completely melts.)*
Verbal

Build Science Skills L2

ACTIVITY

Designing Experiments Instruct students to design an experiment that models glacial deposition of till. Suggest they use a freezer and the following materials: sand, ice cube trays, water, and a pan or tray with a slope, such as the type used with painting rollers. *(Students' designs will vary, but may involve covering sand with water in the ice cube tray and using the freezer to make ice, then placing the ice cubes with sand on the sloped pan or tray to see how sand collects as the ice melts.)*
Kinesthetic, Logical

Customize for Inclusion Students

Gifted Have interested students conduct research to find out what glacial activity their area has experienced. Their research should include current activity if there are glaciers in your area, or historical activity of glaciers and ice sheets during ice ages. They should investigate whether till, stratified drift, or glacial erratics have been deposited, and whether any moraines or glacial features were created. Encourage them to contact local geologists if they can. Then have them prepare a presentation of their findings for the class. If no notable glacial activity has occurred in your area, instruct students to pick a region that was affected by glaciers, such as the Great Lakes region.

Answer to . . .

Reading Checkpoint *Glacial drift is all sediment that is deposited by a glacier.*

Build Science Skills L2

Comparing and Contrasting Have students read the text on pp. 196–197 about outwash plains, kettles, drumlins, and eskers. Ask: **What do outwash plains, kettles, drumlins, and eskers have in common?** *(All are landscape features formed by glaciers.)* **How do they differ?** (*An outwash plain is a deposit of sediment left by the glacial meltwater. A kettle forms when blocks of stagnant ice become buried and eventually melt. This melting leaves pits in the glacial sediment. Drumlins are streamlined hills composed of till. The steep side of a drumlin once faced the direction of the advancing ice and the gentler slope points in the direction the ice moved. Eskers are snake-like ridges composed of sand and gravel that were deposited by streams once flowing in tunnels beneath the glaciers.)*
Verbal

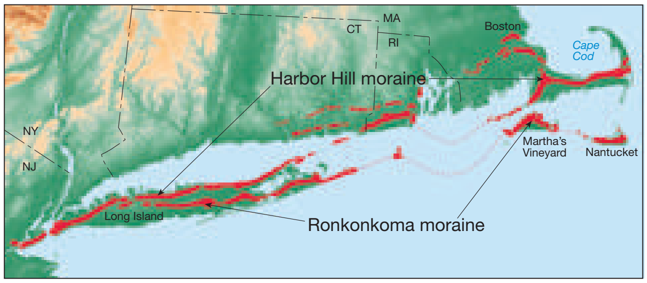


Figure 11 Long Island, Cape Cod, Martha's Vineyard, and Nantucket are remnants of an end moraine.

Terminal and Recessional Moraines Glaciers can periodically retreat, then find equilibrium again and remain stationary for some time. A glacier forms a new end moraine during the stationary period, then another ground moraine once it starts retreating again. This pattern can repeat many times before the glacier completely melts. The farthest end moraine is the terminal end moraine. The end moraines that form when the ice front occasionally becomes stationary during its retreat are recessional end moraines.

End moraines that formed in the recent ice age are prominent in the landscapes of the Midwest and Northeast. The Kettle Moraine is a scenic one that occurs in Wisconsin near Milwaukee. New York's Long Island is part of a series of end moraines stretching from eastern Pennsylvania to Cape Cod, Massachusetts. Figure 11 shows the locations of these end moraines that form part of the Northeast coast.

Outwash Plains At the same time that an end moraine is forming, streams of fast-moving meltwater emerge from the bases of glaciers. As mentioned before, this water is often so choked with fine sediment that it looks like milk. Once it leaves the glacier, the water slows and drops the sediment in a broad, ramp-like accumulation downstream from the end moraine. This type of sediment ramp resulting from an ice sheet is called an outwash plain.

Kettles You can often find depressions and small lakes called kettles within end moraines and outwash plains, as shown in Figure 12. Kettles form when blocks of stagnant ice become buried in drift and eventually melt. This melting leaves pits in the glacial sediment. A well-known example of a kettle is Walden Pond near Concord, Massachusetts. Thousands of kettles dot the landscape of the Upper Midwest in Wisconsin and Minnesota.

Drumlins and Eskers Moraines are not the only landforms deposited by glaciers. Some landscapes have many elongated parallel hills made of till. Other areas have conical hills and narrow winding ridges made mainly of stratified drift. If you know what to look for, the signs of a once-glaciated landscape are unmistakable—especially from an airplane.

Drumlins are streamlined hills composed of till. Drumlins are taller and steeper on one end, and they range in height from 15 to 60 meters and average 0.4 to 0.8 kilometer long. The steep side of the hill faces the direction the ice came from, and the gentler slope points in the direction

Customize for Inclusion Students

Learning Disabled You can revise the procedure described in "Designing Experiments" on p. 195 to help slow and visual learners understand the formation of the depositional features caused by glaciers. Use ice cubes containing pepper and various planar surfaces (one grooved, and one flat) to model these depositional features. You may alternatively choose to have students use these materials to design experiments themselves.

the ice moved. Drumlins occur in clusters called drumlin fields. Near Rochester, New York, one cluster contains nearly 10,000 drumlins. Their streamlining shows they were molded by active glaciers.

Eskers are snake-like ridges composed of sand and gravel that were deposited by streams once flowing in tunnels beneath glaciers. They can be several meters high and many kilometers long. Many eskers are mined for the sand and gravel they contain.

Reading Checkpoint ***What depositional features do glaciers form?***

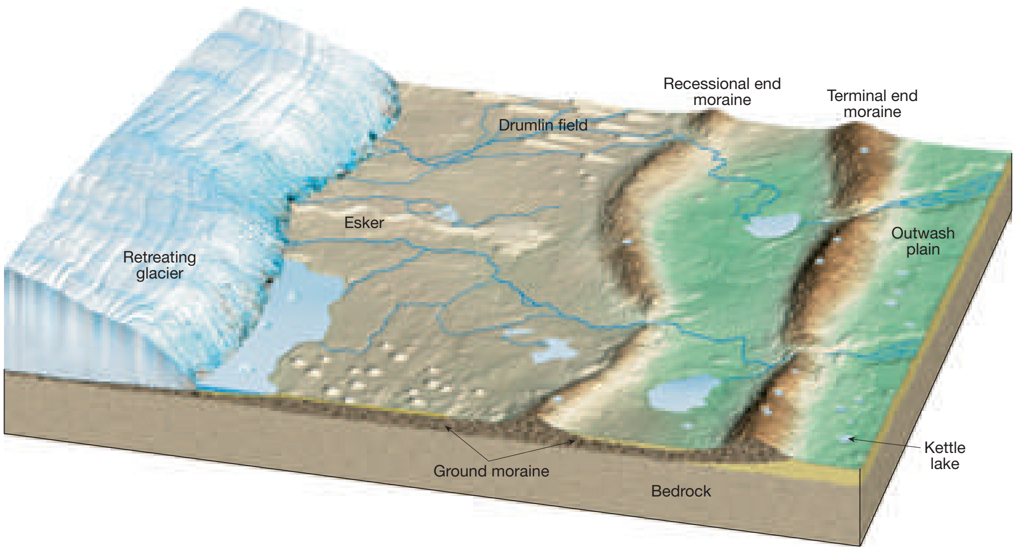


Figure 12 The landscape left by a retreating glacier includes a number of distinctive features. The terminal end moraine marks the farthest extent of the glacier. Recessional moraines occur where a retreating glacier temporarily becomes stationary.
Using Analogies ***How is a glacier like a conveyor belt?***

Glaciers of the Ice Age

During the recent ice age continental ice sheets and alpine glaciers covered a lot more land than they do today. People once thought that glacial deposits had drifted in on icebergs or that they swept across the landscape in a catastrophic flood. However, scientific field investigations during the nineteenth century provided convincing evidence that an extensive ice age explained these deposits and many other features.

During the recent ice age, glaciers covered almost 30 percent of Earth's land, including large portions of North America, Europe, and Siberia, as shown in Figure 13. The Northern Hemisphere had twice the ice of the Southern Hemisphere. The Southern Hemisphere has far less land, so glaciation was mostly confined to Antarctica. By contrast, North America and Eurasia have plenty of land where the ice sheets could spread.

Glaciers of the Ice Age

Integrate Biology

L2

Change in Sea Level A far-reaching effect of the most recent ice age was the worldwide change in sea level that accompanied each advance and retreat of the ice sheets. The snow that forms glaciers ultimately comes from moisture evaporated from the oceans. Therefore, when the ice sheets increased in size, sea level fell and the shorelines shifted seaward. Estimates suggest that sea level was as much as 100 m lower than today. Land that is presently flooded by the oceans was dry. The Atlantic Coast of the United States lay more than 100 km to the east of New York City. France and Britain were joined where the English Channel is today. Alaska and Siberia were connected across the Bering Strait. Southeast Asia was tied by dry land to the islands of Indonesia. Ask: **If Siberia and Alaska were connected by a land bridge, would biologists find evidence of this? Explain.** *(Yes, biologists should find evidence such as fossil remains of the same animals in both locations. In fact, fossil remains suggest that there was a migration of mammoths across the Bering Strait from Asia into North America.)*
Verbal, Logical

Answer to . . .

Figure 12 *It carries rock and debris along with it as it moves, just as a conveyor belt carries items along with it as it moves.*

Reading Checkpoint *moraines, outwash plains, drumlins, eskers*

Section 7.1 (continued)

3 ASSESS

Evaluate Understanding L2

Divide the class into six groups. Have each group write three questions about the material covered in one of the following headings: Types of Glaciers; How Glaciers Move; Glacial Erosion; Landforms Created by Glacial Erosion; Glacial Deposits; Moraines, Outwash Plains, and Kettles; and Glaciers of the Ice Age. Invite students to take turns asking one question of the class.

Reteach L1

Use Figures 4 and 7 to review information about glaciers.

Math Practice

Solution

7. 10 m / 1 month × 1 month / 30 days = 0.33 m/day or about 33 cm/day

---

Figure 13 This map shows the extent of Northern Hemisphere ice sheets during the recent ice age.

The recent ice age began two to three million years ago. Many of the major glacial episodes occurred during the Pleistocene epoch when wooly mammoths and saber-toothed cats roamed the landscape. To some people the Pleistocene is synonymous with the recent ice age, but it actually began before this epoch on the geologic time scale.

Ice Age Effects on Drainage The ice sheets greatly affected the drainage patterns over large regions. For example, before glaciation, the Missouri River flowed northward toward Hudson Bay in Canada. The Mississippi River flowed through central Illinois. Furthermore, the Great Lakes did not exist. Their locations were marked by lowlands with rivers that flowed toward the east. During the recent ice age, glacial erosion transformed these lowlands into wide, deep basins that filled with water and eventually became the Great Lakes.

The formation and growth of ice sheets triggered changes in climates beyond the glacial margins. Regions that are arid today became cooler and wetter. This change in climate resulted in the formation of lakes in such areas as the Basin and Range region of Nevada and Utah. One of these lakes was ancient Lake Bonneville, which covered much of western Utah. The Great Salt Lake is all that remains of this glacial lake.

Section 7.1 Assessment

Reviewing Concepts

1. What are the two basic types of glaciers? Where is each type found?
2. Describe how glaciers move. Which property or properties of ice allow this movement?
3. How does glacial till differ from stratified drift? Describe one glacial feature made of each type of sediment.
4. Name three glacial features formed by erosion and three that are formed by deposition. What does each feature look like?

Critical Thinking

5. **Comparing and Contrasting** Compare and contrast advancing and retreating glaciers.
6. **Inferring** The snowline at the poles is sea level. Close to the equator, the snowline occurs high up on the tallest mountains. What is the relationship between the distance from the equator and snowline?

Math Practice

7. A glacier advances 20 meters over a period of about two months. What is its approximate rate of advance per day?

Section 7.1 Assessment

1. Valley glaciers look like streams of ice flowing between steep rock walls. They exist in high mountains. Ice sheets are enormous ice masses that cover everything but the highest land. The biggest ones are in Greenland and Antarctica.
2. Glaciers slip downhill due to gravity as well as flowing due to actual movement within the ice. The property known as plasticity allows for this.
3. Glacial till is an unsorted mixture of many different sizes. Moraines, which are ridges formed from material dropped by glaciers, are made of till. Stratified drift contains particles sorted by size and weight of the debris. Outwash plains, which are sediment ramps that extend downstream of an end moraine, are composed of stratified drift.
4. Erosion: cirque—a bowl-shaped depression at the head of a glacial valley; arête—snaking, sharp-edged ridge; horn—pyramid-shaped peak. Deposition: end moraine—debris dropped in a ridge at the face of a stationary glacier; ground moraine—a rock-strewn, gently rolling plain formed from sediments dropped by a retreating glacier; drumlins—streamlined hill made of glacial till
5. Both types flow and carry debris. Advancing glaciers accumulate ice faster than ice melts; retreating glaciers melt faster than ice accumulates.
6. The farther away from the equator you travel, the lower the snowline is.

7.2 Deserts

Reading Focus

Key Concepts

- How does running water affect deserts?
- What roles do mechanical and chemical weathering play in forming deserts?

Reading Strategy

Summarizing Write each blue heading in the section on a sheet of paper. Write a brief summary of the text for each heading.

Weathering
?
?
The Role of Water
?
?

Vocabulary

- alluvial fan
- playa lake

Desert landscapes reveal the effects of both running water and wind. As you will see, these combine in different ways in different places to result in a variety of desert landscapes.

Geologic Processes in Arid Climates

If you live in a humid region, visiting a desert might at first seem like encountering an alien planet. Rounded hills and curving slopes are typical of humid regions. By contrast, deserts have angular rocks, sheer canyon walls, and surfaces covered in pebbles or sand, shown in Figure 14. Despite their differences, the same geologic processes operate in both humid regions and deserts.

Figure 14 Desert landscapes vary a great deal. This landscape is in California's Death Valley.

Weathering

In humid regions, well-developed soils support an almost continuous cover of vegetation. In these regions, the slopes and rock edges are rounded and the landscape reflects the strong influence of chemical weathering. **By contrast, much of the weathered debris in deserts has resulted from mechanical weathering.** That debris consists of rock whose minerals remain unchanged. In dry lands, rock weathering of any type is greatly reduced because of the lack of moisture and scarcity of organic acids from decaying plants. **Chemical weathering, however, is not completely absent in deserts. Over long time spans, clays and thin soils do form.** Many iron-bearing silicate minerals oxidize, producing the rust-colored stain found tinting some desert landscapes.

Section 7.2

1 FOCUS

Section Objectives

7.5 **Describe** how running water affects deserts.

7.6 **Explain** the roles mechanical and chemical weathering play in the formation of deserts.

Reading Focus

Build Vocabulary L2

Paraphrase Have students write the definition of each vocabulary term in their own words.

Reading Strategy L2

Weathering Sample answer: Mechanical weathering is dominant in the desert. Chemical weathering does occur, but the process is very slow.

The Role of Water Sample answer: Although it doesn't rain often in the desert, the erosional effects of rain are significant.

2 INSTRUCT

Geologic Processes in Arid Climates

Build Science Skills L2

Observing Have students look closely at Figure 14. Ask: **If someone showed you this photograph, what are three features that would lead you to conclude that this was a desert climate?** (*Sample answers: sparse vegetation; only small, shrub-like vegetation present; lots of exposed soil and gravel*)
Visual, Logical

Glaciers, Deserts, and Wind 199

Section 7.2 (continued)

Build Reading Literacy

L1

Refer to **p. 586D** in **Chapter 21,** which provides the guidelines for SQ3R (Survey, Question, Read, Recite, Review).

SQ3R Teach this independent-study skill as a whole-class exercise. Direct students to survey the section and write headings such as Geologic Processes in Arid Climates. As they survey, ask students to write one question for each heading, such as "What type of weathering occurs in a desert climate?" Then, have students write answers to the questions as they read the section. After students finish reading, demonstrate how to recite the questions and answers, explaining that vocalizing in your own words helps you retain what you have learned. Finally, have students review their notes the next day.
Verbal

Use Visuals

L1

Figure 16 Have students look carefully at Figure 16. Ask: **When rain falls at the top of these barren mountains, what will the water look like when it reaches the bottom?** *(The water will be dirty because it will contain a lot of sediment that it has picked up as it flowed down the mountainside.)* **What happens to the sediment when the water reaches the gentle slopes in the foreground of this picture?** *(The rain water loses velocity and dumps its load of sediment on the gentle slopes.)*
Verbal

Figure 15 A Most of the time stream channels in deserts remain dry. **B** This is the same stream shortly after a heavy shower. Ephemeral streams can cause a large amount of erosion in a short time.
Predicting ***How long will the water flow in this stream?***

A


B


Reading Checkpoint *Why do deserts experience less chemical weathering than humid regions?*

The Role of Water Permanent streams are normally found in humid regions. However, in the desert, you'll find bridges with no water beneath them and dips in the road where empty stream channels cross. **In the desert, most streams are ephemeral—they only carry water after it rains.** A typical ephemeral stream might flow for only a few days or just a few hours during a year. In some years, the channels may not carry any water. In the western states people call these dry creeks *washes* or *arroyos.*

Customize for Inclusion Students

Learning Disabled For students with difficulty reading and writing, customize the Writing in Science feature on p. 202 to allow students to make a multimedia presentation instead of a written report.

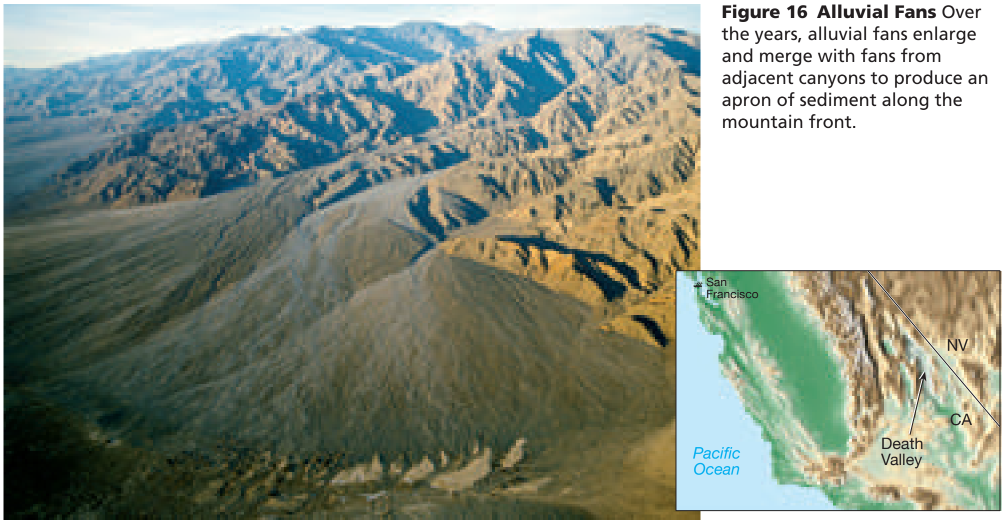


Figure 16 Alluvial Fans Over the years, alluvial fans enlarge and merge with fans from adjacent canyons to produce an apron of sediment along the mountain front.

Ephemeral streams are known for dangerous flash flooding after heavy rains. During heavy showers, so much rain falls that the soil cannot absorb it. The lack of vegetation allows water to quickly run off the land, as shown in Figure 15. The floods end as quickly as they start. Because there are fewer plants in deserts to anchor the soil, the amount of erosion caused during a single-short lived rain event is impressive. Floods in humid regions are different. A flood on a river like the Mississippi can take days to reach its crest and days to subside.

Basin and Range: A Desert Landscape

Because arid regions typically lack permanent streams, they have interior drainage. This means that they have intermittent streams that do not flow out of the desert to the ocean. In the United States, the dry Basin and Range provides an excellent example. The region includes southern Oregon, all of Nevada, western Utah, southeastern California, southern Arizona, and southern New Mexico. The name Basin and Range is an apt description for this region, because it contains more than 200 relatively small mountain ranges that rise 900 to 1500 meters above the basins that separate them.

When the occasional torrents of water produced by sporadic rains move down the mountain canyons, they are heavily loaded with sediment. Emerging from the confines of the canyon, the runoff spreads over the gentler slopes at the base of the mountains and quickly loses velocity. Consequently, most of its load is dumped within a short distance. The result is a cone of debris known as an **alluvial fan** at the mouth of a canyon, as shown in Figure 16.

Basin and Range: A Desert Landscape

Teacher Demo

Desert Water Erosion L2

Purpose Students will observe how water erodes a barren landscape and how alluvial fans form.

Materials sharpened pencil, paper cup, scissors, 1/2 of a drinking straw, modeling clay, cookie sheet, ruler, large beaker, water, soil, two 2" × 4" boards about 15 cm long

Procedure Use the sharpened pencil to make a hole in the side of the paper cup near the bottom. Insert one end of the straw into the hole in the cup. Seal the hole around the straw with modeling clay. Cover the cookie sheet with a thin layer of soil. Elevate the cookie sheet about 10 cm with a board. Set the cup at the top of the cookie sheet. Hold your finger over the end of the straw to keep the water from flowing. Use the beaker to fill the cup with water. Remove your finger and let the water flow. Observe what happens to the soil. Observe how far the soil flowed past the end of the cookie sheet. Elevate the cookie sheet 5 cm and repeat the experiment. Observe what happens to the soil and how far the soil flowed past the end of the cookie sheet. Note any differences in the two elevations.

Expected Outcomes Students will observe the soil flow off the cookie sheet just as the soil flows off a barren landscape. Students also should observe that soil will not flow as far when the slope is less steep. Alluvial fans form when the slope is not steep.
Visual

Facts and Figures

Many of the world's deserts are located in two belts. One belt is located along the Tropic of Cancer in the Northern Hemisphere. The deserts located in this belt are the Gobi in China, the deserts in southwestern North America, the Sahara in North Africa, and the Arabian and Iranian deserts in the Middle East. The second belt is located along the Tropic of Capricorn in the Southern Hemisphere. These deserts include the Patagonia in Argentina, the Kalahari in southern Africa, and the Great Victoria and Great Sandy deserts of Australia. These belts are formed when hot, moist air at the equator rises, cools, and loses its moisture. Then, the air descends, picking up moisture and drying out the land, creating these desert regions along the tropics.

Answer to . . .

Figure 15 *for a few hours to a few days*

Reading Checkpoint *Water is necessary for chemical weathering, so arid climates experience less chemical weathering than humid regions. Also, fewer plants exist to decay and contribute organic acids.*

Section 7.2 (continued)

3 ASSESS

Evaluate Understanding L2

Have students write three review questions for the section. Invite students to take turns asking questions to the class.

Reteach L1

Use Figures 14, 15, and 16 to review the main ideas in this section.

Writing in Science

First the ephemeral stream will be dry. Then, a sudden rush of water will occur that builds both in volume and velocity for several hours. The flood will then subside as quickly as it started.

Q&A

Q *I heard that deserts are expanding. Is that true?*

A Yes. The problem is called desertification, and it refers to the alteration of land to desert-like conditions as the result of human activities. It commonly takes place on the margins of deserts and results mostly from inappropriate land use. It is triggered when the modest natural vegetation in marginal areas is removed by plowing or grazing. When drought occurs, as it often does in these regions, and the vegetative cover has been destroyed beyond the minimum to hold the soil against erosion, the destruction becomes irreversible. Desertification is occurring in many places but is particularly serious in the region south of the Sahara Desert known as the Sahel.

On the rare occasions of abundant rainfall, or snowmelt in the mountains, streams may flow across the alluvial fans to the center of the basin, converting the basin floor into a shallow **playa lake.** Playa lakes last only a few days or weeks, before evaporation and infiltration remove the water. The dry, flat lake bed that remains is called a *playa.*

Humid regions have complex systems of rivers and streams that drain the land. Streams in dry regions lack this extensive drainage system. **Most desert streams dry up long before they ever reach the ocean. The streams are quickly depleted by evaporation and soil infiltration.**

Some permanent streams do manage to cross arid regions. The Colorado and Nile Rivers begin in well-watered mountains with huge water supplies. The rivers are full enough at the beginning to survive their desert crossings. The Nile River, for example, leaves the lakes and mountains of central Africa and covers almost 3000 kilometers of the Sahara without a single tributary adding to its flow. In humid regions, however, rivers generally gain water from both incoming tributaries and groundwater.

The point to remember about running water in the desert is this: although it is infrequent, it is an important geological force. **Most desert erosion results from running water. Although wind erosion is more significant in deserts than elsewhere, water does most of the erosional work in deserts.** Wind plays a different primary role in the desert. It transports and deposits the sediments to create dunes.

Section 7.2 Assessment

Reviewing Concepts

1. How are ephemeral streams different form streams in humid locations?
2. How do weathering processes affect deserts?
3. Why is erosion by running water important in deserts?
4. How does a river survive crossing an arid region?

Critical Thinking

5. **Comparing and Contrasting** Compare and contrast the Nile River with the Mississippi River. Which factor is most responsible for their differences?
6. **Applying Concepts** Explain how evaporation affects drainage systems in desert areas.

Writing in Science

Suppose you are standing on a bridge over an ephemeral stream in the desert. Write a paragraph describing what you might see following a sudden downpour.

Section 7.2 Assessment

1. Ephemeral streams are not permanent but have a greater propensity to produce flash floods, which cause substantial erosion.
2. Water and wind cause mechanical weathering and produce angular rocks, sheer canyon walls, and pebble-covered surfaces.
3. Because there are fewer plants in deserts to anchor the soil, there can be a great amount of erosion caused during a single short-lived rain event.
4. It must be full enough at the beginning to survive the soil infiltration and evaporation that occur in the desert.
5. Both carry water. The Nile has few tributaries. The Mississippi drainage system is highly branched. The Mississippi takes longer to crest and subside. Climate is the factor most responsible for the rivers' differences.
6. Streams in desert areas lack extensively branched drainage systems. They do not flow out of the desert to oceans, and instead have interior drainage, helping evaporation to dry up ephemeral streams.

7.3 Landscapes Shaped by Wind

Reading Focus

Key Concepts

- How does deflation cause erosion in the desert?
- How does abrasion shape desert landscapes?
- What types of landforms are deposited by wind?
- How do sand dunes differ?

Vocabulary

- deflation
- desert pavement
- loess
- dune

Reading Strategy

Outlining Before you read, make an outline of this section. Use the green headings as the main topics and the blue headings as subtopics. As you read, add supporting details.

Landscapes Shaped by Wind

I. Wind Erosion
  A. Deflation
  B. Abrasion
II. ____?____
  A. ____?____

Wind Erosion

Compared with running water, wind does not do nearly as much erosional work on the land, even in deserts. But wind is still an important force. Humid areas can resist wind erosion because moisture binds soil particles together and plants anchor the soil. But desert soils are dry and have less vegetation to hold soil in place. Therefore, wind does its most effective erosional work in deserts.

Strong desert winds pick up, transport, and deposit great quantities of fine sediment. Farmers of the Great Plains experienced the power of wind erosion during the 1930s. After they plowed the natural vegetation from this semi-arid region, a severe drought set in. The land was left exposed to wind erosion. Vast dust storms swept away the fertile topsoil. The area became known as the Dust Bowl.

Wind erodes in the desert in two ways: deflation and abrasion. Deflation is the lifting and removal of loose particles such as clay and silt. Coarser sand particles roll or skip along the surface in a process called saltation. These large sand particles make up the bed load. In portions of the Dust Bowl, deflation lowered the land by a meter or more in only a few years, as shown in Figure 17.

Deflation also results in shallow depressions called blowouts. You can see thousands of blowouts in the Great Plains. They range from small dimples less than 1 meter deep and 3 meters wide to depressions more than 45 meters deep and several kilometers across.

Figure 17 The mounds in this photo show the level of the land before deflation removed the topsoil. The mounds are 1.2 meters tall and are anchored by vegetation. The photo was taken in July 1936 in Granville, North Dakota and reveals the extent of the damage in the Dust Bowl. **Applying Concepts** ***How did farmers contribute to ruining the land during the Dust Bowl?***

Section 7.3

1 FOCUS

Section Objectives

7.7 **Describe** two ways that wind can cause erosion.
7.8 **Identify** types of landforms that are deposited by the wind.
7.9 **Describe** how sand dunes differ.

Reading Focus

Build Vocabulary L2

Concept Map Have students construct a concept map using all of the vocabulary terms. Students should place the main concept (Landscapes Shaped by Wind) in the center oval and use descriptive linking phrases to connect the terms. Instruct students to place the terms in ovals and connect the ovals with lines on which linking words are placed.

Reading Strategy L2

II. Wind Deposits; **A.** Loess; **B.** Sand Dunes; **III.** Types of Sand Dunes; **A.** Barchan Dunes; **B.** Transverse Dunes; **C.** Barchanoid Dunes; **D.** Longitudinal Dunes; **E.** Parabolic Dunes; **F.** Star Dunes

2 INSTRUCT

Wind Erosion

Address Misconceptions L2

Students may think that an area shrouded in mist cannot be a desert. This is not true. Deserts shrouded in mist form along coastlines. Cold waters from the Arctic and Antarctic regions and cold water from ocean depths move toward the equator and cool the air currents above them. This cool air carries fog and mist, but little rain. These misty air currents flow across the coastal regions of southern California, Baja California, southwest Africa, and Chile.

Answer to . . .

Figure 17 *Mechanized cultivation removed prairie grass from large areas, leaving soil vulnerable to wind.*

Use Visuals L1

Figure 18 Have students look closely at Figure 18A. Ask: **What is occurring in the first picture of Figure 18A?** *(Deflation of the desert surface begins. Fine sediment is removed from the surface of the desert floor.)* **What is occurring in the second picture of Figure 18A?** *(Deflation continues as fine sediment is removed, leaving only coarse particles.)* **What is occurring in the third picture of Figure 18A?** *(All fine particles are removed. The remaining coarse particles have been compressed into desert pavement.)*
Visual, Verbal

Wind Deposits

Build Reading Literacy L1

Refer to **p. 392D** in **Chapter 14**, which provides the guidelines for preview.

Preview Have students read the bold subheads and examine the figures in the section. Then, ask students to list the important concepts they learned or will learn in the section. *(how landscapes are shaped by wind and what wind erosion and wind deposits can do)*
Visual, Verbal

Integrate Language Arts L2

Dust Bowl Literature John Steinbeck's novel *The Grapes of Wrath* is about an Oklahoma farming family who are forced to leave their home and move to California in a desperate attempt to survive during the Dust Bowl and the Depression. Select a passage from this novel to share with the class.
Verbal

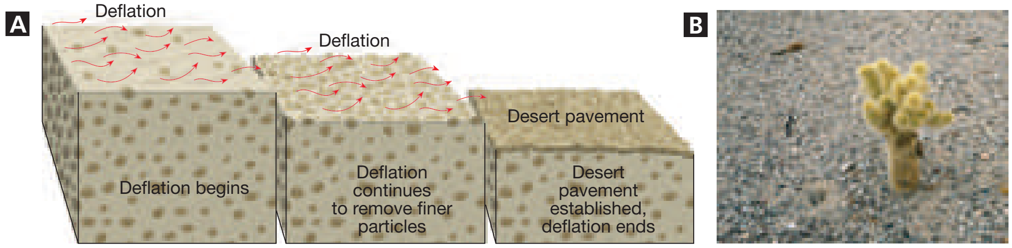


Figure 18 A These cross sections show how deflation removes the sand and silt of the desert surface until only coarser particles remain. These coarser particles concentrate into a tightly packed layer called desert pavement. **B** Desert pavement like this in Arizona's Sonoran Desert protects the surface from further deflation. **Predicting** ***What will happen if a vehicle disturbs this desert pavement?***

In portions of many deserts, the surface is characterized by a layer of course pebbles and cobbles that are too large to be moved by the wind. Deflation creates a stony surface layer called **desert pavement** when it removes all the sand and silt and leaves only coarser particles. See Figure 18. The remaining surface of coarse pebbles and cobbles is protected from further deflation—unless vehicles or animals break it up. If something does disturb the surface, the wind begins eroding once again.

Wind can erode by abrasion, too. Abrasion happens when wind-blown sand cuts and polishes exposed rock surfaces. Blowing sand can grind away at boulders and smaller rocks, sometimes sandblasting them into odd shapes. Abrasion is often credited for features such as balanced rocks that stand high atop narrow pedestals or the detailing on tall pinnacles. However, these features are not the results of abrasion. Sand rarely travels more than a meter above the surface, so the wind's sandblasting effect is limited in a vertical extent. However, in some areas, telephone poles have been cut through near the base.

Reading Checkpoint ***What is deflation?***

Wind Deposits

The wind can create landforms when it deposits its sediments, especially in deserts and along coasts. Both layers of loess and sand dunes are landscape features deposited by wind. These blankets of silt and mounds of sand are striking features in some parts of the world.

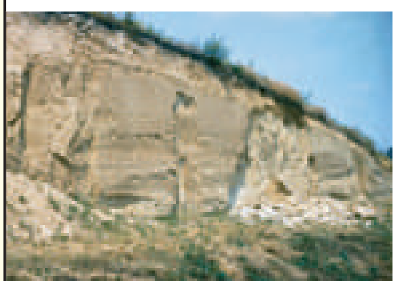


Figure 19 This loess bluff near the Mississippi River in southern Illinois is about 3 meters high.

Loess **Loess** is windblown silt that blankets the landscape. Dust storms over thousands of years picked up this material, transported it, and then deposited it. The thickest and most extensive deposits of loess on Earth occur in western and northern China. The silt was derived from nearby deserts. This fine, buff-colored sediment gives the Yellow River its name. You also can find loess in the United States. See Figure 19. Strong winds sweeping across glacial sediments created significant loess deposits in portions of South Dakota, Nebraska, Iowa, Missouri, Illinois, and the Columbia Plateau in the Pacific Northwest.

Customize for English Language Learners

Help beginning language learners by using a Cloze strategy to extract key information from the text about wind deposits. After reading the section Wind Deposits, have students fill in the blanks in the following sentences: **The wind can create landforms when it deposits its ________, especially in deserts and along ________. Both layers of loess and ________ are landscape features deposited by the ________. Unlike deposits of ________, which forms blanket-like layers over broad areas, winds commonly deposit ________ in mounds or ridges called ________.** *(sediments, coasts, sand dunes, wind, loess, sand, dunes)*

Figure 20 Sand slides down the steeper face of a dune in New Mexico's White Sands National Monument. Wind blows sand up the opposite, windward, face of the dune, then it drops down this sheltered side. Slippage along the steep side results in migration of the dune in the direction the wind blows.

Figure 21 These cross beds are part of the Navajo Sandstone in Zion National Park, Utah.

Sand Dunes Like running water, wind releases its load of sediment when its velocity falls and the energy available for transport diminishes. Sand begins to accumulate wherever an obstruction crosses its path and slows its movement. **Unlike deposits of loess, which form blanket-like layers over broad areas, winds commonly deposit sand in mounds or ridges called dunes.** Dunes can occur in places where the wind encounters an obstruction. The wind's velocity falls and the sand particles drop to the ground. Dunes can begin near obstructions as small as a clump of vegetation or a rock. Once the sand starts to mound up it serves as its own obstruction, and it traps more and more sand. With enough sand and long periods of steady wind, the mound of sand becomes a dune.

Dunes often are steeper on the sheltered side and more gently sloping inclined on the side facing the wind. Wind blows sand grains up the gentler windward side. Once the sand blows over the crest of the dune, the wind slows and the sand drops out. The sheltered side of the dune becomes steeper, and the sand eventually slides down the slope, as shown in Figure 20. In this way, the dune tends to migrate in the direction the wind blows.

As sand is deposited on the sheltered side of the dune, it forms layers inclined in the direction the wind is blowing. These sloping layers are called cross beds. When the dunes are eventually buried under other layers of sediment and become sedimentary rock, the cross beds remain as a record of their origin, as shown in Figure 21.

Reading Checkpoint *How do obstructions help to form dunes?*

Go Online NSTA SCiLINKS

For: Links on wind erosion
Visit: www.SciLinks.org
Web Code: cjn-2073

Teacher Demo

Wind Erosion L2

Purpose Students will observe how wind erodes the landscape.

Materials sand, large piece of cardboard, water

Procedure Make two mounds of sand on the cardboard. Sprinkle water over one and leave the other one dry. Blow across the wet sand. Then, blow across the dry sand.

Expected Outcomes Students will observe the wet sand does not move. They will also observe that the dry sand is blown away by the movement of air just as wind moves the sand in a desert or in a dry region.
Visual, Logical

Go Online NSTA SCiLINKS

Download a worksheet on wind erosion for students to complete, and find additional teacher support from NSTA SciLinks.

Facts and Figures

What caused the Dust Bowl? Clearly, the fact that portions of the Great Plains experienced some of North America's strongest winds is important. However, it was the huge expansion of agriculture that set the stage for this disastrous period of soil erosion. Mechanization allowed the rapid transformation of the grass-covered prairies of this semiarid region into farms. Between 1870 and 1930, the area of cultivation in the region expanded nearly tenfold, from about 10 million acres to more than 100 million acres. As long as precipitation was adequate, the soil remained in place. However, when a prolonged drought struck in the 1930s, the unprotected fields were vulnerable to the wind. The results were severe crop loss, crop failures, and economic hardship.

Answer to . . .

Figure 18 *Further deflation will remove more sand and silt.*

Reading Checkpoint *Deflation occurs when wind lifts and removes loose particles such as clay and silt.*

Reading Checkpoint *Obstructions reduce wind velocity and cause sand particles to drop to the ground.*

Types of Sand Dunes

Build Science Skills L2

Interpreting Diagrams Have students study Figure 22. Ask: **Which sand dunes form from wind that blows in a single direction?** *(barchan, transverse, barchanoid, and parabolic)* **Which sand dunes form from wind that blows in multiple directions?** *(longitudinal and star)*
Verbal, Logical

Integrate Language Arts L2

Word Roots Tell students that one of the meanings of the Latin root *trans-* is "across." Ask students to discuss why *transverse* is an appropriate name for this type of dune. *(The wind blows across the dune.)*
Verbal

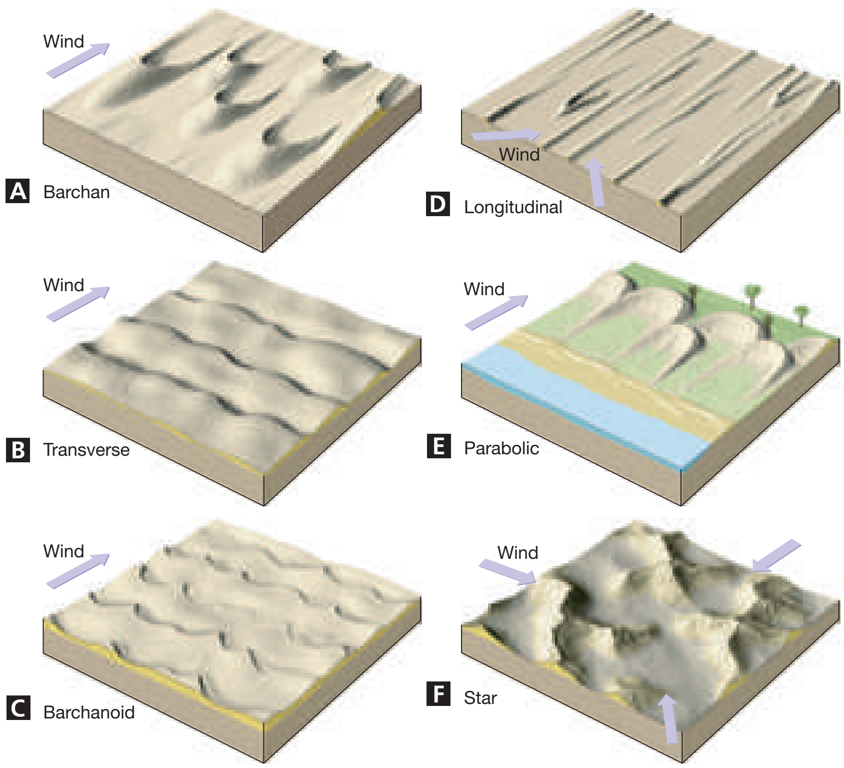
Types of Sand Dunes

Dunes are not just random heaps of sand. They occur in a variety of consistent forms worldwide. **What form sand dunes assume depends on the wind direction and speed, how much sand is available, and the amount of vegetation.** Figure 22 shows six different types of dunes.

