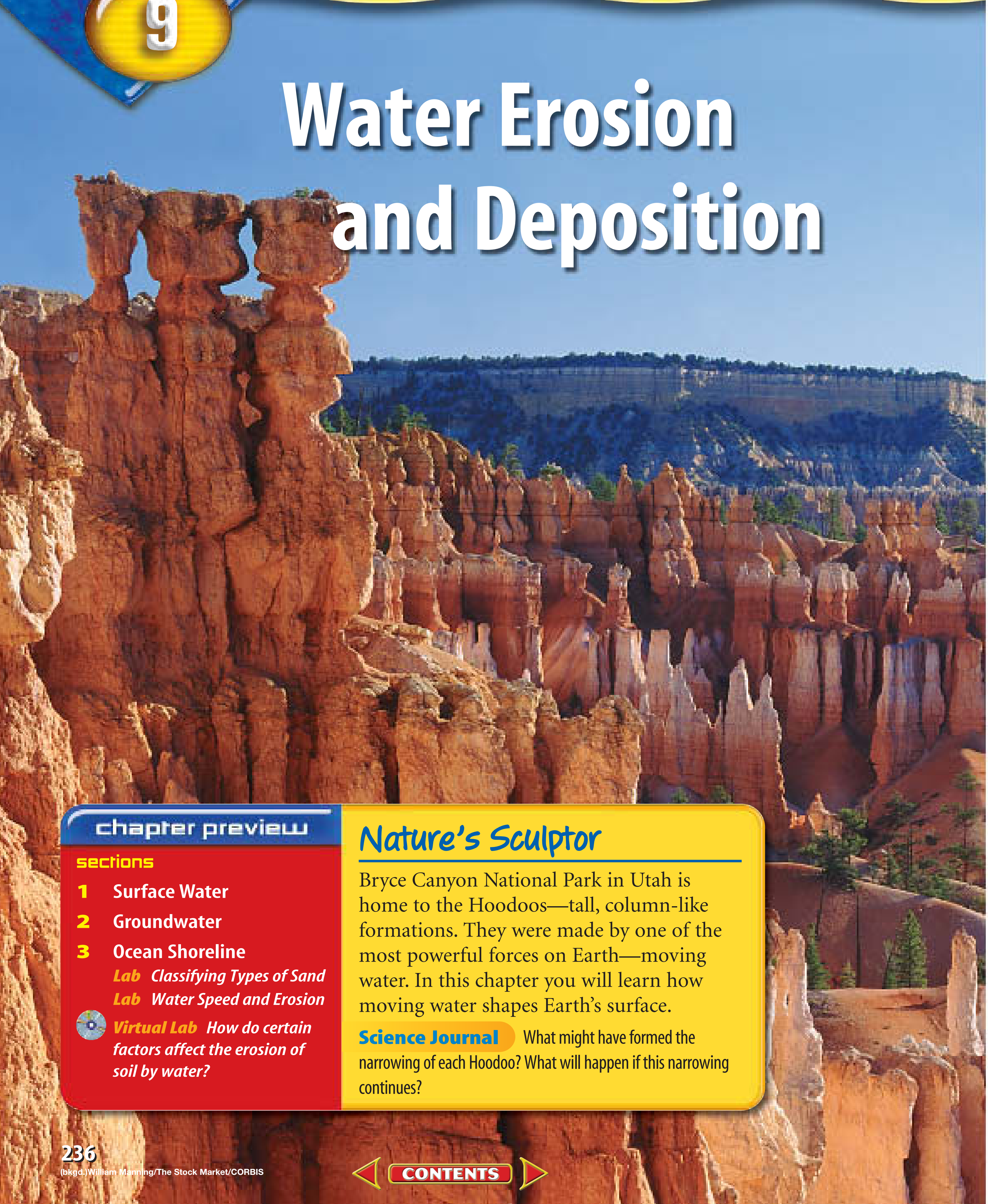
Español

chapter 9

Water Erosion and Deposition



chapter preview

sections

Nature's Sculptor

Bryce Canyon National Park in Utah is home to the Hoodoos—tall, column-like formations. They were made by one of the most powerful forces on Earth—moving water. In this chapter you will learn how moving water shapes Earth's surface.

Science Journal What might have formed the narrowing of each Hoodoo? What will happen if this narrowing continues?

(bkgd.)William Manning/The Stock Market/CORBIS

Start-Up Activities

Launch LAB

Model How Erosion Works

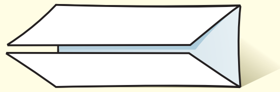
Moving water has great energy. Sometimes rainwater falls softly and soaks slowly into soil. Other times it rushes down a slope with tremendous force and carries away valuable topsoil. What determines whether rain soaks into the ground or runs off and wears away the surface?

1. Place an aluminum pie pan on your desktop.
2. Put a pile of dry soil about 7 cm high into the pan.
3. Slowly drip water from a dropper onto the pile and observe what happens next.
4. Drip the water faster and continue to observe what happens.
5. Repeat steps 1 through 4, but this time change the slope of the hill by increasing the central pile. Start again with dry soil.
6. **Think Critically** In your Science Journal, write about the effect the water had on the different slopes.

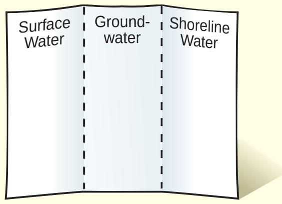
FOLDABLES™ Study Organizer

Characteristics of Surface Water, Groundwater, and Shoreline Water Make the following Foldable to help you identify the main concepts relating to surface water, groundwater, and shoreline water.

STEP 1 **Fold** the top of a vertical piece of paper down and the bottom up to divide the paper into thirds.



STEP 2 **Turn** the paper horizontally; **unfold and label** the three columns as shown.



Read for Main Ideas As you read the chapter, list the concepts relating to surface water, groundwater, shoreline water.

Science Online

Preview this chapter's content and activities at earth.msscience.com

(bkgd.)William Manning/The Stock Market/CORBIS, (inset)Aaron Haupt

section 1

Surface Water

as you read

What You'll Learn

- **Identify** the causes of runoff.
- **Compare** rill, gully, sheet, and stream erosion.
- **Identify** three different stages of stream development.
- **Explain** how alluvial fans and deltas form.

Why It's Important

Runoff and streams shape Earth's surface.

Review Vocabulary
erosion: transport of surface materials by agents such as gravity, wind, water, or glaciers

New Vocabulary
- runoff
- drainage basin
- channel
- meander
- sheet erosion

Runoff

Picture this. You pour a glass of milk, and it overflows, spilling onto the table. You grab a towel to clean up the mess, but the milk is already running through a crack in the table, over the edge, and onto the floor. This is similar to what happens to rainwater when it falls to Earth. Some rainwater soaks into the ground and some evaporates, turning into a gas. The rainwater that doesn't soak into the ground or evaporate runs over the ground. Eventually, it enters streams, lakes, or the ocean. Water that doesn't soak into the ground or evaporate but instead flows across Earth's surface is called **runoff.** If you've ever spilled milk while pouring it, you've experienced something similar to runoff.

Factors Affecting Runoff What determines whether rain soaks into the ground or runs off? The amount of rain and the length of time it falls are two factors that affect runoff. Light rain falling over several hours probably will have time to soak into the ground. Heavy rain falling in less than an hour or so will run off because it cannot soak in fast enough, or it can't soak in because the ground cannot hold any more water.

Figure 1 In areas with gentle slopes and vegetation, little runoff and erosion take place. Lack of vegetation has led to severe soil erosion in some areas.

Tim Davis/Stone/Getty Images

Other Factors Another factor that affects the amount of runoff is the steepness, or slope, of the land. Gravity, the attractive force between all objects, causes water to move down slopes. Water moves rapidly down steep slopes so it has little chance to soak into the ground. Water moves more slowly down gentle slopes and across flat areas. Slower movement allows water more time to soak into the ground.

Vegetation, such as grass and trees, also affects the amount of runoff. Just like milk running off the table, water will run off smooth surfaces that have little or no vegetation. Imagine a tablecloth on the table. What would happen to the milk then? Runoff slows down when it flows around plants. Slower-moving water has a greater chance to sink into the ground. By slowing down runoff, plants and their roots help prevent soil from being carried away. Large amounts of soil may be carried away in areas that lack vegetation, as shown in **Figure 1.**

INTEGRATE Physics

Effects of Gravity When you lie on the ground and feel as if you are being held in place, you are experiencing the effects of gravity. Gravity is the attracting force all objects have for one another. The greater the mass of an object is, the greater its force of gravity is. Because Earth has a much greater mass than any of the objects on it, Earth's gravitational force pulls objects toward its center. Water runs downhill because of Earth's gravitational pull. When water begins to run down a slope, it picks up speed. As its speed increases, so does its energy. Fast-moving water, shown in **Figure 2,** carries more soil than slow-moving water does.

INTEGRATE Career

Conservation Farmers sometimes have to farm on some kind of slope. The steeper the slope, the more erosion will occur. Not only is slope an important factor but other factors have to be considered as well. The Natural Resources Conservation Service, a government agency, studies these factors to determine soil loss from a given area. Find out what other factors this agency uses to determine soil loss.

Figure 2 During floods, the high volume of fast-moving water erodes large amounts of soil.

Figure 3 Heavy rains can remove large amounts of sediment, forming deep gullies in the side of a slope.

Water Erosion

Suppose you and several friends walk the same way to school each day through a field or an empty lot. You always walk in the same footsteps as you did the day before. After a few weeks, you've worn a path through the field. When water travels down the same slope time after time, it also wears a path. The movement of soil and rock from one place to another is called erosion.

Rill and Gully Erosion You may have noticed a groove or small ditch on the side of a slope that was left behind by running water. This is evidence of rill erosion. Rill erosion begins when a small stream forms during a heavy rain. As this stream flows along, it has enough energy to erode and carry away soil. Water moving down the same path creates a groove, called a **channel**, on the slope where the water eroded the soil. If water frequently flows in the same channel, rill erosion may change over time into another type of erosion called gully erosion.

During gully erosion, a rill channel becomes broader and deeper. **Figure 3** shows gullies that were formed when water carried away large amounts of soil.

Sheet Erosion Water often erodes without being in a channel. Rainwater that begins to run off during a rainstorm often flows as thin, broad sheets before forming rills and streams. For example, when it rains over an area, the rainwater accumulates until it eventually begins moving down a slope as a sheet, like the water flowing off the hood of the car in **Figure 4.** Water also can flow as sheets if it breaks out of its channel.

