

Chapter 18

Erosion by Wind and Waves

Chapter Outline

1 Wind Erosion

How Wind Moves Sand and Dust

Effects of Wind Erosion

Wind Deposition

Loess

2 Wave Erosion

Shoreline Erosion

Beaches

Longshore-Current Deposits

3 Coastal Erosion and Deposition

Absolute Sea-Level Changes

Relative Sea-Level Changes

Preserving the Coastline



Why It Matters

Wind and waves are powerful forces of erosion. Wind may carry away soil that is needed for farming. Waves may wash away coastlines, which are important economic areas. This curved and pitted rock, on Kangaroo Island off the southern shore of Australia, was shaped by wind and waves.

Inquiry Lab

 20 min

Shake It Up



Use a **magnifying glass** or **dissecting microscope** to observe the samples of **shoreline sediment** provided by your teacher. Record your observations, noting similarities and differences among the samples. Place all of the samples in the same **jar**, add **water** until the jar is three-quarters full, and seal the jar. Shake the jar for 1 min to represent shoreline wave action. Then let the jar rest, and observe the rates of deposition for different-sized particles. Record your observations.

Questions to Get You Started

1. Describe the relationship between particle size and rate of deposition in the jar.
2. Based on your observations, how would you expect different-sized particles to settle on a real shoreline?



Word Parts

Root Words The word *saltation*, a key term in Section 1, may remind you of the salt that you sprinkle on food. Actually, *saltation* is from the Latin word *saltatio*, which means “a dancing” or “dance.” This Latin root makes sense, because saltation is the way that wind and water move sand—by bounces and jumps.

Your Turn Choose four key terms or italicized terms in Sections 1 and 2. Using print or online sources, research the root word of each term. Record your findings in a table like the one below.

Term	Root Word	Definition of Root Word	Definition of Term
(desert or stone) pavement	pavimentum (Latin)	beaten floor	a surface of closely packed small rocks

Mnemonics

Longshore Current A mnemonic is a sentence or phrase that can help you remember specific information. For example, a longshore current is a water current that travels near and parallel to the shoreline. You can use the following mnemonic to help you remember the direction and location of a longshore current:

A longshore current flows **along** the shoreline.

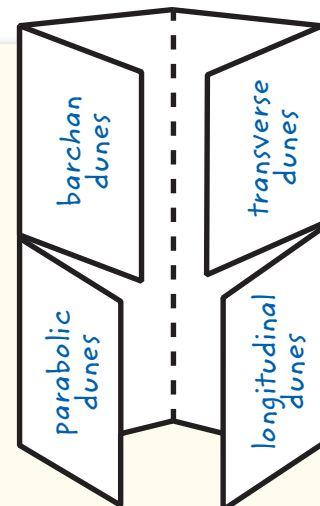
Your Turn Say this mnemonic a few times to help you learn and remember the direction in which a longshore current flows. Find the other key terms in the chapter, and make up mnemonics that will help you remember their definitions.

FoldNotes

Four-Corner Fold A four-corner fold is useful when you want to compare the characteristics of four topics. You can organize the characteristics of the four topics side by side under the flaps.

Your Turn As you read about dunes in Section 1, make a four-corner fold by following the instructions in **Appendix A**. Label the four outer flaps with the names of the four types of dunes: barchan dunes,

parabolic dunes, transverse dunes, and longitudinal dunes. Take notes about each type of dune underneath the appropriate flap.



For more information on how to use these and other tools, see **Appendix A**.

Wind Erosion

Key Ideas

- Describe two ways that wind erodes land.
- Compare the two types of wind deposits.

Key Terms

saltation **dune**
deflation **loess**
ventifact

Why It Matters

Blowing wind moves sand, soil, dust, and other particles all over Earth. As a result, wind helps to shape the land, which can be a benefit to those who live there.

Wind contains energy. Some of this energy can move a sailboat or turn a wind turbine, but this energy can also erode the land. As wind passes over the land, the wind can carry sand or dust. Sand is loose fragments of weathered rocks and minerals. Most grains of sand are made of quartz. Other common minerals that make up sand are mica, feldspar, and magnetite.

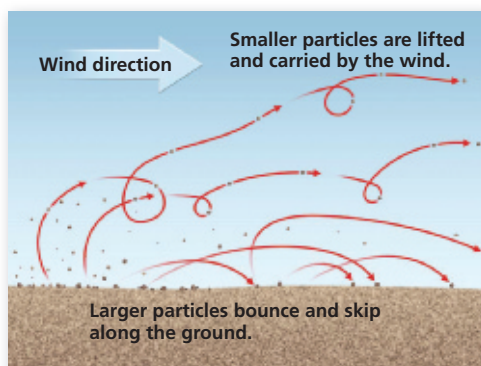
Dust consists of particles that are smaller than the smallest sand grain. Most dust particles are microscopic fragments of rocks and minerals that come from the soil or volcanic eruptions. Other sources of dust are plants, animals, bacteria, pollution from the burning of fuels, and certain manufacturing processes.

How Wind Moves Sand and Dust

Wind cannot keep sand aloft. Instead, sand grains are rolled by the wind along the ground (surface creep) or are moved by a series of jumps and bounces called **saltation**. Saltation occurs when rolling sand grains collide and some bounce up, as shown in **Figure 1**. Once in the air, a sand grain moves ahead a short distance and then falls. As a sand grain falls, it strikes other sand grains. Saltating sand grains move in the same direction that the wind blows. However, the grains rarely rise more than 1 m above the ground, even in very strong winds.

Because dust particles are very small and light, even gentle air currents can keep dust particles suspended in the air. Dust from volcanic eruptions can remain in the atmosphere for several years. Strong winds may lift large amounts of dust and create dust storms, such as the one shown in **Figure 1**. Some dust storms cover hundreds of square kilometers and darken the sky for several days.

Figure 1 Heavy sand grains move by rolling or by making low, arcing jumps when blown by the wind (left). Dust is light enough to be suspended for days, as shown in this dust storm in Phoenix, Arizona (right).



saltation the movement of sand or other sediments by short jumps and bounces that is caused by wind or water

Figure 2 Desert pavement, such as this example in Calico Hills, California, prevents erosion of the material beneath it.



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Topic: Wind Erosion

Code: HQX1669

Effects of Wind Erosion

While wind erosion happens everywhere there is wind, the landscapes that are most dramatically shaped by wind erosion are deserts and coastlines. In these areas, fewer plant roots anchor soil and sand in place to reduce the amount of wind erosion. Also, in the desert, where there is little moisture, soil layers are thin and are likely to be swept away by the wind. Moisture makes soil heavy and causes some soil and rock particles to stick together, which makes them difficult to move.

 **Reading Check** Why does wind erosion happen faster in dry climates than in moist climates? (See Appendix G for answers to Reading Checks.)

Desert Pavement

One common form of wind erosion is deflation. **Deflation** is the process by which wind removes the top layer of fine, very dry soil or rock particles and leaves behind large rock particles. Deflation is one of many processes that may form a surface of closely packed small rocks called *desert pavement*, or *stone pavement*, as shown in **Figure 2**. Desert pavement protects the underlying land from erosion by forming a protective barrier over underlying soil.

Deflation Hollows

Deflation is a serious problem for farmers because it blows away the best soil for growing crops. Deflation may form shallow depressions in areas where the natural plant cover has been removed. As the wind strips off the topsoil, a shallow depression called a *deflation hollow* forms. A deflation hollow may expand to a width of several kilometers and to a depth of 5 to 20 m.

deflation a form of wind erosion in which fine, dry soil particles are blown away

Ventifacts

When pebbles and small stones in deserts and on beaches are exposed to wind abrasion, the surfaces of the rocks become flattened and polished on two or three sides. Rocks that have been pitted or smoothed by wind abrasion are called **ventifacts**. The word *ventifact* comes from the Latin word *ventus*, which means “wind.” The direction of the prevailing wind in an area can be determined by the appearance of ventifacts.