Barchan Dunes Solitary sand dunes shaped like crescents are called barchan dunes. These form on flat, hard ground where supplies of sand and vegetation are limited. Barchan dunes move slowly and only reach heights of about 30 meters. If the wind direction is constant, barchan dunes remain symmetrical. One tip of the dune can grow larger than the other if the wind direction varies somewhat.

Transverse Dunes If prevailing winds are steady, sand is plentiful, and vegetation is sparse, dunes form in a series of long ridges. They are called transverse dunes because these ridges are perpendicular to the direction of the wind. Transverse dunes are typical in many coastal areas.

Types of Sand Dunes Figure 22



Customize for Inclusion Students

Visually Impaired Use dampened sand to create models of each type of sand dune pictured in Figure 22 for students with visual impairments.

They also comprise the “sand seas” found in parts of the Sahara and Arabian deserts. Transverse dunes in both of these deserts reach heights of 200 meters, measure 1 to 3 kilometers across, and extend for distances of 100 kilometers or more.

Barchanoid Dunes A common dune form that is intermediate between a barchan and transverse dune is the barchanoid dune. These scalloped rows of sand form at right angles to the wind. The rows resemble a series of barchans that have been positioned side by side. You can see them at White Sands National Monument in New Mexico.

Longitudinal Dunes Longitudinal dunes are long ridges of sand that form parallel to the prevailing wind. These dunes occur where sand supplies are moderate and the prevailing wind direction varies slightly. In portions of North Africa, Arabia, and central Australia, longitudinal dunes can reach nearly 100 meters high and extend for more than 100 kilometers.

Parabolic Dunes Parabolic dunes look like backward barchans. Their tips point into the wind instead of away from it. They form where some vegetation covers the sand. Parabolic dunes often form along the coast where strong onshore winds and abundant sand are available.

Star Dunes Star dunes are isolated hills of sand mostly found in parts of the Sahara and Arabian deserts. Their bases resemble stars and they usually have three or four sharp ridges that meet in the middle. Star dunes develop in areas of variable wind direction, and they sometimes reach heights of 90 meters.

Q & A

Q *Aren’t deserts mostly covered with sand dunes?*

A Many people think a desert is covered in drifting sand dunes. Some deserts do have striking sand dunes. But sand dunes worldwide represent only a small percentage of the total desert area. Dunes cover only one-tenth of the world’s largest desert, the Sahara, and only one-third of the world’s sandiest desert, the Arabian, is covered in dunes.

Section 7.3 Assessment

Reviewing Concepts

1. How does deflation lower the surface of the desert?
2. What would you expect to see in areas subject to abrasion?
3. What was the Dust Bowl, and why did it occur?
4. How does a dune help itself to grow?
5. What factors determine the shape of sand dunes?

Critical Thinking

5. **Comparing and Contrasting** Compare and contrast loess and sand dunes.
6. **Designing Experiments** Describe how you would conduct an experiment to determine the wind speed necessary to suspend sand, silt, and clay particles.

Connecting Concepts

Which dune type would you expect to travel the least? Explain your answer.

3 ASSESS

Evaluate Understanding

L2

Ask students to write three quiz questions using the information in this section. Have students work in groups to quiz each other.

Reteach

L1

Have students explain in their own words how the sand dunes are formed in Figure 22.

Connecting Concepts

Star dunes would travel the least, because variable winds will move the dunes back and forth rather than in a single direction.

Section 7.3 Assessment

1. Wind removes the loose clay and silt particles from the surface.
2. polished rock surfaces; oddly shaped rocks called ventifacts
3. a vast area of the Great Plains where wind erosion occurred in the 1930s; because a drought made the plowed ground vulnerable to wind erosion
4. It serves as its own wind obstruction, causing the wind to slow and sand to drop out.
5. wind direction and speed, how much sand is available, amount of vegetation
6. Both are wind-blown deposits. Loess is made of silt; dunes are made of sand.
7. Answers should include a reasonable way to alter and measure the wind speed, as well as to collect particles.

How the Earth Works

1 FOCUS

Objectives

In this feature, students will
- define erosion and identify its agents.
- describe the effects of erosion on different landforms.

Reading Focus

Build Vocabulary L2

Define Terms Write the word *erosion* on the board. Have students define it. Have students brainstorm a list of places that show the effects of erosion in your region. Remind them of beaches, canyons, and other appropriate places.

2 INSTRUCT

Bellringer L2

Ask students if they have ever collected rocks from a river or ocean. Ask: **What was the texture of the rocks you collected?** *(Most of them are smooth.)* Ask: **What would account for the smoothness of these rocks?** *(The constant motion of the water on the rocks wears down rough points and makes the surface smooth.)* Discuss how running water affects hard objects and land over time.
Logical

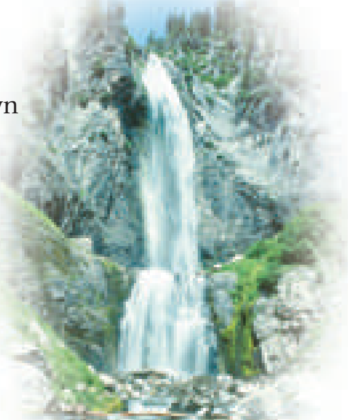
Use Visuals L1

Have students study the pictures and diagrams on this page and the next. Ask: **Are the effects of erosion obvious from year to year? Why or why not?** (*In most cases, the effects are not obvious because erosion is a gradual process. In the case of erosion due to desert storms, the effects are more immediately obvious.)*
Visual

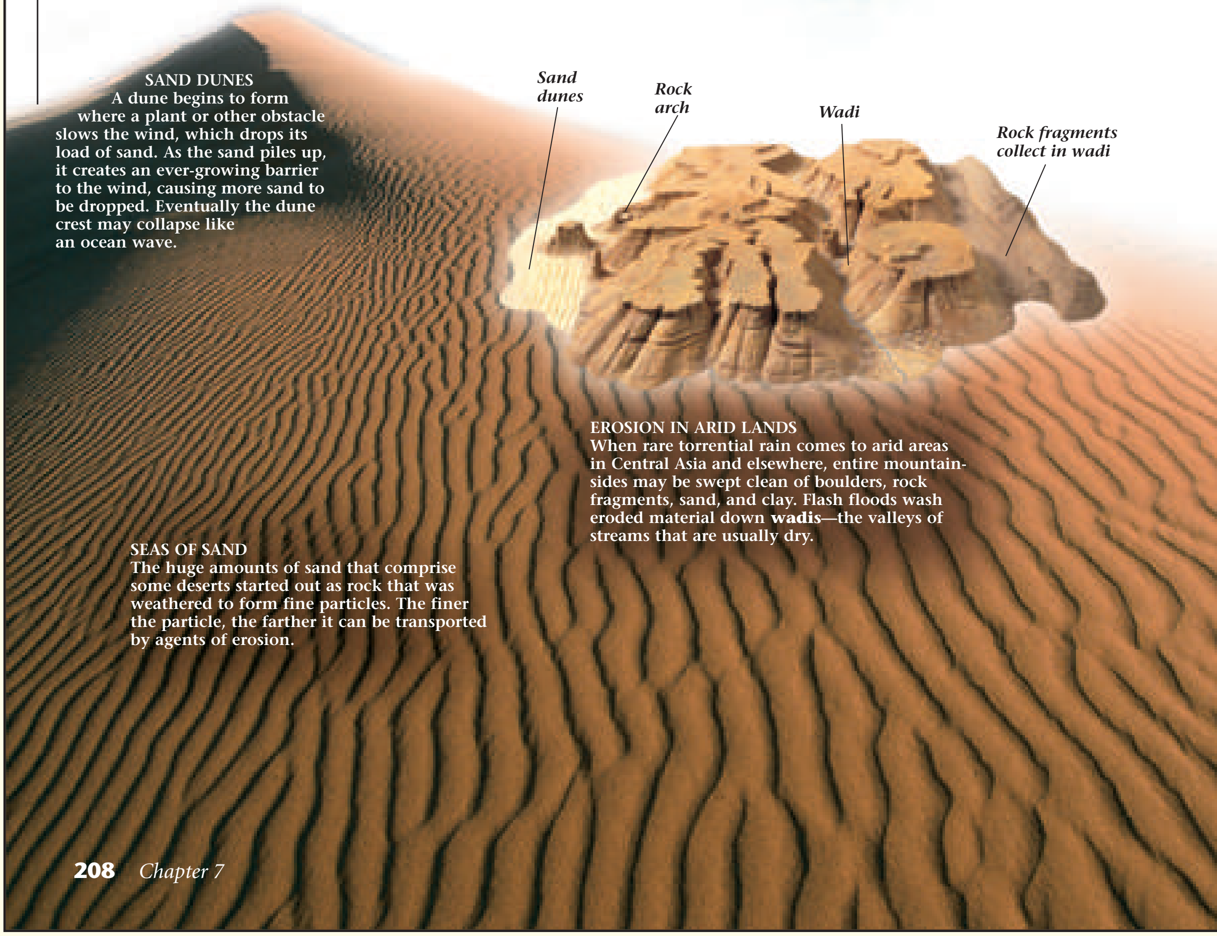
How the Earth Works

Erosion

Erosion is the process by which rocks are broken down by weathering and the loose material is carried away. Rock material can be moved by streams and rivers, by waves, by glacial ice, or by wind. The number of fragments that are moved and the distance that they travel are affected by factors such as the size and weight of the particles and the speed at which the eroding agent is moving. The eroded material is carried to another site where it is deposited as **sediment.** Erosion affects the landscapes of Central Asia, the Caucasus, and all regions of the world.



WATER FLOWING
As water flows from highlands to the sea, sharp descents result in rapids and waterfalls. Flowing water is an important agent of erosion.



SAND DUNES
A dune begins to form where a plant or other obstacle slows the wind, which drops its load of sand. As the sand piles up, it creates an ever-growing barrier to the wind, causing more sand to be dropped. Eventually the dune crest may collapse like an ocean wave.

EROSION IN ARID LANDS
When rare torrential rain comes to arid areas in Central Asia and elsewhere, entire mountainsides may be swept clean of boulders, rock fragments, sand, and clay. Flash floods wash eroded material down **wadis**—the valleys of streams that are usually dry.

SEAS OF SAND
The huge amounts of sand that comprise some deserts started out as rock that was weathered to form fine particles. The finer the particle, the farther it can be transported by agents of erosion.

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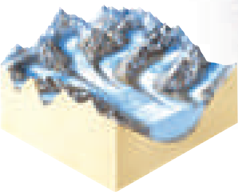
Customize for Inclusion Students

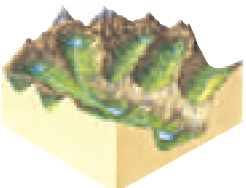
Gifted Have students research ways to minimize erosion at the library or on the Internet. Ask them to create a flowchart or diagram that shows what people can do to minimize erosion. Students can present their diagrams to the class and explain them.

EROSION BY GLACIAL ICE
Huge masses of moving ice are called **glaciers.** Over thousands or millions of years, they can scour mountainsides and dramatically change the shapes of valleys.

1. Before glaciation *A narrow, V-shaped river valley is surrounded by rounded mountains.*



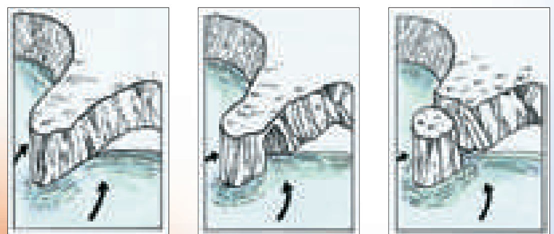
2. During glaciation *Moving ice erodes mountaintops and carves wider valleys.*



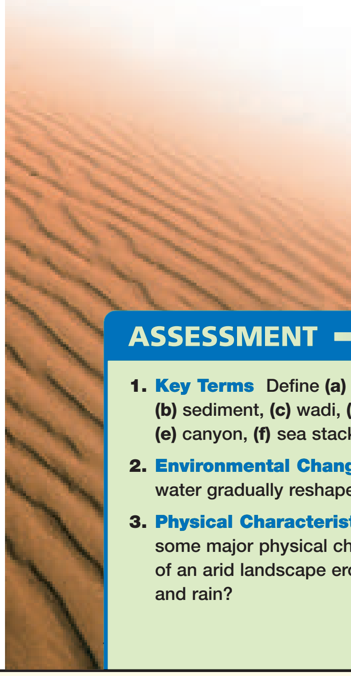
3. After glaciation *The result is a U-shaped valley with rugged, sharp peaks above.*

STREAM EROSION
Streams erode their banks and beds, continually widening and deepening them. In some cases, a canyon may result. A **canyon,** such as this one in Utah, is a deep valley with vertical sides that have been eroded by river water.

WAVE ACTION
Coastlines are constantly eroded by waves that are formed by winds blowing over water. Cracked and soft rocks are eroded away first, leading to the creation of arches. If the arch roof collapses, a **sea stack** results.

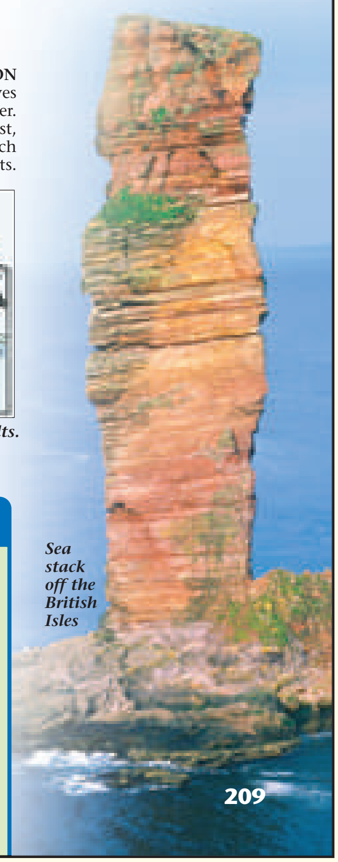


1. Waves curve around headland. *2. An arch forms.* *3. A sea stack results.*



ASSESSMENT

1. **Key Terms** Define **(a)** erosion, **(b)** sediment, **(c)** wadi, **(d)** glacier, **(e)** canyon, **(f)** sea stack.
2. **Environmental Change** How does water gradually reshape the land?
3. **Physical Characteristics** What are some major physical characteristics of an arid landscape eroded by wind and rain?
4. **Physical Processes** Analyze the three diagrams of glacial erosion. How can glaciers change the shapes of mountain valleys?
5. **Critical Thinking** **Analyzing Causes and Effects** How can erosion on farmlands cause a reduction in agricultural production?



Sea stack off the British Isles

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3 ASSESS

Evaluate Understanding L2

Have students write sentences using the key terms from this feature. Remind them that the sentences should include the definition of each term. Encourage students to use more than one key term per sentence when possible.

Reteach L1

Draw a two-column chart on the board. Label the columns *Eroding Agent* and *Effects*. Have students use information from the text to describe how streams, waves, glaciers, and other eroding agents change the landscape.

Assessment

1. (a) the transport of loose material broken down by weathering; **(b)** eroded material that is deposited; **(c)** a valley of a usually dry stream; **(d)** a huge mass of moving ice; **(e)** a deep valley with vertical sides that have been eroded by river water; **(f)** a column of eroded coastline
2. Flowing water in the form of waterfalls, rivers, oceans, or rain breaks up rocks and other loose material.
3. Sample answer: sand dunes formed and unformed by wind, wadis created during flash floods, sand formed from rocks eroded by wind
4. Glaciers can change narrow, V-shaped valleys into wider, U-shaped valleys.
5. The soil's nutrients wash or blow away, making the land less productive.

Section 8.1

1 FOCUS

Section Objectives

8.1 **Compare and contrast** the epicenter and focus of an earthquake.

8.2 **Identify** the cause of earthquakes.

8.3 **Compare and contrast** aftershocks and foreshocks.

Reading Focus

Build Vocabulary L2

Word Parts Tell students that the prefix *epi-* is from the Greek word for "on" or "above." Ask them to guess what the word *epicenter* means based on this *(above the center)*. What other words can students come up with that have the same prefix? *(epidermis, epidemic)*

Reading Strategy L2

a. vibration of Earth due to release of pressure
b. focus
c. location inside Earth where energy is released in earthquake
d. epicenter
e. spot on surface of Earth directly above focus
f. fault
g. large fracture in Earth's crust and mantle

2 INSTRUCT

Earthquakes

Use Visuals L1

Figure 1 Direct student's attention to the facade of the building. Ask: **How many stories do you think this building was originally?** *(at least three)* **What happened to the other stories?** *(They were crushed in the motion of the earthquake.)*
Visual

8.1 What Is an Earthquake?

Reading Focus

Key Concepts

- What is a fault?
- What is the cause of earthquakes?

Vocabulary

- earthquake
- focus
- epicenter
- fault
- elastic rebound hypothesis
- aftershock
- foreshock

Reading Strategy

Building Vocabulary Copy the table below. Then as you read the section, write a definition for each vocabulary term in your own words.

Vocabulary	Definition
earthquake	a. ?
b. ?	c. ?
d. ?	e. ?
f. ?	g. ?

Each year, more than 30,000 earthquakes occur worldwide that are strong enough to be felt. Fortunately, most of these earthquakes are minor tremors and do very little damage. Generally, only about 75 major earthquakes take place each year. Most of these occur in remote regions. However, occasionally a large earthquake occurs near a city. Under these conditions, an earthquake is one of the most destructive natural forces on Earth, as shown in Figure 1.

Figure 1 This damage occurred in San Francisco's Marina District from the 1989 Loma Prieta earthquake.

Earthquakes

An **earthquake** is the vibration of Earth produced by the rapid release of energy. Earthquakes are often caused by slippage along a break in Earth's crust.

Focus and Epicenter The point within Earth where the earthquake starts is called the **focus.** The released energy radiates in all directions from the focus in the form of waves. These waves are similar to the waves produced when a stone is dropped into a calm pond. The impact of the stone sets water waves in motion. An earthquake is similar because it produces seismic waves that radiate throughout Earth.

The focus of an earthquake is the place within Earth where the earthquake originates. When you see a news report about an earthquake, the reporter always mentions the place on Earth's surface where the earthquake has been located. The **epicenter** is the location on the surface directly above the focus, as shown in Figure 2.

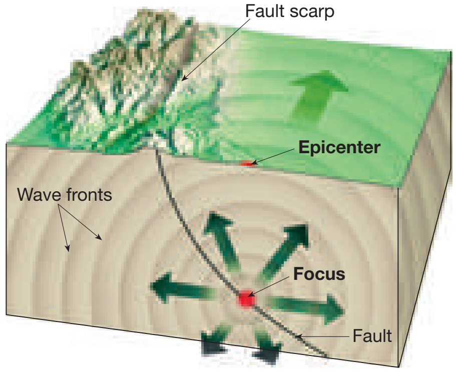


Figure 2 The focus of each earthquake is the place within Earth where the earthquake originated. The foci (plural of focus) are located along faults. The surface location directly above the focus is called the epicenter.
Predicting *Where do you think the damage from an earthquake is usually greatest?*

Faults A lot of evidence shows that Earth is constantly changing. We know that Earth's crust has been uplifted at times. We have found many ancient wave-cut features meters above the level of the highest tides. Offsets in fence lines, roads, and other structures indicate that horizontal movements of Earth's crust are also common, as seen in Figure 3. Earthquakes are usually associated with large fractures in Earth's crust and mantle called **faults.** **Faults are fractures in Earth where movement has occurred.**

Reading Checkpoint *What is a fault?*

Cause of Earthquakes

Before the great 1906 San Francisco earthquake, the actual causes and effects of earthquakes were not understood. The San Fransisco earthquake caused horizontal shifts in Earth's surface of several meters along the northern portion of the San Andreas Fault. The 1300-kilometer San Andreas fracture extends north and south through southern California. Studies following the 1906 quake found that during this single event, the land on the western side of the San Andreas Fault moved as much as 4.7 meters to the north compared to the land on the eastern side of the fault.

Based on these measurements and related studies, a hypothesis was developed to explain what had been observed. Figure 4 on page 220 illustrates this hypothesis. Part A shows an existing fault. In part B, forces within Earth slowly deform the crustal rocks on both sides of the fault, shown by the bent features of the rocks. These forces cause the rocks to bend and store elastic energy, just like a wooden stick does if it is bent. Elastic energy is the same kind of energy that is stored when you stretch a rubber band. Eventually, the resistance caused by internal friction that holds the rocks together is overcome. The rocks slip at the weakest point (the focus). The movement will exert forces farther along the fault, where additional slippage will occur until most of the built-up energy is released. This slippage allows the deformed rock to snap back in place. The vibrations we call an earthquake occur as the rock elastically returns to its original shape.

Figure 3 Slippage along a fault caused an offset in this orange grove east of Calexico, California. The white arrows show the direction of movement on either side of the fault.

Cause of Earthquakes

Build Science Skills L2

Using Models ACTIVITY Have students use a plastic, flexible ruler to model the vibrations that cause earthquakes. Students should place the ruler on the edge of their desk, with approximately half of the ruler hanging off the edge. Tightly holding the other half to the desk, they should bend the ruler down. Releasing the ruler will model the release of energy along a fault. Students will be able to visualize the waves generated along the fault as the energy is released.
Kinesthetic, Visual

Teacher Demo

Sweet Stress L2

Purpose Students witness the buildup of stress and the result of the release of energy in an earthquake through the use of a candy bar as a model.

Materials chocolate-covered candy bar with nougat center (such as Three Musketeers)

Procedure Unwrap the candy bar and ask students to describe the surface of the chocolate coating. Grab both ends of the candy bar and slowly begin to bend the ends down. Ask students to observe the cracks on the surface as the stress is built up. Keep bending the candy bar until it breaks or snaps. Ask students to describe the final moments of the candy bar as well as what happened when the candy bar broke.
Visual, Logical

Customize for English Language Learners

Earthquakes only happen in certain areas of the world. These areas are called Earthquake belts. The rim or edge of the Pacific Ocean is the largest of these belts. Another belt stretches from China to Southeast Asia to Africa and Europe. A third earthquake belt lies under the Atlantic Ocean. With a partner, look at a map of the world. Identify the areas where there are earthquake belts. List on a piece of paper the names of the oceans or land masses where you think there are earthquake belts.

Answer to . . .

Figure 2 *at the epicenter*

Reading Checkpoint *A fault is a fracture in Earth where movement has occurred.*

Use Community Resources L2

Help students conduct a Web search of their town's geologic history. Compile a list of any earthquakes or notable seismic activity, and have students investigate major events further. They can consult reference and online sources, or gather firsthand knowledge by interviewing people who experienced any events. See if their research leads to any evidence of property damage or rock deformations in their area, such as a photograph like Figure 3.

If information on local geologic events is not available, have students visit the U.S. Geological Survey's Web site to search for recent earthquakes. Then have groups look at online articles from newspapers in the area of an earthquake.

Use Visuals L1

Figure 4 Ask: **What evidence of deformation is present in the fourth picture?** *(Each stream has been divided in two.)*

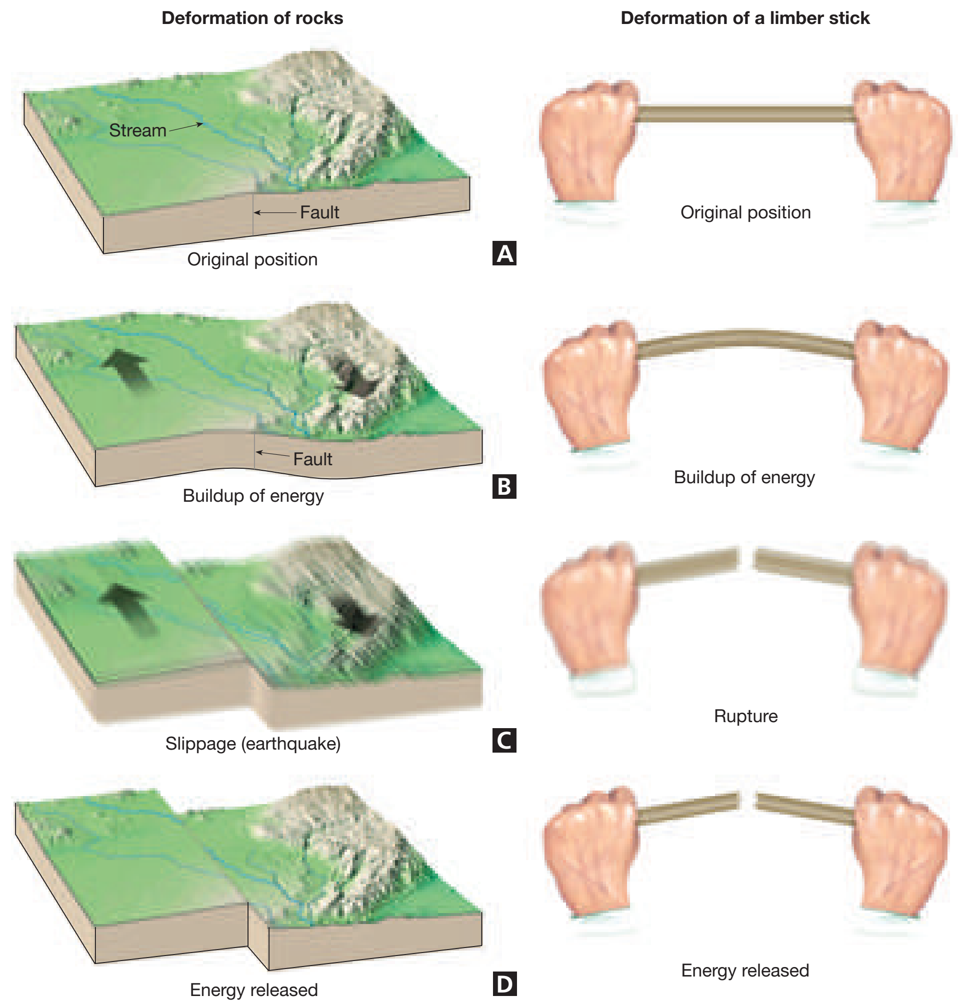
Integrate Physics L2

Potential and Kinetic Energy Read the first paragraph of the section on Elastic Rebound Hypothesis aloud. Ask students to identify the words that relate to energy. Explain that *stored* energy is potential energy, and *the release of energy* is kinetic energy.

Figure 4 As rock is stressed it bends, storing elastic energy. Once the rock is strained beyond its breaking point, it ruptures and releases the stored energy in the form of seismic waves. **Inferring** ***How do you think the temperature of rock would affect its ability to bend or break?***

Elastic Rebound Hypothesis The springing back of the rock into its original place is called elastic rebound. The rock behaves much like a stretched rubber band does when it is released. The explanation says that when rocks are deformed, they first bend and then break, releasing stored energy. This explanation for the release of energy stored in deformed rocks is called the **elastic rebound hypothesis.**

Elastic Rebound



Facts and Figures

San Diego, California, and Santa Barbara, California, are on opposite sides of the San Andreas fault. They are currently approximately 562 km apart. The plates on either side of the San Andreas fault move at about the same rate as your fingernails grow, or about 45 mm/yr. At this rate, San Diego will reach Santa Barbara's current location in approximately 10 million years!

Most earthquakes are produced by the rapid release of elastic energy stored in rock that has been subjected to great forces. When the strength of the rock is exceeded, it suddenly breaks, causing the vibrations of an earthquake. Earthquakes most often happen along existing faults. They occur when the frictional forces on the fault surfaces are overcome.

Aftershocks and Foreshocks The intense shaking of the 1906 San Francisco earthquake lasted about 40 seconds. Most of the movement along the fault occurred in this short time period. However, additional movements along this and nearby faults continued for several days. The movements that follow a major earthquake often produce smaller earthquakes called **aftershocks.** These aftershocks are usually much weaker than the main earthquake, but they can sometimes destroy structures weakened by the main quake. Small earthquakes called **foreshocks** often come before a major earthquake. These foreshocks can happen days or even years before the major quake.

The San Andreas Fault is the most studied fault system in the world. Studies have shown that displacement has occurred along segments that are 100 to 200 kilometers long. Each fault segment behaves a bit differently than the other segments. Some parts of the San Andreas show a slow, gradual movement known as fault creep. This movement happens fairly smoothly. Other segments regularly slip and produce small earthquakes. However, some segments stay locked and store elastic energy for hundreds of years before they break and cause great earthquakes.

Go Online NSTA SCILINKS

For: Links on earthquakes
Visit: www.SciLinks.org
Web Code: cjn-3081

Section 8.1 Assessment

Reviewing Concepts

1. What is a fault?
2. Describe the cause of earthquakes.
3. What is an earthquake?
4. What is the source of an earthquake called?
5. What are foreshocks and aftershocks?

Critical Thinking

6. **Connecting Concepts** How are faults, foci, and epicenters related?
7. **Inferring** What is meant by elastic rebound?
8. **Making Judgments** Why do most earthquakes cause little damage and loss of life?

Math Practice

9. In 25 years, how much movement will result from a fault that slowly slips 1.5 centimeters per year?

Build Reading Literacy L1

Refer to **p. 216D**, which provides the guidelines for compare and contrast.

Compare and Contrast Have students review the section on aftershocks and foreshocks. Ask them to complete a Venn diagram.
Verbal

3 ASSESS

Evaluate Understanding L2

Have students create a diagram that shows the difference between the focus and the epicenter of an earthquake.

Reteach L1

Ask students to use Figure 4 to explain how deformation can occur in rocks. Provide them with a popsicle stick so they can recreate the phenomena.

Math Practice

Solution
9. 25 yr × 1.5 cm/yr = 37.5 cm

Go Online NSTA SCILINKS

Download a worksheet on earthquakes for students to complete, and find additional teacher support from NSTA SciLinks.

Answer to . . .

Figure 4 *Rocks at higher temperatures would bend more before breaking.*

Section 8.1 Assessment

1. A fault is a fracture in Earth where movement has occurred.
2. Earthquakes are caused by the release of elastic energy stored in rock that has been subjected to great forces. This causes the vibrations of an earthquake as the rocks elastically return to their original state.
3. An earthquake is the motion that results as rocks release elastic energy.
4. The source of an earthquake is the focus.
5. Aftershocks are smaller, weaker earthquakes that occur after the main earthquake. Foreshocks are small earthquakes that come before a major earthquake.
6. The focus of an earthquake is the place within Earth where the earthquake begins. The spot on the surface directly above the focus is the epicenter. Most earthquakes are usually associated with large fractures in the crust known as faults.
7. Elastic rebound is the process in which deformed rocks first bend and then break, releasing energy.
8. Most earthquakes do little damage because most of them occur in areas that are not populated.

1 FOCUS

Section Objectives

8.4 **Identify** the three types of seismic waves.
8.5 **Explain** how to locate the epicenter of an earthquake.
8.6 **Describe** the different ways earthquakes are measured.

Reading Focus

Build Vocabulary L2

Word Parts Tell students that the prefix *seismo-* is Greek for "shaking." Ask them to infer what a seismograph and a seismogram are. Challenge them to come up with other terms that begin with the prefix *seismo- (seismology, seismologist).*

Reading Strategy L2

B. Body Waves
II. Locating an Earthquake
A. Earthquake Distance
B. Earthquake Direction
C. Earthquake Zones
III. Measuring Earthquakes
A. Richter Scale
B. Moment Magnitude

8.2 Measuring Earthquakes

Reading Focus

Key Concepts

- What are the types of seismic waves?
- How is an earthquake epicenter located?
- How is the size of an earthquake measured?

Vocabulary

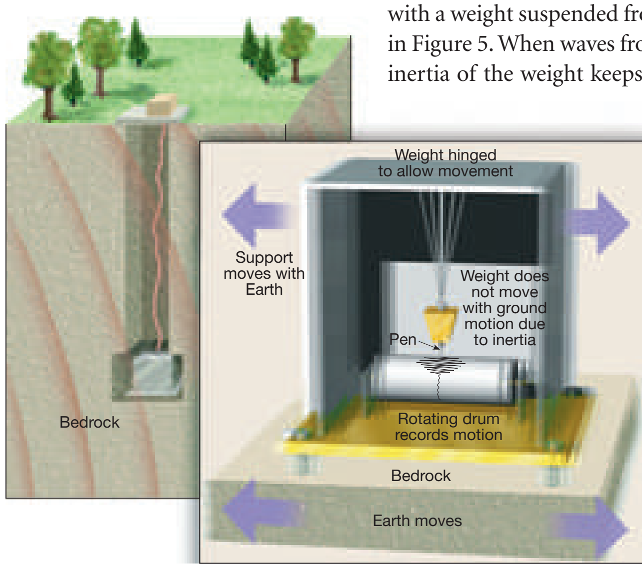
- seismograph
- seismogram
- surface wave
- P wave
- S wave
- moment magnitude

Reading Strategy

Outlining As you read, make an outline of the important ideas in this section. Use the green headings as the main topics and the blue headings as subtopics.

Measuring Earthquakes
I. Earthquake Waves
A. Surface Waves
B. ___?___
II. ___?___
A. ___?___

Figure 5 The seismograph (*seismos* = shake, *graph* = write) amplifies and records ground motion.



The study of earthquake waves, or seismology, dates back almost 2000 years. The first attempts to discover the direction of earthquakes were made by the Chinese. **Seismographs** are instruments that record earthquake waves. The idea behind seismographs can be demonstrated with a weight suspended from a support attached to bedrock as shown in Figure 5. When waves from an earthquake reach the instrument, the inertia of the weight keeps it stationary, while Earth and the support vibrate. Because the weight stays almost motionless, it provides a reference point to measure the amount of movement that occurs as waves pass through the ground below. The movement of Earth compared to the stationary weight can be recorded on a rotating drum, shown in Figure 5.

Modern seismographs amplify and electronically record ground motion, producing a trace, called a **seismogram.** A typical seismogram (*seismos* = shake, *gramma* = what is written) is shown in Figure 6.

Customize for Inclusion Students

Learning Disabled Place the palms of your hands together and slide one quickly against the other. This movement represents two rock surfaces slipping against each other. The finger-tips of the hand that moves forward are like the rock that moves forward. This is called a "push wave" or P wave. The wave travels at about 8 km/s.

Earthquakes also send out a second kind of wave. This time put your hands together with a pencil between them. Slide one hand forward to represent the slipping rock surfaces. The pencil rotates, or twists, as you move your palm. In the same way, rocks twist between slipping surfaces. The twisting rocks send a "twist wave," or S wave, throughout Earth. A twist wave travels more slowly than a push wave, moving through Earth at about 5 km/s.

Earthquake Waves

The energy from an earthquake spreads outward as waves in all directions from the focus. Seismograms show that two main types of seismic waves are produced by an earthquake—surface waves and body waves.

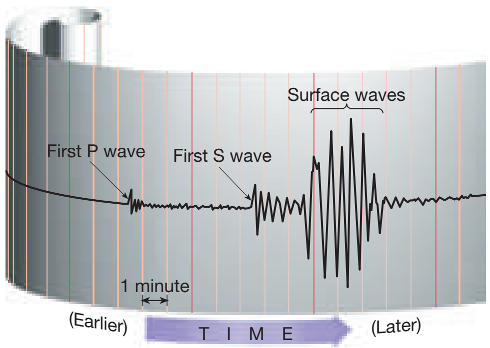


Figure 6 Typical Seismogram The first wave to arrive is the P wave, followed later by S waves. The last waves recorded are the surface waves.
Measuring ***What is the time interval in minutes between the start of the first P wave and the start of the first S wave?***

Surface Waves **Surface waves** are seismic waves that travel along Earth's outer layer. The motion of surface waves is complex. Surface waves travel along the ground and cause the ground and anything resting upon it to move. This movement is like ocean waves that toss a ship. Surface waves move in an up-and-down motion as well as a side-to-side motion, as shown in Figures 7E and 7F. The side-to-side motion is especially damaging to the foundations of buildings. These movements make surface waves the most destructive earthquake waves.

Body Waves The other waves that travel through Earth's interior are called body waves. Body waves are identified as either P waves or S waves, depending on how they travel through the materials within Earth. Figures 7B and 7D shows differences between the two kinds of waves. **P waves** are push-pull waves—they push (compress) and pull (expand) rocks in the direction the waves travel. P waves are also known as compression waves. In contrast, **S waves** shake the particles at right angles to their direction of travel. This can be shown by fastening one end of a rope and shaking the other end, as in Figure 7C. S waves are transverse waves. P waves temporarily change the volume of the material they pass through by alternately compressing and expanding it, as in Figure 7A. S waves temporarily change the shape of the material they pass through. Gases and liquids will not transmit S waves because they do not rebound elastically to their original shape.

A seismogram shows all three types of seismic waves—surface waves, P waves, and S waves. By observing a typical seismic record, as shown in Figure 8 on page 225, you can see that the first P wave arrives at the recording station, then the first S wave, and then surface waves. The waves arrive at different times because they travel at different speeds. Generally, in any solid material, P waves travel about 1.7 times faster than S waves. Surface waves travel the slowest at about 90 percent of the speed of the S waves.

Reading Checkpoint *Which seismic wave travels fastest?*

2 INSTRUCT

Earthquake Waves

Teacher Demo

Seismic Waves L2

Purpose Students will see the ways that the three different seismic waves move though substances with the use of a coiled spring toy.

