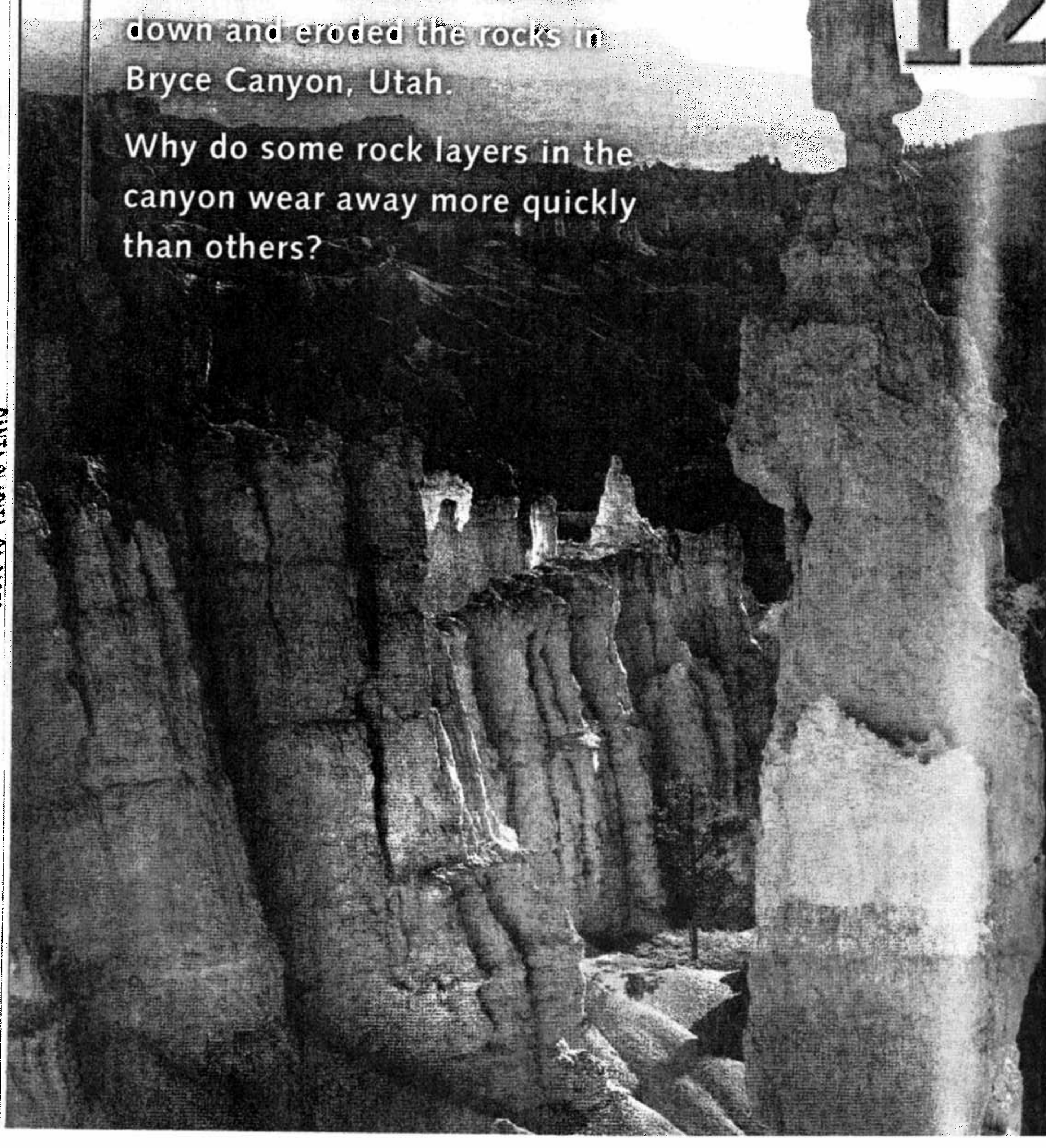
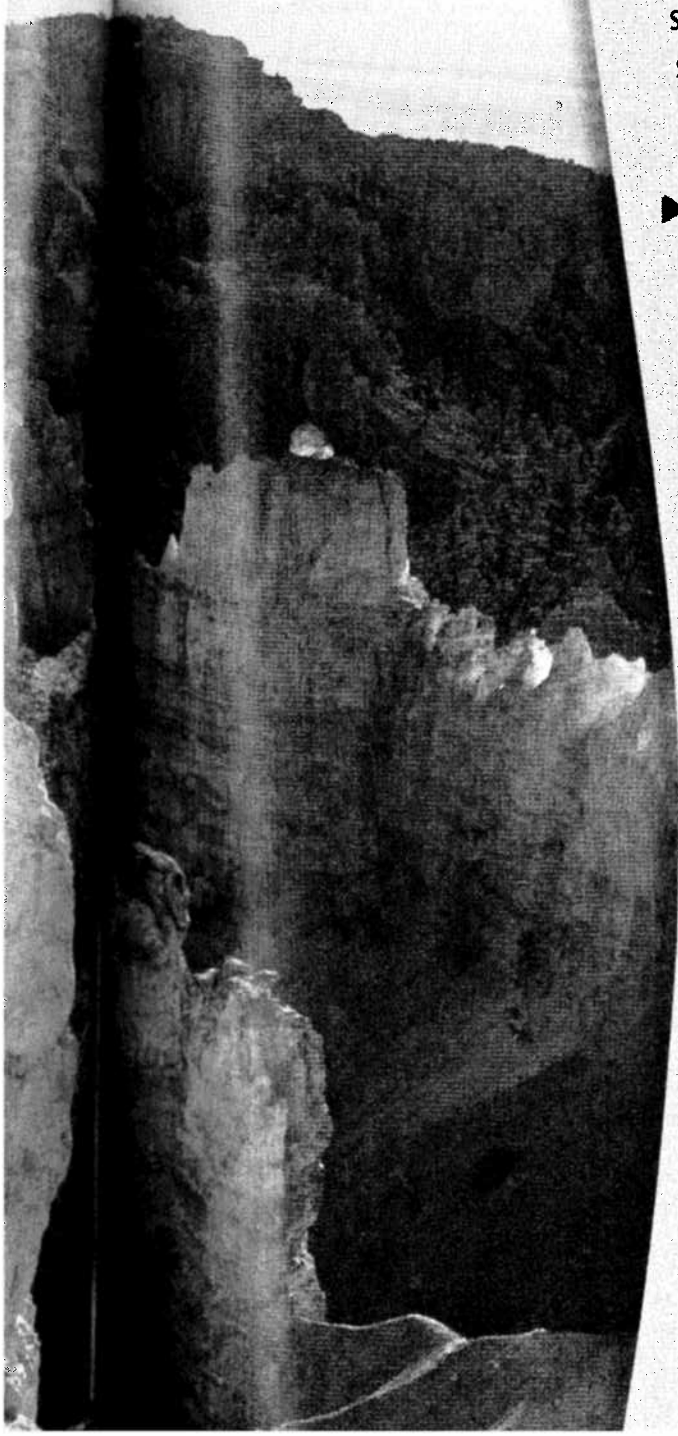
Weathering, Soil, and Erosion

CHAPTER 12



Over time, rainwater has worn down and eroded the rocks in Bryce Canyon, Utah.

Why do some rock layers in the canyon wear away more quickly than others?



CHAPTER 12

PREVIEW

▶ Focus Questions

In this chapter you will study weathering, soil, and erosion and learn more about the key questions below.

Section 1 How does weathering break down rock materials?

Section 2 How does soil form?

Section 3 How does erosion affect Earth's surface?

Section 4 What measures can be taken to protect soil as a resource?

▶ Review Topics

As you investigate weathering, soil, and erosion, you will need to use information from earlier chapters.

- ions **(p. 94)**
- mineral **(p. 96)**
- rock cycle **(p. 119)**

▶ Reading Strategy

Set a Purpose

The focus questions at the top of this page can help you set a purpose in your reading. As you read each section of Chapter 12, keep the focus question for that section in mind. In your notebook, write down ideas and information from the section that answer the focus question.

INTERNET RESOURCES
CLASSZONE.COM

At our Web site, you will find the following Internet support for this chapter.

DATA CENTER

EARTH NEWS

VISUALIZATIONS

- Mechanical Weathering Effects
- Chemical Weathering
- Landscape Formation by Erosion

LOCAL RESOURCES

INVESTIGATIONS

- When Is Mud Dangerous?
- How Does Soil Vary from Place to Place?

