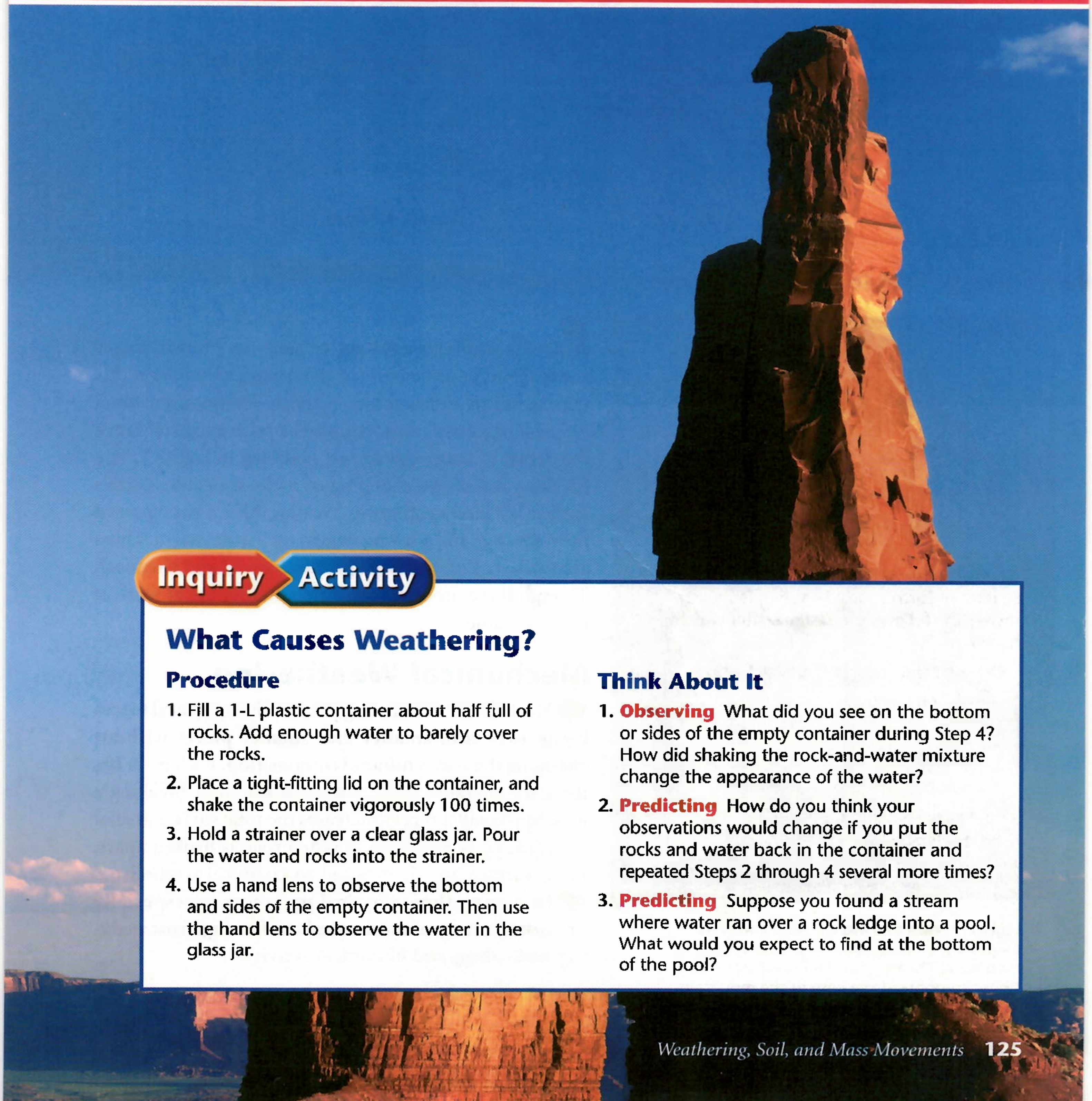
Chapter Preview



Inquiry Activity

What Causes Weathering?

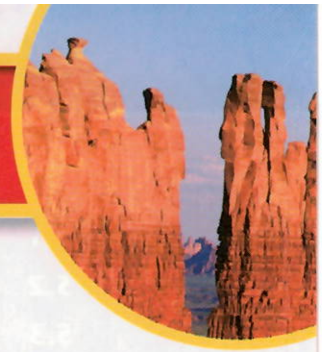
Procedure

1. Fill a 1-L plastic container about half full of rocks. Add enough water to barely cover the rocks.
2. Place a tight-fitting lid on the container, and shake the container vigorously 100 times.
3. Hold a strainer over a clear glass jar. Pour the water and rocks into the strainer.
4. Use a hand lens to observe the bottom and sides of the empty container. Then use the hand lens to observe the water in the glass jar.

Think About It

1. **Observing** What did you see on the bottom or sides of the empty container during Step 4? How did shaking the rock-and-water mixture change the appearance of the water?
2. **Predicting** How do you think your observations would change if you put the rocks and water back in the container and repeated Steps 2 through 4 several more times?
3. **Predicting** Suppose you found a stream where water ran over a rock ledge into a pool. What would you expect to find at the bottom of the pool?

5.1 Weathering



Reading Focus

Key Concepts

- What is mechanical weathering?
- What is chemical weathering?
- What factors affect the rate of weathering?

Vocabulary

- mechanical weathering
- frost wedging
- talus
- exfoliation
- chemical weathering

Reading Strategy

Building Vocabulary Copy the table. As you read the section, define each vocabulary term.

Vocabulary Term	Definition
Mechanical weathering	a. ____?____
Frost wedging	b. ____?____
Talus	c. ____?____
Exfoliation	d. ____?____
Chemical weathering	e. ____?____

Figure 1 Weathering Ice, rain, and wind are slowly breaking down the rock in this mountain. The rock fragments accumulate in sloped deposits at the base of the mountain.

Earth's surface is constantly changing. Internal forces gradually raise some parts of the surface through mountain building and volcanic activity. At the same time, external processes continually break rock apart and move the debris to lower elevations, as shown in Figure 1. The breaking down and changing of rocks at or near Earth's surface is called weathering. Weathering is a basic part of the rock cycle and a key process in the Earth system. There are two types of weathering—mechanical and chemical. Though these processes are different, they are at work at the same time.

Mechanical Weathering

Mechanical weathering occurs when physical forces break rock into smaller and smaller pieces without changing the rock's mineral composition. Each piece has the same characteristics as the original rock. Breaking a rock into smaller pieces increases the total surface area of the rock. Look at Figure 2. When rock is broken apart, more surface area is exposed to chemical weathering. **In nature, three physical processes are especially important causes of mechanical weathering: frost wedging, unloading, and biological activity.**

Mechanical Weathering and Surface Area

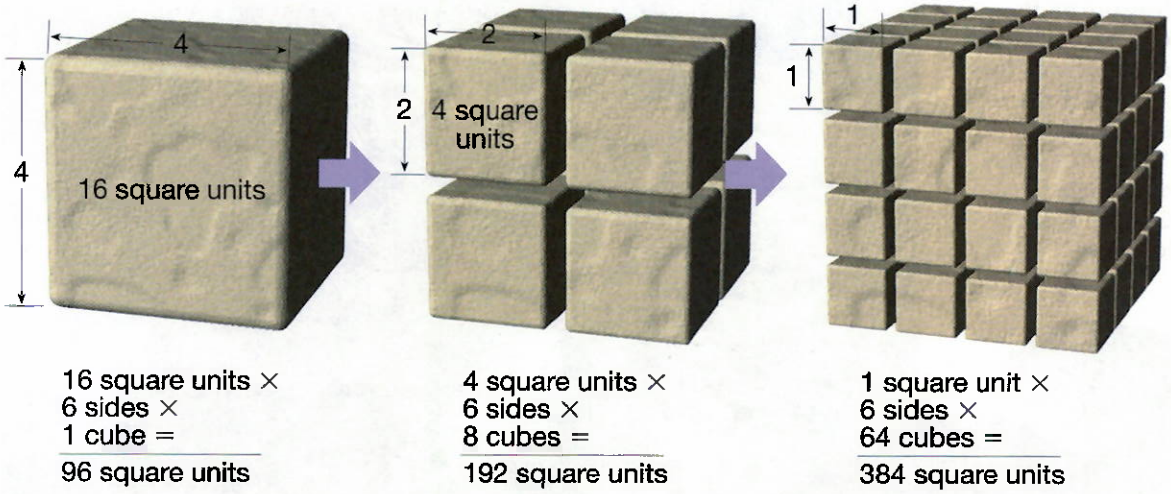


Figure 2 By breaking a rock into smaller pieces, mechanical weathering increases the rock's surface area that can be exposed to chemical weathering.
Calculating ***Calculate the total surface area if each of the 64 cubes shown in the right diagram were broken into 8 equal-sized cubes.***

Frost Wedging When liquid water freezes, it expands by about 9 percent, exerting a tremendous outward force. This force is great enough to burst water pipes during the winter. In nature, water works its way into every crack in rock. When water freezes and expands, it enlarges the cracks. After many freeze-thaw cycles, the rock breaks into pieces. This process, which is shown in Figure 3, is called **frost wedging.** Frost wedging is most common in mountainous regions in the middle latitudes. Here daily freezing and thawing often occur. Sections of rock that are wedged loose may tumble into large piles called **talus,** which typically form at the base of steep, rocky cliffs.

Reading Checkpoint ***Explain how water can cause mechanical weathering.***

Figure 3 Frost Wedging Rainwater entered cracks in this boulder. Each time the water froze, it expanded. Eventually, the boulder split.

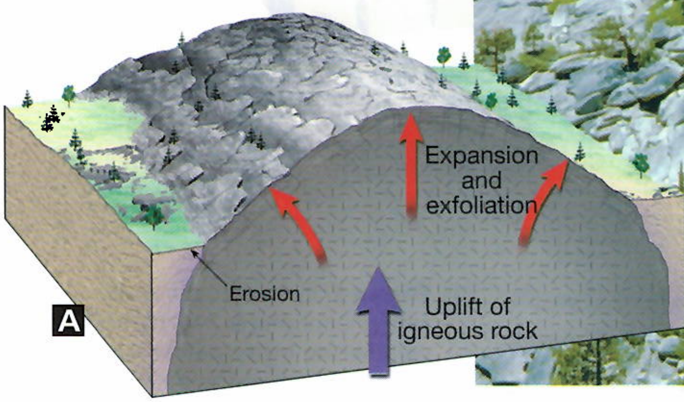


Figure 4 Unloading and Exfoliation A Uplift and erosion expose a buried mass of igneous rock. Reduced pressure on the rock, called unloading, causes the outer rock layers to expand. They separate from the rest of the rock mass. This process is called exfoliation. **B** The granite layers of Half Dome in Yosemite National Park, California, are undergoing exfoliation.

Unloading Large masses of igneous rock may be exposed through uplift and erosion of overlying rocks. When that happens, the pressure exerted on the igneous rock is reduced. This is known as unloading. As illustrated in Figure 4A, unloading causes the outer layers of the rock to expand more than the rock below. Slabs of outer rock separate like the layers of an onion and break loose in a process called **exfoliation.** Exfoliation is especially common in rock masses made of granite. It often produces large, dome-shaped rock formations. Figure 4B shows one of these formations. Other important exfoliation domes are Stone Mountain, Georgia, and Liberty Cap also in Yosemite National Park.

A striking example of the weathering effects of unloading is shown in deep underground mining. Newly cut mine tunnels suddenly reduce the pressure on the surrounding rock. As a result, large rock slabs sometimes explode off the walls of the tunnels.

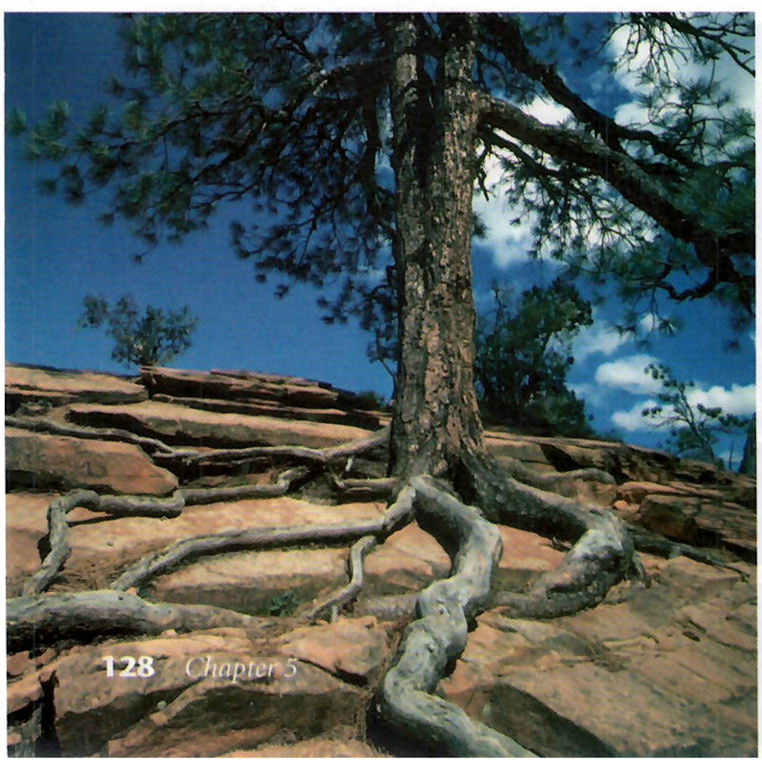


Figure 5 The roots of this tree are causing mechanical weathering by widening the cracks in the rock.

Biological Activity The activities of organisms, including plants, burrowing animals, and humans, can also cause mechanical weathering. As Figure 5 shows, plant roots grow into cracks in rock, wedging the rock apart as they grow. Burrowing animals move rocks to the surface, where weathering is more rapid. Decaying organisms produce compounds called acids that cause chemical weathering.

Humans accelerate mechanical weathering through deforestation and blasting in search of minerals or in the creation of new roads.

Chemical Weathering

Chemical weathering is the transformation of rock into one or more new compounds. The new compounds remain mostly unchanged as long as the environment in which they formed does not change. You can contrast chemical weathering and mechanical weathering with a sheet of paper. Tearing the paper into small pieces is like mechanical weathering of rock. Burning the paper, which changes it into carbon dioxide and water, is like chemical weathering.

Water Water is the most important agent of chemical weathering. Water promotes chemical weathering by absorbing gases from the atmosphere and the ground. These dissolved substances then chemically react with various minerals. Oxygen dissolved in water reacts easily with certain minerals, forming oxides. For example, iron-rich minerals get a yellow to reddish-brown coating of iron oxide when they react with oxygen. Iron oxide is the rust that forms when iron-containing objects are exposed to water. Figure 6A shows this rust on barrels.

Water absorbs carbon dioxide when rain falls through the atmosphere. Water that seeps through the ground also picks up carbon dioxide from decaying organic matter. The carbon dioxide dissolved in water forms carbonic acid. This is the weak acid in carbonated soft drinks. Carbonic acid reacts with many common minerals.

Reading Checkpoint *How are water, oxygen, and carbon dioxide involved in chemical weathering?*

Figure 6 **A** Oxygen reacted with the iron in these barrels, forming iron oxide, or rust. **B** This granite gravestone, placed in 1868, shows little evidence of chemical weathering. **C** The inscription date (1872) on this marble gravestone is nearly illegible due to chemical weathering.

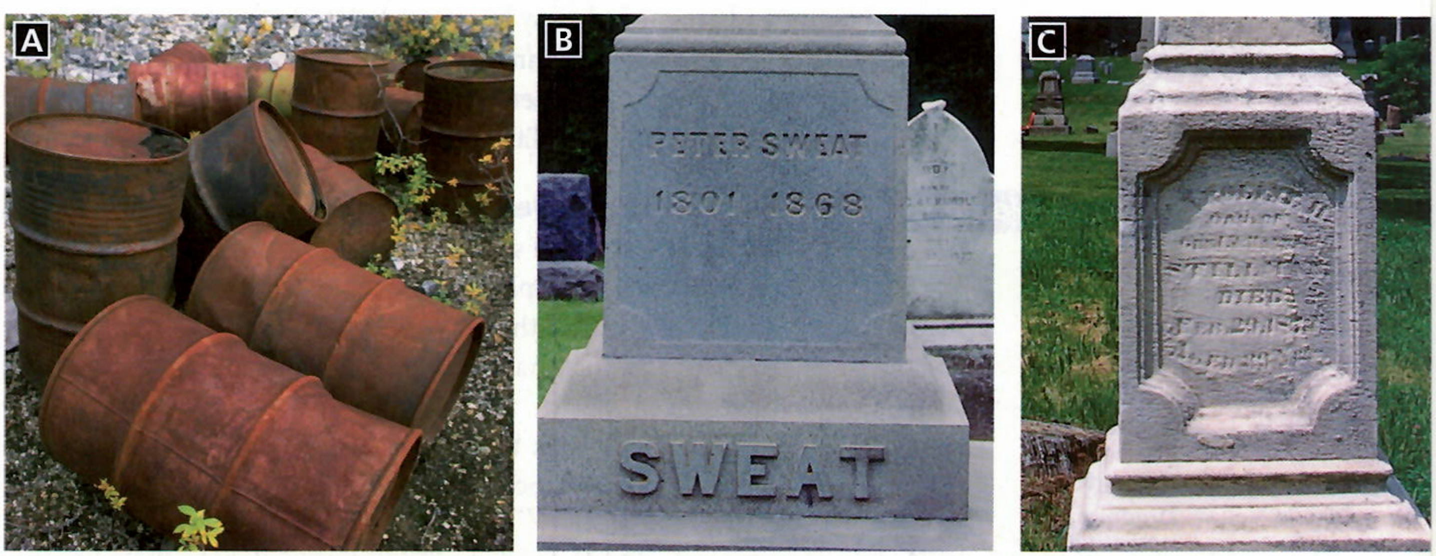


Figure 7 One Effect of Acid Precipitation Acid precipitation contributed to the chemical weathering of this stone building facade in Leipzig, Germany.

Water in the atmosphere also absorbs sulfur oxides and nitrogen oxides. These oxides are produced by the burning of coal and petroleum. Through a series of chemical reactions, these pollutants are converted into acids that are the major cause of acid precipitation. Acid precipitation accelerates the chemical weathering of stone monuments and structures, such as the one shown in Figure 7.

Chemical Weathering of Granite To illustrate how chemical weathering can change the properties of rock, let's consider granite. Recall that granite consists mainly of the minerals feldspar and quartz. When granite is exposed to water containing carbonic acid, the feldspar is converted mostly to clay minerals. Quartz, in contrast, is much more resistant to carbonic acid and remains unchanged. As the feldspar slowly changes to clay, the quartz grains are released from the granite. Rivers transport some of this weathered debris to the sea. The tiny clay particles may be carried far from shore. The quartz grains are deposited near the shore where they become the main component of beaches and sand dunes.

Chemical Weathering of Silicate Minerals Recall that silicate minerals make up most of Earth's crust and are composed largely of just eight elements. When silicate minerals undergo chemical weathering, the sodium, calcium, potassium, and magnesium they contain dissolve and are carried away by groundwater. Iron reacts with oxygen, producing iron oxide. The three remaining elements are aluminum, silicon, and oxygen. These elements usually combine with water and produce clay minerals. See Table 1 for a list of products of weathering.

Table 1 Products of Weathering

Mineral	Residual Products	Materials in Solution
Quartz	Quartz grains	Silica
Feldspars	Clay minerals	Silica K^+, Na^+, Ca^{2+}
Amphibole (hornblende)	Clay minerals Limonite Hematite	Silica Ca^{2+}, Mg^{2+}
Olivine	Limonite Hematite	Silica Mg^{2+}

Spheroidal Weathering Chemical weathering can change the physical shape of rock as well as its chemical composition. For example, when water enters along the joints in a rock, it weathers the corners and edges most rapidly. These parts of the rock have a greater surface area than the faces have. As a result, the corners and edges become more rounded. The rock takes on a spherical shape, as shown in Figure 8A. This process is called spheroidal weathering.

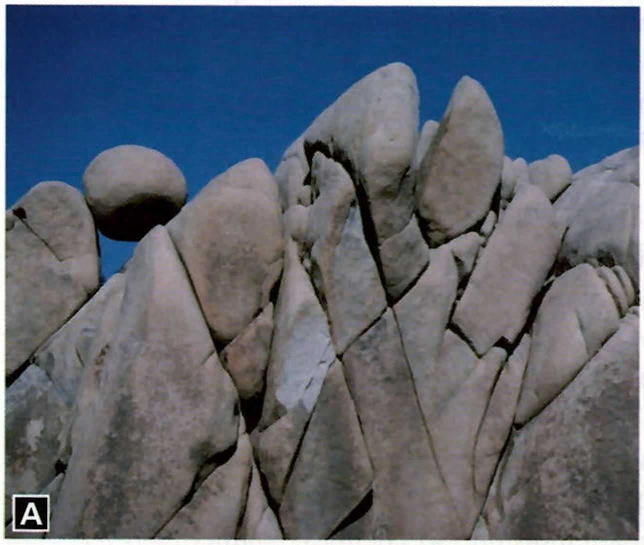


Figure 8 Spheroidal Weathering A The edges of these granite rocks in California's Joshua Tree National Monument were rounded through spheroidal weathering. **B** Spheroidal weathering has caused the outer layers of this rock to loosen and separate.

As Figure 8B shows, spheroidal weathering sometimes causes the outer layers of a rock to separate from the rock's main body. This can happen when the minerals in the rock turn to clay, which swells by adding water. The swelling exerts a force that causes the layers to break loose and fall off. This allows chemical weathering to penetrate deeper into the boulder. Although the effects of this type of spheroidal weathering resemble exfoliation, the two processes are different. Spheroidal weathering is a form of chemical weathering. Exfoliation is caused by unloading. The layers that separate from the rock are not chemically changed.

Rate of Weathering

Mechanical weathering affects the rate of chemical weathering. By breaking rock into smaller pieces, mechanical weathering accelerates chemical weathering by increasing the surface area of exposed rock. **Two other factors that affect the rate of weathering are rock characteristics and climate.**

Rock Characteristics Physical characteristics of rock, such as cracks, are important in weathering because they influence the ability of water to penetrate rock. However, a rock's mineral composition also dramatically affects its rate of weathering. You can see this by visiting a cemetery and comparing old gravestones made from different rock types. Gravestones made of granite, like the one in Figure 6B on page 129, are relatively resistant to chemical weathering. You can easily read the inscriptions on a granite gravestone that is over 100 years old. In contrast, marble gravestones undergo much more rapid chemical weathering, as shown in Figure 6C on page 129. Marble is composed of calcite (calcium carbonate), which easily dissolves even in weak acids.

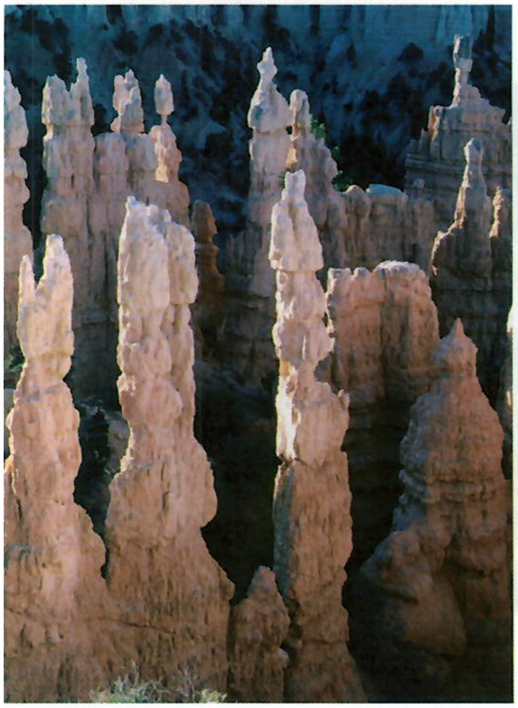


Figure 9 These boldly sculpted pinnacles in Bryce Canyon National Park show differential weathering. **Drawing Conclusions** ***In which parts of these formations is weathering happening most rapidly?***

Silicates are the most abundant mineral group. Silicates weather in the same sequence as their order of crystallization. Olivine crystallizes first and weathers most rapidly. Quartz, which crystallizes last, is the most resistant to weathering.

Climate Climatic factors, especially temperature and moisture, have a strong effect on the rate of weathering. For example, these factors control the frequency of freeze-thaw cycles, which affect the amount of frost wedging. Temperature and moisture also affect the rate of chemical weathering. They influence the kind of vegetation and how much is present. Regions with lush vegetation generally have a thick layer of soil rich in decaying organic matter that releases acids into the water.

The climate most favorable for chemical weathering has high temperatures and abundant moisture. So, chemical weathering is very slow in arid regions. It is also slow in polar regions because the low temperatures there keep moisture locked up as ice.

Differential Weathering Different parts of a rock mass often weather at different rates. This process, called differential weathering, has several causes. Differences in mineral composition are one cause. More resistant rock protrudes as pinnacles, or high peaks, such as those shown in Figure 9. Another cause is the variations in the number and spacing of cracks in different parts of a rock mass.

Section 5.1 Assessment

Reviewing Concepts

1. What happens to a rock's mineral composition during mechanical weathering?
2. What is unloading? How does it contribute to weathering?
3. How does chemical weathering affect the compounds in rock?
4. Name two rock characteristics and two climatic factors that affect the rate of weathering.

Critical Thinking

5. **Using Analogies** Think about the following processes: dissolving a piece of rock salt in a pan of water and grinding a peach pit in a garbage disposal. Which process is more like mechanical weathering, and which is more like chemical weathering?
6. **Applying Concepts** The level of carbon dioxide in the atmosphere is increasing. How might this affect the rate of chemical weathering of Earth's surface rocks? Explain your reasoning.

Math Practice

7. Suppose frost wedging splits a spherical rock 2 m in diameter into two equal-sized hemispheres. Calculate the total surface area of the original rock and of the two hemispheres. (The area of a circle = πr^2, and the surface area of a sphere = $4\pi r^2$, where r is the radius.)

5.2 Soil

Reading Focus

Key Concepts

- What are the major components of soil?
- What are the most important factors in soil formation?
- How does soil vary with depth?
- What are three common types of soil?
- How do human activities affect the rate of soil erosion?

Vocabulary

- regolith
- soil
- soil horizon
- soil profile
- pedalfer
- pedocal
- laterite

Reading Strategy

Comparing and Contrasting Copy the table. After you read, compare the three types of soils by completing the table.

Soil Type	Where It's Found
Pedalfer	a. ___?___
Pedocal	b. ___?___
Laterite	c. ___?___

Soil, an important product of weathering, covers most land surfaces. Along with air and water, it is one of our most important resources. All life depends on a dozen or so elements that come from Earth's crust. Once weathering and other processes create soil, plants absorb the elements and make them available to animals, including humans.

Characteristics of Soil

Weathering produces a layer of rock and mineral fragments called **regolith,** which covers nearly all of Earth's land surface. **Soil is the part of the regolith that supports the growth of plants.** Three important characteristics of soil are its composition, texture, and structure.

Soil Composition **Soil has four major components: mineral matter, or broken-down rock; organic matter, or humus, which is the decayed remains of organisms; water; and air.** The proportions of these components vary in different soils. Figure 10 shows that in a good-quality surface soil, mineral matter and organic matter make up half the total volume. The organic matter in soil, or humus, consists of the decayed remains of animal and plant life. The other half consists of pore spaces where air and water circulate.

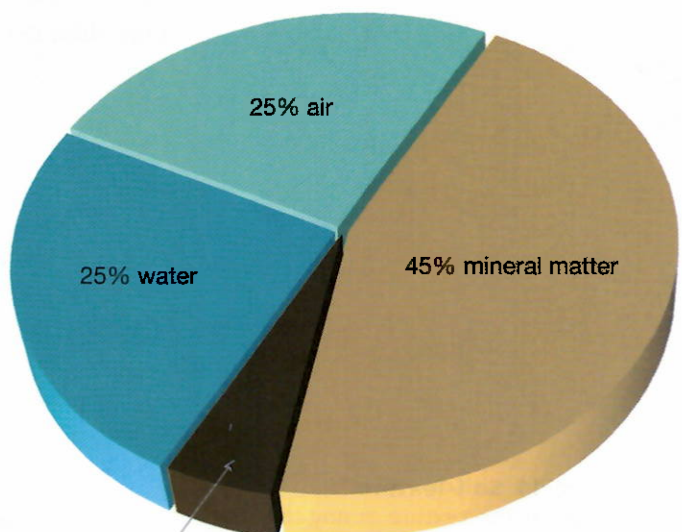


Figure 10 Composition by Volume of Good-Quality Soil
Using Graphs ***What percentage of this soil consists of water and mineral matter?***

Q&A

***Q** I've seen photos of footprints left on the lunar surface by astronauts. Does this mean the moon has soil?*

A Not exactly. The moon has no atmosphere, water, or biological activity. So, the weathering processes that occur on Earth don't take place on the moon. However, the lunar surface is covered by a layer of gray debris called lunar regolith, which was ejected by meteorite impacts over a few billion years. Changes occur so slowly on the lunar surface that the footprints left by the *Apollo* astronauts will probably look fresh for millions of years.

