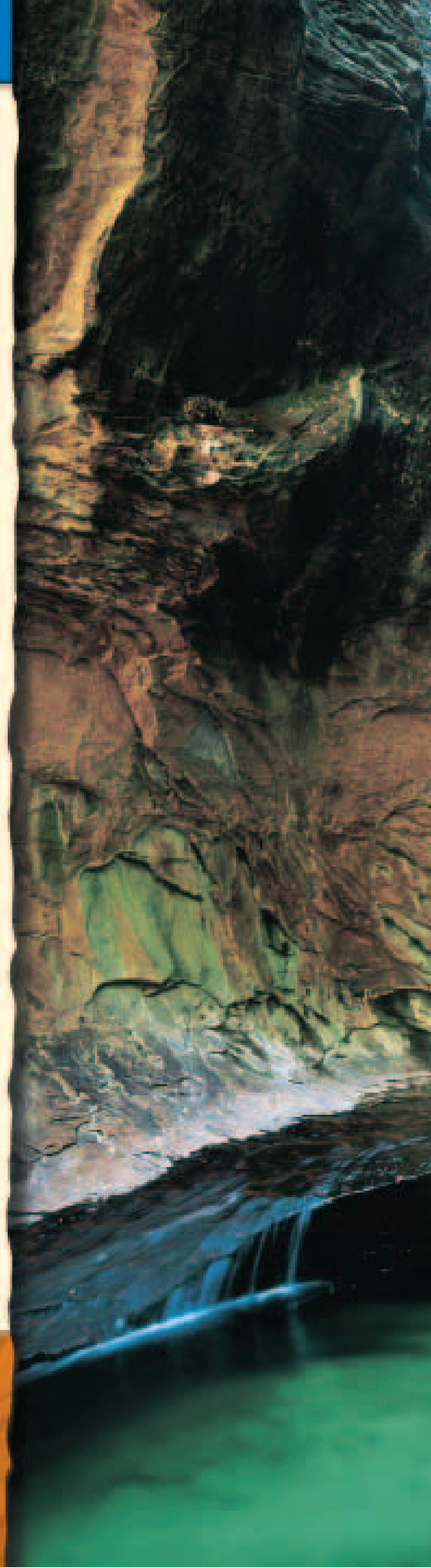
Unit 3

Surface Processes on Earth

Earth has a system of external processes that shape its surface. For example, weathering and erosion change landforms and form soil, an important natural resource. Other external processes such as landslides, glaciers, and avalanches change the landscape. Earth's external processes also have impacts on human populations. Every year, flooding and mudflows, as well as landslides and avalanches cause the loss of life and property in many regions in the world. The photo shows the Emerald Pools in Zion Canyon in Zion National Park in Utah.



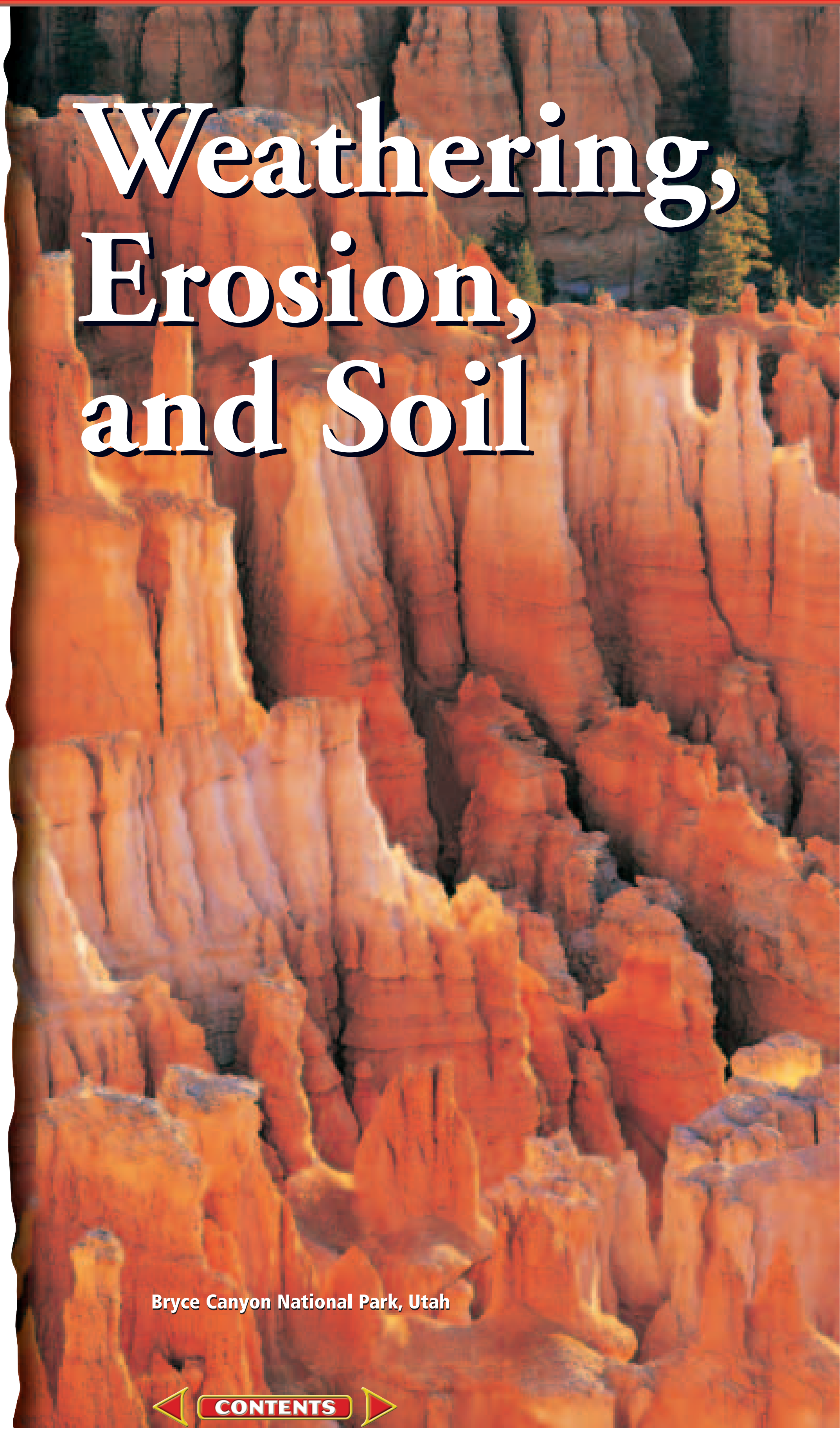
Unit Contents

NATIONAL GEOGRAPHIC

Go to the National Geographic Expedition on page 870 to learn more about topics that are connected to this unit.

Chapter 7

Weathering, Erosion, and Soil



Bryce Canyon National Park, Utah

What You'll Learn

- How the process of weathering breaks down rocks and how erosion transports weathered materials from one place to another.
- How soil is formed and why soil is an important natural resource.

Why It's Important

The processes of weathering and erosion change Earth's landforms and form soil, an important natural resource.

Earth Science Online

To find out more about weathering, erosion, and soil, visit the Earth Science Web Site at earthgeu.com

CONTENTS

Discovery Lab

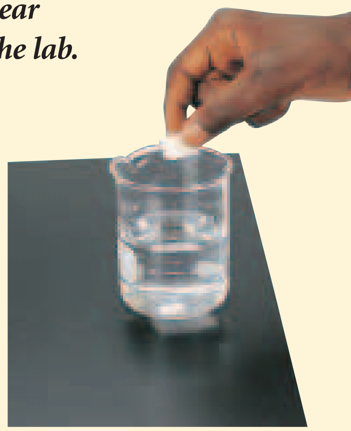
Model Interfaces

Changes can take place at the interface between substances. An interface is where a substance comes in contact with another substance or condition. For example, the surface of a rock is the interface where the rock comes in contact with its environment. The more surface area that is exposed to environmental conditions, the more changes that can take place.

1. Fill two 250-mL beakers with water at room temperature.
2. Drop a sugar cube in one beaker and 5 mL of granulated sugar in the other beaker at the same time. Record the time.
3. Slowly and continuously stir the solution in each beaker. Use caution in stirring so as not to crack or break the beaker.
4. Observe the sugar in both beakers. Record the amount of time it takes for the sugar to completely dissolve in each beaker of water.

CAUTION: Always wear safety goggles and an apron in the lab.

Observe In your science journal, describe what happened to the sugar cube and the granulated sugar. Explain why one form of sugar dissolved faster than the other. Infer how you could decrease the time required to dissolve the other form of sugar.



SECTION 7.1 Weathering

OBJECTIVES

- **Distinguish** *between weathering and erosion.*
- **Identify** *variables that affect the rate of weathering.*

VOCABULARY

weathering
erosion
mechanical weathering
frost wedging
exfoliation
chemical weathering
hydrolysis
oxidation

In 1880, an impressive granite monument, Cleopatra's Needle, was moved from Egypt to Central Park, in New York City. Although the monument had existed in Egypt for more than 3500 years, in less than 75 years in New York City's climate, the monument had become dramatically worn and damaged. Today, markings on the surface can barely be read.