Materials coiled spring toy

Procedure Have a student hold one end of the spring toy. Hold the other end of the toy and step away from the student to stretch the spring out. Gather approximately one fifth of the spring in your hand and let go. Ask students to explain what they observed as the bunch of coils moves down the extending spring. Explain to students that this is how a P wave travels through a medium. Again, with the spring stretched out, gently move the toy from side to side in a snake-like motion. Students should observe how the toy moves as a result of such motion. Explain that this is how an S wave moves. Finally, move your end of the toy in a rolling motion (like winding a fishing reel) creating waves. Students should realize they are observing the motion of surface waves.
Kinesthetic, Visual

Integrate Language Arts L2

Ancient cultures had their own ways of explaining earthquakes. For example, an ancient Indian legend explains how elephants carried Earth on their backs. When the elephants grew tired and lowered their heads, an earthquake occurred. An ancient Siberian legend says that Earth was pulled on a sled by dogs. Whenever one of the dogs stopped to scratch its fleas, an earthquake resulted. Challenge students to discover more ancient legends about earthquakes, and then to make up their own myth or legend that might serve as an explanation for earthquakes.
Verbal

Answer to . . .

Figure 6 *approximately 5 minutes*

Reading Checkpoint *P waves*

Locating an Earthquake

Build Reading Literacy L1

Refer to **p. 156D** in **Chapter 6,** which provides the guidelines for reciprocal teaching.

Reciprocal Teaching Have students read the section with a partner. One partner reads a paragraph out loud. Then the other partner summarizes the paragraph's contents and explains the main concepts. The partners continue to switch roles with each new paragraph until they have finished the section. **Intrapersonal**

Build Reading Literacy L1

Refer to **p. 216D** which provides the guidelines for this reading strategy.

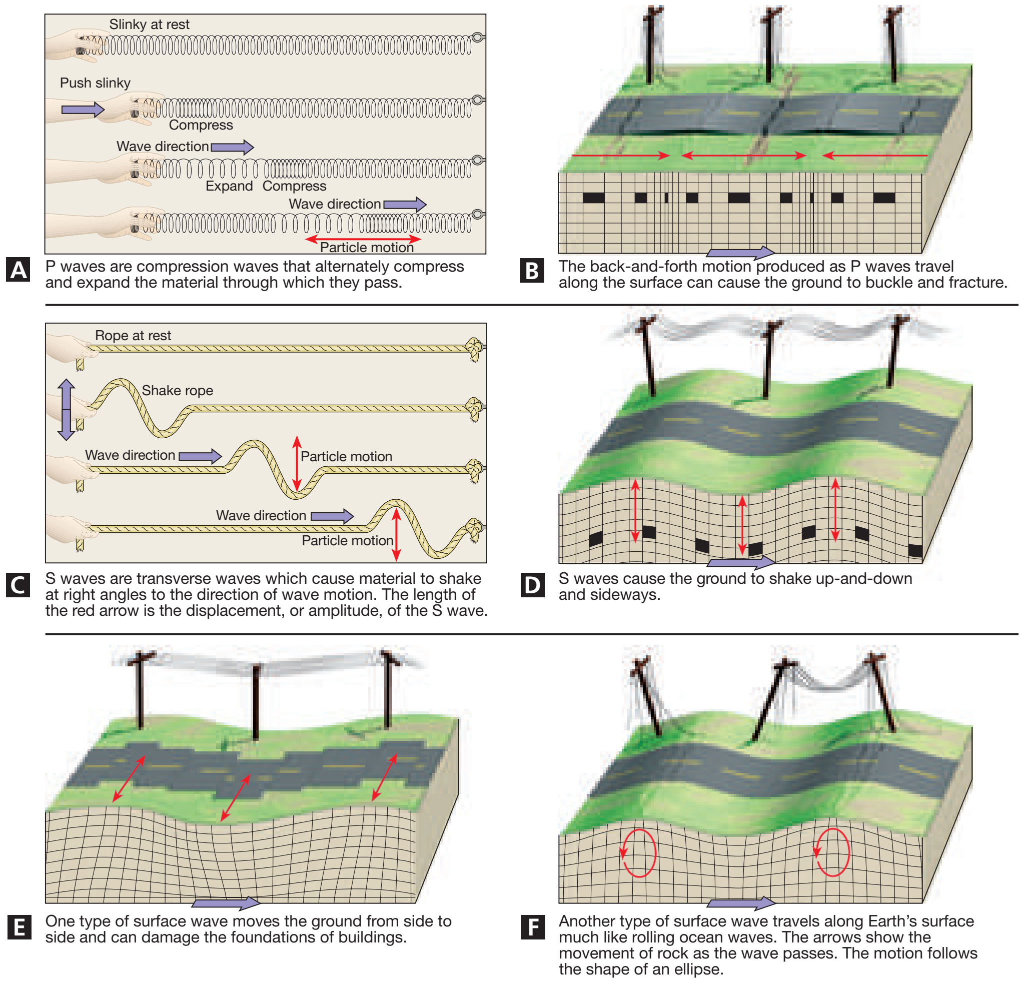
Compare and Contrast Ask students to use the visuals and the captions in Figure 7 to describe how the three types of waves are different. *(P waves compress and expand material in the same horizontal direction of the waves' energy. S waves are transverse waves that cause the ground to shake up and down, perpendicular to the waves' direction. Surface waves travel along the outer layer and can move in both up-and-down motions and side-to-side motions.)*

Figure 7 Each type of seismic wave has characteristic motions.

Locating an Earthquake

The difference in velocities of P and S waves provides a way to locate the epicenter. You can compare this difference to a race between two cars. The winning car is faster than the losing car. The P wave always wins the race, arriving ahead of the S wave. The longer the race, the greater will be the difference in arrival times of the P and S waves at the finish line (the seismic station). The greater the interval measured on a seismogram between the arrival of the first P wave and the first S wave, the greater the distance to the earthquake source.

Seismic Waves



A P waves are compression waves that alternately compress and expand the material through which they pass.

B The back-and-forth motion produced as P waves travel along the surface can cause the ground to buckle and fracture.

C S waves are transverse waves which cause material to shake at right angles to the direction of wave motion. The length of the red arrow is the displacement, or amplitude, of the S wave.

D S waves cause the ground to shake up-and-down and sideways.

E One type of surface wave moves the ground from side to side and can damage the foundations of buildings.

F Another type of surface wave travels along Earth's surface much like rolling ocean waves. The arrows show the movement of rock as the wave passes. The motion follows the shape of an ellipse.

Customize for Inclusion Learners

Learning Disabled Ask students to simulate P waves and S waves with a slinky and jump rope. Instruct them to recreate the scenarios pictured in Figure 7A and 7C if they require help getting started.

224 Chapter 8

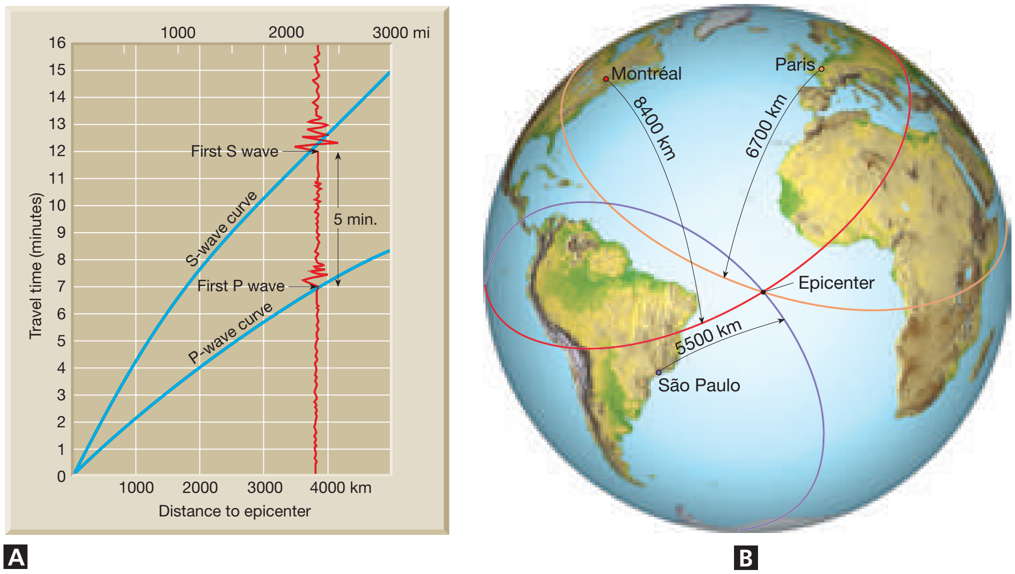


Figure 8 Locating an Earthquake A A travel-time graph is used to determine the distance to the epicenter. The difference in arrival times of the first P wave and the first S wave in the graph is 5 minutes. So the epicenter is roughly 3800 kilometers away. **B** The epicenter is located using the distance obtained from three seismic stations. The place the circles intersect is the epicenter.

Earthquake Distance A system for locating earthquake epicenters was developed by using seismograms from earthquakes whose epicenters could be easily pinpointed from physical evidence. Travel-time graphs are constructed from these seismograms, as shown in Figure 8A. Using the sample seismogram in Figure 6 and the travel-time curves in Figure 8A, we can determine the distance from the recording station to the earthquake in two steps. First, find the time interval between the arrival of the first P wave and the first S wave on the seismogram. Second, find on the travel-time graph the equivalent time spread between the P and S wave curves. From this information, you can see that this earthquake occurred 3800 kilometers from the seismograph.

Earthquake Direction Now we know the distance, but what about the direction? The epicenter could be in any direction from the seismic station. As shown in Figure 8B, the precise location can be found when the distance is known from three or more different seismic stations. On a globe, we draw a circle around each seismic station. Each circle represents the distance of the epicenter from each station. The point where the three circles intersect is the epicenter of the quake. **Travel-time graphs from three or more seismographs can be used to find the exact location of an earthquake epicenter.**

Integrate Math L2

The epicenter of an earthquake is located using information on the arrival times of the P and S waves at three seismograph stations. Ask: **Why must three seismograph stations be used? Why aren't two enough to locate the epicenter?** *(The intersection of three circles will yield a more exact location. If only two stations were used, these two circles would most likely intersect at two points. This would give two possible locations for the same earthquake.)* **Logical, Visual**

Use Visuals L1

Figure 8 Make sure students understand how to read the travel-time graph. Explain that distance is expressed in both kilometers (bottom) and miles (top), and tell them that one kilometer equals approximately 0.6 miles. Ask: **If a station records 2 minutes elapsed time between the arrival of the first P wave and the arrival of the first S wave, how far in kilometers is that station from the epicenter?** *(about 1000 km)* A good way to help students comprehend all the information compiled in a travel-time graph is to create one on the board. Plot data points to simulate how seismic recordings are used to create P and S wave curves.

Measuring Earthquakes

Quick Lab

Measuring the Distance to Epicenters L2

Objective
After completing this activity, students should be able to use a travel-time graph and data from a seismogram to determine information about the epicenter of an earthquake.

Skills Focus Inferring, Predicting

Prep Time 5 minutes

Class Time 20 minutes

Expected Outcome Students will successfully use the travel-time graph and seismogram to answer the questions.

Analyze and Conclude
1. 1000 km = approximately 2 minutes
2000 km = approximately 3.5 minutes
2400 km = approximately 4 minutes
3000 km = approximately 4.4 minutes
2. The farther away from the epicenter, the greater the time between the arrival of the first P wave and the first S wave.
3. The vibrations recorded on the seismogram would probably become less pronounced, with peaks that were not as high, or in some other way different, as the distance to the epicenter increases.

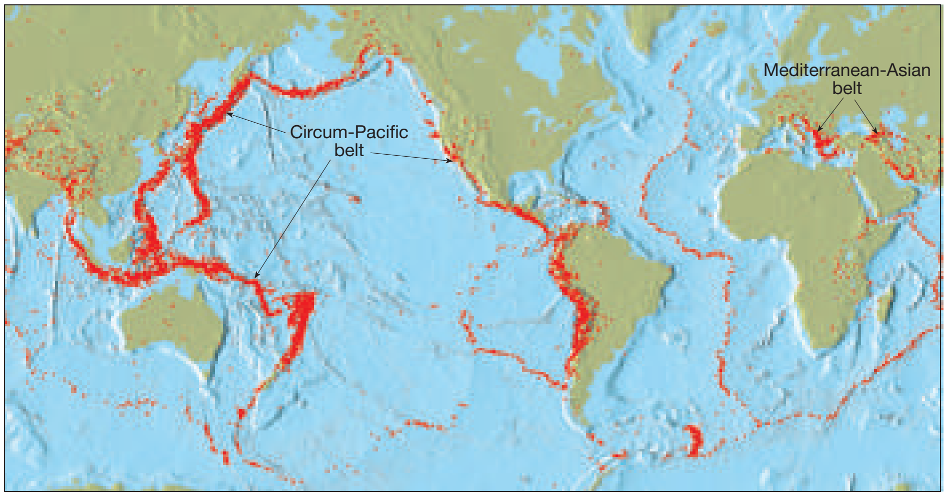


Figure 9 Distribution of the 14,229 earthquakes with magnitudes equal to or greater than 5 from 1980 to 1990.
Observing *Where do you find most of the earthquakes—in the interiors of the continents or at the edges?*

Quick Lab

Measuring the Distance to Epicenters

Procedure

1. Look at Figures 6 and 8A. Figure 6 is a seismogram and Figure 8A is a travel-time graph. Use the graph to answer the Analyze and Conclude questions.
2. Make sure to use only the bottom scale on the x-axis, measured in kilometers, to answer the questions.

Analyze and Conclude

1. **Reading Graphs** What is the difference in arrival times in minutes between the first P wave and first S wave for stations that are the following distances from an epicenter: 1000 km, 2000 km, 2400 km, and 3000 km?
2. **Inferring** How does the difference in arrival times of the first P wave and first S wave on a seismogram change? How does it change if the station is farther from the epicenter?
3. **Predicting** How do you think the vibrations recorded on a seismogram would change as the distance to the epicenter increases?

Earthquake Zones About 95 percent of the major earthquakes occur in a few narrow zones, as shown in Figure 9. Most of these earthquakes occur around the outer edge of the Pacific Ocean. This zone is known as the circum-Pacific belt. Active earthquake areas in this zone include Japan, the Philippines, Chile, and Alaska's Aleutian Islands. A second zone of earthquake activity occurs along the Mediterranean Sea. This is the Mediterranean-Asian belt. Another continuous belt extends for thousands of kilometers through the world's oceans. This zone coincides with the oceanic ridge system.

Reading Checkpoint *Where do most earthquakes occur?*

Measuring Earthquakes

Historically, scientists have used two different types of measurements to describe the size of an earthquake—intensity and magnitude. Intensity is a measure of the amount of earthquake shaking at a given location based on the amount of damage. Intensity is not a quantitative measurement because it is based on uncertain personal damage estimates. Quantitative measurements, called magnitudes, were developed that rely on calculations using seismograms. Magnitudes are a measure of the size of seismic waves or the amount of energy released at the source of the earthquake.

Facts and Figures

The circum-Pacific belt, or the Ring of Fire, accounts for approximately 75 percent of the world's earthquake activity. It also contains some of the major volcanic mountains and mountain ranges on Earth. That is why it is called the Ring of Fire. The following is a list of the mountain ranges and volcanoes that are part of the Ring of Fire: the Andes Mountains and the volcanoes Cotopaxi and Azul, the Mexican volcanoes Popocatepetl and Paricutin, the Cascade Mountains and Mount Saint Helens, the Aleutian Islands, and Mount Fuji volcano in Japan.

Richter Scale A familiar but outdated scale for measuring the magnitude of earthquakes is the Richter scale. The Richter scale is based on the amplitude of the largest seismic wave (P, S, or surface wave) recorded on a seismogram. Earthquakes vary greatly in strength, so Richter used a logarithmic scale. A tenfold increase in wave amplitude equals an increase of 1 on the magnitude scale. For example, the amount of ground shaking for a 5.0 earthquake is 10 times greater than the shaking produced by an earthquake of 4.0 on the Richter scale.

Seismic waves weaken as the distance between the earthquake focus and the seismograph increases. The Richter scale is only useful for small, shallow earthquakes within about 500 kilometers of the epicenter. Most of the earthquake measurements you hear on news reports use the Richter scale. Scientists, however, no longer use it.

Moment Magnitude In recent years, scientists have been using a more precise means of measuring earthquakes. It is called the moment magnitude scale. The **moment magnitude** is derived from the amount of displacement that occurs along a fault zone. It doesn't measure the ground motion at some distant point. The moment magnitude is calculated using several factors. These factors include the average amount of movement along the fault, the area of the surface break, and the strength of the broken rock: (surface area of fault) × (average displacement along fault) × (rigidity of rock). Together these factors provide a measure of how much energy rock can store before it suddenly slips and releases this energy during an earthquake. **Moment magnitude is the most widely used measurement for earthquakes because it is the only magnitude scale that estimates the energy released by earthquakes.**

Table 1 describes the damage and incidence of earthquakes of different magnitudes. Compare this information to the earthquakes listed in Table 2 on page 228.

Table 1 Earthquake Magnitudes and Expected World Incidence

Moment Magnitudes	Effects Near Epicenter	Estimated Number per Year
< 2.0	Generally not felt, but can be recorded	> 600,000
2.0–2.9	Potentially perceptible	> 300,000
3.0–3.9	Rarely felt	> 100,000
4.0–4.9	Can be strongly felt	13,500
5.0–5.9	Can be damaging shocks	1,400
6.0–6.9	Destructive in populous regions	110
7.0–7.9	Major earthquakes; inflict serious damage	12
8.0 and above	Great earthquakes; destroy communities near epicenter	0–1

Address Misconceptions

L2

Many students may think that small- to medium-sized earthquakes in an area will reduce the chances of a major earthquake in the same region because the smaller earthquakes will release all of the built-up energy. To challenge this misconception, ask students to consider the amount of energy released in an earthquake. Ask: **How much more ground shaking does an earthquake with a measure of 8.0 on the Richter scale have compared with an earthquake with a measure of 3.0 on the Richter scale?** *(about 100,000 times more ground shaking)* **How many smaller earthquakes measuring 3.0 on the Richter scale would need to occur to equal the same amount of ground shaking of an 8.0 earthquake?** *(about 100,000 smaller earthquakes)*
Logical

Build Reading Literacy

L1

Refer to **p. 474D** in **Chapter 17**, which provides guidelines for monitor your understanding.

Monitor Your Understanding
Display a world map with the names of major cities. Help students find the locations where the earthquakes listed in Table 2 occurred. Then ask students whether the earthquake's location is in any of the earthquake zones described on page 226. *(Most are in the circum-Pacific belt. Armenia—1988; Iran—1990; Latur, India—1993; and Izmit, Turkey—1999 are in the Mediterranean-Asian belt. The Charleston, SC, earthquake of 1886 is not in any of the zones described in the text.)*

Answer to . . .

Figure 9 *at the edges*

Reading Checkpoint *along the edge of the Pacific Ocean*

Earthquakes and Earth's Interior 227

Section 8.2 (continued)

3 ASSESS

Evaluate Understanding L2

Have students write three review questions for this section. Students should then break into groups of three or four and ask each other their questions.

Reteach L1

Review the types of seismic waves from earthquakes by asking students to explain what they see in Figure 7.

Writing in Science

An earthquake measuring a moment magnitude of 6 could prove to be potentially devastating to structures not built to new earthquake standards. Poorly built structures would suffer significant damage. However, structures that were constructed with earthquake safety in mind would most likely fare well. Students should use Tables 1 and 2 from the text as a reference in looking at the damage caused by earthquakes with a moment magnitude of 6 or more.

Table 2 Some Notable Earthquakes

Year	Location	Deaths (est.)	Magnitude†	Comments
*1886	Charleston, South Carolina	60		Greatest historical earthquake in the eastern United States
*1906	San Francisco, California	1500	7.8	Fires caused extensive damage.
1923	Tokyo, Japan	143,000	7.9	Fire caused extensive destruction.
1960	Southern Chile	5700	9.6	Possibly the largest-magnitude earthquake ever recorded
*1964	Alaska	131	9.2	Greatest North American earthquake
1970	Peru	66,000	7.8	Large rockslide
*1971	San Fernando, California	65	6.5	Damages exceeded $1 billion.
1985	Mexico City	9500	8.1	Major damage occurred 400 km from epicenter.
1988	Armenia	25,000	6.9	Poor construction practices caused great damage.
*1989	Loma Prieta, California	62	6.9	Damages exceeded $6 billion.
1990	Iran	50,000	7.3	Landslides and poor construction practices caused great damage.
1993	Latur, India	10,000	6.4	Located in stable continental interior
*1994	Northridge, California	57	6.7	Damages exceeded $40 billion.
1995	Kobe, Japan	5472	6.9	Damages estimated to exceed $100 billion.
1999	Izmit, Turkey	17,127	7.4	Nearly 44,000 injured and more than 250,000 displaced.
1999	Chi Chi, Taiwan	2300	7.6	Severe destruction; 8700 injuries
2001	El Salvador	1000	7.6	Triggered many landslides
2001	Bhuj, India	20,000†	7.9	1 million or more homeless

*U.S. earthquakes
†Widely differing magnitudes have been estimated for some earthquakes. When available, moment magnitudes are used.
SOURCE: U.S. Geological Survey

Section 8.2 Assessment

Reviewing Concepts

1. List the two categories of seismic waves.
2. Briefly describe how the epicenter of an earthquake is located.
3. Describe the two different ways to measure the size of an earthquake.
4. In what order do the basic types of seismic waves reach a seismograph?

Critical Thinking

5. **Comparing and Contrasting** Describe the differences in speed and mode of travel between primary waves and secondary waves.
6. **Applying Concepts** How does a seismograph measure an earthquake?

Writing in Science

Descriptive Paragraph Write a paragraph describing in your own words what would occur in an earthquake that has been measured as a moment magnitude of 6.0.

Section 8.2 Assessment

1. The two categories of seismic waves are body waves (P and S) and surface waves.
2. The epicenter of an earthquake is located using data taken from at least three different seismograph stations. The time that the first P wave arrives at the station is then subtracted from the time that the first S wave arrives. This value can then be turned into a distance using a travel-time diagram. This distance means that the epicenter is that far from the station. A circle is drawn around each seismograph station and the circles meet where the earthquake epicenter is likely to be found.
3. Earthquakes can be measured by their intensity (or level of damage done) or by the magnitude (amplitude of seismic waves).
4. P wave, S wave, surface wave
5. P waves push and pull rocks in the direction of travel. Their velocity is greater than the velocity of S waves. S waves shake the particles of material at right angles to their direction of travel.
6. In concept, a seismograph has a weight which is suspended from a support that is attached to bedrock. When the bedrock shakes, the weight remains stationary which allows it to act as a reference point. The movement of Earth can then be compared to the weight and recorded on a stationary drum.

8.3 Destruction from Earthquakes

Reading Focus

Key Concepts

- What destructive events can be triggered by earthquakes?
- Can earthquakes be predicted?

Vocabulary

- liquefaction
- tsunami
- seismic gap

Reading Strategy

Monitoring Your Understanding Preview the Key Concepts, topic headings, vocabulary, and figures in this section. List two things you expect to learn. After reading, state what you learned about each item you listed.

What I Expect To Learn	What I Learned
a. ____?____	b. ____?____
c. ____?____	d. ____?____

The Good Friday Alaskan Earthquake in 1964 was the most violent earthquake to jar North America in the 20th century. The earthquake was felt throughout Alaska. It had a moment magnitude of 9.2 and lasted 3 to 4 minutes. The quake left 131 people dead and thousands homeless. The state's economy was also badly damaged because the quake affected major ports and towns. Had the schools and businesses been open on this holiday, the death toll would surely have been much higher.

Seismic Vibrations

The 1964 Alaskan earthquake gave geologists new insights into the role of ground shaking as a destructive force. **The damage to buildings and other structures from earthquake waves depends on several factors. These factors include the intensity and duration of the vibrations, the nature of the material on which the structure is built, and the design of the structure.**

Building Design All multistory buildings in Anchorage, Alaska, were damaged by the vibrations. However, the more flexible wood-frame buildings, such as homes, were less damaged. Figure 10 offers an example of how differences in construction can affect earthquake damage. You can see that the steel-frame building on the left withstood the vibrations. However, the poorly designed building on the right was badly damaged. Engineers have learned that unreinforced stone or brick buildings are the most serious safety threats during earthquakes.

Figure 10 Earthquake Damage This five-story building in Anchorage, Alaska, collapsed from the great earthquake of 1964. Very little structural damage was incurred by the steel-framed building to the left. **Inferring** ***Why do some buildings undergo little damage, while nearby buildings are nearly destroyed?***

Section 8.3

1 FOCUS

Section Objectives

8.7 **Describe** the factors contributing to earthquake damage.
8.8 **Identify** other dangers associated with earthquakes.
8.9 **Explain** the potential for earthquake prediction.

Reading Focus

Build Vocabulary L2

Paraphrase Ask students to write the vocabulary words on a sheet of paper. Instruct students to write a definition, in their own words, for each term as they encounter the term while going through the chapter. After writing their own definition, they should also write a complete sentence with the term.

Reading Strategy L2

Sample answers:
a. how seismic vibrations can cause damage
b. Damage depends on the building design, intensity and length of time of the vibrations, and the material that the building was constructed on.
c. dangers associated with earthquakes
d. These include tsunamis, landslides, and fire.

2 INSTRUCT

Seismic Vibrations

Reading Strategy L2

Invite a structural engineer to speak to the class about the construction of earthquake-safe buildings. Have students ask about specific regulations for building codes in your area.
Interpersonal

Customize for Inclusion Students

Gifted When we consider how many earthquakes there are in one year, the number of earthquakes that cause terrible damage is actually very small. The amount of damage an earthquake causes depends on many conditions. For example, if a building is well constructed and built on solid ground, it may survive an earthquake. Most injuries and deaths during earthquakes are because of poor construction or substandard building sites. Another serious problem is not knowing how to respond to an earthquake. When people panic and rush out of buildings there is a danger of being trampled, suffocated, or injured by falling debris. Go to the Red Cross website at http://www.redcross.org/services/disaster and read about earthquake safety.

Answer to . . .

Figure 10 *Damage to buildings often depends on the construction and design of the building. For example, buildings made of wood often are more flexible than buildings made of concrete.*

Address Misconceptions

L2

Many students may have heard that the safest place in a house during an earthquake is in a doorway. Challenge this misconception by pointing out that modern doorways are no stronger than other sections of a house and usually have doors that could swing and injure someone. Encourage students to come up with another plan for earthquake safety. This should involve ducking under a sturdy table or desk and staying clear of objects that could tip over, such as file cabinets and bookcases.

Build Reading Literacy

L1

Refer to **p. 334D** in **Chapter 12**, for guidelines on outlining content.

Outline Have students read the section. Then have students use the headings as major divisions in an outline. Allow students to refer to their outlines when answering the questions in Section 8.3 Assessment.
Visual

Tsunamis

Build Science Skills

L2

Observing Have pairs of students investigate recent or historically significant tsunamis. (They may use library resources or conduct a Web search.) After students have had time to obtain information, have them compare their findings with another group.
Interpersonal, Verbal

Q & A

Q *What is the largest wave triggered by an earthquake?*

A The largest wave ever recorded occurred in Lituya Bay, about 200 kilometers west of Juneau, Alaska. On July 9, 1958, an earthquake triggered an enormous rockslide that dumped 90 million tons of rock into the upper part of the bay. The rockslide created a huge splash wave that swept over the ridge facing the rockslide. The splash uprooted or snapped off trees 522 meters above the bay. Even larger splash waves may have occurred 65 million years ago when an estimated 900-meter wave is thought to have resulted from a meteorite impact in the Gulf of Mexico.

Liquefaction Where loosely consolidated sediments are saturated with water, earthquakes can cause a process known as **liquefaction.** Under these conditions, what had been stable soil turns into a liquid that is not able to support buildings or other structures. Buildings and bridges may settle and collapse. Underground storage tanks and sewer lines may float toward the surface.

Reading Checkpoint *When does liquefaction occur?*

Tsunamis

Most deaths associated with the 1964 Alaskan quake were caused by seismic sea waves, or **tsunamis.** These destructive waves often are called tidal waves by news reporters. However, this name is incorrect because these waves are not produced by the tidal effect of the moon or sun.

Causes of Tsunamis **A tsunami triggered by an earthquake occurs where a slab of the ocean floor is displaced vertically along a fault. A tsunami also can occur when the vibration of a quake sets an underwater landslide into motion.** Once formed, a tsunami resembles the ripples created when a pebble is dropped into a pond. A tsunami travels across the ocean at speeds of 500 to 950 kilometers per hour. Despite this speed, a tsunami in the open ocean can pass without notice because its height is usually less than 1 meter, and the distance between wave crests can range from 100 to 700 kilometers. However, when the wave enters shallower coastal water, the waves are slowed and the water begins to pile up to heights that sometimes are greater than 30 meters, as shown in Figure 11.

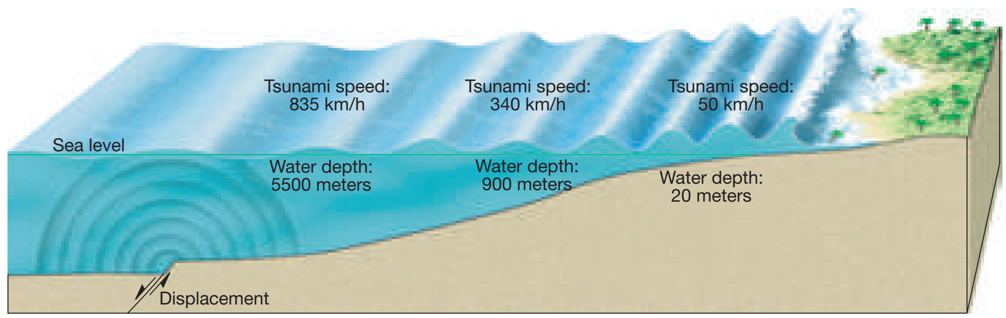


Figure 11 Movement of a Tsunami A tsunami is generated by movement of the ocean floor. The speed of a wave moving across the ocean is related to the ocean depth. Waves moving in deep water travel more than 800 kilometers per hour. Speed gradually slows to 50 kilometers per hour at depths of 20 meters. As waves slow down in shallow water, they grow in height until they topple and hit shore with tremendous force.

Tsunami Warning System The destruction from a large tsunami in the Hawaiian Islands led to the creation of a tsunami warning system for coastal areas of the Pacific. Large earthquakes are reported to the Tsunami Warning Center in Honolulu from seismic stations around the Pacific. Scientists use water levels in tidal gauges to determine whether a tsunami has formed. Within an hour of the reports, a warning is issued. Although tsunamis travel very rapidly, there is sufficient time to evacuate all but the area closest to the epicenter. Fortunately, most earthquakes do not generate tsunamis. On the average, only one or two destructive tsunamis are generated worldwide every year. Only about one tsunami in every 10 years causes major damage and loss of life.

Reading Checkpoint *What areas are protected by the tsunami warning system?*

Other Dangers

The vibrations from earthquakes cause other dangers, including landslides, ground subsidence, and fires.

Landslides With **many earthquakes, the greatest damage to structures is from landslides and ground subsidence, or the sinking of the ground triggered by the vibrations.** The violent shaking of an earthquake can cause the soil and rock on slopes to fail, resulting in landslides. Figure 12 shows some of the damage landslides can cause. Earthquake vibration can also cause large sections of the ground to collapse, liquefy, or subside. Ground subsidence can cause foundations to collapse, as shown in Figure 12. It can also rupture gas and water pipelines.

Figure 12 This landslide caused by the 1964 Alaskan earthquake destroyed many homes. More than 200 acres of land slid toward the ocean.
Interpreting Photos ***Assuming the land was originally horizontal, to what angle have the trees on the left side of the photo been tilted?***

Fire The 1906 San Francisco earthquake reminds us of the major threat of fire. The city contained mostly large wooden structures and brick buildings. The greatest destruction was caused by fires that started when gas and electrical lines were cut. Many of the city's water lines had also been broken by the quake, which meant that the fires couldn't be stopped. A 1923 earthquake in Japan caused an estimated 250 fires. They devastated the city of Yokohama and destroyed more than half the homes in Tokyo. The fires spread quickly due to unusually high winds. More than 100,000 people died in the fires.

Other Dangers

Build Science Skills L2

Using Models
Students should create a model of a house on a small hill using sand, potting soil, and thin wire netting. The model should be no more than 30 cm high. Then, students will shake their model in such a way that mimics an earthquake. They will then observe what happens to the hill and the buildings placed on it. Ask: **What happens to the buildings on the slope?** *(Answers will vary but students should see that the buildings slid down the slope.)* **What impact could water have on the model earthquake?** *(The damage would probably be worse if the hillside was saturated with water.)*
Kinesthetic

Use Community Resources L2

Instruct students to ask their village or city officials about local tsunamis, landslides, or fires that resulted from an earthquake. Some sources to contact might be fire departments, city halls, and newspaper or media archives. Ask them to brainstorm appropriate questions and ask the official they hope to interview.

Facts and Figures

The 1906 earthquake in San Francisco was one of the most devastating in the United States. The earthquake and resulting fires caused an estimated 3,000 deaths and $524 million in property loss. Damage in San Francisco alone was estimated at $20 million; outside the city, it was estimated at $4 million. The duration of the shaking in San Francisco was about 1 minute.

The earthquake damaged buildings and structures in all parts of the city and county of San Francisco. On the San Andreas fault, buildings were completely destroyed or torn apart; trees fell to the ground. The surface of the ground was torn and heaved into furrow-like ridges. Roads crossing the fault line were impassable. Pipelines were broken, shutting off the water supply to the city. The fires that ignited soon after the earthquake quickly raged through the city because of the lack of water to control them.

Answer to . . .

Figure 12 *45°*

Reading Checkpoint *Liquefaction occurs when loosely consolidated soils saturated with water are shaken by earthquake waves.*

Reading Checkpoint *coastal areas of the Pacific*

Predicting Earthquakes

Integrate Biology

L2

Can Animals Predict Earthquakes? There is much speculation as to the ability of animals to predict earthquakes. Documented cases have shown snakes and bees rapidly leaving their homes, excessive dog barking, and erratic behavior in domesticated and wild animals prior to major earthquakes. The US Geological Survey, however, is more skeptical. They acknowledge the abundance of cases of reported behavioral changes prior to an earthquake but there aren't enough reproducible connections to conclusively state that animals are predicting the earthquakes. Have students research specific cases of odd animal behavior prior to earthquakes and present their findings in a newspaper article.
Verbal

3 ASSESS

Evaluate Understanding

L2

Have students work in groups to develop a short public service announcement on the other dangers facing areas that have experienced an earthquake.

Reteach

L1

Ask students to use the diagram in Figure 11 to explain how tsunamis are generated and how they move to shore.

Connecting Concepts

If there were some way to measure the amount of energy stored in rocks, this might lead to the prediction of earthquakes. If scientists could observe and measure the buildup of stress within rocks, they might be able to determine the amount of stress the rocks could withstand before the energy needed to be released. This could provide an estimate of time for an earthquake.

Go Online NSTA SCILINKS

Download a worksheet on predicting earthquakes for students to complete, and find additional teacher support from NSTA SciLinks.

Figure 13 Effects of Subsidence Due to Liquefaction This tilted building rests on unconsolidated sediment that imitated quicksand during the 1985 earthquake in Mexico.

Predicting Earthquakes

The earthquake in Northridge, California, in 1994 caused 57 deaths and about $40 billion in damage. Scientists warn that quakes of similar or greater strength will occur. But can earthquakes be predicted?

Short-Range Predictions The goal of short-range prediction is to provide an early warning of the location and magnitude of a large earthquake. Researchers monitor possible precursors—things that precede and may warn of a future earthquake. They measure uplift, subsidence, and strain in the rocks near active faults. They measure water levels and pressures in wells. Radon gas emissions from fractures and small changes in the electromagnetic properties of rocks are also monitored. **So far, methods for short-range predictions of earthquakes have not been successful.**

Long-Range Forecasts Long-range forecasts give the probability of a certain magnitude earthquake occurring within 30 to 100-plus years. These data are important for updating building codes, which have standards for designing earthquake-resistant structures. Long-range forecasts are based on the idea that earthquakes are repetitive or cyclical. In other words, as soon as one earthquake is over, the forces in Earth will begin to build strain in the rocks again. Eventually the rocks will slip again, causing another earthquake. Scientists study historical records of earthquakes to see if there are any patterns of recurrence. They also study seismic gaps. A **seismic gap** is an area along a fault where there has not been any earthquake activity for a long period of time. There has been only limited success in long-term forecasting. **Scientists don't yet understand enough about how and where earthquakes will occur to make accurate long-term predictions.**

Go Online SCILINKS NSTA

For: Links on predicting earthquakes
Visit: www.SciLinks.org
Web Code: cjn-3082

Section 8.3 Assessment

Reviewing Concepts

1. What destructive events can be triggered by an earthquake?
2. What physical changes have been used in the attempts to predict earthquakes?
3. What is a tsunami?
4. What is a seismic gap?

Critical Thinking

5. **Making Judgments** Do you think scientists are close to being able to accurately predict earthquakes? Explain your answer.
6. **Drawing Conclusions** Why is it incorrect to refer to tsunamis as tidal waves?

Connecting Concepts

Earthquakes In Section 8.1, you learned about the elastic energy stored in rocks before an earthquake and the elastic rebound hypothesis. How could this information be used to try to predict earthquakes?

Section 8.3 Assessment

1. Events such as landslides, tsunamis, and fires can be triggered by earthquakes.
2. Physical changes such as uplift, subsidence, strain in rocks along faults, water levels in wells, and radon gas emissions from fractures have been measured in hopes of predicting earthquakes.
3. A tsunami is a seismic sea wave created by an underwater earthquake or a landslide under the ocean floor generated by an earthquake.
4. A seismic gap is an area along a fault that has not had any earthquake activity for a long period of time.
5. Answers will vary. Sample answer: Scientists don't yet understand enough about how and where earthquakes occur to make accurate predictions.
6. Tidal waves are caused by the gravitational pull of the moon and sun. Tsunamis are large waves caused by earthquake movements.

8.4 Earth's Layered Structure

Reading Focus

Key Concepts

- What is Earth's internal structure?
- What is the composition of Earth's interior?

Vocabulary

- crust
- mantle
- lithosphere
- asthenosphere
- outer core
- inner core
- Moho

Reading Strategy

Sequencing Copy the flowchart. After you read, complete the sequence of layers in Earth's interior.

Earth's Internal Structure

Lithosphere → a. ? → b. ? → Outer core → c. ?

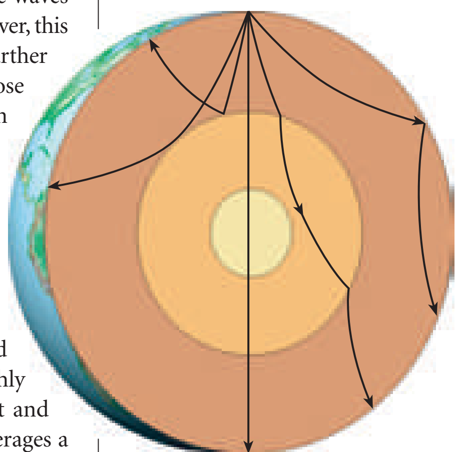
Earth's interior lies not very far beneath our feet, but we can't reach it. The deepest well has drilled only 12 kilometers into Earth's crust. With such limited access, how do we know what Earth's interior is like? Most knowledge of the interior comes from the study of earthquake waves that travel through Earth.