The percentage of organic matter in soil varies greatly. Certain bog soils are composed almost entirely of organic matter. Desert soils may contain only a tiny amount. In most soils, organic matter or humus is an essential component. It is an important source of plant nutrients and increases the soil's ability to retain water. Poor soils can be enriched with the addition of humus.

The water and air components of soil are also vital for plant growth. Soil water provides the moisture needed for chemical reactions that sustain life. Soil water provides nutrients in a form that plants can use. Air is the source of the carbon dioxide plants use to produce sugar during photosynthesis.

Soil Texture Most soils contain particles of different sizes. Soil texture refers to the proportions of different particle sizes. To classify soil texture, the U.S. Department of Agriculture has established categories based on the percentages of clay, silt, and sand in soil. The diagram in Figure 11 shows how the percentages differ for each category. For example, point A, near the left-center part of the diagram, represents a soil composed of 40 percent clay, 10 percent silt, and 50 percent sand. Such a soil is called a sandy clay. In soils called loam, which occupy the central part of the diagram, neither clay, silt, nor sand is dominant.

Texture strongly influences a soil's ability to support plant life. Sandy soils may drain and dry out too quickly, while clay-rich soils drain very slowly. Plant roots often have difficulty penetrating soils that contain a high percentage of clay and silt. Loam soils are usually best for plant growth. They retain water better and store more nutrients than do soils composed mainly of clay or sand.

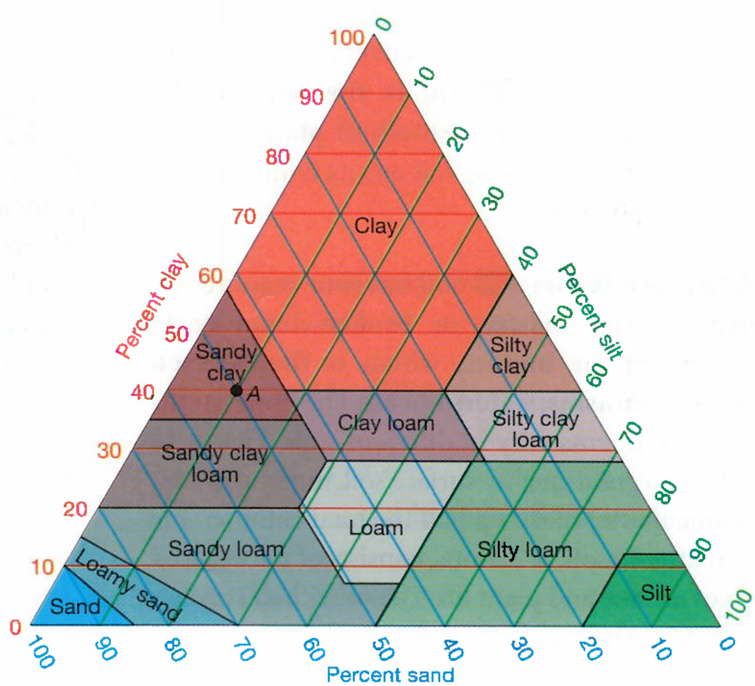


Figure 11 Soil-Texture Diagram The texture of any soil can be represented by a point on this diagram.
Interpreting Diagrams ***What type of soil consists of 10 percent clay, 60 percent silt, and 30 percent sand?***

Soil Structure Soil particles usually form clumps that give soils a particular structure. Soil structure determines how easily a soil can be cultivated and how susceptible it is to erosion. Soil structure also affects the ease with which water can penetrate the soil. This, in turn, influences the movement of nutrients to plant roots.

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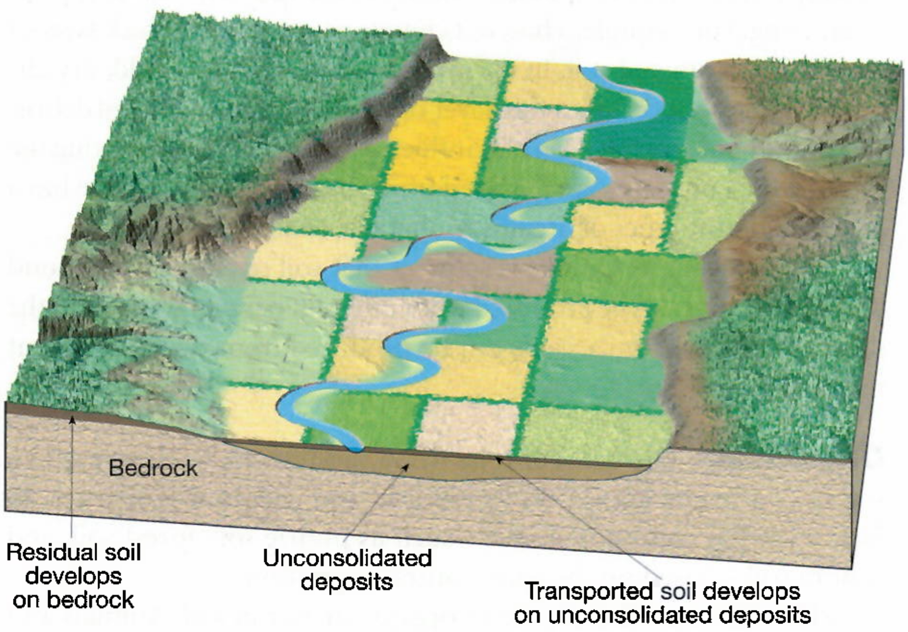
Soil Formation

Soil forms through the complex interaction of several factors. **The most important factors in soil formation are parent material, time, climate, organisms, and slope.** Although these factors all interact, we'll examine them separately.

Figure 12 Parent Materials and Soils



Parent Material The source of the mineral matter in soil is known as the parent material. Notice in Figure 12 that parent material may be either bedrock or unconsolidated deposits, such as those in a river valley. The soil that forms on bedrock is called residual soil. The soil that forms on unconsolidated deposits is called transported soil. Its parent material was moved from another location by gravity, water, wind, or ice.

Reading Checkpoint ***What is the difference between residual soil and transported soil?***

The nature of the parent material influences soils in two ways. First, it affects the rate of weathering and the rate of soil formation. Because unconsolidated deposits are already partly weathered, they provide more surface area for chemical weathering. Therefore, transported soil usually develops more rapidly than residual soil develops. Second, the chemical makeup of the parent material affects the soil's fertility. Fertility influences the types of plants the soil can support.

Time The longer a soil has been forming, the thicker it becomes. The parent material largely determines the characteristics of young soils. As weathering continues, however, the influence of the parent material can be overshadowed by the other factors, especially climate.

Climate Climate has the greatest effect on soil formation. Variations in temperature and precipitation influence the rate, depth, and type of weathering. For example, a hot, wet climate may produce a thick layer of chemically weathered soil. In the same amount of time, a cold, dry climate might produce only a thin layer of mechanically weathered debris. The amount of precipitation also influences soil fertility by affecting the rate at which nutrients are removed from the soil. Finally, climate has a big effect on the types of organisms that live on and in the soil.

The influence of climate is so great that soil scientists have found that similar soils can be produced from different parent materials in the same climate. Dissimilar soils can be produced from the same parent material in different climates.

Organisms The types of organisms and how many there are in a soil have a major impact on its physical and chemical properties. In fact, scientists name some soils—such as prairie soil, forest soil, and tundra soil—based on the soils' natural vegetation.

Plants are the main source of organic matter in soil. Animals and microorganisms may also contribute. Because organic matter releases nutrients when it decays, it contributes to soil fertility. As you read in Section 5.1, the decay of organic matter also produces acids that speed up weathering.

Microorganisms, including fungi, bacteria, and single-celled protozoans, play an active role in decomposing dead plants and animals. Some bacteria also aid soil fertility by converting nitrogen gas into nitrogen compounds that plants can use.

Burrowing animals mix the mineral and organic matter in soil. Earthworms, for example, feed on organic matter as they burrow through soil. The earthworms in a single hectare (10,000 square meters) can mix thousands of kilograms of soil each year. The holes made by burrowing animals also help water and air to penetrate into soil.

Slope The slope of the land can vary greatly over short distances. Such variations can result in very different soil types. Many of the differences are related to the amount of erosion and the water content of the soil.

On steep slopes, erosion is accelerated. Little water can soak in, so the soil generally holds too little moisture for vigorous plant growth. As a result, soils are usually thin or nonexistent on steep slopes, as shown in Figure 13A. In contrast, flat areas have little erosion and poor drainage. As Figure 13B shows, the waterlogged soils that form here are typically thick and dark. The dark color results from large amounts of organic matter.

The direction a slope faces also affects soil formation. In the temperate zone of the Northern Hemisphere, south-facing slopes receive much more sunlight than do north-facing slopes. Consequently, soils on south-facing slopes are usually warmer and drier. These differences may influence the types of plants that grow in the soil.

Although you have read about five separate factors that affect soil formation, remember that they all work together to form soil. No single factor is responsible for a soil's composition.

Reading Checkpoint ***Explain how the slope of the land affects soil thickness.***

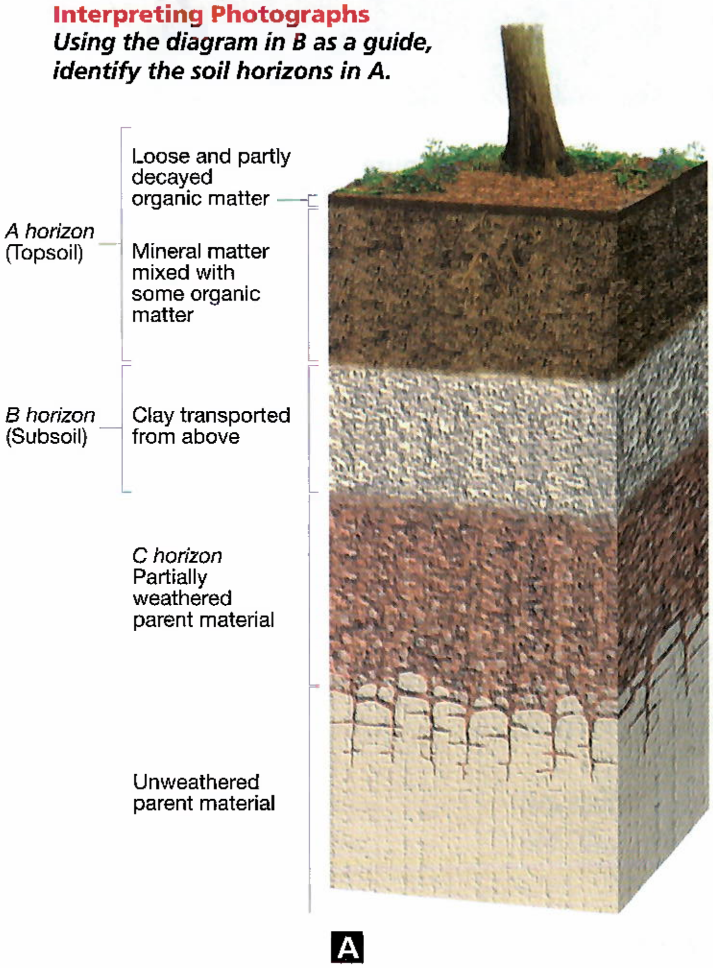
Figure 13 Slope and Soil Thickness A Little or no soil develops on steep slopes. **B** Flat areas often have very thick soil.

The Soil Profile

The processes that form soil operate from the surface downward. **Soil varies in composition, texture, structure, and color at different depths.** These variations divide the soil into zones known as **soil horizons.** A vertical section through all of the soil horizons is called a **soil profile.** In some soil profiles, the soil horizons blend gradually from one to another. In others, like the one shown in Figure 14A, the soil horizons are quite distinct. Mature soils usually have three distinct soil horizons, which are identified in Figure 14B. From the surface downward, these horizons are called the A, B, and C horizons.

A Horizon The A horizon is commonly known as topsoil. Its upper part consists mostly of organic matter, including loose leaves and partly decomposed plant structures. It is teeming with insects, fungi, and microorganisms. The lower part of the A horizon is a mixture of mineral matter and organic matter.

Figure 14 Soil Profiles A The A, B, and C horizons have different characteristics. **B** Three soil horizons are visible in this soil. **Interpreting Photographs** ***Using the diagram in B as a guide, identify the soil horizons in A.***



B Horizon The B horizon, or subsoil, contains fine clay particles washed out of the A horizon by water that filters through pore spaces. In some soils, the clay that accumulates in the B horizon forms a compact, impenetrable layer called hardpan. The B horizon is the lower limit of most plant roots and burrowing animals.

C Horizon Between the B horizon and the unaltered parent material is the C horizon, which contains partially weathered parent material. While the A and B horizons barely resemble the parent material, the C horizon does.

Soil Types

Recall that climate is the most important factor in soil formation. Climate also has a major effect on the type of soil that forms. **Three common types of soil are pedalfer, pedocal, and laterite.**

Pedalfer **Pedalfers** usually forms in temperate areas that receive more than 63 cm of rain each year. This soil type is present in much of the eastern half of the United States, most often in forested areas. The B horizon in pedalfers contains large amounts of iron oxide and aluminum-rich clays, giving it a brown to red-brown color.

Pedocal **Pedocals** are found in the drier western United States in areas that have grasses and brush vegetation. Because chemical weathering is slower in dry climates, pedocals generally contains less clay than pedalfers. Pedocals contain abundant calcite, or calcium carbonate, and are typically a light gray-brown.

Figure 15 The Temple at Angkor Wat, Cambodia This temple was constructed of laterite bricks between 1113 and 1150.

Laterite **Laterites** form in hot, wet tropical areas. Chemical weathering is intense under such conditions. So laterites are usually deeper than soils that develop over a similar period in temperate areas. The large quantity of water that filters through these soils removes most of the calcite and silica. Iron oxide and aluminum oxide are left behind. The iron oxide gives laterite a distinctive orange or red color.

When dried, laterite becomes very hard and practically waterproof. For centuries, people in portions of South and Southeast Asia have made bricks by digging up laterite, shaping it, and allowing it to harden in the sun. Ancient structures built of laterite bricks, such as the one shown in Figure 15, are well preserved even today.

Figure 16 Clearing a Tropical Rain Forest in Borneo The laterite soil cannot support agriculture for more than a few years.

Plants that die in a tropical rain forest decompose rapidly because bacterial activity is high in hot and wet climates. As a result, laterite contains almost no organic matter. The roots of living rain forest plants quickly absorb the nutrients released during decomposition. So, even though the vegetation may be dense, the soil itself contains few available nutrients. Most of the nutrients in a tropical rain forest are present in the plants themselves.

Today, large areas of tropical rain forest are being cleared for timber and to provide land for agriculture, as shown in Figure 16. However, laterite is one of the poorest soils for agriculture. Because laterite contains little organic matter and few nutrients, it cannot nourish crops. The nutrients it does have are soon washed out by the plentiful rainwater that filters through the soil. In only a few years, the soil in a freshly cleared area may be completely useless for growing crops. Without trees or crop plants to anchor the soil and shield the ground from the full force of heavy rains, the soil erodes quickly.

Reading Checkpoint ***Why is the soil in a tropical rain forest poorly suited for agriculture?***

Soil Erosion

Soils are just a tiny fraction of all Earth materials, yet they are a vital resource. Because soils are necessary for the growth of rooted plants, they are the foundation of the human life-support system. However, soils are among our most abused resources. The loss of fertile topsoil is a growing problem as human activities disturb more of Earth's surface.

Figure 17 Soil Erosion by Raindrops A raindrop can splash soil particles more than a meter away from where it strikes the soil.

How Water Erodes Soil Soil erosion is a natural part of the constant recycling of Earth materials known as the rock cycle. Water, wind, and other agents move soil from one place to another. Every time it rains, raindrops strike the soil surface with surprising force. As Figure 17 shows, each drop acts like a tiny bomb, blasting soil particles off the surface. Water flowing across the surface then carries away the dislodged particles. Because thin sheets of water move the soil particles, this process is called sheet erosion.

After flowing as a thin sheet for a short distance, the water forms tiny streams called rills. As more water enters the rills, they erode the soil further, creating trenches known as gullies, like those shown in Figure 18. Although most dislodged soil particles do not move far during each rainfall, large quantities eventually make their way downslope to a stream. The stream transports these soil particles, which are now called sediment, and eventually deposits them.

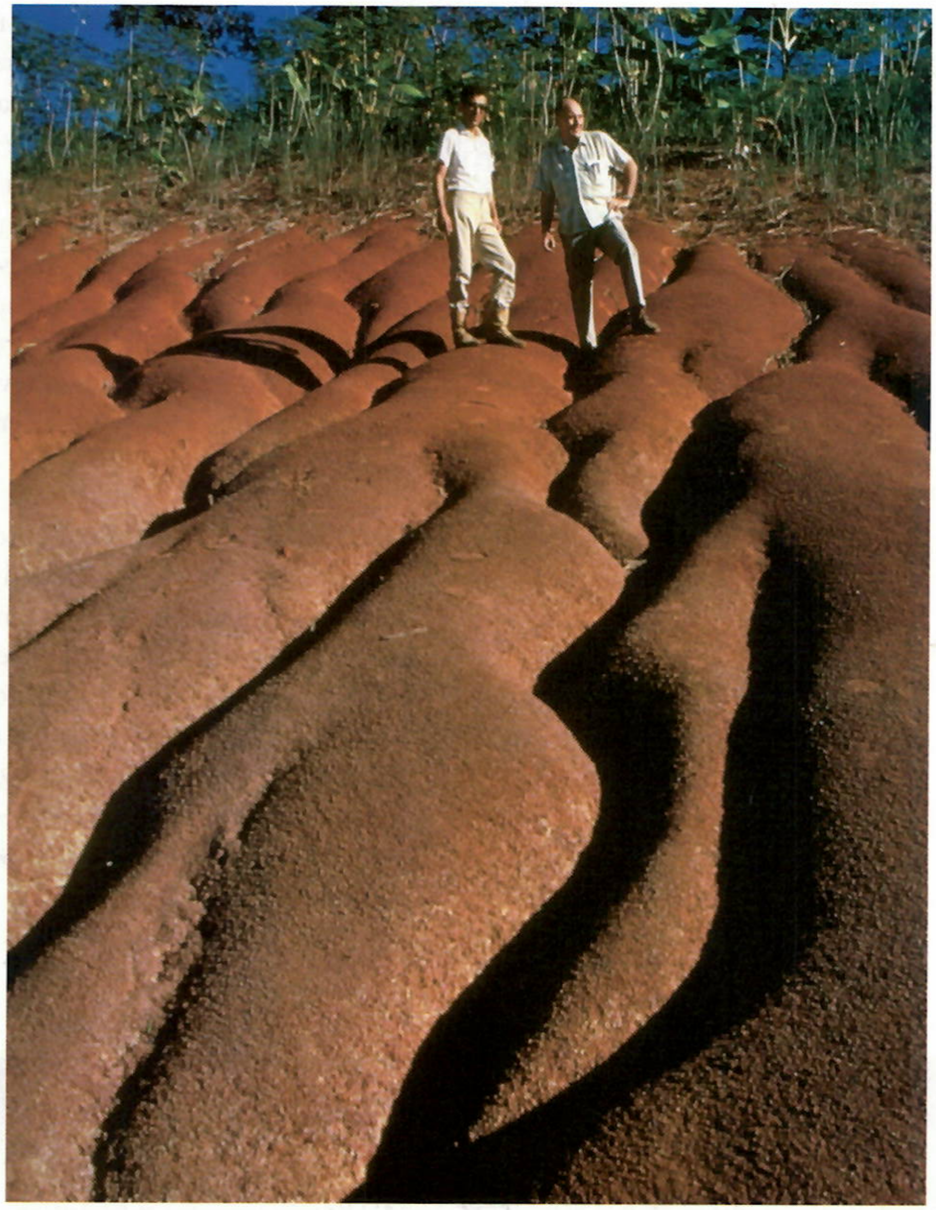


Figure 18 Gullies The unprotected soil in this field in southern Colombia is deeply eroded.

Rates of Erosion In the past, soil eroded more slowly than it does today because more land was covered by trees, grasses, and other plants. **However, human activities that remove natural vegetation, such as farming, logging, and construction, have greatly accelerated erosion.** Without plants, soil is more easily carried away by wind and water.

Scientists can estimate the rate of erosion due to water by measuring the amount of sediment in rivers. These estimates indicate that before humans appeared, rivers carried about 9 trillion kg of sediment to the oceans each year. In contrast, the amount of sediment currently transported to the sea by rivers is about 24 trillion kg per year.

Wind generally erodes soil much more slowly than water does. During a prolonged drought, however, strong winds can remove large quantities of soil from unprotected fields. That's exactly what happened during the 1930s in the part of the Great Plains that came to be known as the Dust Bowl.

The rate of soil erosion depends on soil characteristics and on factors such as climate, slope, and type of vegetation. In many regions, including about one-third of the world's croplands, soil is eroding faster than it is being formed. This results in lower productivity, poorer crop quality, and a threatened world food supply.

Reading Checkpoint ***How do human activities affect rates of erosion?***

Sediment Deposition Another problem caused by excessive soil erosion is the deposition of sediment. Rivers that accumulate sediment must be dredged to remain open for shipping. As sediment settles in reservoirs, they become less useful for storing water, controlling floods, and generating electricity.

Some sediments are contaminated with agricultural pesticides. When these chemicals enter a river or lake, they endanger organisms that live in or use the water, including humans. Sediments also contain soil nutrients, which may come from natural processes and from added fertilizers. Excessive nutrient levels in lakes stimulate the growth of algae and plants. This can accelerate a process that eventually leads to the early death of the lake.

Controlling Erosion Although we cannot completely eliminate soil erosion, we can significantly slow it by using soil conservation measures. You have seen how a misunderstanding of the composition of rain forest soil has led to the destruction of millions of acres leaving only severely leached, unproductive land. Conservation measures include steps taken to preserve environments and protect the land. These measures include planting rows of trees called windbreaks, terracing hillsides, plowing along the contours of hills, and rotating crops. Preserving fertile soil is essential to feeding the world's rapidly growing population.

Section 5.2 Assessment

Reviewing Concepts

1. List the four major components of soil.
2. How does climate affect soil formation?
3. Describe the contents of the three soil horizons found in most mature soils.
4. What climates are usually associated with pedalfer, pedocal, and laterite?
5. How can an activity such as road construction affect the rate of soil erosion?

Critical Thinking

6. **Relating Cause and Effect** A gardener notices that rain showers usually produce long-lasting puddles on the soil in her garden. Is it more likely that the soil contains too much sand or too much clay? Explain.
7. **Predicting** Which activity would cause more sediment to be deposited in a river that flows through a gently sloping valley—cultivating the valley or cultivating the hills that surround the valley? Explain.

Connecting Concepts

Weathering and Soil Using what you learned about chemical weathering in Section 5.1, explain why the soils formed in a hot, wet climate and a cold, dry climate are different.

5.3 Mass Movements

Reading Focus

Key Concepts

- What is mass movement?
- What factors trigger mass movements?
- How do geologists classify mass movements?

Vocabulary

- mass movement
- rockfall
- rockslide
- slump
- mudflow
- earthflow
- creep

Reading Strategy

Previewing Copy the table. Before you read the section, rewrite the green topic headings as *what* questions. As you read, write an answer to each question.

Question	Answer
a. ____?____	b. ____?____
c. ____?____	d. ____?____

Earth's land surface consists of slopes, some steep and others very gradual. While most slopes appear stable, they are always changing. The force of gravity causes material to move downslope. **The transfer of rock and soil downslope due to gravity is called mass movement.** Some types of mass movement are so slow that you cannot see them. Others, such as landslides like the one illustrated in Figure 19, are very sudden.

The combined actions of weathering and mass movement produce most landforms. Once weathering weakens and breaks rock apart, mass movement moves the debris downslope. There a stream usually carries it away. Stream valleys are the most common of Earth's landforms.

Q&A

Q *Are snow avalanches a type of mass movement?*

A Yes. These thundering downslope movements of snow and ice can also transport large quantities of rock, soil, and trees. About 10,000 snow avalanches occur each year in the mountainous western United States. Besides damaging buildings and roads at the bottom of slopes, they are especially dangerous to skiers. In an average year, snow avalanches claim between 15 and 25 lives in the United States and Canada. Snow avalanches are a growing problem as more people participate in winter sports and recreation.

Figure 19 Landslide This home in Pacific Palisades, California, was destroyed by a landslide triggered by the January 1994 Northridge earthquake.

Figure 20 Mudflow In October 1998, heavy rains from Hurricane Mitch led to massive mudflows in Central America.
Formulating Hypotheses ***What human activities before the rains might have contributed to the mudflows?***

Triggers of Mass Movements

Gravity is the force behind mass movements. Several factors make slopes more susceptible to the pull of gravity. **Among the factors that commonly trigger mass movements are saturation of surface materials with water, oversteepening of slopes, removal of vegetation, and earthquakes.**

Water Heavy rains and rapid melting of snow can trigger mass movement by saturating surface materials with water. This was the case when torrential downpours associated with Hurricane Mitch caused devastating mudflows, as shown in Figure 20. When the pores in sediment become filled with water, the particles slide past one another more easily. You can demonstrate this effect with sand. If you add water until the sand becomes slightly moist, the sand grains will stick together. However, if you add enough water to fill all the pores between the sand grains, the sand-water mixture will ooze downhill. Clay also becomes very slick when it is wet.

Oversteepened Slopes Loose soil particles can maintain a relatively stable slope up to a certain angle. That angle ranges from about 25 to 40 degrees, depending on the size and shape of the particles. If the steepness of a slope exceeds the stable angle, mass movements become more likely. Such slopes are said to be oversteepened. An oversteepened slope can result when a stream undercuts a valley wall or waves pound against the base of a cliff. People may also create oversteepened slopes by excavating during the construction of roads and buildings.

Reading Checkpoint ***How do oversteepened slopes trigger mass movements?***

Removal of Vegetation Plants make slopes more stable because their root systems bind soil and regolith together. When plants are removed by forest fires or by human activities such as logging or farming, the likelihood of mass movement increases. An example that illustrates the stabilizing effect of plants occurred several decades ago on steep slopes near Menton, France. Farmers replaced olive trees, which have deep roots, with carnations, a more profitable but shallow-rooted crop. Planting carnations made the slopes less stable. A landslide on one of the slopes killed 11 people.

Earthquakes Earthquakes are one of the most dramatic triggers of mass movements. An earthquake and its aftershocks can dislodge enormous amounts of rock and unconsolidated material. In many areas, these mass movements cause more damage than the ground vibrations themselves. The landslide shown in Figure 19 was triggered by an earthquake.

Types of Mass Movements

Geologists classify mass movements based on the kind of material that moves, how it moves, and the speed of movement. We'll consider five basic types of mass movement: rockfalls, slides, slumps, flows, and creep.

Rockfalls A **rockfall** occurs when rocks or rock fragments fall freely through the air. This type of mass movement is common on slopes that are too steep for loose material to remain on the surface. Many rockfalls result from the mechanical weathering of rock caused by freeze-thaw cycles or plant roots. Rockfalls sometimes trigger other mass movements.

Slides In a slide, a block of material moves suddenly along a flat, inclined surface. Slides that include segments of bedrock are called **rockslides.** They often occur in high mountain areas such as the Andes, Alps, and Canadian Rockies. Rockslides are among the fastest mass movements, reaching speeds of over 200 km per hour. Some rockslides, such as the one shown in Figure 21, are triggered by rain or melting snow.