Why do you think this has happened? Changes occur every day to Earth's rocks and surface features. Just as the granite of Cleopatra's Needle has undergone changes, so, too, does granite in Earth's crust. The process by which rocks on or near Earth's surface break down and change is called **weathering.** The removal and transport of weathered material from one location to another is known as **erosion.** The processes of weathering and erosion have been going on since the crust of Earth formed, billions of years ago.

Figure 7-1 This 3600-year-old monument, Cleopatra's Needle was moved from Egypt to Central Park, New York City. After many years in New York City's climate, some markings on the monument have all but disappeared as a result of weathering.

MECHANICAL WEATHERING

Before the agents of erosion can pick up and transport Earth materials, these materials must undergo some form of weathering. Weathering caused the result seen in ***Figure 7-1.*** Mechanical and chemical weathering are the two processes that can wear down rocks and minerals. Both types of weathering occur at the same time on Earth's landforms.

The process by which rocks and minerals break down into smaller pieces is **mechanical weathering,** also called physical weathering. Mechanical weathering does not involve any change in a rock's composition, only changes in the size and sometimes the shape of the rock, as shown in ***Figure 7-2.*** A variety of factors are involved in mechanical weathering.

Temperature Temperature plays a significant role in mechanical weathering. When water freezes, it expands and increases in volume by approximately nine percent. Thus, ice takes up approximately nine percent more space than liquid water does. You have observed this increase in volume if you have ever made ice in an ice-cube tray in a freezer. In many places on Earth's surface, water collects in the cracks of rocks and rock layers. If the temperature drops to the freezing point of water, it freezes, expands, exerts pressure on the rocks, and may cause them to split, as shown in ***Figure 7-3A.*** When the temperature then increases, the ice in the cracks of rocks and rock layers melts. The repeated thawing and freezing of water in the cracks of rocks is called **frost wedging.** Frost wedging is also responsible for the formation of potholes in many roads in the northern United States in early spring, as shown in ***Figure 7-3B.***

Pressure Pressure is another factor in mechanical weathering. Bedrock at great depths is under pressure from the overlying rock layers. When the overlying rock layers are removed, the pressure on the bedrock below is reduced. The bedrock surface, formerly

Figure 7-2 The mechanical weathering of these rocks occurred in Monument Valley in Arizona. ***How do you know that these formations occurred as a result of weathering?***

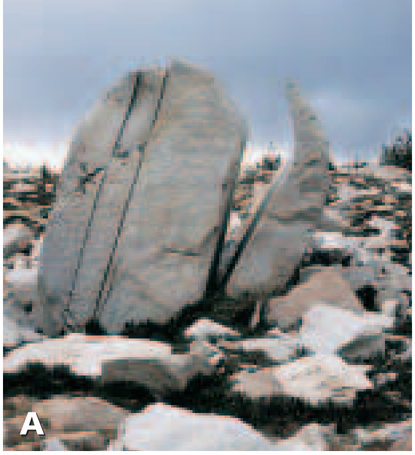


Figure 7-3 Frost wedging has split this granite boulder in the Sierra Nevada, California **(A).** Frost wedging also causes potholes to develop in early spring in Washington State **(B).** This boulder in Baja, California, is undergoing the process of exfoliation **(C).** This birch tree is growing out of a crack in bedrock in New Jersey **(D).**

buried, is then able to expand, and long, curved cracks can form. These cracks, also known as joints, occur parallel to the surface of the rock. Reduction of pressure also allows existing cracks in the bedrock to widen.

Over time, the outer layers of rock are stripped away in succession, similar to an onion's layers being peeled off one by one. The process by which outer rock layers are stripped away is called **exfoliation,** shown in ***Figure 7-3C.*** Exfoliation often results in dome-shaped formations such as Liberty Cap and Half Dome in Yosemite National Park and Stone Mountain in Georgia. Sometimes, the effects of reduced pressure on rock layers are dramatic. For example, when several layers of overlying rocks are removed from a deep mine, the sudden decrease of pressure can cause large pieces of rock to explode off the walls of the mine tunnels.

The roots of trees and other plants can wedge themselves into cracks in rocks. As the roots grow and expand, they can exert pressure on the rocks to split, as shown in ***Figure 7-3D.***

Chemical Weathering

The process by which rocks and minerals undergo changes in their composition as the result of chemical reactions is called **chemical weathering.** Significant agents of chemical weathering include water, oxygen, carbon dioxide, and acids. Chemical reactions between rocks and water result in the formation of new minerals and the release of dissolved substances. The new minerals have different properties from those of the original rocks. For example, rust on an iron chain has a different chemical composition from that of the iron on which it formed. To some extent, the composition of rocks determines the effects that chemical weathering will have on them.

Using Math

Using Numbers
When water freezes, it expands and increases in volume by nine percent. What is the volume of ice that will form from 100 cm^3 of water?

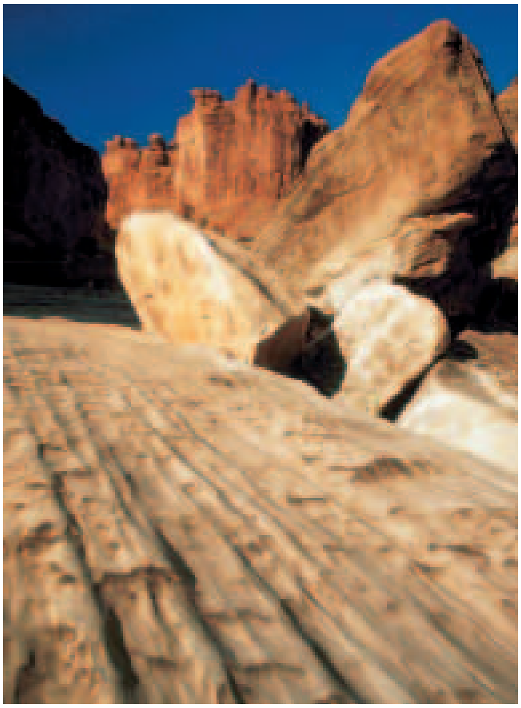


Figure 7-4 The surface of this limestone rock was chemically weathered by the activities of water. The rock is located in Slickhorn Canyon, Glen Canyon National Recreation Area, in Arizona.

Some minerals, such as calcite, may dissolve completely. Rocks that contain calcite, such as limestone and marble, are also greatly affected by chemical weathering. Buildings and monuments made of these rocks readily show signs of wear resulting from weathering.

Temperature is another significant factor in chemical weathering because it influences the rate at which chemical reactions occur. Usually, chemical reaction rates increase as temperature increases. With all other factors being equal, the rate of chemical weathering reactions doubles with each 10°C increase in temperature.

Water Water is an important agent in chemical weathering because it can dissolve many kinds of minerals and rocks, as shown in ***Figure 7-4.*** Water has an active role in some reactions, while it simply serves as a medium through which other reactions occur. The reaction of water with other substances is known as **hydrolysis.** Hydrolysis occurs in the decomposition of silicate minerals, such as the decomposition of potassium feldspar into kaolinite, a fine-grained clay mineral common in soils.

Oxygen Like water, oxygen can combine with other substances. The chemical reaction of oxygen with other substances is called **oxidation.** Approximately 21 percent of Earth's atmosphere is oxygen gas. Iron in rocks and minerals readily combines with this atmospheric oxygen to form minerals with the oxidized form of iron as shown in the following reaction.

$$\underset{\text{magnetite}}{2Fe_3O_4} + \frac{1}{2}O_2 \rightarrow \underset{\text{hematite}}{3Fe_2O_3}$$

Common minerals that contain the reduced form of iron include magnetite, hornblende, biotite, and pyrite.

Figure 7-5 This limestone cave in Guatemala was formed when carbonic acid dissolved the calcite in the limestone rock.

Carbon Dioxide Another atmospheric gas that contributes to the chemical weathering process is carbon dioxide, which is produced by living organisms during the process of respiration. When carbon dioxide combines with water in the atmosphere, it forms a weak carbonic acid that falls to Earth's surface as precipitation. The formation of carbonic acid is shown in the following reaction.

$$\underset{\text{water}}{H_2O} + \underset{\text{carbon dioxide}}{CO_2} \rightarrow \underset{\text{carbonic acid}}{H_2CO_3}$$

Carbonic acid reacts with minerals such as calcite in limestone and marble to dissolve rocks. For example, limestone caverns, as shown in ***Figure 7-5,*** can form when carbonic acid dissolves the calcite in limestone rocks. Carbonic acid can also affect silicate minerals such as mica, and feldspar by reacting with elements in the minerals, such as magnesium and calcium. This chemical weathering process results in the formation of clay minerals. High concentrations of carbonic acid accumulate in soil, where decaying organic matter and plant respiration produce high levels of carbon dioxide. When water from precipitation seeps into the ground and combines with carbon dioxide, large amounts of carbonic acid become available for the process of chemical weathering.