12.1

KEY IDEA

Over time, rocks are broken down by mechanical and chemical weathering.

KEY VOCABULARY

- weathering
- mechanical weathering
- chemical weathering
- frost wedging
- abrasion
- exfoliation
- hydrolysis
- acid rain
- oxidation

Weathering

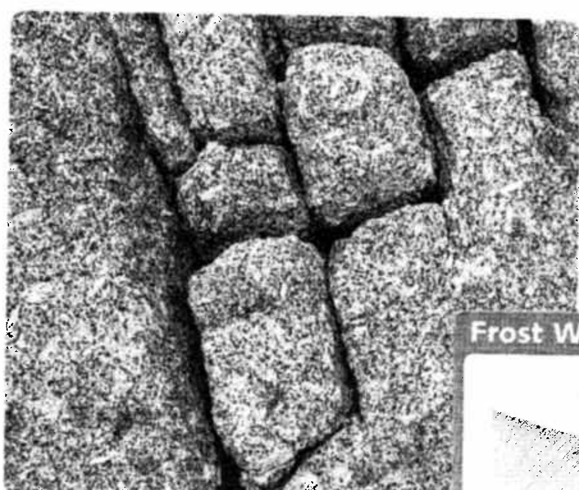
Granite forms deep underground, where pressures and temperatures are high, and water and oxygen are lacking. When granite is pushed up to Earth's surface, pressures and temperatures decrease dramatically. The granite is exposed to water and oxygen. As a result of these changes, the granite begins to weather. **Weathering** is the breakup of rock due to exposure to processes that occur at Earth's surface. Geologists group weathering processes under two headings—mechanical weathering and chemical weathering. **Mechanical weathering,** or disintegration, takes place when rock is split or broken into smaller pieces of the same material without changing its composition. Mechanical weathering is also called physical weathering. **Chemical weathering,** or decomposition, takes place when the rock's minerals are changed into different substances. Although mechanical and chemical weathering are often studied separately, they almost always act together.

Mechanical Weathering

Mechanical weathering processes include frost wedging, wetting and drying, abrasion by rock materials, plant and animal activity, and exfoliation that occurs as a result of upward expansion.

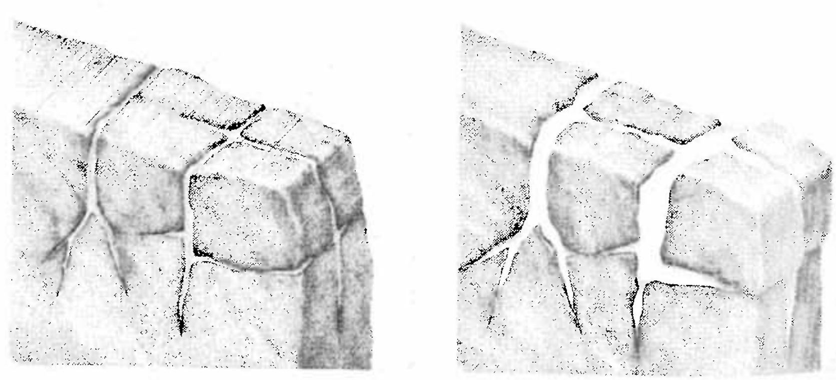
Ice and Water

Water occupies about 10 percent more space when it freezes. This expansion puts great pressure on the walls of a container. Consider a pail of water left outdoors in freezing weather. The pail may split open when the water freezes. In the same way, water held in the cracks of a rock wedges the rock apart when it freezes. This process is called **frost wedging,** or ice wedging, and is common in places where the temperature varies from below the freezing point of water (0°C) to above the freezing point. It occurs mostly in porous rocks and in rocks with many cracks.



FROST WEDGING The process of frost wedging widens cracks in rocks.

Frost Wedging



1. Rainwater enters existing cracks in a rock.
2. The water expands as it freezes, wedging the rock apart.

Frost wedging also occurs in places where there are frequent freezes and thaws. Bare mountaintops are especially susceptible to frost wedging. The vast fields of large, sharp-cornered boulders that are often found on mountaintops are pieces of the mountain that have been broken off by frost wedging.

Frost wedging also causes potholes to form on paved streets and highways. Here the process is helped by ice heaving, which happens when water in the ground freezes and lifts the pavement above it. When the ice thaws, the pavement collapses, leaving a pothole.

In addition, liquid water plays a role in mechanical weathering. Repeated wetting and drying can break up shale and other rocks that contain clay. These clays, which absorb water easily, swell up when they are wet and shrink when they are dry. Repeated swelling and shrinking cause the rocks to break apart.

VISUALIZATIONS
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Observe the effects of mechanical weathering.
Keycode: ES1201

Abrasion

Water, wind, and ice are capable of moving rocks. Water can tumble sand, pebbles, and even boulders along streambeds. Wind can blow sand and small pebbles across a rocky plain. Glaciers, which are moving masses of ice, carry rocks over great distances. Even gravity moves rocks.

As moving sand, pebbles, and larger rocks grind and scrape against one another, these rock materials are worn away. This type of mechanical weathering is called **abrasion.** The sand that you walk on at the beach is a product of abrasion. Rocks and pebbles get ground down into fine particles of sand as they are carried by rivers, streams, and ocean waves.

Plants and Animals

The growth of plants and the activities of animals contribute to the mechanical weathering of rock. When mosses and other small plants grow on rocks, they wedge their tiny roots into pores and crevices. As the roots grow, the rock splits. Larger shrubs and trees may grow through cracks in boulders, causing the cracks to widen.

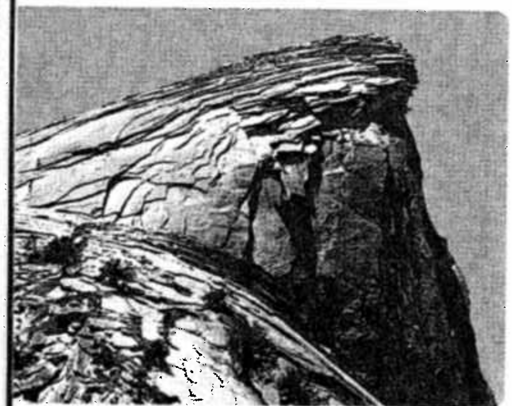
Ants, earthworms, rabbits, woodchucks, and other animals dig holes in the soil. These holes allow air and water to reach the bedrock and weather it. Burrowing animals also bring rock fragments to the surface, where the fragments weather more rapidly.

TREE ROOTS **This tree's roots are growing between cracks in the rock below. As the tree grows, the roots widen the cracks.**