Figure 21 Rockslide The scar on the side of this mountain in northwestern Wyoming was made by an enormous rockslide that happened more than 75 years ago. The debris in the slide formed a dam 70 m high across the Gros Ventre River.

Figure 22 Slump Heavy rains triggered this slump in Santa Barbara, California. Notice the crescent-shaped cliff just above the slump.

Slumps A **slump** is the downward movement of a block of material along a curved surface. The material in a slump usually does not travel very fast or very far. As the block moves, its upper surface sometimes tilts backward. Slumps leave a crescent-shaped cliff just above the slump, which you can see in Figure 22. They are common on oversteepened slopes where the soil contains thick accumulations of clay.

Flows Flows are mass movements of material containing a large amount of water, which move downslope as a thick fluid. Flows that move quickly, called **mudflows,** are common in semiarid mountainous regions, such as parts of southern California. In these regions, protective vegetation is sparse. A heavy downpour or rapid snowmelt can flood canyons with a mixture of soil, rock, and water. The mixture may have the consistency of wet concrete. It follows the contours of the canyon, taking large boulders and trees along with it. As you saw in Figure 20, mudflows in populated areas are very dangerous and destructive. In 1988, a massive mudflow triggered by the eruption of Nevado del Ruiz, a volcano in Colombia, killed 25,000 people.

Earthflows are flows that move relatively slowly—from about a millimeter per day to several meters per day. Their movement may continue for years. Earthflows occur most often on hillsides in wet regions. When water saturates the soil and regolith on a hillside, the material breaks away, forming a tongue-shaped mass like the one shown in Figure 23. Earthflows range in size from a few meters long and less than 1 m deep to over 1 km long and more than 10 m deep.

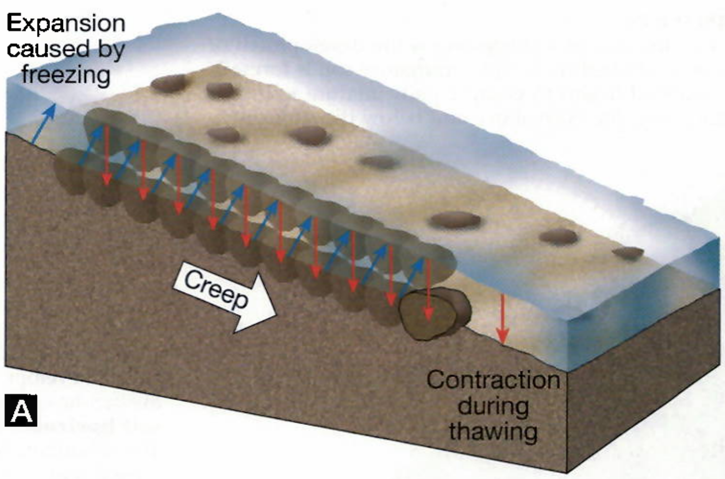
Reading Checkpoint ***How do mudflows differ from earthflows?***

Figure 23 Earthflow This small, tongue-shaped mass movement occurred on a newly formed slope along a recently built highway. **Comparing and Contrasting** ***Which other type of mass movement looks most similar to an earthflow?***

Creep The slowest type of mass movement is **creep,** which usually travels only a few millimeters or centimeters per year. One factor that contributes to creep is alternating between freezing and thawing, as Figure 24A shows. Freezing expands the water in soil, lifting soil particles at right angles to the slope. Thawing causes contraction, which allows the particles to fall back to a slightly lower level. Each freeze-thaw cycle moves the particles a short distance downhill.

Because creep is so slow, you cannot observe it directly as it happens. However, the effects of creep are easy to recognize. As Figure 24B shows, creep causes structures that were once vertical to tilt downhill. Creep can also displace fences and crack walls and underground pipes.

Figure 24 Creep A Repeated expansion and contraction of the soil on a slope results in a gradual downhill movement of the soil. **B** Years of creep have caused these gravestones to tilt. **Inferring** ***In which direction is creep occurring in this photograph?***



Section 5.3 Assessment

Reviewing Concepts

1. What is mass movement?
2. How does water trigger mass movements?
3. How does a rockfall differ from a rockslide?
4. What is the slowest type of mass movement?

Critical Thinking

5. **Applying Concepts** When highway engineers build a road in a mountainous area, they insert drainage pipes into the slopes alongside the road. Explain why.
6. **Making Judgments** Which mass movement—a slump, a mudflow, or an earthflow—poses the greatest risk to human life? Explain your reasoning.

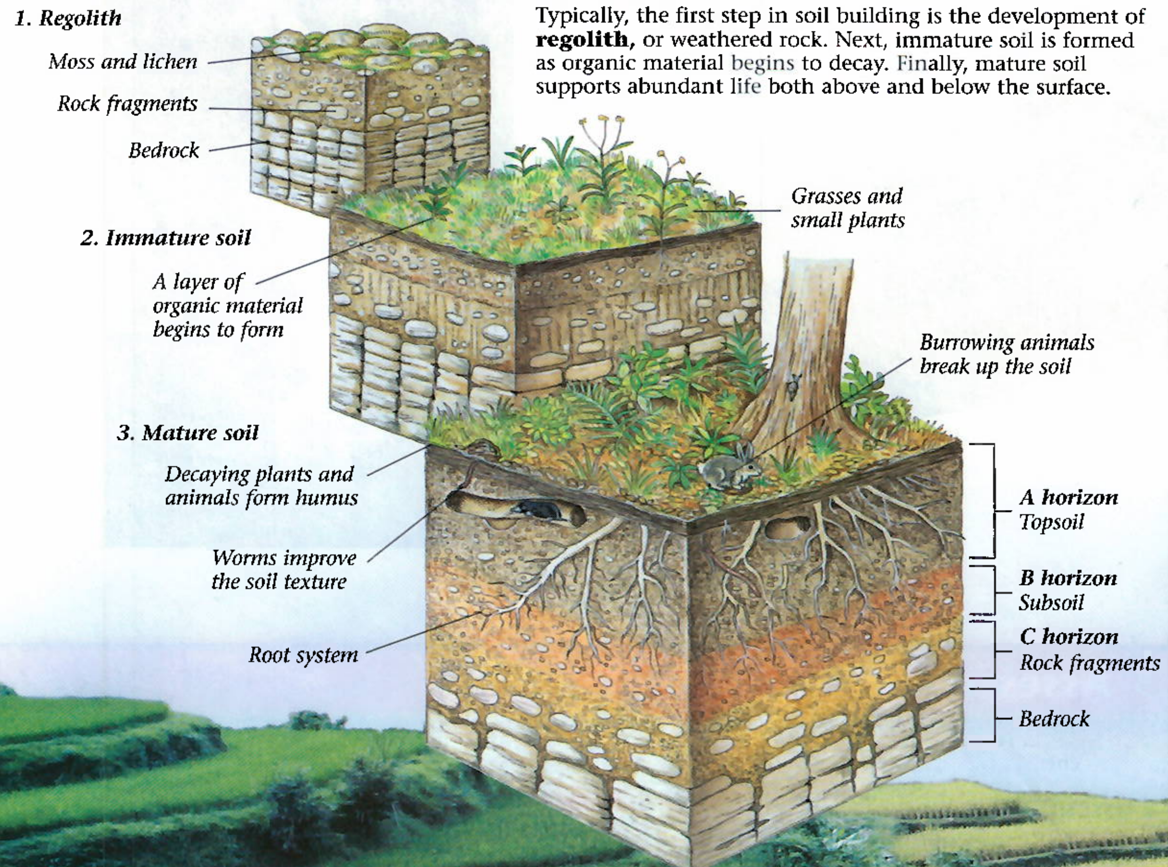
Writing in Science

Explanatory Paragraph Explain how people can make mass movements more likely. Include two examples in your explanatory paragraph.

Soil

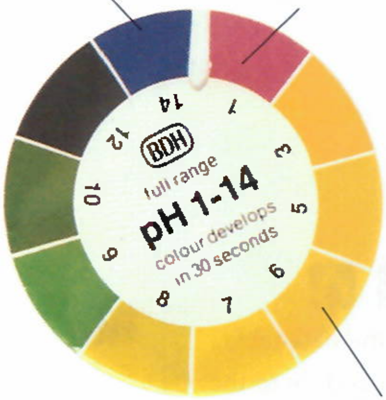
On the surface of the Earth, **soil** is the thin layer of loose material in which plants grow. Soil consists partly of mineral particles, and partly of **organic matter** derived from living plants and animals and their remains. Other key components of soil are water and air. Complex natural processes build soil over many thousands of years. The process begins when rock is broken down by weathering. Next, plants take root in the weathered rock. Then, organic material in the soil, called **humus,** is formed from decaying vegetation and animals. Different types of soil occur because of variations in climate, types of vegetation, and types of rock. In large countries like Russia, there is a wide variety of soil types.

SOIL FORMATION
Typically, the first step in soil building is the development of **regolith,** or weathered rock. Next, immature soil is formed as organic material begins to decay. Finally, mature soil supports abundant life both above and below the surface.



SOIL HORIZONS
As soil develops, distinct layers, called **soil horizons,** appear. The A horizon is topsoil that is rich in minerals and organic matter. The B horizon is poorer in humus but rich in minerals washed down from above. Further below lie the C horizon of weathered rock and, below that, unweathered bedrock.

CREEP
In a process called **creep,** soil moves gradually and constantly downhill because of gravity. Trees on a slope often show the effects of this process. Terrace farming is an agricultural method used to slow the process of creep.



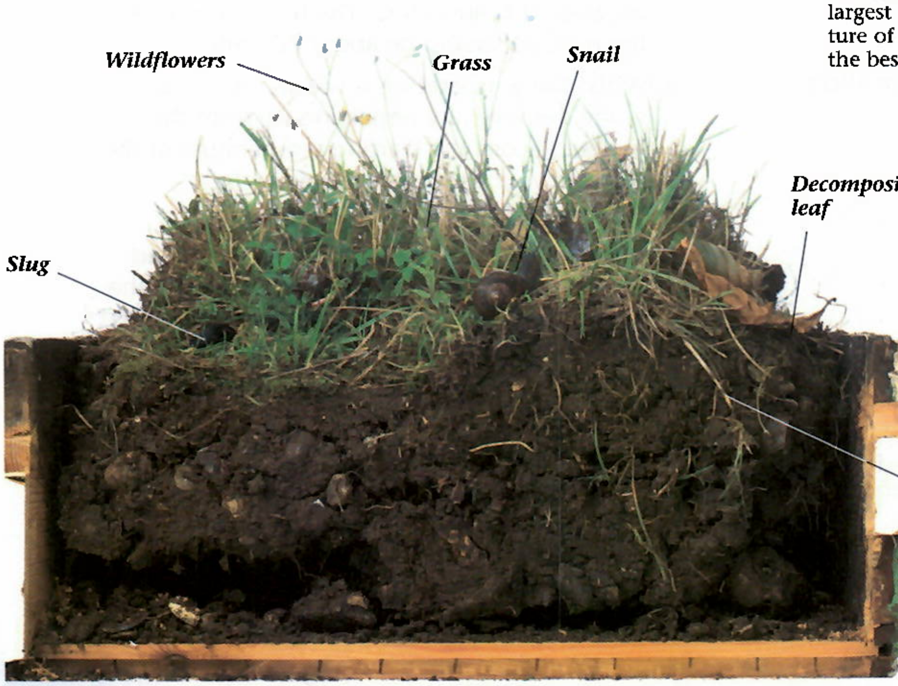
SOIL pH
The pH scale measures acidity or alkalinity on a scale of 0 to 14. When a chemical solution called an indicator is added to a soil sample, the indicator changes color, showing the soil's pH. Most plants thrive only in soils with a pH between 5 and 9.


Clay soil


Silty soil

SOIL TEXTURE
Soil texture depends on the size and nature of soil particles. Clay soils have the smallest grains, silty soils have medium-sized grains, and sandy soils have the largest grains. **Loam,** a mixture of clay, silt, and sand, is the best soil for agriculture.


Sandy soil



LIFE IN THE SOIL
Soil is home to a vast array of life, including microorganisms, ants, termites, worms, and rodents. Fungi and bacteria convert dead plant and animal matter into chemicals that enrich the soil. Burrowing creatures improve the soil by mixing it.


Spodosol is a sandy soil found in northern coniferous forests.


Aridisols, found in deserts, have high concentrations of salts

SOIL CLASSIFICATION
Some experts recognize thousands of different soil types. The U.S. Department of Agriculture has devised a comprehensive soil classification system for categorizing soils. Each type of soil can be identified by the characteristics of its horizons.

ASSESSMENT

1. **Key Terms** Define **(a)** soil, **(b)** organic matter, **(c)** humus, **(d)** regolith, **(e)** soil horizon, **(f)** creep, **(g)** loam.
2. **Physical Processes** Describe the three stages of soil formation.
3. **Physical Characteristics** How do various types of soil differ from one another?
4. **Natural Resources** What soil characteristics are most beneficial for agriculture?
5. **Critical Thinking Making Comparisons** Study the cross-sections of spodosol and aridisol. **(a)** How are they alike? **(b)** How do they differ? **(c)** Do research to learn more about their different characteristics.

Exploration Lab

Effect of Temperature on Chemical Weathering

Water is the most important agent of chemical weathering. One way water promotes chemical weathering is by reacting with the minerals in rocks. In this lab, you will examine the effect of temperature on chemical weathering by measuring the rate at which antacid tablets dissolve in water at different temperatures. These tablets contain calcium carbonate, the mineral found in rocks such as limestone and marble.

Problem How does temperature affect the rate of chemical weathering?

Materials

- 250-mL beaker
- thermometer
- hot water (40–50°C)
- ice
- 5 antacid tablets
- stopwatch
- graph paper

Skills Measuring, Using Tables and Graphs, Drawing Conclusions, Inferring

Procedure

1. On a sheet of paper, copy the data table.
2. Add a mixture of hot water and ice to the beaker. Use the thermometer to measure the temperature of the mixture. Add either more hot water or more ice until the temperature is between 0°C and 10°C. The total volume of the mixture should be about 200 mL.
3. When the temperature is within the correct range, remove any remaining ice from the beaker. Record the starting temperature of the water in your data table. Remove the thermometer from the beaker.
4. Drop an antacid tablet into the beaker. Start the stopwatch as soon as the tablet enters the water. Stop the stopwatch when the tablet has completely dissolved and no traces of the tablet are visible. (Don't wait for the bubbling to stop.) Record the time in your data table.
5. Place the thermometer in the beaker and wait for the temperature of the water to stabilize. Record the final temperature of the water in your data table.

Data Table

Starting Temperature (°C)	Dissolving Time(s)	Final Temperature (°C)	Average Temperature (°C)

6. Calculate the average temperature by adding the starting and final temperatures and dividing by 2. Record the result in your data table.
7. Repeat Steps 2 through 6 four more times, once at each of the following temperature ranges: 10–20°C, 20–30°C, 30–40°C, and 40–50°C. Adjust the relative amounts of hot water and ice to produce the correct water temperatures. The total volume of water and ice should always be about 200 mL.
8. On graph paper, make a graph with average temperature on the *x*-axis and dissolving time on the *y*-axis. Plot your data on the graph. Draw a smooth curve through the data points.

Analyze and Conclude

1. **Analyzing Data** At which temperature did the antacid tablet dissolve most rapidly?
2. **Analyzing Data** At which temperature did the antacid tablet dissolve most slowly?
3. **Drawing Conclusions** What is the relationship between temperature and the rate at which antacid tablets react with water?
4. **Formulating Hypotheses** Based on your observations, form a hypothesis about the relationship between temperature and the rate of chemical weathering.
5. **Designing Experiments** How could you test your hypothesis?
6. **Predicting** What would your results have been if you had ground each tablet into a fine powder before dropping it into the water? Would your conclusion be the same or different? Explain.
7. **Inferring** Would a limestone building weather more rapidly in Homer, Alaska, or in Honolulu, Hawaii? (Both cities receive about the same amount of precipitation in an average year.) Explain your reasoning.

Go Further Look for signs of chemical weathering on old stone buildings in your community. Consult your local library or historical society to find out when the buildings were constructed and what type of stone they are made of.

CHAPTER 5

Study Guide

5.1 Weathering

Key Concepts

- Mechanical weathering occurs when physical forces break rock into smaller and smaller pieces without changing the rock's mineral composition.
- In nature, three physical processes are especially important causes of mechanical weathering: frost wedging, unloading, and biological activity.
- Chemical weathering is the transformation of rock into one or more new compounds.
- Two factors that affect the rate of weathering are rock characteristics and climate.

Vocabulary

mechanical weathering, *p. 126;* frost wedging, *p. 127;* talus, *p. 127;* exfoliation, *p. 128;* chemical weathering, *p. 129*

5.2 Soil

Key Concepts

- Soil is the part of the regolith that supports the growth of plants.
- Soil has four major components: mineral matter, or broken down rock; organic matter, or humus, which is the decayed remains of organisms; water; and air.
- The most important factors in soil formation are parent material, time, climate, organisms, and slope.
- Soil varies in composition, texture, structure, and color at different depths.
- Three common types of soil are pedalfer, pedocal, and laterite.
- Human activities that remove natural vegetation, such as farming, logging, and construction, have greatly accelerated erosion.

Vocabulary

regolith, *p. 133;* soil, *p. 133;* soil horizon, *p. 138;* soil profile, *p. 138;* pedalfer, *p. 139;* pedocal, *p. 139;* laterite, *p. 139*

5.3 Mass Movements

Key Concepts

- The transfer of rock and soil downslope due to gravity is called mass movement.
- Among the factors that commonly trigger mass movements are saturation of surface materials with water, oversteepening of slopes, removal of vegetation, and earthquakes.
- Geologists classify mass movements based on the kind of material that moves, how it moves, and the speed of movement.

Vocabulary

mass movement, *p. 143;* rockfall, *p. 145;* rockslide, *p. 145;* slump, *p. 146;* mudflow, *p. 146;* earthflow, *p. 146;* creep, *p. 147*

CHAPTER 5

Assessment

Interactive textbook with assessment at PHSchool.com

Reviewing Content

Choose the letter that best answers the question or completes the statement.

1. The breaking down and changing of rocks at or near Earth's surface is called
- **a.** mass movement.
- **b.** sheet erosion.
- **c.** weathering.
- **d.** uplift.

2. Which of the following is NOT a cause of mechanical weathering?
- **a.** dissolving
- **b.** frost wedging
- **c.** unloading
- **d.** burrowing

3. In which type of climate does chemical weathering occur most rapidly?
- **a.** cold, dry
- **b.** cold, wet
- **c.** warm, dry
- **d.** warm, wet

4. Organic matter in soil is also called
- **a.** regolith.
- **b.** humus.
- **c.** talus.
- **d.** loam.

5. A soil's texture is determined by its
- **a.** water content.
- **b.** mineral composition.
- **c.** thickness.
- **d.** particle sizes.

6. In soils with distinct soil horizons, the topmost zone is the
- **a.** parent material.
- **b.** A horizon.
- **c.** B horizon.
- **d.** C horizon.

7. Compared to past rates of soil erosion, the current rate is
- **a.** lower.
- **b.** about the same.
- **c.** higher.
- **d.** impossible to determine.

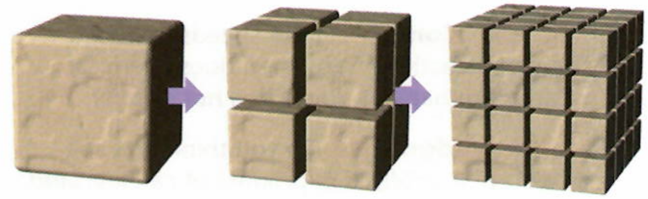
8. Which of the following does NOT usually trigger mass movements?
- **a.** growth of native vegetation on slopes
- **b.** formation of oversteepened slopes
- **c.** saturation of surface materials with water
- **d.** vibration of the ground during an earthquake

9. When a block of material moves downward along a curved surface, the process is called
- **a.** a rockslide.
- **b.** a rockfall.
- **c.** a slump.
- **d.** an earthflow.

10. Which of the following best describes a mudflow?
- **a.** movement too slow to be observed directly
- **b.** material moving downslope as a thick fluid
- **c.** material falling freely through the air
- **d.** sudden movement along a flat, inclined surface

Understanding Concepts

11. What happens to the total surface area of the cubes in the process shown below? What type of weathering does this process represent?



12. What is exfoliation? Give an example of a feature produced by exfoliation.

13. How does mechanical weathering promote chemical weathering?

14. How is carbonic acid formed in nature? What happens when this acid reacts with feldspar?

15. Which factor has the greatest effect on soil formation? Explain.

16. How does slope affect the formation of soil?

17. Describe the major characteristics of A, B, and C horizons.

18. Distinguish between pedalfer and pedocal.

19. List three negative effects of soil erosion.

20. Explain how weathering and mass movement together produce most landforms.

21. What is the force behind mass movements? What other factors can trigger mass movements?

22. Distinguish between rockfalls and rockslides.

23. Distinguish between mudflows and earthflows.

24. How do freezing and thawing contribute to creep?

Assessment *continued*

Critical Thinking

25. **Inferring** Roads in northern states such as Maine and Michigan need to be repaired more often than roads in southern states such as Florida and Louisiana. What form of mechanical weathering could account for this?

26. **Comparing and Contrasting** How do the effects of mechanical weathering on rock differ from the effects of chemical weathering?

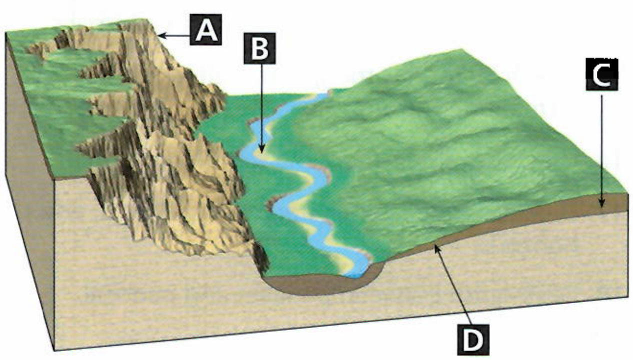
27. **Predicting** Granite and marble are exposed at the surface in a hot, wet region. Which of the rocks will weather more rapidly? Why?

28. **Applying Concepts** Heat speeds up most chemical reactions. Why then does chemical weathering happen slowly in a hot desert?

29. **Making Judgments** Do you think that soil erosion is an artificial byproduct of careless land use by humans? Explain.

Analyzing Data

Use the diagram below to answer Questions 30–32.



30. **Comparing and Contrasting** Compare the thickness of the soil in the areas labeled A and B.

31. **Interpreting Diagrams** What name is given to the soil that develops in the area labeled B? In the area labeled C?

32. **Inferring** Why is the soil in the area labeled D thinner than the soil in the area labeled C?

Concepts in Action

33. **Using Analogies** Explain how the following scenario is analogous to weathering: One evening you place a sealed jar full of water in a freezer. The next morning, the water has turned to ice and the jar is cracked.

34. **Applying Concepts** A committee has been established to design a stone memorial commemorating 100 soldiers who died in battle. The committee decides to use a large block of marble for the memorial. Considering only the memorial's durability, would it be better to use the whole block as a single memorial for all 100 soldiers or to divide it into 100 blocks of equal size, one for each soldier?

35. **Classifying** How would you determine the texture of the soil in your area?

36. **Making Judgments** Should a homeowner in a dry, mountainous area remove all vegetation from surrounding slopes to reduce fire danger? Explain why or why not.

37. **Writing in Science** Write a paragraph describing one type of mass movement. Include a specific example of a time when such a mass movement made the news.

Performance-Based Assessment

Observing Look for places in your community where people have taken specific actions to reduce erosion. Such places may include sites where buildings are being constructed or roads are being built or repaired. Make a list of each action and explain how it is intended to reduce erosion.

Standardized Test Prep

Test-Taking Tip

Watch for Qualifiers
The words *best* and *least* are examples of qualifiers. If a question contains a qualifier, more than one answer will contain correct information. However, only one answer will be complete and correct for the question asked. Look at the question below. Eliminate any answers that are clearly incorrect. Then choose the remaining answer that offers the best explanation for the question asked.

Which mass movement is LEAST dangerous to people walking below a slope?
(A) rockslide
(B) rockfall
(C) creep
(D) mudflow

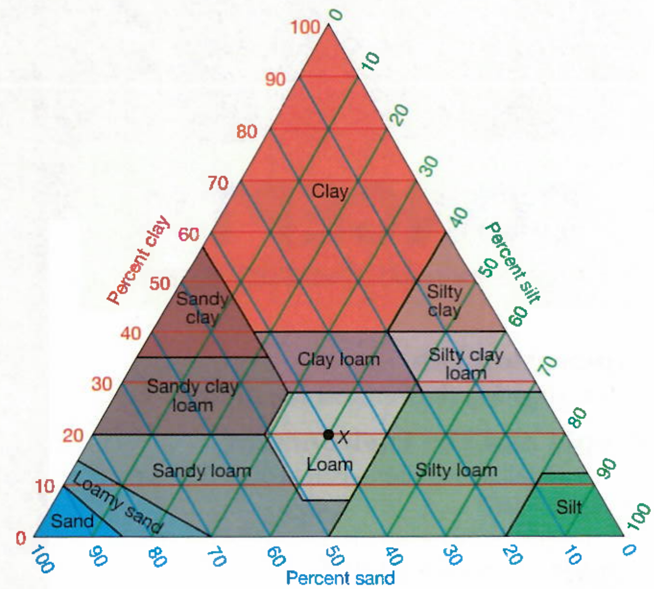
(Answer: C)

Choose the letter that best answers the question or completes the statement.

1. Which of the following best describes regolith?
   (A) a soil that contains large amounts of iron oxide and aluminum-rich clays
   (B) a mixture of mineral matter, organic matter, water, and air
   (C) a large pile of rock fragments at the base of a steep cliff
   (D) the layer of rock and mineral fragments that covers nearly all of Earth's land surface

2. In which mass movement do rock fragments fall freely through the air?
   (A) rockslide
   (B) rockfall
   (C) slump
   (D) earthflow

Use the diagram below to answer Questions 3 and 4.



3. What are the percentages of clay, silt, and sand in the soil at the point labeled X?
   (A) 60 percent clay, 80 percent silt, and 60 percent sand
   (B) 0 percent clay, 40 percent silt, and 60 percent sand
   (C) 20 percent clay, 40 percent silt, and 40 percent sand
   (D) 50 percent clay, 40 percent silt, and 10 percent sand

4. The name given to soil that contains 60 percent clay, 20 percent silt, and 20 percent sand is
   (A) clay. (B) loam.
   (C) silty clay loam. (D) sandy loam.

Answer the following questions in complete sentences.

5. How does the surface area of an exposed rock affect its rate of weathering?

6. What role does acid precipitation play in weathering?

7. When a tropical rain forest is cleared, why does the soil usually become useless for growing crops after only a few years?

8. Explain how water can trigger an earthflow.

CHAPTER 6

Running Water and Groundwater

CONCEPTS in Action

Exploration Lab
Investigating the Permeability of Soils

People and the Environment
The Ogallala Aquifer—How Long Will the Water Last?

GEODe EARTH SCIENCE
Sculpturing Earth's Surface
↳ Hydrologic Cycle
Running Water
Groundwater

Discovery CHANNEL SCHOOL

Video Field Trip

Dams

Take a field trip to China with the Discovery Channel and learn about the construction of the Three Gorges dam on the Yangtze River. Answer the following questions after watching the video.