Acid Precipitation Another agent of chemical weathering is acid precipitation, which is caused mainly by the oxidation of sulfur dioxide and nitrogen oxides that are released into the atmosphere by human activities. Sulfur dioxide forms from the industrial burning of fossil fuels, while nitrogen oxides are emitted from motor-vehicle exhausts. These two gases combine with oxygen and water in the atmosphere to form sulfuric and nitric acids.

We describe how acidic a solution is by using the pH scale. ***Figure 7-6*** illustrates the pH scale. The lower the pH number, the greater the acidity of a substance. Acid precipitation is precipitation that has a

Earth Science Online

Topic: Weathering
To find out more about weathering, visit the Earth Science Web Site at earthgeu.com

Activity: Identify an example of weathering in your state. Is it the result of mechanical weathering, chemical weathering, or both?

ENVIRONMENTAL CONNECTION

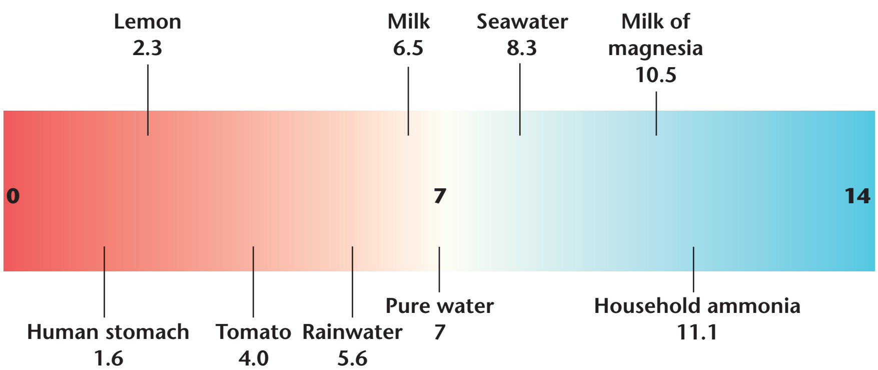


Figure 7-6 The pH scale is used to determine the acidity of substances.

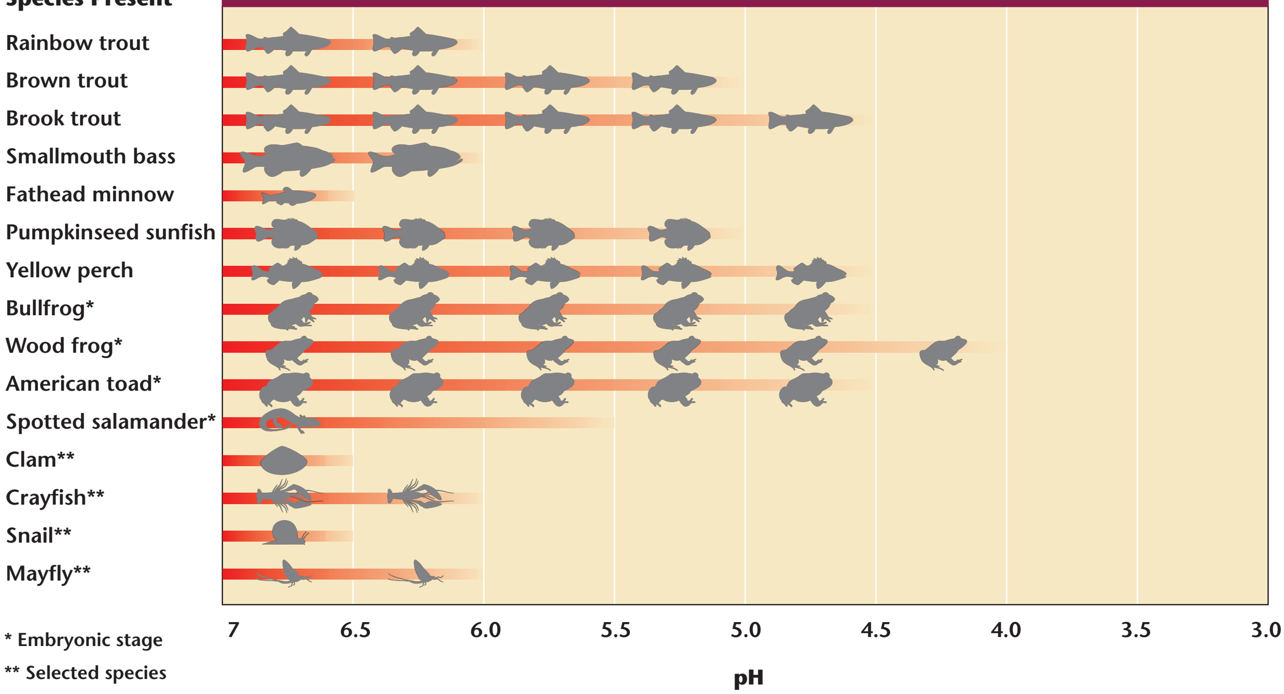
pH value below 5.6, the pH of normal rainfall. Because acids can be harmful to many organisms and destructive to nonliving things, acid precipitation creates problems. It adversely affects fish and aquatic plant populations in lakes. Most freshwater lakes have a natural pH in the range of 6 to 8. These lakes can support many kinds of amphibians, aquatic invertebrates, and fish. However, when the lake water becomes too acidic, the species diversity decreases as shown in ***Table 7-1.*** The table indicates which organisms can survive at a particular pH. As you can see, wood frogs are able to survive at a lower pH than other species.

What Affects the Rate of Weathering?

The natural weathering of Earth materials occurs very slowly. For example, it may take 2000 years to weather 1 cm of limestone, and yet most rocks weather at even slower rates. Certain conditions and interactions can accelerate or slow the weathering process as demonstrated in the *GeoLab* at the end of the chapter.

Climate The climate of an area is a major influence on the rate of chemical weathering of Earth materials. Variables of climate include precipitation, temperature, and evaporation. The interaction between temperature and precipitation has the greatest effect on a region's rate of weathering. Chemical weathering occurs readily in

Table 7-1 Effects of Acid Precipitation on Aquatic Species



World Map of Chemical Weathering

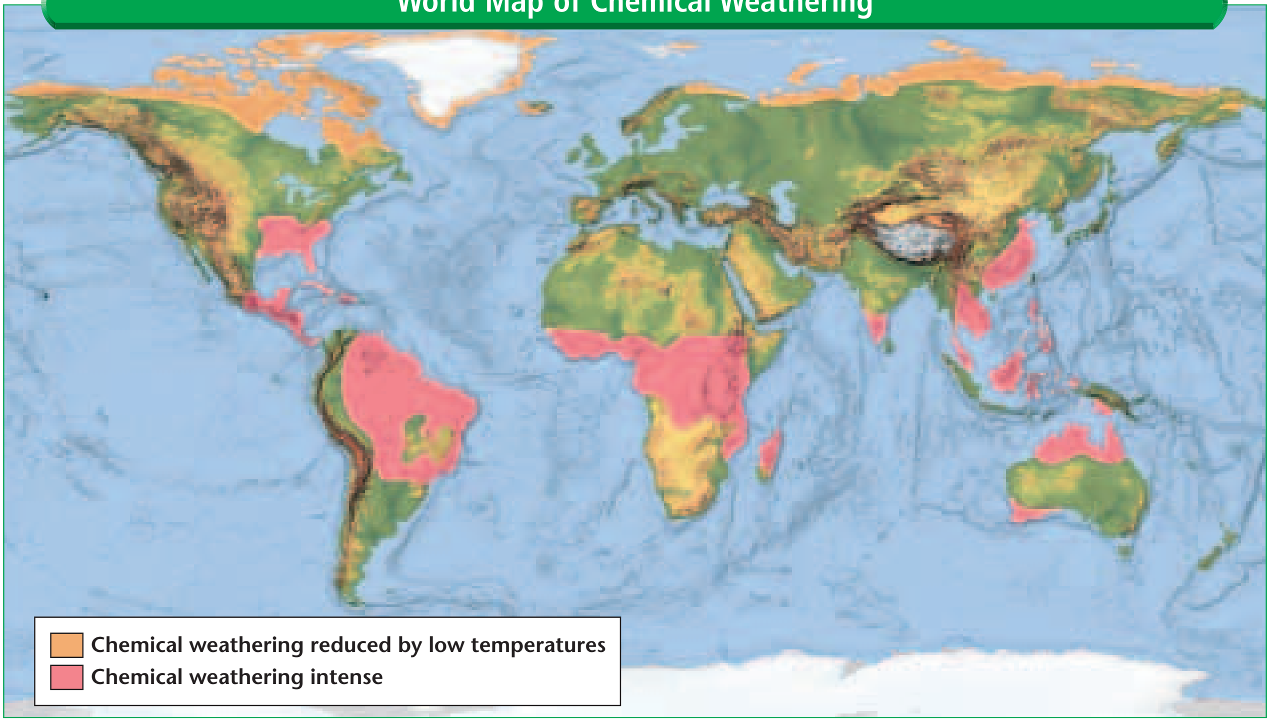


Figure 7-7 This world map shows areas where chemical weathering occurs. ***What areas in the world are subject to the most intense chemical weathering?***

climates with warm temperatures, abundant rainfall, and lush vegetation. These climatic conditions produce thick soils that are rich in organic matter. When water from heavy rainfalls combines with the carbon dioxide in this organic matter to produce high levels of carbonic acid, the weathering process is accelerated. Chemical weathering is evident in tropical Central America, Southeast Asia and other areas as shown in ***Figure 7-7.***

Conversely, physical weathering occurs readily in cool, dry climates. Physical weathering rates are highest in areas where water undergoes repeated freezing and thawing. Conditions in such climates do not favor chemical weathering because cool temperatures slow or inhibit chemical reactions. Little or no chemical weathering occurs in areas that are frigid year-round.