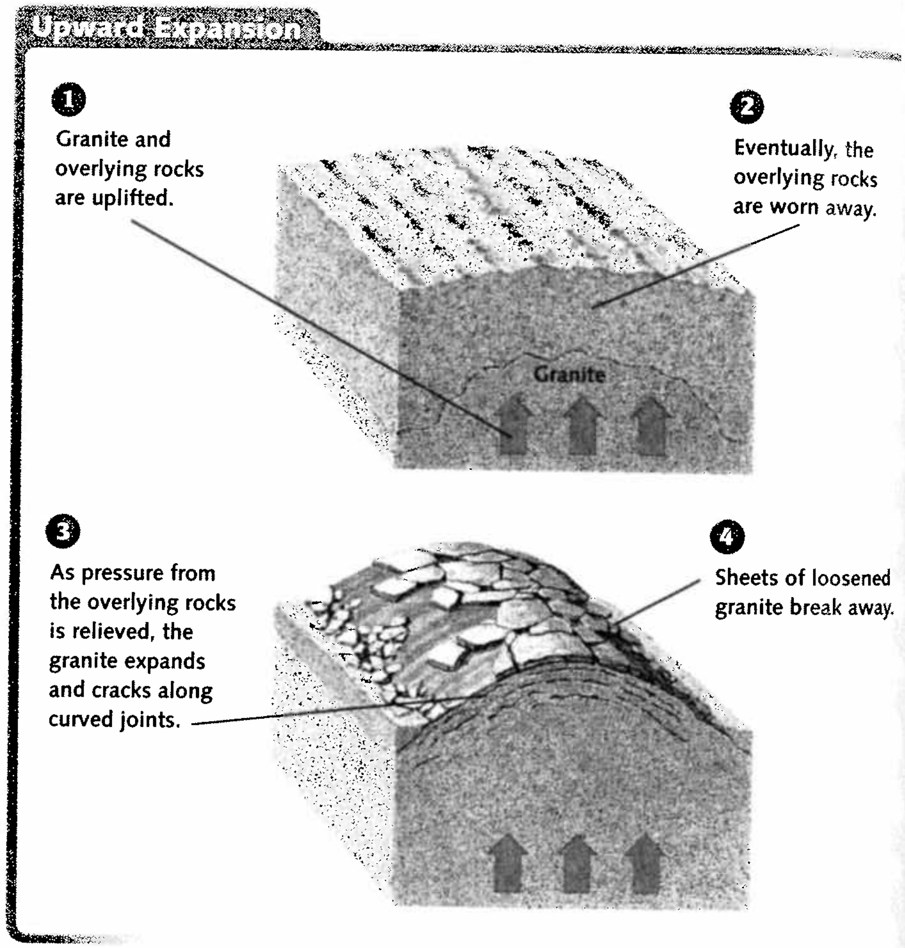
Upward Expansion

The upward expansion of rocks that are formed deep underground may result in a mechanical weathering process called **exfoliation** (ehks-FOH-lee-AY-shuhn). For example, granite becomes exposed when it is lifted up and the rocks above it are worn away. The removal of these overlying rocks reduces the pressure along the surface of the granite. Upward expansion causes the granite to break along curved joints that are parallel to the surface. Such joints can be seen in exposed peaks or outcrops. Over time, large sheets of loosened rock break away from an exposed outcrop, as shown in the diagram below.

Exfoliation forms rounded mountain peaks called exfoliation domes. Spectacular exfoliation domes occur in Yosemite National Park, California. Other exfoliation domes include Stone Mountain in Georgia and Sugarloaf Mountain near Rio de Janeiro, Brazil.



EXFOLIATION Sheets of granite break away from Half Dome, an exfoliation dome in Yosemite National Park, California.



Chemical Weathering

Chemical weathering occurs almost everywhere because water or water vapor is found almost everywhere. All chemical weathering involves water or water vapor. Other agents of weathering include acids and oxygen.

Water and Chemical Weathering

The chemical weathering by reaction of water with other substances is called **hydrolysis** (hy-DRAHL-ih-sihs). Common minerals that undergo hydrolysis include feldspar, hornblende, and augite. When these minerals are exposed to water, they dissolve into ions. These ions slowly react with the water and form clay minerals such as kaolinite.

Water's chemical effect on minerals is increased by the presence of acids that are dissolved in the water. A common acid found in water is carbonic acid. This weak acid is formed when carbon dioxide, one of the

VISUALIZATIONS
CLASSZONE.COM
Observe the chemical weathering of feldspar to clay.
Keycode: ES1202

gases present in Earth's atmosphere, dissolves in rainwater falling through the air. When rainwater containing carbonic acid seeps into the ground, it reacts chemically with many common minerals, including feldspar, hornblende, augite, and biotite mica. Elements such as potassium, sodium, magnesium, and calcium are dissolved, and the original minerals are turned into clay minerals.

Carbonic acid has an even greater effect on calcite. When carbonic acid reacts with calcite, the calcite dissolves completely. Unless the calcite is impure, no clay minerals remain after the reaction. The dissolving action of carbonic acid has hollowed out great underground caverns in limestone bedrock. You will learn more about caverns in Chapter 14.

BARBADOS, WEST INDIES Rainwater containing carbonic acid has dissolved limestone bedrock, forming Harrison's Cave.

Sulfur dioxide, nitrogen compounds, and carbon dioxide released by industries react with water in the atmosphere to form **acid rain.** Acid rain is rainwater that contains unusually high amounts of acids that can be traced to these pollutants. In addition to the damage that acid rain inflicts on the environment, acid rain also increases the rate of chemical weathering. Acid rain can cause structures made of concrete, stone, and metal to wear out more quickly.

Acids that are formed by the decay of dead plants and animals are dissolved by rainwater and carried through the ground to the bedrock. These acids react with minerals and contribute to chemical weathering.

Oxygen and Chemical Weathering

The brown or red color of some exposed rocks may be the result of a process called **oxidation** (AHK-sih-DAY-shuhn). Oxidation, which is the chemical reaction of oxygen with other substances, is very effective at weathering minerals that have iron in their chemical formulas. These minerals include magnetite, pyrite, and the dark-colored ferromagnesian silicates—hornblende, augite, and biotite. Oxidation of these minerals results in the formation of different types of rust, or iron oxides. Sometimes the rust that forms is a red iron oxide called hematite. Sometimes a yellowish-brown rust called limonite is formed.

Scientific Thinking

INVESTIGATE

Consider the climate and physical features of the region in which you live. Does it rain frequently? Is it arid or windy? How does the temperature vary during the year? What types of rocks are common in your region? Based on your knowledge of the climate and physical features of your area, predict what types of weathering are likely to occur.

Rates of Weathering

Under average conditions, weathering is a slow process. Several factors affect the rate of weathering, including the amount of a rock's surface area that is exposed to weathering influences. The composition of rocks and climate also affect rates of weathering.

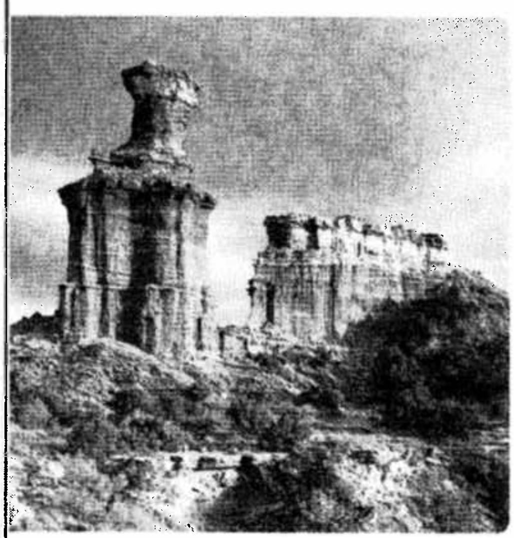
Surface Exposure

The rate at which a rock weathers is affected by the amount of the rock's surface that is exposed to chemical weathering processes. As shown below, when a rock is broken into smaller pieces by mechanical weathering, more of its surfaces are exposed. Thus, breaking a rock into smaller pieces causes the rock to weather more quickly.

Surface Exposure and Weathering

1 Mechanical weathering breaks a large rock into smaller pieces.

2 More rock surfaces are exposed to weathering, contributing to the breakdown of the rock.



ROCK LAYERS This rock formation is in Palo Duro Canyon State Park, Texas. The sedimentary rock layers in the formation are primarily claystone and shale.

Composition of Rock

Depending on their composition, various rocks respond differently to the same weathering processes. The rock layers in the photograph at the left have different compositions, so, even though the rock layers have been exposed to the same weathering processes, the layers have weathered at different rates. In some places, remnants of rock that are more resistant to weathering have protected the layers of less-resistant rock beneath. The taller formation in the photograph has a cap of more-resistant rock.

The rate at which a given rock weathers also depends on the type of weathering to which it is exposed. Because quartz does not react much with water, oxygen, or acids, it is almost unchanged by chemical weathering. Because quartz is hard and does not have cleavage, it also resists mechanical weathering. Gradually, however, quartz is broken into smaller particles.

In contrast, feldspar, hornblende, biotite mica, augite, calcite, and gypsum are affected by both mechanical and chemical weathering. Mechanical weathering breaks these minerals into small fragments. Chemical weathering turns these fragments into clay minerals.

Some minerals, such as calcite, gypsum, and halite, are also dissolved and carried off in solution.

Sandstones, quartzites, and quartz-pebble conglomerates are only as durable as the cements that hold them together. When the cement gives out, these rocks fall apart into the grains that compose them. Rocks that are cemented with calcite are subject to more rapid weathering. Rocks cemented with silica are more resistant to weathering. Quartzites and silica-cemented sandstones and conglomerates are among the most durable of all sedimentary rocks.

Shales are the most easily weathered of the sedimentary rocks. They split easily between layers and, in time, crumble into the clay minerals from which they were formed.

Marbles and limestones are fairly resistant to mechanical weathering. However, the calcite that constitutes marble and limestone undergoes slow attack by acids in water. In moist climates, where rainwater contains dissolved acid, rocks made of calcite are less durable than quartzites or sandstones. In dry climates there is little dissolved acid, and limestones are among the most durable rocks.

