

Chapter 16

The Marine Environment

What You'll Learn

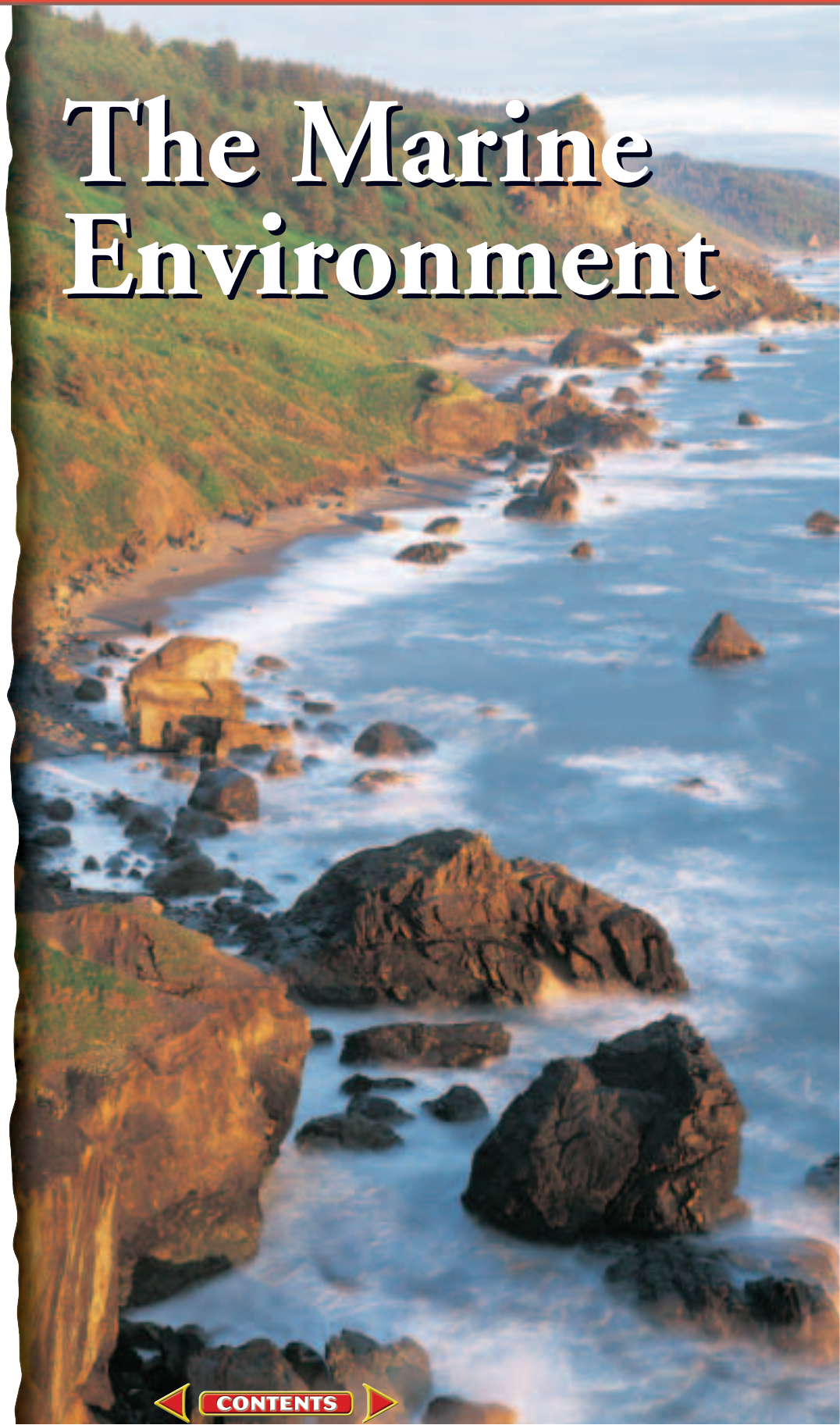
- How wave action affects shorelines and produces erosional and depositional coastal features.
- What major features and sediments are found on the ocean floor.

Why It's Important

The oceans cover 71 percent of Earth's surface and have a major impact on weather and climate. Shoreline features provide recreational opportunities as well as protection from major storms along coastlines.



To learn more about the marine environment, visit the Earth Science Web Site at earthgeu.com



Discovery Lab

Composition of Chalk

Although you may not live anywhere near a coast, parts of your environment were shaped by the ocean. For example, you may be just a few meters away from former seafloor deposits that are now part of the bedrock underground. One such seafloor deposit is chalk. How can you tell that chalk formed on the seafloor?

1. Grind up a small piece of natural chalk into a powder. Make a slide of the powdered chalk.
2. Observe the chalk powder through a microscope. Describe the powder. Are the grains irregular in shape or

size? Do some of the grains have patterns?

3. Analyze the powder and hypothesize the origin of the chalk.



CAUTION:
Always wear safety goggles and an apron in the lab. Use caution to prevent chalk dust from becoming airborne.



Observe In your science journal, describe the composition of the powdered chalk. What is the origin of the chalk? On what evidence do you base your conclusion?

SECTION

16.1

Shoreline Features

OBJECTIVES

- **Explain** how shoreline features are formed and modified by marine processes.
- **Describe** the major erosional and depositional shoreline features.

VOCABULARY

wave refraction
beach
estuary
longshore bar
longshore current
barrier island

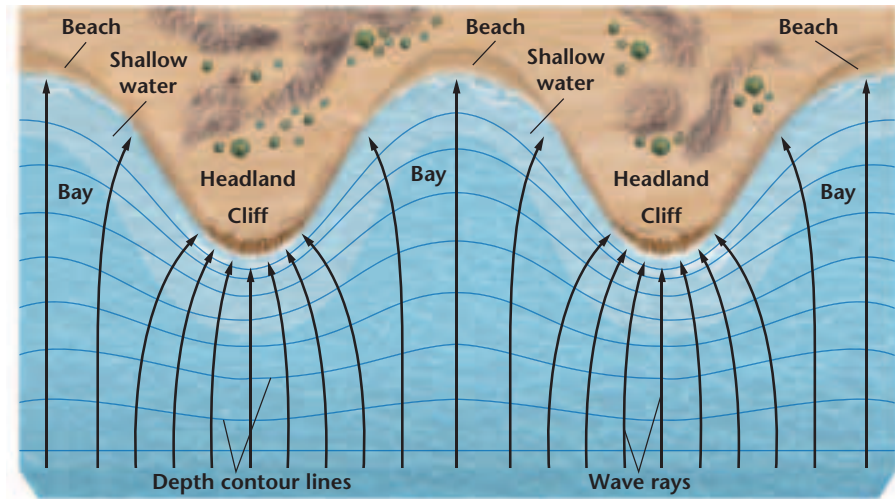
Some of the most interesting places on our planet are the seashores, the places where the land meets the sea. They are places of continuous, often dramatic geologic activity, places where you can see geological changes occurring almost daily. Shorelines are shaped by the action of waves, tides, and currents. As waves erode some coastlines, they create some of the most impressive rock formations on Earth. In other areas, waves deposit loose material and build wide, sandy beaches. To understand how waves act in different areas of the coast, let's reexamine the behavior of breakers.

EROSIONAL LANDFORMS

You learned in Chapter 15 that waves increase in height and become breakers as they approach a shoreline. Large breakers can hurl thousands of metric tons of water, together with suspended rock fragments, against a shore with such destructive force that they are capable of eroding even solid rock. This destructive action of breakers is most evident at rocky headlands, which are points of land sticking out into the ocean.