Figure 4 When water accumulates, it can flow in sheets like the water seen flowing over the hood of this car.

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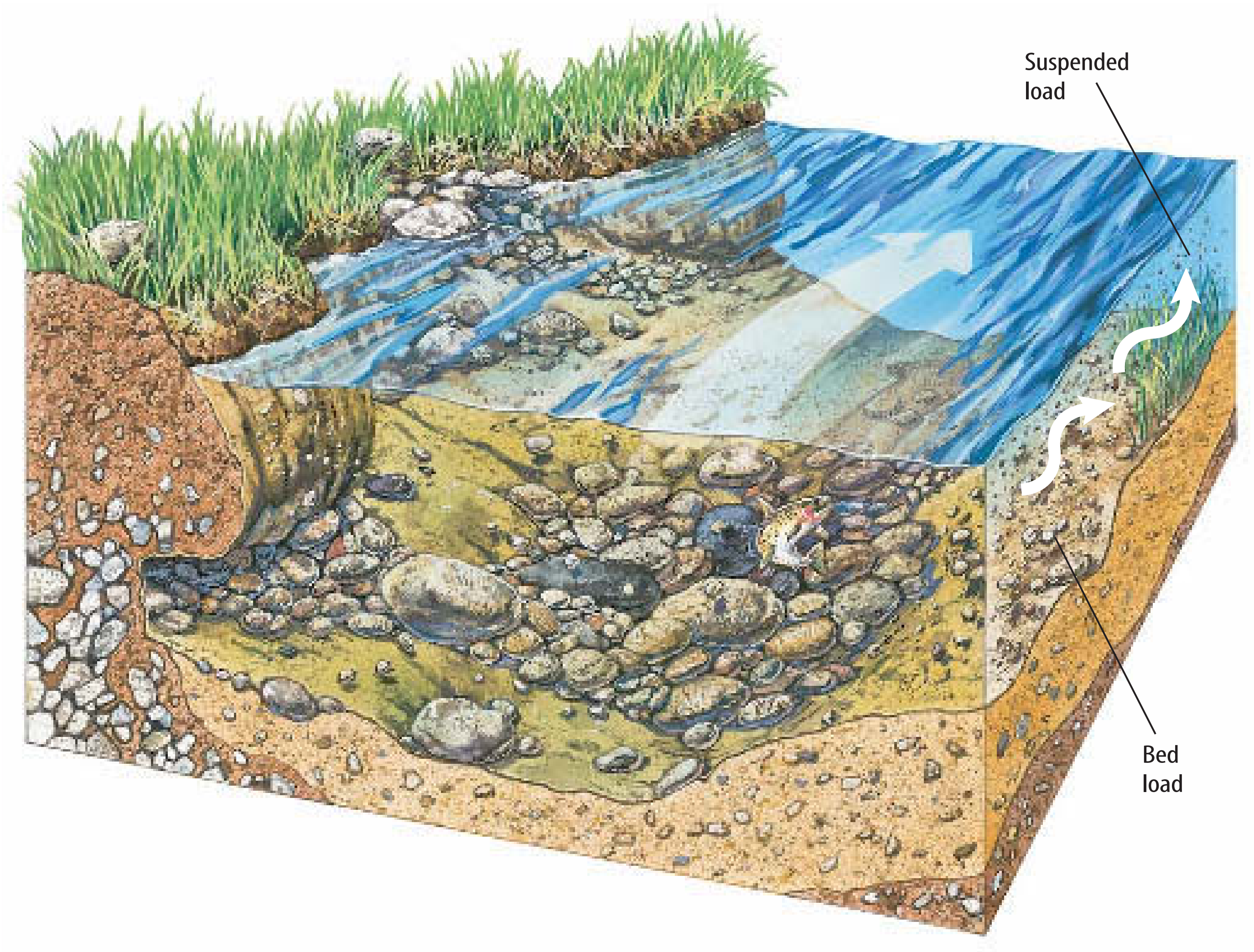
Floodwaters spilling out of a river can flow as sheets over the surrounding flatlands. Streams flowing out of mountains fan out and may flow as sheets away from the foot of the mountain. **Sheet erosion** occurs when water that is flowing as sheets picks up and carries away sediments.

Stream Erosion Sometimes water continues to flow along a low place it has formed. As the water in a stream moves along, it picks up sediments from the bottom and sides of its channel. By this process, a stream channel becomes deeper and wider.

The sediment that a stream carries is called its load. Water picks up and carries some of the lightweight sediments, called the suspended load. Larger, heavy particles called the bed load just roll along the bottom of the stream channel, as shown in **Figure 5.** Water can even dissolve some rocks and carry them away in solution. The different-sized sediments scrape against the bottom and sides of the channel like a piece of sandpaper. Gradually, these sediments can wear away the rock by a process called abrasion.

Figure 5 This cross section of a stream channel shows the location of the suspended load and the bed load.
Describe *how the stream carries dissolved material.*



River System Development

Have you spent time near a river or stream in your community? Each day, probably millions of liters of water flow through that stream. Where does all the water come from? Where is it flowing to?

Science Online

Topic: Drainage Basins
Visit earth.msscience.com for Web links to information about drainage basins in your region.

Activity Locate the drainage basin in which you live. Make a poster showing the shape, or boundary, of the drainage basin. Also, include the main river, or trunk, and the major tributaries, or branches.

River Systems

Streams are parts of river systems. The water comes from rills, gullies, and smaller streams located upstream. Just as the tree in **Figure 6** is a system containing twigs, branches, and a trunk, a river system also has many parts. Runoff enters small streams, which join together to form larger streams. Larger streams come together to form rivers. Rivers grow and carry more water as more streams join.

Drainage Basins

A **drainage basin** is the area of land from which a stream or river collects runoff. Compare a drainage basin to a bathtub. Water that collects in a bathtub flows toward one location—the drain. Likewise, all of the water in a river system eventually flows to one location—the main river, or trunk. The largest drainage basin in the United States is the Mississippi River drainage basin shown in **Figure 6.**

Reading Check *What is a drainage basin?*

Figure 6 River systems can be compared with the structure of a tree.

The system of twigs, branches, and trunk that make up a tree is similar to the system of streams and rivers that make up a river system.

A large number of the streams and rivers in the United States are part of the Mississippi River drainage basin, or watershed.
State *what river represents the trunk of this system.*

Stages of Stream Development

Streams come in a variety of forms. Some are narrow and swift moving, and others are wide and slow moving. Streams differ because they are in different stages of development. These stages depend on the slope of the ground over which the stream flows. Streams are classified as young, mature, or old. **Figure 8** shows how the stages come together to form a river system.

The names of the stages of development aren't always related to the actual age of a river. The New River in West Virginia is one of the oldest rivers in North America. However, it has a steep valley and flows swiftly. As a result, it is classified as a young stream.

Figure 7 A meander is a broad bend in a river or stream. As time passes, erosion of the outer bank increases the bend.

Young Streams A stream that flows swiftly through a steep valley is a young stream. A young stream may have white-water rapids and waterfalls. Water flowing through a steep channel with a rough bottom has a high level of energy and erodes the stream bottom faster than its sides.

Mature Streams The next stage in the development of a stream is the mature stage. A mature stream flows more smoothly through its valley. Over time, most of the rocks in the streambed that cause waterfalls and rapids are eroded by running water and the sediments it carries.

Erosion is no longer concentrated on the bottom in a mature stream. A mature stream starts to erode more along its sides, and curves develop. These curves form because the speed of the water changes throughout the width of the channel.

Water in a shallow area of a stream moves slower because it drags along the bottom. In the deeper part of the channel, the water flows faster. If the deep part of the channel is next to one side of the river, water will erode that side and form a slight curve. Over time, the curve grows to become a broad arc called a **meander** (mee AN dur), as shown in **Figure 7.**

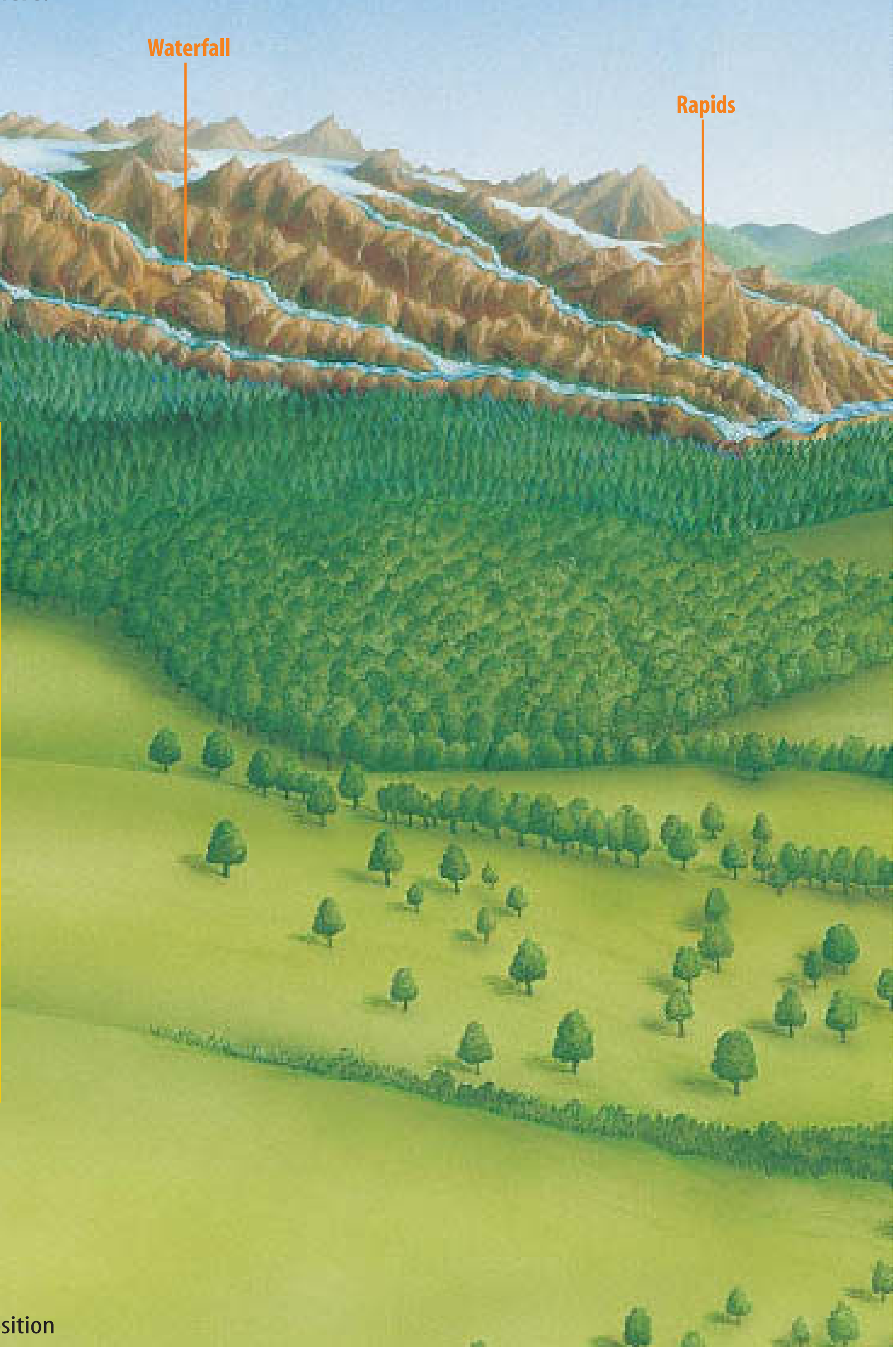
The broad, flat valley floor formed by a meandering stream is called a floodplain. When a stream floods, it often will cover part or all of the floodplain.