1. What led to the decision to build a dam on the Yangtze River?
2. Name two disadvantages of the Three Gorges Dam.

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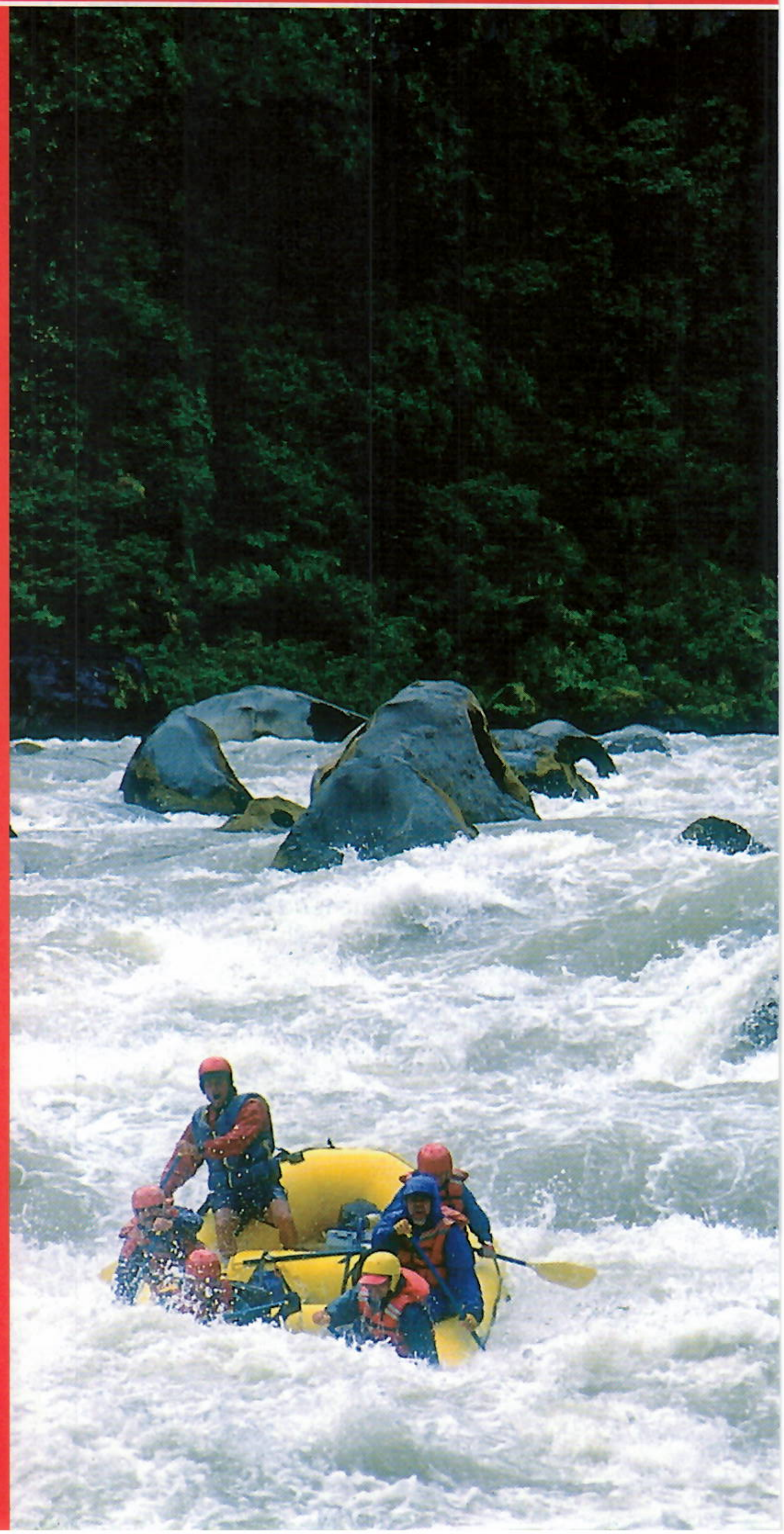
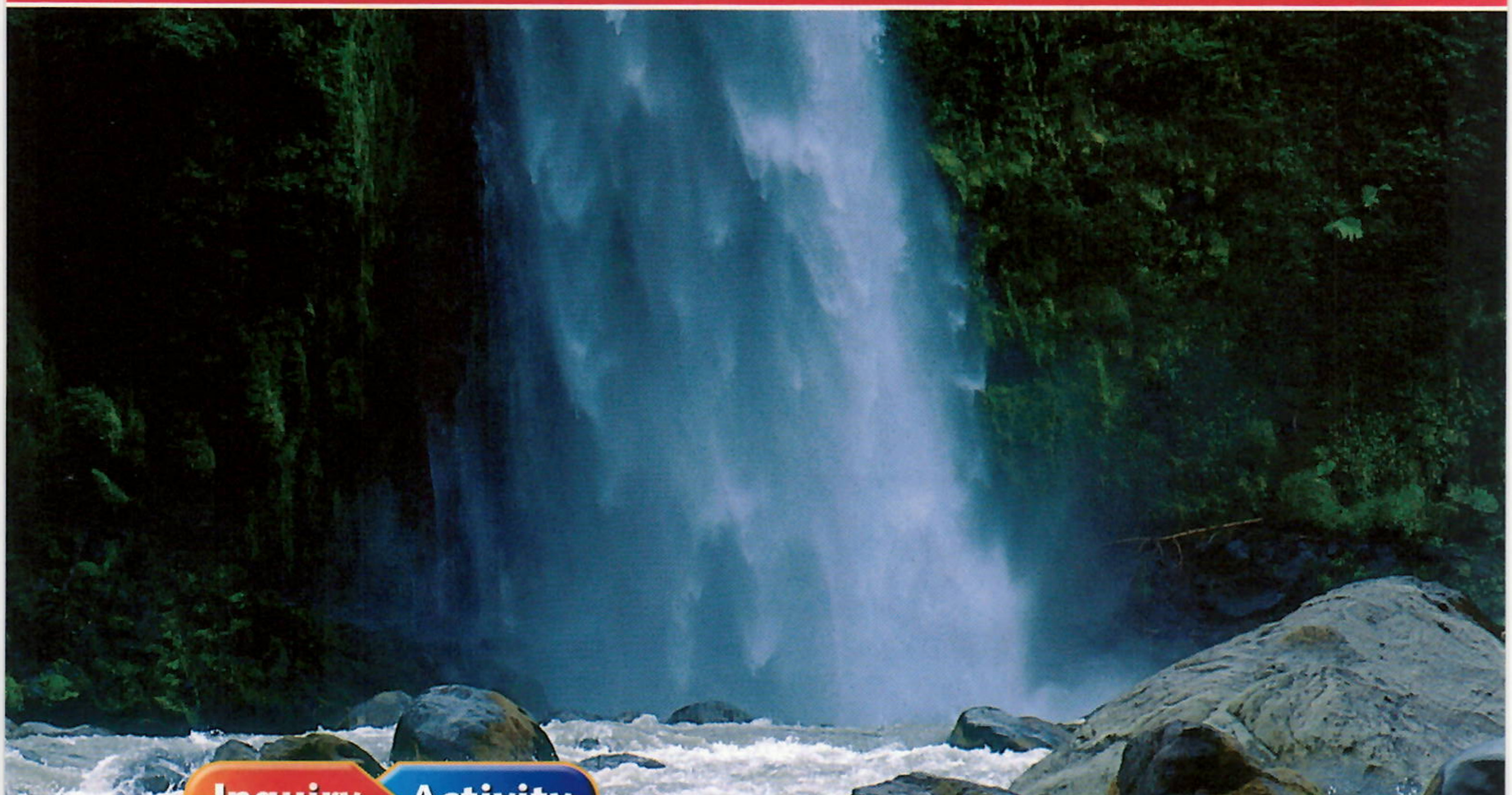


This photograph shows Lost Yak Rapids ▶ on Chile's Rio Bio Bio.

Chapter Preview



Inquiry Activity

How Do Local Bodies of Water Affect Your Community?

Procedure

1. Identify an important body of water in or near your community. It could be a river, lake, dam reservoir, stream, ocean, or estuary.
2. List the ways the people of your community use this body of water.
3. Observe and record the ways this body of water has affected (or still affects) the local landscape.

Think About it

1. **Classifying** Is the body of water used for recreation (boating, swimming, fishing), for industry and business (transportation or waste disposal for factories and power plants), for drinking water, or a combination of these purposes?
2. **Inferring** If your community uses this body of water as a source of drinking water, how might that affect other possible uses of the water?
3. **Drawing Conclusions** Has this body of water shaped the landscape in the area? How?

6.1 Running Water

Reading Focus

Key Concepts

- What is the water cycle?
- What does it mean to say Earth's water cycle is balanced?
- What is the most important factor in determining the power of a stream to erode and transport material?
- How do gradient and discharge change between a stream's source and its mouth?
- What is a stream's base level?

Vocabulary

- water cycle
- infiltration
- transpiration
- gradient
- stream channel
- discharge
- tributary
- base level
- meander

Reading Strategy

Building Vocabulary Copy the table. As you read the section, define in your own words each vocabulary term listed in the table.

Vocabulary Term	Definition
Water cycle	?
Infiltration	?
Transpiration	?

Water is everywhere on Earth—oceans, glaciers, rivers, lakes, air, soil, and living tissue. All of these reservoirs make up Earth's hydrosphere. Most of it—about 97.2 percent—is stored in oceans, as Figure 1 shows. Ice sheets and glaciers account for another 2.15 percent, leaving only 0.65 percent to be divided among lakes, streams, groundwater, and the atmosphere. The water found in glaciers, ice sheets, lakes, streams, groundwater, and the atmosphere may seem like a tiny percent of Earth's water, but the actual quantities are great.

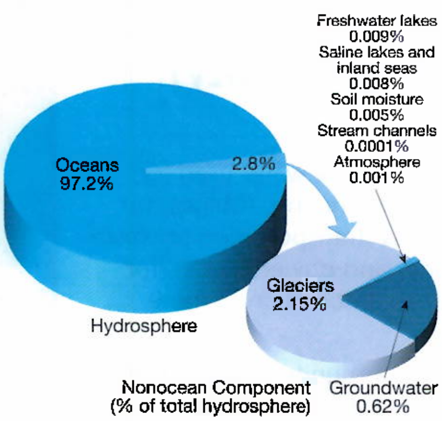


Figure 1 Distribution of Earth's Water
Using Graphs ***What percentage of Earth's water is not held in its oceans?***

The Water Cycle

Water constantly moves among the oceans, the atmosphere, the solid Earth, and the biosphere. This unending circulation of Earth's water supply is the water cycle. This cycle is possible because water readily changes from one state of matter—solid, liquid, or gas—to another at temperatures and pressure common on Earth's surface.

The water cycle, shown in Figure 2, is a gigantic worldwide system powered by energy from the sun. The atmosphere provides the most important link between the oceans and land. Water evaporates into the atmosphere from the ocean, and to a lesser extent from the continents. Winds transport this moisture-rich air until conditions cause the moisture to condense into clouds. Precipitation—rain and snow—then falls to Earth. Precipitation that falls into oceans has completed

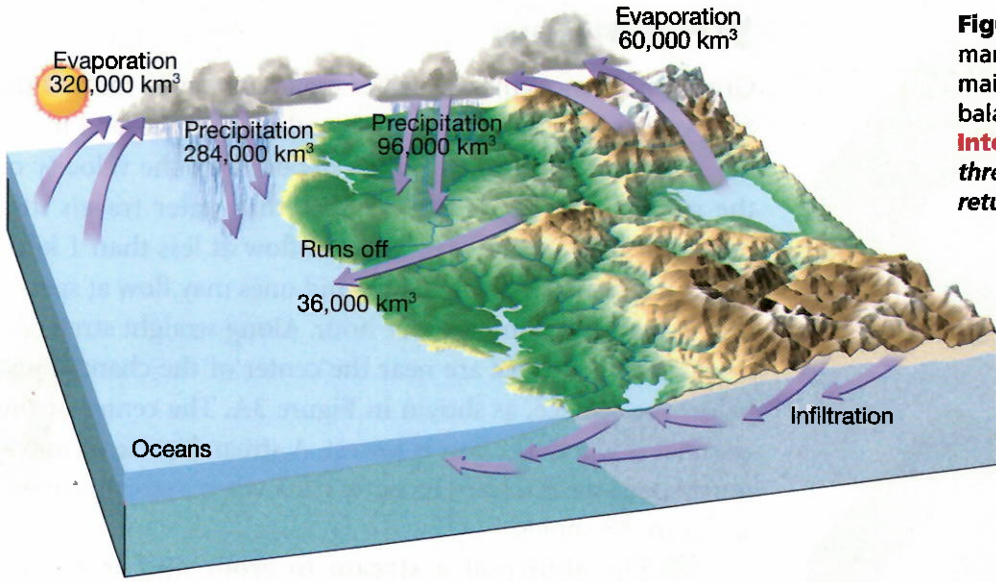


Figure 2 The Water Cycle The many processes of the water cycle maintain Earth's overall water balance.
Interpreting Diagrams ***In which three ways does precipitation return to oceans?***

one full cycle and is ready to begin another. However, water that falls on land must make its way back to the ocean to complete the full cycle.

Reading Checkpoint ***What is Earth's hydrosphere?***

What happens to precipitation that falls on land? Some of it slowly soaks into the ground through infiltration. **Infiltration** is the movement of surface water into rock or soil through cracks and pore spaces. The water gradually moves through the land and actually seeps into lakes, streams, or the ocean. When the rate of rainfall exceeds Earth's ability to absorb it, the excess water flows over the surface into lakes and streams in a process called runoff. Much of that runoff returns to the atmosphere because of evaporation from the soil, lakes, and streams. Plants also absorb water and release it into the atmosphere through **transpiration.**

When precipitation falls in very cold areas—at high elevations or high latitudes—the water may not immediately soak in, run off, or evaporate. Instead, it may become part of a glacier. Glaciers store large amounts of water on land. If present-day glaciers were to melt and release all their water, ocean levels would rise by several dozen meters.

Earth's Water Balance

Even with all these processes occurring, Earth's water cycle is balanced. **Balance in the water cycle means the average annual precipitation over Earth equals the amount of water that evaporates.** There are local imbalances. For example, precipitation exceeds evaporation over continents. Over oceans, evaporation exceeds precipitation. However, the fact that the level of world oceans is not changing very much indicates the system is balanced.

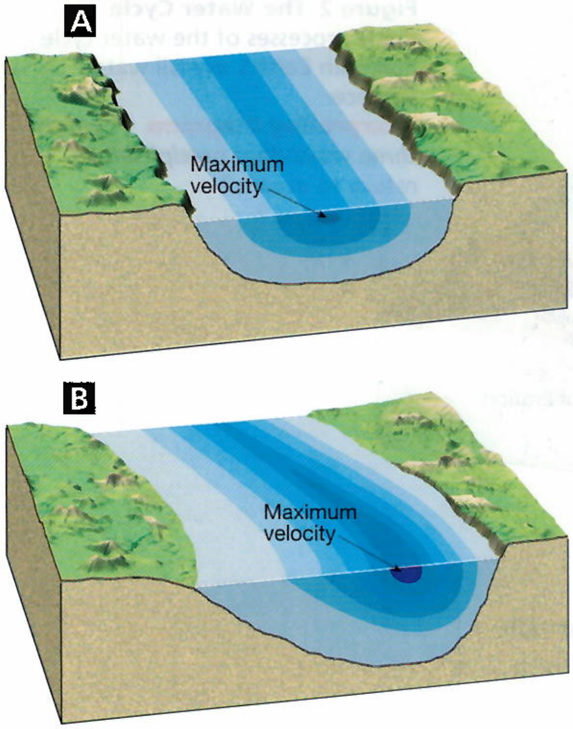


Figure 3 **A** Along straight stretches, stream velocity is highest at the center of the channel. **B** When a stream curves, its zone of maximum speed shifts toward the outer bank.
Interpreting Diagrams ***How does velocity change with depth in the middle of the stream?***

Streamflow

Gravity influences the way water makes its way to the oceans. Streams and rivers carry water downhill from the land to the sea. The time this journey takes depends on the velocity of the stream. Velocity is the distance that water travels in a period of time. Some slow streams flow at less than 1 kilometer per hour, whereas a few rapid ones may flow at speeds that exceed 30 kilometers per hour. Along straight stretches, the highest velocities are near the center of the channel just below the surface, as shown in Figure 3A. The center of the channel is where friction is lowest. A stream's zone of maximum speed shifts toward its outer bank when a stream curves, as Figure 3B shows.

The ability of a stream to erode and transport materials depends largely on its velocity. Even slight changes in velocity greatly change the amount of sediment that water can transport. Several factors determine the velocity of a stream. They include its gradient; the shape, size, and roughness of its channel; and its discharge.

Gradient **Gradient** is the slope or steepness of a stream channel. Gradient is usually expressed as the vertical drop of a stream over a certain distance. Portions of the Mississippi River have very low gradients of 10 centimeters per kilometer or less. By contrast, some mountain streams tumble downhill at a rate of more than 40 meters per kilometer. This mountain stream's gradient is 400 times steeper than that of the lower Mississippi. Gradient varies over a stream's length and between streams. The steeper the gradient, the more energy the stream has as it flows downhill. Compare the steep and gentle gradients in Figure 4.

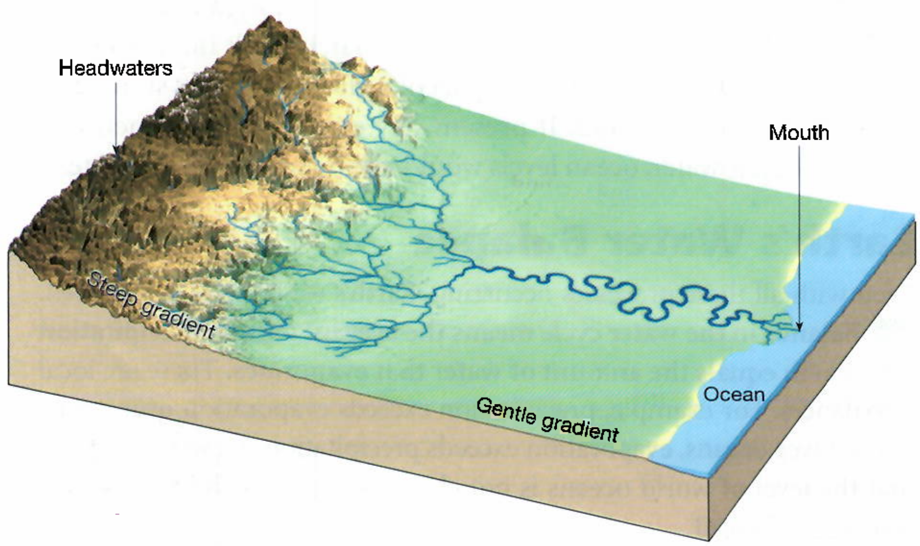


Figure 4 This cross section along the length of a stream shows a steeper gradient upstream, and a gentler gradient downstream.

Channel Characteristics A **stream channel** is the course the water in a stream follows. As the water flows, it encounters friction from the sides and the bottom of its channel. This friction slows its forward movement. The shape, size, and roughness of the channel affect the amount of friction. For example, an irregular channel filled with boulders creates enough turbulence to slow the stream significantly. Water in a smooth channel flows more easily. Larger channels also have more efficient water flow because a smaller proportion of water is in contact with the channel surfaces.

Discharge The **discharge** of a stream is the volume of water flowing past a certain point in a given unit of time. Discharge is usually measured in cubic meters per second. Table 1 lists the world's largest rivers in terms of discharge. The discharges of most rivers change with rainfall and snowmelt. The size and velocity of the stream also changes when discharge changes. The stream channel widens and deepens to handle additional water. As the size of the channel increases, there is less friction and the water flows more swiftly.

Building urban centers around a stream channel can also affect discharge. For example, the magnitude and frequency of floods can increase. The construction of streets, parking lots, and buildings covers soil that once soaked up water. Less water soaks into the ground and runoff increases, especially at times of heavy rainfall. Also, because less water soaks into the ground, the dry season flow of streams is reduced greatly. Urbanization is just one example of how humans can interfere with the normal flow of streams.

Reading Checkpoint *What factors determine the velocity of a stream?*

Table 1 World's Largest Rivers Ranked by Discharge

Rank	River	Country	Average Discharge m^3/s
1	Amazon	Brazil	212,400
2	Congo	Zaire	39,650
3	Yangtze	China	21,800
4	Brahmaputra	Bangladesh	19,800
5	Ganges	India	18,700
6	Yenisei	Russia	17,400
7	Mississippi	United States	17,300
8	Orinoco	Venezuela	17,000
9	Lena	Russia	15,500
10	Parana	Argentina	14,900

Changes from Upstream to Downstream

One useful way to study a stream is to look at its profile. A profile is a cross-sectional view of a stream from its source, or headwaters, to its mouth—the point downstream where the river empties into another body of water. In Figures 4 and 5, you can see that the most obvious feature of a typical stream profile is a decreasing gradient or slope from its headwaters to its mouth.

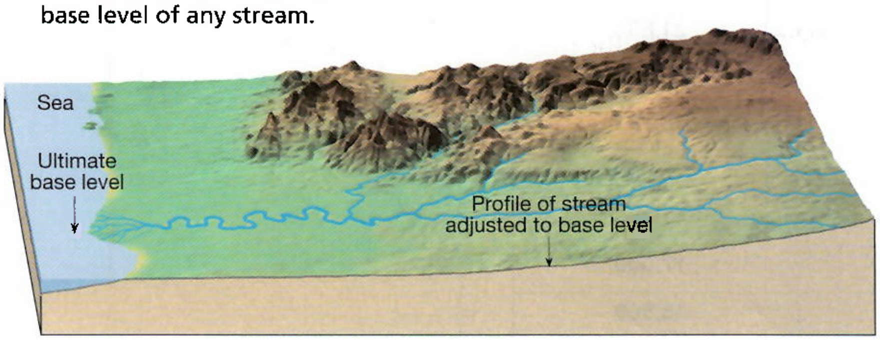
While gradient decreases between a stream's headwaters and mouth, discharge increases. The amount of discharge increases because more and more tributaries enter the main channel as it moves downstream. A **tributary** is a stream that empties into another stream. In most humid regions, the groundwater supply adds even more water. As the river moves downstream, its width, depth, and velocity change with the increased volume of water it carries.

The observed increase in the average velocity of the water downstream contradicts what people may think about mountain streams. Most people believe that mountain streams are swift and lowland rivers are slow. Although a mountain stream may look like a violent, gushing flow of water, its average velocity is often less than the average velocity of a river near its mouth.

The difference in velocity is mostly due to the great efficiency of the larger downstream channel. In the headwaters area where the gradient may be steep, water often flows in a small channel over many boulders. The small channel and rough bed increase fiction. This increase in friction scatters the water in all directions and slows its movement. However, downstream the channel is usually smoother so that it offers less resistance to flow. The width and depth of the channel also increase toward the mouth to handle the greater discharge. These factors permit the water to flow more rapidly.

Reading Checkpoint *What is a stream profile?*

Figure 5 Sea level is the ultimate base level of any stream.



Base Level

Streams can't erode their channels endlessly. There is a lower limit to how deep a stream can erode. **Base level is the lowest point to which a stream can erode its channel.** The base level is the level at which the mouth of a stream enters the ocean, a lake, or another stream.

Figure 6 A river in a broad, flat-floored valley near base level often has a channel with many meanders. **Inferring** ***Is the river in this picture close to or high above its base level?***

Figure 7 When land is gradually uplifted, a meandering river adjusts to being higher above base level by downcutting. The result can be a landscape with incised meanders, such as these in Utah's Canyonlands National Park.

There are two types of base level—ultimate base level and temporary base level. As Figure 5 shows, sea level is the ultimate base level because it's the lowest level that stream erosion can lower the land. Temporary base levels include lakes, resistant layers of rock, and main streams that act as base level for their tributaries. For example, when a stream enters a lake, its velocity quickly approaches zero. Its ability to erode ceases. The lake prevents the stream from eroding below its level at any point upstream from the lake. However, because the outlet of the lake can cut downward and drain the lake, the lake is only a temporary obstacle to the stream's ability to erode its channel.

A stream in a broad, flat-bottomed valley that is near its base level often develops a course with many bends called **meanders,** as shown in Figure 6. If base level dropped or the land was uplifted the river, which is now considerably above base level, would have excess energy and would downcut its channel. The result could be incised meanders—a winding river in a steep, narrow valley, as shown in Figure 7.

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Section 6.1 Assessment

Reviewing Concepts

1. What is the water cycle?
2. How is Earth's water cycle balanced?
3. Where is most of Earth's water located?
4. What part does infiltration play in the water cycle?
5. What factor most influences the power of a stream to erode and transport material?
6. How do gradient and discharge change between a stream's headwaters and its mouth?
7. How might lowering base level affect stream erosion?

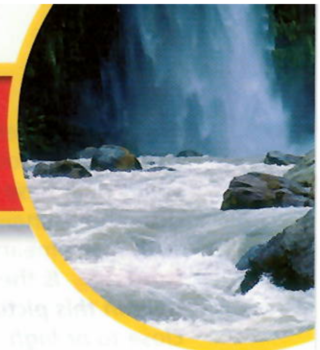
Critical Thinking

8. **Relating Cause and Effect** What would happen if evaporation exceeded precipitation over the continents and oceans?
9. **Comparing and Contrasting** How does the development of urban areas along streams and rivers affect discharge during periods of heavy rainfall?

Math Practice

10. A stream that is 27 kilometers long drops 90 meters in elevation from its headwaters to its mouth. What is the stream's gradient?

6.2 The Work of Streams



Reading Focus

Key Concepts

- How do streams erode their channels and transport sediment?
- How does stream deposition occur?
- What are the two types of stream valleys?
- What causes floods, and what are the major flood control measures?
- What is the relationship between a stream and a drainage basin?

Vocabulary

- bed load
- capacity
- alluvium
- delta
- natural levee
- floodplain
- flood
- drainage basin
- divide

Reading Strategy

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

What I Expect to Learn	What I Learned

Streams are Earth's most important agents of erosion. They can downcut or erode their channels. They can also transport enormous amounts of sediment. Most of the sediment a stream carries comes from weathering. Weathering produces huge amounts of material that are delivered to the stream by sheet flow, mass movements, and groundwater. Eventually, streams drop much of this material to create many different depositional features.

Erosion

Streams generally erode their channels lifting loose particles by abrasion, grinding, and by dissolving soluble material. When the flow of water is turbulent enough, it can dislodge loose particles from the channel and lift them into the moving water. In this manner, the force of running water rapidly erodes some streambeds and banks. The stronger the current is, the more erosional power it has and the more effectively the water will pick up particles.

Sand and gravel carried in a stream can erode solid rock channels like sandpaper grinds down wood. Moreover, pebbles caught in swirling stream currents can act like cutting tools and bore circular "potholes" into the channel floor.

Reading Checkpoint *What are three ways that streams erode their channels?*

Sediment Transport

Streams transport sediment in three ways.

1. **in solution (dissolved load)**
2. **in suspension (suspended load)**
3. **scooting or rolling along the bottom (bed load)**

Dissolved Load Most of the dissolved load enters streams through groundwater. Some of this load also enters by dissolving rock along the stream's course. The amount of material the stream carries in solution changes depending on climate and the geologic setting. Usually the dissolved load is expressed as parts of dissolved material per million parts of water (parts per million, or ppm). Some rivers may have a dissolved load of 1000 ppm or more. However, the average figure for the world's rivers is estimated at 115 to 120 ppm. Streams supply almost 4 billion metric tons of dissolved substances to the oceans each year.

Suspended Load Most streams carry the largest part of their load in suspension. The visible cloud of sediment suspended in the water is the most obvious portion of a stream's load. Streams usually carry only sand, silt, and clay this way. However, streams also transport larger particles during a flood because water velocity increases. The total amount of material a stream carries in suspension increases dramatically during floods, as shown in Figure 8.

Figure 8 During this 1997 flood, the suspended load in the muddy Ohio River is clearly visible. The greatest erosion and sediment transport occur during floods. **Applying Concepts** ***What other types of load might account for the muddiness of the river?***

Bed Load Bed load is that part of a stream's load of solid material that is made up of sediment too large to be carried in suspension. These larger, coarser particles move along the bottom, or bed, of the stream channel. The suspended and dissolved loads are always moving. But the bed load moves only when the force of the water is great enough to move the larger particles. The grinding action of the bed load is very important in eroding the stream channel.

Competence and Capacity The ability of streams to carry a load is determined by two factors: the stream's competence and its capacity. Competence of a stream measures the largest particles it can transport. A stream's competence increases with its velocity. In fact, the competence of a stream increases four times when the velocity doubles.

The **capacity** of a stream is the maximum load it can carry. Capacity is directly related to a stream's discharge. The greater the volume of water in a stream is, the greater its capacity is for carrying sediment.