Scientists once thought that large rock structures, such as desert basins, natural bridges, rock pinnacles, and rocks perched on pedestals, were formed by wind erosion. However, scientists now think that it is more likely that such large features were produced by erosion due to surface water and weathering. Erosion of large masses of rock by wind-blown sand happens very slowly and happens only close to the ground, where saltation occurs.

ventifact any rock that is pitted, grooved, or polished by wind abrasion

dune a mound of wind-deposited sand that moves as a result of the action of wind

Wind Deposition

The wind drops particles when it slows down and can no longer carry them. These deposited particles are continually covered by additional deposits. Eventually, cementation and pressure from overlying layers bind the fragments together. This process is one way that sedimentary rocks form.

Academic Vocabulary

fragment (FRAG muhnt) a particle or piece that has broken off or been detached from something larger

Dunes

The best-known wind deposits are **dunes**, which are mounds of wind-deposited sand. Dunes form where the soil is dry and unprotected and where the wind is strong, such as in deserts and along the shores of oceans and large lakes. A dune begins to form when a barrier slows the speed of the wind. When wind speed slows, sand accumulates on both sides of the barrier, as shown in **Figure 3**. As more sand is deposited, the dune itself acts as a barrier, grows, and buries the original barrier.

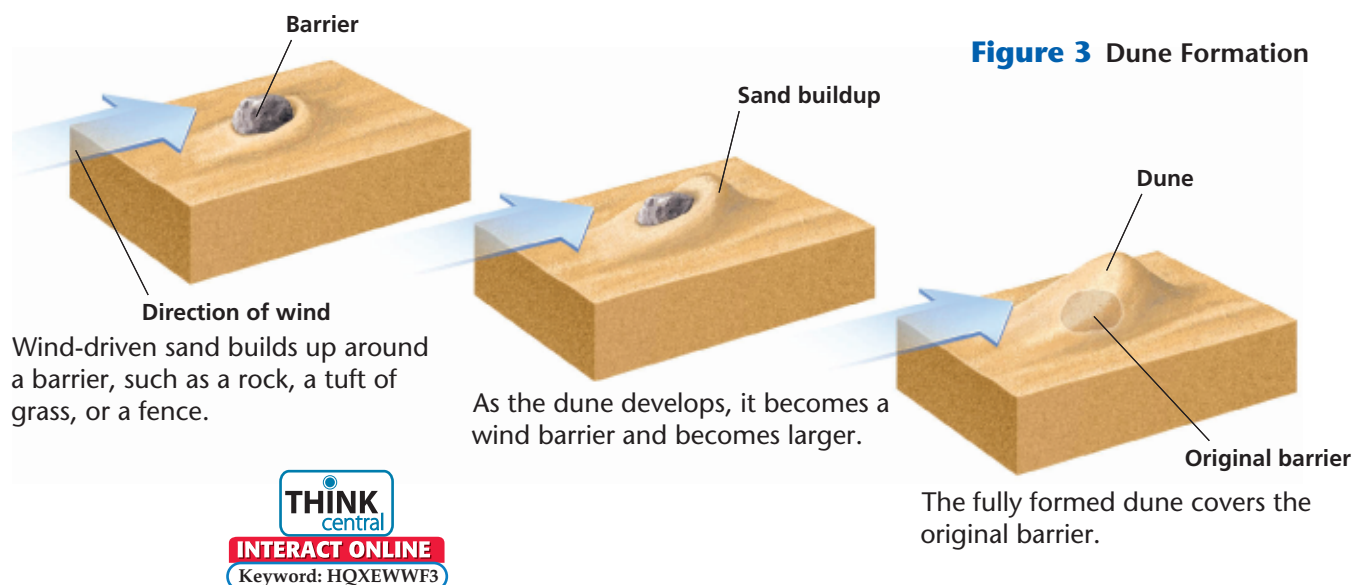
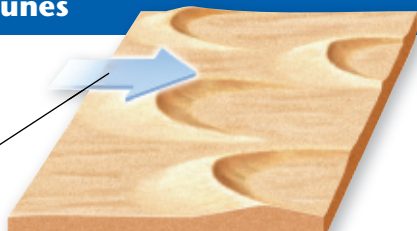
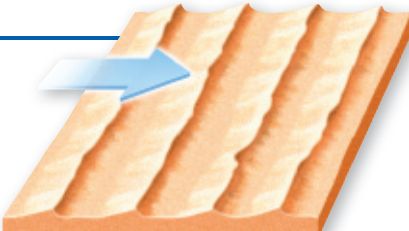


Table 1

Types of Dunes	
Barchan dunes When sand is limited, strong winds form these crescent-shaped dunes. 	 Wind direction
	Parabolic dunes U-shaped parabolic dunes can form when plants anchor the edges of barchan dunes and invert their shape.
Transverse dunes When sand is plentiful, barchan dunes can join together in long ridges to form transverse dunes. 	
	Longitudinal dunes These dunes are similar to transverse dunes except they lie parallel to the direction of the wind.

Types of Dunes

The force and direction of the wind shapes sand dunes. Commonly, the gentlest slope of a dune is the side that faces the wind. Sand that is blown over the crest of the dune tumbles down the opposite side, which is called the *slipface*. The slipface has a steeper slope than the windward side does. Two long, pointed extensions may form as wind sweeps around the ends of the dune and gives the dune a crescent shape. Crescent-shaped dunes that have an open side facing away from the wind are called *barchan dunes* (BAHR kahn doonz). A *parabolic dune* is a crescent-shaped dune whose open side faces into the wind. The long crescent ends stay behind, held in place by vegetation.

In desert or coastal areas that have a large amount of sand, a series of ridges of sand may form in long, wavelike patterns. These ridges are called *transverse dunes*. Transverse dunes form at right angles to the wind direction. A type of dune that is similar to a transverse dune, called a *longitudinal dune*, also forms in the shape of a ridge. But longitudinal dunes lie parallel to the direction the wind blows. **Table 1** illustrates several types of dunes and explains how the shape of dunes relates to wind direction.



Reading Check

How do barchan dunes differ from transverse dunes?



Figure 4 Wind erodes sand from the windward side of the dune and deposits it on the slipface. *Which direction is this sand dune migrating?*

Dune Migration

The movement of dunes is called *dune migration*. If the wind usually blows from the same direction, dunes will move downwind. Dune migration occurs as sand is blown over the crest from the windward side and builds up on the slipface, as shown in **Figure 4**. In mostly level areas, dunes migrate until they reach a barrier. To prevent dunes from drifting over highways and farmland, people often build fences or plant grasses, trees, and shrubs.

Quick Lab Modeling Desert Winds



20 min



Procedure

- 1 Spread a mixture of **dust**, **sand**, and **gravel** on a table placed outdoors.
- 2 Place an **electric fan** at one end of the table.
- 3 Put on **safety goggles** and a **filter mask**. Aim the fan across the sediment you have laid out. Start the fan on the lowest speed. Record any observations.
- 4 Turn the fan to medium speed and record any observations. Then, turn the fan to its highest speed to imitate a desert wind-storm. Record any observations.

Analysis

1. In what direction did the sediment move?
2. What was the relationship between the wind speed and the sediment size that was moved?
3. How does the remaining sediment compare to desert pavement?
4. How did the sand move in this activity? How do your observations relate to dune migration?
5. Using the same materials, how would you model dune migration? How would you model the formation of the different kinds of dunes?

Figure 5 These loess deposits are located in Vicksburg, Mississippi. Much of the surrounding land is fertile farmland.

READING TOOLBOX

Root Words

Use print or online sources to research the root word of *loess*. Add your findings to the table you started at the beginning of the chapter.

loess fine-grained sediments of quartz, feldspar, hornblende, mica, and clay deposited by the wind



Loess

The wind carries dust higher and much farther than it carries sand. Fine dust may be deposited in such thin layers that it is not noticed. However, thick deposits of yellowish, fine-grained sediment, called **loess** (LOH ES), can form by the accumulation of windblown dust. Although loess is soft and easily eroded, it sometimes forms steep bluffs, such as those shown in **Figure 5**.

A large area in northern China is covered in a deep layer of loess. The material in this deposit came from the Gobi Desert, in Mongolia. Deposits of loess are also located in central Europe. In North America, loess is located in the midwestern states, along the eastern border of the Mississippi River valley, and in eastern Oregon and Washington State. These deposits probably formed as dust from dried beds of glacial lakes and from outwash plains blew across the region. Loess deposits are extremely fertile and provide excellent soil for grain-growing regions.