Layers Defined by Composition

If Earth were made of the same materials throughout, seismic waves would spread through it in straight lines at constant speed. However, this is not the case. Seismic waves reaching seismographs located farther from an earthquake travel at faster average speeds than those recorded at locations closer to the event. This general increase in speed with depth is due to increased pressure, which changes the elastic properties of deeply buried rock. As a result, the paths of seismic waves through Earth are refracted, or bent, as they travel. Figure 14 shows this bending. **Earth's interior consists of three major zones defined by its chemical composition—the crust, mantle, and core.**

Crust The **crust,** the thin, rocky outer layer of Earth, is divided into oceanic and continental crust. The oceanic crust is roughly 7 kilometers thick and composed of the igneous rocks basalt and gabbro. The continental crust is 8–75 kilometers thick, but averages a thickness of 40 kilometers. It consists of many rock types. The average composition of the continental crust is granitic rock called granodiorite. Continental rocks have an average density of about 2.7 g/cm^3 and some are over 4 billion years old. The rocks of the oceanic crust are younger (180 million years or less) and have an average density of about 3.0 g/cm^3.

Figure 14 The arrows show only a few of the many possible paths that seismic waves take through Earth.
Inferring *What causes the wave paths to change?*



Section 8.4

1 FOCUS

Section Objectives

8.10 **List** the layers of Earth based on composition and physical properties.
8.11 **Describe** the composition of each layer of Earth.

Reading Focus

Build Vocabulary L2

LINCS Have students: **L**ist the parts of the vocabulary that they know, such as *core, sphere,* and *litho-*. **I**magine what the interior of Earth might look like and how the terms might fit together. **N**ote a reminding, sound-alike term, such as apple core or atmosphere. **C**onnect the terms, perhaps in a long sentence or as labels on a diagram. **S**elf-test.

Reading Strategy L2

a. asthenosphere
b. lower mantle
c. inner core

2 INSTRUCT

Layers Defined by Composition

Use Visuals L1

Figure 14 Have students look at the model of Earth and seismic waves in the diagram. Ask: **One seismic wave travels straight through the center of Earth. Would this be a P wave or an S wave?** *(P wave)*
Visual

Answer to . . .

Figure 14 *Seismic rays change direction because as pressure increases with depth, elastic properties of rocks change.*

Layers Defined by Physical Properties

Build Reading Literacy L2

Refer to **p. 502D** in **Chapter 18,** which provides the guidelines for using visualization.

Visualize Have students keep their books closed. Tell them to listen carefully while you read the paragraph about defining the layers of Earth based on physical properties. Ask students to describe how they visualize the interior of Earth. Then, ask students to work in pairs and discuss how they visualized the process.
Visual

Teacher Demo

Floating Crackers L2

Purpose To model for students the characteristics and behavior of the lithosphere and asthenosphere.

Materials shallow baking pan, package of chocolate pudding, 2 cups of milk, several animal crackers

Procedure Review with students the general characteristics and thicknesses of the lithosphere and asthenosphere. You may want to introduce the idea of the lithosphere being broken into smaller pieces called plates. These plates move about on top of the asthenosphere. Then make the pudding and pour it into the shallow baking pan. This will model the asthenosphere. Once the pudding has set, place the animal crackers on top of the asthenosphere to represent the lithosphere.

Expected Outcomes Students should see that the lithospheric plates are relatively thin compared to the asthenosphere. They also can see how the lithosphere "floats" on top of the asthenosphere, without sinking into it. The asthenosphere has a solid consistency yet has some ability to move.
Logical, Visual

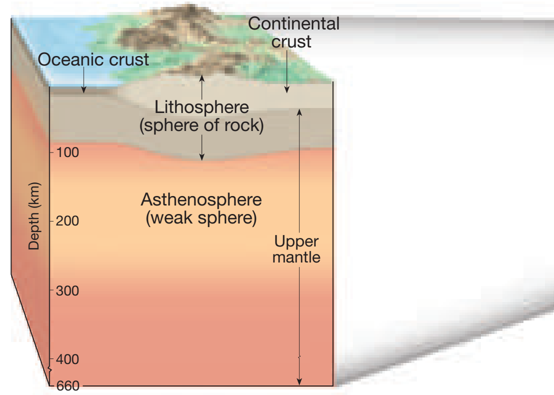


Figure 15 Earth's Layered Structure The left side of the globe shows that Earth's interior is divided into three different layers based on compositional differences—the crust, mantle, and core. The right side of the globe shows the five main layers of Earth's interior based on physical properties and mechanical strength—the lithosphere, asthenosphere, mesosphere, outer core, and inner core. The block diagram shows an enlarged view of the upper portion of Earth's interior.

Mantle Over 82 percent of Earth's volume is contained in the **mantle**—a solid, rocky shell that extends to a depth of 2890 kilometers. The boundary between the crust and mantle represents a change in chemical composition. The dominant rock type in the uppermost mantle is peridotite, which has a density of 3.4 g/cm^3.

Core The core is a sphere composed of an iron-nickel alloy. At the extreme pressures found in the center of the core, the iron-rich material has an average density of almost 13 g/cm^3 (13 times heavier than water).

Reading Checkpoint *What is the composition of the core?*

Layers Defined by Physical Properties

Earth's interior has a gradual increase in temperature, pressure, and density with depth. When a substance is heated, the transfer of energy increases the vibrations of particles. If the temperature exceeds the melting point, the forces between particles are overcome and melting begins.

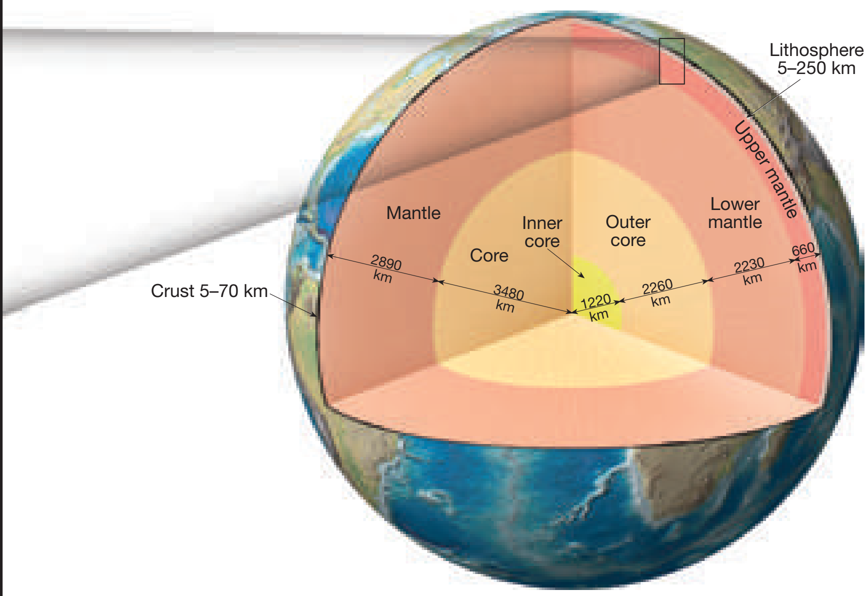
If temperature were the only factor that determined whether a substance melted, our planet would be a molten ball covered with a thin, solid outer shell. Fortunately, pressure also increases with depth and increases rock strength. Depending on the physical environment (temperature and pressure), a material may behave like a brittle solid, a putty, or a liquid. **Earth can be divided into layers based on physical properties—the lithosphere, asthenosphere, outer core, and inner core.**

Lithosphere and Asthenosphere Earth's outermost layer consists of the crust and uppermost mantle and forms a relatively cool, rigid shell called the **lithosphere**. This layer averages about 100 kilometers in thickness.

Customize for English Language Learners

Imagine that Earth was a ball. If you could cut it in half, you would see that Earth is made up of layers. The deepest layer is a solid core of metal, which is surrounded by a core of liquid metal. The liquid metal spins as Earth rotates. These two parts are thick and unbelievably hot. The next layer is called the mantle. The mantle is much cooler than the core, but it is still so hot that some of the rock is completely liquid.

A brittle crust of solid rock covers the mantle. All life on Earth exists on the top layer of this crust. Now imagine that you are taking a trip through Earth. Write and illustrate a journal entry for your trip. Share your journal entry with the class.



Beneath the lithosphere lies a soft, comparatively weak layer known as the **asthenosphere.** The asthenosphere has temperature/pressure conditions that may result in a small amount of melting. Within the asthenosphere, the rocks are close enough to their melting temperatures that they are easily deformed. Thus, the asthenosphere is weak because it is near its melting point, just as hot wax is weaker than cold wax. The lower lithosphere and asthenosphere are both part of the upper mantle.

Lower Mantle From a depth of about 660 kilometers down to near the base of the mantle lies a more rigid layer called the lower mantle. Despite their strength, the rocks of the lower mantle are still very hot and capable of gradual flow. The bottom few hundred kilometers of the mantle, laying on top of the hot core, contains softer, more flowing rock like that of the asthenosphere.

Inner and Outer Core The core, which is composed mostly of an iron-nickel alloy, is divided into two regions with different physical properties. The **outer core** is a liquid layer 2260 kilometers thick. The flow of metallic iron within this zone generates Earth's magnetic field. The **inner core** is a sphere having a radius of 1220 kilometers. Despite its higher temperature, the material in the inner core is compressed into a solid state by the immense pressure.

Reading Checkpoint ***Why is the inner core solid?***

Build Science Skills L2

Calculating The mantle makes up roughly 82 percent of Earth. The mantle is composed of two different layers, the upper mantle and the lower mantle. The mantle reaches to a depth of approximately 2900 km. **Using the numbers given on Figure 15, what percent of the mantle is upper mantle?** *(660 km/2900 km = 23 percent)* **What percent is lower mantle?** *(2230 km/2900 km = 77 percent)*
Logical

Integrate Language Arts L2

Word Parts Students can remember vocabulary by recognizing word parts in certain words. For example, the Greek suffix *litho-* means "rock, or stone." Ask: **What other word part is a clue to meaning of vocabulary terms such as lithosphere and asthenosphere?** *(–sphere)* **What do you think it means?** *(Sample answer: rounded)*

Answer to . . .

Reading Checkpoint *The core is composed of an iron-nickel alloy.*

Reading Checkpoint *because it is under extreme pressure and is compressed into a solid as a result*

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Discovering Earth's Layers

Integrate Physics L2

Physical and Chemical Properties Have students read the caption for Figure 16. Then ask students for examples of physical and chemical properties. Make a two-column chart on the board and compile a list of physical and chemical properties. *(Examples of physical properties: conductivity, hardness, melting point, density, pressure. Examples of chemical properties: flammability, reactivity.)* Ask: **What physical properties change between the mantle and outer core?** *(hardness, density, pressure, state; outer core is liquid, mantle is solid)*

Build Reading Literacy L1

Refer to **p. 186D** in **Chapter 7**, which provides guidelines for relating text and visuals.

Relate Text and Visuals Instruct students to look at Figure 16. Refer them to the key and point out that P waves and S waves are different colors in the picture. Ask: **What happens when P waves hit the mantle-core boundary?** *(They bend around the core, or go through the core.)* **What sentences in the text support this observation?** *("It was observed that P waves were bent around the liquid outer core. . . P waves that travel through the core. . . ")* **What happens when S waves meet the boundary?** *(They stop travelling.)* **What sentence in the text supports this?** *("It was further shown that S waves could not travel through the outer core.")*

Discovering Earth's Layers

In 1909, a Croatian seismologist, Andrija Mohorovičić, presented evidence for layering within Earth. By studying seismic records, he found that the velocity of seismic waves increases abruptly below about 50 kilometers of depth. This boundary separates the crust from the underlying mantle and is known as the Mohorovičić discontinuity. The name is usually shortened to **Moho.**

Another boundary was discovered between the mantle and outer core. Seismic waves from even small earthquakes can travel around the world. This is why a seismograph in Antarctica can record earthquakes in California or Italy. However, it was observed that P waves were bent around the liquid outer core beyond about 100 degrees away from an earthquake. The outer core also causes P waves that travel through the core to arrive several minutes later than expected. This region, where bent P waves arrive, is sometimes called the shadow zone.

The bent wave paths can be explained if the core is composed of material that is different from the overlying mantle. The P waves bend around the core in a way similar to sound waves being bent around the corner of a building. For example, you can hear people talking from around the side of a building even if you cannot see them. In this way, rather than actually stopping the P waves in the shadow zone, the outer core bends them, as you can see modeled in Figure 16. It was further shown that S waves could not travel through the outer core. Therefore, geologists concluded that this region is liquid.

Reading Checkpoint *What is the Moho?*

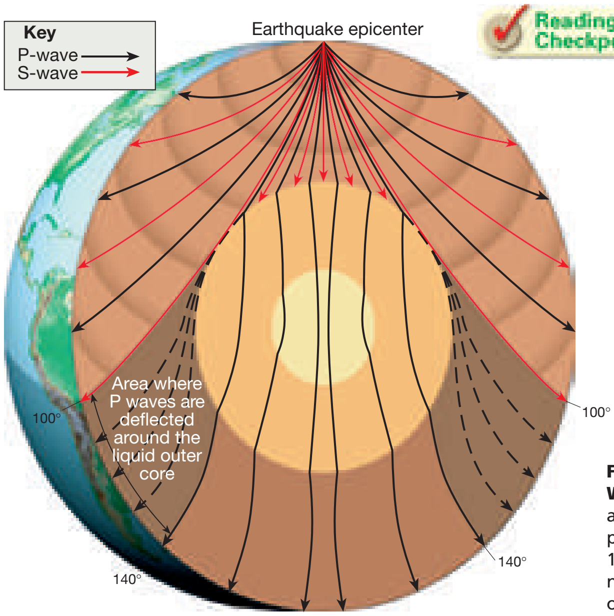


Figure 16 Earth's Interior Showing P and S Wave Paths The change in physical properties at the mantle-core boundary causes the wave paths to bend sharply. Any location more than 100 degrees from an earthquake epicenter will not receive direct S waves because the liquid outer core will not transmit them.

Facts and Figures

Andrija Mohorovičić was a Croatian scientist who lived from 1857 to 1936. Best known for his work as a seismologist, Mohorovičić also contributed to the sciences of meteorology and astronomy.

He established a station to follow thunderstorms, conducted climatic studies that lead to the conclusion that temperature in the atmosphere decreases with an increase in altitude, and published widely on clouds, rainstorms, and winds. After studying the seismic waves from the October 8, 1909, earthquake in the Kupa valley of Croatia, he made a very important discovery. At a depth of approximately 50 km, there was a dramatic change in material within Earth. This was based on his observation of a change in velocity of seismic waves at this depth. This inconsistency became known as the Moho, which is the boundary between the crust and the mantle.

Discovering Earth's Composition

We have examined Earth's structure, so now let's look at the composition of each layer. **Early seismic data and drilling technology indicate that the continental crust is mostly made of lighter, granitic rocks.** Until the late 1960s, scientists had only seismic evidence they could use to determine the composition of oceanic crust. The recovery of ocean-floor samples was made possible with the development of deep-sea drilling technology. **The crust of the ocean floor has a basaltic composition.**

The composition of the rocks of the mantle and core is known from more indirect data. Some of the lava that reaches Earth's surface comes from the partially melted asthenosphere within the mantle. In the laboratory, experiments show that partially melting the rock called peridotite produces a substance that is similar to the lava that erupts during volcanic activity of islands such as Hawaii.

Surprisingly, meteorites that collide with Earth provide evidence of Earth's inner composition. Meteorites are assumed to be composed of the original material from which Earth was formed. Their composition ranges from metallic meteorites made of iron and nickel to stony meteorites composed of dense rock similar to peridotite. Because Earth's crust contains a smaller percentage of iron than do meteorites, geologists believe that the dense iron, and other dense metals, sank toward Earth's center during the planet's formation. Lighter substances may have floated to the surface, creating the less-dense crust. **Earth's core is thought to be mainly dense iron and nickel, similar to metallic meteorites. The surrounding mantle is believed to be composed of rocks similar to stony meteorites.**

Section 8.4 Assessment

Reviewing Concepts

1. List the major layers of Earth's internal structure based on physical properties. List the layers in order from Earth's center to the surface.
2. What is the composition of Earth's core?
3. What evidence indicates that Earth's outer core is liquid?
4. What is the composition of the mantle?

Critical Thinking

5. **Comparing and Contrasting** Compare the physical properties of the asthenosphere and the lithosphere.
6. **Inferring** Why are meteorites considered important clues to the composition of Earth's interior?

Writing in Science

Creative Writing Write a short fictional story about a trip to Earth's core. Make sure the details about the layers of Earth's interior are scientifically accurate.

Discovering Earth's Composition

3 ASSESS

Evaluate Understanding L2

Ask students to draw two cross sections of Earth: one where the layers are defined by composition and one where the layers are defined by physical properties. Have students exchange papers and check each other's work.

Reteach L1

Use Figure 15 to review the layers of Earth.

Writing in Science

Stories will vary but students should include accurate information on the lithosphere, upper mantle, lower mantle, as well as the inner and outer core.

Section 8.4 Assessment

1. inner core, outer core, lower mantle, asthenosphere, lithosphere (upper mantle)
2. The core is made of an iron-nickel alloy.
3. the fact that S waves do not travel though this layer
4. The mantle is composed of peridotite.
5. The lithosphere is a cool, rigid shell formed from the crust and upper mantle. On average it is 100 km thick. The asthenosphere is a soft, weak layer that experiences the conditions needed to produce a small amount of melting.
6. Meteorites are thought to be made of the same material from which Earth was formed. Therefore, when they are found, they can give us an indication of the composition of the interior of Earth.

Answer to . . .

Reading Checkpoint: *The Moho is the boundary between the crust and the mantle.*

Earthquakes and Earth's Interior 237

How the Earth Works

1 FOCUS

Objectives

In this feature, students will
- explain what causes an earthquake.
- describe the possible physical effects of an earthquake.

Reading Focus

Build Vocabulary L2

Key Terms Write the key terms on the board. Ask volunteers to write definitions beside them. Then have the class work together to use the words in sentences that describe the causes and effects of earthquakes.

2 INSTRUCT

Bellringer L1

Ask students what comes to mind when they think of earthquakes. Discuss earthquake experiences they may have had or heard about.
Verbal

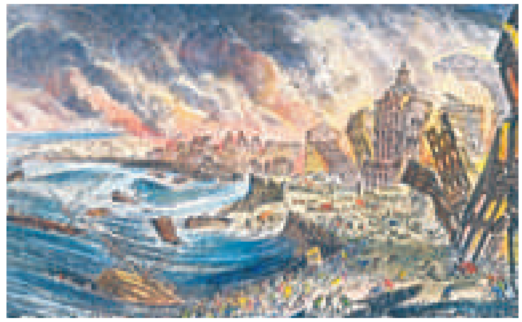
Use Visuals L1

Have students read and examine the photographs on this page and the next. Ask: **What do you suppose people in these regions had to do after the earthquake?** *(They had to find people who were trapped under snow and rubble, rebuild buildings, and fix streets.)*
Visual

How the Earth Works

Effects of Earthquakes

An **earthquake** is a shaking of the ground caused by sudden movements in the Earth's crust. The biggest quakes are set off by the movement of tectonic plates. Some plates slide past one another gently. However, others get stuck, and the forces pushing the plates build up. The stress mounts until the plates suddenly shift their positions and cause the Earth to shake. Most earthquakes last less than one minute. Even so, the effects of an earthquake can be devastating and long-lasting.



TSUNAMI
In 1755, an earthquake in Lisbon, Portugal, caused a tsunami, as illustrated in this painting. A **tsunami** is a huge sea wave that is set off by an undersea earthquake or volcanic eruption. When tsunamis break on shore, they often devastate coastal areas. Tsunamis can race at speeds of about 450 miles per hour and may reach heights of about 100 feet (30.5 m).

LANDSLIDE
In January 2001, an earthquake struck El Salvador. It caused the landslide that left these Salvadoran women homeless. A **landslide** is a sudden drop of a mass of land down a mountainside or hillside. Emergency relief workers from around the world often rush to the site of an earthquake disaster like the one that occurred in El Salvador.

Customize for Inclusion Students

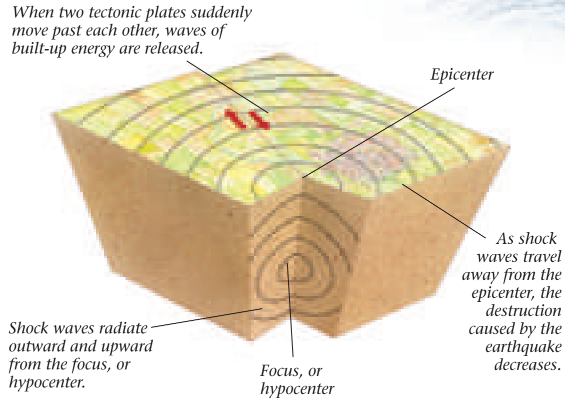
Gifted Ask students to research a historic earthquake, like the one that hit Lisbon in 1755. Have them imagine that they survived it and are writing a story about it for a foreign newspaper. Encourage them to use factual details and fictional interviews in their stories. Before they begin, remind them that the first paragraph should answer these questions: *Who? What? Where? When?* and *Why?*

238 Chapter 8

INFRASTRUCTURE DAMAGE
When an earthquake occurred in Los Angeles in 1994, underground gas and water lines burst, causing fires and floods. Earthquakes often cause tremendous damage to the **infrastructure**—the network of services that supports a community. Infrastructure includes power utilities, water supplies, and transportation and communication facilities.

AVALANCHE
Earthquakes may trigger an **avalanche**—a sudden fall of a mass of ice and snow. In 1970, a severe earthquake off the coast of Peru caused a disastrous slide of snow and rock that killed some 18,000 people in the valley below.

WHEN THE EARTH CRACKS
Most people killed or injured by an earthquake are hit by debris from buildings. Additional damage can be caused by **aftershocks**—tremors that can occur hours, days, or even months after an earthquake. The scene above shows the city of Anchorage, Alaska, after a major earthquake. Extensive ground tremors caused the street to break up as the soil below it collapsed. Buildings and cars were dropped more than 10 feet (3 m) below street level.



SEISMIC WAVES
As tectonic forces build, rock beneath the surface bends until it finally breaks. The tectonic plates suddenly move, causing **seismic waves,** or vibrations, to travel through the ground. The waves radiate outward from an underground area called the focus, or hypocenter. Damage is usually greatest near the **epicenter,** the point on the surface directly above the focus.

ASSESSMENT

1. **Key Terms** Define **(a)** earthquake, **(b)** tsunami, **(c)** landslide, **(d)** infrastructure, **(e)** avalanche, **(f)** aftershock, **(g)** seismic wave, **(h)** epicenter.
2. **Physical Processes** What physical processes cause an earthquake to occur?
3. **Environmental Change** How can an earthquake cause changes to the physical characteristics of a place?
4. **Natural Hazards** **(a)** How can an earthquake change the human characteristics of a place? **(b)** How does the international community respond to a devastating earthquake?
5. **Critical Thinking** **Solving Problems** What can a community do to reduce the amount of earthquake damage that might occur in the future?

3 ASSESS

Evaluate Understanding L2

Work with students to model how an earthquake happens. Encourage them to build models using everyday classroom materials, such as books for tectonic plates and paper strips for seismic waves.

Reteach L1

Group students in groups of four or five. Have each group create an earthquake safety pamphlet. Tell students to find out the recommended ways to protect themselves during an earthquake. Have them create a pamphlet that explains and illustrates safety instructions. Each group should have researchers, an editor to compile the instructions, and an illustrator to create the pictures. Post the completed pamphlets on a bulletin board.

Assessment

1. (a) a shaking of the ground caused by sudden movements in Earth's crust; **(b)** a huge sea wave that is set off by an undersea earthquake or volcanic eruption; **(c)** a sudden drop of a mass of land down a mountainside or hillside; **(d)** the network of services that supports a community; **(e)** a sudden fall of a mass of ice and snow; **(f)** tremors that can occur days, or even months, after an earthquake; **(g)** vibrations that travel through the ground; **(h)** the point on the surface directly above the focus
2. sudden movements in Earth's crust
3. Earthquakes can change the level of the land, cause fires and floods, and cover areas with snow and ice.
4. (a) Sample answer: Damage from an earthquake can destroy buildings and make a place uninhabitable; **(b)** Emergency relief workers from around the world may arrive to help with rescue and cleanup efforts. People around the world may donate money to help victims survive until they rebuild their lives.
5. Sample answers: Design buildings to withstand the shock of an earth quake. Build villages, towns, and cities far from fault lines.

Section 9.1

1 FOCUS

Section Objectives

9.1 **Describe** the hypothesis of continental drift.

9.2 **Evaluate** the evidence in support of continental drift.

9.3 **Identify** the main objections to Wegener's hypothesis of continental drift.

Reading Focus

Build Vocabulary L2

Word Forms Before students read this section, ask them to write a sentence or two describing the meaning of the word *drift*. Then have them write a prediction for what they think continental drift means. After students read the section, have them examine their predictions and discuss whether their predictions must be changed.

Reading Strategy L2

a. continental puzzle
b. matching fossils
c. matching rocks and structures
d. ancient climates

2 INSTRUCT

An Idea Before Its Time

Use Visuals L1

Figure 1 Point out the small areas of brown and light blue between Africa and South America. Ask: **What could cause the brown-shaded regions of overlap?** *(accumulation of sediments deposited by rivers and stretching of the plates)* **What do you think the light blue areas represent?** *(the continental shelf)*
Visual

9.1 Continental Drift

Reading Focus

Key Concepts

- What is the hypothesis of continental drift?
- What evidence supported continental drift?

Vocabulary

- continental drift
- Pangaea

Reading Strategy

Summarizing Copy the table. Fill it in as you read to summarize the evidence of continental drift.

Hypothesis	Evidence
Continental Drift	a. continental puzzle
	b. ____?____
	c. ____?____
	d. ____?____

Will California eventually slide into the ocean? Have continents really drifted apart over the centuries? Early in the twentieth century, most geologists thought that the positions of the ocean basins and continents were fixed. During the last few decades, however, new data have dramatically changed our understanding of how Earth works.

Figure 1 A Curious Fit This map shows the best fit of South America and Africa at a depth of about 900 meters. The areas where continents overlap appear in brown.
Inferring ***Why are there areas of overlap?***

An Idea Before Its Time

The idea that continents fit together like pieces of a jigsaw puzzle came about when better world maps became available. Figure 1 shows the two most obvious pieces of this jigsaw puzzle. However, little significance was given this idea until 1915, when Alfred Wegener, a German scientist, proposed his radical hypothesis of **continental drift.** **Wegener's continental drift hypothesis stated that the continents had once been joined to form a single supercontinent.** He called this supercontinent **Pangaea,** meaning *all land.*

Wegener also hypothesized that about 200 million years ago Pangaea began breaking into smaller continents. These continents then drifted to their present positions, as shown on page 250. Wegener and others collected much evidence to support these claims. Let's examine their evidence.

Evidence: The Continental Puzzle Wegener first thought that the continents might have been joined when he noticed the similarity between the coastlines on opposite sides of the South Atlantic Ocean. He used present-day shorelines to show how the continents fit together. However, his opponents correctly argued that erosion continually changes shorelines over time.

Evidence: Matching Fossils **Fossil evidence for continental drift includes several fossil organisms found on different landmasses.** Wegener reasoned that these organisms could not have crossed the vast oceans presently separating the continents. An example is *Mesosaurus*, an aquatic reptile whose fossil remains are limited to eastern South America and southern Africa, as shown in Figure 2. If *Mesosaurus* had been able to swim well enough to cross the vast South Atlantic Ocean, its fossils should be more widely distributed. This is not the case. Therefore, Wegener argued, South America and Africa must have been joined somehow.

The idea of land bridges was once the most widely accepted explanation for similar fossils being found on different landmasses. Most scientists believed that during a recent glacial period, the lowering of sea level allowed animals to cross the narrow Bering Strait between Asia and North America. However, if land bridges did exist between South America and Africa, their remnants should still lie below sea level. But no signs of such land bridges have ever been found in the Atlantic Ocean.

Reading Checkpoint *How does the distribution of* Mesosaurus *fossils provide evidence for continental drift?*

Q & A

Q *If all the continents were once joined as Pangaea, what did the rest of Earth look like?*

A When all the continents were together, there must also have been one huge ocean surrounding them. This ocean is called *Panthalassa* (*pan* = all, *thalassa* = sea). Today all that remains of Panthalassa is the Pacific Ocean, which has been decreasing in size since the breakup of Pangaea.

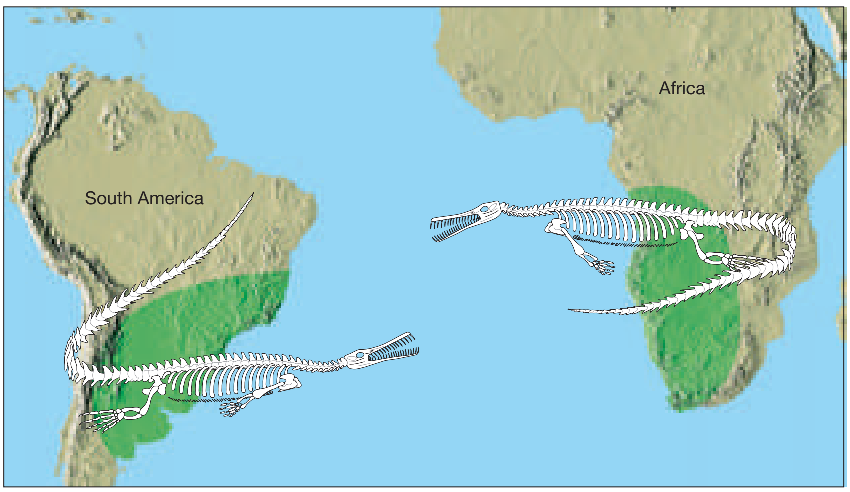


Figure 2 Location of Mesosaurus Fossils of *Mesosaurus* have been found on both sides of the South Atlantic and nowhere else in the world. Fossil remains of this and other organisms on the continents of Africa and South America appear to link these landmasses at some time in Earth's history.

Teacher Demo

Evidence: Matching Fossils **L2**

Purpose Students compare two groups of fossils from two continents to identify those fossils that are common to both continents.

Materials 2 groups of photographs or samples of fossils, including at least one type of fossil found in both groups

Procedure Have students examine the two groups of fossils. Tell them that the two groups were found on different continents. Ask them to identify any fossils that were found on both continents. Have students infer the implications of this observation.

Expected Outcome Students should infer that the two continents had to be connected at some point in the past when the organism in the fossil lived.
Visual, Logical

Customize for Inclusion Students

Visually Impaired Puzzle pieces of continents can be made out of sandpaper by gluing a map onto the back of a piece of sandpaper and cutting out the continents. This learning tool can be used by both visually impaired students and students who learn tactilely. Remind students who use these pieces that the piece must be held with the rough side down for correct geographical orientation of the continent.

Answer to . . .

Figure 1 *Areas where there are rivers or streams have deposited large amounts of sediments.*

Reading Checkpoint Mesosaurus *occurs only in eastern South America and southern Africa.*

Use Visuals

L1

Figure 3 Have students study the maps showing the breakup of Pangaea. Ask: **In the breakup of Pangaea, what continents appear to have separated first?** *(North America and Africa)* **What ocean began to form when North America and Africa separated?** *(Atlantic Ocean)* **How was India formed?** *(India broke away from Gondwanaland. It moved north and eventually collided with Asia.)*
Visual, Logical

Address Misconceptions

L2

Some students may think that the continents have remained in approximately the same positions since the breakup of Pangaea. Make transparencies of the five parts of Figure 3. Superimpose the transparencies two at a time to show students the changes. Ask students to come up to the projection to point out changes in the location of continents from one transparency to another. Ask which continent has moved the farthest. *(Asia)*
Visual, Logical

Breakup of Pangaea

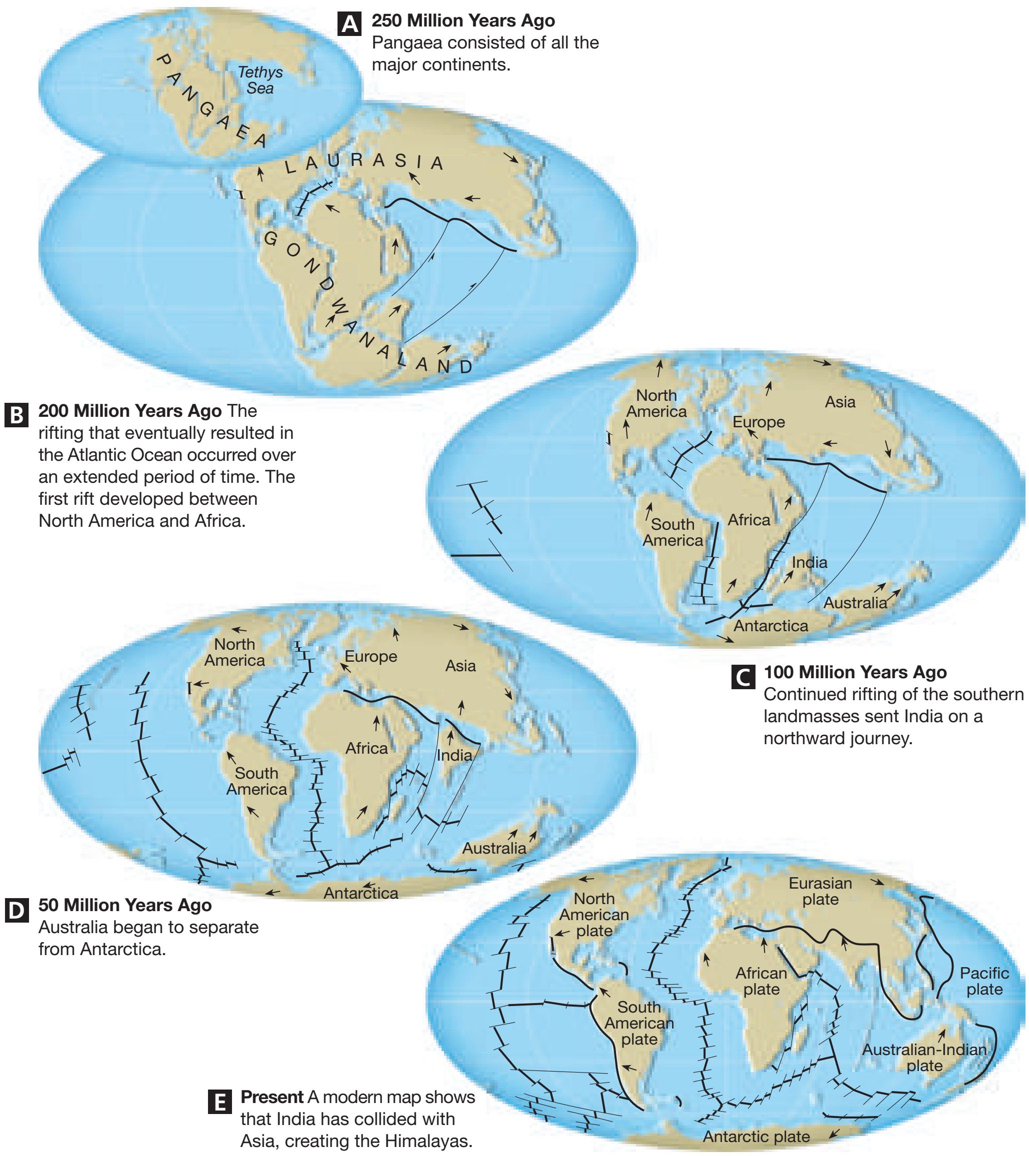
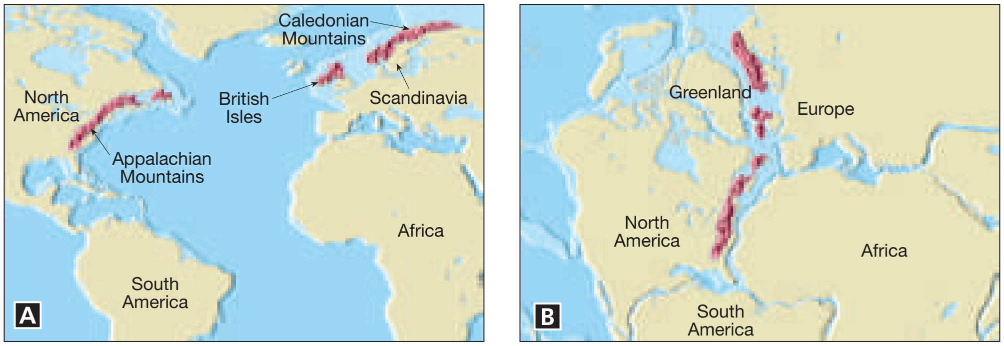


Figure 3 Pangaea broke up gradually over a period of 200 million years.

Facts and Figures

Recently, a unique species of purple frog that lives underground was discovered in southwestern India. DNA analysis showed that the frog was related to a group of frogs that live only in the Seychelles Islands off the eastern coast of Africa and almost 3000 km across the Indian Ocean from India. Biologists think that the two frog populations are additional evidence for continental drift.

Matching Mountain Ranges



Evidence: Rock Types and Structures Anyone who has worked a jigsaw puzzle knows that the pieces must fit together to form a clear picture. The clear picture in the continental drift puzzle is one of matching rock types and mountain belts. If the continents existed as Pangaea, the rocks found in a particular region on one continent should closely match in age and type those in adjacent positions on the adjoining continent.

Rock evidence for continental drift exists in the form of several mountain belts that end at one coastline, only to reappear on a landmass across the ocean. For example, the Appalachian mountain belt runs northeastward through the eastern United States, ending off the coast of Newfoundland, as shown in Figure 4A. Mountains of the same age with similar rocks and structures are found in the British Isles and Scandinavia. When these landmasses are fit together as in Figure 4B, the mountain chains form a nearly continuous belt.

Reading Checkpoint *How does the location of mountain chains provide evidence of continental drift?*

Evidence: Ancient Climates Wegener was a meteorologist, so he was interested in obtaining data about ancient climates to support continental drift. And he did find evidence for dramatic global climate changes. Wegener found glacial deposits showing that between 220 million and 300 million years ago, ice sheets covered large areas of the Southern Hemisphere. Layers of glacial till were found in southern Africa and South America, as well as in India and Australia. Below these beds of glacial debris lay scratched and grooved bedrock carved by the ice. In some locations, the scratches and grooves showed that the ice had moved from what is now the sea onto land. It is unusual for large continental glaciers to move from the sea

Figure 4 A The Appalachian Mountains run along the eastern side of North America and disappear off the coast of Newfoundland. Mountains that are similar in age and structure are found in the British Isles and Scandinavia. **B** When these landmasses are united as Pangaea, these ancient mountain chains form a nearly continuous belt.