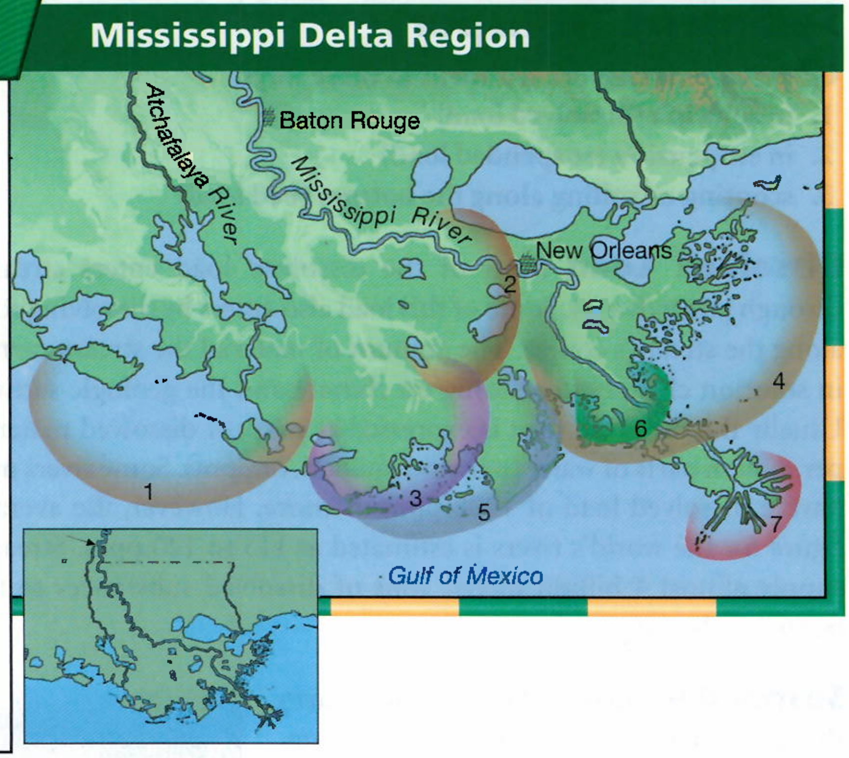
MAP MASTER™ Skills Activity

Figure 9

Movement This map shows the growth of the Mississippi River delta over the past 5,000 to 6,000 years. As you can see, the river has built a series of sub-deltas, one after the other. The numbers indicate the order in which they were deposited.

Locating In which overall direction has the Mississippi River built its delta over the past few thousand years?

Locating How has the growth of the delta changed the location of the mouth of the Mississippi River in relation to New Orleans?



Deposition

Whenever a stream slows down, the situation reverses. As a stream's velocity decreases, its competence decreases and sediment begins to drop out, largest particles first. Each particle size has a critical settling velocity. **Deposition occurs as streamflow drops below the critical settling velocity of a certain particle size. The sediment in that category begins to settle out.** Stream transport separates solid particles of various sizes, large to small. This process is called sorting. It explains why particles of similar size are deposited together.

The sorted material deposited by as stream is called **alluvium**. Many different depositional features are made of alluvium. Some occur within stream channels. Some occur on the valley floor next to the channel. And others occur at the mouth of a stream.

Deltas When a stream enters the relatively still waters of an ocean or lake, its velocity drops. As a result, the stream deposits sediment and forms a delta. A **delta** is an accumulation of sediment formed where a stream enters a lake or ocean. As a delta grows outward, the stream's gradient lessens and the water slows down. The channel becomes choked with sediment settling out of the slow-moving water. As a result, the river changes direction as it seeks a shorter route to base level. The main channel often divides into several smaller channels called distributaries as shown in sub-delta 7 in Figure 9. These shifting channels act in the opposite way of tributaries.

Rather than carrying water into the main channel like tributaries, distributaries carry water away. After many shifts of the channel, a delta may grow into a triangular shape, like the Greek letter delta (Δ). However, not all deltas have this idealized shape. Differences in the shapes of shorelines and variations in the strength of waves and currents result in different shapes of deltas.

Natural Levees Some rivers occupy valleys with broad, flat floors. Successive floods over many years can build natural levees along them. A **natural levee** is a landform that parallels some streams. They form when a stream overflows its banks. When it overflows, its velocity rapidly decreases and leaves coarse sediment deposits in strips that border the channel. As the water spreads out over the valley, less sediment is deposited. This uneven distribution of material produces the gentle slope of the natural levee.

Figure 10 The Yellowstone River is an example of a V-shaped valley. The rapids and waterfall show that the river is vigorously downcutting the channel.

Stream Valleys

Narrow Valleys The Yellowstone River, shown in Figure 10, is an excellent example of a narrow valley. **A narrow V-shaped valley shows that the stream's primary work has been downcutting toward base level.** Rapids and waterfalls are the most prominent features of a narrow valley. Both rapids and waterfalls occur where the stream profile drops rapidly. The variations in the erosion of the underlying bedrock cause these rapid drops.

Wide Valleys Once a stream has cut its channel closer to base level, downward erosion becomes less dominant. More of the stream's energy is directed from side to side. The result is a widening of the valley as the river cuts away first at one bank and then at the other.

The side-to-side cutting of a stream eventually produces a flat valley floor, or **floodplain.** A floodplain is appropriately named because during a flood the river overflows its banks and floods the plain.

Streams that flow on floodplains move in meanders. Once a bend in a channel begins to form, it grows larger. Most of the erosion occurs on the outside of the meander—often called the cut bank—where velocity and turbulence are greatest. Much of the debris the stream removes at the cut bank moves downstream where it is deposited as point bars. Point bars form in zones of decreased velocity on the insides of meanders. In this way, meanders move side to side by eroding the outside of bends and depositing on the inside.

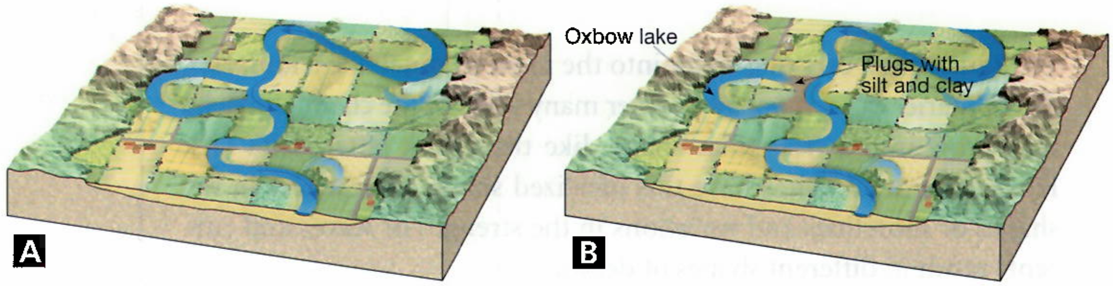


Figure 11 **A** One meander has overtaken the next, forming a ring of water on the floodplain. **B** After deposits of sediment cut off the ring, an oxbow lake forms.

Erosion is more effective on the downstream side of a meander because of the slope of the channel. The bends gradually travel down the valley. Sometimes the downstream movement of a meander slows when it reaches a more resistant portion of the floodplain. This resistance allows the next meander upstream to overtake it, as shown in Figure 11. Gradually the neck of land between the meanders is narrowed. Eventually the river may erode through the narrow neck of land to the next loop. The new, shorter channel segment is called a cutoff and, because of its shape, the abandoned bend is called an oxbow lake. Such a situation is shown in the bottom portion of Figure 6 on page 163.

Floods and Flood Control

A **flood** occurs when the discharge of a stream becomes so great that it exceeds the capacity of its channel and overflows its banks. Floods are the most common and most destructive of all natural geologic hazards.

Most floods are caused by rapid spring snow melt or storms that bring heavy rains over a large region. Heavy rains caused the devastating floods in the upper Mississippi River Valley during the summer of 1993, as shown in Figure 12.

Unlike far-reaching regional floods, flash floods are more limited in extent. However, flash floods occur with little warning, and they can be deadly as walls of water sweep through river valleys. Several factors

MAP MASTER™ Skills Activity

Mississippi River Flooding

Figure 12

Region These satellite images show the confluence of the Missouri and Mississippi rivers. The first photo shows the rivers during normal flow. **Interpreting Photographs** What does the second satellite image show? How do you know?

influence flash floods: rainfall intensity and duration, surface conditions, and topography. As you have learned, many urban areas are susceptible to flash floods. Mountainous areas are also susceptible because steep slopes can send runoff into narrow canyons.

Human interference with the stream system can worsen or even cause floods. A prime example is the failure of a dam or an artificial levee. These structures are designed to contain floods of a certain size. If that size is exceeded, water can then spill over or break through a dam or levee and rush downstream causing a disastrous flood.

There are several flood control strategies. **Measures to control flooding include artificial levees, flood control dams, and placing limits on floodplain development.**

Artificial Levees Artificial levees are earthen mounds built on the banks of a river. These levees increase the volume of water a channel can hold. When levees confine a river during periods of high water, the river often deposits material in its channel as the discharge diminishes. This discharge is sediment that would have been dropped on the floodplain. Because the stream cannot deposit material outside of its channel the bottom of the channel is gradually built up. When the channel is built up, it takes less water to overflow the levee. As a result, people may have to raise the height of the levee periodically to protect the floodplain behind it. Moreover, many artificial levees are not built to withstand periods of extreme flooding. For example, there were many levee failures in the Midwest during the summer of 1993 when the upper Mississippi experienced record flooding.

Flood-Control Dam Flood-control dams store floodwater and then let it out slowly. Since the 1920s, thousands of dams have been built on nearly every major river in the United States. Many dams have other non-flood related functions, such as providing water for irrigation and for hydroelectric power generation.

Although dams may reduce flooding and provide other benefits, building dams has consequences. For example, dams trap sediment. Deltas and floodplains downstream can erode because silt no longer replenishes them during floods. Built up sediment behind a dam means the volume of the stored water will gradually diminish. This build-up reduces the effectiveness of the dam for flood control. Large dams also cause ecological damage to river environments.

Limiting Development Today many scientists and engineers advocate sound floodplain management instead of building structures. That often means preserving floodplains in their natural state. Minimizing development on floodplains allows them to absorb floodwaters with little harm to homes and businesses.

Q & A

Q *Sometimes a major flood is described as a 100-year flood. What does that mean?*

A The phrase "100-year flood" is misleading because it makes people believe that such an event happens only once every 100 years. In truth, a huge flood can happen any year. The phrase "100-year flood" is really a statistical designation. It indicates that there is a 1-in-100 chance that a flood this size will happen during any year. Perhaps a better term would be the "1-in-100 chance flood."

Drainage Basins

Every stream has a drainage basin. **A drainage basin is the land area that contributes water to a stream.** An imaginary line called a **divide** separates the drainage basins of one stream from another. Divides range in scale from a ridge separating two small gullies on a hillside to a continental divide, which splits continents into enormous drainage basins. The Mississippi River has the largest drainage basin in North America. See Figure 13. The river and its tributaries collect water from more than 3.2 million square kilometers of the continent.

Figure 13 Mississippi River Drainage Basin Divides are the boundaries that separate drainage basins from each other.

Section 6.2 Assessment

Reviewing Concepts

1. How do streams erode their channels?
2. What causes floods?
3. What is the relationship between a stream and a drainage basin?
4. How do streams transport sediments?

Critical Thinking

5. **Analyzing Concepts** How does urban development interfere with the natural function of floodplains?
6. **Summarizing** Explain the formation of one of the landforms that streams create by deposition.

Writing in Science

Descriptive Paragraph Use library sources or the Internet to research the causes of a recent major flood. Write a paragraph that tells the name of the flood, when it happened, where it happened, and the conditions that led to the flood itself.

6.3 Water Beneath the Surface

Reading Focus

Key Concepts

- Where is groundwater and how does it move?
- How do springs form?
- What are some environmental threats to groundwater supplies?
- How and where do most caverns form?
- What landforms are common in an area of karst topography?

Vocabulary

- zone of saturation
- groundwater
- water table
- porosity
- permeability
- aquifer
- spring
- geyser
- well
- artesian well
- cavern
- travertine
- karst topography
- sinkhole

Reading Strategy

Previewing Copy the table below. Before you read the section, rewrite the green topic headings as how, why, and what questions. As you read, write an answer to each question.

Question	Answer
How does water move underground?	

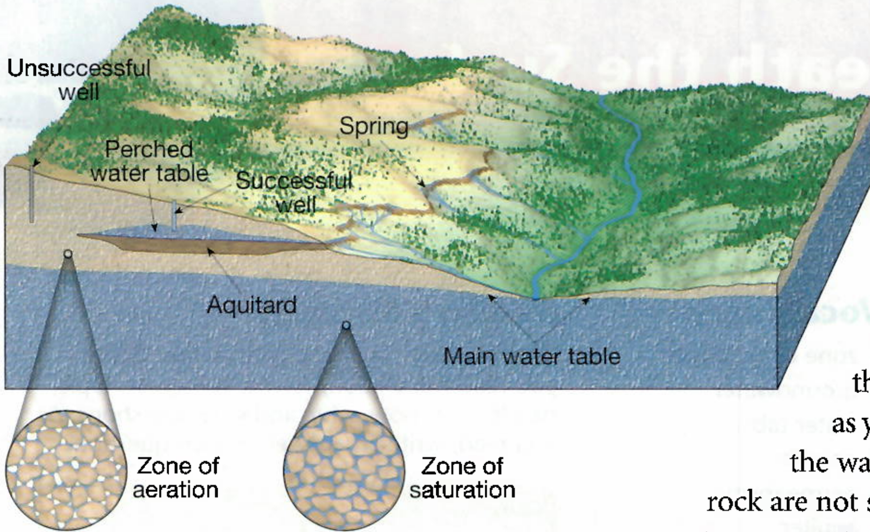
The ground beneath your feet isn't as solid as you might think. It includes countless tiny pore spaces between grains of soil and sediment. It also contains narrow joints and fractures in bedrock. Together these spaces add up to an immense volume of tiny openings where water collects underground and moves.

Underground water in wells and springs provides water for cities, crops, livestock, and industry. In the United States, it is the drinking water for more than 50 percent of the population. It also provides 40 percent of the irrigation water and more than 25 percent of industry's needs.

Distribution and Movement of Water Underground

When rain falls, some of the water runs off, some evaporates, and the rest soaks into the ground to become subsurface water. The amount of water that ends up underground in an area depends on the steepness of slopes, the nature of surface materials, the intensity of rainfall, and the type and amount of vegetation.

Distribution Some of the water soaks into the ground, but it does not travel far. Molecular attraction holds it in place as a surface film on soil particles. This near-surface zone is called the belt of soil moisture. Roots, voids left by decayed roots, and animal and worm burrows crisscross this zone. These features help rainwater seep into soil.



Much of the water in soil seeps downward until it reaches the zone of saturation. The zone of saturation is the area where water fills all of the open spaces in sediment and rock. Groundwater is the water within this zone. The upper limit of the zone of saturation is the **water table,** as you can see in Figure 14. The area above the water table where the soil, sediment, and rock are not saturated is the zone of aeration. Wells cannot pump water from this zone. The water clings too tightly to the rocks and soil. Only below the water table—where water pressure is great enough to allow water to enter wells—can water be pumped.

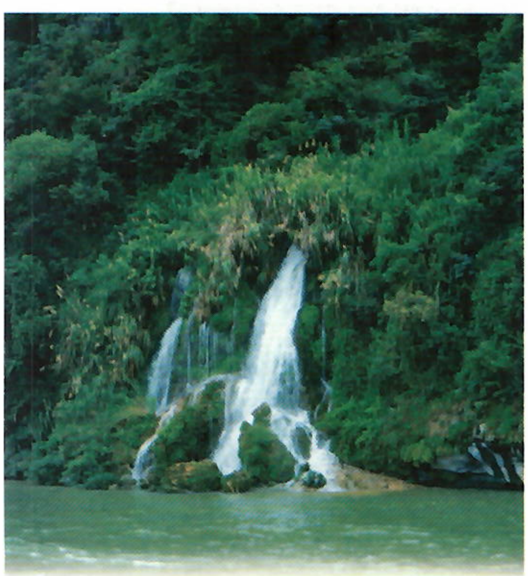
Figure 14 This diagram shows the relative positions of many features associated with subsurface water. **Applying Concepts** ***What is the source of the spring in the center of the illustration?***

Movement The flow and storage of groundwater vary depending on the subsurface material. The amount of groundwater that can be stored depends on porosity. **Porosity** is the percentage of the total volume of rock or sediment that consists of pore spaces. Spaces between sedimentary particles form pore spaces. Joints, faults, and cavities also are formed by the dissolving of soluble rocks such as limestone.

Rock or sediment may be very porous and still block water's movement. The **permeability** of a material is its ability to release a fluid. **Groundwater moves by twisting and turning through interconnected small openings. The groundwater moves more slowly when the pore spaces are smaller.** If the spaces between particles are too small, water cannot move at all. For example, clay has high porosity. But clay is impermeable because its pore spaces are so small that water can't move through them.

Impermeable layers that get in the way or prevent water movement are aquitards. Larger particles, such as sand, have larger pore spaces. Water moves through them easily. Permeable rock layers or sediments that transmit groundwater freely are **aquifers.** Aquifers are important because they are the source of well water.

Figure 15 A spring flows from a valley wall into a stream.



Springs

A spring forms whenever the water table intersects the ground surface. A **spring** is a flow of groundwater that emerges naturally at the ground surface, as shown in Figure 15. Springs form when an aquitard blocks downward movement of groundwater and forces it to move laterally.

Hot Springs A hot spring is 6°C to 9°C warmer than the mean annual air temperature where the spring occurs. There are more than 1000 hot springs in the United States.

Temperatures in deep mines and oil wells usually rise with an increase in depth at an average of 2°C per 100 meters. So when groundwater circulates at great depths, it becomes heated. If it rises to the surface, the water may emerge as a hot spring. This process heats many hot springs in the eastern United States. However, more than 95 percent of the hot springs in the United States are in the West. The source of heat for most of these hot springs is cooling igneous rock. In some places, hot acidic groundwater mixes with minerals from adjacent rock to form thick, bubbling mineral springs called mudpots.

Geysers A **geyser** is an intermittent hot spring or fountain in which a column of water shoots up with great force at various intervals. Geysers often shoot up columns of water 30 to 60 meters. After the jet of water stops, a column of steam rushes out—usually with a thundering roar. Perhaps the most famous geyser in the world is Old Faithful in Yellowstone National Park. It erupts about once each hour.

Geysers occur where extensive underground chambers exist within hot igneous rocks. Follow the formation of a geyser in Figure 16. As relatively cool groundwater enters the chambers, the surrounding rock heats it. The weight of the overlying water creates great pressure at the bottom of the chamber. This pressure prevents the water from boiling at the normal surface temperature of 100°C. However, the heat makes the water expand, and it forces some of the water out at the surface. This loss of water reduces the pressure in the chamber. The boiling point drops. Some of the water deep within the chamber then turns to steam and makes the geyser erupt. Following the eruption, cool groundwater again seeps into the chamber. Then the cycle begins again.

Reading Checkpoint *What is a geyser?*

Geyser Eruption Cycle

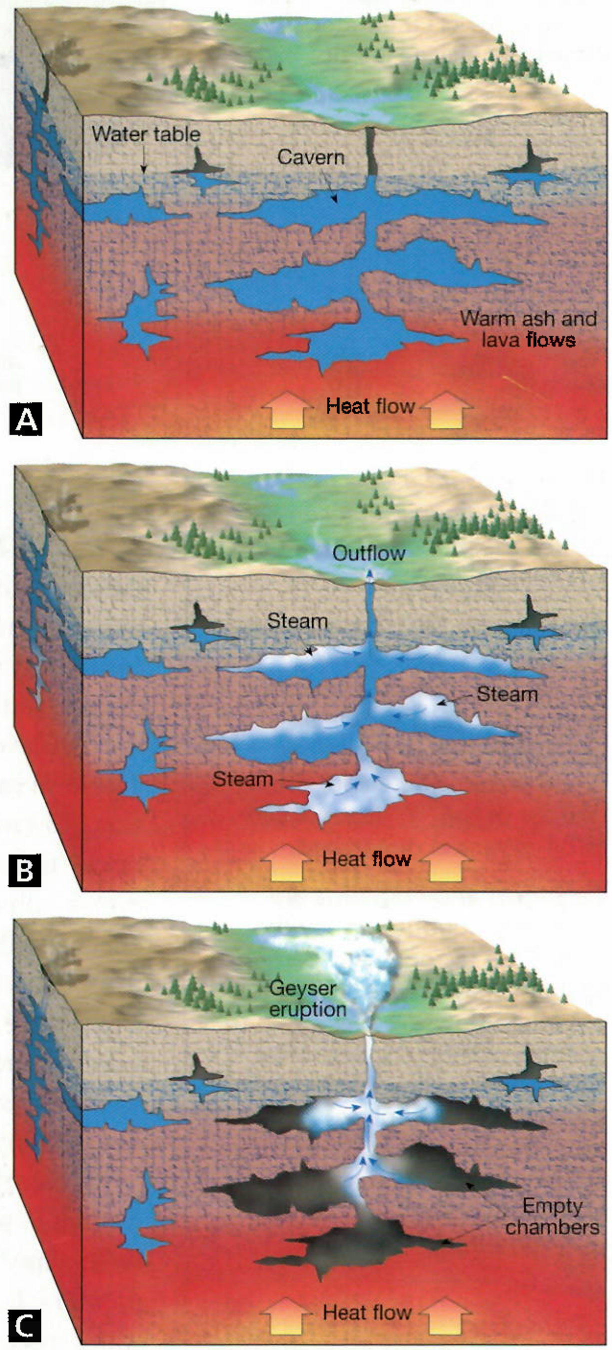


Figure 16 A Groundwater enters underground caverns and fractures in hot igneous rock where it is heated to near its boiling point. **B** Heating causes the water to expand, with some being forced out at the surface. The loss of water reduces the pressure on the remaining water, thus reducing its boiling temperature. Some of the water flashes to steam. **C** The rapidly expanding steam forces the hot water out of the chambers to produce a geyser. The empty chambers fill again, and the cycle starts anew.

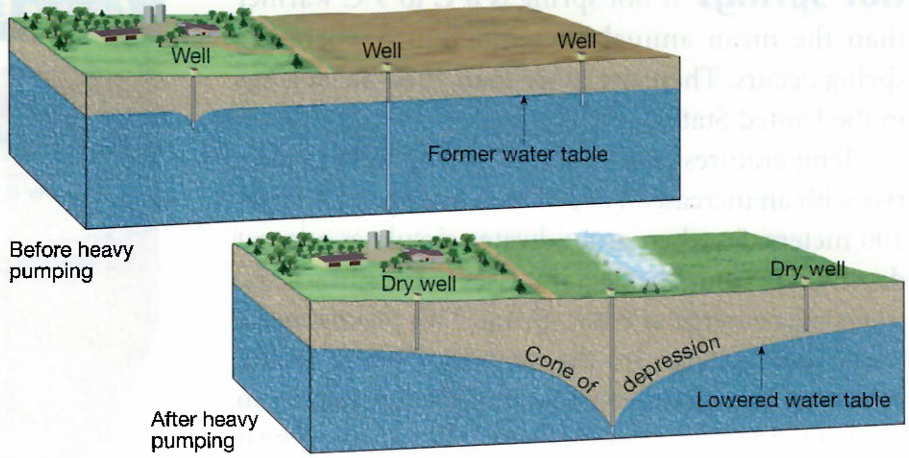


Figure 17 A cone of depression in the water table often forms around a pumping well. If heavy pumping lowers the water table, some wells may be left dry.

Q&A

Q *I have heard people say that supplies of groundwater can be located using a forked stick. Can this actually be done?*

A What you describe is a practice called "water dowsing." In the classic method, a person holding a forked stick walks back and forth over an area. When water is detected, the bottom of the "Y" is supposed to be attracted downward.

Geologists and engineers are extremely doubtful, to say the least. Case histories and demonstrations may seem convincing, but when dowsing is exposed to scientific scrutiny, it fails. Most "successful" examples of water dowsing occur in places where water would be hard to miss. In a region of adequate rainfall and favorable geology, it is difficult to drill and *not* find water!

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Wells

A **well** is a hole bored into the zone of saturation. Irrigation for agriculture is by far the single greatest use of well water in the United States—more than 65 percent of groundwater used annually. Industrial uses of groundwater rank a distant second, followed by the amount used by homes.

The level of the water table may change considerably during a year. The level can drop during the dry season and rise following periods of rain. To ensure a continuous water supply, a well must penetrate far below the water table. The water table around the well drops whenever a substantial amount of water is withdrawn from a well. This effect is called drawdown, and it decreases with an increase in distance from the well. The result of a drawdown is a cone of depression in the water table. This cone of depression is shown in Figure 17. For most small domestic wells, the cone of depression is tiny. However, when wells are used for irrigation or industry, a very wide and steep cone of depression can result.

Water must be pumped out of most wells. However, water rises on its own in some wells, sometimes overflowing the surface. An **artesian well** is any formation in which groundwater rises on its own under pressure. For such a situation to occur, two conditions must exist. First, water must be in an aquifer that is tilted so that one end is exposed at the surface, where it can receive water. Second, there must be aquitards both above and below the aquifer to stop the water from escaping. The pressure created by the weight of the water above forces the water to rise when a well taps the aquifer.

Reading Checkpoint ***How does an artesian well differ from most wells?***

Environmental Problems Associated with Groundwater

As with many valuable natural resources, groundwater is being threatened at an increasing rate. **Overuse and contamination threatens groundwater supplies in some areas.**

Treating Groundwater as a Nonrenewable Resource

Groundwater seems like an endlessly renewable resource. However, supplies are finite. In some regions, the amount of water available to recharge an aquifer is much less than the amount being withdrawn.

The High Plains provides one example of severe groundwater depletion. In some parts of the region, intense irrigation has gone on for a long time. Even if pumping were to stop now, it could take thousands of years for the groundwater to be fully replenished.

The ground may sink when water is pumped from wells faster than natural processes can replace it. As water is withdrawn, the ground subsides because the weight of the overburden packs relatively loose sediment grains more tightly together.

This type of subsidence is extreme in the San Joaquin Valley of California, as shown in Figure 18. Land subsidence due to groundwater withdrawal for irrigation began there in the mid-1920s. It exceeded eight meters by 1970. During a drought in 1976 and 1977, heavy groundwater pumping led the ground to sink even more. Land subsidence affected more than 13,400 square kilometers of irrigable land—one half the entire valley.

Figure 18 The marks on the utility pole indicate the level of the surrounding land in years past. Between 1925 and 1975 this part of the San Joaquin Valley sank almost 9 meters because of the withdrawal of groundwater and the resulting compaction of sediments.

Groundwater Contamination The pollution of groundwater is a serious matter, particularly in areas where aquifers provide much of the water supply. Common sources of groundwater pollution are sewage from septic tanks, farm wastes, and inadequate or broken sewers.

If sewage water that is contaminated with bacteria enters the groundwater system, it may become purified through natural processes. The harmful bacteria can be mechanically filtered by the sediment through which the water passes, destroyed by chemical oxidation, and/or assimilated by other organisms. For purification to occur, however, the aquifer must be of the correct composition.

For example, extremely permeable aquifers have such large openings that contaminated groundwater may travel long distances without being cleansed. In this case, the water flows too quickly and is not in contact with the surrounding material long enough for purification to occur. This is the problem at Well 1 in Figure 19A.

Reading Checkpoint ***What are some common sources of groundwater pollution?***

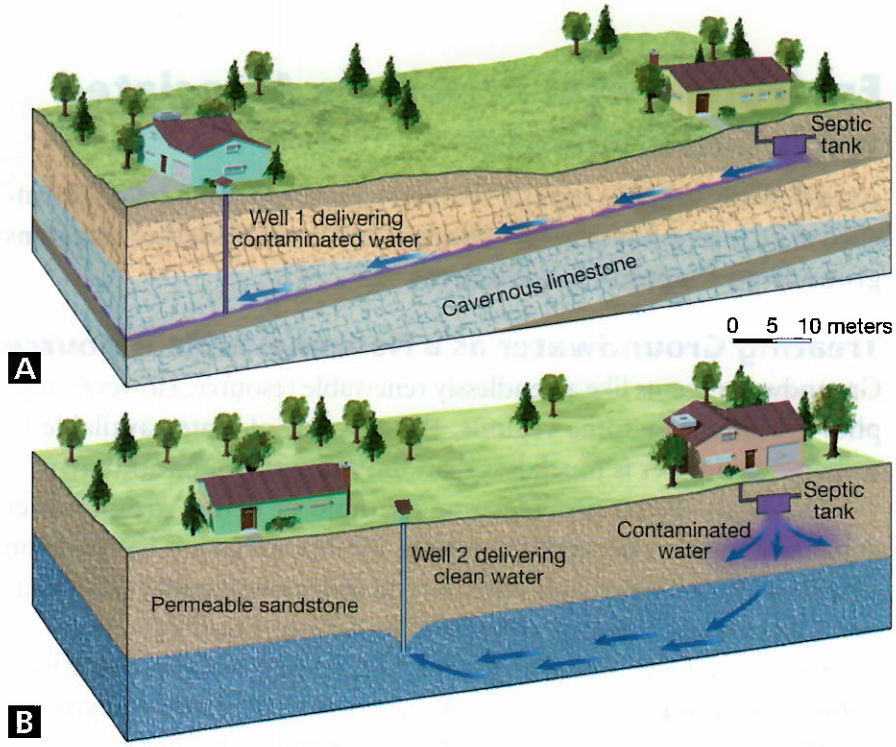

Figure 19 **A** Although the contaminated water has traveled more than 100 meters before reaching Well 1, the water moves too quickly through the cavernous limestone to be purified. **B** As the discharge from the septic tank percolates through the permeable sandstone, it is purified in a short distance.