Section 1 Review

Key Ideas

- 1. Describe** how wind transports sediment by saltation.
- 2. Define** *deflation*, and explain how *deflation hollows* form.
- 3. Describe** how ventifacts form.
- 4. Describe** how sand dunes form and how dunes migrate.
- 5. Explain** how the wind moves loess.
- 6. Identify** two reasons why wind erosion has a major effect on deserts.
- 7. Compare** the four main shapes of dunes.

Critical Thinking

- 8. Analyzing Processes** Explain how wind erosion might contribute to the formation of desert pavement.
- 9. Determining Cause and Effect** Why does planting grass, trees, or shrubs help prevent dunes from covering roads?
- 10. Analyzing Processes** Explain why the position of dunes would not be helpful for navigation in the desert.

Concept Mapping

- 11.** Use the following terms to create a concept map: *saltation*, *deflation*, *dune*, *deflation hollow*, *desert pavement*, *wind*, *sand particle*, *top soil layer*, and *migration*.

Wave Erosion

Key Ideas

- Compare the formation of six features produced by wave erosion.
- Explain how beaches form.
- Describe the features produced by the movement of sand along a shore.

Key Terms

headland
beach
longshore current

Why It Matters

The endless pounding of the surf produces spectacular shorelines, which, themselves, never stay the same.

As wind moves over the ocean, the wind produces waves and currents that erode the coastline. Wave erosion changes the shape of shorelines, the places where the ocean and the land meet.

Shoreline Erosion

The power of waves striking rock along a shoreline can sometimes shake the ground as much as a small earthquake would. The great force of waves may break off pieces of rock and throw the pieces back against the shore. These sediments grind together in the tumbling water. This abrasive action, which is known as *mechanical weathering*, eventually reduces most of the rock fragments to small pebbles and sand grains.

Much of the erosion along a shoreline takes place during storms, which cause large waves that release tremendous amounts of energy, as shown in **Figure 1**. A severe storm can noticeably change the appearance of a shoreline in a single day.

Chemical weathering also affects the rock along a shoreline. The waves force salt water and air into small cracks in the rock. Chemicals in the air and water react with the rock and enlarge the cracks. Enlarged cracks expose more of the rock to mechanical and chemical weathering.



Figure 1 Large waves break apart rock on shorelines and change the shoreline's appearance. *Where is erosion occurring in the photo shown here?*

headland a high and steep formation of rock that extends out from shore into the water

READING TOOLBOX

Four-Corner Fold

Make a four-corner fold. Label the outer flaps with the names of four land features that are formed by wave erosion: Sea Cliffs, Sea Caves, Sea Arches, and Sea Stacks. Take notes about each type of land feature under the appropriate flap.

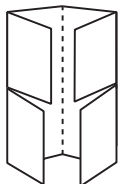


Figure 2 Wave erosion of sea cliffs causes cliff retreat and forms isolated sea stacks. Sea cliffs develop where waves strike directly against rock that is along a shoreline.

Sea Cliffs

In places where waves strike directly against rock, the waves slowly erode the base of the rock. The waves cut under the overhanging rock, until the rock eventually collapses to form a steep sea cliff. The rate at which sea cliffs erode depends on the amount of wave energy and on the resistance of the rock along the shoreline. Soft rock, such as limestone, erodes very rapidly. Harder rock, such as granite, shows little change over hundreds of years. Resistant rock formations that project out from shore are called **headlands**. Areas that have less resistant rock form *bays*. **Figure 2** shows bays and several other coastal landforms produced by wave erosion.

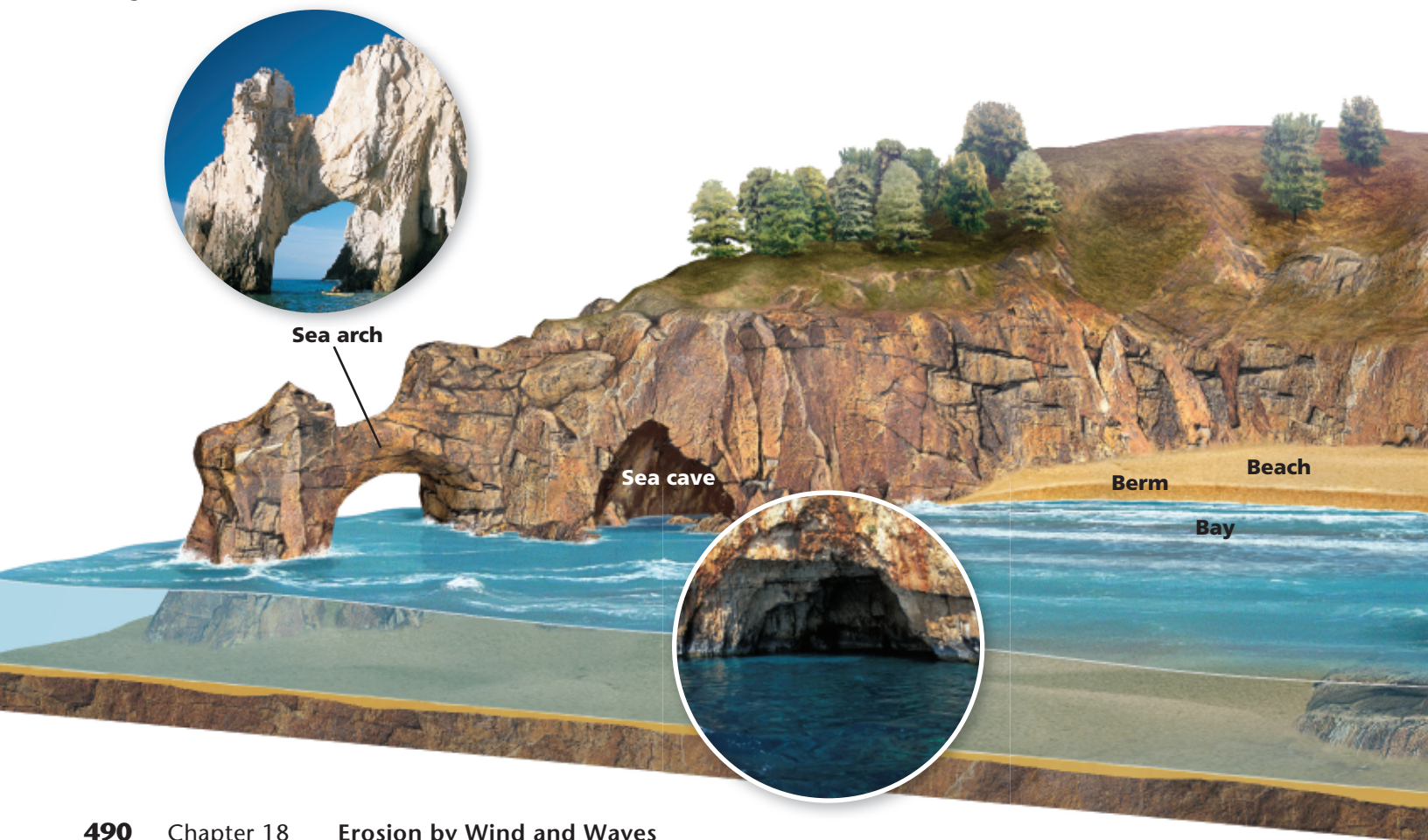
Sea Caves, Arches, and Stacks

Waves often cut deep into fractured and weak rock along the base of a cliff to form a large hole, or a *sea cave*. When waves cut completely through a headland, a *sea arch* forms. Offshore columns of rock that once were connected to a sea cliff or headland, are called *sea stacks*.

Terraces

As a sea cliff is worn, a nearly level platform, called a *wave-cut terrace*, usually remains beneath the water at the base of the cliff. Eroded material may be deposited offshore to create an extension to the wave-cut terrace called a *wave-built terrace*.