Climate

Climate is another factor that affects weathering processes. In general, warm, wet climates are conducive to both chemical and mechanical weathering processes. For example, most igneous rocks and many metamorphic rocks weather rapidly in wet climates. When these rocks are exposed at the surface, they often become cracked because of differences in temperature and pressure. Mechanical weathering widens the cracks in the rocks, exposing minerals to chemical weathering processes.

In regions with cold or dry climates, mechanical weathering plays a greater role than chemical weathering in breaking down rocks. For example, windblown rock materials can wear away rock surfaces in dry desert climates.

12.1 Section Review

1. Compare mechanical and chemical weathering.
2. How are ice and water involved in mechanical weathering?
3. How is upward expansion related to mechanical weathering?
4. What is hydrolysis, and how is it involved in chemical weathering?
5. Explain how oxygen is connected to chemical weathering.
6. Identify three factors that control the rate at which a rock weathers.
7. **CRITICAL THINKING** Compare the weathering processes that take place in a dry desert region with those that occur in a humid tropical region.
8. **SOCIAL STUDIES** Describe some ways that human activities affect weathering processes.

20-Minute

Mini LAB

Surface Area and Chemical Weathering

Materials

- two clear containers
- water
- two steel wool pads
- scissors

Procedure

1. Fill the two containers with water. Place one steel wool pad in one of the containers.
2. Cut up the other pad in eighths and put the pieces in the second container.
3. After three days, observe the contents of the two containers.

Analysis

Which steel wool pad rusted more quickly? Estimate how many times faster that pad rusted. Explain how you made your estimate. How could you make the steel wool pad rust even faster?

12.2

KEY IDEAS

Soil is made of weathered rock and organic material.

Climate and other factors affect the composition of soil.

KEY VOCABULARY

- soil
- parent material
- residual soil
- transported soil
- soil profile
- soil horizon
- topsoil
- subsoil

Soil

Weathering has attacked the rocks of Earth's surface since the beginning of geologic time. It has helped to wear down mountains and to shape countless landforms. Weathering has led to valuable mineral deposits and has provided materials for sedimentary rocks. Most important, weathering has helped form a priceless resource—Earth's life-supporting soil. **Soil** is made of loose, weathered rock and organic material in which plants with roots can grow.

How Soil Forms

The material from which a soil is formed is called its **parent material.** Based on a soil's parent material, soil can be classified as either a residual or a transported soil.

A soil whose parent material is the bedrock beneath the soil is called a **residual soil.** The soil of the Bluegrass region of Kentucky is an example of a residual soil. The parent material is the underlying limestone bedrock.

In some parts of North America, deposits left by winds, rivers, and glaciers have covered the bedrock. Soils formed from transported materials are called **transported soils.** The soils of New England and much of the Midwestern United States are transported soils. Their parent material is loose soil, boulders, sands, and gravels deposited by glaciers during the last ice age.

A soil forms as its parent material is weathered away. The rate of weathering differs from location to location, depending on the type of rocks that make up the parent material. Climate is also an important factor. Over time, a layer of soil covers the parent material. Organic material—decaying plant and animal remains—are mixed with materials that have weathered away from the bedrock. Soil scientists use the term *mature* to refer to soils that have had a long time to form.

Soil scientists can study soils by digging until they reach the parent material. The cross section of earth exposed by the digging is called the **soil profile.** In mature soils, three distinct zones, or **soil horizons,** can be seen in the soil profile. These are called the A-, B-, and C-horizons.

SOIL HORIZONS The A-, B-, and C-horizons can be seen in this profile of soil near Mobile, Alabama.

The soil of the A-horizon is called **topsoil.** Topsoil is generally gray to black in color. It tends to be darker than soil in other horizons because it usually contains humus. Humus is organic material that forms from decayed plant and animal materials. Although topsoil may contain both sand and clay, the clay tends to wash down to the B-horizon over time. Leftover sand makes the topsoil sandy.

The B-horizon begins with the **subsoil.** The subsoil is usually red or brown from iron oxides that formed in the A-horizon and have been washed down into the B-horizon. The subsoil also contains clay that has washed down from the topsoil. Soluble minerals such as calcium and magnesium may also have washed into soil of the B-horizon.

The C-horizon is made of slightly weathered parent material, such as rock fragments. The unweathered bedrock of the parent material lies directly beneath the C-horizon.

Characteristics of Soil Horizons

	Color	Composition
A-Horizon	Usually dark to light gray	Fine particles of weathered rock materials mixed with humus
B-Horizon	Often red or brown	Clay, iron oxides, and dissolved minerals washed down from the A-horizon
C-Horizon	Dependent on parent material	Partially weathered parent material (rock fragments)

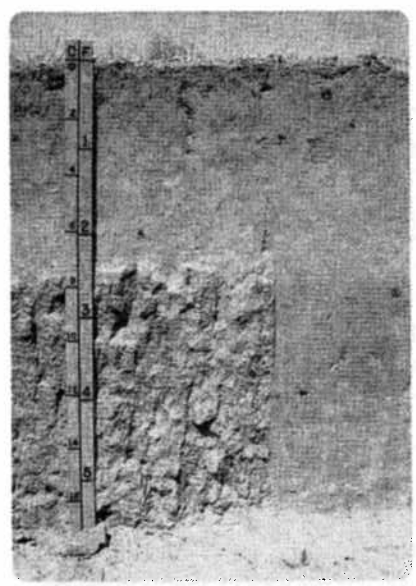
Soil Composition

The rock material in soil contains three noticeable parts: sand, silt, and clay. The amounts of these materials in a particular soil can affect the soil's ability to hold water and air, both of which are essential for plant growth. For example, soil that is very sandy holds water easily but dries out quickly.

What factors affect soil composition? One factor is time. Another is the parent material, though this factor becomes less important as a soil matures. Plants and animals affect soil composition by increasing the amount of organic material in the soil. Topography can also affect soil composition. Water flows down a sloping surface quickly, so the soil that is not eroded away by the water is often dry and resistant to plant growth. Because plant growth is limited, less organic material builds up in the soil.

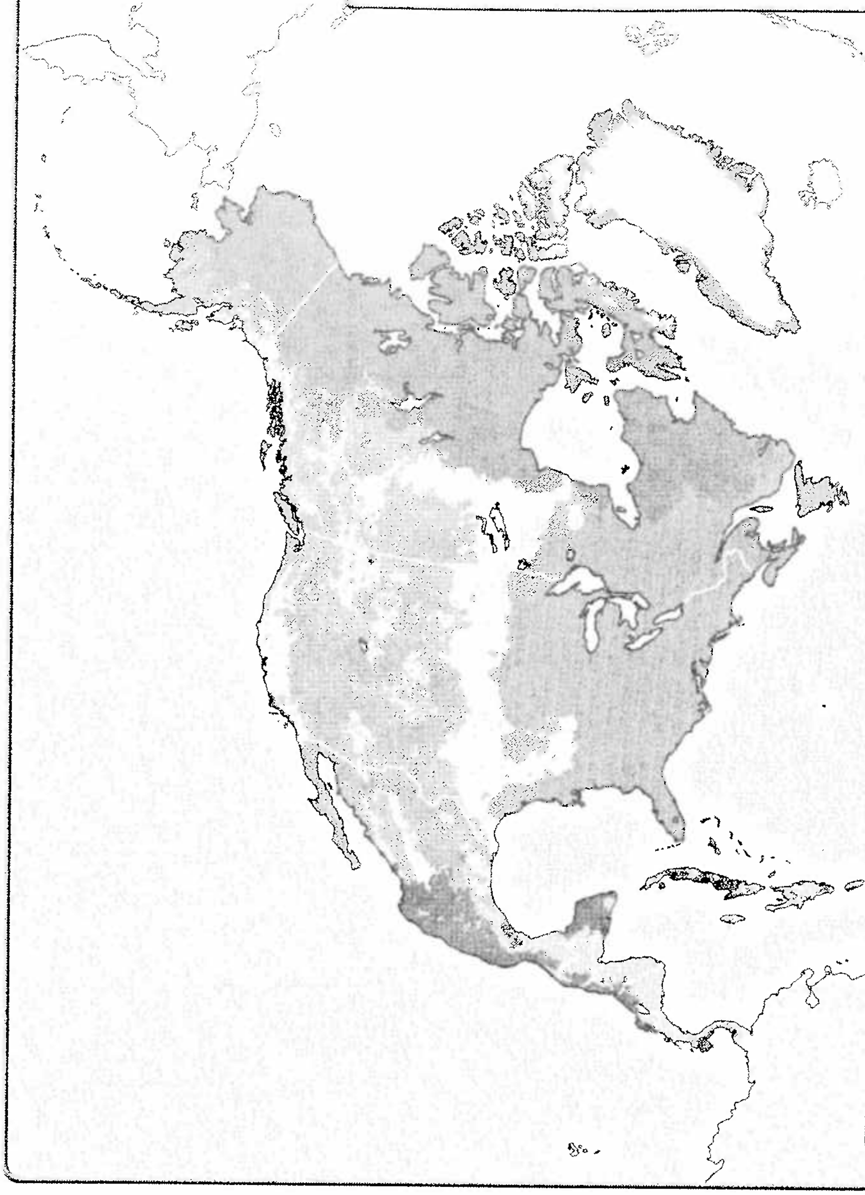
One of the most important factors affecting soil composition is climate. For example, scientists have found that mature soils in a wet tropical climate strongly resemble each other no matter what the parent material is. Heavy rains wash nutrients from these soils. Rainfall and high temperatures lead to the weathering of clay minerals. Much of the silica that results from this weathering is also washed out of tropical soils.