Figure 20 Agricultural chemicals sprayed on farm fields can seep into soil and contaminate underground water supplies.

Figure 21 If landfills leak, harmful waste buried in them can escape into groundwater.

However, when the aquifer is composed of sand or permeable sandstone, the water can sometimes be purified after traveling only a few dozen meters through it. The openings between sand grains are large enough to permit water movement, yet the movement of the water is slow enough to allow enough time for its purification. This is the case at Well 2 in Figure 19B.

Other sources and types of contamination also threaten supplies, as you can see in Figures 20 and 21. These include fertilizers that are spread across the land, pesticides, and highway salt. In addition, chemicals and industrial materials—some hazardous—may leak from pipelines, storage tanks, landfills, and holding ponds. As rainwater oozes through the refuse, it may dissolve contaminants. If this material reaches the water table, it will mix with and contaminate groundwater. In coastal areas, heavy use can deplete aquifers, causing underground saltwater to enter wells.

Once the source of the problem has been identified and eliminated, the most common practice is to abandon the water supply. Abandoning the water supply allows the pollutants to flush out gradually. It's the least costly and easiest solution, but the aquifer must stay unused for years. To speed up this process, engineers sometimes pump out and treat polluted water. The aquifer then recharges naturally, or the treated water is pumped back in. This process can be risky, because there is no way to be sure that treatment has removed all the pollution. Prevention remains the most effective solution to groundwater contamination.

Some substances in groundwater are natural. Ions of substances (from adjacent rock) such as calcium and iron make some water "hard." Hard water forms scum with soap instead of suds. It can also deposit residue that clogs pipes. But hard water is generally not a health risk.

Caverns

Figure 22 The dissolving action of groundwater creates caverns. These dripstone features are in Three Fingers Cave in New Mexico.

The most spectacular results of groundwater's ability to erode rock are limestone caverns. Soluble rocks, especially limestone, underlie millions of square kilometers of Earth's surface. Limestone is nearly insoluble in pure water. But water containing small quantities of carbonic acid dissolves it easily. Most natural water contains the weak acid because rainwater dissolves carbon dioxide from the air and decaying plants. Therefore, when groundwater comes in contact with limestone, the carbonic acid reacts with calcite in the rocks. Calcium bicarbonate forms. As groundwater carries away calcium carbonate in solution, it slowly erodes rock. A **cavern** is a naturally formed underground chamber, such as the one you see in Figure 22. There are thousands of caverns in the United States. Most are fairly small, but some have spectacular dimensions. Carlsbad Caverns in southeastern New Mexico is a famous example. One chamber has an area equivalent to 14 football fields, and it is high enough to fit the U.S. Capitol building inside it.

Erosion forms most caverns at or below the water table in the zone of saturation. Here, acidic groundwater follows lines of weakness in the rock, such as joints and bedding planes. As time passes, the dissolving process slowly creates cavities and enlarges them into caverns. Material the groundwater dissolves eventually flows into streams and then the ocean.

The features that produce the greatest curiosity for most cavern visitors are depositional stone formations. These formations give some caverns a wonderland appearance. They form from seemingly endless dripping of water over great spans of time. The calcium carbonate that is left behind produces the limestone we call **travertine.** These cave deposits are commonly called dripstone.

Although the formation of caverns takes place in the zone of saturation, the deposition of dripstone features is not possible until the caverns are above the water table in the zone of aeration. The formation of caverns in the zone of aeration commonly occurs as nearby streams cut their valleys deeper. As the elevation of the stream drops, the water table also lowers, leaving the caverns high and largely dry.

Figure 23 Soda straw stalactites in Great Basin National Park's Lehman Caves.
Relating Cause and Effect ***What part do these drops of water play in the formation of the stalactites?***

Dripstone Features Perhaps the most familiar dripstone features are stalactites. Stalactites are icicle-like stone pendants that hang from the ceiling of a cavern. They form when water seeps through cracks in the cavern ceiling. When water reaches air in the cave, some of the dissolved carbon dioxide escapes from the drop and calcite begins to separate out. Deposition occurs as a ring around the edge of the water drops. As drops fall, each one leaves a tiny trace of calcite behind. This calcite creates a hollow limestone tube called a soda straw, as shown in Figure 23. Often the hollow tube becomes plugged or its supply of water increases. When a stalactite becomes plugged or the water supply increases, the water flows and deposits along the outside of the tube. As deposition continues, the stalactite takes on the more common conical shape.

Stalagmites are formations that develop on the floor of a cavern and reach up toward the ceiling. The water supplying the calcite for stalagmite growth falls from the ceiling and splatters over the surface of the cavern floor. As a result, stalagmites do not have a central tube. They are usually more massive and more rounded on their upper ends than stalactites. Given enough time, a downward-growing stalactite and an upward-growing stalagmite may join to form a column.

Reading Checkpoint ***What is a dripstone deposit?***

Karst Topography

Many areas of the world have landscapes that have been shaped largely by the dissolving power of groundwater. These areas are said to have **karst topography.** This term comes from the *Krs* region of Slovenia, where such topography is strikingly developed. In the United States, karst landscapes occur in many areas that are underlain by limestone. These areas include parts of Kentucky, Tennessee, Alabama, southern Indiana, and central northern Florida.

Karst areas typically have irregular terrain, with many depressions called sinkholes. A **sinkhole** is a depression produced in a region where groundwater has removed soluble rock. In the limestone areas of Florida, Kentucky, and southern Indiana, there are tens of thousands of these depressions. They vary in depth from just a meter or two to more than 50 meters.

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Sinkholes commonly form in one of two ways. Some develop gradually over many years without any physical disturbance to the rock. In these situations, downward-seeping rainwater containing carbon dioxide dissolves limestone below the soil. These depressions are fairly shallow and have gentle slopes. Sinkholes can also form suddenly when the roof of a cavern collapses. The depressions created in this way are steep-sided and deep. When they form in populated areas, they may be a serious geologic hazard, as shown in Figure 24.

Figure 24 This small sinkhole formed suddenly in 1991 when the roof of a cavern collapsed. It destroyed this home in Frostproof, Florida.

In addition to a surface pockmarked by sinkholes, karst regions usually show a striking lack of surface drainage (streams). Following a rainfall, runoff is quickly funneled below ground through sinkholes. It then flows through caverns until it finally reaches the water table. Where streams do exist at the surface, their paths are usually short. The names of such streams often give a clue to their fate. In the Mammoth Cave area of Kentucky, for example, there is Sinking Creek, Little Sinking Creek, and Sinking Branch. Some sinkholes become plugged with clay and debris, creating small lakes or ponds.

Section 6.3 Assessment

Reviewing Concepts

1. Where is groundwater located under the surface?
2. How does water move underground?
3. What are some environmental threats to groundwater supplies?
4. How and where do most caverns form?
5. What landforms are common in an area of karst topography?

Critical Thinking

6. **Comparing and Contrasting** What is the difference between stalactites and stalagmites?
7. **Analyzing Concepts** How is groundwater a nonrenewable resource?
8. **Analyzing Concepts** Explain why caverns form in the zone of saturation, while dripstone features form in the zone of aeration?

Writing in Science

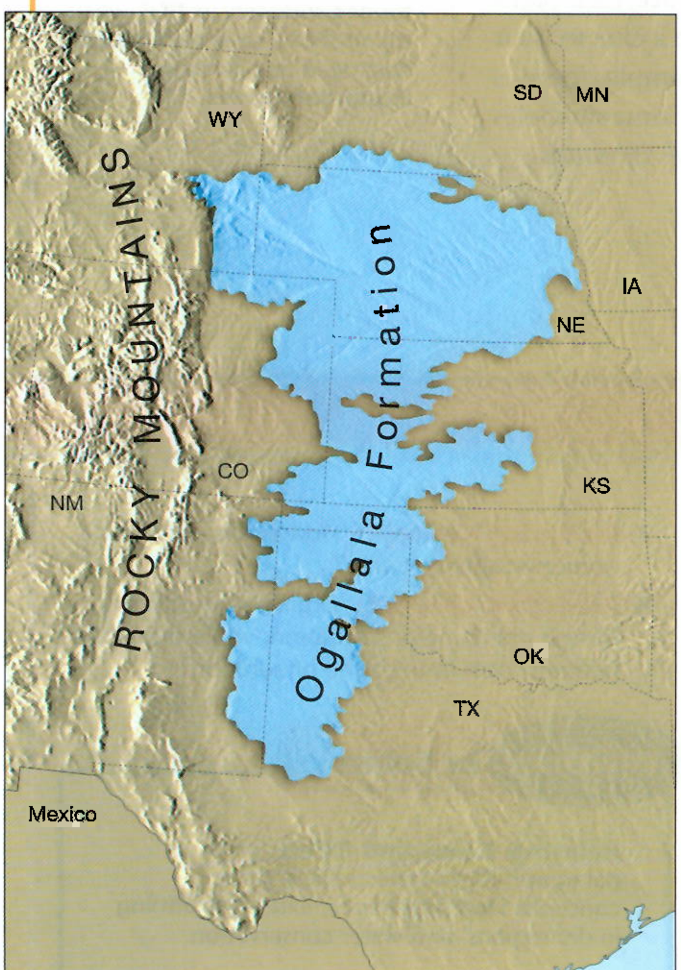
Relating Cause and Effect Write a paragraph that connects these three concepts: land subsidence, extensive farming in dry regions, and water conservation.

people and the ENVIRONMENT

The Ogallala Aquifer—How Long Will the Water Last?

The High Plains extend from the western Dakotas south to Texas. Despite being a land of little rain, this is one of the most important agricultural regions in the United States. The reason is a vast supply of groundwater that makes irrigation possible throughout most of the region. The source of most of this water is the Ogallala Formation, the largest aquifer in the United States.

Geologically, the Ogallala Formation consists of a number of sandy and gravelly rock layers. The sediments came from the erosion of the Rocky Mountains and were carried eastward by sluggish streams. Erosion has removed much of the formation from eastern Colorado, severing the Ogallala's connection to the Rockies.



The Ogallala Formation, the largest aquifer in the United States, averages 60 meters thick. However, in some places it is as thick as 180 meters. Groundwater in the aquifer originally traveled downslope from the Rocky Mountains and from surface precipitation that soaked into the ground over thousands of years. Because of its high porosity and great size, the Ogallala Formation accumulated a large amount of groundwater—enough to fill Lake Huron! Today, with the connection between the aquifer and the Rockies gone (erosion has removed much of the formation in eastern Colorado), all of the Ogallala's recharge must come from the meager rainfall of the Plains.

In the late 1800s, people first started to use the Ogallala for irrigation. However, the capacity of pumps available at the time limited water withdrawal. Then in the 1920s, large-capacity irrigation pumps were invented. High Plains' farmers began tapping the Ogallala for irrigation. Today, there are nearly 170,000 wells irrigating more than 65,000 square kilometers of land.

The increase in irrigation has caused a drastic drop in the Ogallala's water table, especially in the High Plains. Declines in the water table of 3 to 15 meters are common. In places, however, the water table is now 60 meters below its original level.

Although the decline in the water table has slowed in parts of the southern High Plains, substantial pumping continues—often in excess of recharge. The future of irrigated farming here is clearly in jeopardy.

The southern High Plains will return sooner or later to dry-land farming. The transition will come sooner and with fewer ecological and economic crises if the agricultural industry is weaned gradually from its dependence on groundwater irrigation. If nothing is done until all the accessible water in the Ogallala aquifer has been removed, the transition will be ecologically dangerous and economically dreadful.*

*National Research Council. *Solid-Earth Sciences and Society.* Washington, DC: National Academy Press, 1993, p. 148.

Figure 25 The Ogallala Formation underlies about 450,000 square kilometers of the High Plains, making it the largest aquifer in the United States.

Exploration Lab

Investigating the Permeability of Soils

The permeability of soils affects the way groundwater moves—or if it moves at all. Some soils are highly permeable, while others are not. In this lab, you will determine the permeability of various soils, and draw conclusions about their effect on the movement of water underground.

Problem How does the permeability of soil affect its ability to move water?

Materials

- 100 mL graduated cylinder
- beaker
- small funnel
- 3 pieces of cotton
- samples of coarse sand, fine sand, and soil
- clock or watch with a second hand

Skills Observing, Measuring, Comparing and Contrasting, Analyzing Data, Interpreting Data

Procedure

1. Place a small, clean piece of cotton in the neck of the funnel. Fill the funnel above the cotton with coarse sand. Fill the funnel about two-thirds of the way.
2. **Measure** Pour water into the graduated cylinder until it reaches the 50 mL mark.
3. With the bottom of the funnel over the beaker, pour the water from the graduated cylinder slowly into the sand in the funnel.
4. **Measure** In a data table like the one shown, keep track of the time from the second you start to pour the water into the funnel. Measure the amount of time that it takes the water to drain through the funnel filled with coarse sand.
5. Record the time it takes for the water to drain through the sand in the data table.
6. Empty and clean the measuring cylinder, funnel, and beaker.
7. Repeat Steps 1 through 7, first using fine sand, and then using soil.

Analyze and Conclude

1. **Comparing and Contrasting** Of the three materials you tested, which has the greatest permeability? Which had the least permeability?
2. **Analyzing Data** Why were different amounts of water recovered in the beaker for each material tested?
3. **Interpreting Data** What effect would the differences you observed in this lab have on the movement of groundwater through different soils?

Data Table

	Time Needed for Water to Drain Through Funnel	Water Collected in Beaker (mL)
Coarse Sand		
Fine Sand		
Soil		

CHAPTER 6

Study Guide

6.1 Running Water

Key Concepts

- Water constantly moves among the oceans, the atmosphere, the solid Earth, and the biosphere. This unending circulation of Earth's water supply is the water cycle
- Balance in the water cycle means the average annual precipitation over Earth equals the amount of water that evaporates.
- The ability of a stream to erode and transport materials depends largely on its velocity.
- While gradient decreases between a stream's headwaters and mouth, discharge increases.
- Base level is the lowest point to which a stream can erode its channel.

Vocabulary

water cycle, *p. 158;* infiltration, *p. 159;* transpiration, *p. 159;* gradient, *p. 160;* stream channel, *p. 161;* discharge, *p. 161;* tributary, *p. 162;* meander, *p. 163*

6.2 The Work of Streams

Key Concepts

- Streams generally erode their channels by dissolving soluble material, by lifting loose particles, and by abrasion, or grinding.
- Streams transport their load of sediment in three ways: (1) in solution (dissolved load), (2) in suspension (suspended load), and (3) scooting or rolling along the bottom (bed load).
- Deposition occurs as streamflow drops below the critical settling velocity of a certain particle size.
- There are two general types of stream valleys: narrow V-shaped valleys and wide valleys with flat floors.
- Most floods are caused by rapid spring snow melt and storms that bring heavy rains over a large region.
- Measures to control flooding include the construction of artificial levees, building flood control dams, and placing limits on floodplain development.
- A drainage basin is the land area that contributes water to a stream.

Vocabulary

bed load, *p. 165;* capacity, *p. 165;* delta, *p. 166;* natural levee, *p. 167;* floodplain, *p. 167;* flood, *p. 168;* drainage basin, *p. 170;* divide, *p. 170*

6.3 Water Beneath the Surface

Key Concepts

- Much of the water in soil seeps downward until it reaches the zone of saturation. The zone of saturation is the area where water fills all of the open spaces in sediment and rock. Groundwater is the water within this zone.
- Groundwater moves by twisting and turning through interconnected small openings. The groundwater moves more slowly when the pore spaces are smaller.
- A spring forms whenever the water table intersects the ground surface.
- Overuse and contamination threatens groundwater supplies in some areas.
- Erosion forms most caverns at or below the water table in the zone of saturation.
- Karst areas typically have irregular terrain, with many depressions called sinkholes.

Vocabulary

zone of saturation, *p. 172;* groundwater, *p. 172;* water table, *p. 172;* porosity, *p. 172;* permeability, *p. 172;* aquifer, *p. 172;* spring, *p. 172;* geyser; *p. 173;* well, *p. 174;* artesian well; *p. 174;* cavern, *p. 177;* travertine, *p. 177;* karst topography, *p. 178;* sinkhole, *p. 178*

CHAPTER 6

Assessment

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Reviewing Content

Choose the letter that best answers the question or completes the statement.

1. The energy for the water cycle comes from the
   a. ocean.
   b. sun.
   c. atmosphere.
   d. soil.

2. How does water move from plants to the atmosphere ?
   a. infiltration
   b. precipitation
   c. transpiration
   d. condensation

3. By what process do streams and rivers move material?
   a. weathering
   b. infiltration
   c. mass wasting
   d. erosion

4. A river's discharge is generally greatest
   a. at its source.
   b. on its floodplain.
   c. at its mouth.
   d. at the sides of its channel.

5. When do streams and rivers deposit sediment?
   a. when their velocity decreases
   b. when they are in the midst of flooding
   c. when their velocity increases
   d. when they plunge over waterfalls

6. A stream's drainage basin is all the water that
   a. flows into it.
   b. infiltrates from it into the ground.
   c. is removed from it for drinking water.
   d. is within 100 kilometers of its channel.

7. What is a stream's bed load?
   a. material that moves along its bottom
   b. material that is carried in solution
   c. material that floats on its surface
   d. material that is carried in suspension

8. Where is groundwater located?
   a. zone of aeration
   b. zone of reduction
   c. zone of saturation
   d. zone of distribution

9. Water in an artesian well
   a. dries up after a short amount of time.
   b. rises on its own under pressure.
   c. has been contaminated by saltwater.
   d. is heated by cooling igneous rocks.

10. Caverns form when rocks such as limestone are dissolved by a mixture of water and
    a. carbonic acid.
    b. sulfur dioxide.
    c. nitrogen.
    d. ammonia.

11. Which of these landforms is characteristic of an area with karst topography?
    a. mountains
    b. canyons
    c. sinkholes
    d. drumlins

Understanding Concepts

12. Write a list of numbered statements that summarize the major steps in the water cycle.

13. How does a stream's gradient affect is velocity?

14. Why does a stream's base level affect how it downcuts its channel?

15. Which type of stream valley is formed primarily by downcutting?

16. What are the main causes of floods?

17. What is the relationship between a spring and the water table?

18. Why are leaking landfills and septic tanks of concern to people who use groundwater?

19. How do stalactites form?

20. What type of rock is often associated with the formation of caverns and karst topography?

21. How do dripstone columns form?

Assessment *continued*

Critical Thinking

22. **Analyzing Concepts** Why must Earth's water cycle be balanced in order for the system to work?

23. **Relating Cause and Effect** How would a reduction in friction in a stream channel affect the stream's velocity?

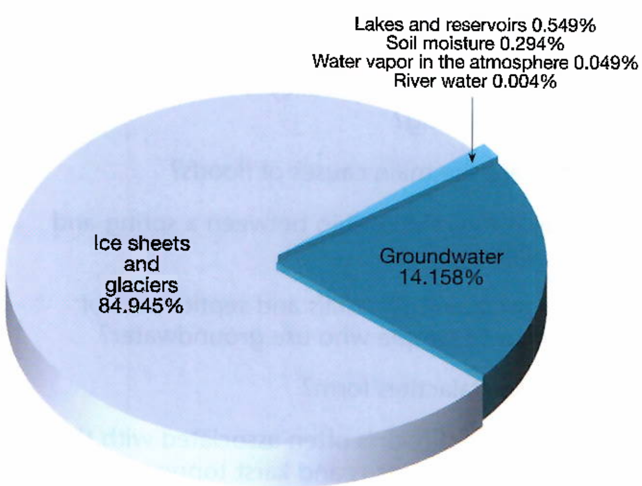
24. **Applying Concepts** A stream's discharge decreases. Explain how this affects the stream's capacity.

25. **Summarizing** Briefly explain how a material can be porous but also impermeable.

26. **Drawing Conclusions** The bedrock under a region is primarily a very hard rock that doesn't easily erode. The area is also very arid. Is it likely that this area has a karst landscape? Explain your answer.

Analyzing Data

Use the graph below to answer Questions 27–30.



27. **Using Graphs** Where is the greatest percentage of Earth's fresh water located?

28. **Calculating** What percentage of Earth's fresh water is held in rivers, lakes, and reservoirs?

29. **Calculating** Oceans hold about 97 percent of Earth's water. The rest of the water is fresh. What percentage of Earth's water is freshwater that people can use for drinking, cooking, and growing crops?

30. **Drawing Conclusions** Taking into account your answer to Question #29 above, explain why many people think of Earth's supply of fresh water as a resource that must be protected.

Concepts in Action

31. **Applying Concepts** A person drills a well into an area where there is a known aquifer underground. But the well doesn't produce water. What might be the cause of the problem? What does this person need to know about the water table in this area to solve the problem?

32. **Predicting** Erosion reduces the size of pebbles on the bottom of a stream channel. Which of the following would be most affected: the stream's competence, velocity, or discharge? Explain your answer.

33. **Connecting Concepts** Explain what deltas and natural levees have in common.

34. **Writing in Science** Imagine you live in a town that floods often. The people in your community want to take measures to decrease the amount of flooding and property damage. The community has identified three choices: a set of natural levees, a flood control dam, or clearing development from the river floodplain. Write a letter to the editor supporting one of these choices.

Performance-Based Assessment

Drawing Diagrams Draw a graphic organizer that shows the major steps of the water cycle. Label each step.

Standardized Test Prep

Test-Taking Tip

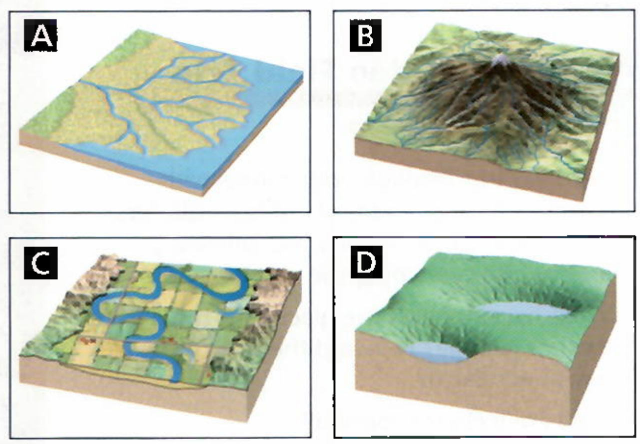
Evaluating and Revising
Frequently, a scientifically accurate answer choice may not answer the question that is being asked. Keep these tips in mind.

- Verify what the question is asking.
- Determine if an answer choice is a true statement or not.
- Determine if a true answer choice actually answers the question.
- Be cautious with inserted or deleted words that make a false statement seem accurate.

Practice using these tips in Question 3.

Choose the letter that best answers the question or completes the statement, or write a brief answer to the question.

1. Which of these processes of the water cycle is a direct effect of the sun's energy?
   (A) formation of precipitation
   (B) runoff of water over soil
   (C) evaporation
   (D) seeping of water into soil
2. Which factor is most important in determining the erosive power of a stream?
   (A) stream discharge
   (B) dissolved load
   (C) stream velocity
   (D) channel width
3. Rejuvenation causes streams to resume downcutting their channels because
   (A) the stream's greatest velocity is at its bottom.
   (B) the stream's bed load helps erode the stream's bottom.
   (C) natural levees restrict the lateral movement of stream waters.
   (D) uplift creates a new base level for the stream.
4. When a soil is impermeable, it
   (A) allows water to flow freely through it.
   (B) has no water in it at all.
   (C) does not allow water to pass through it.
   (D) has large pore spaces.
5. Which of these features is a landform associated with karst topography?
   (A) sinkholes
   (B) streams
   (C) natural levees
   (D) deltas
6. What are the major environmental problems associated with the use of groundwater?
7. What is a cone of depression and how does it form?
8. Which of the following drawings shows a feature of stream deposition?



CHAPTER 7

Glaciers, Deserts, and Wind

CONCEPTS in Action

Exploration Lab
Interpreting a Glacial Landscape

How the Earth Works
Erosion

GEODe Earth Science
Sculpturing Earth's Surface
↳ Glaciers
Deserts

Discovery Channel School

Video Field Trip

Glaciers

Take a field trip through cold waters with Discovery Channel and find out how glaciers helped shape Earth. Answer the following questions after watching the video.

1. What happened to the glaciers at the end of the last ice age? How did the end of the ice age affect Earth?
2. How are icebergs formed?