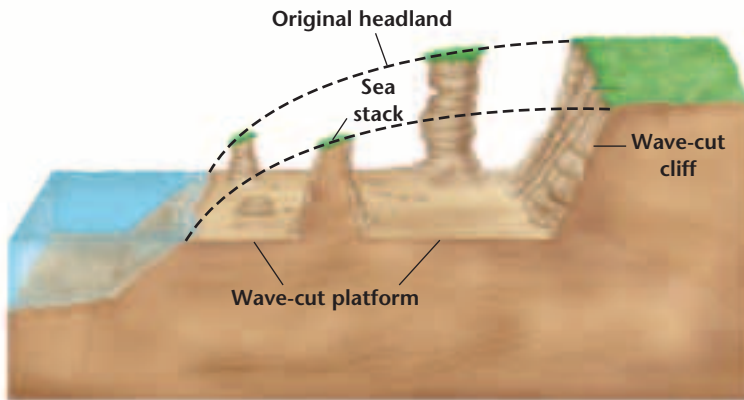


Figure 16-1 Wave crests advance toward the shore-line and slow down when they encounter shallow water. This causes the wave crests to bend toward the headlands and move in the direction of the arrows. Wave rays, drawn perpendicular to the wave crests, show the direction of wave travel and bending of wave crests.



Waves move faster in deep water than in shallow water. This difference in wave speed causes initially straight wave crests to bend when part of the crest moves into shallow water, a process known as **wave refraction**, illustrated in *Figure 16-1*. Along an irregular coast with headlands and bays, the wave crests bend towards the headlands. As a result, most of the breaker energy is concentrated along the relatively short section of the shore around the tips of the headlands, while the remaining wave energy is spread out along the much longer shoreline of the bays. The headlands thus undergo severe erosion. The material eroded from the headlands is swept into the bays, where it is deposited in the form of crescent-shaped beaches. Can you guess what the long-term effect of this process is? The headlands are worn back and the bays are filled in until the shoreline straightens. Given enough time, irregular shorelines are straightened by wave action.

Figure 16-2 A headland can be modified by wave erosion. The dotted lines indicate the original shape of the headland.



Landforms of Rocky Headlands Many headlands have spectacular rock formations. Generally, as a headland is gradually worn away, a flat erosional surface called a wave-cut platform is formed. The wave-cut platform terminates against a steep wave-cut cliff, as illustrated in *Figure 16-2*. Differential erosion, the removal of weaker rocks or rocks near sea level, produces many of the other characteristic landforms of rocky headlands. As shown in *Figure 16-3*, sea stacks are isolated rock towers or similar erosional remnants left on wave-cut platforms, and sea arches are formed as stronger rocks are undercut by wave erosion. Sea caves are tubelike passages

blasted into the headland at sea level by the never-ending assault of the breakers.

BEACHES

Have you ever visited any of the beaches along the coastline of the United States? Long stretches of our coastlines are lined with wide, sandy beaches. A **beach** is a sloping band of sand, pebbles, gravel, or mud at the edge of the sea. Beaches are composed of loose sediments deposited and moved about by waves along the shoreline. The size of sediment particles depends on the energy of the waves striking the coast and on the source of the sediment. Beaches pounded by large waves or formed on rocky coasts usually consist of coarse materials such as pebbles and cobbles.

The composition of beach material also depends upon the source of the material. Some Hawaiian beaches consist of black sand, tiny grains of minerals derived from the volcanic rocks that make up most of the Hawaiian Islands. The white and pink sand that form the beaches of southern Florida and the Bahamas has the consistency of cornmeal; these beaches are composed mostly of small fragments of local corals and seashells. Beaches near the mouths of large rivers are composed of the sandy sediments that are washed in by river water and made up of small grains of quartz and feldspar.

ESTUARIES

If you look at the map of the eastern coast of the United States shown in *Figure 16-4*, you will see rivers and streams entering the ocean. The area where the lower end of a freshwater river or stream enters the ocean is an **estuary**.

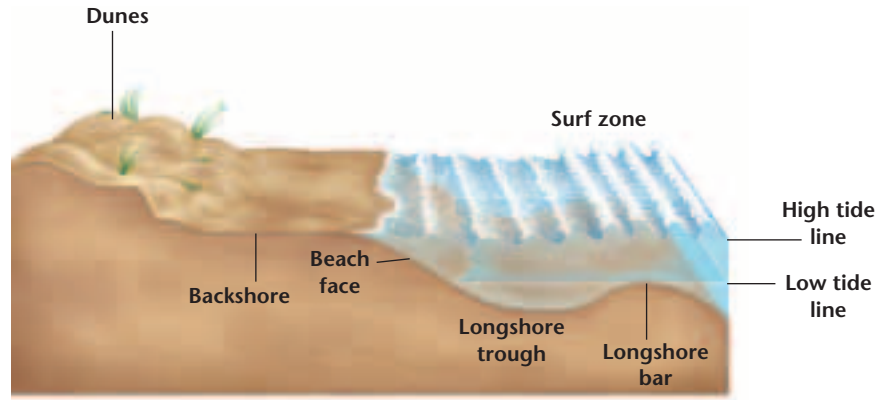
Figure 16-4 Estuaries provide an abundant supply of food and shelter to the young of commercially-important marine organisms. Sea grasses in estuaries also trap sediment and help filter out some water pollutants.



Figure 16-3 These sea stacks and sea arches along the rugged coastline of Washington State were formed by wave refraction at a rocky headland.



Figure 16-5 The sloping beach face is shaped by daily wave action, while the dunes behind the beach are affected only by large storm waves. Coastal dunes form from beach sand blown inland. The submerged longshore bar is located in the surf zone.



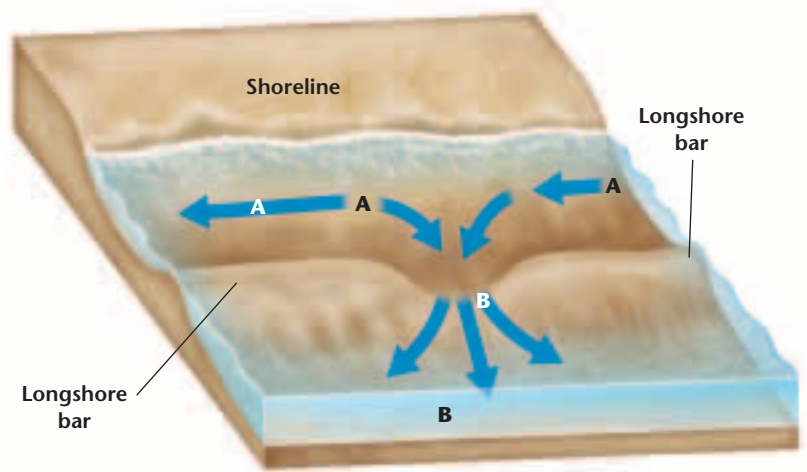
The water in estuaries is brackish, a mixture of freshwater and salt water. Estuaries are nurseries to the young of many different species, including ocean fishes. *Figure 16-4* reveals many large estuaries, such as Chesapeake Bay and Pamlico Sound.

LONGSHORE CURRENTS

Suppose you stood on a beach at the edge of the water and began to walk out into the ocean. As you walked, the water would get deeper for a while, but then it would become shallow again. The shallow water offshore lies above a sand bar, called the **longshore bar**, that forms in front of most beaches, as illustrated in *Figure 16-5*. Waves break on the longshore bar in the area known as the surf zone. The deeper water closer to shore than the longshore bar is called the longshore trough. The waves striking the beach are almost parallel to the shoreline, although the waves seaward of the longshore bar are generally not parallel to the shore. This is another case of wave refraction. The slowing of the waves in shallow water causes the wave crests to bend towards the shore. As water from incoming breakers spills over the longshore bar, a current flowing parallel to the shore, called the **longshore current**, is produced. This current varies in strength and direction from day to day. Over the course of a year, because of prevailing winds and wave patterns, one direction usually dominates.

Movement of Sediments Longshore currents move large amounts of sediments along the shore. Fine-grained material such as sand is suspended in the turbulent, moving water, and larger particles are pushed along the bottom by the current. Additional sediment is moved back and forth on the beach face by incoming and retreating waves. Incoming waves also move sediment at an angle to the shoreline in the direction of wave motion. Overall, the transport of sediment is in the direction of the longshore current. On both the Atlantic and Pacific Coasts of the United States, longshore transport is generally to the south.