 **Reading Check** List three features that are caused by shoreline erosion.



Beaches

Waves create features by eroding the land and depositing sediment. A deposit of sediment along an ocean or lake shore is called a **beach**. Beaches form where more sediment is deposited than is removed. After a beach forms, the rate at which sediment is deposited and the rate at which sediment is removed may vary.

beach an area of the shoreline that is made up of deposited sediment

Composition of Beaches

The sizes and kinds of materials that make up beaches vary. In general, the smaller the particle is, the farther it traveled before it was deposited. The composition of beach materials depends on the minerals in the source rock. Some beaches may consist of fragments of shells and coral that are washed ashore. In other locations, sand beaches form from sediment deposited by rivers or glaciers. Other beaches are composed of large pebbles.

The Berm

Each wave that reaches the shore moves sand slightly. The sand piles up to produce a sloping surface. During high tides or large storms, sand is deposited at the back of this slope. So, most beaches have a raised section called the *berm*, as shown in **Figure 2**. The berm is high and steep during the winter because large storms remove sand from the beach on the seaward side of the berm. The sand that is removed may be deposited offshore to form a long underwater ridge called a *sand bar*. In the summer, waves may move the sand back to the shore to widen the beach.

Math Skills

Wave Depth A wave will break when the depth of the wave is equal to one and a half times the height of the water column. This statement can be represented by the following formula.

$$D = \frac{3}{2} H$$

If the tallest wave in a specific area is 6 m, what is the maximum depth at which wave erosion would occur in that area?



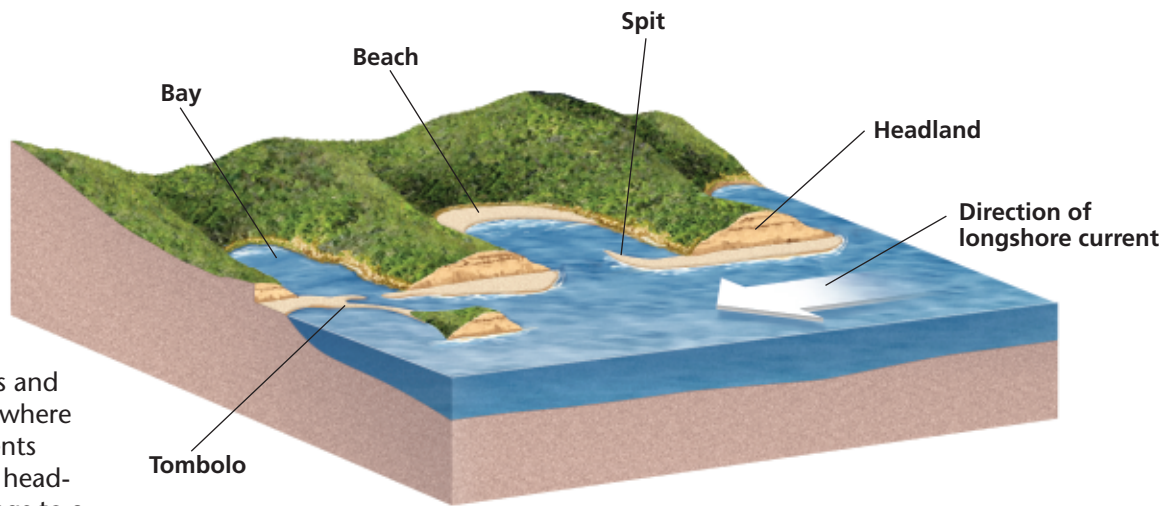


Figure 3 Spits and tombolos form where longshore currents deposit sand at headlands, at openings to a bay, or on offshore islands.

Academic Vocabulary

individual (IN duh VII oo uhl) existing as a single, separate entity; particular

longshore current a water current that travels near and parallel to the shoreline

Longshore-Current Deposits

The direction in which a wave approaches the shore determines how the wave will move sediment. Most waves approach the beach at an angle and retreat in a direction that is more perpendicular to the shore. So, waves move individual sand grains in a zig-zag motion. The general movement of sand along the beach is in the direction in which the waves strike the shore.

Waves moving at an angle to the shoreline often create longshore currents. A **longshore current** is a movement of water parallel to and near the shoreline. Longshore currents transport sand parallel to the shoreline, as shown in **Figure 3**.

Along a relatively straight coastline, sand keeps moving until the shoreline changes direction at bays and headlands. The longshore current slows, and sand is deposited at the far end of the headland. A long, narrow deposit of sand connected at one end to the shore is called a *spit*. Currents and waves may curve the end of a spit into a hook shape. Beach deposits may also connect an offshore island to the mainland. Such connecting ridges of sand are called *tombolos*.

Section 2 Review

Key Ideas

1. **Compare** the formation of six features that are produced by shoreline erosion.
2. **Identify** two factors that determine the composition of beach materials.
3. **Explain** how beaches form.
4. **Compare** sea arches, sea caves, and sea stacks.
5. **Describe** three features produced by the movement of sand along a shore.

Critical Thinking

6. **Making Inferences** How do seasonal changes affect beaches?
7. **Identifying Relationships** How does the speed at which water moves affect the deposition of materials of differing sizes?

Concept Mapping

8. Use the following terms to create a concept map: *shoreline erosion, sea arch, sea cave, sea cliff, wave-cut terrace, wave-built terrace, and terrace*.

Key Ideas

- Explain how changes in sea level affect coastlines.
- Describe the features of a barrier island.
- Analyze the effect of human activity on coastal land.

Key Terms

estuary
barrier island
lagoon

Why It Matters

The same wave energy that erodes shorelines can be harnessed to produce electricity.

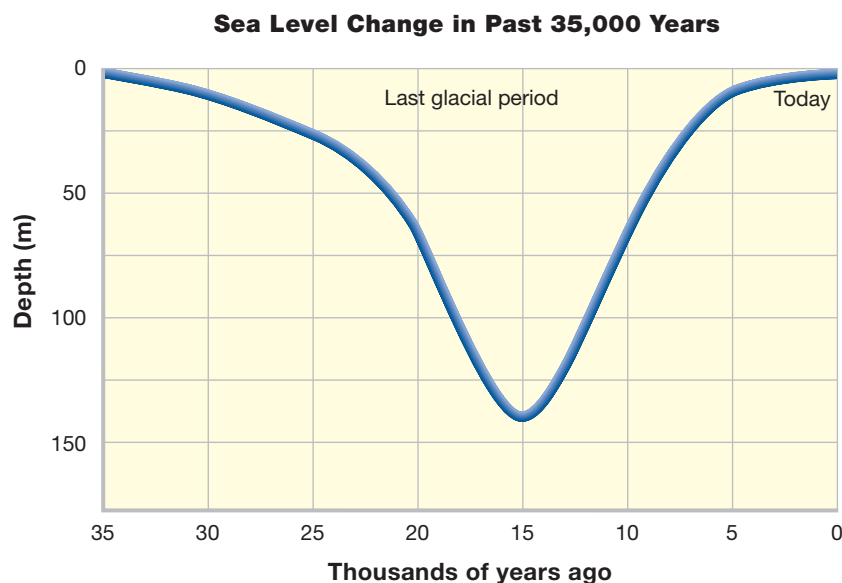
The boundaries between land and the ocean are among the most rapidly changing parts of Earth's surface. Coastal areas extend from relatively shallow water to several kilometers inland. Coastlines are affected by the long-term rise and fall of sea level and by the long-term uplifting or sinking of the land that borders the water. These and other more rapid processes, such as wave erosion and deposition, constantly change the appearance of coastlines.

Absolute Sea-Level Changes

A change in the amount of ocean water causes sea level to rise or fall, so coastlines are covered or exposed. During the last glacial period, which ended about 15,000 years ago, some of the water that is now in the ocean existed as continental ice sheets. Scientists estimate that the ice sheets held about 70 million cubic kilometers of ice. Now, the ice sheets in Antarctica and Greenland hold only about 25 million cubic kilometers of ice.

During the last glacial period, the water that made up the additional 45 million cubic kilometers of ice is thought to have come from the oceans. As a result, sea level was as much as 140 m lower during the last glacial period than it is today. Since the last glacial period, the ice sheets have been melting, as shown in **Figure 1**. Over the last 5,000 years, sea level has been rising at a rate of about 1 mm per year. If, in the distant future, the polar icecaps were to melt completely, the oceans would rise over 50 m and submerge low-lying coastal regions. The locations of many large cities, such as New York, Los Angeles, Miami, and Houston would be submerged.