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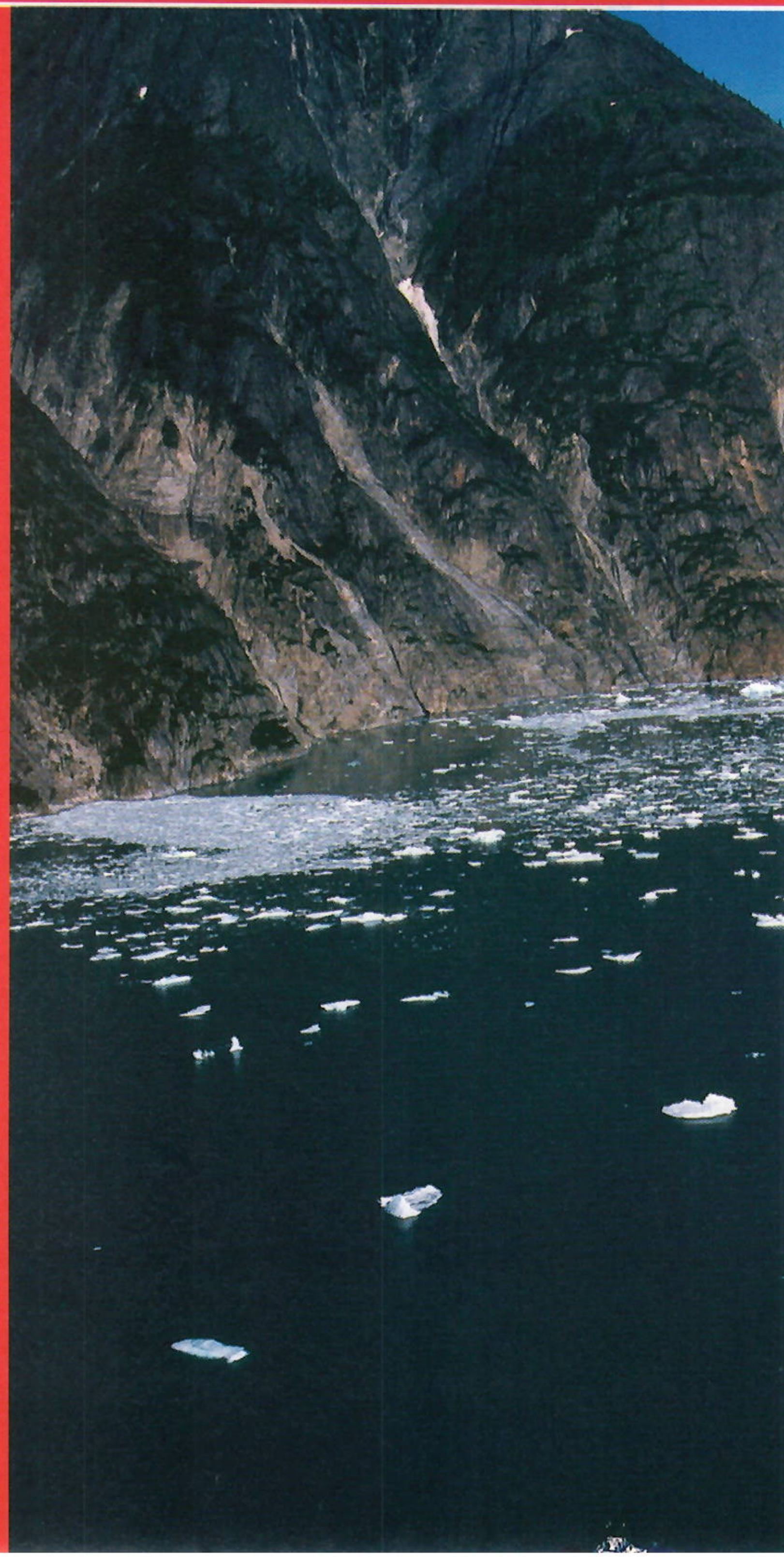
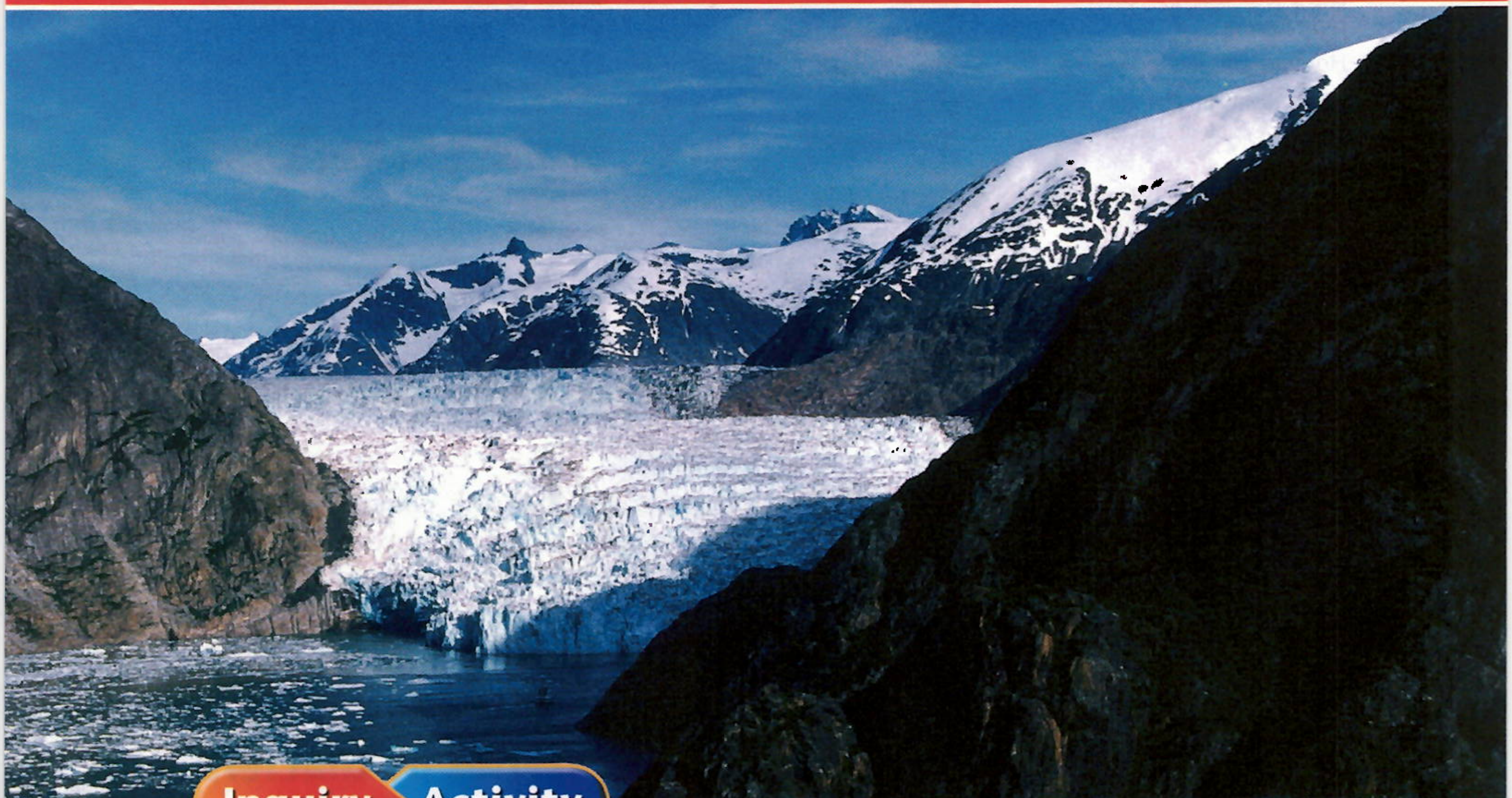


This fjord at Tracy Arm, Alaska, formed as a glacier carved the valley that became submerged as sea level rose.

Chapter Preview



Inquiry Activity

How Does Pressure Affect Ice Crystals?

Procedure

1. Obtain a beaker full of ice crystals, either by collecting snow outside or by scraping ice crystals from the inside surfaces of a freezer. Use a magnifying glass to observe the loose crystals. Sketch their appearance in your science notebook.
2. Use your hands to mold a snowball from the crystals. Then squeeze the snowball as hard as you can, making the snowball compact.
3. Use a table knife to cut the snowball in half. Observe the compressed crystals with your magnifying glass and sketch them.

Think About It

1. **Drawing Conclusions** How did the ice crystals change after you squeezed them? Describe how pressure seems to affect ice crystals.
2. **Predicting** The raw material for glaciers is snow. Predict how snowflakes will change under the increasing pressure of overlying snow.

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.

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.

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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.

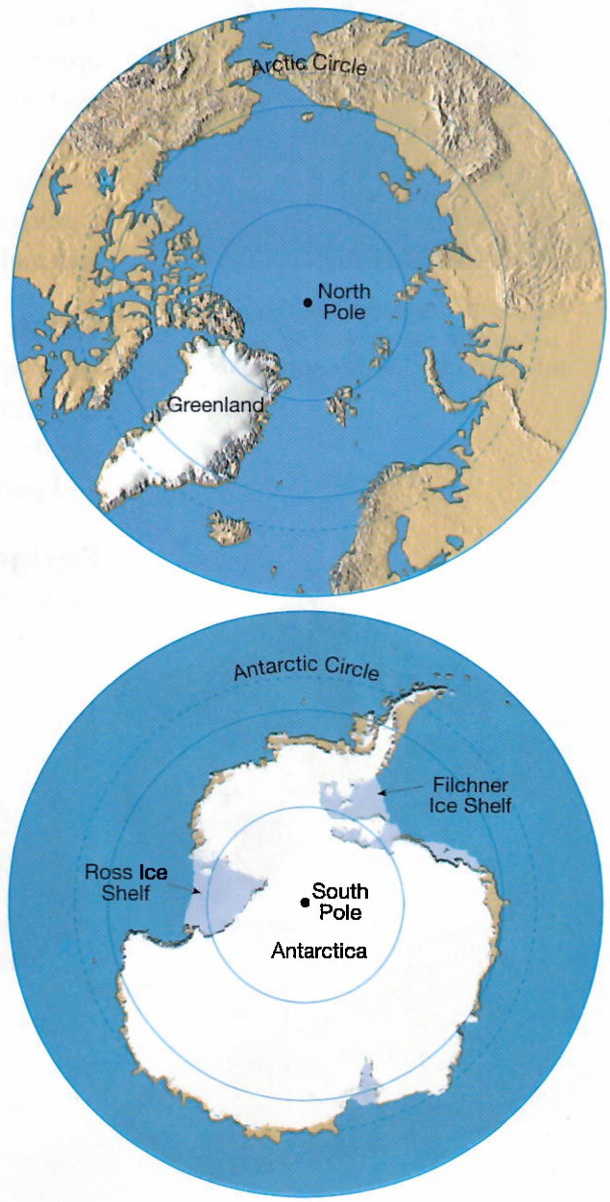


Figure 2 The only present-day ice sheets are those covering Greenland and Antarctica.

Reading Checkpoint *Where do ice sheets exist on Earth today?*

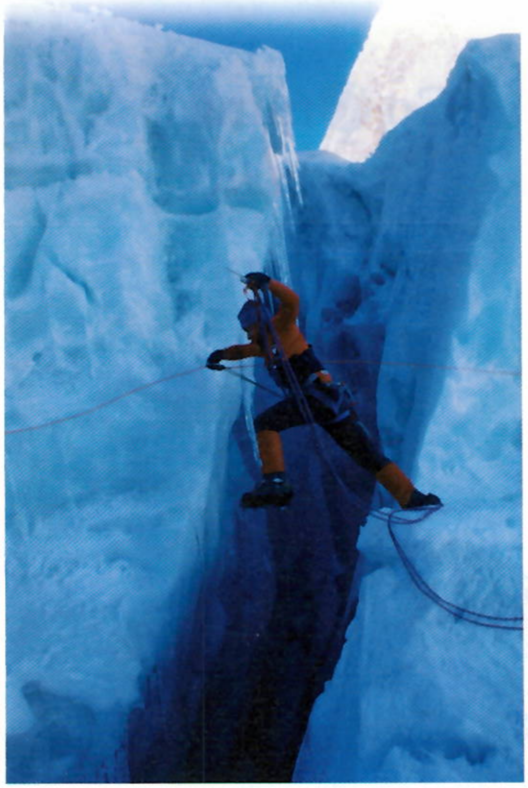


Figure 3 Crevasses like this one in Pakistan can extend 50 meters into a glacier's brittle surface ice.

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.

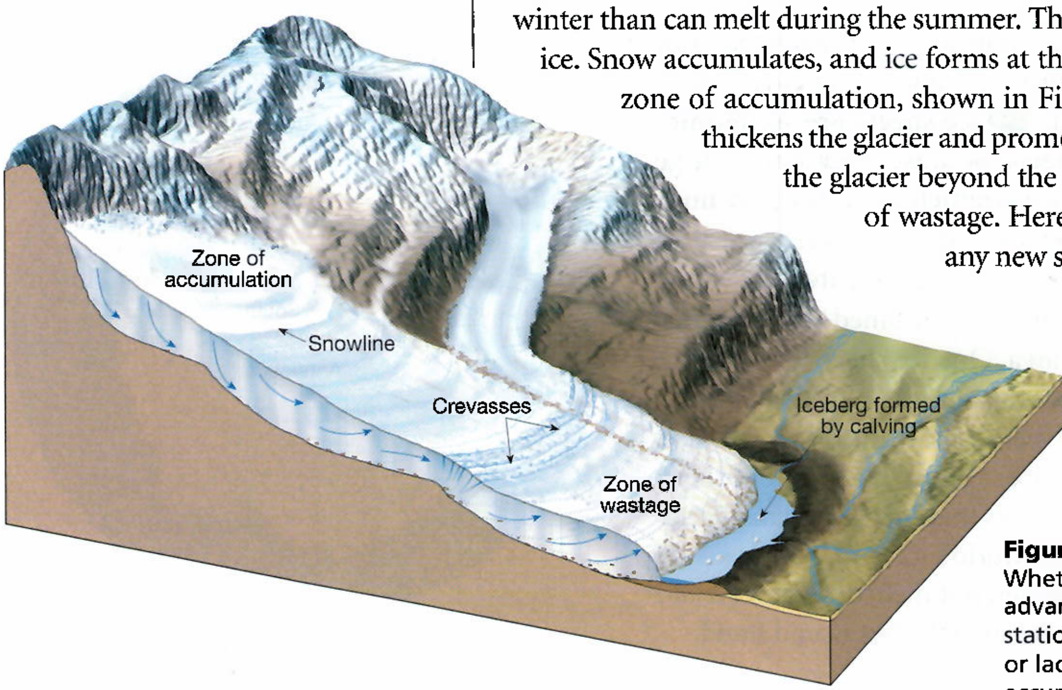


Figure 4 How a Glacier Moves Whether the margin of a glacier advances, retreats, or remains stationary depends on the balance or lack of balance between accumulation and wastage.

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.

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.

Reading Checkpoint ***What causes a glacier to retreat?***

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.**

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.

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?*

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?*

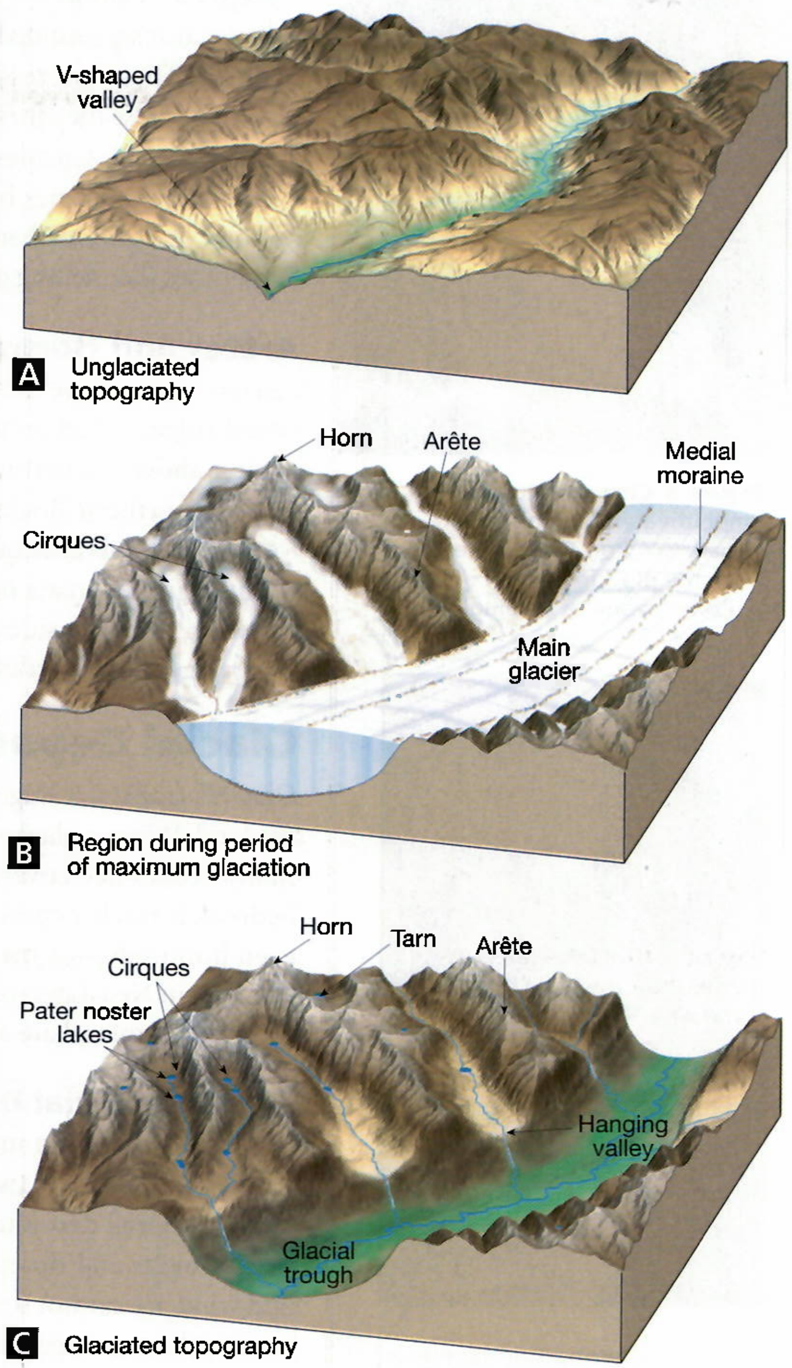


Figure 7 Erosional Landforms Caused by Valley Glaciers **A** shows what the valley glaciers looked like in this mountainous region. **B** reveals the modified landscape and its features. **Inferring** *What direction did the main valley glacier flow? How do you know?*

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.

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.

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.

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.

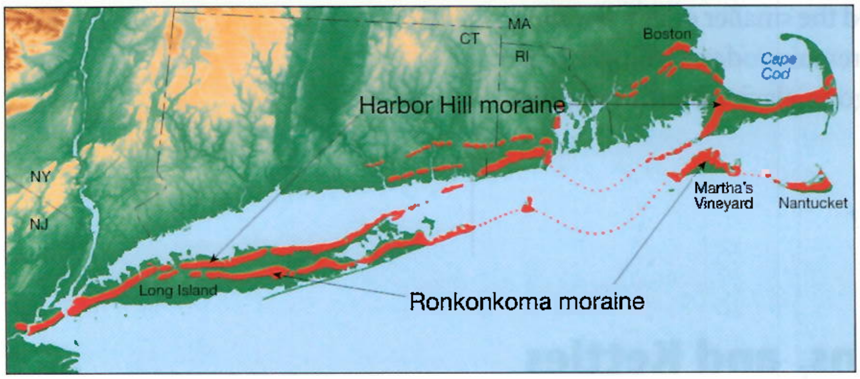


Figure 11 Long Island, Cape Cod, Martha's Vineyard, and Nantucket are remnants of an end moraine.

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 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?***

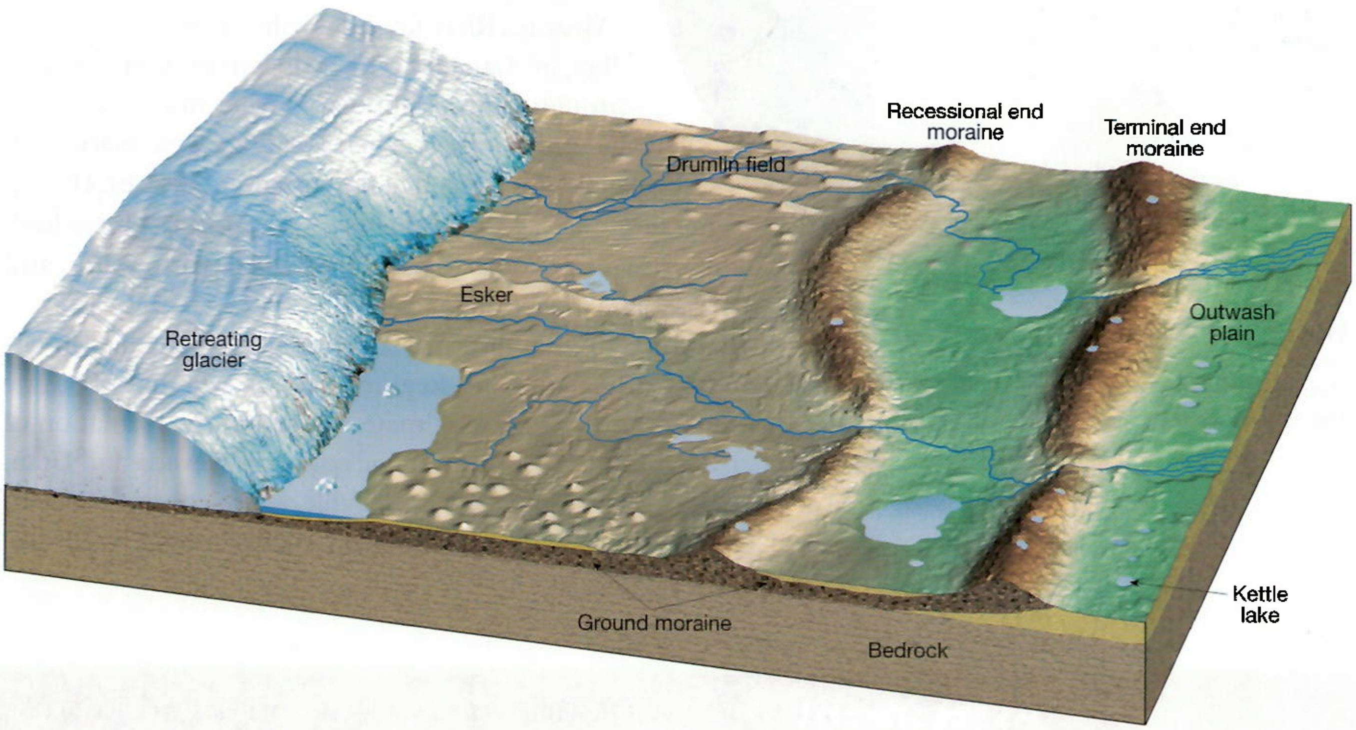


Figure 12 The landscape left by a retreating glacier includes a number of distinctive features. The terminal end moraine marks the farthest extent of the glacier. Recessional moraines occur where a retreating glacier temporarily becomes stationary.
Using Analogies ***How is a glacier like a conveyor 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.

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?

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.

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.

Figure 14 Desert landscapes vary a great deal. This landscape is in California's Death Valley.

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.*

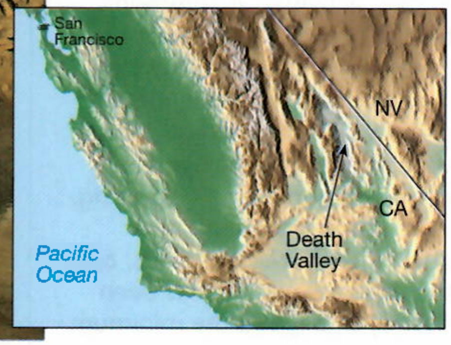


Figure 16 Alluvial Fans Over the years, alluvial fans enlarge and merge with fans from adjacent canyons to produce an apron of sediment along the mountain front.

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.

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.

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.

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?***

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.

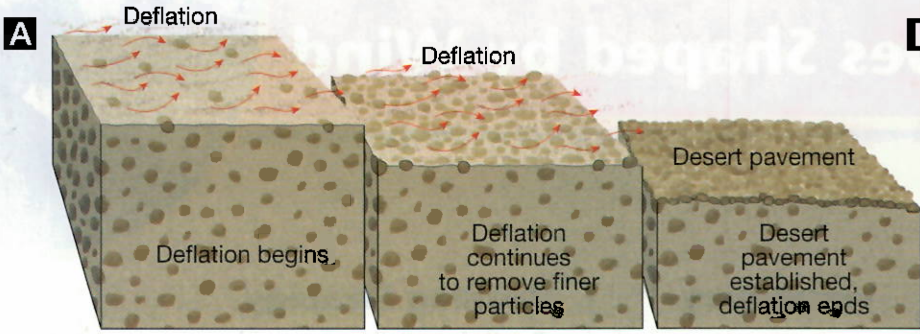


Figure 18 **A** These cross sections show how deflation removes the sand and silt of the desert surface until only coarser particles remain. These coarser particles concentrate into a tightly packed layer called desert pavement. **B** Desert pavement like this in Arizona's Sonoran Desert protects the 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.

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 SCI LINKS NSTA

For: Links on wind erosion
Visit: www.SciLinks.org
Web Code: cjn-2073

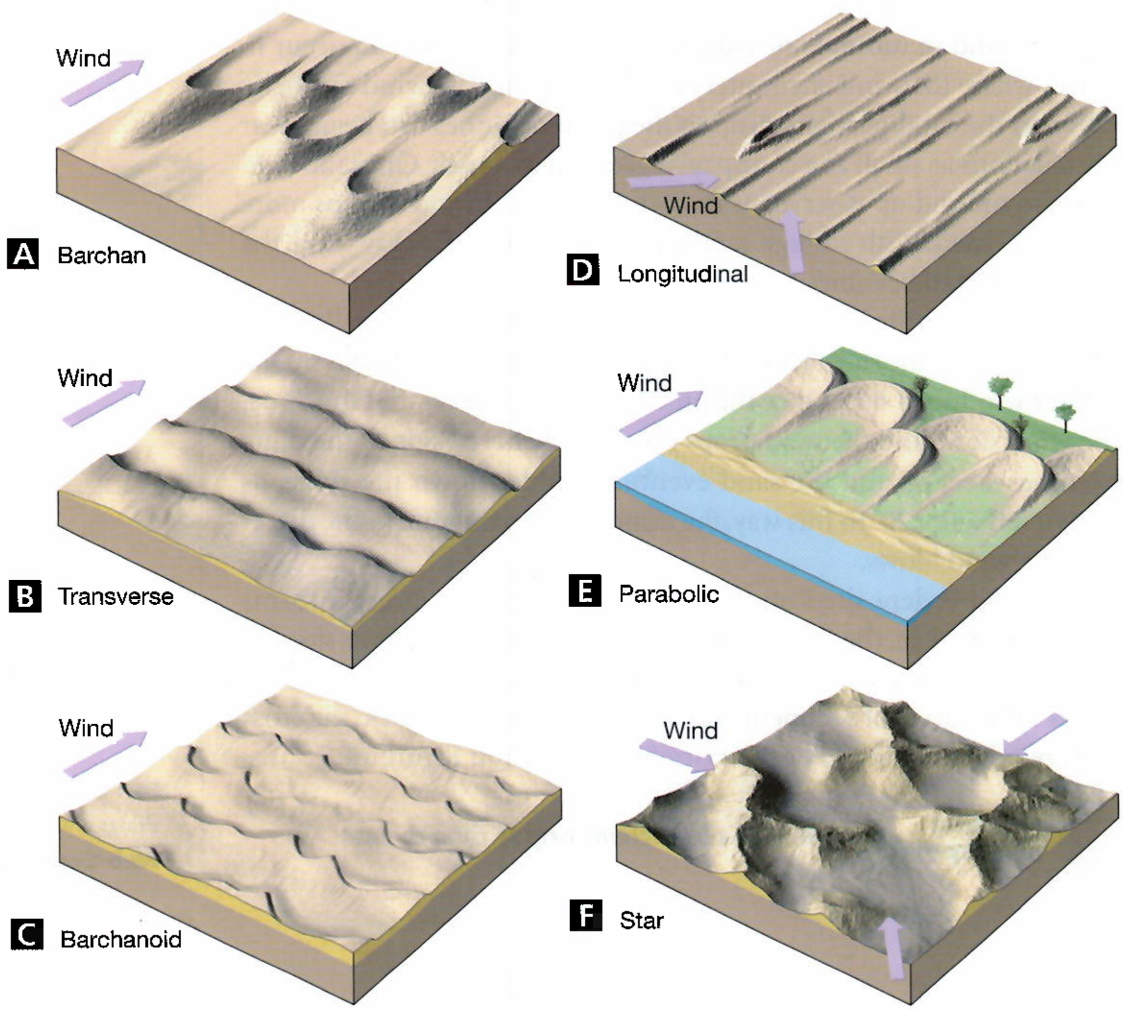
Types of Sand Dunes

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**



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

6. **Comparing and Contrasting** Compare and contrast loess and sand dunes.
7. **Designing Experiments** Describe how you would conduct an experiment to determine the wind speed necessary to suspend sand, silt, and clay particles.

Connecting Concepts

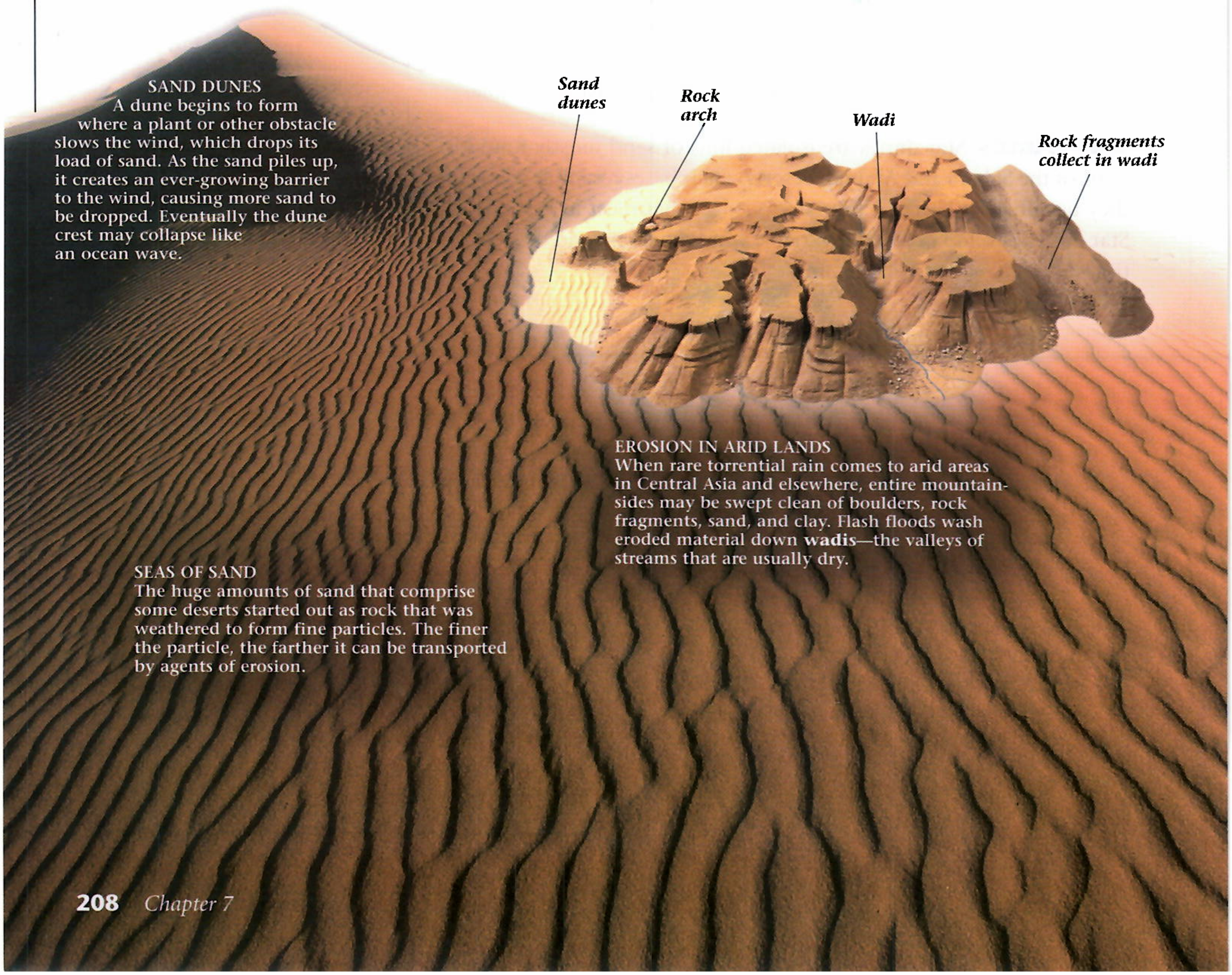
Which dune type would you expect to travel the least? Explain your answer.