Scientists classify soils based on their composition and have identified thousands of different types of soil. The map on page 266 shows some broad classifications for soils in North America. These classifications show a strong link between soil composition and climate.



TROPICAL SOIL The red coloring in this tropical soil comes from iron oxides left behind after rainwater washes away other dissolved materials.

North American Soils



ARCTIC SOILS form in the cold climates found at high latitudes and very high elevations. Because of the cold climate, rock materials weather more slowly. As a result, soil profiles are shallow.

TEMPERATE GRASSLAND SOILS form in regions with temperate climates that receive enough rain to support grass, but not heavy tree growth. The soils are often fertile for farming.

TEMPERATE FOREST SOILS form in temperate regions that receive enough rain to support heavy tree growth. The soils are often fertile for farming.

TROPICAL GRASSLAND SOILS form in dry tropical regions that are consistently warm year-round and have both wet and dry seasons. Because of the hot, wet climate, rock materials weather quickly. As a result, soil profiles are deep.

TROPICAL FOREST SOILS form in humid tropical regions where the temperature is consistently warm and rainy year-round. Because of the climate, rock materials weather quickly, and soil profiles are deep.

DESERT SOILS form in regions with little or no rainfall. Because of the lack of moisture, vegetation is limited, contributing to wind erosion. Desert soils are generally sandy.

ICE covers some regions year-round.

12.2 *Section Review*

1. Describe the difference between a residual soil and a transported soil.
2. Sketch a soil profile and label the A-, B-, and C-horizons. Describe what you are likely to find in each soil horizon.
3. What rock materials are found in soil?
4. CRITICAL THINKING Use the information in the map above. How does the amount of rainfall appear to affect whether a soil is a grassland or a forest soil? Explain your thinking.
5. GEOGRAPHY How do you think the type of soil found in a particular region might affect the lives of people living in the region?

SCIENCE & Society

Preserving Rainforest Topsoil: The Environment

Looking at photographs of the lush tropical rainforests of Asia, Africa, and Latin America, you might assume that the soil is rich in nutrients. In fact, the topsoil there is thin and low in nutrients.

What happens to the nutrients stored in the plant and animal life of a rainforest? How can farmers tend their land to keep the topsoil productive?

SLASH-AND-BURN is a method used to clear forested land quickly for agricultural use. Here, rainforest in Thailand is being burned.

In the humid rainforest environment, dead organisms decompose rapidly, and the forest's living organisms directly absorb most of the nutrients released as a result. The soil is enriched only temporarily, however.

SUSTAINING the land in Costa Rica, this Arbofilia environmental group member plants trees in the Puriscal region.

Forest-dwelling peoples have traditionally cleared small sections of forest by chopping down and burning trees, a technique known as slash-and-burn. Burning releases nutrients from the trees into the soil to provide good cropland for several years. Once the nutrients are used up, the farmers leave the land to lie fallow—they stop farming the land to allow natural growth to return—for decades before planting there again.

Today, however, urban sprawl, poverty, and other pressures are limiting the time left for the soil to recover. Overuse and single-crop farming soon strip the topsoil of nutrients so that the land ceases to produce plentiful harvests. Farmers are then forced to clear more land.

Such unsustainable slash-and-burn farming is now a major cause of deforestation in the rainforests. Addressing the problem is difficult because many slash-and-burn farmers have no other way to support themselves. One possible solution is for farmers to adopt the traditional farming methods still practiced by the Lacandon Maya of the Selva Lacandona rainforest in Mexico. The Lacandons slash and burn a small plot in the forest. Over several years there, they plant more than 70 different trees and plant crops that help to restore nutrients to the soil. Eventually, they let the plot lie fallow, much as their ancestors have done. This system, known as agroforestry, is recognized as an excellent way to farm the forest without damaging the soil. ■

Extension

SCIENCE NOTEBOOK

Large-scale commercial logging is another major cause of deforestation and is also indirectly responsible for loss of topsoil. How do you think logging contributes to soil loss?

DATA CENTER
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Learn more about rainforests and conservation programs.
Keycode: ES1203

12.3

KEY IDEA

Mass movements and erosion carry away weathered materials and reshape Earth's surface.

KEY VOCABULARY

- mass movement
- erosion
- talus
- landslide
- creep
- slump
- earthflow
- mudflow
- volcanic neck

TALUS has collected at the bottom of this slope in Idaho.

Mass Movements and Erosion

Typically, weathered rock materials do not stay in place. Wherever the ground slopes, gravity causes soil and rock fragments to fall, slide, or move at slow speeds to lower levels. Rain or wind may remove sand and dust from the side of a hill. A river transports weathered material downstream.

Mass movement refers to the downward transportation of weathered materials by gravity. **Erosion** is the removal and transport of materials by natural agents such as wind and running water.

Mass Movements

Soil partially protects the bedrock beneath it from weathering. By removing soil and loose rock materials, mass movements continually expose fresh bedrock to weathering, thus speeding up weathering processes. You can see the results of mass movement at the base of many steep slopes. Geologists use the term **talus** (TAY-luhs) to refer to rock fragments that have been weathered from a cliff and pulled down by gravity. Talus piles rest against the cliff at angles as great as nearly 40 degrees.

Landslide is a term commonly used for the movement of a mass of bedrock or loose soil and rock down the slope of a hill, mountain, or cliff. Landslides are most likely to occur on steep slopes. Roads or houses built on or into the sides of steep slopes are at risk of being damaged by a landslide. The risk is even greater in regions near volcanoes and in earthquake-prone regions, where eruptions and seismic tremors can trigger landslides.

People can avoid injury from landslides by knowing when the danger is greatest. Landslides tend to occur after heavy rains or during the spring, when large amounts of snow are melting. Rain and water from melted snow add weight to soil, making it easier for gravity to pull soil down a slope. Rain and snowmelt also may create a layer of water between the soil and the underlying bedrock. This layer may make it easier for gravity to pull soil down a slope.

Geologists use various terms—creep, slump, earthflow, and mudflow, for example—to describe different types of landslides.

Creep

Creep is a slow, imperceptible movement of soil down a slope. Its effects are noticeable, however, because creep causes fence posts, poles, and other objects fixed in the soil to lean downhill. The presence of water in the soil contributes to creep.

Slump

Sometimes blocks of land tilt and move downhill along a surface that curves into the slope. This type of movement is called **slump.** Slump tends to occur because a slope has become too steep for the bottom of the slope to support the soil at the top of the slope. For example, if the rock and soil at the bottom of a slope become worn away, the top of the slope becomes unstable and slumps downward.

Earthflows

During an **earthflow,** a mass of weathered material that has been saturated with water flows downhill. The downhill movement is slower and less fluid than a mudflow. Factors affecting the velocity of an earthflow include the amount of water present, the composition of the soil, and the steepness of the slope.

Some earthflows take place relatively quickly, perhaps over a period of days. Other earthflows may last for a period of years. Geologists have found evidence that part of the Slumgullion earthflow in Colorado has been moving for about 300 years. The active section of this massive earthflow is about 3.9 kilometers long.