The different rates of weathering caused by different climatic conditions can be illustrated by a comparison of Asheville, North Carolina, and Phoenix, Arizona. Phoenix has dry, warm, conditions; temperatures do not drop below the freezing point of water, and humidity is low. In Asheville, temperatures sometimes drop below the freezing point during the colder months. Asheville has more monthly rainfall and higher levels of humidity than Phoenix does, as

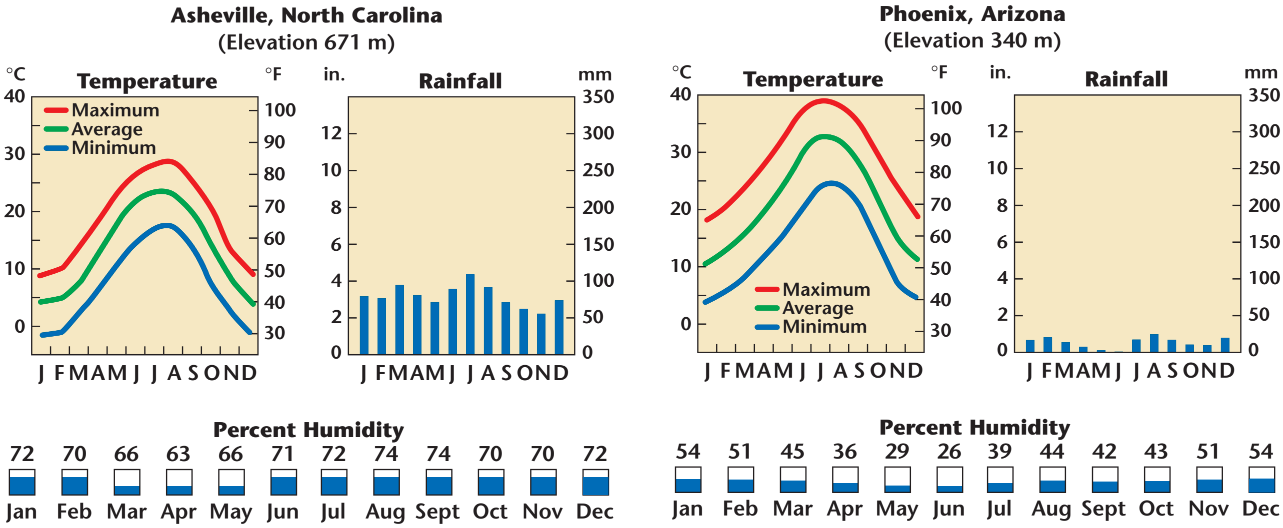


Figure 7-8 These graphs show a comparison of climatic conditions in Asheville and Phoenix.

shown in ***Figure 7-8.*** Because of these differences in their climates, rocks and minerals in Asheville experience a higher rate of mechanical and chemical weathering than those in Phoenix do.

Rock Type and Composition A wide variety of rocks and minerals cover Earth's surface. The characteristics of rocks, including how hard or resistant they are to being broken down, depend on their type and composition. In general, sedimentary rocks are more easily weathered than harder igneous and metamorphic rocks. The dramatic landscape in the Bisti Badlands of New Mexico exhibits rock layers with different degrees of resistance to weathering, as illustrated in ***Figure 7-9.***

Figure 7-9 In the Bisti Badlands in New Mexico, these formations of resistant sandstone are situated on top of softer coal layers. ***What do you think caused the rocks to form in this way?***

CONTENTS

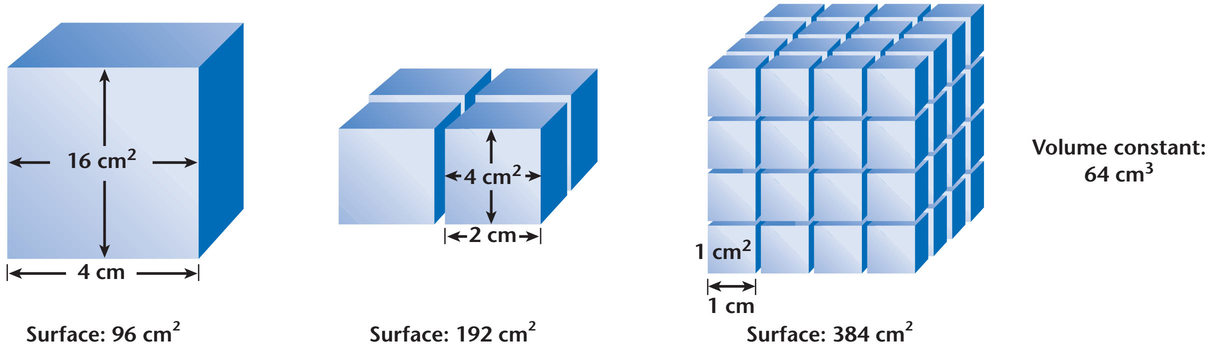


Figure 7-10 In this example, the original object has a surface area of 96 cm^2. When the same object is broken up into two pieces or more, the surface area increases.

Surface Area Mechanical weathering breaks up rocks into smaller pieces. As the pieces get smaller, their surface area increases, as illustrated in ***Figure 7-10.*** This means that more total surface area is available for chemical weathering. Thus, the greater the total surface area, the more weathering that occurs, as you learned in the *Discovery Lab.*

Topography and Other Variables Earth materials cover the surfaces of slopes and level areas. Materials on level areas are likely to remain in place as they undergo changes, whereas materials on slopes have a greater tendency to move as a result of gravity. As material moves down a slope, it exposes underlying rock surfaces and thus provides more opportunities for weathering to occur. As you learned earlier, organisms also affect the rate of weathering. Decaying organic matter and living plant roots release carbon dioxide, which combines with water to produce acid, which in turn increases the weathering rate.

SECTION ASSESSMENT

1. Distinguish between weathering and erosion.
2. List several variables that affect the rate of weathering.
3. What two climatic factors are most important in the weathering process?
4. **Thinking Critically** Describe how one variable may affect another variable in the weathering process.

SKILL REVIEW

5. **Making Graphs** Make a graph of the relationship between the rate of weathering and the surface area of a material. Plot the weathering rate on the *y*-axis and the surface area on the *x*-axis. For more help, refer to the *Skill Handbook*.

SECTION 7.2 Erosion and Deposition

OBJECTIVES

- **Analyze** *the impact of living and nonliving things on the processes of weathering and erosion.*
- **Describe** *the relationship of gravity to all agents of erosion.*

VOCABULARY

deposition
rill erosion
gully erosion

As you have learned, erosion is the process that transports Earth materials from one place to another. A number of different agents transport weathered materials on Earth. Running water in streams and rivers, glaciers, wind, and ocean currents and waves all pick up and carry materials. Humans, plants, and animals also play a role in the erosional process. Erosion can result from the loss of plant cover, as shown in ***Figure 7-11.*** The land becomes barren as increasing amounts of soil are lost to wind and water erosion. At some point, the movement of transported materials will slow down. When this happens, the materials are dropped in another location in a process known as **deposition,** the final stage of the erosional process.

GRAVITY'S ROLE IN EROSION

Gravity is associated with many erosional agents, because the force of gravity tends to pull all materials downslope. Without gravity, glaciers would not move downslope and streams would not flow. Gravity is also an agent of mass movements such as landslides, mudflows, and avalanches, which you will learn about in Chapter 8.

EROSION BY RUNNING WATER

With the exception of the extremely strong winds associated with tornadoes and hurricanes, water has more power to move large particles of weathered material than wind does. As you might expect, stream erosion is greatest when a large volume of water is moving rapidly, such as during spring thaws and torrential downpours. Water flowing down steep slopes also has greater potential to erode Earth materials, because the steeper the slope, the faster the water flows. Not only does swiftly flowing water have greater erosional power than wind, but it can also carry more material along with it and over a greater distance.