Go Online SciLinks NSTA

For: Links on continental drift
Visit: www.SciLinks.org
Web Code: cjn-3091

Build Science Skills L2

Using Models Have students use a child's jigsaw puzzle with several large pieces to demonstrate matching rock types and mountain belts as follows. Students should put the puzzle together on a piece of cardboard. After putting it together, the puzzle should be covered with another piece of cardboard and flipped over. On the back of the puzzle, students should draw lines representing a mountain belt that extends across several puzzle pieces. Students will understand when the puzzle is put together how mountain chains form continuous belts across land masses.
Kinesthetic, Visual

ACTIVITY

Build Reading Literacy L1

Refer to **p. 246D** which provides the guidelines for relating cause and effect.

Relate Cause and Effect Have students read the section on pp. 251–252 about ancient climates as evidence for continental drift. Ask: **Why did Wegener believe that the existence of glaciers in tropical regions of the Southern Hemisphere was evidence of continental drift rather than climatic change?** *(The Northern Hemisphere was once tropical, as evidenced by coal deposits that were formed from tropical plants. If the Northern Hemisphere had once been closer to the equator, the Southern Hemisphere probably had also been further south, closer to the South Pole. It was not likely that such a large change in climate could have taken place without continental drift.)*
Logical

Facts and Figures

Scientists think that 200 million years ago, what is now Pennsylvania was located farther south, near the equator. Fossils from coal fields in Pennsylvania show that the plants from which the coal formed had large leaf-like structures that are typical of tropical plants. The trunks of the plants had no growth rings, also typical of tropical plants because there is little seasonal temperature fluctuation to produce the rings. Scientists believe that these fossils are evidence that Pennsylvania once had a tropical climate and was located closer to the equator.

Go Online NSTA SciLinks

Download a worksheet on continental drift for students to complete, and find additional teacher support from NSTA SciLinks.

Answer to . . .

Reading Checkpoint *If mountain chains can be continued across present-day oceans, they provide evidence that the areas were once connected.*

Quick Lab

Charting the Age of the Atlantic Ocean

L2

Objective
After completing this activity, students will be able to calculate the length of time it takes two land masses to separate, given the rate of spreading.

Skills Focus Calculating, Inferring

Prep Time none

Class Time 10 minutes

Teaching Tips You might want to review conversion factors with students.

Expected Outcome The two continents took more than 130 million years to separate.

Analyze and Conclude
1. 130.3 million years
2. The rate would probably have varied over time because the driving mechanism was most likely not uniform. Few Earth processes are uniform over time.
Logical

For Enrichment

L3

Have students research the following question: Pangaea began to break up and South America and Africa began to separate 200 million years ago. What types of living organisms were found on Earth when the two continents reached their current positions?

Quick Lab

Charting the Age of the Atlantic Ocean

Procedure

1. The distance between two locations across the Atlantic Ocean, one in South America and one in Africa, is approximately 4300 km.
2. Assume that these two locations were once joined as part of Pangaea.

Analyze and Conclude

1. **Calculating** If the two landmasses moved away from each other at a rate of 3.3 cm/y, how long did it take these two locations to move to their current positions?
2. **Inferring** Do you think the Atlantic Ocean would have formed at a constant rate or would that rate have varied over time? Why?

onto land. It is also interesting that much of the land area that shows evidence of this glaciation now lies near the equator in a subtropical or tropical climate.

Could Earth have been cold enough to allow the formation of continental glaciers in what is now a tropical region? Wegener rejected this idea because, during this same time period, large tropical swamps existed in the Northern Hemisphere. The lush vegetation of these swamps eventually became the major coal fields of the eastern United States, Europe, and Siberia.

Wegener thought there was a better explanation for the ancient climate evidence he observed. Thinking of the landmasses as a supercontinent, with South Africa centered over the South Pole, would create the conditions necessary to form large areas of glacial ice over much of the Southern Hemisphere. The supercontinent idea would also place the northern landmasses nearer the tropics and account for their vast coal deposits, as shown in Figure 5.

Reading Checkpoint ***Summarize the climate evidence for continental drift.***

Glacier Evidence

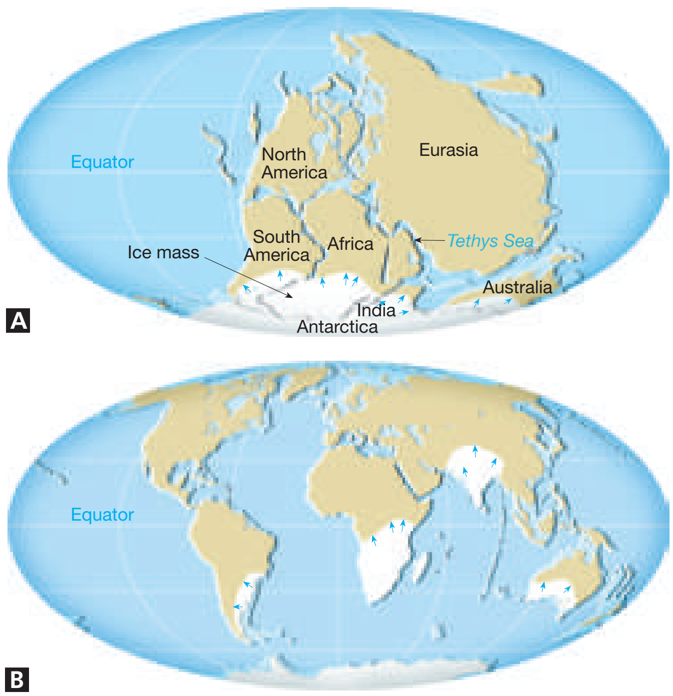


Figure 5 **A** The area of Pangaea covered by glacial ice 300 million years ago. **B** The continents as they are today. The white areas indicate where evidence of the old ice sheets exists. **Interpreting Diagrams** ***Where were the continents located when the glaciers formed?***

Rejecting a Hypothesis

Wegener's drift hypothesis faced a great deal of criticism from other scientists. One objection was that Wegener could not describe a mechanism that was capable of moving the continents across the globe. Wegener proposed that the tidal influence of the Moon was strong enough to give the continents a westward motion. However, physicists quickly responded that tidal friction of the size needed to move the continents would stop Earth's rotation.

Wegener also proposed that the larger and sturdier continents broke through the oceanic crust, much like ice breakers cut through ice. However, no evidence existed to suggest that the ocean floor was weak enough to permit passage of the continents without the ocean floors being broken and deformed in the process.

Most scientists in Wegener's day rejected his hypothesis. However, a few geologists continued to search for additional evidence of continents in motion.

Reading Checkpoint *Why was Wegener's hypothesis rejected?*

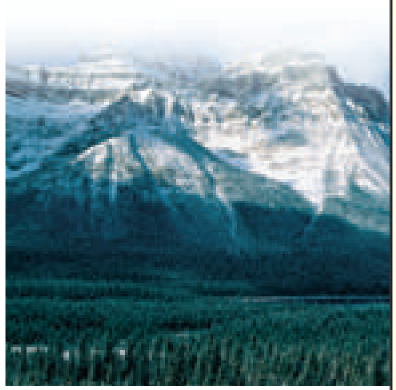
A New Theory Emerges During the years that followed Wegener's hypothesis, major strides in technology enabled scientists to map the ocean floor. Extensive data on earthquake activity and Earth's magnetic field also became available. By 1968, these findings led to a new theory, known as plate tectonics. This theory provides the framework for understanding most geologic processes, such as the formation of the mountains shown in Figure 6.

Q&A

Q *Some day will the continents come back together and form a single landmass?*

A Yes, but not anytime soon. Based on current plate motions, it appears that the continents may meet up again in the Pacific Ocean—in about 300 million years.

Figure 6 Mountain ranges are commonly formed at plate boundaries. This photograph shows part of the Canadian Rockies in Banff National Park, Alberta, Canada.



Section 9.1 Assessment

Reviewing Concepts

1. What is the hypothesis of continental drift?
2. List the evidence that supported the hypothesis of continental drift.
3. What was one of the main objections to Wegener's continental drift hypothesis?
4. What is Pangaea?

Critical Thinking

5. **Applying Concepts** Would the occurrence of the same plant fossils in South America and Africa support continental drift? Explain.
6. **Drawing Conclusions** How did Wegener explain the existence of glaciers in the southern landmasses, and the lush tropical swamps in North America, Europe, and Siberia?

Writing in Science

Descriptive Paragraph Write a paragraph describing Pangaea. Include the location and climate of Pangaea. Use the equator as your reference for position.

Rejecting a Hypothesis

Build Science Skills L2

Using Tables and Graphs Have students make a table listing the reasons why Wegener's hypothesis was criticized by some people and accepted by others. **Intrapersonal, Verbal**

3 ASSESS

Evaluate Understanding L2

To assess students' knowledge of section content, have them write two or three sentences describing each of the four lines of evidence for Wegener's continental drift hypothesis.

Reteach L1

Have students explain in their own words why Figure 2 shows evidence for continental drift.

Writing in Science

Pangaea was a supercontinent made up of all the major continents joined together. It began breaking into smaller continents about 200 million years ago. Pangaea was located near the South Pole. The southern part of Pangaea, made up of South America, Africa, India, Australia, and Antarctica, had a cold climate with large continental glaciers.

Section 9.1 Assessment

1. a hypothesis that proposes that the continents where once joined to form one supercontinent
2. matching continental outlines, matching fossils, matching rocks and structures, ancient climates
3. He could not provide a mechanism to explain the movement of the continents.
4. the supercontinent proposed by Wegener's hypothesis of continental drift
5. Yes, a land plant most likely could not travel across a large ocean such as the Atlantic. If the plant is found in both Africa and South America, those areas had to have been joined when the plant was growing.
6. It is difficult to imagine that Earth had cooled enough to form glaciers in tropical latitudes, so in order to explain the glaciers, those areas had to have been closer to the poles than in the present day. Also, the glacial grooves indicate the ice was coming from an area that at present is ocean. Large continental glaciers form only on land, so that area had to be land.

Answer to . . .

Figure 5 *The continents were near the South Pole when the glaciers formed.*

Reading Checkpoint *Glaciers in southern South America, southern Africa, India, and Australia are found in areas that now have tropical climates. There is also evidence for tropical climates and coal swamps in areas that are now at higher latitudes, such as northern Europe and the northeastern United States.*

Reading Checkpoint *He could not provide a mechanism for the movement of the continents.*

Section 9.2

1 FOCUS

Section Objectives

9.4 **Explain** the theory of plate tectonics.
9.5 **Describe** lithospheric plates.
9.6 **Identify** the three types of plate boundaries.

Reading Focus

Build Vocabulary L2

Concept Map Have students make a concept map using the term *plate tectonics* as the starting point. All the vocabulary terms in this section should be used.

Reading Strategy L2

a. plates move together
b. plates move apart
c. plates slide past each other

2 INSTRUCT

Earth's Major Plates

Build Science Skills L2

Using Analogies ACTIVITY
Crack the shell of a hard-boiled egg. Ask students if the egg reminds them of anything. The egg can be seen as a tiny model of Earth. The thin eggshell is analogous to Earth's crust, divided into plates. Within the shell is the firm mantle. Have students move the pieces of shell around. They should notice how the shell buckles in some places and exposes "mantle" in other places. This movement is analogous to the movement of Earth's crust. However, Earth's movement results in the formation of mountains, earthquakes, and new ocean floor.
Kinesthetic, Visual

9.2 Plate Tectonics

Reading Focus

Key Concepts

- What is the theory of plate tectonics?
- What are lithospheric plates?
- What are the three types of plate boundaries?

Vocabulary

- plate tectonics
- plate
- divergent boundary
- convergent boundary
- transform fault boundary

Reading Strategy

Comparing and Contrasting Copy the table. After you read, compare the three types of plate boundaries by completing the table.

Boundary Type	Relative Plate Motion
convergent	a. ____?____
divergent	b. ____?____
transform fault	c. ____?____

Earth's Major Plates

According to the plate tectonics theory, the uppermost mantle, along with the overlying crust, behaves as a strong, rigid layer. This layer is known as the lithosphere. The outer shell lies over a weaker region in the mantle known as the asthenosphere. The lithosphere is divided into segments called **plates,** which move and continually change shape and size. Figure 8 on pages 256-257 shows the seven major plates. The largest is the Pacific plate, covering most of the Pacific Ocean. Notice that several of the large plates include an entire continent plus a large area of the seafloor. This is a major departure from Wegener's continental drift hypothesis, which proposed that the continents moved through the ocean floor, not with it. Note also that none of the plates is defined entirely by the margins of a continent.

The lithospheric plates move relative to each other at a very slow but continuous rate that averages about 5 centimeters per year—about as fast as your fingernails grow. This movement is driven by the unequal distribution of heat within Earth. Hot material found deep in the mantle moves slowly upward as part of Earth's internal convection system. At the same time, cooler, denser slabs of oceanic lithosphere descend into the mantle, setting Earth's rigid outer shell into motion. The grinding movements of Earth's lithospheric plates generate earthquakes, create volcanoes, and deform large masses of rock into mountains.

Reading Checkpoint *What is plate tectonics?*

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Types of Plate Boundaries

All major interactions among individual plates occur along their boundaries. **The three main types of boundaries are convergent, divergent, and transform fault boundaries.**

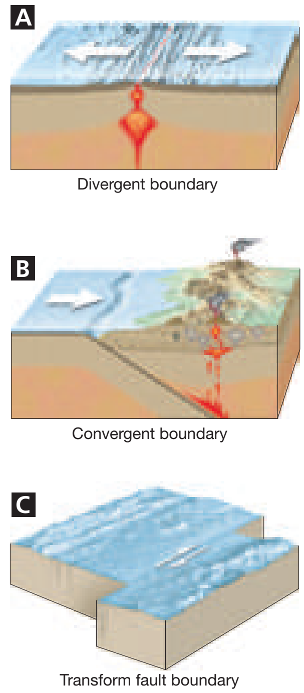
Divergent boundaries **Divergent boundaries** (also called spreading centers) occur when two plates move apart. This process results in upwelling of material from the mantle to create new seafloor, as shown in Figure 7A. A relatively new divergent boundary is located in Africa, in a region known as the East African Rift valley.

Convergent boundaries **Convergent boundaries** form where two plates move together. This process results in oceanic lithosphere plunging beneath an overriding plate, and descending into the mantle, as shown in Figure 7B. At other locations, plates carrying continental crust are presently moving toward each other. Eventually, these continents may collide and merge. Thus, the boundary that once separated two plates disappears as the plates become one.

Transform fault boundaries **Transform fault boundaries** are margins where two plates grind past each other without the production or destruction of lithosphere, as shown in Figure 7C. The San Andreas Fault zone in California is an example of a transform fault boundary.

Each plate contains a combination of these three types of boundaries. Although the total surface area of Earth does not change, plates may shrink or grow in area. This shrinking or growing depends on the locations of convergent and divergent boundaries. The Antarctic plate is growing larger. The Philippine plate is descending into the mantle along its margins and is becoming smaller. New plate boundaries can be created because of changes in the forces acting on these rigid slabs.

Figure 7 Three Types of Plate Boundaries



Section 9.2 Assessment

Reviewing Concepts

1. Define the term *lithospheric plate*.
2. List the three types of plate boundaries.
3. What theory proposes that Earth's outer shell consist of a number of rigid slabs?

Critical Thinking

4. **Comparing and Contrasting** Compare the plate motions in the three types of boundaries.
5. **Drawing Conclusions** What is the major difference in the role of the ocean floor between the continental drift hypothesis and the theory of plate tectonics?

Connecting Concepts

Plate Boundaries Use what you have learned about plate tectonics to compare Wegener's continental drift hypothesis to the theory of plate tectonics.

Types of Plate Boundaries

Build Reading Literacy L1

Refer to **p. 502D** in **Chapter 18**, which provides the guidelines for this visualizing strategy.

Visualize Have students read the section on types of plate boundaries and then try to form a mental picture of each type of boundary. Ask: **In which type of boundary do the plates move without changing the lithosphere?** *(transform fault boundary)*
Visual, Verbal

3 ASSESS

Evaluate Understanding L2

To assess students' knowledge of section content, have them draw diagrams of the three types of plate boundaries. Each diagram should have a caption describing the movement of the plates.

Reteach L1

Have students use any materials they wish, such as blocks of wood, to illustrate the plate movements in the three types of boundaries.

Connecting Concepts

In Wegener's hypothesis, the continents moved through the ocean floor. The ocean floor did not move and was not part of the block of continental crust. The boundaries of the continents were defined by either the shorelines or continental shelves. In plate tectonics, the plates are divided by boundaries along which different types of motion and deformation occur. The ocean floors are part of the plates and move along with the continents.

Section 9.2 Assessment

1. a section of the crust and upper mantle (the lithosphere) that moves as a unit
2. convergent, divergent, and transform fault boundaries
3. the theory of plate tectonics
4. In convergent boundaries, the two plates move together. In divergent boundaries, the two plates move apart. In transform fault boundaries, the two plates grind past each other.
5. In the continental drift hypothesis, the continents plowed through the ocean floors; in the plate tectonics theory, the ocean floors are an integral part of the lithospheric plates and move with the continents.

Answer to . . .

Reading Checkpoint: *A theory that states that Earth's rigid outer shell is broken into plates made up of the crust and upper mantle, also known as the lithosphere. A plate moves as a unit with respect to the surrounding plates.*

Section 9.2 (continued)

MAP MASTER Skills Activity

Answer
Locate South American plate. Divergent: Caribbean plate, Mid-Atlantic Ridge; Southeast Indian Ridge, Antarctic plate. Convergent: Nazca plate, South American plate; Australian-Indian plate, Eurasian plate. Transform fault: Antarctic plate, Pacific plate; Caribbean plate, North American plate

Use Visuals L1

Figure 8 Have students examine the figure. They may need help from an atlas or a globe to locate the features in the questions. Ask: **How do you think the Andes Mountains were formed?** *(The Nazca plate collided with the South American plate.)* **How do you think the Red Sea was formed?** *(The African plate and the Arabian plate moved apart, forming a rift that became the Red Sea.)* **Which plate is the largest? Where is it located?** *(The Pacific plate; it is mostly within the Pacific Ocean.)*
Visual

Teacher Demo

A Convergent Model L2

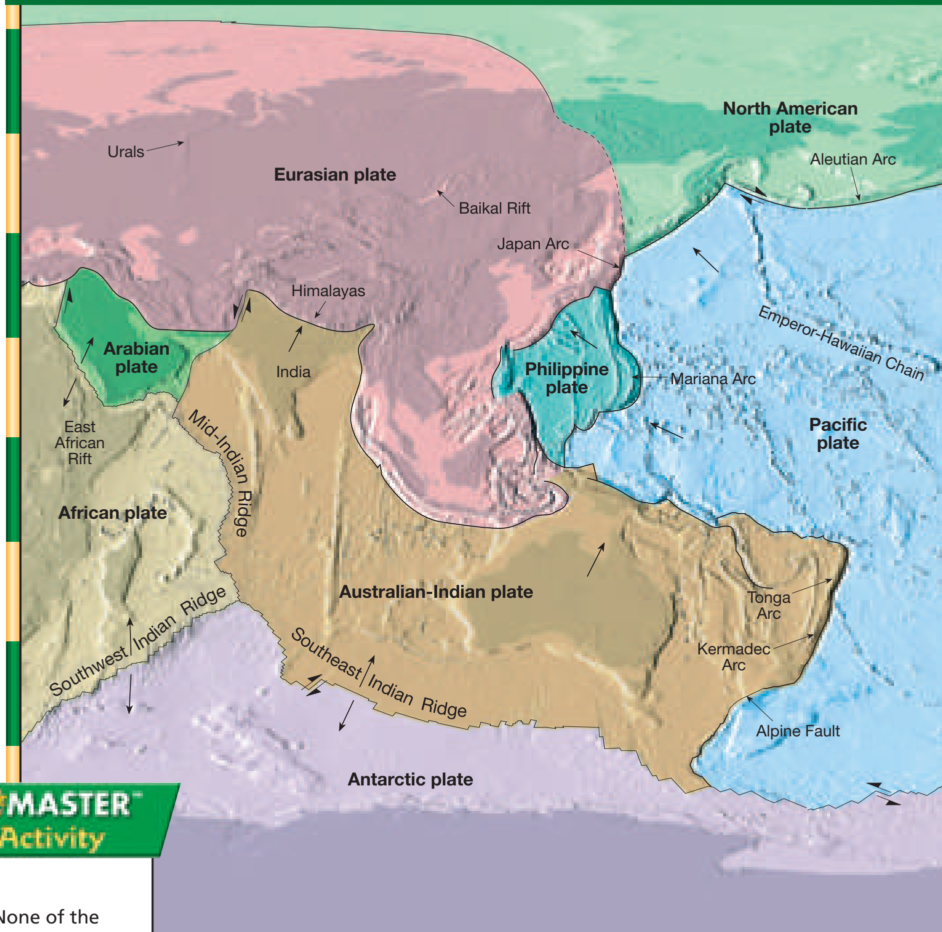
Purpose Students will observe what happens when two plates collide in a model of a convergent boundary.

Materials two slabs of modeling clay, wax paper

Procedure Place the slabs of clay on the wax paper on a table so they will slide easily. Push the two slabs of clay together to model a collision of two plates.

Expected Outcome The clay slabs will buckle up to create folds and breaks that resemble mountains.
Kinesthetic, Visual

Earth's Tectonic Plates



Seven Major Plates
North American
South American
Pacific
African
Eurasian
Australian-Indian
Antarctic

Intermediate Plates
Caribbean
Nazca
Philippine
Arabian
Cocos
Scotia

MAP MASTER Skills Activity

Figure 8

Location None of the plates are defined entirely by the margins of a continent. Over a dozen smaller plates have been identified but are not shown.

Locate Find a major plate that includes an entire continent plus a large area of seafloor. Name two other examples of a divergent boundary, a convergent boundary, and a transform fault boundary.

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Customize for English Language Learners

Students who are learning disabled will benefit by having globes in the classroom. You might want to mark the major plates on a globe so students can better visualize how Earth's lithosphere is divided into tectonic plates.

Address Misconceptions **L2**

Students may think that the movement of lithospheric plates causes Earth's surface area to become either larger or smaller (depending on which way the plates move.) Explain that individual plates can become larger or smaller, but Earth's total surface area cannot change. Give students a basketball or soccer ball and ask them to imagine what will happen to the interior of the ball if the surface area changed. *(If surface area decreased, the interior would become compressed and internal pressure would increase. If surface area increased, either the interior would expand or the lithosphere would separate from the mantle.)*
Visual, Logical

Use Community Resources **L2**

Invite a geologist or physicist in your community to talk to the class about global positioning systems (GPS), how they work, and what they are used for. Encourage students to think about and ask questions about how GPS can be used to measure the movements of landmasses.
Verbal, Interpersonal

Facts and Figures

The continents are still moving, and eventually they will probably collide to form a single landmass again. Earth scientists predict that the continents will probably merge again somewhere in the Pacific Ocean. When will this happen? Research suggests that, based on the current rate of plate movements, a single landmass is formed about once every 500 million years. Since it has been about 200 million years since Pangaea broke up, the next supercontinent may form in a few hundred million years.

Section 9.3

1 FOCUS

Objectives

- **9.7** **Explain** how seafloor spreading and continental rifting cause formation of new lithosphere.
- **9.8** **Describe** the process of lithosphere destruction that takes place at subduction zones.
- **9.9** **Differentiate** among subduction at oceanic-continental, oceanic-oceanic, and continental-continental convergent boundaries.
- **9.10** **Describe** the action of plates at a transform fault boundary.

Reading Focus

Build Vocabulary L2

Word Parts Have students break the word *subduction* into roots, prefixes, or suffixes. They may need to use a dictionary to find the meaning of some parts. *(Subduction comes from the Latin prefix* sub-, *meaning "below" and the Latin root word* ducere, *meaning "to draw or pull." Thus, subduction means to draw or pull below.)*

Reading Strategy L2

I. Divergent Boundaries
   A. Ocean Ridges and Seafloor Spreading
   B. Continental Rifts
II. Convergent Boundaries
   A. Oceanic-Continental
   B. Oceanic-Oceanic
   C. Continental-Continental
III. Transform Fault Boundaries

Go Online NSTA SciLINKS

Download a worksheet on plate boundaries for students to complete, and find additional teacher support from NSTA SciLinks.

9.3 Actions at Plate Boundaries

Reading Focus

Key Concepts

- What is seafloor spreading?
- What is a subduction zone?

Vocabulary

- oceanic ridge
- rift valley
- seafloor spreading
- subduction zone
- trench
- continental volcanic arc
- volcanic island arc

Reading Strategy

Outlining Before you read, make an outline of this section. Use the green headings as the main topics and the blue headings as subtopics. As you read, add supporting details.

Actions at Boundaries
I. Divergent Boundaries
A. ____ ? ____
B. ____ ? ____
II. ____ ? ____

Tremendous forces are at work where tectonic plates meet. Let's take a closer look at what happens at the three types of plate boundaries.

Divergent Boundaries

Most divergent plate boundaries are located along the crests of oceanic ridges. These plate boundaries can be thought of as *constructive plate margins* because this is where new oceanic lithosphere is generated. Look again at the divergent boundary in Figure 7A on page 255. As the plates move away from the ridge axis, fractures are created. These fractures are filled with molten rock that wells up from the hot mantle below. Gradually, this magma cools to produce new slivers of seafloor. Spreading and upwelling of magma continuously adds oceanic lithosphere between the diverging plates.

Oceanic Ridges and Seafloor Spreading Along well-developed divergent plate boundaries, the seafloor is elevated, forming the **oceanic ridge**. The system of ocean ridges is the longest physical feature on Earth's surface, stretching more than 70,000 kilometers in length. This system winds through all major ocean basins like the seam on a baseball. The term *ridge* may be misleading. These features are not narrow like a typical ridge. They are 1000 to 4000 kilometers wide. Deep faulted structures called **rift valleys** are found along the axes of some segments. As you can see in Figure 9, rift valleys and spreading centers can develop on land, too.

Go Online NSTA SciLINKS

For: Links on plate boundaries
Visit: www.SciLinks.org
Web Code: cjn-3093

Spreading Center

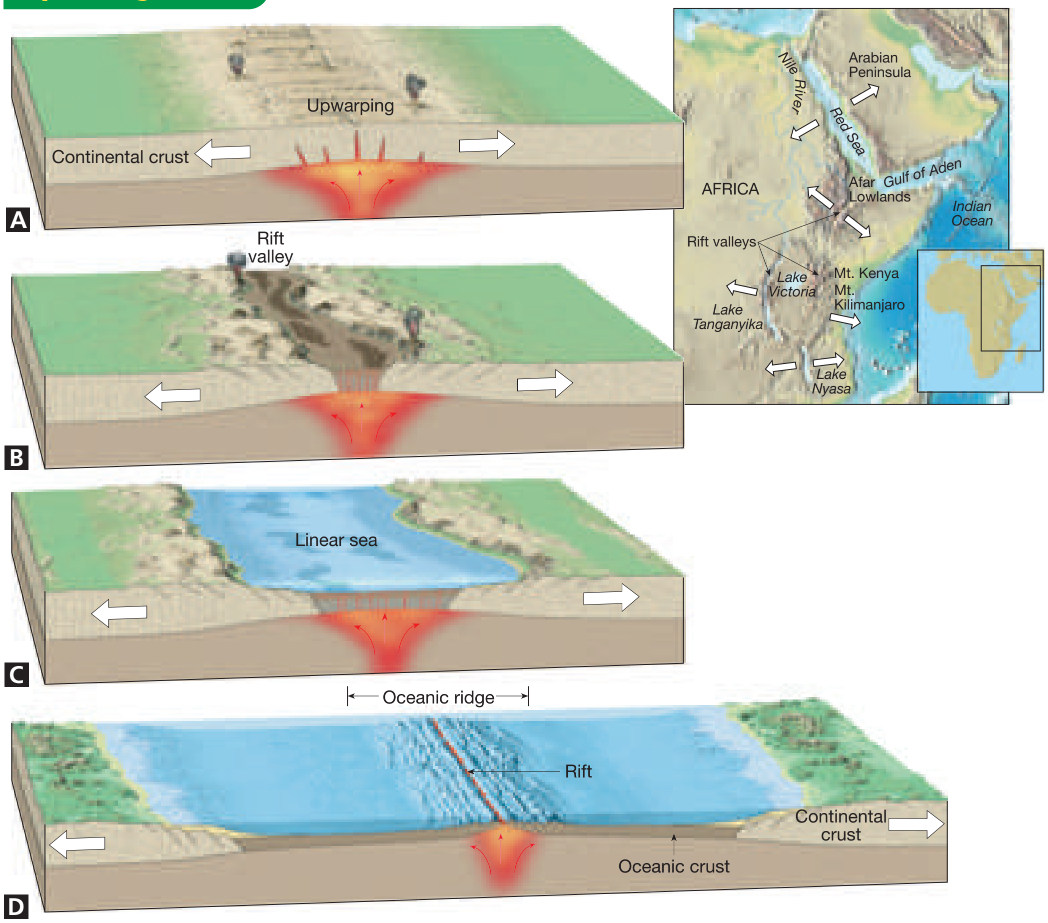


Figure 9 The East African rift valleys may represent the initial stages of the breakup of a continent along a spreading center. **A** Rising magma forces the crust upward, causing numerous cracks in the rigid lithosphere. **B** As the crust is pulled apart, large slabs of rock sink, causing a rift zone. **C** Further spreading causes a narrow sea. **D** Eventually, an ocean basin and ridge system is created.

Relating Cause and Effect ***What causes the continental crust to stretch and break?***

Seafloor spreading is the process by which plate tectonics produces new oceanic lithosphere. Typical rates of spreading average around 5 centimeters per year. These rates are slow on a human time scale. However, they are rapid enough so that all of Earth's ocean basins could have been generated within the last 200 million years. In fact, none of the ocean floor that has been dated is older than 180 million years.

2 INSTRUCT

Divergent Boundaries

Build Math Skills L1

Conversion Factors Remind students to label the units of each factor when solving the following problem. Doing this ensures that all the conversion factors are included and the answer has the correct units. Tell students that seafloor spreading occurs at an average rate of 5 cm per year. At this rate, how long would it take for a narrow sea that is 1 km wide to form? *(about 20,000 years)*
Logical

Use Visuals L1

Figure 9 Point out the rising magma in each of the diagrams. Ask: **What happens to the rising magma in the diagram?** *(It fills the cracks formed by the diverging plates.)* **Why is this process called seafloor spreading? Does the seafloor actually get thinner and spread out?** *(The seafloor does not get thinner. Rather, the seafloor spreads apart and new rock is constantly added to the ridge.)*
Visual

Build Science Skills L2

ACTIVITY

Using Models Give students two colors of modeling clay (one color for the magma and the other color for the crust) and have them model the activity that occurs at a divergent boundary.
Kinesthetic, Visual

Customize for English Language Learners

Encourage students to work in groups to brainstorm different types of boundaries. Their types of boundaries can come from other sciences, such as cell membranes, or from everyday life, such as the boundary between a sidewalk and the strip of grass between the sidewalk and the curb. Ask students what all these boundaries have in common and how they are different.

Answer to . . .

Figure 9 *The continental crust is stretched and broken by the upwarping of the crust, caused by rising magma.*

Teacher Demo

Creating a Continental Rift L2

Purpose Students will observe how fractures grow to create a continental rift as a result of the stretching of the lithosphere.

Materials 2 slices of individually wrapped American cheese, dull knife or fingernail, metric ruler

Procedure Using your fingernail or a dull knife, make a small cut in the center of a cheese slice parallel to one edge. Pull on the two cheese edges parallel to the cut. You will be pulling perpendicular to the direction of the cut. Observe how the small defect (the cut) concentrates the tearing. Observe the shape of the fracture that forms, especially the pointed tips where the tearing is taking place, and how the fracture tips move faster as the fracture gets bigger.

Now, make a cut near the center of the second piece of cheese. Make a second parallel cut about 2 cm below and 2 cm to the right of the first cut. Pull on the cheese as before. Fractures will begin to form from each of the cuts. As the tips of these fractures begin to move past each other, they will begin to curve toward each other and eventually link up into a single fracture.

Safety Do not allow students to eat the cheese.

Expected Outcome Students should infer that the fractures in the cheese are analogous to the formation of faults that result in the development of a rift valley.
Visual, Logical

Figure 10 East African Rift Valley This valley may be where the African continent is splitting apart.
Interpreting Diagrams ***What stage in the drawings on page 259 does this photograph show?***

Continental Rifts When spreading centers develop within a continent, the landmass may split into two or more smaller segments. Examples of active continental rifts include the East African rift valley and the Rhine Valley in Northwest Europe.

The most widely accepted model for continental breakup suggests that forces that are stretching the lithosphere must be acting on the plate. These stretching forces by themselves are not large enough to actually tear the lithosphere apart. Rather, the rupture of the lithosphere is thought to begin in those areas where plumes of hot rock rise from the mantle. This hot-spot activity weakens the lithosphere and creates domes in the crust directly above the hot rising plume. Uplifting stretches the crust and makes it thinner, as shown in Figure 9A. Along with the stretching, faulting and volcanism form a rift valley, as in Figure 9B

The East African rift valley, shown in Figure 10, may represent the beginning stage in the breakup of a continent. Large mountains, such as Kilimanjaro and Mount Kenya, show the kind of volcanic activity that accompanies continental rifting. If the stretching forces continue, the rift valley will lengthen and deepen, until the continent splits in two. At this point, the rift becomes a narrow sea with an outlet to the ocean, similar to the Red Sea. The Red Sea formed when the Arabian Peninsula rifted from Africa about 20 million years ago. In this way, the Red Sea provides scientists with a view of how the Atlantic Ocean may have looked in its infancy.

Reading Checkpoint *How do rifts begin to form?*

Facts and Figures

The first rift that developed as Pangaea began to break apart 200 million years ago resulted in the separation of North America and Africa. Large quantities of basalts were produced. These basalts can be found today as weathered rock beds along the eastern seaboard of the United States. They are buried beneath rocks that form the continental shelf and have been radiometrically dated as being between 200 million and 165 million years old. The rifting eventually formed the Atlantic Ocean basin.

Convergent Boundaries

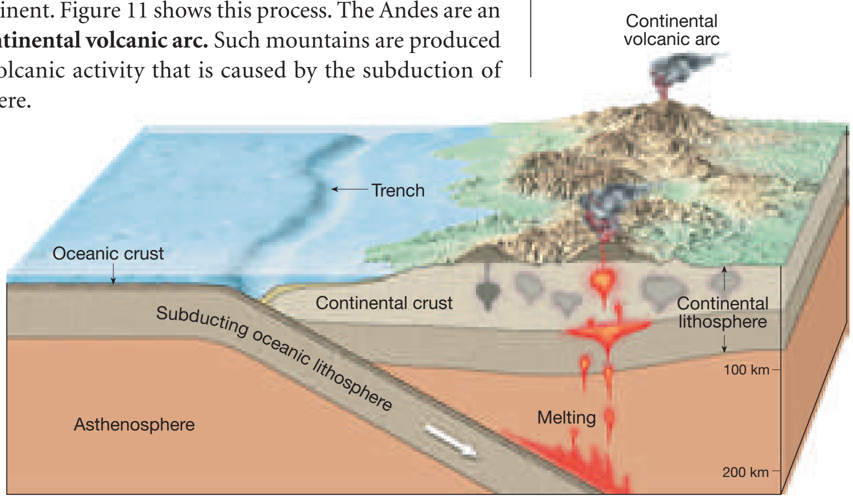
Although new lithosphere is constantly being added at the oceanic ridges, our planet is not growing larger. Earth's total surface area remains the same. How can that be? To accommodate the newly created lithosphere, older portions of oceanic plates return to the mantle along convergent plate boundaries. Because lithosphere is "destroyed" at convergent boundaries, they are also called *destructive plate margins.* As two plates slowly converge, the leading edge of one is bent downward, allowing it to slide beneath the other. Destructive plate margins where oceanic crust is being pushed down into the mantle are called **subduction zones.** The surface feature produced by the descending plate is an ocean **trench,** as shown in Figure 11. **A subduction zone occurs when one oceanic plate is forced down into the mantle beneath a second plate.**

Convergent boundaries are controlled by the type of crust involved and the forces acting on the plate. Convergent boundaries can form between two oceanic plates, between one oceanic plate and one continental plate, or between two continental plates.

Oceanic-Continental When the leading edge of a continental plate converges with an oceanic plate, the less dense continental plate remains floating. The denser oceanic slab sinks into the asthenosphere. When a descending plate reaches a depth of about 100 to 150 kilometers, some of the asthenosphere above the descending plate melts. The newly formed magma, being less dense than the rocks of the mantle, rises. Eventually, some of this magma may reach the surface and cause volcanic eruptions.

The volcanoes of the Andes, located along western South America, are the product of magma generated as the Nazca plate descends beneath the continent. Figure 11 shows this process. The Andes are an example of a **continental volcanic arc.** Such mountains are produced in part by the volcanic activity that is caused by the subduction of oceanic lithosphere.

Figure 11 Oceanic-Continental Convergent Boundary Oceanic lithosphere is subducted beneath a continental plate.
Inferring ***Why doesn't volcanic activity occur closer to the trench?***



Convergent Boundaries

Build Reading Literacy L1

Refer to **p. 420D** in **Chapter 15**, which provides the guidelines for this predicting strategy.

Predict Have students read the section on p. 260 about continental rifts. Ask: **Predict what a rift valley might look like if it stopped developing.** *(The valley would probably be filled with ancient volcanic rocks that formed from the magma that rose to the surface.)*
Logical

Use Visuals L1

Figure 11 Have students study the diagram showing an oceanic-continental convergent boundary. Ask: **Which plate is subducted? Which plate floats?** *(The oceanic plate is subducted. The continental plate floats.)* **Why do the two plates in the diagram always move the way they do?** *(The oceanic plate is denser than the continental plate, so it slides under the continental plate and sinks into the asthenosphere.)*
Visual, Logical

Answer to . . .