NATIONAL GEOGRAPHIC

VISUALIZING STREAM DEVELOPMENT

Figure 8

Although no two streams are exactly alike, all go through three main stages—young, mature, and old—as they flow from higher to lower ground. A young stream, below, surging over steep terrain, moves rapidly. In a less steep landscape, right, a mature stream flows more smoothly. On nearly level ground, the stream—considered old—winds leisurely through its valley. The various stages of a stream's development are illustrated here.



A A young stream begins at a source—here, a melting mountain glacier. From its source, the stream flows swiftly downhill, cutting a narrow valley.

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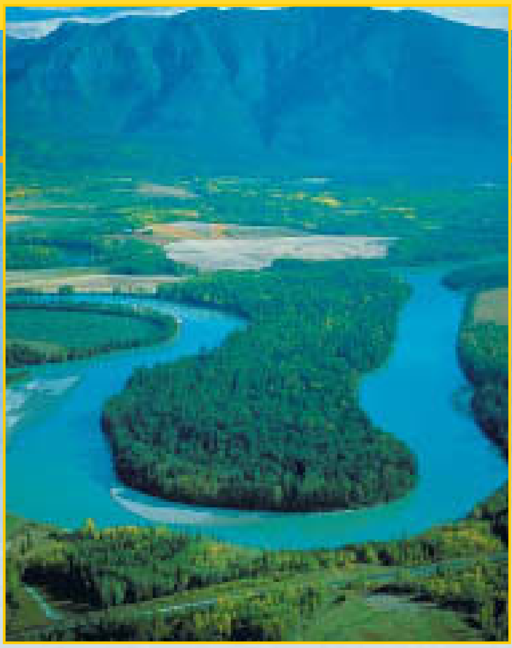

B A mature stream flows smoothly through its valley. Mature streams often develop broad curves called meanders.

C Old streams flow through broad, flat floodplains. Near its mouth, the stream gradually drops its load of silt. This sediment forms a delta, an area of flat, fertile land extending into the ocean.

(l)Harald Sund/The Image Bank/Getty Images, (r)Loren McIntyre

Science Online

Topic: Classification of Rivers

Visit earth.msscience.com for Web links to information about major rivers in the United States. Classify two of these streams as young, mature, or old.

Activity Write a paragraph about why you think the Colorado River is a young, mature, or old stream.

Old Streams The last stage in the development of a stream is the old stage. An old stream flows smoothly through a broad, flat floodplain that it has deposited. South of St. Louis, Missouri, the lower Mississippi River is in the old stage.

Major river systems, such as the Mississippi River, usually contain streams in all stages of development. In the upstream portion of a river system, you find whitewater streams moving swiftly down mountains and hills. At the bottom of mountains and hills, you find streams that start to meander and are in the mature stage of development. These streams meet at the trunk of the drainage basin and form a major river.

Reading Check *How do old streams differ from young streams?*

Too Much Water

Sometimes heavy rains or a sudden melting of snow can cause large amounts of water to enter a river system. What happens when a river system has too much water in it? The water needs to go somewhere, and out and over the banks is the only choice. A river that overflows its banks can bring disaster by flooding homes or washing away bridges or crops.

Dams and levees are built in an attempt to prevent this type of flooding. A dam is built to control the water flow downstream. It may be built of soil, sand, or steel and concrete. Levees are mounds of earth that are built along the sides of a river. Dams and levees are built to prevent rivers from overflowing their banks. Unfortunately, they do not stop the water when flooding is great. This was the case in 1993 when heavy rains caused the Mississippi River to flood parts of nine midwestern states. Flooding resulted in billions of dollars in property damage. **Figure 9** shows some of the damage caused by this flood.

As you have seen, floods can cause great amounts of damage. But at certain times in Earth's past, great floods have completely changed the surface of Earth in a large region. Such floods are called catastrophic floods.

Figure 9 Flooding causes problems for people who live along major rivers. Floodwater broke through a levee during the Mississippi River flooding in 1993.

C. Davidson/Comstock

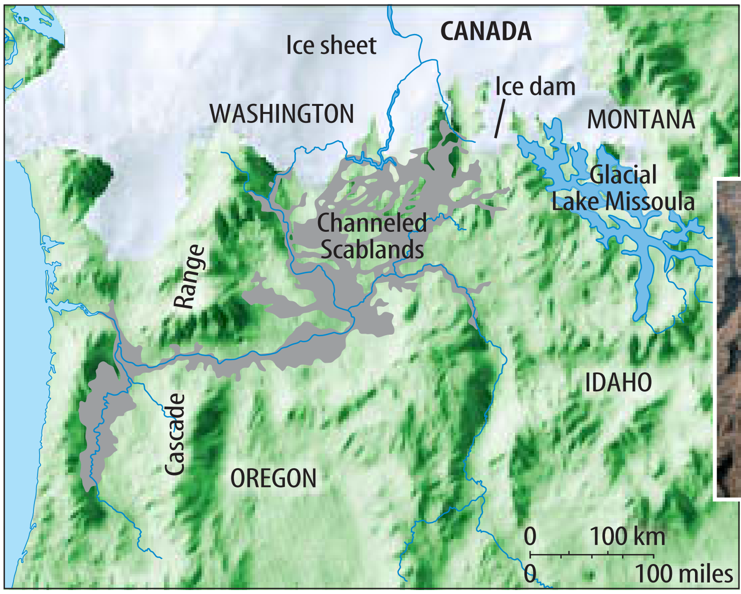

Figure 10 The Channeled Scablands formed when Lake Missoula drained catastrophically.

These channels were formed by the floodwaters.

Catastrophic Floods During Earth's long history, many catastrophic floods have dramatically changed the face of the surrounding area. One catastrophic flood formed the Channeled Scablands in eastern Washington State, shown here in **Figure 10.** A vast lake named Lake Missoula covered much of western Montana. A natural dam of ice formed this lake. As the dam melted or was eroded away, tremendous amounts of water suddenly escaped through what is now the state of Idaho into Washington. In a short period of time, the floodwater removed overlying soil and carved channels into the underlying rock, some as deep as 50 m. Flooding occurred several more times as the lake refilled with water and the dam broke loose again. Scientists say the last such flood occurred about 13,000 years ago.

Deposition by Surface Water

You know how hard it is to carry a heavy object for a long time without putting it down. As water moves throughout a river system, it loses some of its energy of motion. The water can no longer carry some of its sediment. As a result, it drops, or is deposited, to the bottom of the stream.

Some stream sediment is carried only a short distance. In fact, sediment often is deposited within the stream channel itself. Other stream sediment is carried great distances before being deposited. Sediment picked up when rill and gully erosion occur is an example of this. Water usually has a lot of energy as it moves down a steep slope. When water begins flowing on a level surface, it slows, loses energy, and deposits its sediment. Water also loses energy and deposits sediment when it empties into an ocean or lake.

Mini LAB

Observing Runoff Collection

Procedure

1. Put a plastic **rain gauge** into a narrow **drinking glass** and place the glass in the **sink.**
2. Fill a plastic **sprinkling can** with **water.**
3. Hold the sprinkling can one-half meter above the sink for 30 s.
4. Record the amount of water in the rain gauge.
5. After emptying the rain gauge, place a **plastic funnel** into the rain gauge and sprinkle again for 30 s.
6. Record the amount of water in the gauge.

Analysis

Explain how a small amount of rain falling on a drainage basin can have a big effect on a river or stream.

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Figure 11 This satellite image of the Nile River Delta in Egypt shows the typical triangular shape. The green color shows areas of vegetation.

Agriculture is important on the Nile Delta.

Deltas and Fans Sediment that is deposited as water empties into an ocean or lake forms a triangular, or fan-shaped, deposit called a delta, shown in **Figure 11.** When the river waters empty from a mountain valley onto an open plain, the deposit is called an alluvial (uh LEW vee ul) fan. The Mississippi River exemplifies the topics presented in this section. Runoff causes rill and gully erosion. Sediment is picked up and carried into the larger streams that flow into the Mississippi River. As the Mississippi River flows, it cuts into its banks and picks up more sediment. Where the land is flat, the river deposits some of its sediment in its own channel. As the Mississippi enters the Gulf of Mexico, it slows, dropping much of its sediment and forming the Mississippi River delta.

section 1 review

Summary

Runoff

- Rainwater that doesn't soak into the ground or evaporate becomes runoff.
- Slope of land and vegetation affect runoff.

Water Erosion

- Water flowing over the same slope causes rills and gullies to form.

River System Development

- A drainage basin is an area of land from which a stream or river collects runoff.

Self Check

1. **Explain** how the slope of an area affects runoff.
2. **Compare and contrast** rill and gully erosion.
3. **Describe** the three stages of stream development.
4. **Think Critically** How is a stream's rate of flow related to the amount of erosion it causes? How is it related to the size of the sediments it deposits?

Applying Skills

5. **Compare and contrast** the formation of deltas and alluvial fans.