INVESTIGATIONS
CLASSZONE.COM

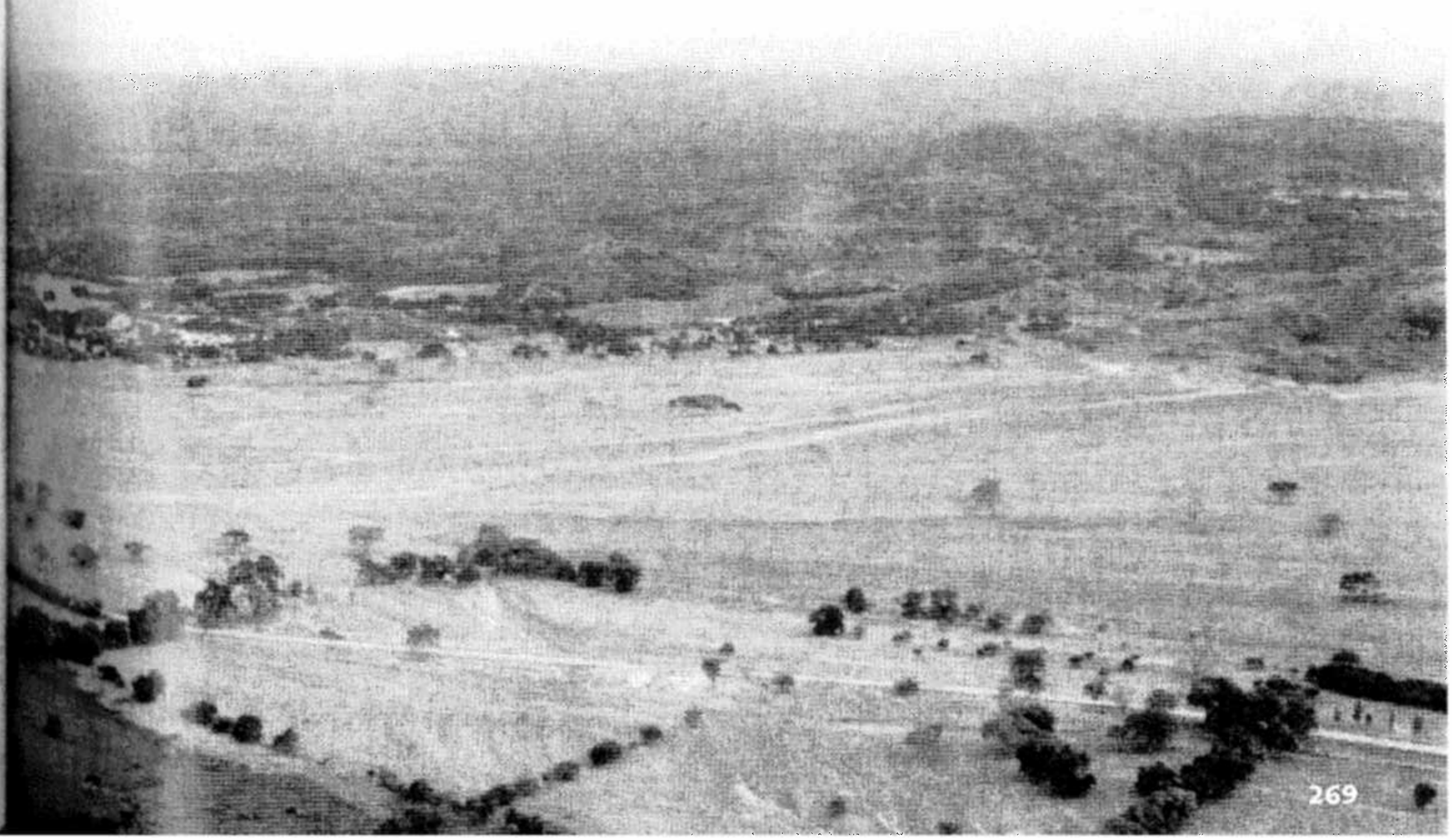
When Is Mud Dangerous? Analyze the conditions that create potential mudflows.
Keycode: ES1204

Mudflows

A **mudflow** is the rapid movement of water that contains large amounts of suspended clay and silt. Mudflows contain more water than earthflows and have been known to travel at up to 100 kilometers per hour down steep mountains. Mudflows are capable of moving rocks, boulders, trees, and houses. They tend to occur in drier regions that experience infrequent but heavy rainfall. Although mudflows occur most often on steep, barren slopes that erode easily, they can also occur on gentle slopes that are prone to erosion.

Lahars, which you learned about in Chapter 9, are mudflows that accompany volcanic eruptions. Heat from erupted materials melts snow and ice on top of a volcano. Water cascades down the slopes of the volcano, carrying mud along with it. The photograph below shows a lahar that followed the 1985 eruption of Nevado del Ruiz, a volcano in Colombia. The devastating lahars from this eruption traveled about 100 kilometers. In the town of Armero alone, over 20,000 people were killed.

MUDFLOW A lahar that followed the 1985 eruption of a volcano in Colombia buried the town of Armero, located in the center of this photograph.



VISUALIZATIONS CLASSZONE.COM

Examine a landscape formed by erosion.
Keycode: ES1205

Erosion and Landforms

Rivers and streams, glaciers, wind, and ocean waves and currents are all agents of erosion. By removing and transporting earth materials, these agents play as important a part in shaping a landscape as the forces associated with plate tectonics. Climate and the composition of rock are two other important factors that affect erosion in a given region.

The topography of a region depends on the balance at any given time between forces that uplift the land and agents of erosion that wear down the land. Even as rocks are uplifted, weathering and erosion are acting on the rocks. Sometimes uplift is more apparent than erosion. The Himalayas are being uplifted more quickly than they are being eroded. As a result, these mountains are growing higher over time. Their topography is rugged and sharp. In contrast, erosion is now the dominant process in the Appalachians. The effects of erosion are apparent in these mountains. Their topography is more smooth and rounded than the topography of the Himalayas.

The effect of erosion on topography is also influenced by climate. In regions with humid climates, water is the primary agent of erosion. Because water is such an effective agent of erosion, humid regions tend to have more rounded topography. The topography in regions with dry climates tends to be sharp and jagged.

VOLCANIC NECK Agathla Peak, Arizona, is a core of hardened magma, the remains of an eroded volcano.

The composition of rock also affects rates of erosion. Some types of rock are more resistant to erosion than other types of rock. For example, the rock structure in the photograph at the left is all that remains of an extinct volcano. The outer layers of the volcano have been eroded away, leaving behind a more resistant plug of igneous rock called a **volcanic neck.** The volcanic neck is made of hardened magma—the molten rock that originally rose upward in the volcano when it was active. In later chapters of this unit, you will read about how weathering and erosion are involved in shaping other landforms.

12.3 Section Review

1. Explain what the term *mass movement* means, and give some examples of mass movements.
2. Explain how the climate of a region affects erosion and topography.
3. CRITICAL THINKING Volcanologists often study the area around a volcano to identify places where lahars have occurred in the past. How could such studies benefit communities near the volcano?
4. PHYSICS Gravity is a force that pulls objects downward. Friction is a force that resists the sliding motion of one surface against another surface. Explain how these forces affect rocks and earth on a mountain slope.

Soil as a Resource

12.4

KEY IDEA

Soil is an important resource that can be conserved and protected.

KEY VOCABULARY

- soil fertility
- soil depletion
- salinization

Because soil supports plant life, which in turn supports animal and human life, it is an important renewable resource. Yet less than 25 percent of Earth's land can be used to grow crops. Rough mountain regions often have no soil cover. Polar regions are too cold to grow crop plants. Desert regions are too hot and dry.

As human populations continue to grow, the amount of land available for farming is becoming even more limited. Areas with the most fertile soil are often the same places where people want to build houses. Thus, it is important to conserve and protect the soil that is available as a resource.

Soil Fertility

Soil fertility is the ability of soil to grow plants. The proportions of mineral matter, water, and organic matter in soil determine the types of plants that will grow in the soil. Soil that is fertile for potatoes may be less fertile for wheat. In part this is because potatoes require a different quantity of soil nutrients and water than wheat does. A number of problems, which include soil depletion and salinization, threaten soil fertility.

Soil Depletion

Crop plants and natural vegetation use up nutrients in soil. When the plants die, they decompose in the ground, and the nutrients are returned to the soil. When crops are harvested, however, the nutrients are removed from the soil. **Soil depletion** occurs when the soil gradually becomes so lacking or depleted in nutrients that it can no longer grow a usable crop.