Figure 7-11 Major erosion can occur on steep slopes as a result of the loss of plant cover due to the clearcutting of a forest.

Running water moves along Earth's surface from higher to lower elevations. Small streams at high elevations flow down to join larger streams at lower elevations. Such a network of streams drains an area called a watershed as the water works its way down toward the ocean.

The erosion by running water in small channels, on the side of a slope is called **rill erosion,** shown in ***Figure 7-12A.*** Rills commonly form on a slope. When a channel becomes deep and wide, it can evolve into **gully erosion,** as shown in ***Figure 7-12B.*** Gullies can be more than 3 m deep. They can be a major problem in farming and grazing areas.

Coastal Deposition and Erosion

Rocks exposed to their surrounding environment are slowly weathered away, as modeled in the *MiniLab* on this page. Each year, streams and rivers carry billions of metric tons of sediments and weathered materials to coastal areas. The Mississippi River alone carries 750 million metric tons of eroded material off the continent and into the Gulf of Mexico annually. When a

MiniLab

How do rocks weather?

Model how rocks are exposed to their surrounding environment and slowly weather away.

Procedure

1. Carve your name deeply into a bar of soap with a toothpick. Weigh the soap.
2. Measure and record the depth of the letters carved into the soap.
3. Place the bar of soap on its edge in a catch basin.
4. Sprinkle water over the bar of soap until a noticeable change occurs in the depth of the carved letters.
5. Measure and record the depth of the carved letters.

Analyze and Conclude

1. How did the depth of the letters carved into the bar of soap change?
2. Did the shape, size, or weight of the bar of soap change?
3. Where did the missing soap go?
4. What additional procedure could you follow to determine whether any soap wore away?

Figure 7-12 Rill erosion has occurred on these rocks in Badlands National Park **(A).** The removal of too much vegetation caused gully erosion in this farming area **(B).**

Figure 7-13 This photograph, taken aboard the space shuttle, shows the huge amount of sediment deposited at the Nile Delta.

river enters a large body of water, such as the ocean, the water slows down and deposits large amounts of sediments. The build-up of sediments forms deltas, such as the Nile Delta, shown in ***Figure 7-13.*** The volume of river flow and the action of tides determine the shapes of deltas, most of which contain fertile soil. Coastal areas also undergo erosion by ocean waves and wind. You will learn more about coastal erosion in the *Science & the Environment* feature at the end of this chapter.

In the ocean, weathering and erosional processes continue. The work of ocean currents, waves, and tides carves out cliffs, arches, and other features along the continents' edges. In addition, sand particles accumulate on shorelines and form dunes and beaches. Erosion of materials also occurs along the ocean floor and at continental and island shorelines. The constant movement of water and the availability of accumulated weathered material result in a continuous erosional process, especially along ocean shorelines. Sand along a shoreline is repeatedly picked up, moved, and deposited by ocean currents. In this way, sandbars form from offshore sand deposits. If the sandbars continue to be built up with sediments, they can become barrier islands. Many barrier islands, as shown in ***Figure 7-14,*** have formed along the Gulf and Atlantic Coasts of the United States.

Figure 7-14 A barrier island such as the Queens Atlantic Beach in New York was formed from the buildup of sandbars.

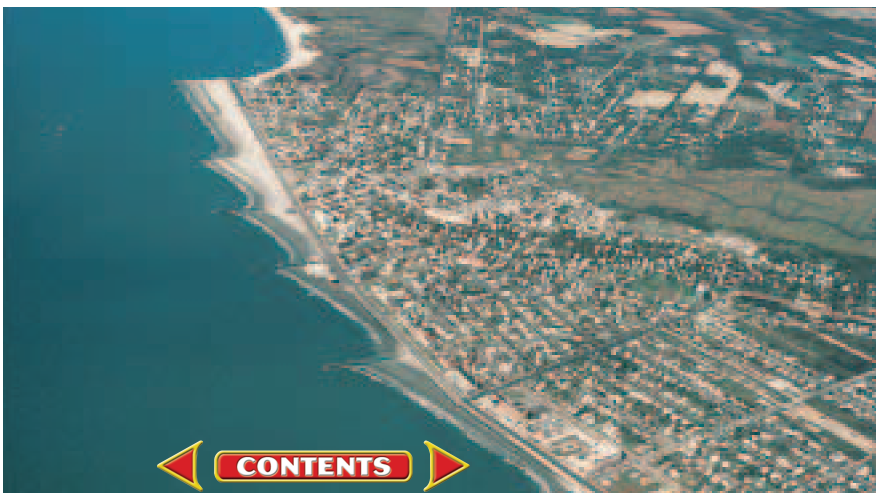


Figure 7-15 Groins at Cape May, New Jersey, are used to protect the beaches from wave erosion. Groins are vertical walls of rock placed perpendicular to the shore to trap sand from ocean currents.

CONTENTS

Figure 7-16 This rock in Yosemite National Park, California, was polished by the activity of a glacier.

Erosion also occurs on islands, where the constant movement of water wears away at the shorelines. Changing tides and conditions associated with coastal storms can have a great impact on coastal erosion as well. Human development and population growth along shorelines have led to attempts to control the ocean's movements of sand. However, efforts to keep the sand on one beachfront disrupt the natural migration of sand along the shore, thereby depleting sand from another area. ***Figure 7-15*** shows one method used to help prevent beach erosion. You will learn more about ocean and shoreline features in Chapters 15 and 16.

Glacial Erosion

Although glaciers currently cover less than ten percent of Earth's surface, their erosional effects are large-scale and dramatic. Glaciers scrape and gouge out large sections of Earth's landscape. Because they are so dense, glaciers have the capacity to carry huge rocks and piles of debris over great distances. Glacial movements scratch and grind some surfaces, while they polish others, as shown in ***Figure 7-16.*** The landscape features left in the wake of glacial movements include valleys with majestic waterfalls, lakes, and variously shaped deposits of sediment. Such features are common in New England. The erosional effects of glaciers also include deposition. For example, soils in the northern sections of the United States are deposits of material once carried by glaciers. In these and other ways, glaciers continue to affect erosional processes on Earth, even though the time of the most recent ice age is long past. You will learn more about glaciers in the next chapter.

Figure 7-17 The plant's roots have protected the soil from the wind erosion that has eroded the surrounding area in Death Valley, California.

Wind Erosion

Wind is a major erosional agent in areas on Earth that experience both limited precipitation and high temperatures. Such areas typically have little vegetative cover to hold soil in place. Wind can easily pick up and move these fine, dry particles. When conditions become ideal for wind erosion, the effects can be dramatic and devastating. The abrasive action of wind-blown particles can damage both natural features and human-made structures. Wind erosion is common in Death Valley. ***Figure 7-17*** is in Death Valley. Shore areas also experience wind erosion. Even though winds can blow against the force

Figure 7-18 The construction of a new highway in Ohio requires the removal of large amounts of soil.

of gravity and easily move materials uphill, wind erosion is relatively insignificant when compared to the erosion accomplished by running water and glacial activity.

Wind Barriers One farming method that reduces the effects of wind erosion is the planting of wind barriers, also called windbreaks. Wind barriers are trees or other vegetation planted perpendicular to the direction of the wind. In many cases, a wind barrier may be simply a row of trees along the edge of a field. In addition to reducing soil erosion, wind barriers can trap blowing snow, conserve moisture, and protect crops from the effects of the wind.

ENVIRONMENTAL CONNECTION

Erosion by Plants, Animals, and Humans

Plants and animals living on the surface of Earth also play a role in erosion. As plants and animals carry on their life processes, they move Earth's surface materials from one place to another. For example, Earth materials are relocated as animals burrow into soil and shovel it to another place. Humans also excavate areas and move soil from one location to another. Planting a garden, developing a new athletic field, and building a highway, shown in ***Figure 7-18,*** are all examples of human activities that result in the moving of Earth materials from one place to another. The effects of erosion by the activities of plants, animals, and humans, however, are minimal in comparison to the erosional effects of water, wind, and glaciers.

Section Assessment

1. In the erosional process, what is gravity's role in relationship to the other agents of erosion?
2. Describe the agents of erosion and how they affect Earth's landforms.
3. What is the difference between rill erosion and gully erosion? Which is the most damaging?
4. **Thinking Critically** In what ways do the activities of humans affect the processes of erosion and weathering?

Skill Review

5. **Making and Using Tables** Make a data table that compares the various agents of erosion. In your table, rate each agent's overall ability to erode and list any conditions necessary for each type of erosion to occur. Note which erosional agent is most powerful and which is most dominant on Earth. For more help, refer to the *Skill Handbook.*

SECTION 7.3 *Formation of Soil*

Soil is an important natural resource because it is essential to life on Earth. It would be difficult to imagine a world without soil. Humans and other organisms are dependent on plants, which grow in soil, for food and other basic needs. If you were to make a list of all the things that humans obtain directly and indirectly from soil, you might be surprised by the number of items on your list. In addition to wood from trees, such things as oxygen from plants, food from plants, and meat from animals that are dependent on plants are all products of soil. Soil even helps to filter pollutants.