Figure 10 *Large slabs of rock sink, causing a rift zone.*

Figure 11 *The plate doesn't get deep enough for melting to occur until farther from the trench.*

Reading Checkpoint *Rifts begin when the lithosphere is stretched and a plume of hot rock from the mantle weakens and then splits the lithosphere.*

Address Misconceptions
L2

A commonly held misconception is that the volcanoes in a volcanic island arc are interconnected and that an eruption of one volcano in the arc will trigger eruptions in all the volcanoes. Draw a cross-sectional diagram similar to Figure 12. Show a separate magma chamber for each volcano in the arc.
Visual

Use Visuals
L1

Figure 12 Have students study the diagram showing an oceanic-oceanic convergent boundary. Ask: **How is an oceanic-oceanic convergent boundary different from an oceanic-continental convergent boundary?** *(Volcanoes form on the ocean floor in an oceanic-oceanic boundary rather than on Earth's surface.)* **What is formed by sustained volcanic activity at an oceanic-oceanic convergent boundary?** *(an island chain, called a volcanic island arc)*
Visual, Verbal

Use Visuals
L1

Figure 13 Have students study the diagram showing a continental-continental convergent boundary. Ask: **Why isn't the continental lithosphere subducted far into the asthenosphere in this diagram?** *(The continental lithosphere is buoyant and does not sink into the asthenosphere to a great depth.)* **Why aren't volcanoes formed in a continental-continental convergent boundary?** *(Because molten magma that forms down deep is unable to rise all the way to the tops of the mountains. The magma cools within the cores of the mountains to form large granitic plutons.)*
Visual, Verbal

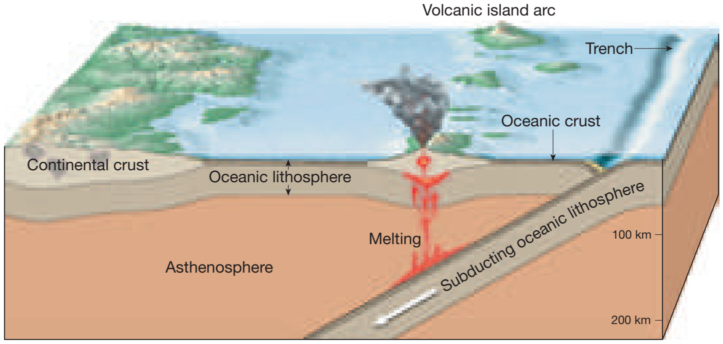


Figure 12 Oceanic-Oceanic Convergent Boundary One oceanic plate is subducted beneath another oceanic plate, forming a volcanic island arc. **Predicting** ***What would happen to the volcanic activity if the subduction stopped?***

Oceanic-Oceanic When two oceanic slabs converge, one descends beneath the other. This causes volcanic activity similar to what occurs at an oceanic-continental boundary. However, the volcanoes form on the ocean floor instead of on a continent, as shown in Figure 12. If this activity continues, it will eventually build a chain of volcanic structures that become islands. This newly formed land consisting of an arc-shaped chain of small volcanic islands is called a **volcanic island arc.** The Aleutian Islands off the shore of Alaska are an example of a volcanic island arc. Next to the Aleutians is the Aleutian trench.

Continental-Continental When an oceanic plate is subducted beneath continental lithosphere, a continental volcanic arc develops along the margin of the continent. However, if the subducting plate also contains continental lithosphere, the subduction eventually brings the two continents together, as shown in Figure 13. Continental lithosphere is buoyant, which prevents it from being subducted to any great depth. The result is a collision between the two continents, which causes the formation of complex mountains such as the Himalayas in South Asia.

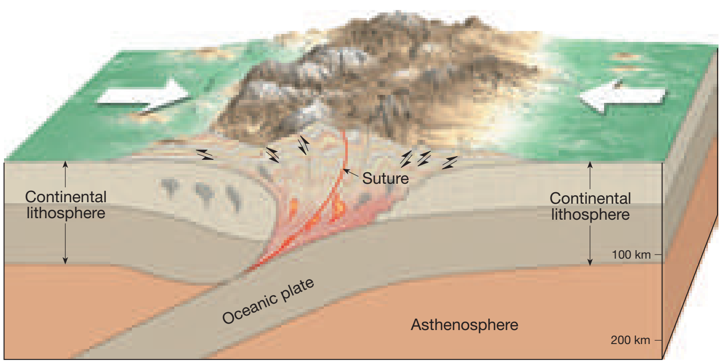


Figure 13 Continental-Continental Convergent Boundary Continental lithosphere cannot be subducted because it floats. The collision of two continental plates forms mountain ranges.

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Facts and Figures

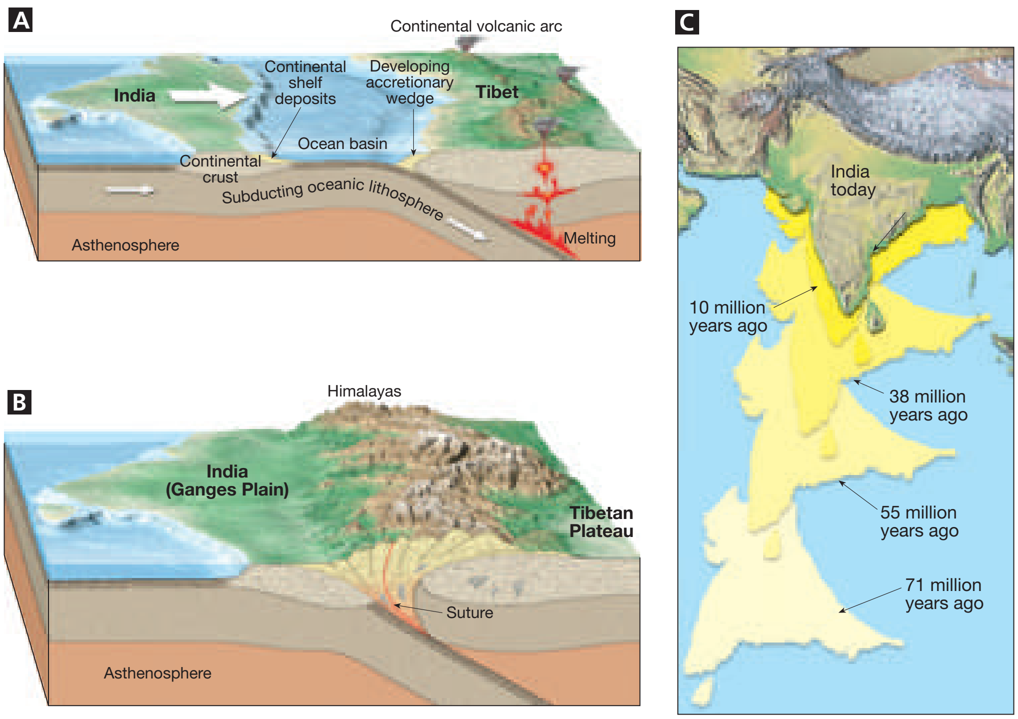
Only two volcanic island arcs are located in the Atlantic Ocean—the Lesser Antilles adjacent to the Caribbean Sea and the Sandwich Islands in the South Atlantic. There have been many volcanic eruptions in the Lesser Antilles. In 1902 on the island of Martinique, Mount Pelé erupted, killing 28,000 people and destroying the town of St. Pierre. More recently, the Soufriere Hills Volcano on the island of Montserrat erupted from 1995 until 1997. Although volcanic activity has since decreased, seismic activity has increased. There were several earthquakes on Montserrat in early 2004.

Before continents collide, the landmasses involved are separated by an ocean basin. As the continents move toward each other, the seafloor between them is subducted beneath one of the plates. When the continents collide, the collision folds and deforms the sediments along the margin as if they were placed in a giant vise. A new mountain range forms that is composed of deformed and metamorphosed sedimentary rocks, fragments of the volcanic arc, and possibly slivers of oceanic crust.

This kind of collision occurred when the subcontinent of India rammed into Asia and produced the Himalayas, as shown in Figure 14. During this collision, the continental crust buckled and fractured. Several other major mountain systems, including the Alps, Appalachians, and Urals, were also formed as a result of continental collisions.

Figure 14 **A** The leading edge of the plate carrying India is subducted beneath the Eurasian plate. **B** The landmasses collide and push up the crust. **C** India's collision with Asia continues today.

Collision of India and Asia



Build Science Skills

L2

Using Analogies The discussion on this page uses an analogy of a giant vise to help students visualize and understand what happens to the lithosphere during a continental-continental collision. Be sure students understand what a vise is. *(a tool that holds an object by squeezing two plates together, usually by turning a large screw)* If they are not familiar with the term, have them look it up in a dictionary, or have another student describe it. Revisit the text and discuss why the analogy is useful. *(A squeezing vise could fold and deform material as colliding continents fold and deform rock)* Ask: **What other analogies might be used to describe continental-continental collisions?** *(Sample answers: small entry rug crumpling as it gets caught between an opening door and a wall, two cars colliding)*
Intrapersonal, Logical

Facts and Figures

The Himalayas include the highest mountains on Earth. When India and Asia collided, the leading edge of the Indian plate was forced partially under Asia, generating an unusually great thickness of continental lithosphere. This accumulation accounts in part for the high elevation of the Himalayas and may also explain the elevated Tibetan Plateau to the north.

Answer to . . .

Figure 12 *If the subduction stopped, the volcanic activity would probably also soon stop because the source of new magma is the continuing subduction of the oceanic plate.*

Section 9.3 (continued)

Transform Fault Boundaries

Build Science Skills L2

Relating Cause and Effect Remind students that plates in a transform fault boundary move past each other without production or destruction of lithosphere. Ask: **Why does this movement cause earthquakes?** *(The tremendous friction caused by two plates grinding past each other causes earthquakes.)*
Logical

3 ASSESS

Evaluate Understanding L2

To assess students' knowledge of section content, have them write three short paragraphs describing the three convergent boundaries and what results when they converge.

Reteach L1

Have students demonstrate the action of the three convergent boundaries by using their hands to represent the converging plates.

Writing in Science

Answers should be accurate and show an understanding of the process of rifting at a divergent plate boundary.

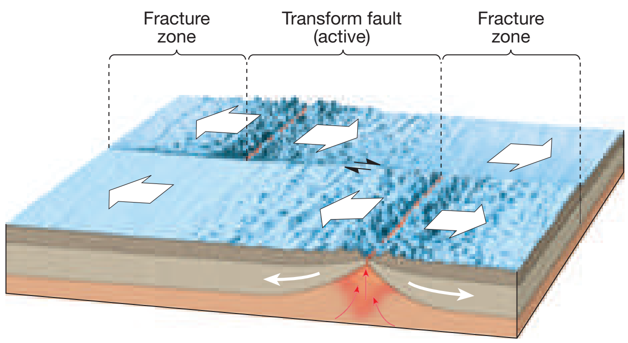


Figure 15 A transform fault boundary offsets segments of a divergent boundary at an oceanic ridge.

Transform Fault Boundaries

The third type of plate boundary is the transform fault boundary. **At a transform fault boundary, plates grind past each other without destroying the lithosphere.** Most transform faults join two segments of a mid-ocean ridge, as shown in Figure 15. These faults are present about every 100 kilometers along the ridge axis. Active transform faults lie between the two offset ridge segments. The seafloor produced at one ridge axis moves in the opposite direction as seafloor is produced at an opposing ridge segment. So between the ridge segments these slabs of oceanic crust are grinding past each other along a transform fault.

Although most transform faults are located within the ocean basins, a few cut through the continental crust. One example is the San Andreas Fault of California. Along the San Andreas, the Pacific plate is moving toward the northwest, past the North American plate. If this movement continues, that part of California west of the fault zone will become an island off the west coast of the United States and Canada. It could eventually reach Alaska. However, a more immediate concern is the earthquake activity triggered by movements along this fault system.

Section 9.3 Assessment

Reviewing Concepts

1. What is seafloor spreading?
2. What is a subduction zone? What types of plate boundaries have subduction zones?
3. Describe the process that occurs when continents converge.
4. What actions of plate boundaries cause the destruction of the lithosphere?

Critical Thinking

5. **Drawing Conclusions** What evidence supports the idea that the Earth is neither growing nor shrinking in size?
6. **Relating Cause and Effect** During the collision between two continents, why doesn't a subduction zone form?
7. **Predicting** How will the angle at which an oceanic plate is subducted affect the distance from the volcanic arc to the trench?

Writing in Science

Creative Writing Write a paragraph that describes the rifting apart of a continent to form a new ocean. The paragraph should be written from the point of view of a person witnessing the events.

Section 9.3 Assessment

1. Seafloor spreading is the creation of new seafloor at oceanic ridges.
2. Subduction zones occur at deep-ocean trenches where slabs of oceanic lithosphere are descending into the mantle. Subduction zones are associated with convergent boundaries, either oceanic-oceanic or oceanic-continental.
3. two continental plates collide with each other, forming a mountain range
4. Lithosphere is destroyed at convergent boundaries in subduction zones.
5. the evidence that the production and destruction of the lithosphere is going on at about the same rate.
6. Continental lithosphere floats and can't be forced down into the mantle at a subduction zone.
7. The higher the angle of subduction, the closer the volcanic arc will be to the trench. If the angle is shallow, the volcanic arc will be located farther behind the trench because the descending plate doesn't reach a depth where melting occurs until farther from the trench.

9.4 Testing Plate Tectonics

Reading Focus

Key Concepts

- What evidence supports the theory of plate tectonics?
- How does paleomagnetism support the theory of plate tectonics?

Vocabulary

- paleomagnetism
- normal polarity
- reverse polarity
- hot spot

Reading Strategy

Predicting Copy the table. Write a prediction of where earthquakes will occur. After you read, if your prediction was incorrect or incomplete, write where earthquakes actually occur.

Probable Locations	Actual Locations
a. ?	b. ?

Evidence for Plate Tectonics

With the birth of the plate tectonics model, researchers from all of the Earth sciences began testing it. You have already seen some of the evidence supporting continental drift and seafloor spreading. Additional evidence for plate tectonics came as new technologies developed.

Paleomagnetism If you have ever used a compass to find direction, you know that the magnetic field has a north pole and a south pole. These magnetic poles align closely, but not exactly, with the geographic poles.

In many ways, Earth's magnetic field is much like that produced by a simple bar magnet. Invisible lines of force pass through Earth and extend from one pole to the other. A compass needle is a small magnet that is free to move about. The needle aligns with these invisible lines of force and points toward the magnetic poles.

Certain rocks contain iron-rich minerals, such as magnetite. When heated above a certain temperature, these magnetic minerals lose their magnetism. However, when these iron-rich mineral grains cool down, they become magnetized in the direction parallel to the existing magnetic field. Once the minerals solidify, the magnetism they possess stays frozen in this position. So magnetized rocks behave much like a compass needle because they point toward the existing magnetic poles. If the rock is moved or if the magnetic pole changes position, the rock's magnetism retains its original alignment. Rocks formed millions of years ago thus show the location of the magnetic poles at the time of their formation, as shown in Figure 16. These rocks possess **paleomagnetism.**

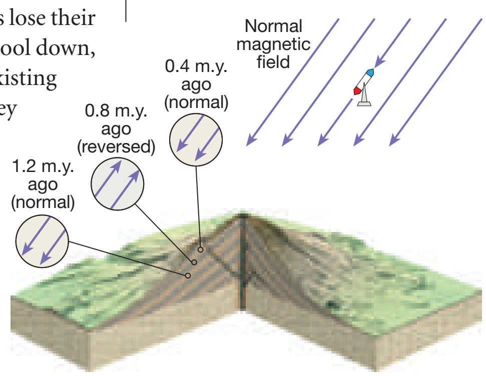


Figure 16 Paleomagnetism Preserved in Lava Flows As the lava cools, it becomes magnetized parallel to the magnetic field present at that time. When the polarity randomly reverses, a record of the paleomagnetism is preserved in the sequence of lava flows.

Section 9.4

1 FOCUS

Section Objectives

9.11 **Explain** how paleomagnetism and magnetic reversals provide evidence that supports the theory of plate tectonics.

9.12 **Evaluate** how earthquakes, ocean drilling, and hot spots provide evidence that supports the theory of plate tectonics.

Reading Focus

Build Vocabulary L2

Word Parts Have students break the vocabulary term paleomagnetism into roots, prefixes, or suffixes. Students may need to use a dictionary to find the meanings of some parts. (Paleo- *is a combination form of the Greek word palaios meaning "ancient." The word magnetism comes from the Greek root words* Magnes (lithos), *literally meaning a stone of Magnesia, an ancient city in Asia Minor.)*

Reading Strategy L2

a. at convergent plate boundaries
b. at all plate boundaries

2 INSTRUCT

Evidence for Plate Tectonics

Integrate Biology L2

Birds and Magnetism Tell students that birds use Earth's magnetic field to locate places to stop and eat along their migration route. In addition, the birds use Earth's magnetic field to navigate. They read the angle at which magnetic fields enter the ground and thus determine their latitude relative to the magnetic poles. Ask: **Why is it so important for birds to locate food sources?** *(The location of these places is critical because birds must have large quantities of food to provide energy during their long migrations.)*
Verbal, Logical

Teacher Demo

Testing Minerals for Magnetism L1

Purpose Students test various minerals with a magnet to determine whether they have magnetic properties.

Materials magnet, minerals (include at least one sample of a mineral that contains iron or cobalt), compass

Procedure Have students test the mineral samples with the magnet to see if they are attracted by it. Have students place the compass near each mineral sample to see if the needle moves. If it does, the material is magnetic.

Expected Outcomes Minerals that contain iron or cobalt, such as lodestone, have magnetic properties. Meteorites also have magnetic properties.
Kinesthetic, Visual

Use Visuals L1

Figure 17 Have students study the figure. Ask: **Could the rocks in a strip possessing reverse polarity ever possess normal polarity?** *(No, once the rocks solidify, their polarity is permanently set.)* **How do you think the width of a strip relates to the seafloor spreading rate?** *(The faster the spreading rate is, the wider the strip will be.)*
Visual, Logical

Polarity of Ocean Crust

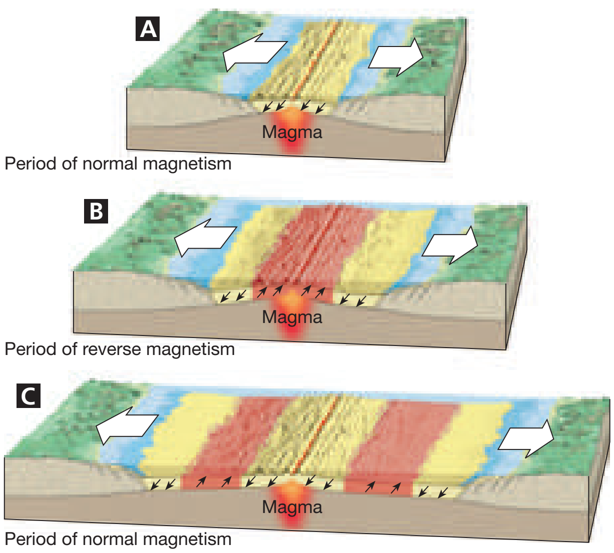


Figure 17 A As new material is added to the ocean floor at the oceanic ridges, it is magnetized according to Earth's existing magnetic field. **B** This process records each reversal of Earth's magnetic field. **C** Because new rock is added in approximately equal amounts to the trailing edges of both plates, strips of equal size and polarity parallel both sides of the ocean ridges. **Applying Concepts** ***Why are the magnetized strips about equal width on either side of the ridge?***

Geophysicists learned that Earth's magnetic field periodically reverses polarity. The north magnetic pole becomes the south magnetic pole, and vice versa. A rock solidifying during one of the periods of reverse polarity will be magnetized with the polarity opposite that of rocks being formed today.

When rocks show the same magnetism as the present magnetic field, they are described as having **normal polarity.** Rocks that show the opposite magnetism are said to have **reverse polarity.** A relationship was discovered between the magnetic reversals and the seafloor-spreading hypothesis. Ships towed instruments called magnetometers across segments of the ocean floor. This research revealed alternating strips of high- and low-intensity magnetism that ran parallel to the ridges. The strips of high-intensity magnetism are regions where the paleomagnetism of the ocean crust is of the normal type. These positively magnetized rocks enhance the existing magnetic field. The low-intensity strips represent regions where the ocean crust is polarized in the reverse direction and, therefore, weaken the existing magnetic field. As new basalt is added to the ocean floor at the oceanic ridges, it becomes magnetized according to the existing magnetic field, as shown in Figure 17. **The discovery of strips of alternating polarity, which lie as mirror images across the ocean ridges, is among the strongest evidence of seafloor spreading.**

Earthquake Patterns **Scientists found a close link between deep-focus earthquakes and ocean trenches. Also, the absence of deep-focus earthquakes along the oceanic ridge system was shown to be consistent with the new theory.**

Compare the distribution of earthquakes shown in Chapter 8 on page 226 with the map of plate boundaries on pages 256–257. The close link between plate boundaries and earthquakes is obvious. When the depths of earthquake foci and their locations within the trench systems are plotted, a pattern emerges.

Customize for English Language Learners

Explain to students that there are many uses of the term *polar*, both in science and in everyday usage. For example, in magnetism, polarity refers to the magnetic poles. In chemistry, polar molecules have partial charges. Polar also means diametrically opposite. Have students look up the various meanings of the term *polar* and use each meaning in a sentence.

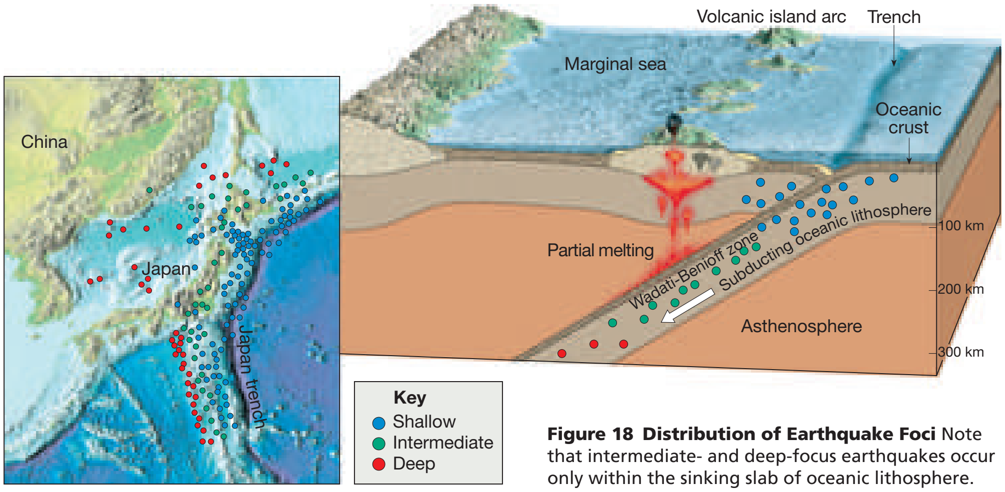


Figure 18 Distribution of Earthquake Foci Note that intermediate- and deep-focus earthquakes occur only within the sinking slab of oceanic lithosphere.

Look at Figure 18. It shows the distribution of earthquakes near the Japan trench. Here, most shallow-focus earthquakes occur within or adjacent to the trench. Intermediate- and deep-focus earthquakes occur toward the mainland.

In the plate tectonics model, deep-ocean trenches are produced where cool, dense slabs of oceanic lithosphere plunge into the mantle. Shallow-focus earthquakes are produced as the descending plate interacts with the lithosphere above it. As the slab descends farther into the mantle, deeper-focus earthquakes are produced. No earthquakes have been recorded below 700 kilometers. At this depth, the slab has been heated enough to soften.

Ocean Drilling Some of the most convincing evidence confirming the plate tectonics theory has come from drilling directly into ocean-floor sediment. The Deep Sea Drilling Project from 1968 to 1983 used the drilling ship *Glomar Challenger* to drill hundreds of meters into the sediments and underlying crust.

When the oldest sediment from each drill site was plotted against its distance from the ridge crest, it was revealed that the age of the sediment increased with increasing distance from the ridge. **The data on the ages of seafloor sediment confirmed what the seafloor-spreading hypothesis predicted. The youngest oceanic crust is at the ridge crest and the oldest oceanic crust is at the continental margins.**

The data also reinforced the idea that the ocean basins are geologically young. No sediment older than 180 million years was found. By comparison, some continental crust has been dated at 4.0 billion years.

Build Science Skills L2

Interpreting Diagrams Have students study Figure 18. Ask:

- **From the map, identify the direction in which the sinking slab of oceanic lithosphere is moving.** *(from right to left)*
- **Locate Korea on the map. Why do you think Korea has relatively few earthquakes compared to Japan?** *(Korea is located far from ocean trenches; Japan is close to a trench.)*
- **What pattern does the map show?** *(Deeper earthquakes occur farther from the trench.)* Be sure students can distinguish the blue dots from the green dots.
- **What can geologists learn from this pattern?** *(They can use the plotted foci to track the plate's descent into the mantle.)*

Visual, Logical

Facts and Figures

During its 15 years of operation, the *Glomar Challenger* drilled 1092 holes and obtained more than 96 km of invaluable core samples. The Ocean Drilling Program has succeeded the Deep Sea Drilling Project and, like its predecessor, is a major international program. A more technologically advanced drilling ship, the *JOIDES Resolution*, now continues the work of the *Glomar Challenger*.

Answer to . . .

Figure 17 *Both sides of the ocean plate are moving away from the ridge at equal rates, so the magnetized strips will be about equal in width.*

Section 9.4 (continued)

Build Reading Literacy L1

Refer to **p. 530D** in **Chapter 19**, which provides the guidelines for making inferences.

Making Inferences Have students read the section about hot spots on this page. Ask: **What can you infer about a hot spot from the description of how the islands in a volcanic island arc form at different times by the hot spot?** *(You can infer that the hot spot is relatively stationary with respect to the mantle, and so moves relative to the plate. If it moved along with the plate, a line of islands would not have formed.)*
Verbal, Intrapersonal

3 ASSESS

Evaluate Understanding L2

To assess students' knowledge of section content, have them make flashcards for the vocabulary terms and the four lines of evidence supporting the plate tectonic theory. For each vocabulary term, the card should include a definition and an example, where applicable. For each line of evidence, the card should give an explanation of why it supports the theory and include an example. Students can use the cards to quiz one another.

Reteach L1

Have students explain in their own words why data produced by drilling into ocean-floor sediment supports the tectonic plate theory.

Writing In Science

The age of the seafloor increases with increasing distance from the spreading center at an ocean ridge. The theory of seafloor spreading states that new ocean lithosphere is created at ocean ridges, so the ocean floor should be younger closer to the ridges and older farther from the ridge.

Answer to . . .

Figure 19 *A new Hawaiian island will form to the southeast of the island of Hawaii.*

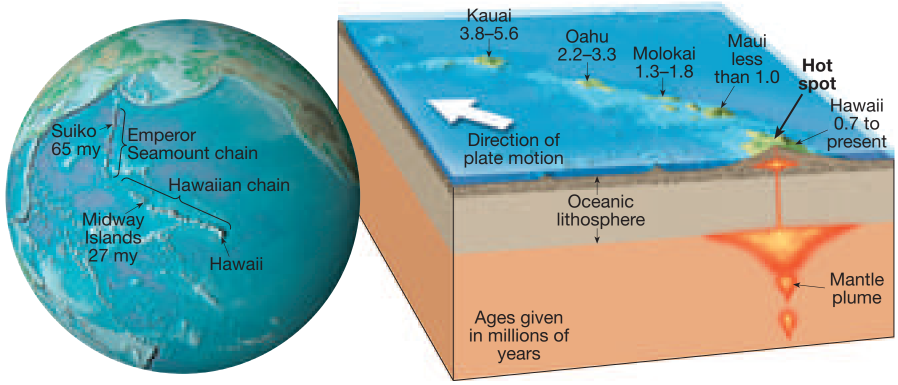


Figure 19 Hot Spot The chain of islands and seamounts that extends from Hawaii to the Aleutian trench results from the movement of the Pacific plate over a stationary hot spot. **Predicting** ***Where will a new Hawaiian island be located?***

Hot Spots Mapping of seafloor volcanoes in the Pacific revealed a chain of volcanic structures extending from the Hawaiian Islands to Midway Island and then north to the Aleutian trench, as shown in Figure 19. Dates of volcanoes in this chain showed that the volcanoes increase in age with increasing distance from Hawaii. Suiko Seamount is 65 million years old. Midway Island is 27 million years old. The island of Hawaii formed less than a million years ago and is still forming today.

A rising plume of mantle material is located below the island of Hawaii. Melting of this hot rock as it nears the surface creates a volcanic area, or **hot spot.** As the Pacific plate moves over the hot spot, successive volcanic mountains have been created. The age of each volcano indicates the time when it was situated over the hot spot. Kauai is the oldest of the large islands in the Hawaiian chain. Its volcanoes are extinct. The youthful island of Hawaii has two active volcanoes—Mauna Loa and Kilauea. **Hot spot evidence supports the idea that the plates move over Earth's surface.**

Section 9.4 Assessment

Reviewing Concepts

1. List and describe the evidence for the plate tectonics theory.
2. Define the term *paleomagnetism.*
3. What is the age of the oldest ocean crust? How do the ages of the ocean crust compare to the age of continental rocks?
4. What is a hot spot?

Critical Thinking

5. **Applying Concepts** How do hot spots and the plate tectonics theory account for the different ages of the Hawaiian Islands?
6. **Predicting** Would earthquakes occur at depths of over 700 kilometers? Why or why not?

Writing In Science

Explanatory Paragraph Write a paragraph explaining why the age pattern of the ocean floor supports seafloor spreading.

Section 9.4 Assessment

1. paleomagnetism: iron-rich minerals in rocks line up with the magnetic field at the time they cool; earthquake patterns: earthquake foci are concentrated at plate boundaries; ocean drilling: the age of the ocean lithosphere was found from drilling; hot spots: the location of hot mantle plumes shows plate motion.
2. Paleomagnetism is the natural magnetism in rocks, which was acquired from Earth's magnetic field at the time the rock formed.
3. The oldest ocean crust is about 180 million years old. Some continental rocks are about 3.9 billion years old.
4. an area where a plume of hot mantle material rises up and causes volcanic activity
5. Hot spots are relatively stationary plumes of hot rock from the mantle. As a plate moves over a hot spot, the hot material causes volcanic activity. The previously formed volcanoes become extinct and increase in age as the distance from the hot spot (and the active volcanic activity) increases.
6. No, below 700 km the plates are no longer rigid enough.

9.5 Mechanisms of Plate Motion

Reading Focus

Key Concepts

- What are the mechanisms of plate motion?
- What causes plate motion?

Vocabulary

- convective flow
- slab-pull
- ridge-push
- mantle plume

Reading Strategy

Identifying Main Ideas Copy the table. As you read, write the main ideas for each topic.

Topic	Main Idea
Slab-pull	a. ___?___
Ridge-push	b. ___?___
Mantle convection	c. ___?___

Causes of Plate Motion

Scientists generally agree that convection occurring in the mantle is the basic driving force for plate movement. During convection, warm, less dense material rises and cooler, denser material sinks. The motion of matter resulting from convection is called **convective flow.** The slow movements of the plates and mantle are driven by the unequal distribution of Earth's heat. The heat is generated by the radioactive decay of elements, such as uranium, found within Earth's mantle and crust.

Slab-Pull and Ridge-Push Several mechanisms produce forces that cause plate motion. One mechanism, called **slab-pull,** occurs because old oceanic crust, which is relatively cool and dense, sinks into the asthenosphere and "pulls" the trailing lithosphere along. **Slab-pull is thought to be the primary downward arm of convective flow in the mantle.** By contrast, **ridge-push** results from the elevated position of the oceanic ridge system. **Ridge-push causes oceanic lithosphere to slide down the sides of the oceanic ridge.** The downward slide is the result of gravity acting on the oceanic lithosphere. Ridge-push, although active in some spreading centers, is probably less important than slab-pull.

Mantle Convection Most models suggest that hot plumes of rock are the upward flowing arms in mantle convection. These rising **mantle plumes** sometimes show themselves on Earth's surface as hot spots and volcanoes.

Section 9.5

1 FOCUS

Section Objectives

9.13 **Compare** the mechanisms of slab-pull and ridge-push as contributing to plate motion.

9.14 **Relate** the unequal distribution of heat in Earth and the mechanism of mantle convection to the movement of tectonic plates.

Reading Focus

Build Vocabulary L2

Paraphrase Have students explain, in their own words, the meaning of the new vocabulary terms in this section. Since each term contains an "action-type" word (*pull*, *push*, *plume*, *convection*), students should be able to form mental images to help with their explanations.

Reading Strategy L2

a. mechanism of plate motion in which the descending slab pulls on the plate
b. mechanism of plate motion in which the force of new crust formed at the high ridges pushes on the plate
c. the major mechanism of plate motion as the upward flow of hot, less dense mantle material and the downward flow of cold, dense material drives plate tectonics

2 INSTRUCT

Causes of Plate Motion

Build Science Skills L2

Using Models Challenge students to use their hands, phone books, or other objects to model slab-pull and ridge-push. Have them explain the processes as they manipulate the model.
Verbal, Kinesthetic

Section 9.5 (continued)

Use Visuals L1

Figure 20 Have students study the figure. Ask: **At what type of boundary does upward convective movement occur?** *(divergent)* **At what type of boundary does downward convective movement occur?** *(convergent)*

3 ASSESS

Evaluate Understanding L2

To assess students' knowledge of section content, have them write a short paragraph explaining convection. Paragraphs should include the cause of convection currents and the movements that occur.

Reteach L1

Demonstrate convection as follows: Heat a beaker of water on a hot plate. When the water is hot, add an ice cube to the water near the edge of the beaker. Drop a few drops of food coloring next to the ice cube. Students will be able to watch the food coloring move through the water by convection.

Connecting Concepts

It would provide the missing mechanism that causes the continents to move.

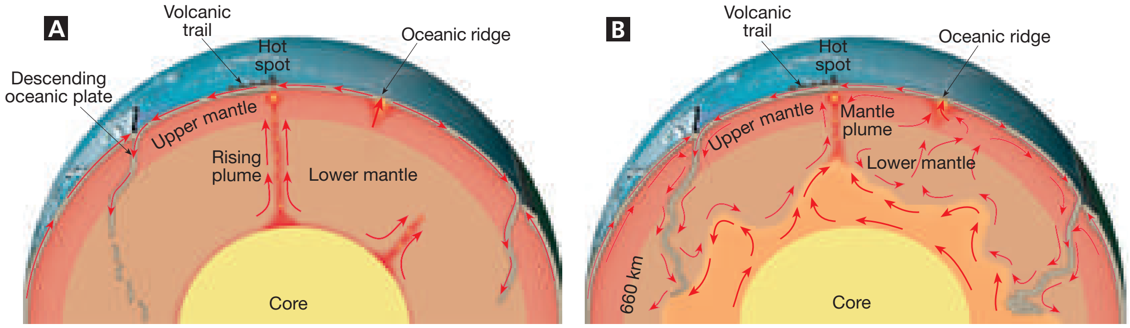


Figure 20 Mantle Convection Models A In the whole-mantle convection model, cold oceanic lithosphere descends into the mantle. Hot mantle plumes transport heat toward the surface. **B** The deep-layer model suggests that Earth's heat causes these layers of convection to slowly swell and shrink in complex patterns. Some material from the lower layer flows upward as mantle plumes.

One recent model is called whole-mantle convection. In this model, slabs of cold oceanic lithosphere descend into the lower mantle. This process provides the downward arm of convective flow, as shown in Figure 20A. At the same time, hot mantle plumes originating near the mantle-core boundary move heat toward the surface. Another model is the deep-layer model. You might compare this model to a lava lamp on a low setting. As shown in Figure 20B, the lower mantle is like the colored fluid in the bottom layer of a lava lamp. Like a lava lamp, heat from Earth's interior causes the two layers to slowly swell and shrink in complex patterns without much mixing. A small amount of material from the lower layer flows upward as mantle plumes, creating hot-spot volcanism at the surface.

There is still much to be learned about the mechanisms that cause plates to move. But one thing is clear. **The unequal distribution of heat within Earth causes the thermal convection in the mantle that ultimately drives plate motion.** Exactly how this convection operates is still being debated.

Section 9.5 Assessment

Reviewing Concepts

1. Describe the mechanisms of plate motion.
2. What drives the slow movement of the plates and the convection in the mantle?
3. What is the main source of heat in Earth's interior?

Critical Thinking

4. **Relating Cause and Effect** How is the theory of plate tectonics related to the radioactive decay of elements within Earth's interior?
5. **Calculating** If Africa and Australia are moving apart at a rate of 4.4 centimeters per year, approximately how long will it take for the ocean between the two continents to increase by 1000 kilometers?

Connecting Concepts

Heat Flow Review Section 9.1. How would the flow of heat generated by radioactive decay benefit the theory of continental drift?

Section 9.5 Assessment

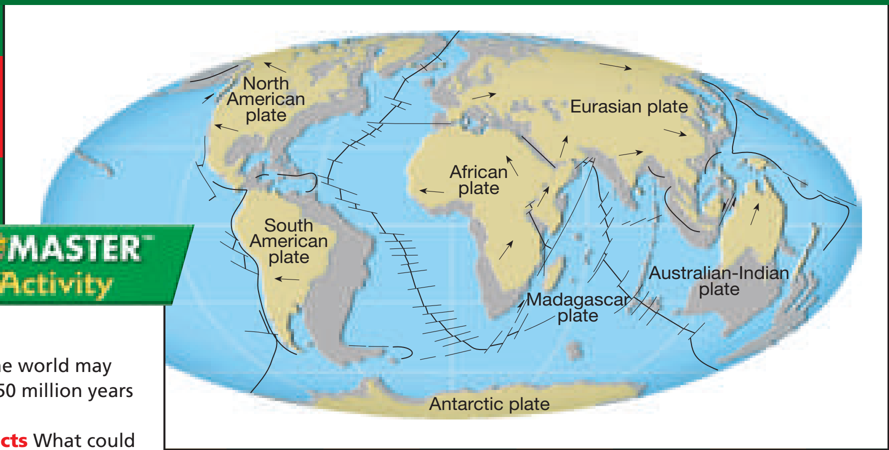
1. slab-pull: force where the descending slab pulls on the plate; ridge-push: force of gravity causing the cold lithosphere to move away from the ridge by sliding down over the asthenosphere, which gets more elevated toward the ridge; mantle convection: motion caused by flow of hot, less-dense material upwards and cold, more-dense material downward
2. the unequal distribution of heat within Earth's interior drives plate motions
3. heat generated by radioactive decay of elements in Earth's interior
4. If radioactive decay stopped, no additional heat would be generated within Earth's interior. This heat drives the mantle convection that is the driving mechanism for plate tectonics, so plate motion would gradually stop.
5. approximately 23 million years

understanding EARTH

Plate Tectonics into the Future

Two geologists, Robert Dietz and John Holden, used present-day plate movements to predict the locations of landmasses in the future. The map below shows where they predict Earth's landmasses will be 50 million years from now if plate movements remain at their present rates.

Future Continent Positions



MAP MASTER™ Skills Activity

Figure 21

Location The world may look like this 50 million years from now.

Identify Effects What could happen to Los Angeles and San Francisco if this proposed movement occurs?

L.A. on the Move

In North America, the Baja Peninsula and the portion of southern California that lies west of the San Andreas Fault will have slid past the North American plate. If this northward motion takes place, Los Angeles and San Francisco will pass each other in about 10 million years. In about 60 million years Los Angeles will begin to descend into the Aleutian trench.

New Sea in Africa

Major changes are seen in Africa, where a new sea emerges as East Africa is ripped away from the mainland. In addition, Africa will have moved slowly into Europe, perhaps creating the next major mountain-building stage on Earth. Meanwhile, the Arabian Peninsula continues to move away from Africa, allowing the Red Sea to widen and close the Persian Gulf.