Good farming practices can prevent soil depletion. Farmers, for example, can allow fields to lay fallow for a period, or they can rotate the types of crops grown on each field from year to year. Farmers do not always follow such practices, however, because it can be expensive in the short term to do so. Instead, farmers often add artificial fertilizers to soil. These fertilizers increase crop yields but pose a serious threat to the environment. Over time, runoff from fields causes nutrients to build up in lakes and rivers, and in coastal environments, where the nutrients stimulate plant growth. The plants, in turn, use up oxygen needed by other organisms. Eventually, the ecological balance of these water environments is destroyed.

SALINIZATION Evaporated irrigation water has caused salt deposits to accumulate in this soil, severely diminishing the soil's fertility.

Salinization

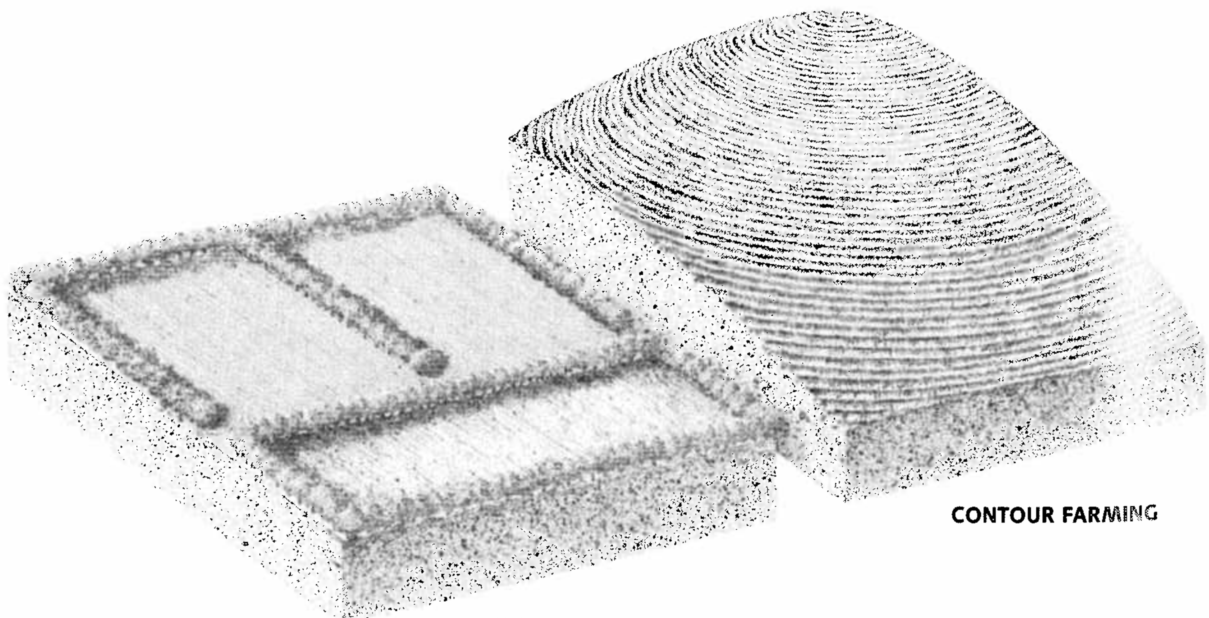
Irrigation can make desert soils very fertile. The problem, however, is that the water brought in to irrigate a desert contains dissolved minerals. As the desert's dry air rapidly evaporates the irrigation water, the minerals that had been dissolved in the water are left behind, deposited on the soil surface. In time, the soil contains so much mineral matter from the evaporated irrigation water that the soil can no longer sustain crop growth—a process called **salinization.** Soil affected by salinization is difficult to reclaim.

Erosion and Soil Conservation

Although erosion by wind and water occurs naturally, it is accelerated by human activity. In many regions, farming, construction, mining, and other activities have left soil relatively unprotected from erosion. As a result, erosion is removing topsoil more quickly than natural processes can restore it. As of 2001, one estimate indicated that soil in the United States was being eroded at a rate 17 times higher than the rate at which it was formed. About 90 percent of available cropland was losing soil faster than it could be replaced.

For farms to remain productive, soil erosion must be controlled using soil conservation methods. These methods include planting windbreaks, constructing terraces, and implementing erosion-reducing farming practices such as contour farming, strip-cropping, and no-till.

Windbreaks, also known as shelterbelts, are belts of trees planted along the edges of fields. These trees slow the wind and reduce wind erosion. Windbreaks are important on level plains where strong winds may blow nearly all the time. Windbreaks are common in the Great Plains region of the United States, where they were planted after the Dust Bowl disaster of the 1930s proved that protection against wind erosion was necessary. Other benefits of windbreaks include protection against water erosion and frost.

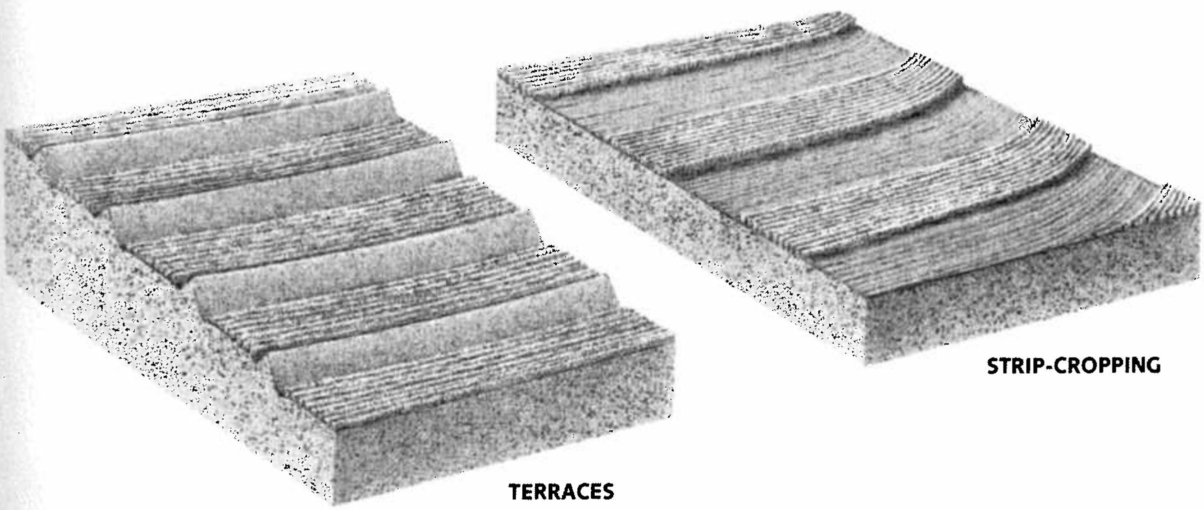


Contour farming is a method that inhibits water from flowing rapidly downhill and carrying soil with it. Instead of plowing up and down a slope, farmers plant crops in rows parallel to land contours. Contour farming is utilized in irrigation-dependent regions where slopes are moderately steep. It has been practiced in various parts of the world for centuries.

Flattening a slope into terraces slows the speed of runoff. As a result, the water can transport less topsoil. In some regions, terraces have been shown to reduce soil erosion by 50 percent or more. Terrace farming is used in the cultivation of rice and other crops, and has been practiced for many centuries in places ranging from China to the Andes.

Another method of reducing soil erosion is strip cropping. Farmers alternate a crop that leaves bare ground between rows with a crop that completely covers the ground. For example, the ground between rows of corn plants is bare. Alfalfa is a crop that covers the ground. By planting alternating strips of a field with corn and alfalfa, farmers can protect the soil from erosion. To reduce water erosion, the strips are planted on the contour, perpendicular to the slope. To reduce wind erosion, the strips are planted perpendicular to the prevailing wind direction. Regions in which strip cropping is practiced include much of the Eastern and Central United States.

Still another method of reducing soil erosion is a technique called no-till. In this method, plowing, planting, fertilizing, and weed control are all done at the same time. Once the field is planted, the ground does not need to be disturbed again until harvest. Because the soil is left alone, there is less chance that it will be eroded. Regions where no-till has been used include the Southern and Midwestern states.



12.4 Section Review

1. Describe some ways to prevent soil depletion.
2. How and where does salinization occur?
3. Describe at least three methods that can be used to protect a field from wind or water erosion.
4. CRITICAL THINKING Terrace farming is used to reduce erosion. Explain how terrace farming could also increase the amount of land available for farming.
5. MATHEMATICS One estimate for the rate at which natural processes can replace topsoil that has been eroded is about 2 millimeters per year. At this rate, how long would it take to form 10 centimeters of new topsoil? Show how you got your answer.