Figure 16-6 Longshore currents (A) are driven by incoming waves. Rip currents (B) return water through gaps in the longshore bar out to sea. Rip currents spread out and weaken beyond the longshore bar.

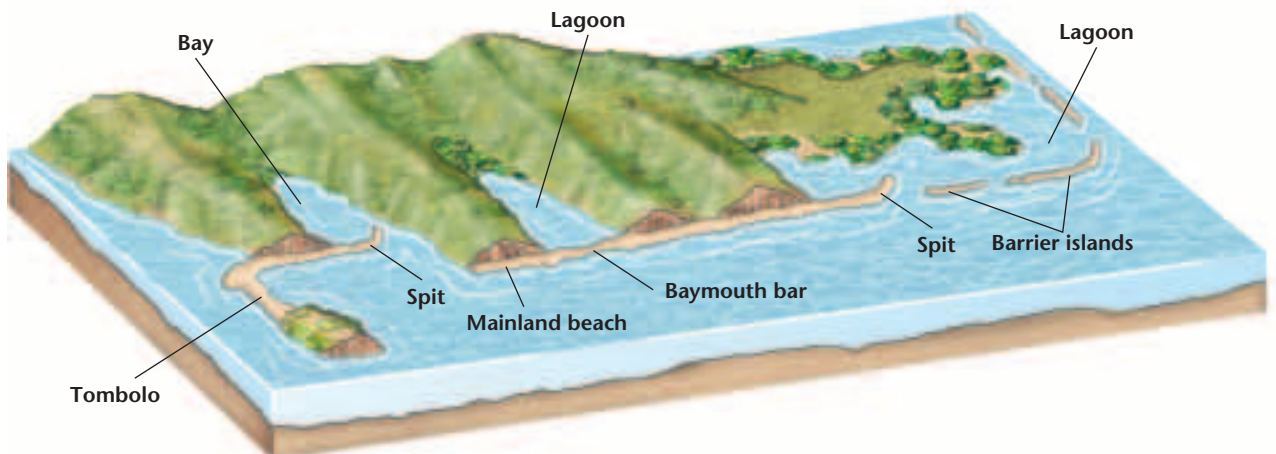


Rip Currents Wave action also produces rip currents, which flow out to sea through gaps in the longshore bar. Rip currents return the water spilled into the longshore trough to the open ocean. These dangerous currents can reach speeds of several kilometers per hour. If you are ever caught in a rip current, you should not try to swim against it, but rather swim parallel to the shore to get out of it. *Figure 16-6* illustrates both longshore and rip currents.

DEPOSITIONAL FEATURES OF SEASHORES

As a result of wave erosion, longshore transport, and sediment deposition, most seashores are in a constant state of change. Sediments are eroded by large storm waves and deposited wherever waves and currents slow down. Sediments moved and deposited by longshore currents build various characteristic coastal landforms, such as spits and barrier islands, illustrated in *Figure 16-7*. A narrow bank of sand that projects into the water from a bend in the coastline is called a spit. A spit, which forms where a shoreline changes direction, is protected from wave action. When a growing spit crosses a bay, a baymouth bar forms.

Figure 16-7 Depositional features of coastlines include spits, baymouth bars, lagoons, and barrier islands.

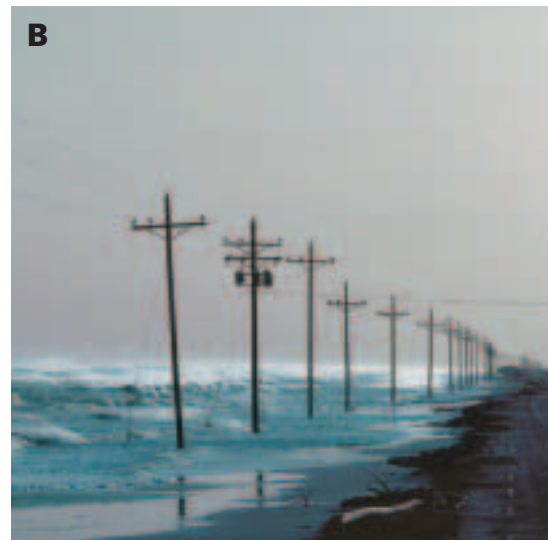


Barrier islands are long ridges of sand or other sediment, deposited or shaped by the longshore current, that are separated from the mainland. Barrier islands can be several kilometers wide and tens of kilometers long. Most of the Gulf Coast and the eastern coast south of New England are lined with an almost continuous chain of barrier islands. The shallow, protected bodies of water behind baymouth bars and barrier islands are called *lagoons*, which essentially are saltwater coastal lakes that are connected to the open sea by shallow, restricted outlets. Another, somewhat peculiar coastal landform is a *tombolo*, a ridge of sand that forms between the mainland and an island and connects the island to the mainland. When this happens, the island is no longer an island, but the tip of a peninsula.

All of these depositional coastal landforms, including large barrier islands, are unstable and temporary. Occasionally, major storms sweep away entire sections of barrier islands and redeposit the material elsewhere. Even in the absence of storms, however, changing wave conditions can slowly erode beaches and rearrange entire shorelines. For example, the shoreline of Cape Cod, Massachusetts, is retreating by as much as 1 m per year. *Figure 16-8* shows some results of retreating shorelines.

You may wonder how longshore transport can build coastal features that rise well above sea level. Several factors play a role in this. At high tide, a longshore current can deposit sediment on a beach so that it extends in the direction of the longshore current. In addition, storm waves can pile up submerged sediments to heights well above the level of the highest tides. Wherever sediments are exposed at low tide, winds pick up dry sand and build sand dunes.

Figure 16-8 Shore erosion during a storm undermined the cliffs on which these houses were built, along the coast of Pacifica, California (**A**). The ocean has eroded the beach near Galveston, Texas, to the extent that the bases of telephone poles along a beach road now are under water (**B**).

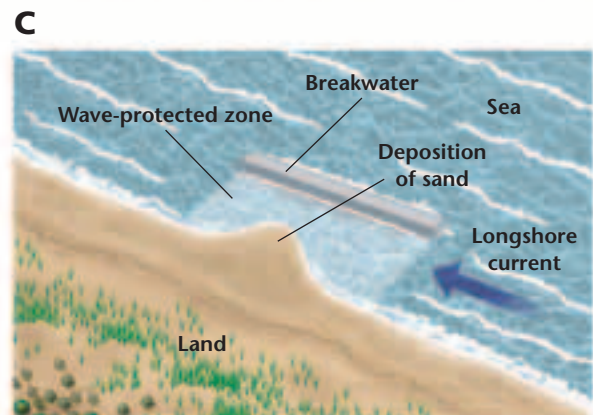
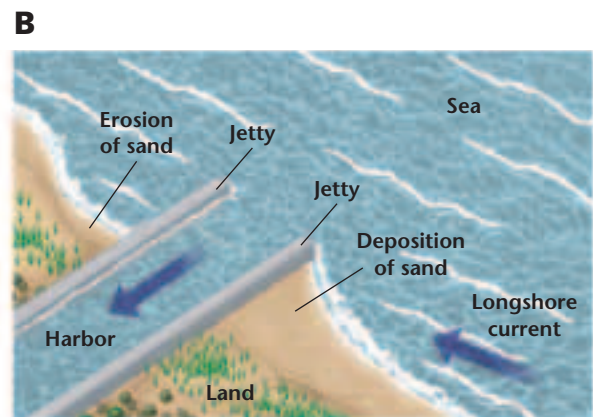


PROTECTIVE STRUCTURES

In many coastal areas, protective structures such as seawalls, groins, jetties, and breakwaters are built in an attempt to prevent beach erosion and destruction of oceanfront properties. **Figure 16-9** illustrates the effects of building structures in areas of longshore transport. These artificial structures interfere with natural shoreline processes and can have unexpected negative effects. For example, seawalls built along the shore to protect beachfront properties from powerful storm waves reflect the energy of such waves back towards the beach, where they worsen beach erosion. Eventually, seawalls are undercut and have to be rebuilt larger and stronger than before. Groins are wall-like structures built into the water perpendicular to the shoreline for the purpose of trapping beach sand. Groins interrupt natural longshore transport and deprive beaches down the coast of sand. The result is aggravated beach erosion down the coast from groins. Similar effects are caused by jetties, which are walls of concrete built to protect a harbor entrance from drifting sand. Jetties trap sand upshore from a harbor and prevent sand from reaching the beaches downshore. Eventually, sand drifts around the jetty and closes the harbor entrance anyway, unless it is removed periodically by dredging. Breakwaters are built in the water parallel to straight shorelines to provide anchorages for small boats.