Atlantic Ocean Grows

In other parts of the world, Australia will be located across the equator and, along with New Guinea, will be on a collision course with Asia. Meanwhile, North and South America will begin to separate, while the Atlantic and Indian oceans will continue to grow as the Pacific Ocean shrinks.

These projections into the future, although interesting, must be viewed with caution because many assumptions must be correct for these events to occur. We can be sure that large changes in the shapes and positions of continents will occur for millions of years to come.

understanding EARTH

Plate Tectonics into the Future L2

MAP MASTER™ Skills Activity

Answer

Identify Effects The cities could have a change in climate as they move north. They may also undergo damage from earthquakes associated with the movement.

Background

Robert Dietz began his career as a marine geologist. He was an early proponent of continental drift and of seafloor spreading, which he named. Much of his early work was conducted in submersibles off the coast of California. John Holden was Dietz's colleague and his illustrator.

Teaching Tip

Have students cut out outlines of the continents and place them on a piece of white poster paper in their current locations. As students read each paragraph of the feature, they should move the continents to their predicted location. When they finish reading the feature, ask students to write a short paragraph describing how plant and animal life would be different on the continents in their new positions. For example, tropical vegetation in southern California would be replaced with plant life that could exist in an Arctic climate.

Verbal, Kinesthetic

Section 10.1

1 FOCUS

Section Objectives

10.1 **Explain** the factors that determine the type of volcanic eruptions that occur.

10.2 **Describe** the various types of volcanic materials that are ejected from volcanoes.

10.3 **List** the three main types of volcanoes.

10.4 **Distinguish** how the different types of volcanic landforms form.

Reading Focus

Build Vocabulary L2

Word Parts Explain to students that the prefix *pyro-* is Latin and Greek for "fire" or "heat." *Clastic* means "made from fragments of preexisting rocks." Pyroclastic materials are hot fragments of preexisting rocks that are blown from the vent of a volcano.

Reading Strategy L2

a. viscosity and dissolved gases
b. What are the types of volcanic materials? lava flows; pyroclastic material, such as ash; volcanic gases
c. What are the types of volcanoes? shield volcanoes, cinder cones, composite cones
d. What are some other volcanic landforms? calderas, pipes, lava plateaus

2 INSTRUCT

Use Visuals L1

Figure 1 During the eruption of Mount St. Helens, the height of the volcano was lowered by 400 meters. Ask: **What would have caused this damage?** *(Force built up within the volcano and blew the top off.)* **Infer where the debris from this blast went.** *(Some of the fine debris particles remained in the air for a time before settling; some of the material flowed down the side of the volcano in the form of mud; some of the material simply tumbled down the side of the volcano.)* **Verbal**

10.1 The Nature of Volcanic Eruptions

Reading Focus

Key Concepts

- What determines the type of volcanic eruption?
- What materials are ejected from volcanoes?
- What are the three main types of volcanoes?
- What other landforms are associated with volcanic eruptions?

Vocabulary

- viscosity
- vent
- pyroclastic material
- volcano
- crater
- shield volcano
- cinder cone
- composite cone
- caldera

Reading Strategy

Previewing Copy the table. Before you read the section, rewrite the green topic headings as questions. As you read, write the answers to the questions.

The Nature of Volcanic Eruptions	
What factors affect an eruption?	a. ___?___

Volcanic eruptions are more than spectacular sights. They are windows to Earth's interior. Because volcanoes eject molten rock that formed at great depth, they provide opportunities to observe the processes that occur deep beneath Earth's surface.

On May 18, 1980, one of the largest volcanic eruptions to occur in North America changed a scenic volcano into the smoldering wreck shown in Figure 1. On this date, Mount St. Helens erupted with tremendous force. The blast blew out the entire north flank of the volcano, leaving a gaping hole. The eruption ejected nearly a cubic kilometer of ash and rock debris. The air over Yakima, Washington, 130 kilometers to the east, was so filled with ash that noon became almost as dark as midnight. Why do volcanoes like Mount St. Helens erupt explosively, while others like Kilauea in Hawaii are relatively quiet?

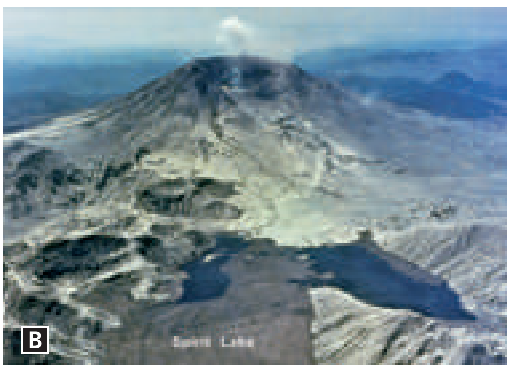


Figure 1 A Mount St. Helens before the May 18, 1980, eruption. **B** After the eruption, Spirit Lake filled with debris.

Table 1 Magma Composition

Composition	Silica Content	Viscosity	Gas Content	Tendency to Form Pyroclastics (ejected rock fragments)	Volcanic Landform
Basaltic	Least (~50%)	Least	Least (1–2%)	Least	Shield Volcanoes Basalt Plateaus Cinder Cones
Andesitic	Intermediate (~60%)	Intermediate	Intermediate (3–4%)	Intermediate	Composite Cones
Rhyolitic	Most (~70%)	Greatest	Most (4–6%)	Greatest	Pyroclastic Flows Volcanic Domes

Factors Affecting Eruptions

The primary factors that determine whether a volcano erupts violently or quietly include magma composition, magma temperature, and the amount of dissolved gases in the magma.

Viscosity **Viscosity** is a substance's resistance to flow. For example, maple syrup is more viscous than water and flows more slowly. Magma from an explosive eruption may be thousands of times more viscous than magma that is extruded quietly.

The effect of temperature on viscosity is easy to see. If you heat maple syrup, it becomes more fluid and less viscous. In the same way, the mobility of lava is strongly affected by temperature. As a lava flow cools and begins to harden, its viscosity increases, its mobility decreases, and eventually the flow halts.

The chemical composition of magmas has a more important effect on the type of eruption. The viscosity of magma is directly related to its silica content. In general, the more silica in magma, the greater is its viscosity. Because of their high silica content, rhyolitic lavas are very viscous and don't flow easily. Basaltic lavas, which contain less silica, tend to be more fluid.

Dissolved Gases During explosive eruptions, the gases trapped in magma provide the force to eject molten rock from the **vent,** an opening to the surface. These gases are mostly water vapor and carbon dioxide. As magma moves nearer the surface, the pressure in the upper part of the magma is greatly reduced. The reduced pressure allows dissolved gases to be released suddenly.

Very fluid basaltic magmas allow the expanding gases to bubble upward and escape relatively easily. Therefore, eruptions of fluid basaltic lavas, such as those that occur in Hawaii, are relatively quiet. At the other extreme, highly viscous magmas slow the upward movement of expanding gases. The gases collect in bubbles and pockets that increase in size until they explosively eject the molten rock from the volcano. The result is a Mount St. Helens.

Quick Lab

Why are some volcanoes explosive?

Procedure

1. Obtain two bottles of noncarbonated water and two bottles of club soda.
2. Open one bottle of the noncarbonated water and one bottle of the club soda. Record your observations.
3. Gently shake each of the remaining unopened bottles. **CAUTION:** *Wear safety goggles and point the bottles away from everyone.*
4. Carefully open each bottle over a sink or outside. Record your observations.

Analyze and Conclude

1. **Observing** What happened when the bottles were opened?
2. **Inferring** Which bottle represents lava with the most dissolved gas?

Factors Affecting Eruptions

Quick Lab

Why are some volcanoes explosive? L2

Objective
After completing this activity, students will be able to explain why trapped gases cause explosive reactions in volcanoes.

Skills Focus **Observing, Inferring, Predicting**

Prep Time 5 minutes

Materials 2 bottles of noncarbonated water, 2 bottles of club soda, paper towels

Class Time 20 minutes

Safety Be sure that students point the open bottles away from everyone.

Teaching Tip Have paper towels available for students to use to clean up after the lab.

Expected Outcome Students will observe dissolved gases and fluid "explode" from the bottle of carbonated liquid.
Kinesthetic, Logical

Analyze and Conclude
1. Answers may vary but should state that the bottles with non-carbonated water opened without any escaping gases or fizzing. The bottles of club soda, when opened, fizzed with the escaping carbon dioxide. After the club soda was shaken, the gases escaped more explosively.
2. the shaken bottle of club soda

For Enrichment L3

Have students research the violent eruption of Krakatau in 1883. Have students prepare a newspaper article detailing the events surrounding the eruption of this volcano. The article should be written as if the volcano had erupted recently.

Customize for English Language Learners

Have students work in pairs to make a chart showing the facts about factors affecting eruptions, volcanic material, types of volcanoes, and other volcanic landforms. Students may want to illustrate their facts with drawings to further their understanding of the concepts. Students can use this chart as a study aid for quizzes and tests.

Volcanic Material

Address Misconceptions L2

Students may have the misconception that earthquakes shaking the region around the volcano are the only reason for volcanic eruptions. Earthquakes are common triggers of volcanic eruptions, but are not the only factors involved. Explain to students that volcanoes can erupt whenever magma builds up enough force to erupt from underground to the surface. The factors that determine the violence of the eruption are magma composition, magma temperature, and the amount of dissolved gases the magma contains.
Verbal

Use Visuals L1

Figure 2 Have students look closely at these photographs. Ask: **How can you tell the aa flow is slow moving?** *(It is rough and jagged rather than smooth.)*
Visual

Teacher Demo

Observing Viscosity L2

Purpose Students will observe fluids that have different viscosities.

Materials 2 large beakers, hot plate, water, 2 large test tubes, test-tube clamp, ice, corn syrup

Procedure Pour corn syrup into the two large test tubes in advance. Put one test tube into a large beaker filled with ice. Put the other test tube into a large beaker half filled with water on a hot plate. Heat the syrup in a hot-water bath until it is very hot. Boiling the syrup is not necessary. Slowly pour the contents of each test tube into another beaker one at a time to demonstrate the nature of fluids with differing viscosities.

Expected Outcome Students will observe that the cold syrup is very viscous and flows very slowly—similar to silica-rich lava. The hot syrup is not viscous and flows very fast—similar to silica-poor lava.
Visual, Verbal

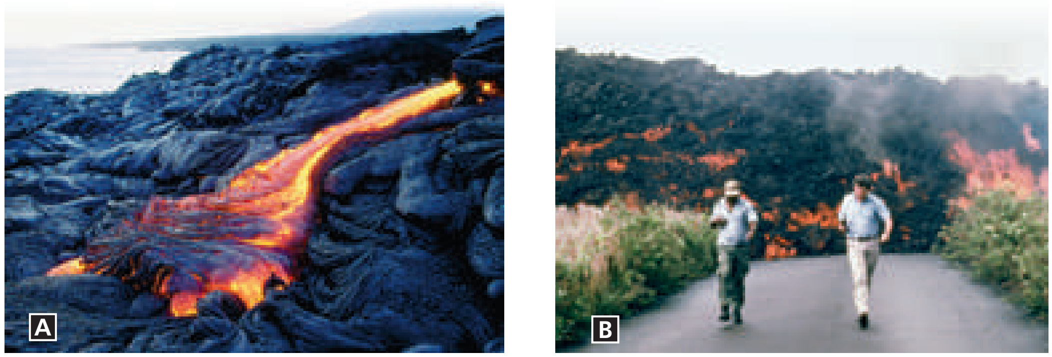


Figure 2 Lava Flows A Typical pahoehoe (ropy) lava flow, Kilauea Hawaii. **B** Example of a slow-moving aa flow.
Drawing Conclusions *Which of the flows has more viscous lava?*

Volcanic Material

Lava may appear to be the main material extruded from a volcano, but this is not always the case. Just as often, explosive eruptions eject huge quantities of broken rock, lava bombs, fine ash, and dust. All volcanic eruptions also emit large amounts of gas.

Lava Flows Hot basaltic lavas are usually very fluid because of their low silica content. Flow rates of 10 to 300 meters per hour are common. In contrast, the movement of silica-rich (rhyolitic) lava is often too slow to be visible. When fluid basaltic lavas harden, they commonly form a relatively smooth skin that wrinkles as the still-molten subsurface lava continues to move. These are known as pahoehoe (pah HOH ee hoh ee) flows and resemble the twisted braids in ropes, as shown in Figure 2. Another common type of basaltic lava called aa (AH ah) has a surface of rough, jagged blocks with dangerously sharp edges and spiny projections.

Gases Magmas contain varied amounts of dissolved gases held in the molten rock by confining pressure, just as carbon dioxide is held in soft drinks. As with soft drinks, as soon as the pressure is reduced, the gases begin to escape. The gaseous portion of most magmas is only about 1 to 6 percent of the total weight. The percentage may be small, but the actual quantity of emitted gas can exceed thousands of tons each day. Samples taken during a Hawaiian eruption consisted of about 70 percent water vapor, 15 percent carbon dioxide, 5 percent nitrogen, 5 percent sulfur, and lesser amounts of chlorine, hydrogen, and argon. Sulfur compounds are easily recognized because they smell like rotten eggs and readily form sulfuric acid, a natural source of air pollution. The composition of volcanic gases is important because they have contributed greatly to the gases that make up the atmosphere.

Pyroclastic Materials When basaltic lava is extruded, dissolved gases propel blobs of lava to great heights. Some of this ejected material may land near the vent and build a cone-shaped structure. The wind will carry smaller particles great distances. Viscous rhyolitic magmas are highly charged with gases. As the gases expand, pulverized rock and lava fragments are blown from the vent. **Pyroclastic material** is the name give to particles produced in volcanic eruptions. **The fragments ejected during eruptions range in size from very fine dust and volcanic ash (less than 2 millimeters) to pieces that weigh several tons.**

Particles that range in size from small beads to walnuts (2–64 millimeters) are called lapilli or more commonly cinders. Particles larger than 64 millimeters in diameter are called blocks when they are made of hardened lava and bombs when they are ejected as glowing lava. Because bombs are semimolten upon ejection, they often take on a streamlined shape as they hurtle through the air.

Reading Checkpoint *What is a volcanic bomb?*

Types of Volcanoes

Volcanic landforms come in a wide variety of shapes and sizes. Each structure has a unique eruptive history. **The three main volcanic types are shield volcanoes, cinder cones, and composite cones.**

Anatomy of a Volcano Volcanic activity often begins when a fissure, or crack, develops in the crust as magma is forced toward the surface. The gas-rich magma moves up this fissure, through a circular pipe, ending at a vent, as shown in Figure 3. Repeated eruptions of lava or pyroclastic material often separated by long inactive periods eventually build the mountain called a **volcano.** Located at the summit of many volcanoes is a steep-walled depression called a **crater.**

Go Online SCILINKS NSTA

For: Links on volcanic eruptions
Visit: www.SciLinks.org
Web Code: cjn-3101

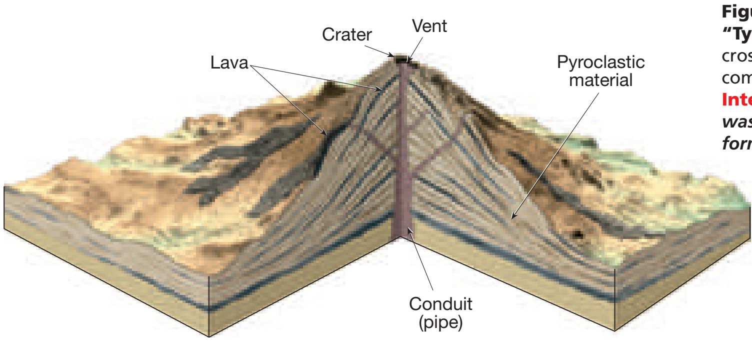


Figure 3 Anatomy of a "Typical" Volcano This cross section shows a typical composite cone. **Interpreting Diagrams** ***How was the volcano in the diagram formed?***

Types of Volcanoes

Build Reading Literacy L1

Refer to **p. 278D** in this chapter, which provides the guidelines for identifying main ideas and details.

Identify Main Idea/Details Have students read Types of Volcanoes on pp. 283–286. Ask them to identify the main idea of each paragraph. Point out that the main idea is usually within the first or second sentence of a paragraph. Encourage students to include this exercise in the notes they use to study.
Verbal

Build Science Skills L2

Interpreting Diagrams/ Photographs Have students study Figure 3. Ask: **Why do you think the term *parasitic cone* is given to this feature in the diagram?** *(This cone does not have its own lava source but gets its lava from another conduit, or pipe.)*
Visual, Logical

Go Online NSTA SCILINKS

Download a worksheet on volcanic eruptions for students to complete, and find additional teacher support from NSTA SciLinks.

Answer to . . .

Figure 2 *The lava in the aa lava flow is more viscous.*

Figure 3 *The volcano was formed as layers of pyroclastic material and lava flows were built up around the vent.*

Reading Checkpoint *a large streamlined chunk of pyroclastic material that is larger than 64 mm in diameter*

Integrate Physics
L2

Geothermal Energy Hot magma near the surface of Earth can be beneficial. Geothermal energy takes advantage of Earth's internal energy and uses it as an energy source. Have students research this renewable source of energy. Students should prepare a short report about this natural energy source. The report should include an illustration showing an example of how geothermal energy can be used in a specific application. **Verbal**

Use Visuals
L1

Figure 4 Have students compare the photograph to the drawing. Ask: **Why might photographs of shield volcanoes make them look not as tall as they really are?** *(Because shield volcanoes are so broad, they often give the impression of being lower than they are.)* **How would you describe the viscosity of the lava at a shield volcano?** *(low viscosity)* **What is the origin of the other islands in the diagram? What do you think they would look like under the sea level?** *(They are shield volcanoes, or parts of shield volcanoes. Beneath the surface, the rocky formations likely flare outward either as individual shield volcanoes or as portions of a volcano shared by one or more of the other islands.)*

The form of a volcano is largely determined by the composition of the magma. As you will see, fluid lavas tend to produce broad structures with gentle slopes. More viscous silica-rich lavas generate cones with moderate to steep slopes.

Shield Volcanoes **Shield volcanoes** are produced by the accumulation of fluid basaltic lavas. Shield volcanoes have the shape of a broad, slightly domed structure that resembles a warrior's shield, as shown in Figure 4. Most shield volcanoes have grown up from the deep-ocean floor to form islands. Examples of shield volcanoes include the Hawaiian Islands and Iceland.

Cinder Cones Ejected lava fragments the size of cinders, which harden in the air, build a **cinder cone.** These fragments range in size from fine ash to bombs but consist mostly of lapilli, or cinders. Cinder cones are usually a product of relatively gas-rich basaltic magma. Although cinder cones are composed mostly of loose pyroclastic material, they sometimes extrude lava.

Cinder cones have a very simple shape as shown in Figure 5A. The shape is determined by the steep-sided slope that loose pyroclastic material maintains as it comes to rest. Cinder cones are usually the product of a single eruption that sometimes lasts only a few weeks and rarely more than a few years. Once the eruption ends, the magma in the pipe connecting the vent to the magma chamber solidifies, and the volcano never erupts again. Because of this short life span, cinder cones are small, usually between 30 meters and 300 meters and rarely exceed 700 meters in height.

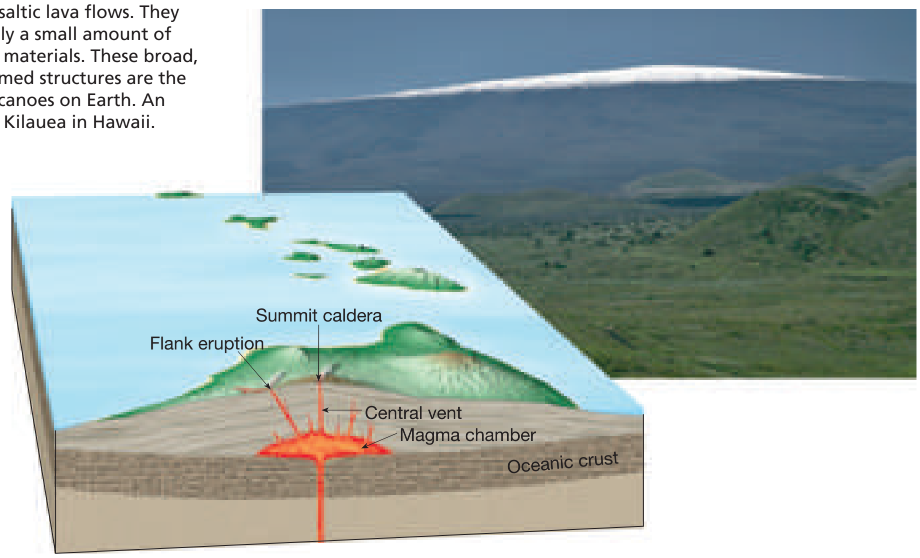
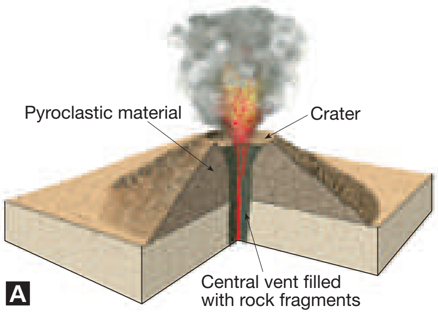


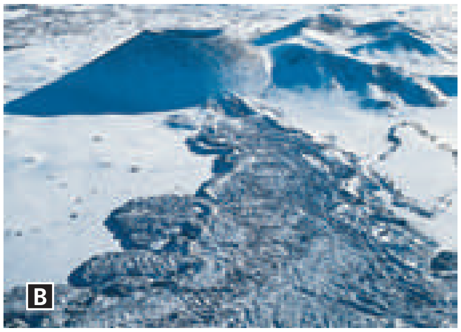
Figure 4 Shield Volcanoes Shield volcanoes are built mainly of fluid basaltic lava flows. They contain only a small amount of pyroclastic materials. These broad, slightly domed structures are the largest volcanoes on Earth. An example is Kilauea in Hawaii.

Facts and Figures

Parícutin is an active volcano in Mexico. It is one of the youngest volcanoes on Earth. On February 20, 1943, Parícutin began erupting from a fissure in a cornfield. By the end of the first year, the cone had reached an elevation of 450 m. Volcanic eruptions finally ended in 1952.

The resulting fire, ash, and lava destroyed two villages. In one of the villages, a local church is still standing at the edge of the lava flow. The top of the church and the bell tower are visible, but the lower portions of the church are buried in lava.





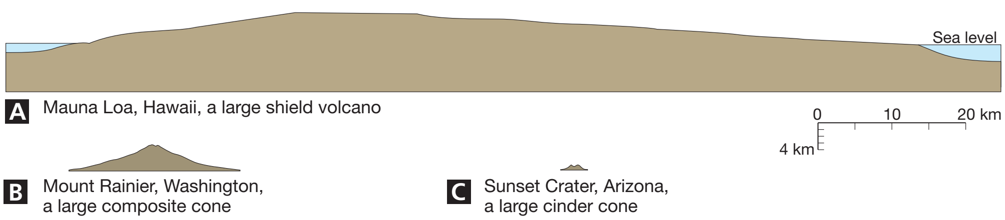
Cinder cones are found by the thousands all around Earth. Some, like the one shown in Figure 5B, near Flagstaff, Arizona, are located in volcanic fields. This field consists of about 600 cones. Others form on the sides of larger volcanoes. Mount Etna, for example, has dozens of cinder cones dotting its flanks.

Figure 5 Cinder Cones **A** A typical cinder cone has steep slopes of 30–40 degrees. **B** This photograph shows SP Crater, a cinder cone north of Flagstaff, Arizona.
Inferring ***What feature is shown in the lower part of the photograph?***

Composite Cones Earth's most beautiful and potentially dangerous volcanoes are composite cones, or stratovolcanoes. Most are located in a relatively narrow zone that rims the Pacific Ocean, appropriately called the Ring of Fire. The Ring of Fire includes the large cones of the Andes in South America and the Cascade Range of the western United States and Canada. The Cascade Range includes Mount St. Helens, Mount Rainier, and Mount Garibaldi. The most active regions in the Ring of Fire are located along curved belts of volcanic islands next to the deep ocean trenches of the northern and western Pacific. This nearly continuous chain of volcanoes stretches from the Aleutian Islands to Japan, the Philippines, and New Zealand.

A **composite cone** is a large, nearly symmetrical structure composed of layers of both lava and pyroclastic deposits. For the most part, composite cones are the product of gas-rich magma having an andesitic composition. The silica-rich magmas typical of composite cones generate viscous lavas that can only travel short distances. Composite cones may generate the most explosive eruptions that eject huge quantities of pyroclastic material. Compare the shape and height of composite cones with other types of volcanoes in Figure 6.

Figure 6 Profiles of Volcanic Landforms **A** Profile of Mauna Loa, Hawaii, the largest shield volcano in the Hawaiian chain. **B** Profile of Mount Rainier, Washington, a large composite cone. **C** Profile of Sunset Crater, Arizona, a typical steep-sided cinder cone.



Teacher Demo

Observing an Explosive Eruption **L2**

Purpose Students will observe the explosive nature of gases trapped in an enclosed container.

Materials 2-L soda bottle, rubber stopper, white vinegar, baking soda, paper towel, rubber band, thin bath or kitchen towel, scissors

Procedure Pour 150 mL of vinegar into the empty soda bottle. For safety, fold the towel around the bottle. Secure the towel at the neck of the bottle with a rubber band. Cut an 8-cm square piece of paper towel. Put about 5 mL of baking soda in the center of the paper towel. Fold the paper towel around the baking soda to make a packet. Drop the packet into the bottle. Put the stopper into the bottle. Do not put the stopper in too tight. Have everyone stand a safe distance away from the bottle.

Expected Outcome Students will observe the explosive forces that are created when trapped gases are released. Point out to students that this is similar to gases trapped inside an active volcano. When enough force is built up, trapped gases can blow the top off of the volcano. Gases, magma, and pyroclastic materials then flow from the volcano through the new opening.
Visual

Answer to . . .

Figure 5 *a lava flow*

Section 10.1 (continued)

Integrate Social Studies L2

Mount Pelée Living in the shadow of a composite cone can be particularly dangerous. In 1902, Mount Pelée erupted in a fiery pyroclastic flow of hot gases infused with incandescent ash and larger rock fragments. The most destructive of pyroclastic flows, a nuée ardente (burning cloud), destroyed the port town of St. Pierre on the Caribbean island of Martinique. The destruction happened in moments. All of the 28,000 inhabitants of the town were killed with the exception of one person who was being held in a dungeon on the outskirts of town. A few people that were on ships in the harbor also were spared.

Shortly after this eruption, scientists arrived on the scene. They discovered masonry walls almost one meter thick knocked over like dominoes. Large trees were uprooted, and cannons were torn from their mounts. Have students use the Internet to research this volcanic eruption and prepare a short report on it. Ask: **What name is given to eruptions that are similar to the one that destroyed St. Pierre?** *(a peelean-type eruption, which is named after Mount Pelée)*
Verbal

Figure 7 Composite Cone Mount Shasta, California, is one of the largest composite cones in the Cascade Range. Shastina is the smaller cone that formed on the left flank of Mt. Shasta.

Fujiyama in Japan and Mount Shasta in California show the classic shape you would expect of a composite cone, with its steep summit and gently sloping flanks, as shown in Figure 7. About 50 such volcanoes have erupted in the United States in the past 200 years. On a global scale, numerous destructive eruptions of composite cones have occurred during the past few thousand years. A few of these have had a major influence on human civilization.

Dangers from Composite Cones One of the most devastating features associated with composite cones are pyroclastic flows. They consist of hot gases, glowing ash, and larger rock fragments. The most destructive of these fiery flows are capable of racing down steep volcanic slopes at speeds of nearly 200 kilometers per hour. Some pyroclastic flows result when a powerful eruption blasts material out the side of a volcano. Usually they form from the collapse of tall eruption columns that form over a volcano during an explosive event. Once gravity overcomes the upward thrust provided by the escaping gases, the material begins to fall. Massive amounts of hot fragments, ash, and gases begin to race downhill under the influence of gravity.

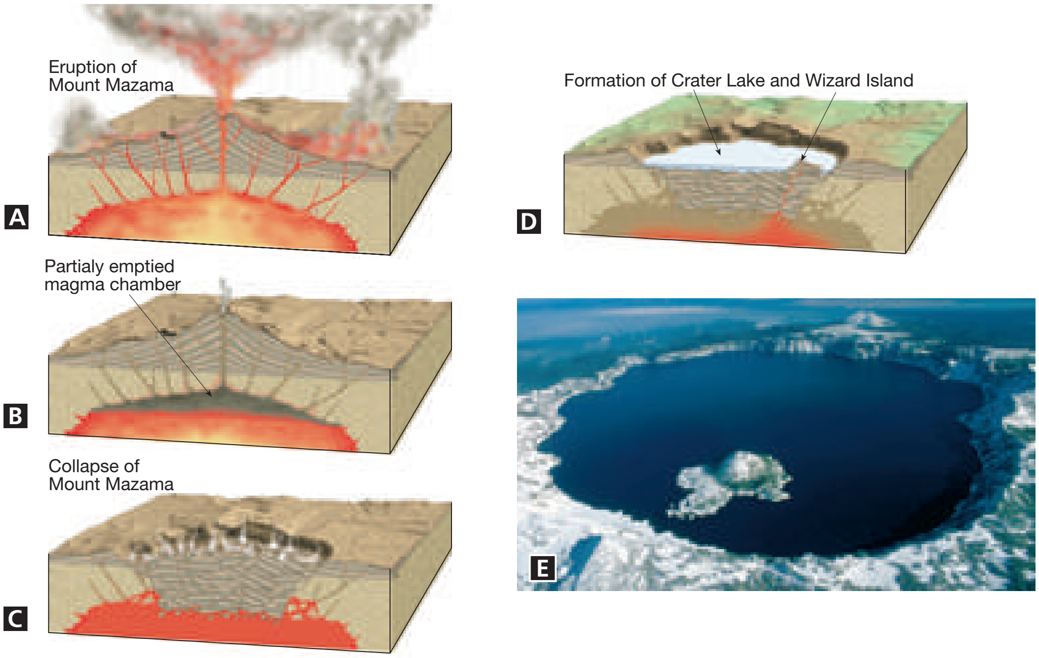
Large composite cones may also generate mudflows called lahars. These destructive mudflows occur when volcanic debris becomes saturated with water and rapidly moves down steep volcanic slopes, often following stream valleys. Some lahars are triggered when large volumes of ice and snow melt during an eruption. Others are generated when heavy rainfall saturates weathered volcanic deposits. Lahars can occur even when a volcano is not erupting.

Reading Checkpoint *What is a lahar?*

Facts and Figures

The five deadliest volcanic eruptions known are (1) Tambora, Indonesia, which occurred in 1815. There were 92,000 deaths, primarily the result of starvation. (2) Krakatau, Indonesia, which occurred in 1883. There were 36,000 deaths, primarily the result of a tsunami. (3) Mount Pelée, Martinique, which occurred in 1902. There were 28,000 deaths, primarily the result of pyroclastic flows. (4) Nevado del Ruiz, Colombia, which occurred in 1985. There were 25,000 deaths, primarily the result of mudflows. (5) Unzen, Japan, which occurred in 1792. There were 14,000 deaths, primarily the result of a volcano collapse and a tsunami.

Caldera Formation



Other Volcanic Landforms

Calderas

A caldera is a large depression in a volcano. Most calderas form in one of two ways: by the collapse of the top of a composite volcano after an explosive eruption, or from the collapse of the top of a shield volcano after the magma chamber is drained. Crater Lake, Oregon, is located in a caldera. This caldera formed about 7000 years ago when a composite cone, Mount Mazama, violently erupted and collapsed, as shown in Figure 8.

Necks and Pipes

Most volcanoes are fed magma through conduits, called pipes, connecting a magma chamber to the surface. Volcanoes are always being weathered and eroded. Cinder cones are easily eroded because they are made up of loose materials. When the rock in the pipe is more resistant and remains standing above the surrounding terrain after most of the cone has been eroded, the structure is called a volcanic neck, as shown in Figure 9A on page 288.

The best-known volcanic pipes are the diamond-bearing pipes of South Africa. The rocks filling these pipes formed at depths of at least 150 kilometers, where pressure is high enough to form diamonds. The process of moving unaltered magma through 150 kilometers of solid rock is unusual, resulting in the rarity of diamonds.

Figure 8 Crater Lake in Oregon occupies a caldera about 10 kilometers in diameter. About 7000 years ago, the summit of former Mount Mazama collapsed following a violent eruption that partly emptied the magma chamber. Rainwater then filled the caldera. Later eruptions produced the cinder cone called Wizard Island.

Other Volcanic Landforms

Use Visuals L1

Figure 8 Have students study the diagrams in Figure 8. Tell students that the word *caldera* means "a cooking pot." Ask: **Why is an eruption that empties or partially empties the magma chamber an important first step for a caldera to form?** *(The magma chamber must be emptied or partially emptied to create a void. Then the volcano collapses into the newly created void to create a deep depression in the landscape.)* **Why is the name caldera a good description of this type of landform?** *(When the volcano collapses, a large well is created that resembles a cooking pot.)*
Verbal, Logical

Use Community Resources L2

Many U.S. Geological Survey (USGS) offices have educational outreach staff and programs. Contact your regional office and ask a USGS scientist to speak to your class about plate tectonics and volcanic activity.
Interpersonal

Answer to . . .

Reading Checkpoint: *a mudflow down the slope of a volcano*

Section 10.1 (continued)

Use Visuals L1

Figure 9 Have students study Figure 9. Ask: **Infer why the volcanic neck is still in place while the surrounding terrain has eroded away.** *(The rock in the volcanic neck is more resistant to erosion than the surrounding terrain.)*
Verbal, Logical

3 ASSESS

Evaluate Understanding L2

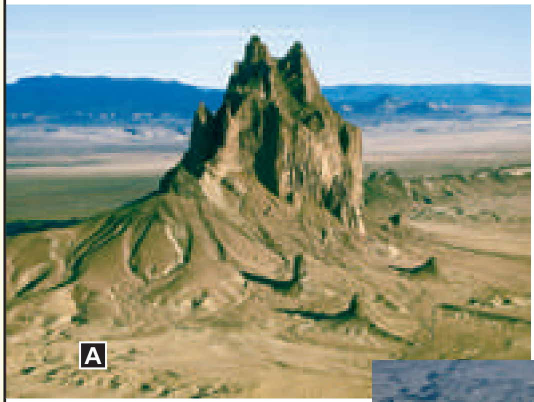
Have students play a quiz game to review the material in this section. Ask each student to write three questions on three separate sheets of paper. Collect the questions. Divide the class into two teams. To play the game, alternate giving a member of each team a question from the collected papers. Give each team a point for each correct response. The team with the most points wins the game.

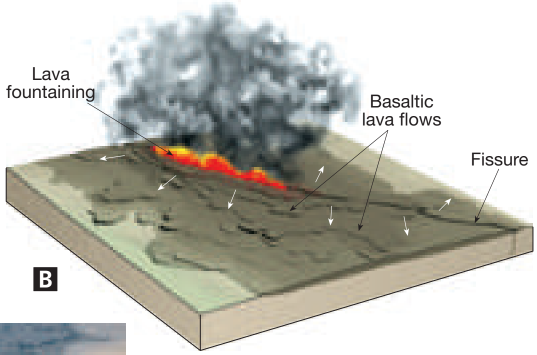
Reteach L1

Set aside any questions that are answered incorrectly from the quiz game above. After the game, give each team the stack of missed questions. Let the entire team work together to give the correct response to the questions.

Writing in Science

Answers will vary, but should accurately classify the volcano and give a clear description of the eruption.





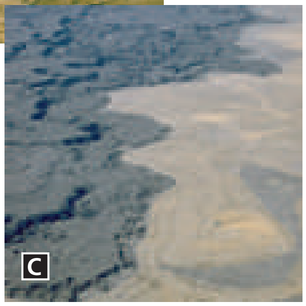


Figure 9 Other Volcanic Landforms A Ship Rock, New Mexico, is a volcanic neck. Ship Rock consists of igneous rock that crystallized in the pipe of a volcano that then was eroded away. **B** Lava erupting from a fissure forms fluid lava flows called flood basalts. **C** These dark-colored basalt flows are near Idaho Falls, Idaho.

Lava Plateaus You probably think of volcanic eruptions as building a mountain from a central vent. But the greatest volume of volcanic material is extruded from fissures. Rather than building a cone, low-viscosity basaltic lava flows from these fissures, covering a wide area, as shown in Figure 9B. The extensive Columbia Plateau in the northwestern United States was formed this way. Here, numerous fissure eruptions extruded very fluid basaltic lava, shown in Figure 9C. Successive flows, some 50 meters thick, buried the landscape, building a lava plateau nearly 1.6 kilometers thick.

Section 10.1 Assessment

Reviewing Concepts

1. What factors determine the type of volcanic eruption?
2. List the materials ejected from volcanoes.
3. Describe the three types of volcanoes.
4. What is a caldera?

Critical Thinking

5. **Comparing and Contrasting** Compare the formation of a lava plateau with the formation of a cinder cone.
6. **Applying Concepts** What type of eruption produces a viscous magma containing 53 percent silica and a gas content of 2 percent?
7. **Calculating** If a pyroclastic flow was traveling 145 kilometers per hour, how long would it take to reach a town 2.5 kilometers from the volcano's crater?

Writing in Science

Summary Research a volcanic eruption. Write a paragraph describing the eruption. Make sure to classify what type of volcano erupted.

Section 10.1 Assessment

1. The type of volcanic eruption is determined by the magma composition, magma temperature, and amount of dissolved gases.
2. The materials ejected from volcanoes include lava, gases, and pyroclastic materials, such as ash, dust, cinders, volcanic blocks, and volcanic bombs.
3. Cinder cones are small, steep cones, composed mainly of loose cinders. Shield volcanoes are large, gently sloping volcanoes composed of layers of mainly quiet lava flows. Composite cones are large, steep cones, composed of layers of lava flows and pyroclastic material from more explosive eruptions.
4. A caldera is a large, collapsed depression in a volcano.
5. A lava plateau is formed by repeated eruptions from a long, narrow fissure that can build up to form a thick deposit of volcanic rock over a large area. A cinder cone is a small volcanic cone that forms from cinders, usually from a single eruption.
6. The eruption would most likely be explosive.
7. The pyroclastic flow would reach the town in just over 1 minute (1.03 minutes).

10.2 Intrusive Igneous Activity

Reading Focus

Key Concepts

- How are intrusive igneous features classified?
- What are the major intrusive igneous features?
- What is the origin of magma?

Vocabulary

- pluton
- sill
- laccolith
- dike
- batholith
- geothermal gradient
- decompression melting

Reading Strategy

Comparing and Contrasting After you read the section, compare the types of plutons by completing the table.

Types of Plutons	Description
Sill	a. ____?____
Laccolith	b. ____?____
Dike	c. ____?____
Batholith	d. ____?____

Although volcanic eruptions are among the most violent and spectacular events in nature, most magma cools deep within Earth. The structures that result form the roots of mountain ranges and some of the most familiar features in the landscape.