OBJECTIVES

- **Describe** *how soil forms.*
- **Explain** *the relationship between the organic and inorganic components of soil.*
- **Identify** *soil characteristics.*
- **Recognize** *soil horizons in a soil profile.*

VOCABULARY

soil
residual soil
transported soil
soil profile
soil horizon

DEVELOPMENT OF SOIL

Except for some steep mountain slopes and extremely cold regions, soil is found almost everywhere on Earth's surface. But what is soil? Weathered rock alone is not soil. **Soil** is the loose covering of broken rock particles and decaying organic matter, called humus, overlying the bedrock of Earth's surface. Soil is the result of chemical and mechanical weathering and biological activity over long periods of time. The soil-forming process begins when weathering breaks solid bedrock into smaller pieces. These pieces of rock continue to undergo weathering and break down into smaller and smaller pieces. Many organisms, such as bacteria, fungi, and insects, begin to live in these weathered materials. Over time, the organisms die, decay, and add nutrients to the weathered materials to form soil, which, in turn, supports a variety of life forms, as shown in ***Figure 7-19.***

The process of continual breakdown of organic materials is thus begun. Nutrients continue to be added to the soil, soil texture improves, and the soil's capacity to hold water increases. While all

Figure 7-19 Burrowing animals, insects, bacteria, and fungi help add organic matter to soil.

Figure 7-20 This freshly plowed field in southwestern Georgia has a residual soil that is red.

soils contain some organic matter in various states of decay, the amount of such matter varies widely among different types of soil. For example, forest soils contain a much higher percentage of organic matter than desert soils do.

Soil Composition

During the process of its development, soil forms in layers. The solid bedrock from which weathered pieces of rock first break off is known as the parent rock. As these pieces of weathered bedrock break off, they rest on top of the parent rock layer. The pieces of rock continue to weather, and the smaller pieces form a layer that rests on top of the larger pieces. Thus, the smallest pieces of weathered rock, along with living and dead organisms, remain in the very top layer. Rainwater seeps through this top layer of materials, dissolves soluble minerals, and carries them into the lower layers of the soil.

Soil located above its parent material is called **residual soil.** Kentucky's bluegrass soil is an example of residual soil, as are the red soils in Georgia, shown in ***Figure 7-20.*** In contrast, **transported soil** has been moved to a location away from its parent bedrock. Agents of erosion, such as running water, wind, and glaciers, may transport soil from its place of origin to new locations. For example, glaciers have transported sediments to form soil from other places to the northern regions of the United States. Streams and rivers, especially during times of flooding, also transport and deposit great amounts of soil on floodplains along their banks at downstream locations. Winds carry and deposit very fine material to new locations as well.

While the parent bedrock determines what kinds of minerals a soil contains, the proportion of minerals in a soil and in the parent bedrock may not be the same. Differences may occur as the result of chemical weathering. The length of time it takes for soil to form also depends on the type of parent rock, as well as the climatic conditions of an area. In general, however, the process of soil formation occurs over a very long period of time; it can take hundreds of years for only a centimeter of soil to form.

Soil Profiles

Digging a deep hole in the ground will expose a soil profile, as when heavy machinery digs out soil in the process of building roads or highways. A **soil profile** is the vertical sequence of soil layers, as illustrated in ***Figure 7-21A.*** Some soils have more distinct layers than

Figure 7-21 A soil profile is the vertical sequence of soil layers **(A).** A gardener is growing plants in rich, black soil **(B).**

others. For example, poorly developed soils show little distinction between layers. A distinct layer, or zone, within a soil profile is called a **soil horizon.** There are three major soil horizons: A, B, and C. High concentrations of organic matter and humus are found in A horizons. Soils rich in humus are usually dark colored; they range from gray to black. ***Figure 7-21B*** shows black soils. Horizons B and C, the layers under horizon A, are less-developed soil. Horizon B contains subsoils that are enriched with clay minerals. Many subsoils have a zone of accumulation consisting of soluble minerals that have been leached, or washed out, from the topsoil. Subsoils may be red or brown in color as a result of the presence of iron oxides. Accumulations of clay in the B horizon can cause the formation of a hard material, commonly called hardpan, which may be so dense that it allows little or no water to pass through it. Horizon C, below horizon B and directly above solid bedrock, contains weathered parent material. Horizons A, B, and C are distinct and well developed in mature soils. However, all horizons may not be present in a given soil.

Topography The topography of a region affects the thickness of developing soil. In sloped areas, where runoff readily occurs, the coarser particles of soil remain on the slopes, while the smaller particles move downslope. As a result, soils on slopes tend to be thin, coarse, and infertile, whereas soils formed in lower areas, such as in valleys, are thick and fertile. Because south-facing slopes receive the most direct sunlight, they have somewhat more vegetation and therefore thicker soils than slopes facing in other directions.

The development of mature soil with distinct horizons takes a very long time. Only over time can vegetation grow and mature in a soil and increase the rate of soil development. Vegetation contributes to the buildup of humus and supplies acids that further promote the weathering process.

Soil Types

A soil's appearance, rate of formation, and productivity are determined to a great extent by climate. Because soils form from different parent bedrock material and undergo different climatic conditions, soils vary greatly from one place to another. Other factors contribute to the development of soil, including the types of plants and animals living in the soil, the topography of the area, and the length of time that the soil has been forming. However, because climatic conditions are the main influence on soil development, soils are often classified based on the climates in which they form. The four major types of soil, are polar, temperate, desert, and tropical. ***Figure 7-22*** shows a map of major soil types.

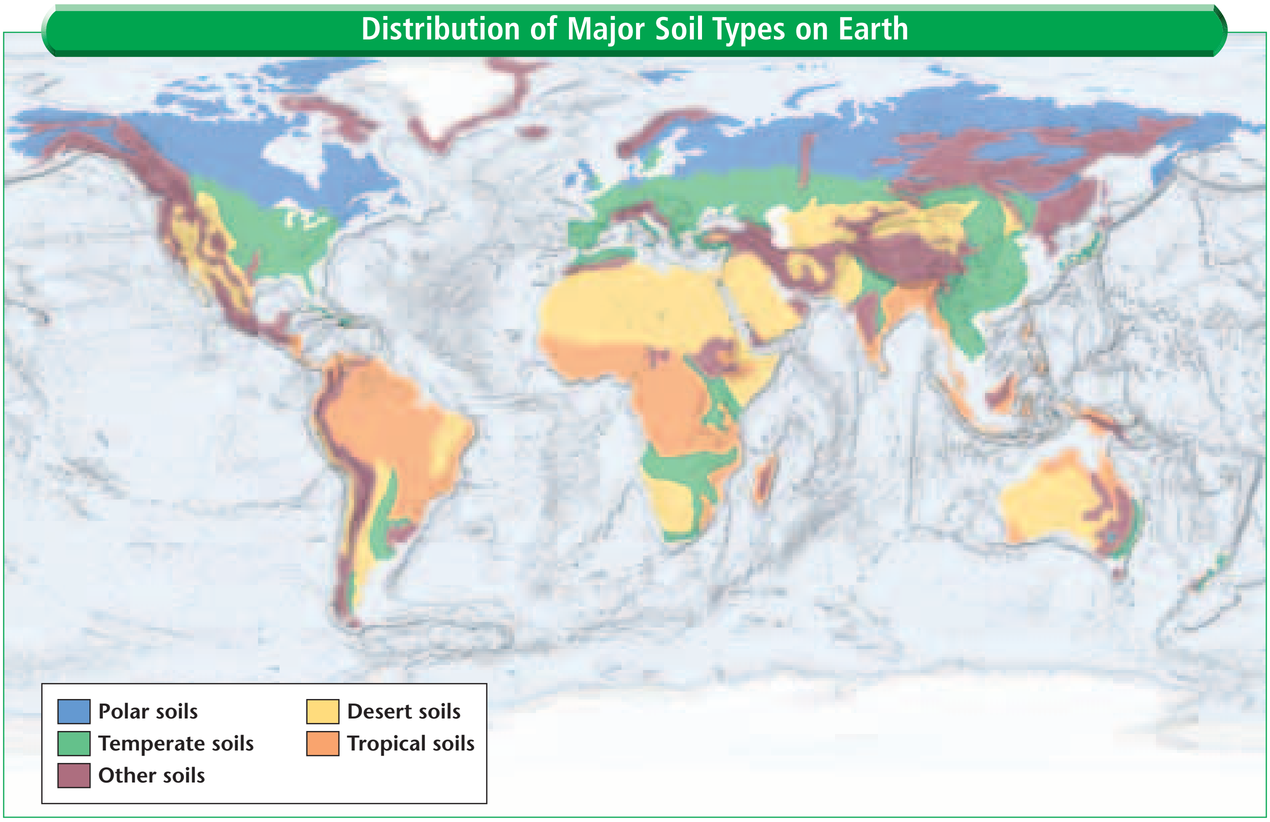


Figure 7-22 The major soil types include polar soils, temperate soils, desert soils, and tropical soils. Some climate regions have a variety of different soil types. They are identified on the map as "other." ***What soil types are found in the United States?***

Polar Soils Polar soils form at high latitudes and high elevations in places such as Greenland, Canada, and Antarctica. These soils have good drainage but no distinct horizons because they are very shallow, sometimes only a few centimeters deep. Permanently frozen ground, called permafrost, is often present under thin polar soils.