Science Online earth.msscience.com/self_check_quiz

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section 2

Groundwater

Groundwater Systems

What would have happened if the spilled milk in Section 1 ran off the table onto a carpeted floor? It probably would have quickly soaked into the carpet. Water that falls on Earth can soak into the ground just like the milk into the carpet.

Water that soaks into the ground becomes part of a system, just as water that stays above ground becomes part of a river system. Soil is made up of many small rock and mineral fragments. These fragments are all touching one another, as shown in **Figure 12,** but some empty space remains between them. Holes, cracks, and crevices exist in the rock underlying the soil. Water that soaks into the ground collects in these pores and empty spaces and becomes part of what is called **groundwater.**

How much of Earth's water do you think is held in the small openings in rock? Scientists estimate that 14 percent of all freshwater on Earth exists as groundwater. This is almost 30 times more water than is contained in all of Earth's lakes and rivers.

as you read

What You'll Learn

- **Recognize** the importance of groundwater.
- **Describe** the effect that soil and rock permeability have on groundwater movement.
- **Explain** how groundwater dissolves and deposits minerals.

Why It's Important

The groundwater system is an important source of your drinking water.

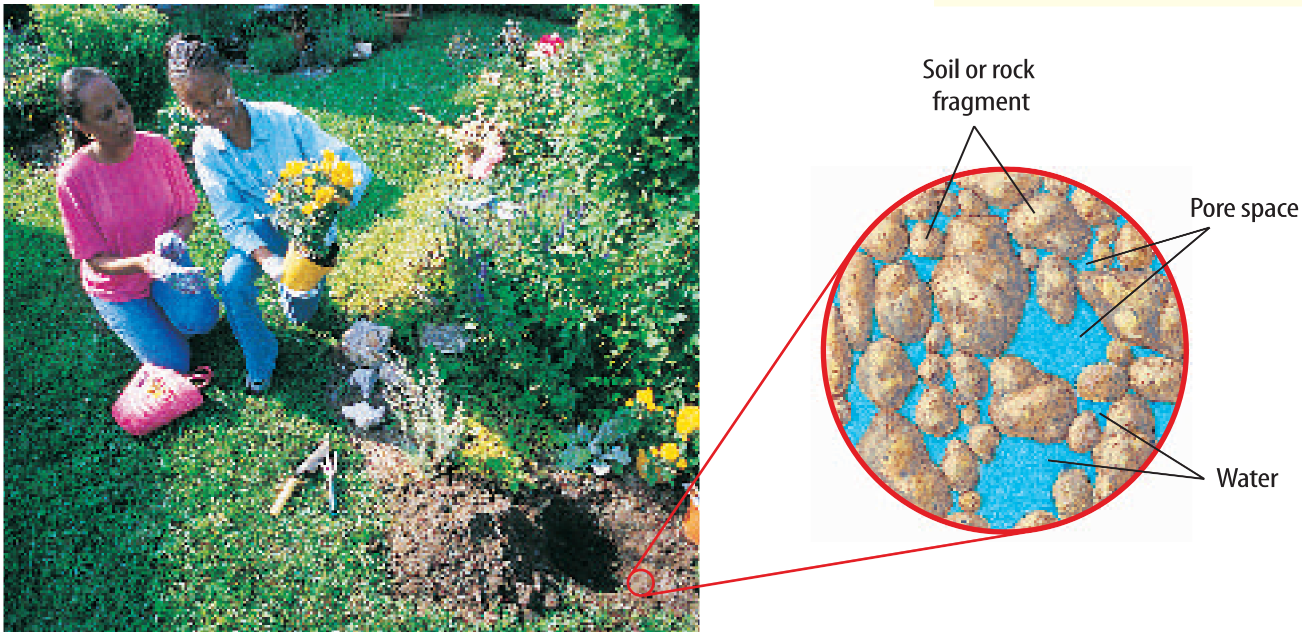
Review Vocabulary

pore: a small, or minute, opening in rock or soil

New Vocabulary

- groundwater
- permeable
- impermeable
- aquifer
- water table
- spring
- geyser
- cave

Figure 12 Soil has many small, connected pores that are filled with water when soil is wet.



Mini LAB

Measuring Pore Space

Procedure

1. Use two identical, **clear-plastic containers.**
2. Put 3 cm of **sand** in one container and 3 cm of **gravel** in the other.
3. Pour **water** slowly into the containers and stop when the water just covers the top of the sediment.
4. Record the volume of water used in each.

Analysis

Which substance has more pore space—sand or gravel?

Try at Home

Permeability A groundwater system is similar to a river system. However, instead of having channels that connect different parts of the drainage basin, the groundwater system has connecting pores. Soil and rock are **permeable** (PUR mee uh bul) if the pore spaces are connected and water can pass through them. Sandstone is an example of a permeable rock.

Soil or rock that has many large, connected pores is permeable. Water can pass through it easily. However, if a rock or sediment has few pore spaces or they are not well connected, then the flow of groundwater is blocked. These materials are **impermeable,** which means that water cannot pass through them. Granite has few or no pore spaces at all. Clay has many small pore spaces, but the spaces are not well connected.

Reading Check *How does water move through permeable rock?*

Groundwater Movement How deep into Earth's crust does groundwater go? **Figure 13** shows a model of a groundwater system. Groundwater keeps going deeper until it reaches a layer of impermeable rock. When this happens, the water stops moving down. As a result, water begins filling up the pores in the rocks above. A layer of permeable rock that lets water move freely is an **aquifer** (AK wuh fur). The area where all of the pores in the rock are filled with water is the zone of saturation. The upper surface of this zone is the **water table.**

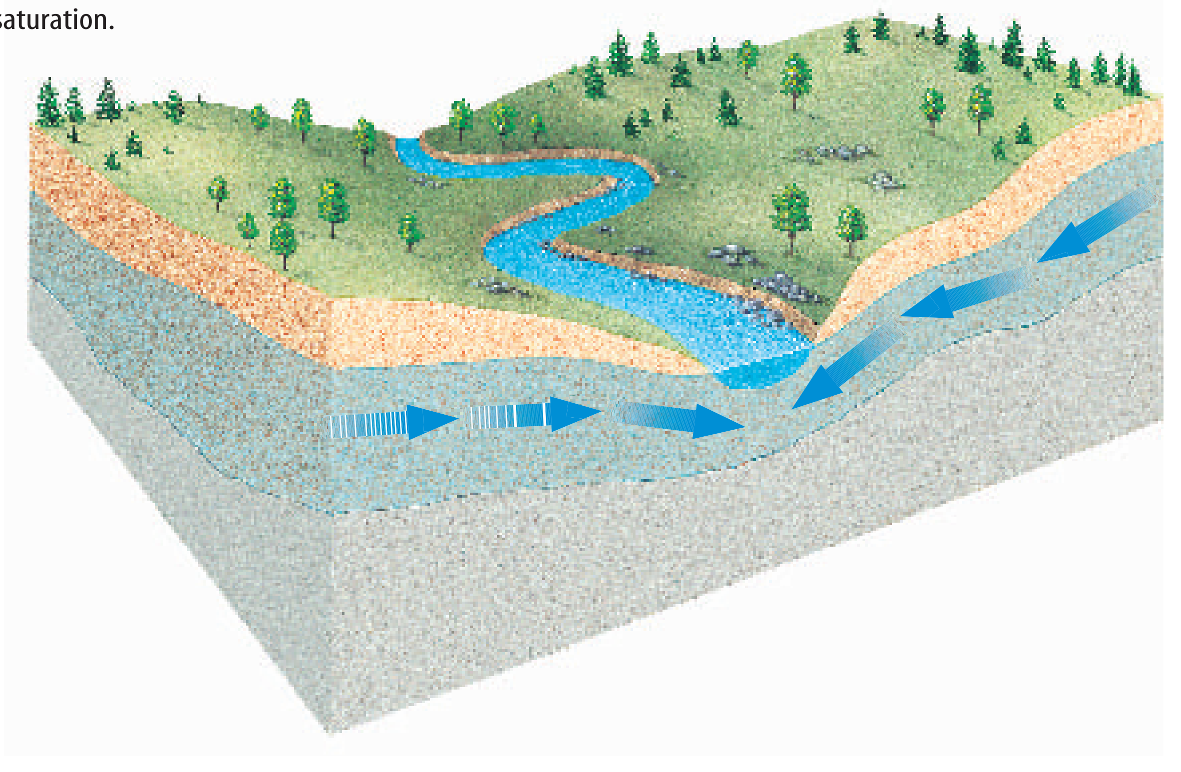


Figure 13 A stream's surface level is the water table. Below that is the zone of saturation.

Water Table

Why are the zone of saturation and the water table so important? An average United States resident uses about 626 L of water per day. That's enough to fill nearly two thousand soft drink cans. Many people get their water from groundwater through wells that have been drilled into the zone of saturation. However, the supply of groundwater is limited. During a drought, the water table drops. This is why you should conserve water.

Applying Math — Calculate Rate of Flow

GROUNDWATER FLOW You and your family are hiking and the temperature is hot. You feel as if you can't walk one step farther. Luckily, relief is in sight. On the side of a nearby hill you see a stream, and you rush to splash some water on your face. Although you probably feel that it's taking you forever to reach the stream, your pace is quick when compared to how long it takes groundwater to flow through the aquifer that feeds the stream. The following problem will give you some idea of just how slowly groundwater flows through an aquifer.

The groundwater flows at a rate of 0.6 m/day. You've run 200 m to get some water from a stream. How long does it take the groundwater in the aquifer to travel the same distance?

Solution

1 *This is what you know:*
- the distance that the groundwater has to travel: $d = 200$ m
- the rate that groundwater flows through the aquifer: $r = 0.6$ m/day

2 *This is what you want to find:* time $= t$

3 *This is the equation you use:* $r \times t = d$ (rate × time = distance)

4 *Solve the equation for* t *and then substitute known values:*

$$t = \frac{d}{r} = \frac{(200\text{ m})}{(0.6\text{ m/day})} = 333.33\text{ days}$$

Practice Problems

1. The groundwater in an aquifer flows at a rate of 0.5 m/day. How far does the groundwater move in a year?
2. How long does it take groundwater in the above aquifer to move 100 m?

Science Online — For more practice, visit earth.msscience.com/math_practice

CORBIS

Figure 14 The years on the pole show how much the ground level dropped in the San Joaquin Valley, California, between 1925 and 1977.