Figure 1 This graph shows how sea level has changed during the past 35,000 years.



Graphing Tides

Procedure

- 1 Research the daily tidal data for a certain area for one calendar month.
- 2 Graph the tide measurements on a line graph.

Analysis

1. When was high tide? When was low tide?
2. What kind of sea-level changes do tides represent?
3. Research the full and new moon dates for the time period you graphed. How does the moon correspond with your high and low tides?

estuary an area where fresh water from rivers mixes with salt water from the ocean; the part of a river where the tides meet the river current

Relative Sea-Level Changes

Absolute sea level changes when the amount of water in the ocean changes. Relative sea level changes when the land or features near the coast change. These changes can be caused by large-scale geologic processes or by localized coastal changes. For example, movements of Earth's crust can cause coastlines to sink or to rise. Coastlines near a tectonic plate boundary may change as tectonic plates move. When coastlines change, the relative sea level of that area also changes.

Submergent Coastlines

When sea level rises or when land sinks, a *submergent coastline* forms. Divides between neighboring valleys become headlands separated by bays and inlets, and submerged peaks may form offshore islands, as shown in **Figure 2**. Beaches are generally short, narrow, and rocky. When U-shaped glacial valleys become flooded with ocean water as sea level rises, spectacular narrow, deep bays that have steep walls, called *fiords* (FYAWRDZ), form.

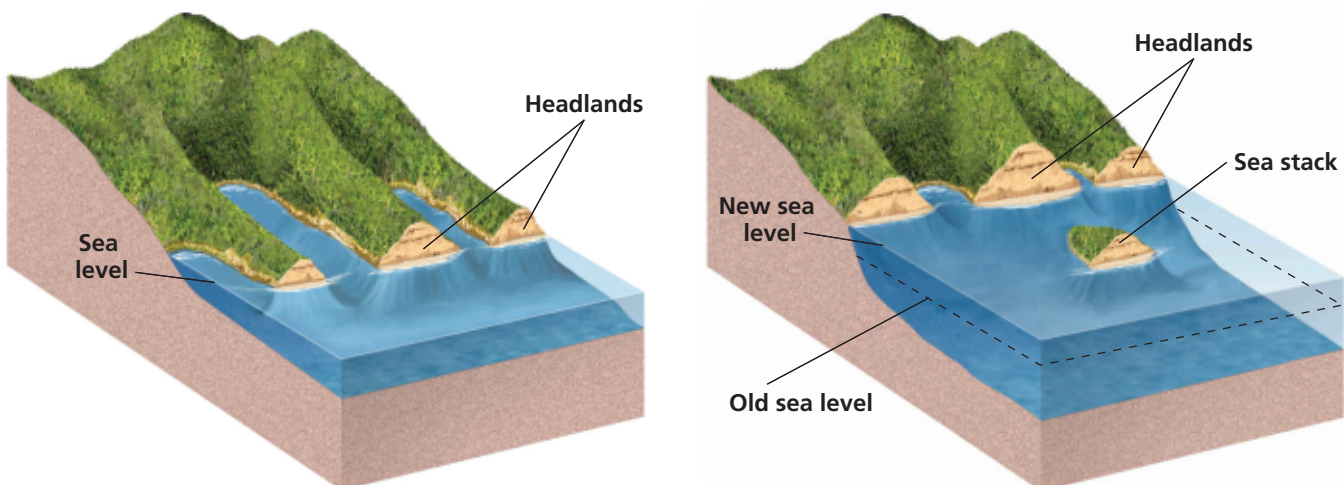
The mouth of a river valley that is submerged by ocean water may become a wide, shallow bay that extends far inland. This type of bay, where salt water and fresh water mix, is called an **estuary** (ES tyoo er ee).

Emergent Coastlines

When the land rises or when sea level falls, an *emergent coastline* forms. If an emergent coastline has a steep slope and is exposed rapidly, the coastline will erode to form sea cliffs, narrow inlets, and bays. A series of wave-cut terraces may be exposed as well.

A gentle slope forms when part of the continental shelf is slowly lifted and exposed. The gentle slope forms a smooth coastal plain that has few bays or headlands and that has many long, wide beaches.

Figure 2 The features of a submergent coastline erode over time as sea level rises.



Barrier Islands

As sea level rises over a flat coastal plain, the shoreline moves inland and isolates dunes from the old shoreline to form barrier islands, such as the one shown in **Figure 3**.

Barrier islands are long, narrow ridges of sand that lie nearly parallel to the shoreline. Barrier islands can be 3 to 30 km offshore and can be more than 100 km long. Between a barrier island and the shoreline is a narrow region of shallow water called a **lagoon**.

Barrier islands also form when sand spits are separated from the land by storms or when waves pile up ridges of sand that were scraped from the shallow, offshore sea bottom. These deposits are then moved toward the shore by waves, currents, and winds. This motion causes most barrier islands to migrate toward the shoreline. Winds blowing toward the land often create a line of dunes that are 3 to 6 m high on the side of the island that faces the shore.

Large waves from storms, especially waves from hurricanes, may severely erode barrier islands. During a storm, sand washes from the ocean side toward the inland side of the island. Some barrier islands are eroding at a rate of about 20 m per year.



Figure 3 Santa Rosa Island is a long, narrow barrier island that is located off the coast of Florida.

barrier island a long ridge of sand or narrow island that lies parallel to the shore

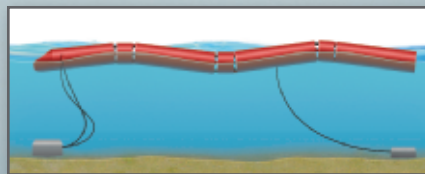
lagoon a small body of water separated from the sea by a low, narrow strip of land

 **Reading Check** How do barrier islands form?

Why It Matters

Wave Power

What if we could capture the ocean's energy and use it in our homes? Ocean waves may one day provide trillions of watts of power. Like solar power and wind power, wave power can produce electricity without pollution. This machine, called Pelamis, converts wave energy into electricity.



YOUR TURN

CRITICAL THINKING

On which shorelines is wave power possible? Explain why.

Figure 4 This beach area near Biloxi, Mississippi was devastated by Hurricane Katrina.



Academic Vocabulary

economic (ek uh NAHM ik) relating to commerce

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Preserving the Coastline

Coastal lands are used for commercial fishing, shipping, industrial and residential development, and recreation. While development of coastal areas is economically important, it can also damage coastal areas in several ways. Pollution is a serious threat to coastal resources. Oil spills are a threat because tankers travel near shorelines and because oil wells are drilled offshore. Garbage, pollution from industry, and sewage from towns on the coast can pollute the coastline. This pollution can damage habitats and kill marine birds and other animals.

Beaches damaged by hurricanes such as Katrina in 2005 will require years of rebuilding, as shown in **Figure 4**. To preserve the coastal zone, private owners and government agencies often work together to set guidelines for coastal protection. Coastal development in some environmentally sensitive areas, such as the North Carolina coast, has been slowed or stopped completely in an attempt to protect these important areas.

Section 3 Review

Key Ideas

1. **Explain** how changes in sea level affect coastlines.
2. **Explain** how the formation of a submergent coastline differs from the formation of an emergent coastline.
3. **Describe** two features of a barrier island.
4. **Explain** why barrier islands are particularly sensitive to erosion.
5. **Describe** two ways in which human activity affects coastlines.

Critical Thinking

6. **Making Predictions** Predict the effect that a season of heavy storms would have on a barrier island.
7. **Identifying Relationships** If Earth were to enter a new glacial period, how might coastlines around the world change?

Concept Mapping

8. Use the following terms to create a concept map: *coastline*, *emergent coastline*, *submergent coastline*, *barrier island*, and *lagoon*.

Where Did All This Sand Come From?