Temperate Soils Temperate soils vary greatly and are able to support such diverse environments as forests, grasslands, and prairies. While the temperate zone in general experiences annual rainfall greater than 50–60 cm, the specific amount of rainfall in an area determines the type of vegetation that will grow in temperate soils. Grasslands, which have an abundance of humus, are characterized by rich, fertile, soils, whereas forest soils are characterized by less deep and less fertile soils that contain aluminum-rich clays and iron oxides, such as those commonly found in the eastern portion of the United States. Soils in the drier, temperate prairies of the western United States support the growth of grasses and bushes. These areas experience annual rainfall of less than 50–60 cm.

Desert Soils Deserts receive low levels of precipitation—less than 25 cm per year. As a result, desert soils often have a high level of accumulated salts and can support only a limited amount of vegetation. Desert soils have little or no organic matter and a very thin A horizon. However, deserts often have abundant nutrients. During periods of precipitation deserts are able to support many plants that are adapted to survival during long periods of drought. Desert soils are also light-colored, coarse, and may contain salts and gypsum.

Tropical Soils Tropical areas experience high temperatures and heavy rainfall. These conditions lead to the development of intensely weathered and often infertile soil, such as that shown in ***Figure 7-23.*** The intense weathering combined with a high degree of bacterial activity leave tropical soils with very little humus and very few nutrients. These soils experience much leaching of soluble materials, such as calcite and silica, but they have high concentrations of iron and aluminum. The characteristic red color of tropical soils is the result of the oxidation of iron. While these soils provide poor growth conditions, high-grade iron ore is mined from Brazilian, Australian, and Jamaican tropical soils.

Figure 7-23 In the rain forests of Malaysia, the tropical soils are intensely weathered and contain very few nutrients.

Table 7-2 Soil Textures	
Soil Particles	**Size**
Very coarse sand	2–1 mm
Coarse sand	1–0.5 mm
Medium sand	0.5–0.25 mm
Fine sand	0.25–0.10 mm
Very fine sand	0.10–0.05 mm
Silt	0.05–0.002 mm
Clay	< 0.002 mm

Soil Textures

Particles of soil are classified according to size as being clay, silt, or sand, with clay being the smallest and sand being the largest, as shown in ***Table 7-2.*** The relative proportions of these particle sizes determine a soil's texture, as you will discover in the *Problem-Solving Lab* on this page. The proportions of different-sized particles present in a soil sample can be determined by first placing the sample along with water in a clear jar, shaking the jar, and allowing the particles to settle. With ample water, sediments will sort as they settle, and the percentage of settled clay, silt, and sand can then be estimated. This information, along with a soil textural triangle, shown in ***Figure 7-24,*** is used to determine a soil's texture. The texture of a soil affects its capacity to retain moisture and therefore its ability to support plant growth.

Soil Fertility

Soil fertility is the measure of how well a soil can support the growth of plants. Factors that affect soil fertility include the availability of minerals and nutrients, the number of microorganisms present, the amount of precipitation available, topography, and the level of acidity. Conditions necessary for growth vary with plant species. Farmers use

Problem-Solving Lab

Interpreting Data in a Table

Classify soils by texture Soils can be classified with the use of a soil textural triangle. Soil texture is determined by the relative proportions of particle sizes that make up the soil. The smallest particles are clay, and the largest are sand.

Analysis

1. Use the soil textural triangle shown in *Figure 7-24* to complete the data table. Record the percentages of particle sizes in the soil samples and the names of their textures.
2. Infer from the data table which soil sample has the greatest percentage of the smallest-sized particles.
3. Which soil sample has a sandy clay loam texture?

Soil Classification

Soil Sample	Percent Sand	Percent Silt	Percent Clay	Texture
1	50	40	10	Loam
2	50	20	30	sandy clay loam
3	20	70	10	silt loam
4	20	20	60	clay

Thinking Critically

4. What can you conclude about the total of the percentages of sand, silt, and clay for each sample? Explain.
5. Name one characteristic of soil other than water-holding capacity that is determined by the soil's particle sizes.

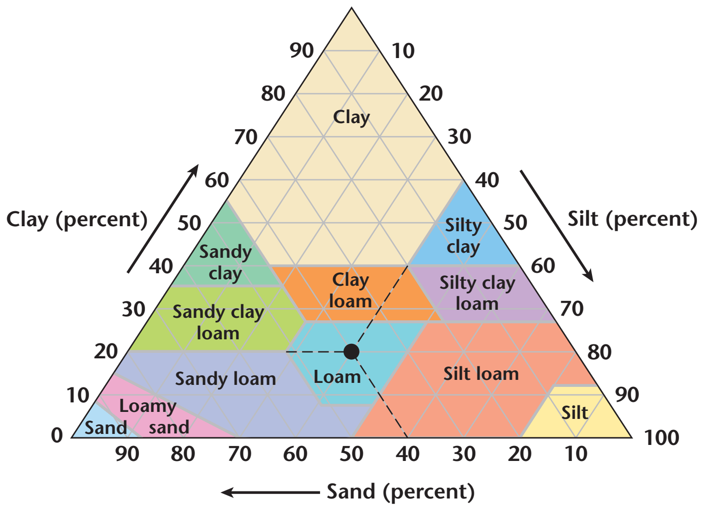


Figure 7-24 A soil textural triangle is used to determine a soil's texture. ***To determine the texture of a soil sample, find its percent for sand, silt and clay. Follow the percent lines for all three soils. The texture for the sample, will be where all three lines intersect. As an example, a soil sample of 40 percent silt, 40 percent sand, and 20 percent clay is the texture of loam.***

natural and commercially produced fertilizers to replace minerals and maintain soil fertility. Commercial fertilizers add nitrate, potassium, and phosphorus to soil. The planting of legumes, such as peas, beans, and clover, allows bacteria to grow on plant roots and replace nitrates in the soil. Pulverized limestone is often added to soil to reduce acidity and enhance crop growth. The addition of compost, organic mulch, and peat moss to soil also helps to maintain its fertility.

Soil Color A soil's composition and the climate in which it develops are the main factors that determine a soil's color. Topsoil is usually dark-colored because it is rich in humus. However, color alone is unreliable as an indicator of soil fertility. Red and yellow soils may be the result of oxidation of iron minerals. However, yellow soils are usually poorly drained and are often associated with environmental problems. Grayish or bluish soils are common in poorly drained regions where soils are constantly wet and lack oxygen.

Section Assessment

1. Explain the stages involved in the formation of soil.
2. Describe three characteristics of soil.
3. Explain the difference between temperate soils and tropical soils.
4. **Thinking Critically** How do the horizons in a typical soil profile differ from one another?

Skill Review

5. **Inferring** Infer what type of soil exists in your area and describe how you would determine whether your inference is correct. For more help, refer to the *Skill Handbook.*

earthgeu.com/self_check_quiz

GeoLab

Effects of Weathering

Many factors affect the rate of weathering of Earth materials. Two major factors that affect the rate at which a rock weathers include the length of time it is exposed to a weathering agent and the composition of the rock.

Preparation

Problem

Investigate the relationship between time and the rate of weathering of halite chips.

Materials

plastic jar with lid
water (300 mL)
halite chips (100 g)
balance
timer
paper towels

Objectives

In this Geolab, you will:

- **Determine** the relationship between the length of time that rocks are exposed to running water and the degree of weathering of the rocks.
- **Describe** the appearance of weathered rocks.
- **Infer** what other factors may influence the rate of weathering.
- **Apply** your results to a real-world situation.

Safety Precautions

Wear splash-resistant safety goggles and an apron while you do this activity. Do not ingest the halite chips.

Weathering Data	
Average Shaking Time in Minutes	Weight of Chips (g)
3	________
6	________
9	Answers will vary.
12	________

Procedure

1. Soak 100 g of halite chips in water overnight.
2. As a class, decide on a uniform method of shaking the jars.
3. Pour off the water and place the halite chips in the plastic jar.
4. Add 300 mL of water to the jar.
5. Secure the lid on the jar.
6. Shake the jar for the assigned period of time.
7. Remove the water from the jar.
8. Use paper towels to dry the halite chips.
9. Use a balance to weigh the chips. Record your measurement in a data table similar to the one provided.