Wells A good well extends deep into the zone of saturation, past the top of the water table. Groundwater flows into the well, and a pump brings it to the surface. Because the water table sometimes drops during very dry seasons, even a good well can go dry. Then time is needed for the water table to rise, either from rainfall or through groundwater flowing from other areas of the aquifer.

Where groundwater is the main source of drinking water, the number of wells and how much water is pumped out are important. If a large factory were built in such a town, the demand on the groundwater supply would be even greater. Even in times of normal rainfall, the wells could go dry if water were taken out at a rate greater than the rate at which it can be replaced.

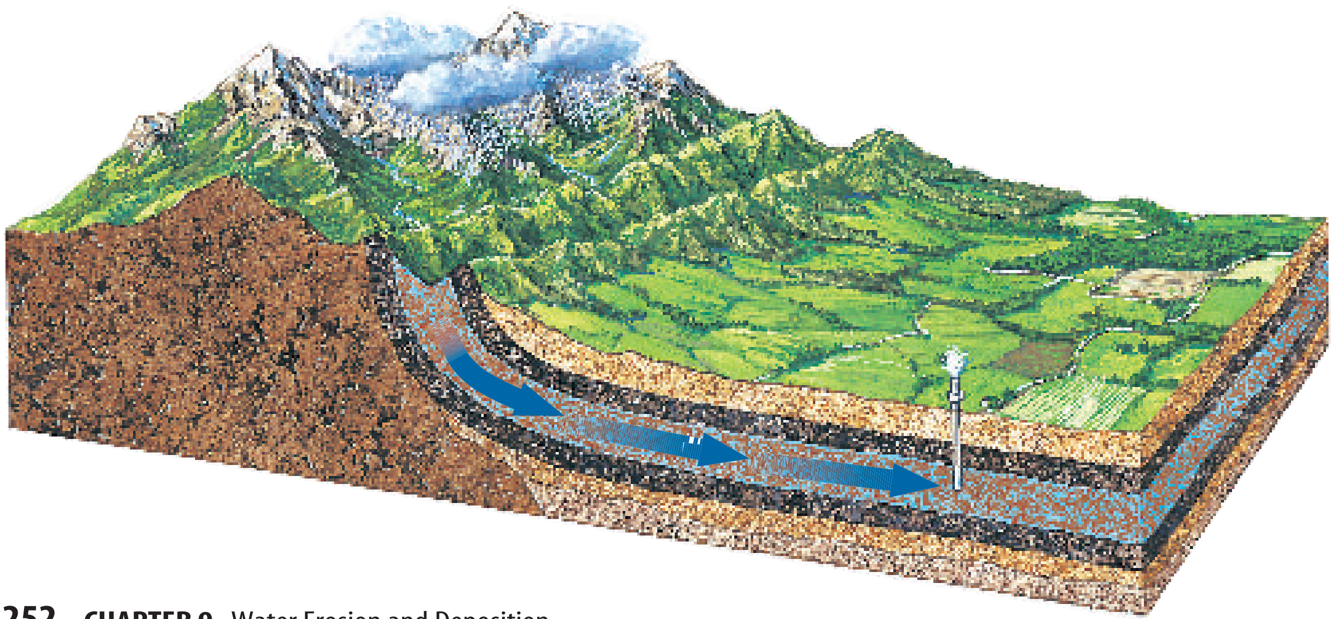
In areas where too much water is pumped out, the land level can sink from the weight of the sediments above the now-empty pore spaces. **Figure 14** shows what occurred when too much groundwater was removed in a region of California.

One type of well doesn't need a pump to bring water to the surface. An artesian well is a well in which water rises to the surface under pressure. Artesian wells are less common than other types of wells because of the special conditions they require.

As shown in **Figure 15,** the aquifer for an artesian well needs to be located between two impermeable layers that are sloping. Water enters at the high part of the sloping aquifer. The weight of the water in the higher part of the aquifer puts pressure on the water in the lower part. If a well is drilled into the lower part of the aquifer, the pressurized water will flow to the surface. Sometimes, the pressure is great enough to force the water into the air, forming a fountain.

Reading Check *How does water move through permeable rock?*

Figure 15 The pressure of water in a sloping aquifer keeps an artesian well flowing.
Describe *what limits how high water can flow in an artesian well.*



file photo

Springs In some places, the water table is so close to Earth's surface that water flows out and forms a **spring.** Springs are found on hillsides or other places where the water table meets a sloping surface. Springs often are used as a source of freshwater.

The water from most springs is a constant, cool temperature because soil and rock are good insulators and protect the groundwater from changes in temperature on Earth's surface. However, in some places, magma rises to within a few kilometers of Earth's surface and heats the surrounding rock. Groundwater that comes in contact with these hot rocks is heated and can come to the surface as a hot spring.

INTEGRATE Chemistry

Acid Rain Effects Acid rain occurs when gases released by burning oil and coal mix with water in the air. Infer what effect acid rain can have on a statue made of limestone.

Geysers When water is put into a teakettle to boil, it heats slowly at first. Then some steam starts to come out of the cap on the spout, and suddenly the water starts boiling. The teakettle starts whistling as steam is forced through the cap. A similar process can occur with groundwater. One of the places where groundwater is heated is in Yellowstone National Park in Wyoming. Yellowstone has hot springs and geysers. A **geyser** is a hot spring that erupts periodically, shooting water and steam into the air. Groundwater is heated to high temperatures, causing it to expand underground. This expansion forces some of the water out of the ground, taking the pressure off the remaining water. The remaining water boils quickly, with much of it turning to steam. The steam shoots out of the opening like steam out of a teakettle, forcing the remaining water out with it. Yellowstone's famous geyser, Old Faithful, pictured in **Figure 16,** shoots between 14,000 and 32,000 L of water and steam into the air about once every 80 min.

Figure 16 Yellowstone's famous geyser, Old Faithful, used to erupt once about every 76 min. An earthquake on January 9, 1998, slowed Old Faithful's "clock" by 4 min to an average of one eruption about every 80 min. The average height of the geyser's water is 40.5 m.

The Work of Groundwater

Although water is the most powerful agent of erosion on Earth's surface, it also can have a great effect underground. Water mixes with carbon dioxide gas to form a weak acid called carbonic acid. Some of this carbon dioxide is absorbed from the air by rainwater or surface water. Most carbon dioxide is absorbed by groundwater moving through soil. One type of rock that is dissolved easily by this acid is limestone. Acidic groundwater moves through natural cracks and pores in limestone, dissolving the rock. Gradually, the cracks in the limestone enlarge until an underground opening called a **cave** is formed.

Barbara Filet

Figure 17 Water dissolves rock to form caves and also deposits material to form spectacular formations, such as these in Carlsbad Caverns in New Mexico.

Cave Formation You've probably seen a picture of the inside of a cave, like the one shown in **Figure 17,** or perhaps you've visited one. Groundwater not only dissolves limestone to make caves, but it also can make deposits on the insides of caves.

Water often drips slowly from cracks in the cave walls and ceilings. This water contains calcium ions dissolved from the limestone. If the water evaporates while hanging from the ceiling of a cave, a deposit of calcium carbonate is left behind. Stalactites form when this happens over and over. Where drops of water fall to the floor of the cave, a stalagmite forms. The words *stalactite* and *stalagmite* come from Greek words that mean "to drip."

Sinkholes If underground rock is dissolved near the surface, a sinkhole may form. A sinkhole is a depression on the surface of the ground that forms when the roof of a cave collapses or when material near the surface dissolves. Sinkholes are common features in places like Florida and Kentucky that have lots of limestone and enough rainfall to keep the groundwater system supplied with water. Sinkholes can cause property damage if they form in a populated area.

In summary, when rain falls and becomes groundwater, it might dissolve limestone and form a cave, erupt from a geyser, or be pumped from a well to be used at your home.

section 2 review

Summary

Groundwater Systems

- Water that soaks into the ground and collects in pore spaces is called groundwater.
- 14 percent of all freshwater on Earth exists as groundwater.
- Groundwater systems have connecting pores.
- The zone of saturation is the area where all pores in the rock are filled with water.

Water Table

- The supply of groundwater is limited.

Self Check

1. **Describe** how the permeability of soil and rocks affects the flow of groundwater.
2. **Describe** why a well might go dry.
3. **Explain** how caves form.
4. **Think Critically** Why would water in wells, geysers, and hot springs contain dissolved materials?

Applying Skills

5. **Compare and contrast** wells, geysers, and hot springs.

Chad Ehlers/Stone/Getty Images
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section 3

Ocean Shoreline

The Shore

Picture yourself sitting on a beautiful, sandy beach like the one shown in **Figure 18.** Nearby, palm trees sway in the breeze. Children play in the quiet waves lapping at the water's edge. It's hard to imagine a place more peaceful. Now, picture yourself sitting along another shore. You're on a high cliff watching waves crash onto boulders far below. Both of these places are shorelines. An ocean shoreline is where land meets the ocean.

The two shorelines just described are different even though both experience surface waves, tides, and currents. These actions cause shorelines to change constantly. Sometimes you can see these changes from hour to hour. Why are shorelines so different? You'll understand why they look different when you learn about the forces that shape shorelines.

as you read

What You'll Learn

- **Identify** the different causes of shoreline erosion.
- **Compare and contrast** different types of shorelines.
- **Describe** some origins of sand.

Why It's Important

Constantly changing shorelines impact the people who live and work by them.