Breakwaters affect the longshore current in much the same way as offshore islands do. The current slows down behind the breakwater and is no longer able to move its load of sediment, which is then deposited behind the breakwater. If the accumulating sediment is left alone, it will eventually fill the anchorage. To prevent this, all such anchorages have to be dredged regularly at great expense. In general, protective structures cause an overall loss of the sediments that maintain beaches.

Figure 16-9 The entrance to Channel Island Harbor in Oxnard, California, is protected by jetties and a breakwater **(A)**. Jetties deprive downshore beaches of sand **(B)**. Breakwaters cause beach sand to accumulate and eventually close the anchorage **(C)**.





Using Math

Using Numbers The highest point in the state of Florida is Walton County, at an elevation of just 105 m above sea level. If the sea level continues to rise at the highest estimated rate of 3.9 mm/y, in how many years will all of Florida be under water?

CHANGES IN SEA LEVEL

At the height of the last ice age, approximately 10 000 years ago, the global sea level was about 130 m lower than it is at present. Since that time, the melting of most of the ice-age glaciers has raised the ocean to its present level. In the last 100 years, the global sea level has risen 10 to 15 cm. It continues to rise slowly; estimates suggest a rise in sea level of 1.5 to 3.9 mm/year. Many scientists contend that this continuing rise in sea level is the result of global warming. Over the last century, Earth's average surface temperature has increased by approximately 0.5°C. As Earth's surface temperature rises, seawater warms up and as it warms, it also expands, which adds to the total volume of the seas. In addition, higher temperatures on Earth's surface cause glaciers to melt, and the meltwater flowing into the oceans increases their volume. Scientists predict that global sea levels could rise another 30 cm in the next 70 years.

Effects of Sea Level Changes If Earth's remaining polar ice sheets, in Greenland and Antarctica, melted completely, their meltwaters would raise sea level by another 70 m. This rise would totally flood some countries, such as the Netherlands, along with some coastal cities in the United States, such as New York City, and low-lying states such as Florida and Louisiana. Fortunately, this isn't likely to happen anytime soon. However, if Earth's surface temperature continues to rise, an unstable part of the Antarctic ice sheet eventually could melt and cause a rise in sea level of about 6 m. Many of the barrier islands of the Atlantic and Gulf Coasts may be former coastal dunes that were drowned by rising sea levels. Other features produced by rising sea levels are the fjords of Norway, shown in **Figure 16-10**. Fjords are deep coastal valleys that were scooped out by glaciers during the ice age and later flooded when these glaciers melted.

Figure 16-10 Fjords are flooded U-shaped valleys carved by glaciers. Fjords may be up to 1200 m deep.





Figure 16-11 This series of elevated marine terraces can be found on San Clemente Island in California.

Effects of Tectonic Forces Other processes that affect local sea levels are tectonic uplift and sinking. If a coastline sinks, there is a relative rise in sea level along that coast. A rising coastline, on the other hand, produces a relative drop in sea level. As a result of tectonic forces in the western United States, much of the West Coast is being pushed up much more quickly than the sea level is rising. Because much of the West Coast was formerly under water, it is called an emergent coast. Emergent coasts tend to be relatively straight because the exposed seafloor topography is much smoother than typical land surfaces with hills and valleys. Other signs of an emergent coast are former shoreline features such as sandy beach ridges located far inland. Among the most interesting of these features are elevated marine terraces, former wave-cut platforms that are now high and dry, well above current sea level. **Figure 16-11** shows striking examples of such platforms. Some old wave-cut platforms in southern California are hundreds of meters above current sea level. You will identify an emergent coast in the *Mapping GeoLab* at the end of this chapter.

SECTION ASSESSMENT

1. Irregular shorelines have headlands and bays. Which of these experiences the most severe erosion by breakers? Why?
2. What are sea stacks, and how are they formed?
3. What effect does a seawall have on a beach?
4. If a coast has elevated marine terraces, is it rising or sinking? Explain.
5. **Thinking Critically** Resort communities such as Ocean City, Maryland, are built on

barrier islands. These communities spend thousands of dollars each year to add sand to the beaches along the shoreline. Explain why this is necessary.

SKILL REVIEW

6. **Predicting** Are rip currents most dangerous on calm days, on stormy days with winds blowing from the land, or on stormy days with winds blowing from the ocean? Explain. For more help, refer to the *Skill Handbook*.

OBJECTIVES

- **Explain** the reason for the existence of continents and ocean basins.
- **Compare** the major geologic features of continental margins and ocean basins.
- **Describe** the different types of marine sediments and their origin.

VOCABULARY

continental margin
 continental shelf
 continental slope
 turbidity current
 continental rise
 abyssal plain
 deep-sea trench
 mid-ocean ridge
 seamount

If you were asked to draw a map of the seafloor, what kind of topographic features would you include? Until recently, most people had little knowledge of the features of the ocean floor. However, modern oceanographic techniques, including satellite imagery, reveal that the topography of the ocean bottom is as varied as that of the continents. *Appendix C* on pages 912–913 shows the major features of the seafloor that have been revealed by modern scientific methods.

OCEANIC AND CONTINENTAL CRUST

The topography of the seafloor is surprisingly rough and irregular, with numerous high mountains and deep depressions. The deepest place on the seafloor, the Marianas Trench in the Pacific Ocean, is just over 11 km deep. This is deeper than the height of Mount Everest, the tallest mountain on Earth.

Recall that Earth has two types of crust: continental crust, with an average thickness of 40 km; and thin oceanic crust, with an average thickness of 6 or 7 km. Crustal elevation depends on crustal thickness, and thus the thick continental crust is always associated with higher elevations on land, and the thin oceanic crust is always associated with the deep ocean basins. You will find out more about surface elevations on Earth in the *Problem-Solving Lab* on the next page. Note that part of the continental section is actually below sea level and that the ocean covers parts of the continents. These submerged parts of continents are called **continental margins**. They represent the shallowest parts of the ocean. As shown in *Figure 16-12*, a continental margin includes

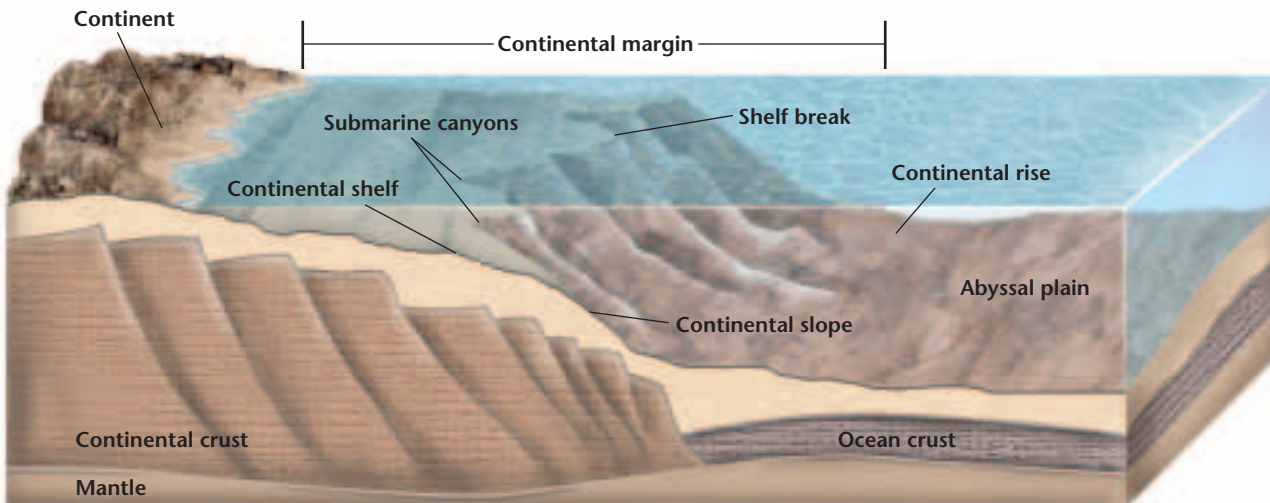


Figure 16-12 The major features of the continental margin are illustrated in this diagram.

the continental shelf, the continental slope, and the continental rise. Study *Figure 16-12* as you read about the features in this section.