Analyze

1. Why did you need to soak the chips before conducting the investigation?
2. How did the mass of the rocks change with the length of time they were shaken?
3. How did the shape of the rocks change as a result of being shaken in a jar with water?
4. What factors could have affected a team's results?

Conclude & Apply

1. What real-world process did you model in this investigation?
2. How would acid precipitation affect this process in the real world?
3. How would the results of your investigation be affected if you used pieces of quartz instead of halite?

Science & the Environment

Shifting Sands

On June 17, 1999, thousands of people gathered on an island off North Carolina to witness an historic event. As the 4800 ton, 65-m tall Cape Hatteras lighthouse began its half-mile journey away from the sea to safety, people cheered. Engineers had scored a victory, however temporary, against the battering of the Atlantic Ocean on a beloved piece of American history.

Cape Hatteras lighthouse is the tallest brick lighthouse in the world. When the lighthouse was built in 1870, it was 500 m from the ocean. The strong beacon helped sailors navigate a coastline so dangerous that it was known as "The Graveyard of the Atlantic." By 1987, this famous light was only 50 m from the sea, and in danger of destruction.

Barrier Islands

The lighthouse is one of several found on barrier islands off the coast of North Carolina. These long, narrow islands of sand running parallel to the coast are relatively young, formed as rising global temperatures caused glaciers to begin melting 15 000 years ago. Sea level rise caused massive coastal flooding, separating dunes and beaches from the mainland and forming the barrier islands. These islands move constantly as wind, waves, and storms shift the unstable sand on which they are built.

Barrier islands are important. The islands absorb the first onslaught of waves and wind coming ashore from the Atlantic, sheltering the mainland from hurricanes and other storms.

Sea Level On the Rise

Earth has continued to warm and glaciers to melt since the last ice age ended, making sea level 100 m higher today than it was 15 000 years ago. The impact on barrier islands is enormous. Erosion on east-facing shorelines and sand accumulation on southwest-facing shorelines has resulted in southwest migration of North Carolina's barrier islands. Hatteras Island is moving, but it is not taking Cape Hatteras lighthouse with it.

Protecting structures built in coastal areas comes at great financial cost. The projected cost in the United States alone is at least $270 billion per 1 m rise in sea level. Various methods are used to protect property, including constructing bulkheads and levees, and pumping sand onto beaches to replace that lost to erosion. Moving Cape Hatteras lighthouse was a controversial method of saving the structure. The expenditure of nearly 12 million dollars on this project was questioned by many as a temporary fix for the permanent problem of barrier island erosion and migration.

Activity

A recent study projects a cost to U.S. taxpayers of between 270 and 450 billion dollars to protect coastal structures from destruction by a 1 meter sea level rise. Is this a wise expenditure of money? Debate this issue with other students in your class.

Study Guide

Summary

SECTION 7.1

Weathering

Main Ideas

- The process of weathering breaks down Earth materials. Chemical weathering results in a change in the composition of a rock, whereas mechanical weathering results only in a change in a rock's size and shape.
- Temperature and pressure are major factors in the process of mechanical weathering. Changes in temperature can cause rocks to split.
- In chemical weathering, chemical reactions between rocks and water result in the formation of new minerals and the release of dissolved substances. The new minerals have different properties from those of the original rocks.

Vocabulary

chemical weathering (p. 155)
erosion (p. 153)
exfoliation (p. 155)
frost wedging (p. 154)
hydrolysis (p. 156)
mechanical weathering (p. 154)
oxidation (p. 156)
weathering (p. 153)

SECTION 7.2

Erosion and Deposition

Main Ideas

- Erosion is the process that moves weathered pieces of rock to new locations.
- Agents of erosion include moving water in streams and oceans, glaciers, wind, and gravity. Gravity is the driving force behind most agents of erosion.

Vocabulary

deposition (p. 162)
gully erosion (p. 163)
rill erosion (p. 163)

SECTION 7.3

Formation of Soil

Main Ideas

- Soil consists of weathered rock and humus, which is decayed organic matter in soil.
- Soil is residual or transported. Residual soil remains on top of its parent bedrock. Transported soil is moved to a location away from its parent bedrock by water, wind, or a glacier.
- A soil profile has horizons A, B, and C. Topsoil is located in horizon A, subsoil is in horizon B, and horizon C contains weathered rock from the bedrock.
- Characteristics of soil include texture, fertility, and color. Parent rock and environmental conditions determine a soil's composition.

Vocabulary

residual soil (p. 168)
soil (p .167)
soil horizon (p. 169)
soil profile (p. 168)
transported soil (p. 168)

earthgeu.com/vocabulary_puzzlemaker

Assessment

Understanding Main Ideas

1. What erosional agent accounts for most of the erosion on Earth's surface?
a. water **c.** glaciers
b. wind **d.** living things

2. What is the underlying force of all agents of erosion?
a. magnetism **c.** friction
b. gravity **d.** light

3. The variables that most affect the weathering process are rock composition and what?
a. topography **c.** living things
b. surface area **d.** climate

4. Humus is found in which horizon?
a. A **c.** C
b. B **d.** D

5. What is the chemical reaction of oxygen with other substances called?
a. precipitation **c.** oxidation
b. hydrolysis **d.** humidity

6. What type of soil has the most humus?
a. polar **c.** tropical
b. temperate **d.** desert

7. On which side of a mountain slope is the greatest amount of vegetation likely to grow?
a. north **c.** east
b. south **d.** west

8. In which area is the topsoil most likely to be thickest?
a. on level land **c.** on a mountain slope
b. on a hillside **d.** in a river bed

9. Deep, rich soils are found in which regions?
a. temperate **c.** polar
b. desert **d.** tropical

10. What is the name of the soil type that is from a location that experiences high temperatures and high precipitation?
a. tropical **c.** desert
b. polar **d.** temperate

Applying Main Ideas

11. How does the size of an exposed rock affect its rate of weathering?

12. Describe how human activities can affect the rate of weathering.

13. What erosional process might convince a person not to purchase a home built on an ocean shore?

14. What do oxidation and hydrolysis have in common in relation to the weathering process?

15. What role does acid precipitation play in the weathering process?

16. How does the use of a wind barrier reduce erosion on a farm?

17. How do glaciers both remove and build up Earth's surface?

18. What unique feature does water exhibit in response to temperature changes?

Test-Taking Tip

PLAN YOUR WORK AND WORK YOUR PLAN Plan your workload so that you do a little each day rather than a lot all at once. The key to retaining information is to repeatedly review and practice it. Studying an hour a night for five days a week will help you remember more than cramming in a five-hour session on Saturday.

earthgeu.com/chapter_test

Assessment

Thinking Critically

19. Name one reason why precipitation today is more acidic than precipitation in the 1800s.

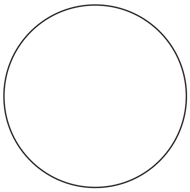
20. If no water existed on Earth, how would erosional processes be affected?

21. Compare the rate of soil formation to the average human lifespan.

22. Describe how carbonic acid is formed.

23. In the blank circle below, divide and label the areas for each of the following components of a soil sample.

60% mineral matter
2% organic matter
30% air
8% water



24. Make a bar graph of the data in question 23.

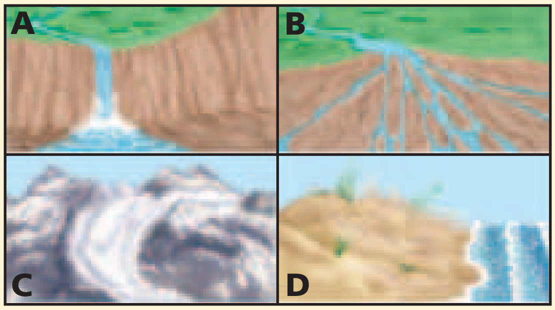
25. Use the following terms to construct a concept map to organize the major ideas in Section 7.2, Erosion and Deposition. For more help, refer to the *Skill Handbook.*

running water	wind	glaciers
u-shaped valleys	gully erosion	little vegetation
rill erosion	polished surfaces	sand dunes

Standardized Test Practice

1. Which is NOT an agent of chemical weathering?
a. water
b. oxygen
c. carbon dioxide
d. wind

INTERPRETING DATA Use the diagrams below to answer questions 2–4.



2. Which picture shows the erosional agent that was responsible for leaving behind U-shaped valleys, hanging valleys, lakes, and deposits of sediment in New England and New York State?
a. A **b.** B **c.** C **d.** D

3. Which picture shows the erosional agent responsible for dunes formed along the Gulf and Atlantic coasts of the U.S.?
a. A **b.** B **c.** C **d.** D

4. What common factor is responsible for three of the four erosional processes pictured?
a. wind
b. heat
c. human intervention
d. gravity

5. Which farming method is used to reduce wind erosion?
a. planting different crops
b. planting wind barriers
c. building earth mounds
d. building stone walls

earthgeu.com/standardized_test

CONTENTS