It is hard to make a mountain move, but it is just as hard to make a sand dune stop moving. Over decades and centuries, sand dunes have buried many towns and structures. Today, sand dunes threaten to blanket towns and cities in parts of Northern China, Saharan Africa, and the Middle East. The rate of a dune's movement depends on the dune's size and location, as well as wind patterns. Scientists study the movement of dunes to better understand dune migration and to help manage dunes in areas where they threaten human populations.



This house is in a Namibian village built in the early 1900s. Today, the town is covered in sand.



This Danish lighthouse was fully functional in 1900. It was closed in the 1960s, taken over by coastal erosion.



Dunes loom over Nouakchott, Mauritania—the largest city in Saharan Africa. Sooner or later, the dunes will move in on the city.

YOUR TURN

UNDERSTANDING CONCEPTS

List three factors that affect the rate at which a sand dune moves.

ONLINE RESEARCH

Sand dunes move through the process of *granular flow*. Use the Internet to learn more about this process. Write a one-page summary of what you learn.

What You'll Do

- **Model** the effects of wave action and longshore currents on a beach.
- **Identify** ways to decrease the effects of wave action on beach sand.

What You'll Need

block, plaster (2)
block, wooden, large
container, plastic, large
pebbles
ruler, metric
sand, 5 to 10 lb
water

Safety



Beaches

Coastal management is a growing concern because beaches are increasingly used for resources and recreation. The supply of sand for many beaches has been cut off by dams built on rivers and streams that would otherwise carry sand to the shoreline. Waves generated by storms also continuously wear away beaches. In some places, breakwaters have been built offshore to protect beaches from washing away. In this lab, you will examine how wave action may change the shape of beaches and how these changes can be reduced.

Ask a Question

- 1 How does wave action affect the amount of sand on a beach? How can these effects be reduced?

Form a Hypothesis

- 2 Form a hypothesis that answers your question. Explain your reasoning.

Test the Hypothesis

- 3 Make a beach in a large, shallow container by placing a mixture of sand and small pebbles at one end of the container. The beach should occupy about one-fourth of the length of the container.
- 4 In front of the sand, add water to a depth of 2 to 3 cm. Record what happens.
- 5 Use the large wooden block to generate several waves by moving the block up and down in the water at the end of the container opposite the beach. Continue this wave action until about half the beach has moved. Describe the beach after this wave action has taken place.



Step 5

- 6 Remove the sand, and rebuild the beach.
- 7 Design three breakwaters that change the flow of water along the beach. Draw your designs on a piece of paper. The two top photos at right are samples of some break-water arrangements.
- 8 Have your teacher approve your designs before you build them into your model beach.
- 9 Use the two plaster blocks to model the first breakwater that you designed. Use a wooden block to generate waves as in step 5. Record your observations.
- 10 Use the wooden block to generate waves that move parallel to the beach. Record your observations.
- 11 Repeat steps 9 and 10 for each of your other two designs. Record your observations.

Analyze the Results

1. **Making Comparisons** How does wave action build up a beach? How does wave action wear away a beach?
2. **Explaining Events** Describe how the sand moved when the waves ran parallel to the beach in step 10.
3. **Analyzing Results** How do breakwaters modify the effect that longshore currents have on the shape of a beach?

Draw Conclusions

4. **Making Predictions** Predict what will happen to a beach that is affected by wave action if it had no source of additional sand.
5. **Drawing Conclusions** What effect would a series of jetties have on a beach?

Extension

Research and Communications Research what can be done to preserve a recreational beach from erosion that is caused by excessive use by people. Write a letter to a local authority outlining a plan of action to protect that beach.



Step 7

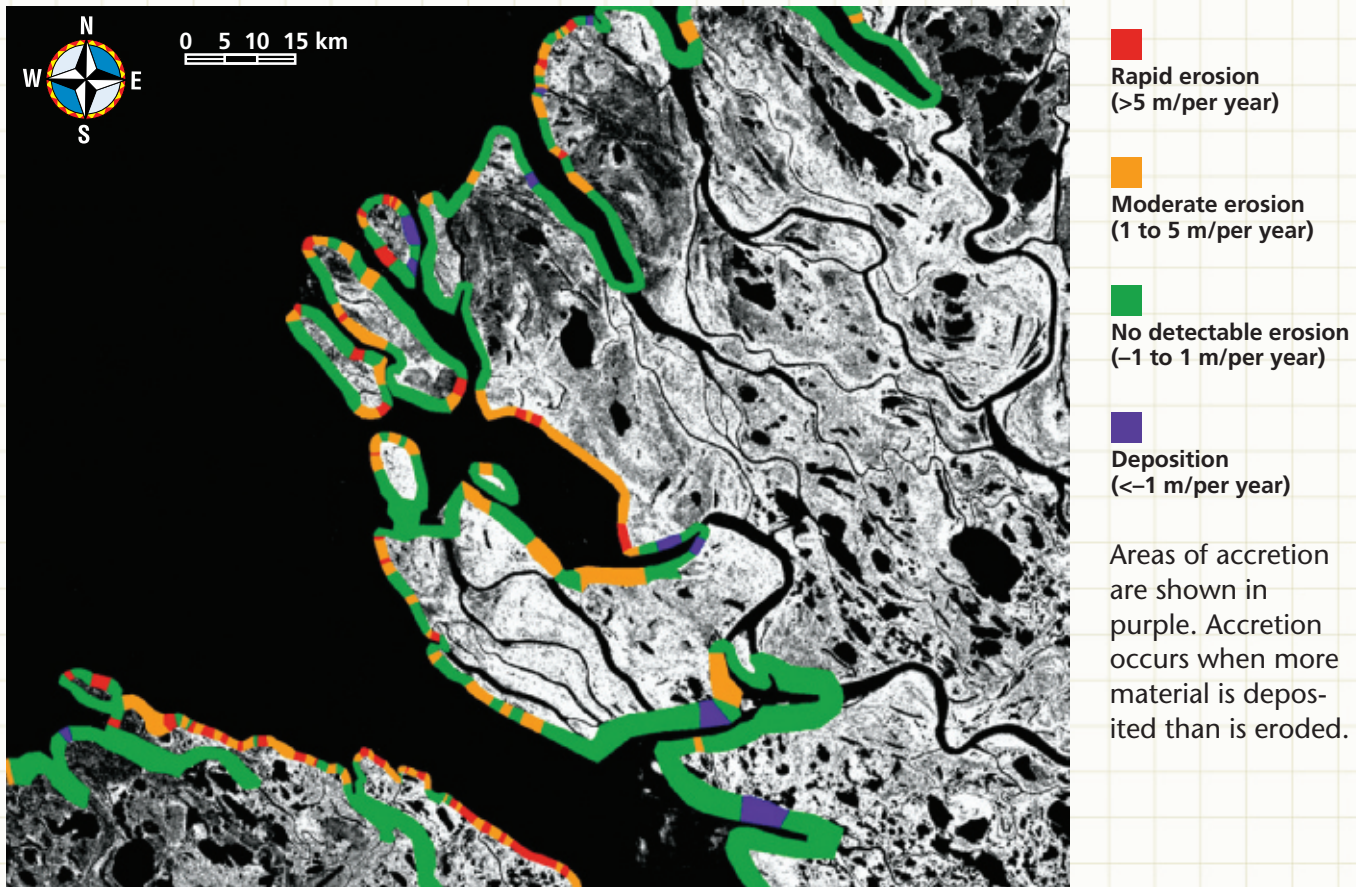


Step 7



Step 10

Coastal Erosion Near the Beaufort Sea



Map Skills Activity

This map shows the coastline of the Beaufort Sea in Canada along with computed amounts of shoreline erosion and accretion. Use the map to answer the questions below.

- Using a Key** How many areas of accretion are shown on the map?
- Using a Key** What is the level of erosion that is present in most areas shown?
- Analyzing Data** Is the estimated overall shoreline change for the entire area shown a positive value (accretion) or a negative value (erosion)?
- Making Comparisons** Is there more erosion on the coastal area toward the north or on the area toward the south?
- Inferring Relationships** Is the area shown in the map more significantly affected by the effects of waves along the shoreline or by the depositional actions of rivers that enter the ocean? Explain your answer.
- Identifying Trends** If present conditions remain the same, what would you expect to happen to the five small islands that are located on the northwest area of the map?