CONTINENTAL SHELVES

The continental margins are the areas where the edges of continents meet the ocean. The shallowest part of a continental margin extending seaward from the shore is the **continental shelf**. Although continental shelves vary greatly in width, the average width is 60 km. On the Pacific Coast of the United States, the continental shelf is only

Problem-Solving Lab

Interpreting Graphs

Compare surface elevations A useful comparison of the heights of the continents to the depths of the oceans is given by the curve in the graph below. Note that the curve has two relatively flat sections, one near sea level, and another at a depth of about 5 km. The flat section near sea level represents the continents; the lower flat section represents the ocean basins.

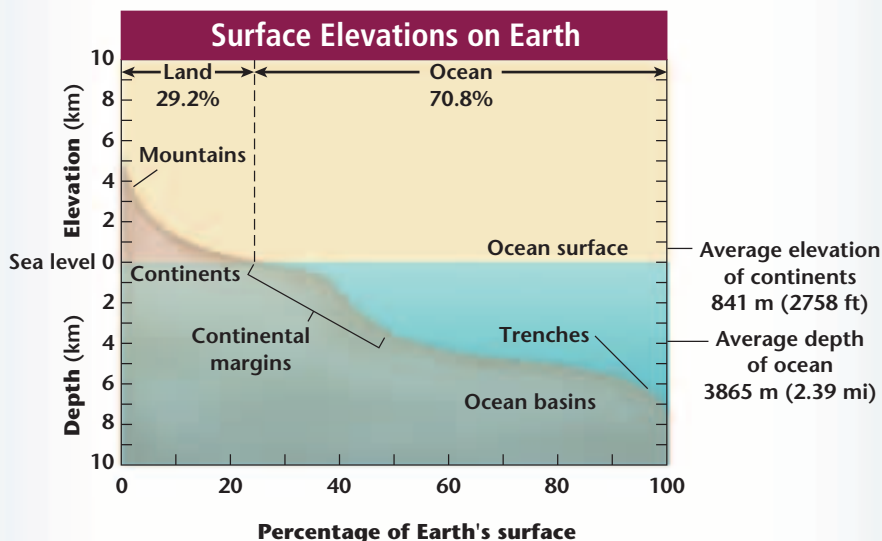
Analysis

1. How tall is the highest mountain on Earth's surface in km approximately?
2. At about what depth would you begin to find trenches on the ocean floor?

3. What percentage of Earth's surface is above current sea level?
4. What percentage of Earth's surface is represented by the continental margin?

Thinking Critically

5. The oceanic crust is that part of the crust that is at a depth of 2 km or more below sea level. What percentage of Earth's surface lies above the oceanic crust?
6. What is the total average difference in surface elevations on Earth?



a few kilometers wide, whereas the continental shelf of the Atlantic Coast is hundreds of kilometers across. The average depth of the water above continental shelves is about 130 m. Recall that sea level during the last ice age was some 130 m lower than at present; therefore, most of the world's continental shelves must have been above sea level at that time. As a result, present day coastlines are radically different from the way they were during the last ice age. At that time, Siberia was attached to North America by the Bering land bridge, Great Britain was attached to Europe, and a large land mass existed where today there are only the widely scattered islands of the Bahamas. When Earth's surface began to warm after the last ice age, and the continental ice sheets began to melt, the sea gradually covered up the continental shelves. Beaches, river valleys, and other coastal landforms from that time are now submerged and located far beyond the present shoreline. Large numbers of commercially valuable fishes now inhabit the shallow, nutrient-rich waters of the continental shelves. In addition, the thick sedimentary deposits on the shelves are significant sources of oil and natural gas.

CONTINENTAL SLOPES

Beyond the continental shelves, the seafloor drops away quickly to depths of several kilometers, with slopes averaging nearly 100 m/km. These sloping regions are the **continental slopes**. To geologists, the continental slope is the true edge of a continent because it generally marks the edge of the continental crust. In many places, this slope is cut by deep submarine canyons, similar to canyons on land, some of which are comparable in size to the Grand Canyon of Arizona. How do you think these canyons formed? On land, canyons like these are cut by rivers. But the sea level never dropped below the edge of the continental shelves, and the water from freshwater rivers flowing into the ocean is less dense than seawater, which means that it floats at the ocean's surface and thus cannot erode the seafloor. These submarine canyons were cut by **turbidity currents**, which are rapidly flowing water currents along the bottom of the sea that carry heavy loads of sediments, similar to mudflows on land. Turbidity currents, illustrated in *Figure 16-13*, may originate as underwater landslides on the continental slope that are triggered by earthquakes, or they may originate from sediment stirred up by large storm waves on the continental shelf. Once formed, a turbidity current can reach speeds exceeding 30 km/h and effectively erode bottom sediments and bedrock. The sediments carried down the

Figure 16-13 Turbidity currents flow along the seafloor because the seawater-sediment mixture of the current is denser than seawater alone.