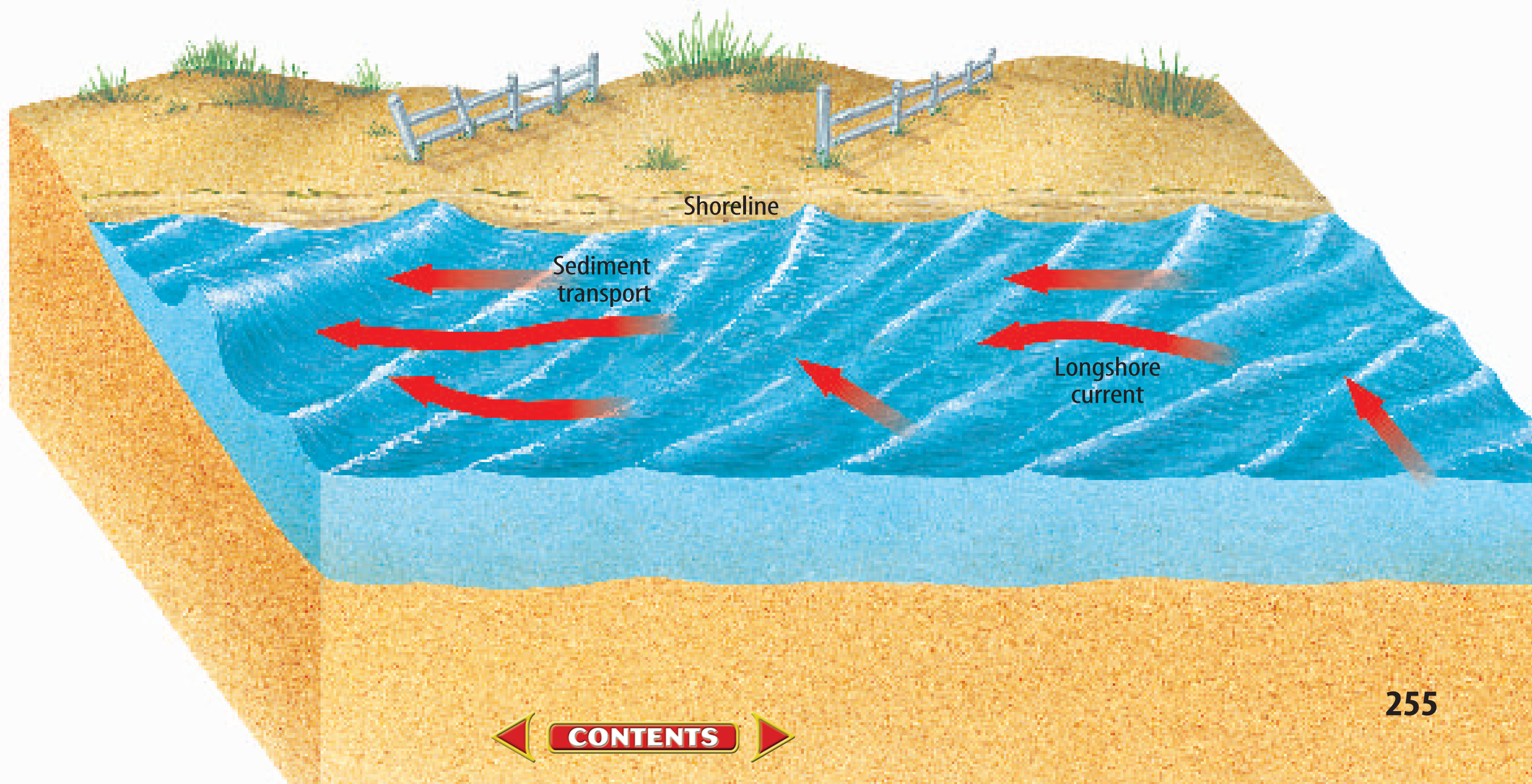
Review Vocabulary

tides: the alternating rise and fall of sea level caused by the gravitational attraction of the Moon and the Sun

New Vocabulary

- longshore current
- beach

Figure 18 Waves, tides, and currents cause shorelines to change constantly. Waves approaching the shoreline at an angle create a longshore current.
Describe *the effects longshore currents have on a shoreline.*



Shoreline Forces When waves constantly pound against the shore, they break rocks into ever-smaller pieces. Currents move many metric tons of sediment along the shoreline. The sediment grains grind against each other like sandpaper. The tide goes out carrying sediment to deeper water. When the tide returns, it brings new sediment with it. These forces are always at work, slowly changing the shape of the shoreline. Water is always in motion along the shore.

The three major forces at work on the shoreline are waves, currents, and tides. Winds blowing across the water make waves. Waves, crashing against a shoreline, are a powerful force. They can erode and move large amounts of material in a short time. Waves usually collide with a shore at slight angles. This creates a **longshore current** of water that runs parallel to the shoreline. Longshore currents, shown in **Figure 18,** carry many metric tons of loose sediments and act like rivers of sand in the ocean.

Reading Check *How does a longshore current form?*

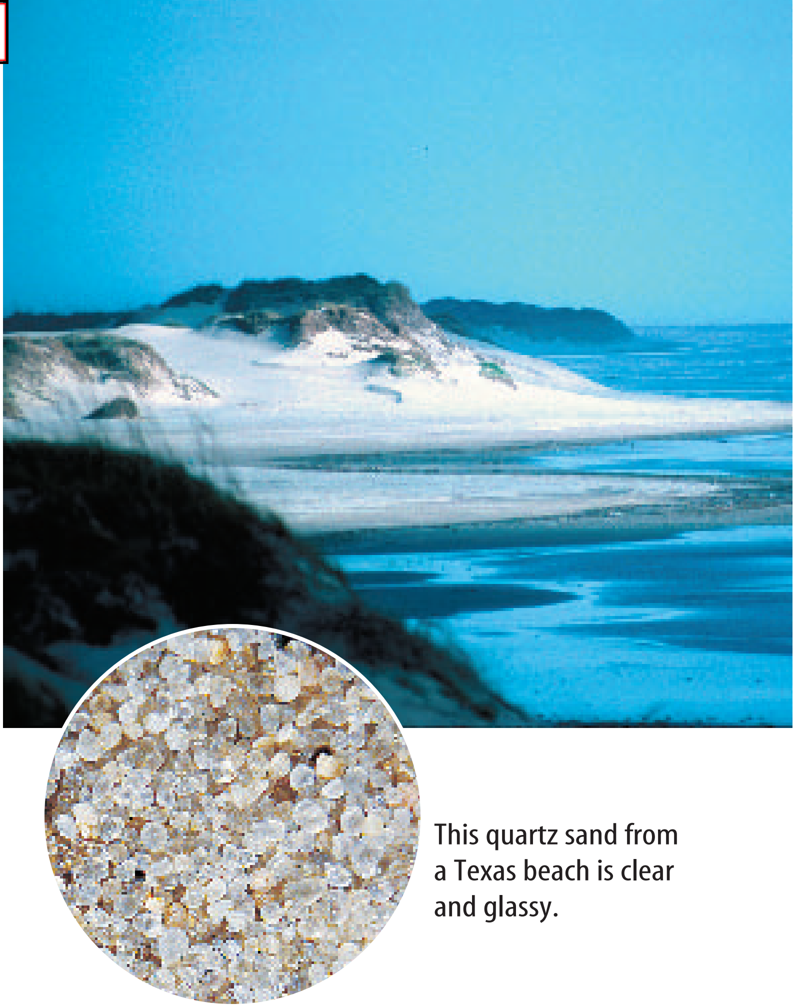
Tides create currents that move at right angles to the shore. These are called tidal currents. Outgoing tides carry sediments away from the shore, and incoming tides bring new sediments toward the shore. Tides work with waves to shape shorelines. You've seen the forces that affect all shorelines. Now you will see the differences that make one shore a flat, sandy beach and another shore a steep, rocky cliff.

Figure 19 Along a rocky shoreline, the force of pounding waves breaks rock fragments loose, then grinds them into smaller and smaller pieces.

Rocky Shorelines

Rocks and cliffs are the most common features along rocky shorelines like the one in **Figure 19.** Waves crash against the rocks and cliffs. Sediments in the water grind against the cliffs, slowly wearing the rock away. Then rock fragments broken from the cliffs are ground up by the endless motion of waves. They are transported as sediment by longshore currents.

Softer rocks become eroded before harder rocks do, leaving islands of harder rocks. This takes thousands of years, but remember that the ocean never stops. In a single day, about 14,000 waves crash onto shore.



This quartz sand from a Texas beach is clear and glassy.

Some Hawaiian beaches are composed of black basalt sand.

Figure 20 Beach sand varies in size, color, and composition.

Sandy Beaches

Smooth, gently sloping shorelines are different from steep, rocky shorelines. Beaches are the main feature here. **Beaches** are deposits of sediment that are parallel to the shore.

Beaches are made up of different materials. Some are made of rock fragments from the shoreline. Many beaches are made of grains of quartz, and others are made of seashell fragments. These fragments range in size from stones larger than your hand to fine sand. Sand grains range from 0.06 mm to 2 mm in diameter. Why do many beaches have particles of this size? Waves break rocks and seashells down to sand-sized particles like those shown in **Figure 20.** The constant wave motion bumps sand grains together. This bumping not only breaks particles into smaller pieces but also smooths off their jagged corners, making them more rounded.

Reading Check *How do waves affect beach particles?*

Sand in some places is made of other things. For example, Hawaii's black sands are made of basalt, and its green sands are made of the mineral olivine. Jamaica's white sands are made of coral and shell fragments.

(tl)Steve Bentsen, (tr)SuperStock, (bl)Runk/Schoenberger from Grant Heilman, (br)Breck P. Kent/Earth Scenes

Figure 21 Shorelines change constantly. Human development is often at risk from shoreline erosion.

Sand Erosion and Deposition

Longshore currents carry sand along beaches to form features such as barrier islands, spits, and sandbars. Storms and wind also move sand. Thus, beaches are fragile, short-term land features that are damaged easily by storms and human activities such as some types of construction. Communities in widely separated places such as Long Island, New York; Malibu, California; and Padre Island, Texas, have problems because of beach erosion.

Barrier Islands Barrier islands are sand deposits that lay parallel to the shore but are separated from the mainland. These islands start as underwater sand ridges formed by breaking waves. Hurricanes and storms add sediment to them, raising some to sea level. When a barrier island becomes large enough, the wind blows the loose sand into dunes, keeping the new island above sea level. As with all seashore features, barrier islands are short term, lasting from a few years to a few centuries.

The forces that build barrier islands also can erode them. Storms and waves carry sediments away. Beachfront development, as in **Figure 21,** can be affected by shoreline erosion.

section 3 review

Summary

The Shore

- An ocean shoreline is where land meets the ocean.
- The forces that shape shorelines are waves, currents, and tides.

Rocky Shorelines

- Rocks and cliffs are the most common features along rocky shorelines.

Sandy Beaches

- Beaches are made up of different materials. Some are made of rock fragments and others are made of seashell fragments.

Sand Erosion and Deposition

- Longshore currents, storms, and wind move sand.
- Beaches are fragile, short-term land features.