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.



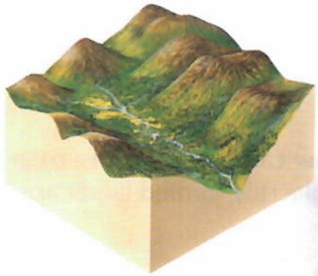
SAND DUNES
A dune begins to form where a plant or other obstacle slows the wind, which drops its load of sand. As the sand piles up, it creates an ever-growing barrier to the wind, causing more sand to be dropped. Eventually the dune crest may collapse like an ocean wave.

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.

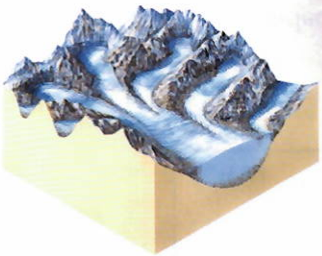
SEAS OF SAND
The huge amounts of sand that comprise some deserts started out as rock that was weathered to form fine particles. The finer the particle, the farther it can be transported by agents of erosion.

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.

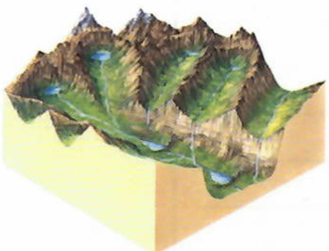
1. Before glaciation A narrow, V-shaped river valley is surrounded by rounded mountains.

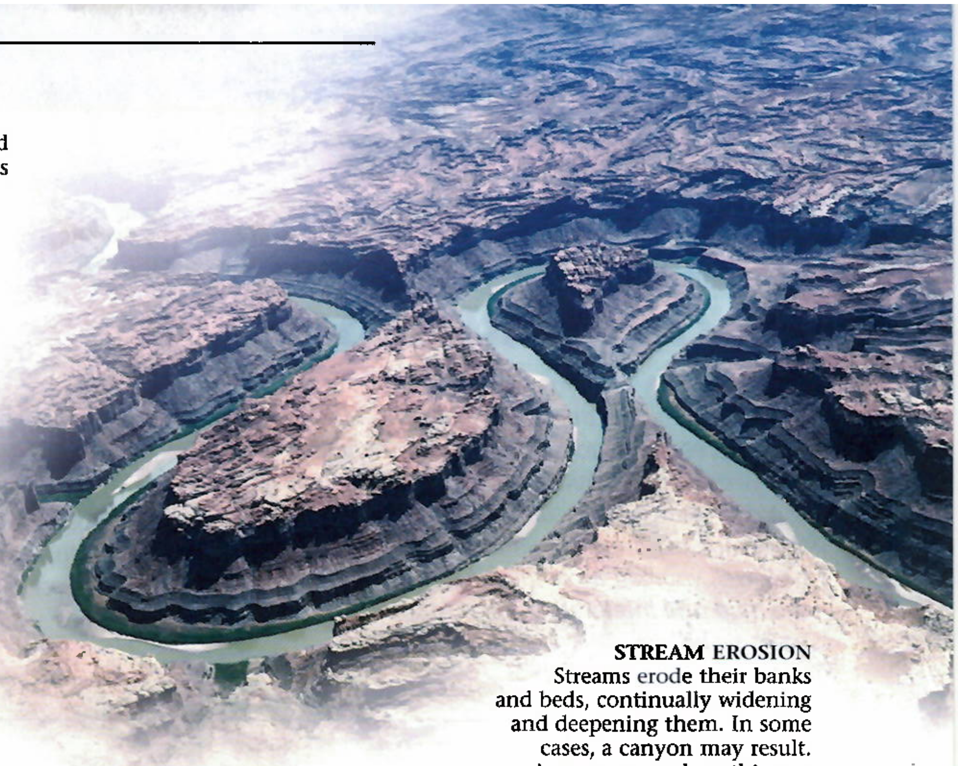


2. During glaciation Moving ice erodes mountaintops and carves wider valleys.



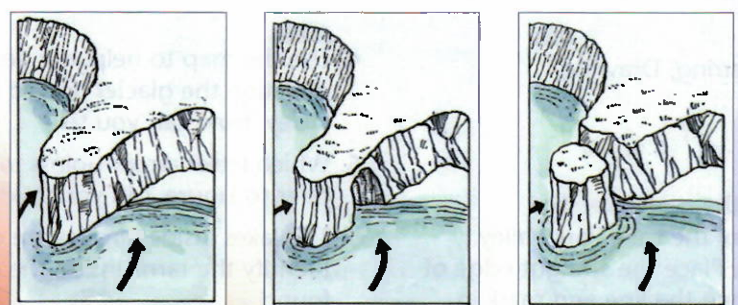
3. After glaciation The result is a U-shaped valley with rugged, sharp peaks above.





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.*

Sea stack off the British Isles

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?

Exploration Lab

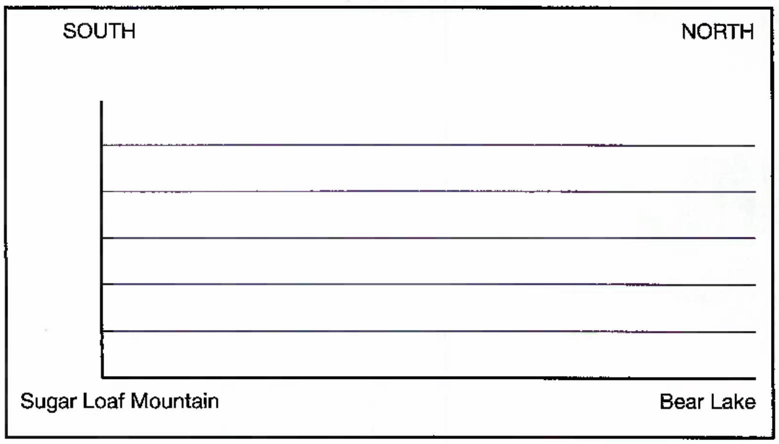
Interpreting a Glacial Landscape

Topographic maps are valuable tools geologists use to interpret landscapes. Especially in the field—when your view can be limited—these maps not only help you determine your location, they can offer a bigger landscape picture than what is actually visible. See how well you can do at identifying glacial features on the map and interpreting them to reconstruct geologic history.

Problem How can a topographic map allow you to interpret a glacially formed landscape?

Materials

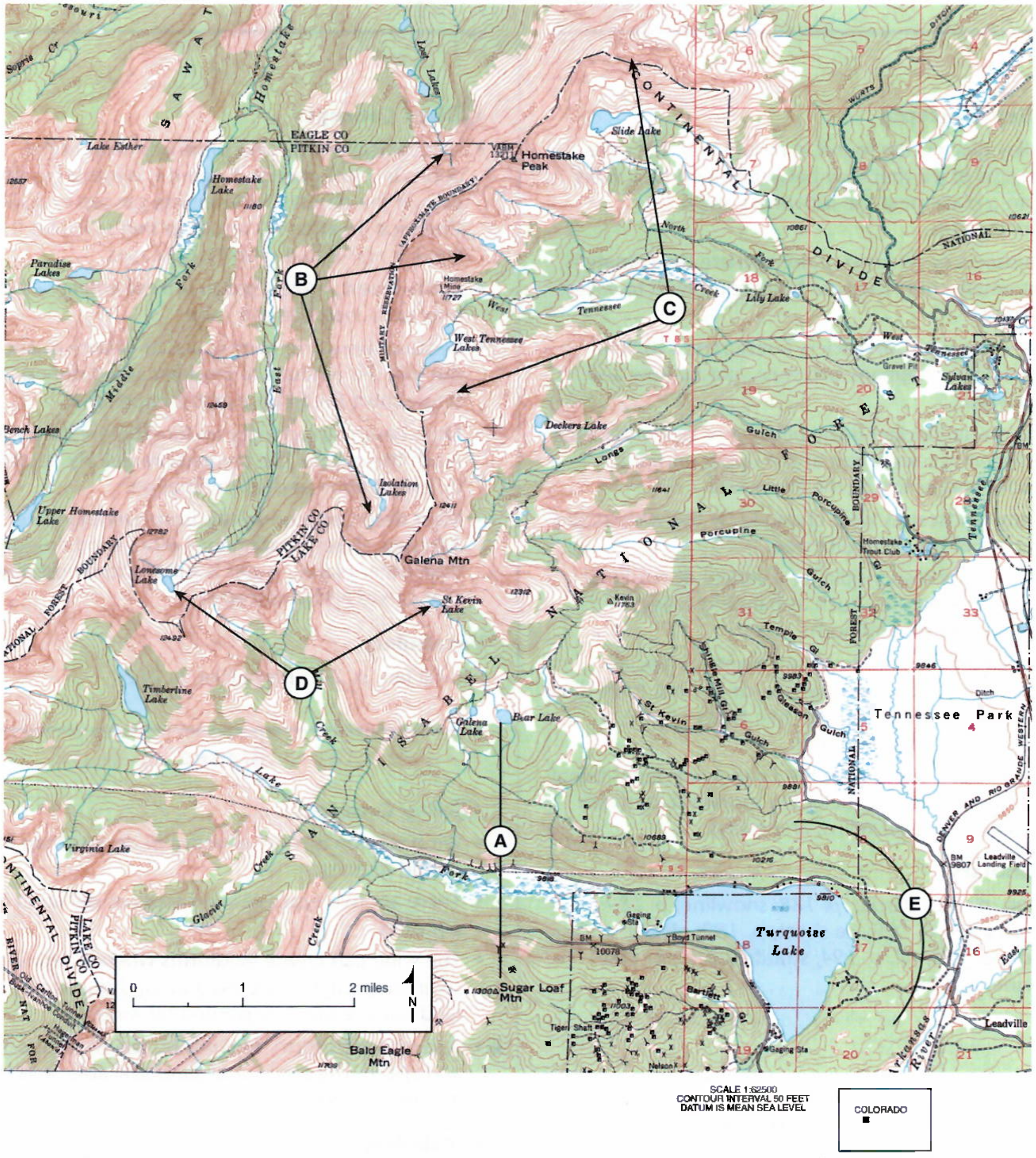
- topographic map
- piece of blank paper
- pencil



Skills Graphing, Inferring, Drawing Conclusions

Procedure

1. Following line A on the map, sketch a topographic profile of the Lake Fork Valley onto the grid above. Place the straight edge of your blank paper along the line and mark in pencil where it meets every fifth contour line (the darker guide contours). Be sure to write the elevation of every fifth contour line along the *y*-axis of the profile grid.
2. How can you tell from your profile that the valley was formed by a glacier?
3. Was the valley shaped by a continental ice sheet or by a valley glacier? Explain how you know.
4. Use the map to help you describe the direction the glacier flowed through this valley. How can you tell?
5. Which letter arrow points to cirques? You can refer to Figure 7 in your textbook for help.
6. The lakes inside cirques are called tarns. Identify the tarns inside the cirques you just found.
7. Which letter arrows point to hanging valleys?
8. Which letter arrows point to arêtes?
9. Name a peak on the map that is a horn.
10. Feature E on the map is composed of glacial till. What type of glacial feature is E, and how did it form?
11. Explain how Turquoise Lake formed.


A
B
C
D
E
Homestake Peak
Galena Mtn
Sugar Loaf Mtn
Bald Eagle Mtn
Turquoise Lake
Tennessee Park
Leadville
Slide Lake
Lily Lake
Isolation Lakes
West Tennessee Lakes
Deckers Lake
St Kevin Lake
Lonesome Lake
Timberline Lake
Galena Lake
Bear Lake
Virginia Lake
Homestake Lake
Upper Homestake Lake
Paradise Lakes
Bench Lakes
Lake Esther
Sylvan Lakes
EAGLE CO
PITKIN CO
LAKE CO
CONTINENTAL DIVIDE
NATIONAL FOREST
SAN ISABEL NATIONAL FOREST
0
1
2 miles
N
SCALE 1:62500
CONTOUR INTERVAL 50 FEET
DATUM IS MEAN SEA LEVEL
COLORADO
QUADRANGLE LOCATION

CHAPTER 7

Study Guide

7.1 Glaciers

Key Concepts

- Valley glaciers are found in mountains. They are streams of ice that flow between steep rock walls from a place near the top where snow accumulates.
- Ice sheets cover large regions where the climate is extremely cold. They are huge compared to valley glaciers.
- The movement of glaciers is referred to as flow. Glacial flow happens two ways: plastic flow and basal slip.
- The glacial budget is the balance or lack of balance between accumulation at the upper end of a glacier and its loss at the lower end.
- Many landscapes were changed by the widespread glaciers of the recent ice age.
- Glaciers are responsible for a variety of erosional landscape features, such as hanging valleys, cirques, arêtes, and horns.
- 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.
- Glaciers are responsible for a variety of depositional landscape features, including moraines, outwash plains, kettles, drumlins, and eskers.

Vocabulary

ice age, *p. 188;* glacier, *p. 188;* snowline, *p. 189;* valley glacier, *p. 189;* ice sheet, *p. 189;* glacial trough, *p. 193;* till, *p. 194;* stratified drift, *p. 194;* moraine, *p. 195*

7.2 Deserts

Key Concepts

- Mechanical weathering produces most of the debris in most deserts. Chemical weathering does exist in the desert; however, the process is slow. Chemical weathering results in thin soils and the familiar rust-tinted desert landscapes.
- In the desert, most streams are ephemeral—they only carry water after it rains.
- 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.
- Most desert streams dry up long before they ever reach the ocean. The streams are quickly depleted by evaporation and soil infiltration.
- Most desert erosion results from running water. Although deserts experience more wind erosion than other places, water is still the foremost agent that carves arid landscapes.

Vocabulary

alluvial fan, *p. 201;* playa lake, *p. 202*

7.3 Landscapes Shaped by Wind

Key Concepts

- Wind erosion is more effective in deserts than in humid regions.
- There are two types of wind erosion: deflation and abrasion.
- The wind can create landforms when it deposits its sediments. Layers of loess and sand dunes are landscape features deposited by wind.
- A sand dune's form depends on the wind direction and speed, the amount of sand available, and the amount of vegetation.

Vocabulary

deflation, *p. 203;* desert pavement, *p. 204;* loess, *p. 204;* dune, *p. 205*

CHAPTER 7

Assessment

Interactive textbook with assessment at PHSchool.com

Interactive Textbook

Reviewing Content

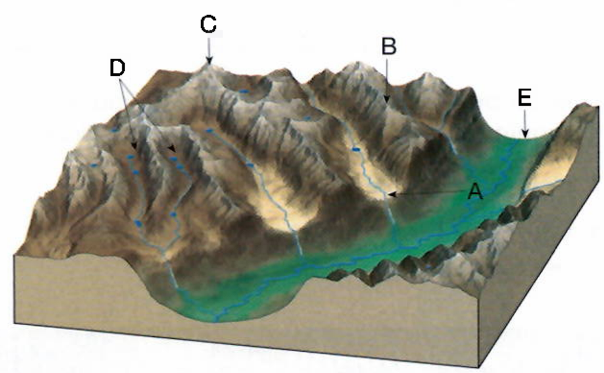
Choose the letter that best answers the question or completes the statement.

1. Icebergs are produced when large pieces of ice break from the front of glacier during a process called
   a. plucking.
   b. deflation.
   c. calving.
   d. abrasion.
2. What type of dune forms at right angles to the wind when there is abundant sand, a lack of vegetation, and a constant wind direction?
   a. barchan
   b. transverse
   c. longitudinal
   d. parabolic
3. During which division of geologic time did the most recent ice age occur?
   a. Pliocene
   b. Paleocene
   c. Pleistocene
   d. Miocene
4. All sediments of glacial origin are
   a. till.
   b. glacial drift.
   c. stratified drift.
   d. outwash.
5. What term is used to describe desert streams that carry water only during periods of rainfall called?
   a. playas
   b. ephemeral
   c. episodic
   d. occasional
6. The two major ways that glaciers erode land are abrasion and
   a. plucking.
   b. tension.
   c. deflation.
   d. slipping.
7. The most noticeable result of deflation in some places are shallow depressions called
   a. sinkholes.
   b. blowouts.
   c. ventifacts.
   d. kettles.
8. In which of these places do extensive yellow loess deposits occur?
   a. Canada   b. Cambodia
   c. China   d. Australia
9. Which of the following is NOT a feature associated with valley glaciers?
   a. horn   b. cirque
   c. arête   d. arroyo
10. The broad, ramp-like surface of stratified drift built adjacent to the downstream edge of most end moraines is a (an)
    a. kettle.
    b. drumlin.
    c. outwash plain.
    d. terminal moraine.

Understanding Concepts

11. Why is the uppermost 50 m of a glacier called the zone of fracture?
12. How do the erosional processes of plucking and abrasion work?

Use the diagram below to answer Question 13.

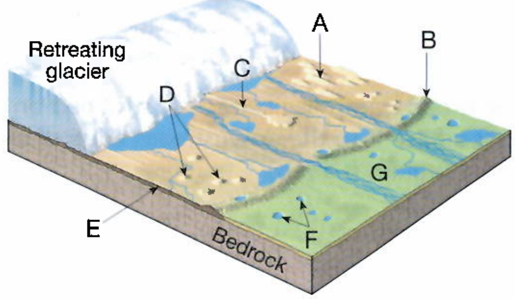


13. The area in the diagram was eroded by valley glaciers. For each feature listed below, write the letter of that feature in the diagram.
    a) cirque
    b) glacial trough
    c) hanging valley
    d) horn
    e) arête

Assessment *continued*

14. Describe each type of moraine:
    a) end moraine
    b) lateral moraine
    c) ground moraine

15. Identify the glacier features in the diagram.



a) drumlin
b) outwash plain
c) esker
d) end moraine

16. Describe how sand dunes migrate.

17. How does the transport of sediment by glaciers differ from transport by water?

18. How do desert streams differ from those in humid regions?

19. What results when desert pavement is disturbed?

20. Describe the relative importance of wind and running water in eroding the desert landscape.

21. How is it possible for ice to flow?

22. Why do crevasses only extend 50 meters or so beneath the surface of a glacier?

Critical Thinking

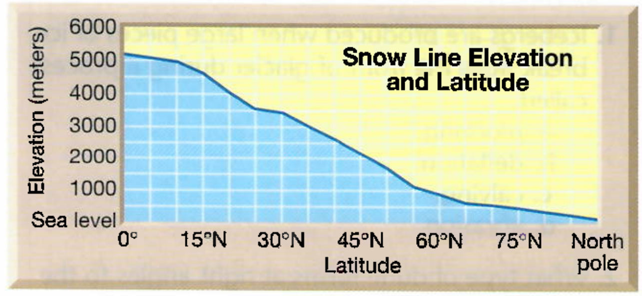
23. **Relating Cause and Effect** Explain how a glacier's budget determines whether it advances, retreats, or remains stationary.

24. **Comparing and Contrasting** In what ways are the erosional actions of wind, water, and glaciers similar? How are they different?

25. **Inferring** Explain why glacial erratics will usually contain different minerals than the rock outcropping where they are found.

Analyzing Data

Use the graph below to answer Questions 26–28.



26. **Inferring** What is the minimum elevation required for year-round snow on a mountain located on the equator?

27. **Inferring** Suppose a 2000-meter mountain was located at 75 degrees north of the equator. What percentage of its height would have year-round snow?

28. **Drawing Conclusions** Write a statement that summarizes the information in the graph.

Concepts in Action

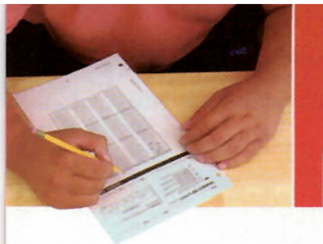
29. **Using Models** Explain how you would model each type of sand dune using a fan, a pan full of sand, and some playing cards.

30. **Classifying** Which types of landscape features described in this chapter resulted from erosion? Which types resulted from deposition?

31. **Writing in Science** Write a paragraph that summarizes the role of climate in the development of the landscapes discussed in this chapter.

Performance-Based Assessment

Researching Eskers are one glacial feature that people have transformed into a resource. Find out why glacial sediments are useful, who mines them, how they mine them, and the extent of their commercial value. Explain whether glacial deposits are considered renewable or nonrenewable resources.



Standardized Test Prep

Test-Taking Tip

Avoiding Careless Mistakes
Students often make mistakes when they fail to read a test question and the possible answers carefully. Read the question carefully and underline key words that may change the meaning of the question, such as *not, except,* or *excluding.* After choosing an answer, reread the question to check your selection.

Choose the letter that best answers the question or completes the statement.

1. Which of the following is NOT associated with water?
   (A) ephemeral stream
   (B) kettle
   (C) hanging valley
   (D) blowout

(Answer: D)

2. Which of the following statements about ice sheets is NOT true?
   (A) They cover 30 percent of Earth's land surface.
   (B) They form where more snow accumulates than melts.
   (C) They are more effective agents of erosion than running water.
   (D) They can flow.

3. Which is NOT true of loess?
   (A) Loess is a blanket of silt covering the landscape.
   (B) The Yellow River in China is named for the loess that it transports.
   (C) Wind carries and deposits the sediments that comprise loess.
   (D) There are no loess deposits in the United States.

4. What is the main factor that causes barchan dunes to form in the opposite direction of parabolic dunes?
   (A) Parabolic dunes are partially anchored by vegetation.
   (B) Barchan dunes have a greater supply of available sand than parabolic dunes.
   (C) The wind that creates barchan dunes is more variable in direction than the wind forming parabolic dunes.
   (D) Barchan dunes can migrate; parabolic dunes cannot.

5. When a stream emerges from a mountain canyon, the stream slope is greatly reduced. As a result the sediment is deposited within a short distance and forms a (an)
   (A) playa lake.
   (B) alluvial fan.
   (C) sinkhole.
   (D) arête.

Answer the following questions in complete sentences.

6. Name the four basic types of moraines. How are they similar? How are they different?

7. Glaciers are solid, but they are a basic part of Earth's water cycle. Are glaciers a part of solid Earth or part of Earth's hydrosphere? Explain your answer.

8. What role do glaciers play in Earth's rock cycle?

CHAPTER 8

Earthquakes and Earth's Interior

CONCEPTS in Action

Quick Lab
Measuring the Distance to Epicenters

Exploration Lab
Locating an Earthquake

How the Earth Works
Effects of Earthquakes

GEODe EARTH SCIENCE: Forces Within → Earthquakes

Discovery Channel School — Video Field Trip
Earth in Motion

Take a field trip to the center of the Earth with the Discovery Channel and find out how earthquakes occur. Answer the following questions after watching the video.

1. Describe how the meeting of two tectonic plates can lead to an earthquake.
2. Where does the greatest damage occur during an earthquake?

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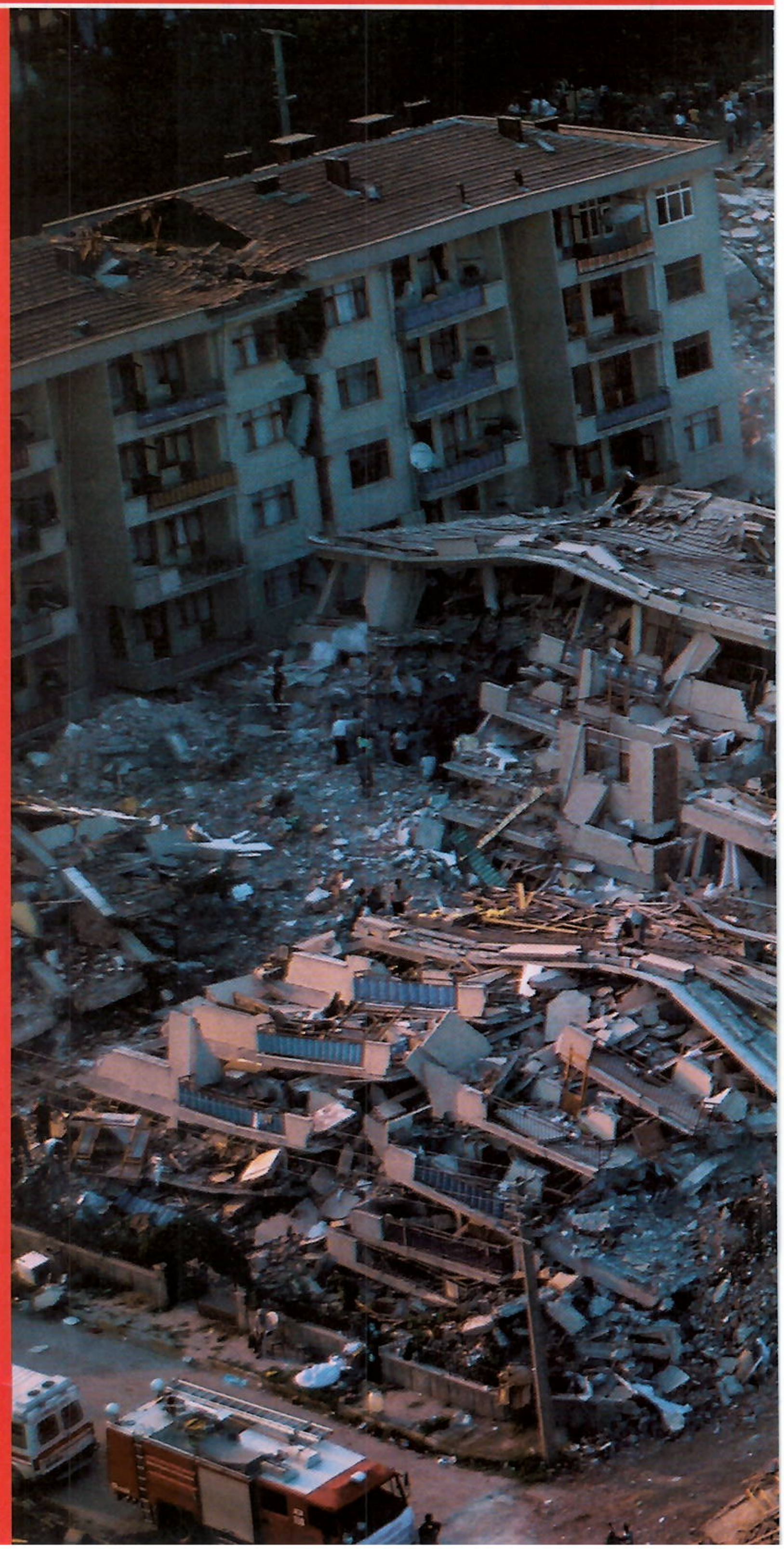

Destruction caused by a major earthquake ▶ that struck northwestern Turkey on August 17, 1999. More than 17,000 people died.