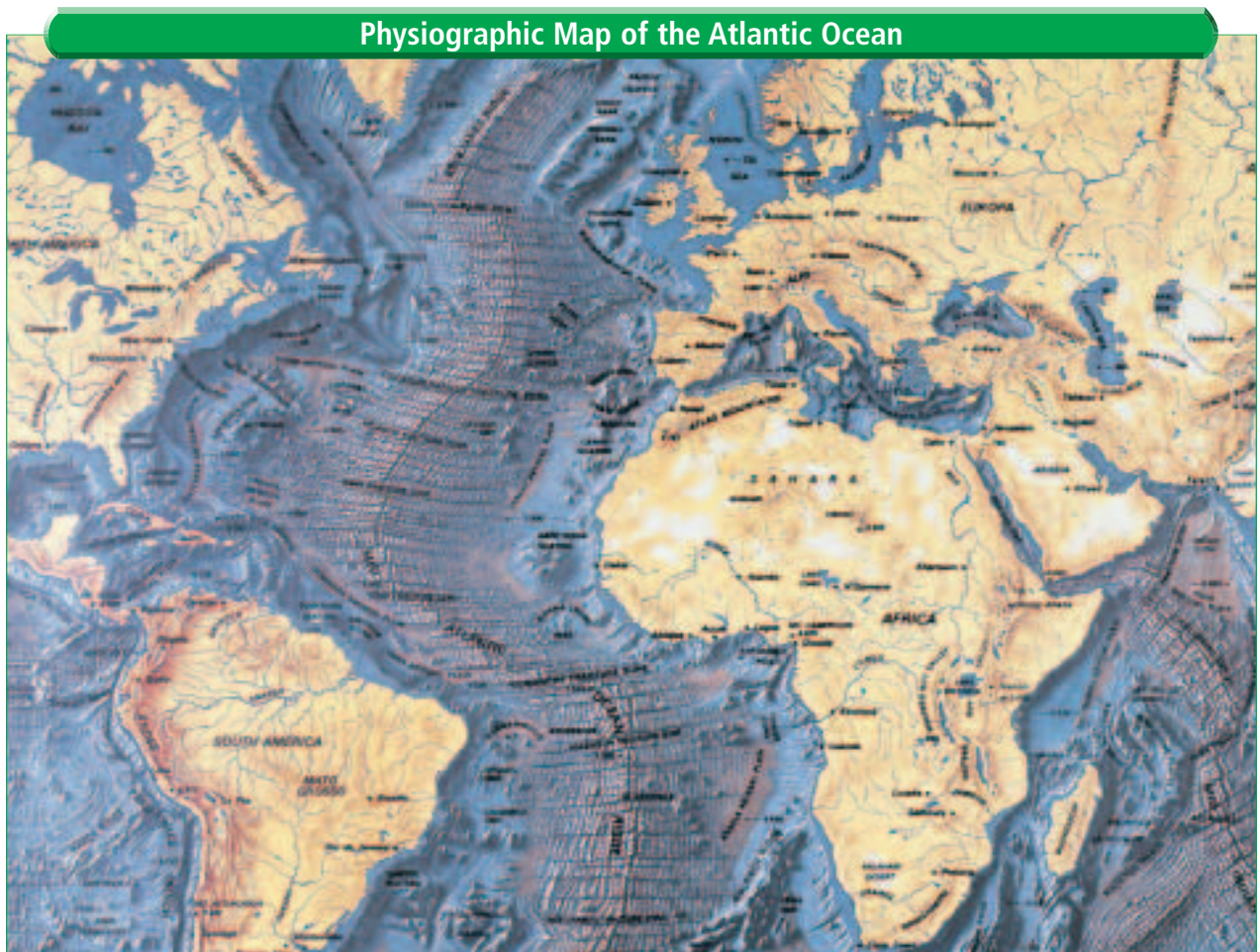


continental slope by these currents eventually come to rest at the bottom of the slope and beyond. The gently sloping accumulation of deposits from turbidity currents that forms at the base of the continental slope is called a **continental rise**. A continental rise may be several kilometers thick. The rise gradually gets thinner and eventually merges with the sediments of the seafloor beyond the continental margin. In some places, especially around the Pacific Ocean, the continental slope ends in deeper depressions, known as deep-sea trenches, in the seafloor. In such places, there is no continental rise at the foot of the continental margin.

OCEAN BASINS

Beyond the continental margin are ocean basins, which are deeper parts of the seafloor that lie above the thin, basaltic, oceanic crust. Ocean basins represent about 60 percent of Earth's surface and contain some of Earth's most interesting topography. *Figure 16-14* shows the topography of the ocean basin beneath the Atlantic Ocean.

Figure 16-14 Features of the ocean basin can be identified in this physiographic map of the Atlantic Ocean.



circumference. Mid-ocean ridges have an average height of 1500 m, but they may be thousands of kilometers wide. The highest peaks in mid-ocean ridges are over 6 km tall and emerge from the ocean as volcanic islands. Mid-ocean ridges are sites of frequent volcanic eruptions and earthquake activity. The crests of these ridges often have valleys called rifts running through their centers. Rifts may be up to 2 km deep.

Mid-ocean ridges do not form continuous lines. The mid-ocean ridges break into a series of shorter, stepped sections, which run at right angles across each mid-ocean ridge. The areas where these breaks occur are called fracture zones. Fracture zones are about 60 km wide, and they curve gently across the seafloor, sometimes for thousands of kilometers. Volcanic and earthquake activity occurs frequently in fracture zones. Some volcanic islands, such as the Azores in the Atlantic Ocean and the Galápagos Islands in the Pacific Ocean, lie along fracture zones.

Hydrothermal Vents Have you ever heard of hydrothermal vents on the seafloor? A hydrothermal vent is a hole in the seafloor through which fluid heated by magma erupts. Most hydrothermal vents are located along the bottom of the rifts in mid-ocean ridges. When the heated fluid that erupts from these vents contains metal oxides and sulfides, they immediately precipitate out of the fluid and produce thick, black, smokelike plumes. This type of hydrothermal vent, known as a black smoker, ejects superheated water with temperatures of up to 350°C. *Figure 16-16* illustrates the black smokers found in the rift valley of a mid-ocean ridge. A second type of vent, known as a white smoker, ejects warm water. Smokers are caused by seawater circulating through the hot crustal rocks in the centers of mid-ocean ridges. The fundamental cause of mid-ocean ridges and the volcanic activity associated with them is plate tectonics, which will be discussed in Chapter 17.

SEAFLOOR VOLCANOES

Satellite radar imagery has revealed that the ocean floor is dotted with tens of thousands of solitary mountains. These mountains are not located near areas of active volcanism. How, then, did they form? You have learned that the ocean basins are volcanically active at mid-ocean ridges and fracture zones. The almost total absence of earthquakes in most other areas of the seafloor suggests that volcanism in those areas must have ceased a long time ago. Thus, most of the mountains on the



Figure 16-16 Unique communities of organisms can be found around black smokers.



Topic: Organisms

To learn more about hydrothermal vent communities, visit the Earth Science Web Site at earthgeu.com

Activity: Research the types of organisms found near hydrothermal vents. List four types of organisms found in these communities.

MiniLab

How fast do sediment grains sink?

Investigate how grain size affects settling speed.



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

1. Obtain five round pebbles and sand grains with approximate diameters of 0.5 mm, 1 mm, 2 mm, 5 mm, and 10 mm.
2. Draw a data table in your science journal with these headings: Type of Particle, Diameter (mm), Distance (cm), Time (sec), Settling Speed (cm/s).
3. Measure the diameters of each specimen using a set of sieves. Record these measurements in your data table.
4. Fill a 250-mL graduated cylinder with cooking oil.
5. Drop the largest specimen into the oil. Measure the time it takes for the specimen to sink to the bottom of the cylinder. If the specimen doesn't fall quickly, measure the time it takes to fall a given distance. Record this time in your data table.
6. Repeat step 5 for the remaining specimens.
7. Calculate the settling speed for each specimen and fill in your data table.
8. Plot the settling speed (cm/s) against particle diameter (mm) on a graph.

Analyze and Conclude

1. How do settling speeds change as particle sizes decrease?
2. How much faster does a 10-mm particle sink compared to a 1-mm particle?
3. How long would it take a 1-mm sand grain and a 0.001-mm clay particle to settle to the bottom of the ocean at a depth of 5 km?

seafloor probably are extinct volcanoes. Investigations of individual volcanoes on the seafloor have revealed that there are two types: seamounts and guyots. **Seamounts** are submerged basaltic volcanoes more than 1 km high. Many linear chains of seamounts are stretched out across the Pacific Ocean Basin in roughly the same direction. Guyots, also called tablemounts, are large, extinct, basaltic volcanoes with flat, submerged tops.

While extinct volcanoes on land erode within a few million years, this doesn't happen on the deep seafloor, because currents are generally too weak to erode solid rock and no other mechanisms of erosion exist. Once they are formed, seafloor structures persist practically forever. The only process that modifies them after they are formed is sedimentation; the oldest seamounts are covered with thick marine sediments.

MARINE SEDIMENTS

The sediments that cover the ocean floor come from a variety of sources, but most come from the continents. Land-derived sediments include mud and sand washed into the oceans by rivers, as well as dust and volcanic ash blown over the ocean by winds. Much of the coarser material supplied by rivers settles out near shorelines or on beaches, but fine-grained material such as silt and clay settles so slowly through water that some tiny particles take centuries to reach the bottom. You will examine how quickly sediment settles in the *MiniLab* on this page.

Ocean currents disperse fine silt, clay, and volcanic ash throughout the ocean basins, and thus the dominant type of sediment on the deep ocean floor is fine-grained, deep-sea mud. Deep-sea mud usually has a reddish color because the iron present in some of the sediment grains becomes oxidized during their journey to the ocean bottom. Closer to

land, the sediments become mixed with coarser materials such as sand, but some sandy sediments occasionally reach the abyssal plains in particularly strong turbidity currents.