Self Check

1. **Identify** major forces that cause shoreline erosion.
2. **Compare and contrast** the features you would find along a steep, rocky shoreline with the features you would find along a gently sloping, sandy shoreline.
3. **Explain** how the type of shoreline could affect the types of sediments you might find there.
4. **List** several materials that beach sand might be composed of. Where do these materials come from?
5. **Think Critically** How would erosion and deposition of sediment along a shoreline be affected if the longshore current was blocked by a wall built out into the water?

Applying Math

6. **Solve One-Step Equations** If 14,000 waves crash onto a shore daily, how many waves crash onto it in a year? How many crashed onto it since you were born?

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LAB

Classifying Types of Sand

Sand is made of different kinds of grains, but did you realize that the slope of a beach is related to the size of its grains? The coarser the grain size is, the steeper the beach is. The composition of sand also is important. Many sands are mined because they have economic value.

Real-World Question

What characteristics can be used to classify different types of beach sand?

Goals

- **Observe** differences in sand.
- **Identify** characteristics of beach sand.
- **Infer** sediment sources.

Materials

samples of different sands (3)
magnifying lens
**stereomicroscope*
magnet

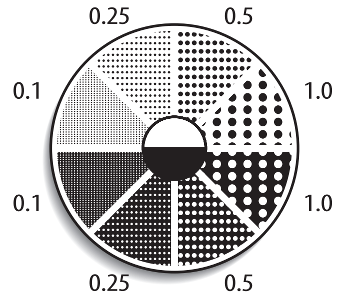
**Alternate materials*

Safety Precautions

Procedure

1. **Design** a five-column data table to compare the three sand samples. Use column one for the samples and the others for the characteristics you will be examining.

Angular | Sub-angular | Sub-rounded | Rounded



Sand gauge
(measurements in mm)

2. **Use the diagram** in the previous column to determine the average roundness of each sample.
3. **Identify** the grain size of your samples by using the sand gauge above. To determine the grain size, place sand grains in the middle of the circle of the sand gauge. Use the upper half of the circle for dark-colored particles and the bottom half for light-colored particles.
4. **Decide** on two other characteristics to examine that will help you classify your samples.

Conclude and Apply

1. **Compare and contrast** some characteristics of beach sand.
2. **Describe** why there are variations in the characteristics of different sand samples.
3. **Explain** what your observations tell you about the sources of the three samples.

Communicating Your Data

Compare your results with those of other students.

LAB

Water Speed and Erosion

Goals

- **Assemble** an apparatus for measuring the effect of water speed on erosion.
- **Observe and measure** the ability of water traveling at different speeds to erode sand.

Materials

paint roller pan
**disposable wallpaper trays*
sand
1-L beaker
rubber tubing (20 cm)
metric ruler
water
stopwatch
fine-mesh screen
wood block
**Alternate materials*

Safety Precautions

Wash your hands after you handle the sand. Immediately clean up any water that spills on the floor.

Real-World Question

What would it be like to make a raft and use it to float on a river? Would it be easy? Would you feel like Tom Sawyer? Probably not. You'd be at the mercy of the current. Strong currents create fast rivers. But does fast moving water affect more than just floating rafts and other objects? How does the speed of a stream or river affect its ability to erode?

Procedure

1. Copy the data table on the following page.
2. Place the screen in the sink. Pour moist sand into your pan and smooth out the sand. Set one end of the pan on the wood block and hang the other end over the screen in the sink. Excess water will flow onto the screen in the sink.
3. Attach one end of the hose to the faucet and place the other end in the beaker. Turn on the water so that it trickles into the beaker. Time how long it takes for the trickle of water to fill the beaker to the 1-L mark. Divide 1 L by your time in seconds to calculate the water speed. Record the speed in your data table.
4. Without altering the water speed, hold the hose over the end of the pan that is resting on the wood block. Allow the water to flow into the sand for 2 min. At the end of 2 min, turn off the water.
5. **Measure** the depth and length of the eroded channel formed by the water. Count the number of branches formed on the channel. Record your measurements and observations in your data table.

KS Studios

Water Speed and Erosion

Water Speed (Liters per Second)	Depth of Channel	Length of Channel	Number of Channel Branches
	Do not write in this book.		

6. Empty the excess water from the tray and smooth out the sand. Repeat steps 3 through 5 two more times, increasing your water speed each time.

Conclude and Apply

1. **Identify** the constants and variables in your experiment.
2. **Observe** Which water speed created the deepest and longest channel?
3. **Observe** Which water speed created the greatest number of branches?
4. **Infer** the effect that water speed has on erosion.
5. **Predict** how your results would have differed if one end of the pan had been raised higher.
6. **Infer** how streams and rivers can shape Earth's surface.

Communicating Your Data

Write a pamphlet for people buying homes near rivers or streams that outlines the different effects that water erosion could have on their property.

KS Studios

Is there hope for America's coastlines or is beach erosion a "shore" thing?

Sands in Time

Water levels are rising along the coastline of the United States. Serious storms and the building of homes and businesses along the shore are leading to the erosion of anywhere from 70 percent to 90 percent of the U.S. coastline. A report from the Federal Emergency Management Agency (FEMA) confirms this. The report says that one meter of United States beaches will be eaten away each year for the next 60 years. Since 1965, the federal government has spent millions of dollars replenishing more than 1,300 eroding sandy shores around the country. And still beaches continue to disappear.

The slowly eroding beaches are upsetting to residents and officials of many communities, who depend on their shore to earn money from visitors. Some city and state governments are turning to beach nourishment—a process in which sand is taken from the seafloor and dumped on beaches. The process is expensive, however. The state of Delaware, for example, is spending 7,000,000 dollars to bring in sand for its beaches.


This beach house will collapse as its underpinnings are eroded.

Other methods of saving eroding beaches are being tried. In places along the Great Lakes shores and coastal shores, one company has installed fabrics underwater to slow currents. By slowing currents, sand is naturally deposited and kept in place.

Another shore-saving device is a synthetic barrier that is shaped like a plastic snowflake. A string of these barriers is secured just offshore. They absorb the energy of incoming waves. Reducing wave energy can prevent sand from being eroded from the beach. New sand also might accumulate because the barriers slow down the currents that flow along the shore.

Many people believe that communities along the shore must restrict the beachfront building of homes, hotels, and stores. Since some estimates claim that by the year 2025, nearly 75 percent of the U.S. population will live in coastal areas, it's a tough solution. Says one geologist, "We can retreat now and save our beaches or we can retreat later and probably ruin the beaches in the process."

Debate Using the facts in this article and other research you have done in your school media center or through Web links at msscience.com, make a list of methods that could be used to save beaches. Debate the issue with your classmates.

Science Online
For more information, visit earth.msscience.com/time

Gary Bogdon/CORBIS Sygma

Reviewing Main Ideas

Section 1 Surface Water

1. Rainwater that does not soak into the ground is pulled down the slope by gravity. This water is called runoff.
2. Runoff can erode sediment. Factors such as steepness of slope and number and type of plants affect the amount of erosion. Rill, gully, and sheet erosion are types of surface water erosion caused by runoff.
3. Runoff generally flows into streams that merge with larger rivers until emptying into a lake or ocean. Major river systems usually contain several different types of streams.
4. Young streams flow through steep valleys and have rapids and waterfalls. Mature streams flow through gentler terrain and have less energy. Old streams are often wide and meander across their floodplains.

Section 2 Groundwater

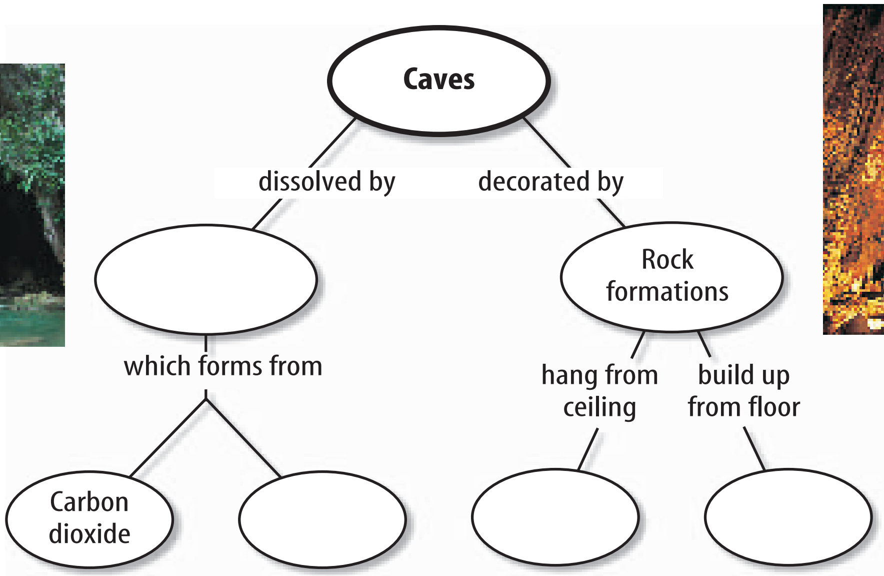
1. When water soaks into the ground, it becomes part of a vast groundwater system.
2. Although rock may seem solid, many types are filled with connected spaces called pores. Such rocks are permeable and can contain large amounts of groundwater.

Section 3 Ocean Shoreline

1. Ocean shorelines are always changing.
2. Waves and currents have tremendous amounts of energy which break up rocks into tiny fragments called sediment. Over time, the deposition and relocation of sediment can change beaches, sandbars, and barrier islands.

Visualizing Main Ideas

Copy and complete the following concept map on caves.



Using Vocabulary

aquifer p. 104
beach p. 111
cave p. 107
channel p. 94
drainage basin p. 96
geyser p. 107
groundwater p. 103
impermeable p. 104
longshore current p. 110
meander p. 97
permeable p. 104
runoff p. 92
sheet erosion p. 95
spring p. 107
water table p. 104

Explain the difference between the vocabulary words in each of the following sets.

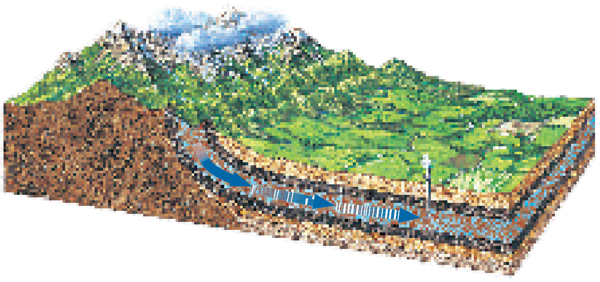
1. runoff—sheet erosion
2. channel—drainage basin
3. aquifer—cave
4. spring—geyser
5. permeable—impermeable
6. sheet erosion—meander
7. groundwater—water table
8. permeable—aquifer
9. longshore current—beach
10. meander—channel

Checking Concepts

Choose the word or phrase that best answers the question.