Section 1**Section 2****Section 3****Key Ideas****Wind Erosion**

- › Saltation and deflation are two ways that wind erodes land. Saltation is the movement of particles by a series of jumps or bounces. Deflation is a form of erosion in which dry soil or rock particles are removed by the wind while larger rock particles are left behind.
- › The two types of wind deposits are dunes, which are generally made of sand, and loess, which is made of dust particles.

Wave Erosion

- › Wave erosion produces many shoreline features, including steep rock cliffs called *sea cliffs*, holes at the bases of cliffs called *sea caves*, rock bridges called *sea arches*, rock columns called *sea stacks*, flat platforms at the bases of cliffs called *terraces*, and sediment deposits along the shore called *beaches*.
- › Beaches form from the deposition of sediments by waves.
- › Longshore currents carry sand parallel to the shoreline, forming narrow deposits of sand called *spits*, and ridges of sand that connect islands to the shore called *tombolos*.

Coastal Erosion and Deposition

- › Coastlines migrate as sea level changes.
- › Barrier islands are long, narrow offshore ridges of sand.
- › Human activities, including development and pollution, threaten coastal resources and habitat.

Key Terms

saltation, p. 483
deflation, p. 484
ventifact, p. 485
dune, p. 485
loess, p. 488

headland, p. 490
beach, p. 491
longshore current,
p. 492

estuary, p. 494
barrier island, p. 495
lagoon, p. 495

- 1. Four-Corner Fold** Make a four-corner fold. Label the outer flaps with the names of different types of landscapes: Coastlines and Beaches, Deserts, Cities and Towns, and Farmland. Under the appropriate flap, describe how erosion from wind and water affects each type of landscape.

READING TOOLBOX
USING KEY TERMS

Use each of the following terms in a separate sentence.

2. *ventifact*
3. *longshore current*
4. *loess*

For each pair of terms, explain how the meanings of the terms differ.

5. *saltation* and *deflation*
6. *headland* and *beach*
7. *barrier island* and *lagoon*

UNDERSTANDING KEY IDEAS

8. Wind forms desert pavement by removing fine sediment and by leaving large rocks behind in a process called
 - a. saltation.
 - b. abrasion.
 - c. deflation.
 - d. ventifact.
9. Wind moves sand by
 - a. saltation.
 - b. emergence.
 - c. abrasion.
 - d. depression.
10. Dunes move primarily by the process called
 - a. abrasion.
 - b. migration.
 - c. deflation.
 - d. submergence.
11. Thinly layered, yellowish, fine-grained deposits are called
 - a. beaches.
 - b. loess.
 - c. dunes.
 - d. desert pavement.

12. The most important erosion agent on shorelines is
 - a. wave action.
 - b. weathering.
 - c. wind.
 - d. the tide.
13. Which of the following shoreline features is *not* produced by wave erosion of sea cliffs?
 - a. spits
 - b. sea stacks
 - c. wave-cut terraces
 - d. sea arches
14. Longshore-current deposition of sand at the end of a headland produces a
 - a. sand bar.
 - b. spit.
 - c. dune.
 - d. sea cliff.
15. Over the last 5,000 years, sea level has changed by
 - a. no significant amount.
 - b. falling about 1 mm per year.
 - c. rising about 1 cm per year.
 - d. rising about 1 mm per year.
16. Barrier islands tend to migrate
 - a. away from the shore.
 - b. along the shore.
 - c. in the summer.
 - d. toward the shore.

SHORT ANSWER

17. What is the difference between an emergent coastline and a submergent coastline?
18. Explain what may happen if shoreline resources are not protected.
19. What factors affect the composition of a beach?
20. Explain the difference between the four main types of dunes.
21. Explain the difference between absolute sea-level change and relative sea-level change.

CRITICAL THINKING

22. **Identifying Relationships** The deserts of the southwestern United States contain many tall, sculpted rock formations. Was wind or water erosion the most likely agent responsible for these formations? Explain.

23. Making Inferences Suppose that one time each month for a year a satellite orbiting Earth takes a photograph of the same sandy, 1 km^2 area of the Sahara. Would the surface features shown in these 12 photographs remain essentially the same, or would they vary? Explain your answer.

24. Inferring Relationships Wave energy decreases when waves travel through shallow water. Based on this information, what effect do you think development of a wave-built terrace has on erosion of the shoreline? Explain your answer.

CONCEPT MAPPING

25. Use the following terms to create a concept map: *wave erosion, beaches, spit, berm, and tombolos*.

MATH SKILLS

Math Skills

26. Making Calculations Suppose it was possible for the sea level to continuously rise at the rate of 1 mm per year and that other factors affecting the coastlines do not change. How many kilometers would the sea level rise in 1 million years?

27. Applying Quantities Every year, 25 km^3 of sand is deposited on a beach by a nearby river, and 28 km^3 of sand is removed by wave action. Is the size of the beach increasing or decreasing? Explain.

WRITING SKILLS

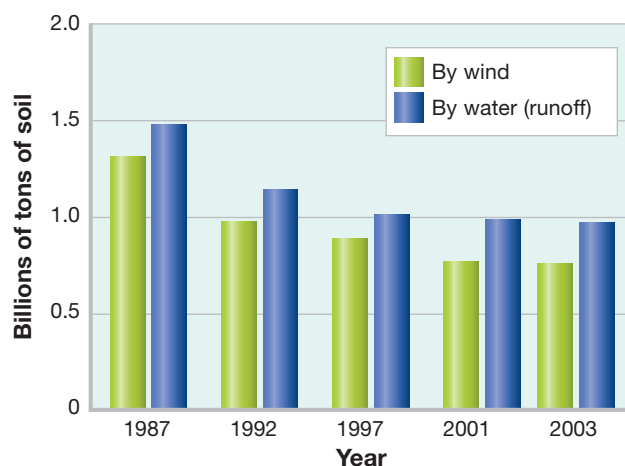
28. Creative Writing Imagine that you are a newspaper reporter who has traveled to another planet. Scientists know that, at one time, both wind and water eroded the surface of the planet. Prepare a news release that describes the landscape you see and explains the processes that produced it.

29. Writing Persuasively You have learned that beautifully colored sunsets and sunrises are the result of dust in the atmosphere. Write a letter or essay to your doubting friend to convince him or her that sunsets and sunrises are caused by dust. Use the evidence that remarkable sunsets were visible around the world for two years after the 1883 eruption of Krakatau, a volcanic island in Indonesia, in your essay.

INTERPRETING GRAPHICS

The graph below shows soil erosion in the United States by wind and water from 1987 to 2003. Use this graph to answer the questions that follow.

Soil Erosion in the United States, 1987–2003



- 30.** Which year had the most combined soil erosion?
- 31.** Which year had the most soil erosion due to water?
- 32.** Do you predict more or less soil erosion by wind in future years? Explain your answer.
- 33.** Would you expect that the amount of soil erosion in the United States would ever be zero? Explain your answer.

Understanding Concepts

Directions (1–5): For each question, write on a separate sheet of paper the letter of the correct answer.

- Which of the following factors most affects the rate at which waves erode land features along the shore?
 - temperature of the waves
 - direction in which waves approach shores
 - shape of the rock formation
 - composition of the rock formation
- Why are dust particles more likely to remain in the atmosphere longer and travel farther than sand particles?
 - Sand grains are carried higher and fall.
 - Dust particles are smaller and lighter.
 - Sand grains are made from rocks.
 - Dust is moved by the process of saltation.
- What is the term for rocks or pebbles that have flat, polished surfaces caused by wind abrasion?
 - bedrock
 - compaction
 - pinnacles
 - ventifacts
- What is the name for a submerged river valley mouth that forms a bay where salt and fresh water mix?

- estuary - atoll	- fiord - lagoon
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- Why is erosion by wind more common in arid climates than in other regions of the world?
 - Arid climates have much thicker soil layers.
 - Arid climates have less frequent dust storms.
 - Arid climates have less plant cover to anchor soil.
 - Arid climates have more moisture to hold soil.

Directions (6–7): For each question, write a short response.

- What is the term for dune movement?
- What factor is most important in determining the composition of beach materials?