Ooze Another major source of deep-sea sediments is the shells and hard parts of marine organisms. You can find out more about one marine organism in the *Science & the Environment* feature at the end of this chapter. When these organisms die, their shells rain down on the ocean floor and accumulate there. Sediments containing a large percentage of particles derived from once-living organisms are called oozes. Most of these particles are small and consist of either calcium carbonate or silica.

The oozes and deep-sea muds of the deep ocean typically accumulate at a rate of only a few millimeters per thousand years. Although the wreck of the *Titanic* has been resting on the ocean bottom since 1912, it has acquired a fine dusting of sediments barely a fraction of a millimeter thick.

Manganese Nodules Another type of sediment, manganese nodules consist of oxides of manganese, iron, copper, and other valuable metals that precipitated directly from seawater. Their growth rates are incredibly slow, and thus they are measured in millimeters per million years. Manganese nodules usually resemble potatoes of variable sizes, as shown in *Figure 16-17*, and cover huge areas of the seafloor.

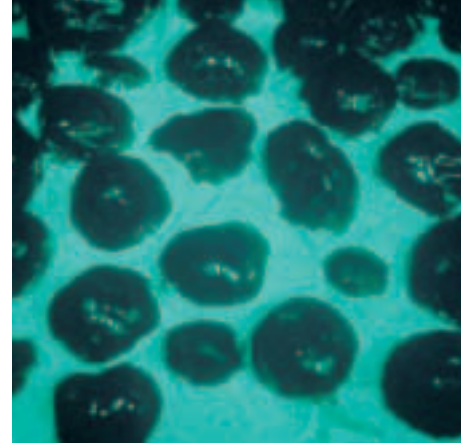


Figure 16-17 Scientists estimate that manganese nodules such as these cover 20 to 50 percent of the Pacific seafloor.

NATIONAL GEOGRAPHIC

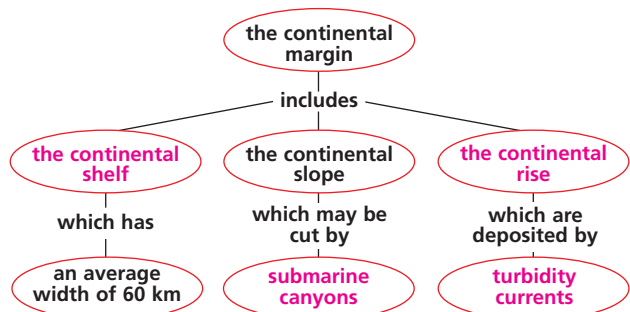
To learn more about the *Titanic*, go to the [National Geographic Expedition](#) on page 880.

SECTION ASSESSMENT

1. What is the relationship between crustal thickness and surface elevation?
2. How are submarine canyons formed?
3. Which sediment grains sink faster, pebbles or sand grains?
4. What is the difference in origin between deep-sea muds and oozes?
5. **Thinking Critically** If there is little volcanic activity on abyssal plains, yet they are dotted with thousands of seamounts, where did these extinct volcanoes come from?

SKILL REVIEW

6. **Concept Mapping** Use the following terms to complete the concept map below: the continental shelf, the continental rise, turbidity currents, submarine canyons. For more help, refer to the *Skill Handbook*.



Identifying Coastal Landforms

Topographic maps of coastal areas show a two-dimensional representation of coastal landforms. You can identify an emergent coast by the landforms along the coastline as well as landforms found inland.

Preparation

Problem

How can you identify and describe the coastal landforms of an emergent coast on a topographic map?

Materials

metric ruler graph paper
drafting compass calculator
pencil

Procedure

1. Determine the map scale and the contour interval.
2. On the inset map, plot a west-east cross section of the coast just north of Islay Creek from the 60 ft depth contour to a point 5000 feet inland. Use a scale of 1:24 000 and a vertical exaggeration of 4.
3. Use both maps to answer the following questions.

Analyze

1. What kind of coastal landform is the Morro Rock Peninsula?
2. What kind of feature is Pillar Rock, and how was it formed?
3. On what coastal feature is Morro Bay State Park located? How was the feature formed?
4. What are the irregular sand hills in Morro Bay State Park?
5. What is the direction of the longshore transport along Morro Bay? Explain.
6. Your west-east cross section shows an elevated flat area next to the shoreline. What kind of coastal landform is this? How was it formed?
7. If sea level dropped 10 m, how would the shoreline change? How far would it move seaward? Would it become more regular or irregular? What would happen to Morro Bay?
8. If sea level rose 6 m, how would the coastal region change? Name three major changes.

Conclude & Apply

1. Is this portion of the California coast emergent or submergent? What features of this coastline provide evidence for your answer?



Science & the Environment



Deep Sea Dangler

Imagine the darkest darkness, the coldest cold, the heaviest pressure. Off in the distance, there is a light, a tiny pinprick of white. It acts as a beacon, drawing you forward. You approach the light with curiosity, when—suddenly—you are pulled forward into the belly of a giant beast. That is the experience of a tiny fish being eaten by a bigger fish deep beneath the ocean's surface.

The animal luring its prey out of the dark with its own light is an anglerfish. Light from the Sun only penetrates to a depth of about 200 m. Below that depth, organisms such as the anglerfish often create their own light.

A Fishing Fish

Like a human angler with a fishing rod, an anglerfish dangles bait in the water from a fin on its back that sticks out in front of the fish. The tip of the fin glows—which is an exciting sight in the darkness. Curious fishes are attracted to the light. Slowly, the anglerfish pulls the bait—and its dinner—closer and closer to its mouth. When it opens its huge jaws, water rushes into its mouth. The prey animal is caught up in the current and ends up in the anglerfish's stomach.

Food is scarce in the deep ocean, so fishes can't afford to let any food go by, even food that seems too big. Deep-sea fishes may have mouths lined with teeth that slant backwards so dinner can't get out once it is caught. Many of these fish also have expandable stomachs. Some deep-sea fishes scavenge for food near the surface at night, but spend the day in the ocean depths. These fishes are eaten by predators like the anglerfish, which stay below 900 m in depth all the time.

Anglerfish Life Cycle

Anglerfish lay eggs in the deep ocean. The eggs float to the ocean surface, where they hatch. The young drift downward until, by maturity, they are submerged in darkness. Male anglerfish are tiny; they attach to the side of the female. In the darkness, this is a way for these fish to make sure that they find a mate. The female is the only one that glows; thus, she does all the fishing and eating for both of them. The male gets food from her bloodstream.

Glowing From Within

Below 1800 m, every swimming animal glows in some way. Living things that glow are bioluminescent. Bioluminescence is a cold light produced by living things. Many bioluminescent fishes get their light from glowing bacteria that live in the fishes. In this symbiotic association, the bacteria get food from the fish, and the bacteria lure food for the fish.

Activity

Use library resources or go to earthgeu.com to research food chains that end with a deep-sea predator such as the anglerfish. Make a diagram of one of these food chains.

CHAPTER 16

Study Guide

Summary

SECTION 16.1

Shoreline Features



Main Ideas

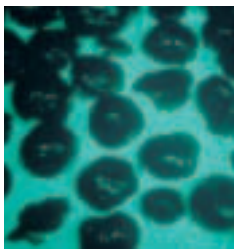
- Wave erosion of headlands produces wave-cut platforms and cliffs, sea stacks, sea arches, and sea caves. Wave refraction concentrates breaker action on headlands.
- Beaches consist of loose sediment deposited along the shoreline. Wave action and longshore currents move sediment along the shore and build barrier islands and other depositional features. Artificial protective structures interfere with longshore transport.
- Sea levels in the past were 130 m lower than at present. When the land is rising, coasts are emergent and relatively straight.