11. Where are beaches most common?
    - **A)** rocky shorelines
    - **B)** flat shorelines
    - **C)** aquifers
    - **D)** young streams

12. What is the network formed by a river and all the smaller streams that contribute to it?
    - **A)** groundwater system
    - **B)** zone of saturation
    - **C)** river system
    - **D)** water table



13. Why does water rise in an artesian well?
    - **A)** a pump
    - **B)** erosion
    - **C)** heat
    - **D)** pressure

14. Which term describes rock through which fluids can flow easily?
    - **A)** impermeable
    - **B)** meanders
    - **C)** saturated
    - **D)** permeable

15. Identify an example of a structure created by deposition.
    - **A)** beach
    - **B)** rill
    - **C)** cave
    - **D)** geyser

16. Which stage of development are mountain streams in?
    - **A)** young
    - **B)** mature
    - **C)** old
    - **D)** meandering

17. What forms as a result of the water table meeting Earth's surface?
    - **A)** meander
    - **B)** spring
    - **C)** aquifer
    - **D)** stalactite

18. What contains heated groundwater that reaches Earth's surface?
    - **A)** water table
    - **B)** cave
    - **C)** aquifer
    - **D)** hot spring

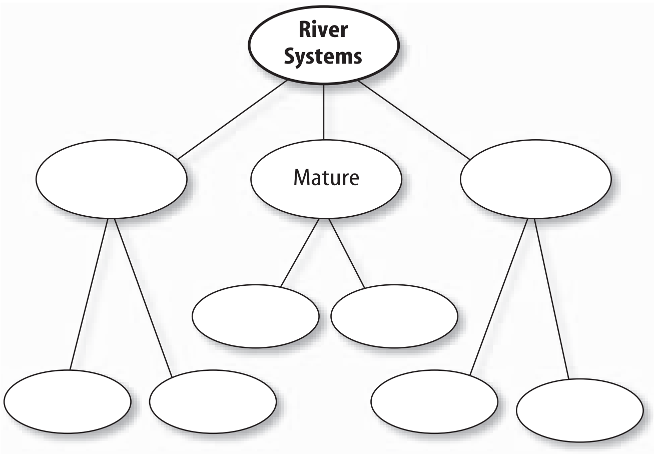
19. What is a layer of permeable rock that water flows through?
    - **A)** an aquifer
    - **B)** a pore
    - **C)** a water table
    - **D)** impermeable

20. Name the deposit that forms when a mountain river runs onto a plain.
    - **A)** subsidence
    - **B)** an alluvial fan
    - **C)** infiltration
    - **D)** water diversion

Science Online CONTENTS earth.msscience.com/vocabulary_puzzlemaker

Thinking Critically

21. Concept Map Copy and complete the concept map below using the following terms: *developed meanders, gentle curves, gentle gradient, old, rapids, steep gradient, wide floodplain*, and *young*.



22. Describe what determines whether a stream erodes its bottom or its sides.

23. Interpret Data The rate of water flowing out of the Brahmaputra River in India, the La Plata River in South America, and the Mississippi River in North America are given in the table below. Infer which river carries the most sediment.

River Flow Rates

River	Flow (m^3/s)
Brahmaputra River, India	19,800
La Plata River, South America	79,300
Mississippi River, North America	175,000

24. Explain why the Mississippi River has meanders along its course.

25. Outline Make an outline that explains the three stages of stream development.

26. Form Hypotheses Hypothesize why most of the silt in the Mississippi delta is found farther out to sea than the sand-sized particles are.

27. Infer Along what kind of shoreline would you find barrier islands?

28. Explain why you might be concerned if developers of a new housing project started drilling wells near your well.

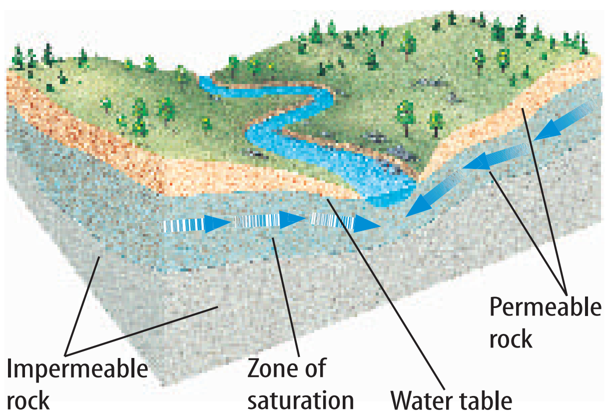
29. Use Variables, Constants, and Controls Explain how you could test the effect of slope on the amount of runoff produced.

Performance Activities

30. Poster Research a beach that interests you. Make a poster that shows different features you would find at a beach.

Applying Math

Use the illustration below to answer questions 31–32.



31. Flow Distance The groundwater in an aquifer flows at a rate of 0.2 m/day. How far does the groundwater move in one week?

32. Flow Time If groundwater in an aquifer flows at a rate of 0.4 m/day, how long does it take groundwater to move 24 m?

Part 1 Multiple Choice

Record your answers on the answer sheet provided by your teacher or on a sheet of paper.

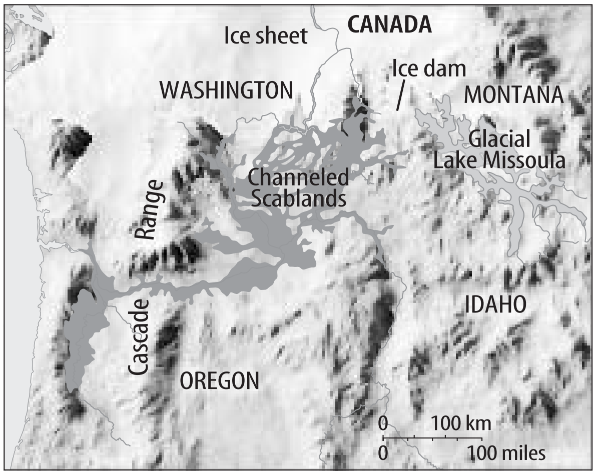
1. Which is erosion over a large, flat area?
   A. gully **C.** runoff
   B. rill **D.** sheet

2. Which is erosion where a rill becomes broader and deeper?
   A. gully **C.** runoff
   B. rill **D.** sheet

3. Which is the area of land from which a stream collects runoff?
   A. drainage basin **C.** runoff
   B. gully **D.** stream channel

4. Which type of soil or rock allows water to pass through them?
   A. impermeable **C.** permeable
   B. nonporous **D.** underground

Refer to the figure below to answer question 5.



5. Which formed the Channeled Scablands?
   A. deposition **C.** rill erosion
   B. floodwaters **D.** sheet erosion

6. Which dissolves limestone to form caves?
   A. carbonic acid **C.** stalactites
   B. hydrochloric acid **D.** stalagmites

7. Which forms on the ceilings of caves as water drips through cracks?
   A. aquifer **C.** stalactite
   B. geyser **D.** stalagmite

8. Which are piles of sand found on barrier islands?
   A. deltas **C.** geysers
   B. dunes **D.** streams

9. Which creates springs and geysers?
   A. groundwater **C.** rills
   B. gullies **D.** runoff

Refer to the figure below to answer question 10 and 11.

10. Which feature is shown?
    A. artesian well **C.** geyser
    B. aquifer **D.** waterfall

11. Which provides the water?
    A. groundwater **C.** stream
    B. runoff **D.** surface water

12. Which is a layer of permeable rock through which water moves freely?
    A. aquifer **C.** geyser
    B. clay **D.** granite

Test-Taking Tip

Correct Answer Bubbles For each question, double check that you are filling in the correct answer bubble for the question number you are working on.

Barbara Filet

Part 2 Short Response/Grid In

Record your answers on the answer sheet provided by your teacher or on a sheet of paper.

13. How does gravity affect water erosion?

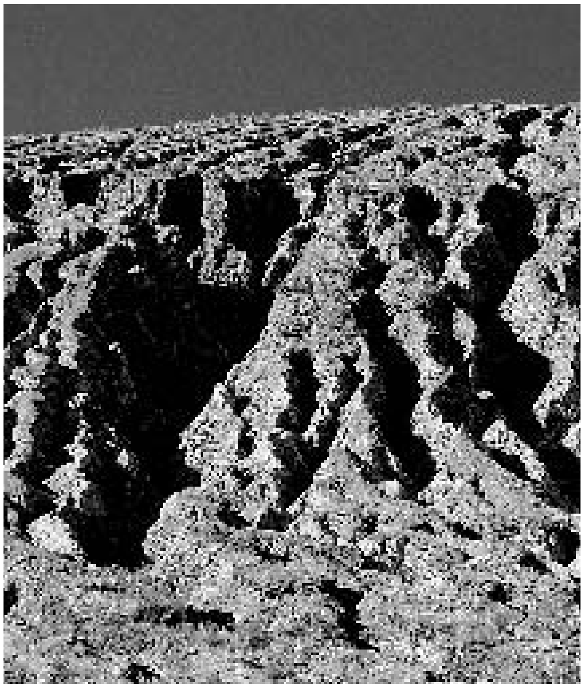
14. Describe the different types of load in a stream.

15. What will happen to homes and businesses located in a floodplain?

16. Explain how the water table and the zone of saturation are related.

17. How would harmful chemicals in the soil enter into the groundwater system?

Refer to the picture below to answer questions 18 and 19.



18. What type of erosion is shown?

19. What led to the erosion shown?

20. What factors affect runoff?

21. What are the characteristics of a mature stream?

Part 3 Open Ended

Record your answers on a sheet of paper.

22. Compare and contrast rocky shorelines and sandy beaches.

23. What are the Outer Banks in North Carolina and how were they formed?

24. What can humans do to try to control flood waters?

25. Explain how waves produce longshore currents.

Refer to the figure below to answer question 26.

26. What stream formation is shown in the diagram above? Explain how differing speeds of water in a stream can cause this type of stream formation.

27. Explain how a drainage basin works. Compare and contrast a drainage basin to the gutter drainage system of a rooftop.

28. Compare and contrast a pumped well and an artesian well.

29. Compare and contrast alluvial fans and deltas.

Grant Heilman Photography