Plutons

The structures that result from the cooling and hardening of magma at depth are called **plutons.** Because all plutons form beneath Earth's surface, they can be studied only after uplift and erosion have exposed them. Plutons occur in a great variety of sizes and shapes. **Intrusive igneous bodies, or plutons, are generally classified according to their shape, size, and relationship to the surrounding rock layers.**

Sills and Laccoliths

Sills and laccoliths are plutons that form when magma is intruded close to the surface. Sills and laccoliths differ in shape and often differ in composition. A **sill** forms when magma is injected along sedimentary bedding surfaces, parallel to the bedding planes. Horizontal sills, like the one shown in Figure 10, are the most common.

For a sill to form, the overlying sedimentary rock must be lifted to a height equal to the thickness of the sill. Although this is a not an easy task, at shallow levels it often requires less energy than forcing the magma up to the surface. Because of this, sills form only at shallow depths, where the pressure exerted by the weight of overlying rock layers is low. As shown in Figure 11A on page 290, sills look like buried lava flows.

Figure 10 Sills This dark, horizontal band is a sill of basalt that intruded into horizontal layers of sedimentary rock in Salt River Canyon, Arizona.
Inferring ***How could you determine if a horizontal igneous rock layer was a lava flow or a sill?***

Section 10.2

1 FOCUS

Section Objectives

10.5 **Classify** intrusive igneous features.
10.6 **Describe** the major intrusive igneous features.
10.7 **Describe** the origin of magma.

Reading Focus

Build Vocabulary L2

Word Parts List on the board the following word parts and meanings: *lakkos*, "reservoir"; *lithos*, "stone"; *bathos*, "depth." Have students identify these word parts in the vocabulary terms. Discuss the terms' meanings with students.

Reading Strategy L2

a. pluton formed parallel with sedimentary rocks, commonly horizontal
b. similar to a sill, but forms a lens-shaped mass that pushes the overlying strata upward
c. pluton that cuts across the preexisting rocks
d. largest intrusive igneous body with a surface exposure of over 100 sq km

2 INSTRUCT

Plutons

Use Visuals L1

Figure 10 Have students study Figure 10. Ask: **Why do sills only form at shallow depths?** *(The overlying sedimentary rock must be lifted to a height equal to the height of the sill, so the weight of the rock cannot be more than the magma can lift.)* **Why does the sill form below the sedimentary rock instead of at the surface?** *(because it requires less force to raise the sedimentary rock than to force the magma to the surface)*
Verbal

Answer to . . .

Figure 10 *The upper surface of a lava flow would not show evidence of contact with another rock layer above it, while the upper surface of a sill shows evidence that it was intruded into preexisting layers of sedimentary rocks. The sedimentary rock layers above the sill could also show evidence of heating and contact metamorphism.*

Build Reading Literacy L1

Refer to **p. 474D** in **Chapter 17**, which provides guidelines for monitoring your understanding.

Monitor Your Understanding Have students read the passages Plutons and Origin of Magma (pp. 289–292). When they reach the bottom of p. 289, have them stop and write down the main ideas in the passages. Have them ask themselves, "Did I have any trouble reading this passage? If so, why?" Then, have them come up with their own strategies to improve their understanding. Have students use this strategy as they continue reading. **Interpersonal, Verbal**

Integrate Social Studies L2

The Henry Mountains These mountains, located in southeastern Utah, are largely composed of several laccoliths believed to be fed by a much larger magma body nearby. The mountain range is named for Joseph Henry, an American scientist. Henry was the first secretary of the Smithsonian Institution. Have students find the Henry Mountains on a map or an atlas. **Verbal**

Types of Igneous Plutons

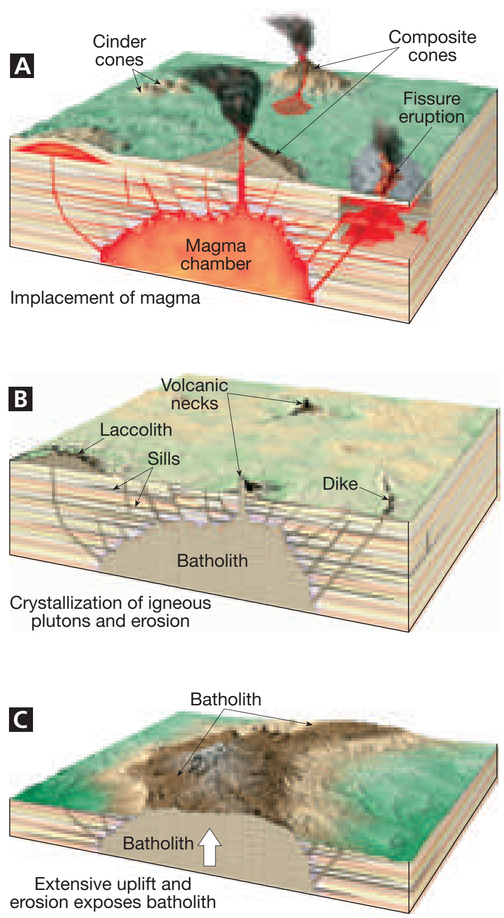


Figure 11 **A** This diagram shows the relationship between volcanism and intrusive igneous activity. **B** This view shows the basic intrusive igneous structures, some of which have been exposed by erosion long after their formation. **C** After millions of years of uplift and erosion, a batholith is exposed at the surface.

Laccoliths are similar to sills because they form when magma is intruded between sedimentary layers close to the surface. However, the magma that generates laccoliths is more viscous. This less-fluid magma collects as a lens-shaped mass that pushes the overlying strata upward. Most laccoliths are not much wider than a few kilometers.

Reading Checkpoint *Compare and contrast sills and laccoliths.*

Dikes Some plutons form when magma is injected into fractures, cutting across preexisting rock layers. Such plutons are called **dikes,** as in Figure 11B. These sheetlike structures have thicknesses ranging from less than a centimeter to more than a kilometer. Most dikes, however, are a few meters thick and extend laterally for no more than a few kilometers.

Some dikes radiate, like spokes on a wheel, from an eroded volcanic neck. The movement of magma probably formed fissures in the volcanic cone from which the magma flowed to form the dikes. **Many dikes form when magma from a large magma chamber invades fractures in the surrounding rocks.**

Batholiths The largest intrusive igneous bodies are **batholiths.** The Idaho batholith, for example, covers an area of more than 40,000 square kilometers and consists of many individual plutons. Indirect evidence from gravity and seismic studies indicates that batholiths are also very thick, possibly extending dozens of kilometers into the crust.

Customize for Inclusion Students

Learning Disabled Make concept maps for each section and cover them with clear contact paper. Then, cut the maps into puzzle pieces. Provide students with the pieces and have them put the puzzle together. After students complete the puzzle, have them make flashcards with concept connections and added notes. For example, students may have cards with the names of plutons on one side and a definition or example on the other. Students also may have key concept cards with an important word missing. For example, **A ________ is a pluton formed when magma is injected along sedimentary bedding surfaces, parallel to the bedding planes.** *(sill)*

An intrusive igneous body must have a surface exposure greater than 100 square kilometers to be considered a batholith. Smaller plutons are called stocks. Many stocks appear to be portions of batholiths that are not yet fully exposed. Batholiths may form the core of mountain ranges, as shown in Figure 12. In this case, uplift and erosion have removed the surrounding rock, exposing the batholith.

Figure 12 Batholiths Mount Whitney in California makes up just a tiny portion of the Sierra Nevada batholith, a huge structure that extends for approximately 400 kilometers.

Origin of Magma

The origin of magma has been controversial in geology for a long time. Based on available scientific evidence, Earth's crust and mantle are composed primarily of solid, not molten, rock. Although the outer core is a fluid, its iron-rich material is very dense and stays deep within Earth. What is the source of magma that produces igneous activity? **Geologists conclude that magma originates when essentially solid rock, located in the crust and upper mantle, partially melts. The most obvious way to generate magma from solid rock is to raise the temperature above the level at which the rock begins to melt.**

Role of Heat What source of heat is sufficient to melt rock? Workers in underground mines know that temperatures get higher as they go deeper. The rate of temperature change averages between 20°C and 30°C per kilometer in the upper crust. This change in temperature with depth is known as the **geothermal gradient.** Estimates indicate that the temperature at a depth of 100 kilometers ranges between 1400°C and 1600°C. At these high temperatures, rocks in the lower crust and upper mantle are near, but not quite at their melting point temperatures. So they are very hot but still essentially solid.

There are several ways that enough additional heat can be generated within the crust or upper mantle to produce some magma. First, at subduction zones, friction generates heat as huge slabs of crust slide past each other. Second, crustal rocks are heated as they descend into the mantle during subduction. Third, hotter mantle rocks can rise and intrude crustal rocks. All of these processes only form relatively small amounts of magma. As you'll see, the vast bulk of magma forms without an additional heat source.

Reading Checkpoint *What is a geothermal gradient?*

Origin of Magma

Address Misconceptions L2

Some students may have the misconception that all mountains are volcanoes (either extinct, dormant, or active). Explain to students that most mountains are the result of crustal deformation. Mountain building is discussed in the next chapter. Ask: **What clues could scientists use to determine if a mountain is the result of volcanic activity?** *(Scientists could look for signs of volcanic activity, such as the presence of igneous rock or plutons.)*
Verbal

Build Science Skills L2

Observing Friction and Heat ACTIVITY Gather two flat rocks. Have students feel the temperature of the rocks before the following activity begins. If an infrared thermometer is available, take the temperature of the rocks. Simulate the motion of two plates at a subduction zone by rubbing and grinding two flat rocks together. After a few minutes, feel the rocks again or take the temperature of the rocks with the infrared thermometer. Students will observe a temperature increase in rocks due to the friction between the two rocks. This is similar to the activity that occurs at a subduction zone. However, the rocks at a subduction zone are much larger and are forced together with a great deal of force, resulting in a great deal of friction and heat. Friction is not a factor in the melting of magma beneath subduction zones.
Kinesthetic, Logical

Facts and Figures

American geologist Ferdinand Vandiveer Hayden lived from 1829 to 1887. Hayden explored and documented information about the American West for over 30 years. The "Hayden surveys" provided scientific information on the geology, botany, and zoology of the American West. In 1867, he was placed in charge of the newly established U.S. Geological and Geographical Survey of the Territories. This department was the precursor of the U.S. Geological Survey, which is now part of the United States Department of the Interior.

Answer to . . .

Reading Checkpoint *Both sills and laccoliths are plutons formed by magma intrusions close to the surface, but they differ in shape and usually differ in composition.*

Reading Checkpoint *the change in temperature with depth*

Integrate Physics

L2

Kinetic Theory and Pressure The kinetic theory can help students visualize the role that pressure plays in the melting of rock. Have students recall that the particles in a solid are closely packed and are bonded to the particles surrounding them. When a substance is heated or gains thermal energy, the kinetic energy of the individual particles increases. Have students recall that temperature is the average kinetic energy of the individual particles in a substance. A substance melts when the particles have enough kinetic energy to overcome the bonds between the particles in a solid. If a substance is under pressure, the particles must gain more thermal energy to overcome the bonds between the particles and the force (pressure) holding the particles in place. Therefore, the substance, in this case the rock, must absorb more thermal energy to overcome the additional force. This gives the substance a higher melting temperature. Have students explain why reducing confining pressure lowers a rock's melting temperature. *(The particles no longer have to overcome the additional force.)*
Verbal, Logical

3 ASSESS

Evaluate Understanding

L2

Have students write three review questions from the chapter. Then have students work with a partner to ask each other their questions.

Reteach

L1

Use Figure 11 to review the different types of igneous plutons.

Connecting Concepts

Sample answer: Convection currents within the mantle bring hot mantle material closer to the surface.

Answer to . . .

Figure 13 *It appears to have a low viscosity because it is flowing relatively easily from a fissure.*

Figure 13 Basaltic Magma at the Surface Lava extruded along the East Rift Zone, Kilauea, Hawaii.
Observing *Does this lava appear to have a high viscosity or a low viscosity? Explain.*

Role of Pressure If temperature were the only factor that determined whether or not rock melts, Earth would be a molten ball covered with a thin, solid outer shell. This is not the case because pressure also increases with depth. Melting, which causes an increase in volume, occurs at higher temperatures at depth because of greater confining pressure. In this way, an increase in confining pressure causes an increase in the rock's melting temperature. The opposite is also true. Reducing confining pressure lowers a rock's melting temperature. When confining pressure drops enough, **decompression melting** is triggered. This process generates magma beneath Hawaii where plumes of hot rock melt as they rise toward the surface.

Role of Water Another important factor affecting the melting temperature of rock is its water content. Water causes rock to melt at lower temperatures. Because of this, "wet" rock buried at depth has a much lower melting temperature than does "dry" rock of the same composition and under the same pressure. Laboratory studies have shown that the melting point of basalt can be lowered by up to 100°C by adding only 0.1 percent water. In addition to a rock's composition, its temperature, depth (confining pressure), and water content determine if it is a solid or liquid.

In summary, magma can be formed in three ways. First, heat may be added when a magma body from a deeper source intrudes and melts crustal rock. Second, a decrease in pressure (without the addition of heat) can result in decompression melting. Third, water can lower the melting temperature of mantle rock enough to form magma.

Section 10.2 Assessment

Reviewing Concepts

1. How are intrusive features classified?
2. List the major intrusive igneous bodies.
3. What are the three major ways that magma forms?
4. What is a pluton?

Critical Thinking

5. **Comparing and Contrasting** Describe the difference between a sill and a dike.
6. **Relating Cause and Effect** What effect does a decrease in confining pressure have on the melting temperature of rocks in the upper mantle?

Connecting Concepts

Convection Currents Recall what you learned about convection currents in Chapter 9. Explain how convection currents could affect the depth at which molten rocks are found.

Section 10.2 Assessment

1. Intrusive features are classified by their shape, size, and relationship to the surrounding rock layers.
2. batholiths, laccoliths, sills, and dikes
3. Magma forms by (1) heat being added to crustal rocks when hotter, deeper mantle rocks rise into the crust; (2) by a decrease in pressure without an increase in temperature; (3) by the addition of water, which can lower the melting point enough to form magma.
4. the structure that results from the cooling and hardening of magma at depth
5. A sill is a pluton that forms when magma is injected along bedding surfaces and parallel to the bedding planes. A dike is a pluton that forms when magma is injected into fractures, cutting across preexisting rock layers.
6. A decrease in confining pressure will decrease the melting temperature, causing decompression melting to occur.

10.3 Plate Tectonics and Igneous Activity

Reading Focus

Key Concepts

- What is the relationship between plate boundaries and igneous activity?
- Where does intraplate volcanism occur?

Vocabulary

- intraplate volcanism

Reading Strategy

Outlining After you read, make an outline of the most important ideas in the section.

I. Plate Tectonics and Igneous Activity
  A. Convergent Plate Boundaries
    1. ____?____
    2. ____?____

More than 800 active volcanoes have been identified worldwide. Most of them are located along the margins of the ocean basins, mainly within the circum-Pacific belt known as the Ring of Fire. A second group of volcanoes is found in the deep-ocean basins, including on Hawaii and Iceland. A third group includes volcanic structures that are irregularly distributed in the interiors of the continents. Until the late 1960s, geologists had no explanation for the distribution of volcanoes. With the development of the theory of plate tectonics, the picture became clearer.

Convergent Plate Boundaries

The basic connection between plate tectonics and volcanism is that plate motions provide the mechanisms by which mantle rocks melt to generate magma. At convergent plate boundaries, slabs of oceanic crust are pushed down into the mantle. As a slab sinks deeper into the mantle, the increase in temperature and pressure drives water from the oceanic crust. Once the sinking slab reaches a depth of about 100 to 150 kilometers, the fluids reduce the melting point of hot mantle rock enough for melting to begin. The magma formed slowly migrates upward forming volcanoes such as Mount St. Helens shown here. As you read about the relationships between plate tectonics and igneous activity, refer to Figure 17 on pages 296–297, which summarizes the relationships.

Figure 14 Convergent Boundary Volcano Mount St. Helens emitting volcanic ash on July 22, 1980, two months after the huge May eruption. Mount St. Helens is located at a convergent boundary between the Juan de Fuca plate and the North American plate.

Section 10.3

1 FOCUS

Section Objectives

10.8 **Explain** the relationship between plate tectonics and volcanism.

10.9 **Explain** where intraplate volcanism occurs.

Reading Focus

Build Vocabulary L2

Definitions Have students write a definition for *continental volcanic arc* and *intraplate volcanism* in their own words. After students read the section, ask them to draw a diagram that illustrates the definitions.

Reading Strategy L2

1. Ocean-Ocean
2. Ocean-Continent
B. Divergent Boundaries
C. Intraplate Igneous Activity

2 INSTRUCT

Convergent Plate Boundaries

Build Science Skills L2

Interpreting Diagrams/Photographs In the caption for Figure 14, it states that Mount St. Helens is located on the convergent boundary of the Juan de Fuca plate and the North American plate. Have students find these plates on a map of Earth's plates. Ask: **How do the sizes of the two plates compare?** *(The Juan de Fuca plate is much smaller than the North American plate.)* **Which plate is subducting?** *(the Juan de Fuca plate)* **Verbal**

Divergent Plate Boundaries

Teacher Demo

Observing Plate Movement

L2

Purpose Students will observe convergent plate movements.

Materials 9 student textbooks, 2 pieces of poster board, thin cardboard or 1-cm stack of notebook paper

Procedure Stack eight textbooks in two equal stacks. Leave about 5 cm between the textbook stacks. The remaining textbook will represent a continental crustal plate. The poster board will represent the subducting oceanic lithosphere. Give the poster board a slight curve so that it will subduct downward. Place the textbook on one of the stacks and the poster board on the other stack. Ask: **What do you predict will happen when these two plates collide?** *(The less rigid plate will subduct under the rigid plate.)* Start moving the "plates" toward each other. The oceanic lithosphere should subduct under the continental plate. Repeat this procedure using two pieces of poster board. Before moving the plates together, ask: **What do you predict will happen when these two plates collide?** *(The two slabs of crust will form a trench as they descend into the mantle.)* One piece of poster board needs to be curved so it will form a trench as it subducts.

Expected Outcomes Students will observe how the oceanic lithosphere subducts under the crustal plate and how two oceanic plates form a trench.
Visual, Kinesthetic

MAP MASTER Skills Activity

Answer

Inferring They occur at divergent boundaries for continental plates and at ocean ridges for oceanic plates.

Go Online NSTA SCILINKS

Download a worksheet on volcanic activity for students to complete, and find additional teacher support from NSTA SciLinks.

MAP MASTER Skills Activity

Major Volcanoes

Figure 15
Location Note the concentration of volcanoes encircling the Pacific basin, known as the Ring of Fire.
Inferring How are the volcanoes in the middle of the Atlantic Ocean related to a plate boundary?

Ocean-Ocean Volcanism at a convergent plate where one oceanic slab descends beneath another results in the formation of a chain of volcanoes on the ocean floor. Eventually, these volcanic structures grow large enough to rise above the surface and are called volcanic island arcs. Several volcanic island arcs border the Pacific basin, including the Aleutians.

Ocean-Continent Volcanism associated with convergent plate boundaries may also develop where slabs of oceanic lithosphere are subducted under continental lithosphere to produce a continental volcanic arc. The mechanisms are basically the same as those at island arcs. The major difference is that continental crust is much thicker and is composed of rocks with a higher silica content than oceanic crust. As the silica-rich crustal rocks melt, the magma may change composition as it rises through continental crust. The volcanoes of the Andes Mountains along the western edge of South America are an example of a continental volcanic arc, as shown in Figure 15.

Go Online NSTA SCILINKS

For: Links on predicting volcanic activity
Visit: www.SciLinks.org
Web Code: cjn-3103

Divergent Plate Boundaries

Most magma is produced along the oceanic ridges during seafloor spreading. Below the ridge axis where the plates are being pulled apart, the solid yet mobile mantle rises upward to fill in the rift where the plates have separated. As rock rises, confining pressure decreases. The rock undergoes decompression melting, producing large amounts of magma. This newly formed basaltic magma is less dense than the mantle rock from which it was formed, so it buoyantly rises.

Partial melting of mantle rock at spreading centers produces basaltic magma. Although most spreading centers are located along the axis of an oceanic ridge, some are not. The East African Rift in Africa is a site where continental crust is being rifted apart.

Customize for English Language Learners

Select and copy an appropriate paragraph from one of the sections, such as the last paragraph on p. 293. Leave the first and last sentences intact, since they are usually the introductory and concluding sentences. For the sentences in the middle, remove key words and replace them with a blank. For example, leave blanks for *convergent* in the second sentence of this paragraph, *mantle* in the third sentence, and the last use of *melting* in the fourth sentence. Have students read the paragraph and fill in the blanks with the appropriate words.

Intraplate Igneous Activity

Kilauea is Earth's most active volcano, but it is in the middle of the Pacific plate, thousands of kilometers from a plate boundary. **Intraplate volcanism** occurs within a plate, not at a plate boundary. Another site of intraplate volcanism is Yellowstone National Park.

Most intraplate volcanism occurs where a mass of hotter than normal mantle material called a mantle plume rises toward the surface. Most mantle plumes appear to form deep within Earth at the core-mantle boundary. These plumes of hot mantle rock rise toward the surface in a way similar to the blobs that form within a lava lamp. Once the plume nears the top of the mantle, decompression melting forms basaltic magma. The result may be a small volcanic region a few hundred kilometers across called a hot spot. More than 40 hot spots have been identified, and most have lasted for millions of years. By measuring the heat flow at hot spots, geologists found that the mantle beneath some hot spots may be 100–150°C hotter than normal.

The volcanic activity on the island of Hawaii, shown in Figure 16, is the result of a hot spot. Where a mantle plume has persisted for long periods of time, a chain of volcanoes may form as the overlying plate moves over it. Mantle plumes are also thought to cause the vast outpourings of lava that create large lava plateaus such as the Columbia Plateau in the northwestern United States.

Figure 16 Intraplate Volcano An eruption of Hawaii's Kilauea volcano. The Hawaiian hot spot activity is currently centered beneath Kilauea and is an example of intraplate volcanic activity.

Section 10.3 Assessment

Reviewing Concepts

1. How are the locations of volcanoes related to plate boundaries?
2. What causes intraplate volcanism?
3. Where is most of the magma produced on Earth on a yearly basis?
4. What is the Ring of Fire?

Critical Thinking

5. **Comparing and Contrasting** What are the differences between volcanic island arcs and continental volcanic arcs?
6. **Predicting** Would it be more likely for a major explosive eruption to occur at an ocean ridge or at a convergent ocean-continental boundary? Explain your answer.

Writing in Science

Explanatory Paragraph Write a paragraph to explain how magma is formed in the crust without adding heat.

Intraplate Igneous Activity

Build Reading Literacy L1

Refer to **p. 186D** in **Chapter 7**, which provides the guidelines for relating text and visuals.

Relate Text and Visuals Have students compare the drawings of the plates and volcanic activity in Figures 15 and 16 to the text explanations in this section.
Visual

3 ASSESS

Evaluate Understanding L2

Have students create a ten-question crossword puzzle or word scramble using the concepts from this section. Have students exchange papers and work the puzzles.

Reteach L1

Use Figure 15 to reteach the concepts in this section.

Writing in Science

Magma can form by decompression melting if the rock begins to rise and the pressure decreases. This causes the temperature at which melting occurs to decrease. If water is added, the temperature at which the rock melts decreases. A body of hotter rock may rise and trigger melting in the crust.

Section 10.3 Assessment

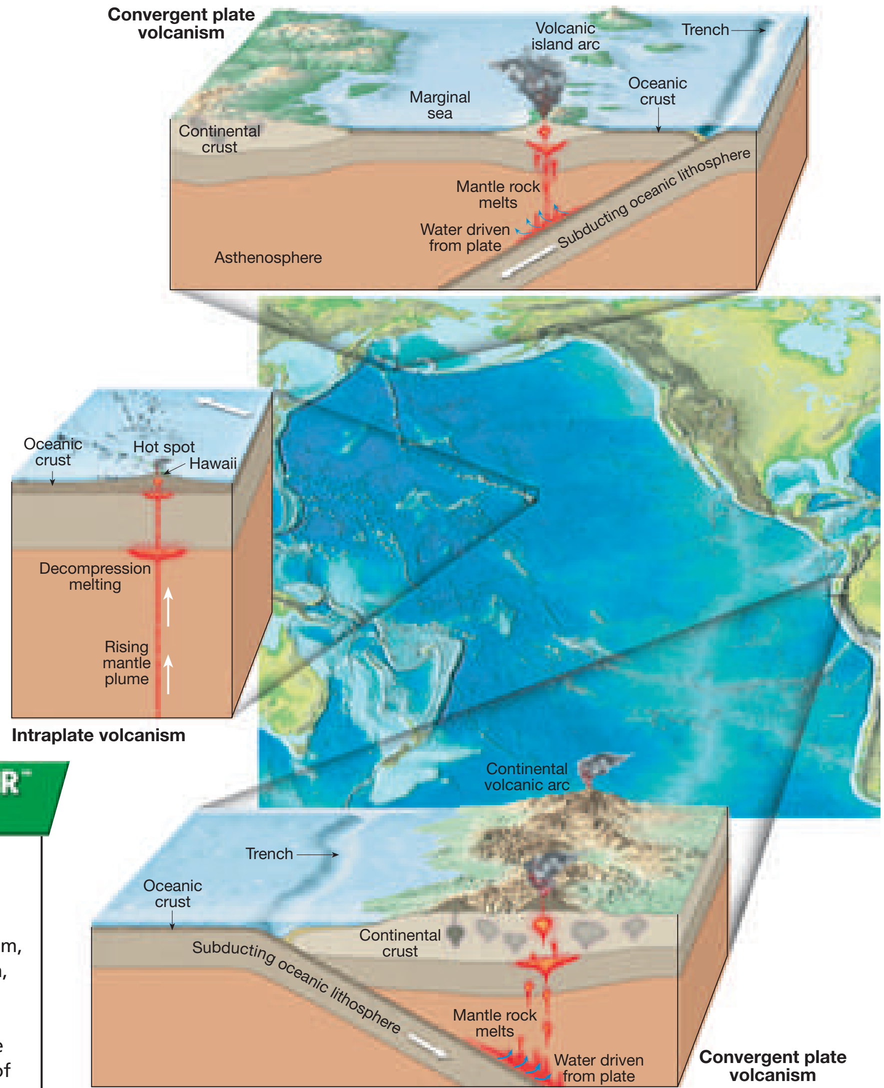
1. Most volcanoes are located at either divergent or convergent plate boundaries, where plate motions provide the mechanisms to form magma.
2. Intraplate volcanism is caused by hot mantle plumes rising up from the core-mantle boundary, causing decompression melting and forming small areas of volcanic activity on the surface.
3. Most of the magma produced each year on Earth is produced at ocean ridges during seafloor spreading.
4. The Ring of Fire is a chain of volcanoes that are located around the edge of the Pacific Basin.
5. A volcanic island arc is formed when two oceanic plates converge and form a subduction zone. The magma produced is of basaltic composition. A continental volcanic arc is formed by subduction of an ocean plate beneath a continental plate. The magma produced is more silica rich than that formed at a volcanic island arc.
6. An explosive eruption would be more likely at a convergent ocean-continental boundary, because the magma produced is more silica rich, more viscous, and contains more water.

MAP MASTER™ Skills Activity

Answer

Drawing Conclusions Volcanoes occur on both continental and oceanic plates in all the zones—convergent plate volcanism, divergent plate volcanism, and intraplate volcanism.

Three Zones of Volcanism

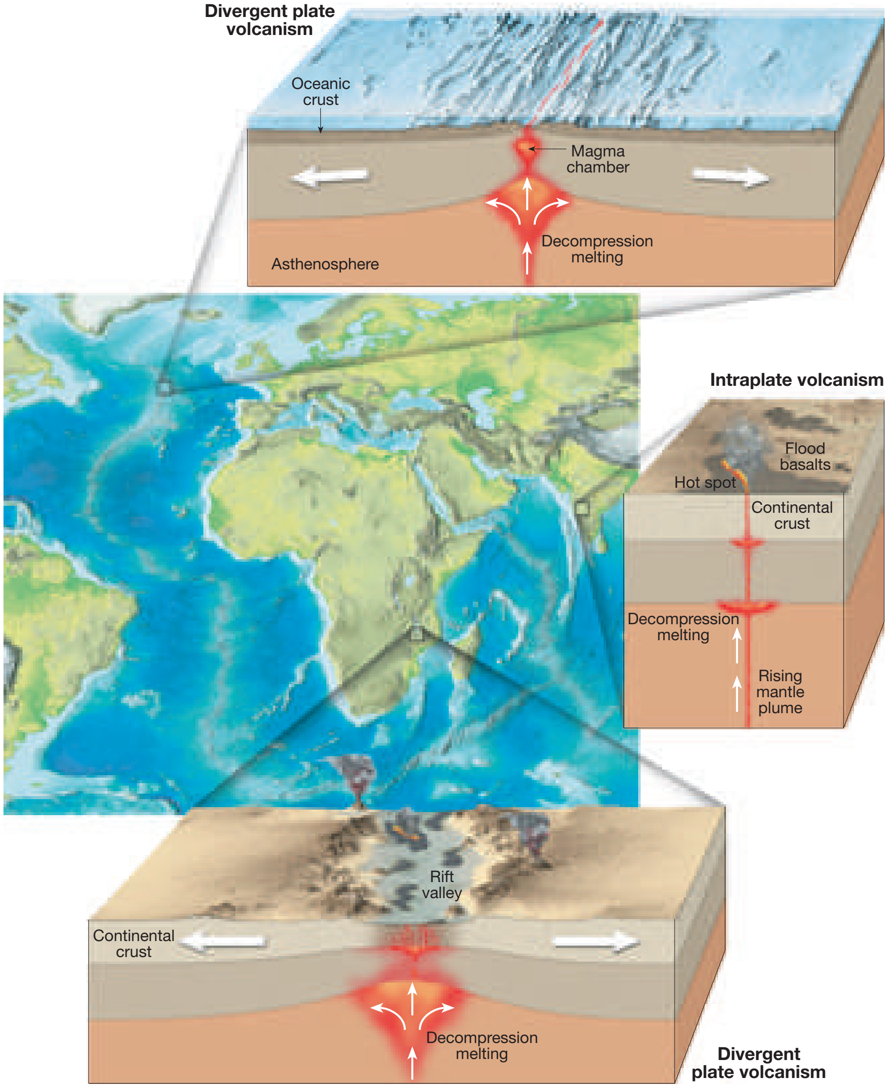


MAP MASTER™ Skills Activity

Figure 17

Regions The three zones of volcanism are convergent plate volcanism, divergent plate volcanism, and intraplate volcanism. Two of these zones are plate boundaries, and the third is the interior area of the plates.

Drawing Conclusions In which zones do volcanoes occur on both continental plates and oceanic plates?



Volcanoes and Other Igneous Activity 297

How the Earth Works

1 FOCUS

Objectives

In this feature, students will
- explain what a volcano is.
- describe the immediate effects of a volcanic eruption.
- identify some long-term effects of a volcanic eruption.

Reading Focus

Build Vocabulary L2

Classify Terms Draw a four-column chart on the board. Label the columns as follows: *Volcanic Effect*, *Definition of Effect*, *Immediate or Long-Term Effect*, and *Local or Worldwide Effect*. Have students use information on these two pages to complete the chart.

2 INSTRUCT

Use Visuals L2

Ask students to read the captions on this page and the next. Have them make a list of places in the United States and in other countries where volcanoes are or have been active.
Visual

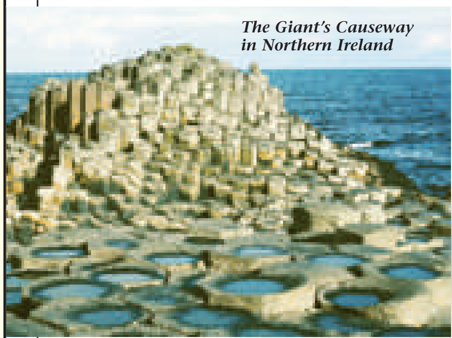
Bellringer L2

Have students list ten effects of a volcanic eruption. Examples may include clouds of smoke, lava trails, and a scorched landscape.
Logical

How the Earth Works

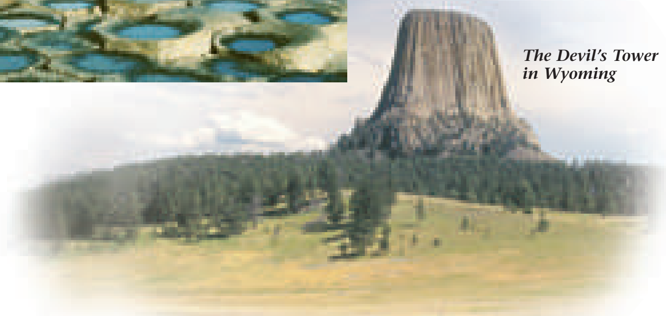
Effects of Volcanoes

A **volcano** is an opening in the Earth's crust from which **lava,** or molten rock, escapes to the surface. The impact of powerful volcanic eruptions is both immediate and long-lasting. Burning rocks are flung out in all directions. Huge clouds of scorching ash and fiery gases billow high into the sky. As a result, the landscape and even the weather can be changed. Soil may become more fertile when enriched with nutrients from volcanic ash. Islands, mountains, and other landforms may be created from the material emitted by volcanoes.



The Giant's Causeway in Northern Ireland

DRAMATIC ROCK FORMATIONS
Lava flows can form amazing rock formations. **Columnar rocks** are volcanic rocks that split into columns as the lava cools. The Devil's Tower in Wyoming (below) is one example of a columnar rock. Another example is the Giant's Causeway (left). This rock formation in Northern Ireland is the result of a lava flow that erupted millions of years ago.



The Devil's Tower in Wyoming

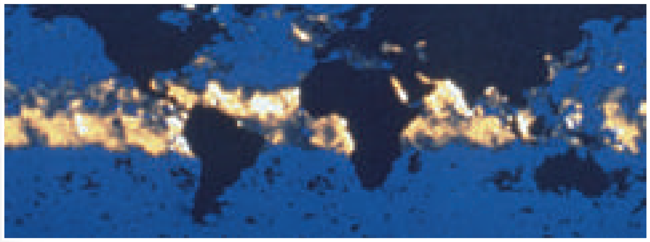
DUST AND GAS
Explosive volcanoes, like Mount St. Helens in Washington (right), spit clouds of ash and fumes into the sky. The debris can completely cover human communities. Another hazard is that volcanic gases may be deadly poisons.

ERUPTING LAVA
Red-hot lava is hurled into the air during an eruption of a volcano on Stromboli, an island off the coast of southern Italy. The Stromboli volcano is one of only a few volcanoes to display continuous eruptive activity over a period of more than a few years.

Facts and Figures

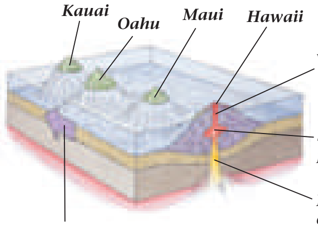
The ancient Roman city of Pompeii was encased in lava when Mount Vesuvius erupted in A.D. 79. The volcano destroyed the city, and most people were buried in ash and lava. Rain hardened the ash, forming perfect molds of people and preserving articles of everyday life. Pompeii's ruins were first discovered in the late sixteenth century. Since 1748, archaeologists have excavated materials that provide a detailed picture of life in a busy Roman port town. In addition to houses, bakeries, restaurants, and factories, scholars have uncovered inscriptions on buildings, tombs, and statues. Even the graffiti on Pompeii's walls gives us clues about the values and concerns of this ancient society.

AFFECTING THE WORLD'S WEATHER
Powerful eruptions emit gas and dust that can rise high into the atmosphere and travel around the world. Volcanic material can reduce average temperatures in parts of the world by filtering out some of the sunlight that warms the Earth.



A satellite image shows the global spread of emissions from the 1991 eruptions of Mount Pinatubo in the Philippines.

A STRING OF ISLANDS
The Hawaiian Islands are the tops of volcanic mountains. They have developed over millions of years as a **plume,** or a very hot spot in the Earth's mantle, erupted great amounts of lava. As the Pacific Plate moves over the stationary plume, it carries older islands in the chain to the northwest. Today, active volcanoes are found on the island of Hawaii and the newly forming island of Loihi.



A crater lake in Iceland

A CRATER LAKE
A **crater lake** is a body of water that occupies a bowl-shaped depression around the opening of an extinct or dormant volcano. An eruption can hurl the water out of the crater. The water can then mix with hot rock and debris and race downhill in a deadly mudslide.

LIFE RETURNS TO THE LAVA
In time, plant life grows on lava. Lichen and moss often appear first. Grass and larger plants slowly follow. The upper surface of the rock is gradually weathered, and the roots of plants help break down the rock to form soil. After many generations, the land may become lush and fertile again.

A few lichens find a home on the lava.

Plants take root in the beginnings of topsoil.

ASSESSMENT

1. **Key Terms** Define **(a)** volcano, **(b)** lava, **(c)** columnar rock, **(d)** plume, **(e)** crater lake.
2. **Natural Resources** How can soil become more fertile as a result of volcanic eruptions?
3. **Environmental Change** **(a)** How can volcanic activity create new landforms? **(b)** How can explosive volcanic eruptions affect the atmosphere and weather around the world?
4. **Natural Hazards** What are some of the ways in which a volcanic eruption can devastate nearby human settlements?
5. **Critical Thinking** **Sequencing** Study the diagram of the Hawaiian Islands and the caption that accompanies it. **(a)** Which island on the diagram is probably the oldest? Why do you think so? **(b)** What will happen to the volcanoes on the island of Hawaii as a result of plate movement?

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3 ASSESS

Evaluate Understanding L2

Have students review the information in the charts they have created. Ask: **What are some positive effects of volcanoes?** *(They create islands, fertilize soil, and create beautiful rock formations.)*

Reteach L1

Have students compare and contrast the formation and eruptions of Mount St. Helens shown in the photograph with the Hawaiian Islands shown in the diagram.

Assessment

1. (a) an opening in Earth's crust from which lava escapes to the surface; (b) molten rock; (c) volcanic rocks that split into columns as the lava cools; (d) a very hot spot in Earth's mantle; (e) a body of water that occupies a bowl-shaped depression around the opening of an extinct or dormant volcano
2. Soil becomes enriched with nutrients from volcanic ash.
3. (a) Underwater plumes erupt great amounts of lava over millions of years, building the tops of underwater volcanic mountains.
(b) Gas and dust from an eruption may rise high into the atmosphere, travel around the world, and filter out sunlight.
4. Volcanic debris can completely cover human communities, and volcanic gases are deadly poisons.
5. (a) Kauai is the oldest island because of the direction in which the plate is moving.
(b) The volcanoes on the island of Hawaii will become extinct as plate movement causes the island to move away from the stationary plume.