Reading Skills

Directions (8–10): Read the passage below. Then, answer the questions.

Black Blizzards

The area that covers parts of Colorado, Kansas, New Mexico, Oklahoma, and Texas had been converted from natural grassland to farmland in the early 1900s. Many of the plants brought in to replace the natural prairie grasses had shallow root systems that could not hold soil in place. Much of the rest of the grassland was turned over to grazing land for hungry livestock.

During the 1930s, a long period of drought set in and the already dry soil turned to dust. In the spring of 1934, high winds blew black dust clouds across the dry wheat fields of these states. Some of the dust settled only when it reached Boston and New York City. The sky turned black at mid-day. And when the dust fell, houses were coated with thick layers of dust. Roads and fences were covered by dust. The remaining crops that had survived the droughts suffocated on the ground as the dust blocked the sunlight and other nutrients. Millions of people left their farms in search of a better life.

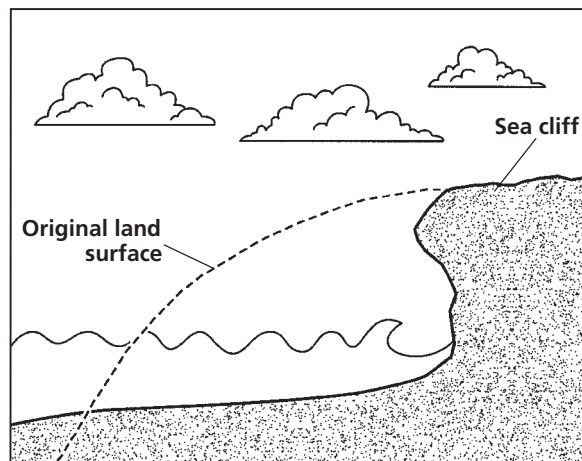
- According to the passage, how far did some of the dust travel during the dust storms of 1934?
 - all the way to the Pacific Ocean
 - all the way to the Atlantic Ocean
 - only as far as the Rocky Mountains
 - only as far as the Great Smokey Mountains
- Which of the following statements can be inferred from the information in the passage?
 - The dust storms from the 1930s continued well into the 1940s.
 - Black blizzards are common occurrences in the states of Texas and Colorado.
 - One of the main causes of the dust storms of the 1930s was misuse of land by humans.
 - Damage from the dust storms of the 1930s can still be seen today in states such as Texas and Oklahoma.
- Briefly describe how high winds and an extensive drought could combine to produce the terrible conditions seen during the 1930s.

Interpreting Graphics

Directions (11–12): For each question below, record the correct answer on a separate sheet of paper.

Base your answer to question 11 on the image of an eroding sea cliff below. The projecting headland of the cliff is composed of granite, and the hillside below it is made of limestone.

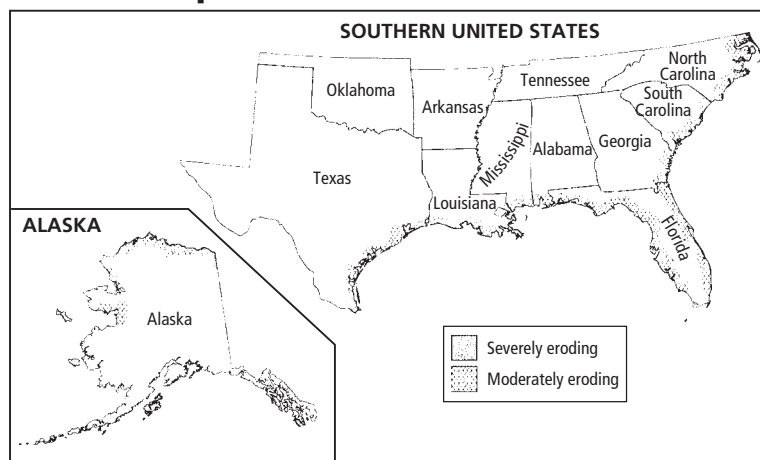
Erosion of a Sea Cliff



11. The coastal landforms shown were most likely formed as a result of the action of
- F. glacial movements.
 - G. seismic activity.
 - H. sea level changes.
 - I. waves and weathering.

Base your answer to question 12 on the map below, which shows shoreline changes across parts of the United States.

Map of Coastal Erosion Patterns



12. How might human activities along the rivers that empty into the Gulf of Mexico and the coastal shoreline play a part in the increasing rate of erosion that is affecting the region?

Test Tip

Do not spend a long period of time on any single question. Mark a question that you cannot answer quickly, and come back to it.

Geology Connections

Science, technology, and society are closely linked. This flowchart shows just a few of the connections in the history of geology.



9,500 B.C.E.

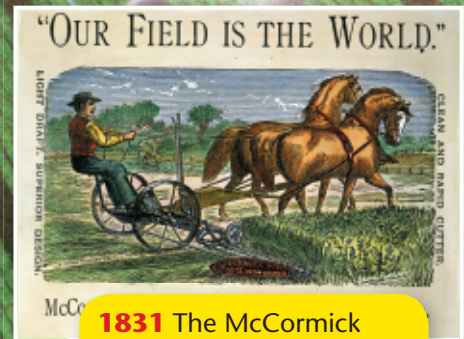
Systematic farming begins in the Fertile Crescent.



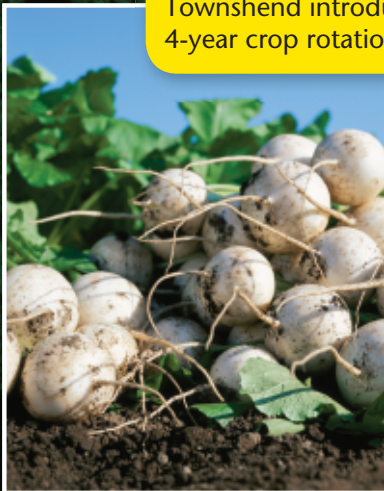
1620 The *Mayflower* carries 102 passengers to Plymouth, Massachusetts.



1790 Farmers make up 90% of the labor force in the United States.



1831 The McCormick reaper makes harvesting grain much more efficient.



1730s Charles "Turnip" Townshend introduces the 4-year crop rotation method.

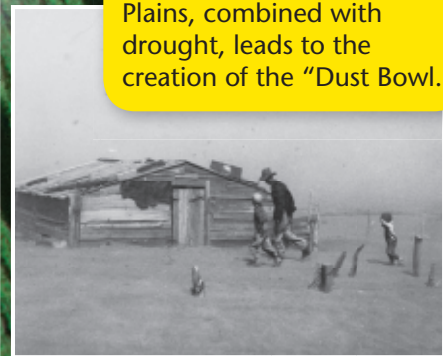


1916 George Washington Carver publishes *Help for the Hard Times* in which he outlines soil conservation suggestions.

1837 John Deere invents a steel walking plow with a curved blade.



1935–1938 Overplowing and overgrazing the Great Plains, combined with drought, leads to the creation of the "Dust Bowl."



HISTORY IN SCIENCE

800 B.C.E. Farmers in the Persian empire develop the *qanat* irrigation system.



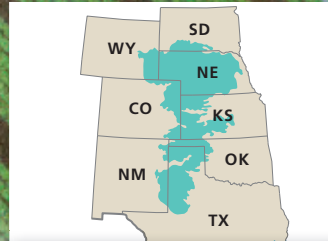
312 B.C.E. The Romans build the *Aqua Appia*, the first of eleven major aqueducts.



1900 American farmers first use sprinkler irrigation systems.



1954 More farms use tractors than animals, such as horses or mules, for farm production processes.



1911 The Ogallala aquifer in the Midwestern United States is first tapped for irrigation.

2000 Every day, 17 billion gallons of water from the Ogallala aquifer are used for irrigation.



2004 Global sales of bottled water exceed \$100 billion per year.



1935 The Natural Resource Conservation Service is established.



2008 The U.S. government offers \$20 million in Conservation Innovation Grants.



YOUR TURN

UNDERSTANDING CONCEPTS

How is farming related to groundwater use?

CRITICAL THINKING

Why would a government want to give grants for innovative conservation technologies or methods?