CHAPTER 12 LAB Activity

Chemical Weathering and Temperature

Skills and Objectives

- ***Model*** a chemical weathering process.
- ***Graph*** the data from the model and ***interpret*** the graph.
- ***Predict*** what will happen when the model is modified.

Materials

- lab apron
- safety goggles
- 5 250-mL beakers
- 5 thermometers
- hot water (40–50°C)
- ice water
- 5 effervescent antacid tablets
- stopwatch
- graph paper
- map of Earth's climates, page 470

Whether it's the granite of a New Hampshire mountain breaking down into sand and clay or the limestone of Kentucky decomposing to form rich soil, all chemical weathering processes involve water. What effect does the temperature of the water have on the rate of chemical weathering?

Carbonic acid is a weak acid that forms when carbon dioxide dissolves naturally in water. A common chemical weathering process is the reaction of carbonate rocks, such as limestone and marble, with carbonic acid. In this lab activity, you will observe the dissolution of effervescent tablets in water of varying temperatures. These tablets contain sodium bicarbonate, which dissolves in water in much the same way that carbonate rocks dissolve in carbonic acid.

Procedure

1. **CAUTION: Put on your lab apron and safety goggles.**
2. Arrange five beakers in a row, numbered from 1–5. Place a thermometer in each beaker.
3. Add combinations of hot and ice water to each beaker so that the temperature of the water matches the following: Beaker 1, 0–10°C; Beaker 2, 10–20°C; Beaker 3, 20–30°C; Beaker 4, 30–40°C; Beaker 5, 40–50°C. Each beaker should contain about 200 mL of water.
4. Remove any ice from Beaker 1. Make sure that the water is within the correct temperature range. When the temperature reading stabilizes, record the start temperature of the water in Beaker 1 on a copy of the data table. Remove the thermometer from the beaker and set it aside.
5. Drop an antacid tablet into Beaker 1. Start the stopwatch at the instant the tablet enters the water. Stop the stopwatch when the last piece of the tablet dissolves. (Do not wait for the bubbling to stop; wait only for all pieces of the tablet to dissolve completely.) Record the time on the stopwatch to the nearest whole second.
6. Place the thermometer back in Beaker 1 and wait until the temperature stabilizes. Record the end temperature of the water in Beaker 1. Calculate the average temperature of Beaker 1 by adding the start and end temperatures and dividing by 2. Record the average temperature of the water in Beaker 1.
7. Repeat Steps 4, 5, and 6 for each of the remaining beakers.

8 Plot a graph of the data for the five trials. Place "Average Temperature (°C)" on the x-axis and "Time (seconds)" on the y-axis. Connect the five points with a smooth curve.

Beaker No.	Start Temp. (°C)	Time (sec.)	End Temp. (°C)	Average Temp. (°C)
1				
2				
3				
4				
5				

Analysis and Conclusions

1. In which beaker did the reaction occur most slowly? In which beaker did the reaction occur most rapidly?

2. Based on your observations, hypothesize the relationship between temperature and the rate of chemical weathering. What are some possible reasons for this relationship? Explain.

3. Look at the temperatures you recorded. Are all of these temperatures likely to occur on Earth's surface? If so, where? Which of the beakers corresponds with the water temperature of your local area?

4. Turn to the map of Earth's climates on page 470. Locate Rio de Janeiro in South America and Seattle in North America. The map key indicates that both cities have climates with abundant moisture.

   a. Compare the likely weathering rate of a limestone in Rio de Janeiro with that of a limestone in Seattle. Is there a difference?

   b. Which of the two locations is likely to have thicker soil?

5. Now locate Barrow, Alaska, on the map. Why is a limestone in Barrow likely to weather very slowly?

6. How would the rate of the reaction have been different if the tablets had been ground into a powder before they were dropped into the water? Would a graph for such a reaction result in a curve above or below the line of your actual data? Do you think the shape of the curves would be the same? Explain your answers.

CHAPTER 12 REVIEW

Summary of Key Ideas

12.1 Mechanical weathering breaks down rocks without changing their composition. Chemical weathering changes the composition of rocks. Some factors that affect the weathering rate of rock are surface exposure, composition, and climate.

12.2 Soil is loose, weathered material capable of supporting rooted plants. A soil may be residual or transported, depending on its parent material. A soil's composition depends on many factors, one of the most important of which is climate.

12.3 Mass movements involve the downward transport of rock materials by gravity. Erosion is the removal or transport of rock materials by natural agents such as water and wind.

12.4 Appropriate farming practices can help protect soil fertility. Windbreaks, contour plowing, terracing, strip cropping, and no-till are methods used to prevent soil erosion.

KEY VOCABULARY

abrasion (p. 259)
acid rain (p. 261)
chemical weathering (p. 258)
creep (p. 268)
earthflow (p. 269)
erosion (p. 268)
exfoliation (p. 259)
frost wedging (p. 258)
hydrolysis (p. 260)
landslide (p. 268)
mass movement (p. 268)
mechanical weathering (p. 258)
mudflow (p. 269)
oxidation (p. 261)
parent material (p. 264)
residual soil (p. 264)
salinization (p. 271)
slump (p. 268)
soil (p. 264)
soil depletion (p. 271)
soil fertility (p. 271)
soil horizon (p. 264)
soil profile (p. 264)
subsoil (p. 265)
talus (p. 268)
topsoil (p. 265)
transported soil (p. 264)
volcanic neck (p. 270)
weathering (p. 258)

Vocabulary Review

Explain the difference between the terms in each pair.

1. mechanical weathering, chemical weathering
2. oxidation, hydrolysis
3. residual soil, transported soil
4. mudflow, creep
5. subsoil, topsoil
6. salinization, soil depletion

Concept Review

7. What is ice wedging, and where is it likely to occur?
8. Explain how plants and animals contribute to mechanical weathering and how they contribute to chemical weathering.
9. What is carbonic acid, and how does it affect chemical weathering processes?
10. Describe some factors that influence the rate at which a rock weathers.
11. Where are you likely to find dark, humus-rich soil in a soil profile?
12. Describe what you would expect to see in the C-horizon of a soil.
13. Use the map on page 266. Compare the soil types in the eastern United States with those in the western United States. What type of soil is found where you live?
14. What is talus?
15. Compare and contrast an earthflow and a mudflow.
16. Give some examples of agents of erosion.
17. Describe some farming methods that can be used to prevent soil erosion.
18. **Graphic Organizer** Copy and complete the cause-and-effect diagram below by giving the cause of soil depletion.

? — *causes* — *soil depletion*

Critical Thinking

19. **Predict** How would the weathering of a bare mountain peak differ from the weathering of bedrock under a forest?
20. **Compare** Why are streets and highways damaged so much more in the winter months than in the summer months in much of the United States? Compare the processes of weathering in the two seasons.
21. **Analyze** Sandstones cemented by calcite usually weather much more rapidly than those cemented by silica. Why?
22. **Predict** What effect would a long, dry period have on the frequency of earthflows and mudflows?

Interpreting Graphs

The type of weathering that dominates in an area depends upon the climate in that area. Two key factors that affect climate are precipitation (rain and snow) and temperature. The graph shows the relationship between precipitation, temperature, and weathering. For example, a climate with an average yearly temperature (AYT) of 5°C and average yearly precipitation (AYP) of 75 centimeters would have moderate chemical weathering with frost action. Use the graph to answer the questions.

23. Determine the major type of weathering that occurs in Washington, D.C., where the AYT is 23°C and the AYP is 104 centimeters.
24. If the AYT in Washington, D.C., dropped 26°C but the AYP stayed the same, what kind of weathering would dominate?
25. Phoenix, Arizona, has an AYT of 20°C and an AYP of 20 centimeters. How would the climate in Phoenix have to change for moderate chemical weathering to become dominant?
26. According to the graph, no frost action occurs at a mean annual temperature above 13°C. What is a possible reason?
27. In general, how does a climate with strong chemical weathering differ from a climate with strong mechanical weathering?

Internet Extension

INVESTIGATIONS CLASSZONE.COM

How Does Soil Vary from Place to Place? Compare and contrast soils from different regions.

Keycode: ES1206

Writing About the Earth System

SCIENCE NOTEBOOK Describe some ways that Earth's hydrosphere, atmosphere, biosphere, and geosphere are involved in the weathering and erosion of rock materials. Then look back at the diagram of the rock cycle in Section 6.1. Does the rock cycle involve all of these spheres? Explain.

Weathering and Climate