Vocabulary

barrier island (p. 418)
beach (p. 415)
estuary (p. 415)
longshore bar (p. 416)
longshore current (p. 416)
wave refraction (p. 414)

SECTION 16.2

The Seafloor



Main Ideas

- The oceans cover the thin oceanic crust and the lower parts of the thicker continental crust. The submerged part of a continent is the continental margin, the shallowest part of the ocean.
- A continental margin consists of the continental shelf, the continental slope, and the continental rise. Turbidity currents cut submarine canyons in the continental slopes and deposit their sediments in the form of continental rises.
- The flat part of the seafloor is the abyssal plain. Most deep-sea trenches are in the Pacific Ocean. Mid-ocean ridges extend through all ocean basins. Countless active and extinct volcanoes are on the mid-ocean ridges and deep seafloor.
- Most deep-sea sediments are fine-grained and accumulate slowly. Sediments may be derived from land or living organisms, or they may precipitate from seawater. Oozes are rich in sediment derived from organisms. Deep-sea muds are mostly derived from the land. Manganese nodules are precipitated from seawater.

Vocabulary

abyssal plain (p. 426)
continental margin (p. 422)
continental rise (p. 425)
continental shelf (p. 423)
continental slope (p. 424)
deep-sea trench (p. 426)
mid-ocean ridge (p. 426)
seamount (p. 428)
turbidity current (p. 424)

CHAPTER 16 Assessment

Understanding Main Ideas

- Which coastal features are usually found in the bays along irregular coasts with headlands?
 - sea stacks
 - wave-cut cliffs
 - wave-cut platforms
 - beaches
- Which of the following coastal landforms is NOT produced by longshore transport?
 - a barrier island
 - a sand spit
 - a baymouth bar
 - an estuary
- What percentage of Earth's surface is below sea level?
 - 10 percent
 - 30 percent
 - 50 percent
 - 70 percent
- What do the sediments of the abyssal plains mostly consist of?
 - sand and gravel
 - oozes
 - seashells
 - mud
- Where are most deep-sea trenches located?
 - in the Atlantic Ocean
 - in the Indian Ocean
 - in the Pacific Ocean
 - in the Arctic Ocean
- Which is the longest mountain system on Earth?
 - the Hawaii-Emperor seamount chain
 - the mid-ocean ridge system
 - the Himalayas
 - the Rocky Mountains
- Which letter indicates the continental shelf?
 - A
 - B
 - C
 - D
- Which feature is indicated by the letter A?
 - a guyot
 - a continental slope
 - a continental rise
 - an estuary
- Under which circumstances do waves move faster?
 - in shallow water
 - over the longshore bar
 - in deep water
 - behind breakwaters
- Which features are not caused by differential erosion?
 - wave-cut platforms
 - barrier islands
 - sea stacks
 - sea arches
- Which marks the true edge of a continent?
 - submarine canyon
 - continental slope
 - continental shelf
 - abyssal plain
- Which seafloor feature can be found along rifts in the mid-ocean ridges?
 - hydrothermal vents
 - manganese nodules
 - deep sea trenches
 - seamounts

Use the map below to answer questions 7 and 8.



Test-Taking Tip

PROCESS OF ELIMINATION On any multiple-choice test, there are two ways to find the correct answer to each question. You can either choose the right answer immediately or you can eliminate the answers that you know are wrong. It may be easier to find wrong answers than right ones. Find the ones you know are wrong and cross them out. You may be surprised at how few choices are left!

CHAPTER 16 Assessment

13. Which represents the flattest part of Earth's surface?
- a. deep-sea trenches
 - b. continental margins
 - c. abyssal plains
 - d. mid-ocean ridges
14. Which features of the seafloor are cut by turbidity currents?
- a. longshore bars
 - b. submarine canyons
 - c. abyssal plains
 - d. baymouth bars
15. Which is not associated with mid-ocean ridges?
- a. black smokers
 - b. guyots
 - c. fracture zones
 - d. hydrothermal vents

Applying Main Ideas

16. Describe the effect that wave refraction has on incoming wave crests that approach the shore of a straight coast at an angle.
17. Explain how incoming waves along a shoreline create the longshore current.
18. Is global sea level currently rising, falling, or staying the same? During the last ice age, was the sea level higher, lower, or the same as at present? Explain.
19. Explain the relationship between oozes and the sedimentary rock known as chalk.
20. Why are the continental shelves considered part of the continents when they are presently covered by the oceans?

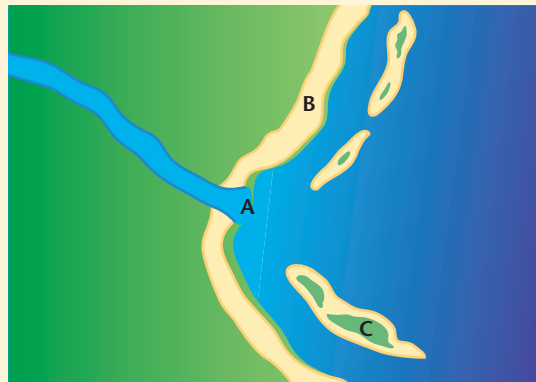
Thinking Critically

21. Is it possible to have submergent coasts when global sea level is falling? Explain your reasoning.
22. Why are submergent coasts more irregular than emergent coasts?
23. Why do geologists think that seamounts are extinct volcanoes?

Standardized Test Practice

INTERPRETING SCIENTIFIC ILLUSTRATIONS

Use the illustration below to answer questions 1–5.



1. What shoreline feature is indicated by letter A?
- a. a barrier island
 - b. a spit
 - c. an estuary
 - d. a bay
2. What type of water typically would be found in the area indicated by letter A?
- a. freshwater
 - b. salt water
 - c. brackish water
 - d. very cold water
3. What shoreline feature is indicated by letter B?
- a. a tombolo
 - b. a spit
 - c. a lagoon
 - d. a beach
4. What shoreline feature is indicated by letter C?
- a. a barrier island
 - b. the longshore bar
 - c. an estuary
 - d. a beach
5. Which of these forms the area indicated by letter C?
- a. large storm waves
 - b. gaps in the longshore bar
 - c. the longshore current
 - d. a rip current

UNIT 4

GeoDigest

For a **preview** of Earth's atmosphere and oceans, study this GeoDigest before you read the chapters. After you have studied these chapters, you can use the GeoDigest to **review** the unit.

The Atmosphere and the Oceans

Atmosphere

Atmospheric Basics Earth's atmosphere is made up primarily of nitrogen and oxygen. The atmosphere consists of several layers of different temperatures. The lowest layer, the troposphere, is the most important for weather. In this layer, temperatures generally decrease with altitude. Solar energy absorbed by Earth's surface is transferred through the atmosphere by radiation, conduction, and convection. The weight of air exerts a force called atmospheric pressure. In the troposphere, atmospheric pressure generally decreases with increasing altitude. Wind is the movement of air resulting from differences in pressure. Wind speed is affected by friction. Clouds form when warm, moist air is forced upward, expands, and cools. Clouds are classified according to the altitudes at which they form and according to their shapes. Precipitation such as rain, snow, sleet, and hail occurs when cloud droplets collide to form larger droplets. The water cycle is the continual movement of water between Earth's surface and the atmosphere through the processes of evaporation, condensation, and precipitation.

Meteorology

Weather Basics Meteorology is the study of the atmosphere. Weather is the current state of the atmosphere. Climate is the average of weather patterns of an area over a long period of time. Differing amounts of solar radiation received by different parts of Earth lead to uneven heating; the motion of water and air balances this heat. The



Lightning

Coriolis effect deflects air and, with the heat imbalance, creates global wind systems. An air mass is a body of air that takes on the same characteristics as the land over which it formed. A front is the boundary between two air masses. High-pressure systems cause fair weather. Low-pressure systems cause precipitation and clouds.

Weather Analysis Accuracy and density of data are important in forecasting weather. Balloon-borne instruments called radiosondes collect data about temperature, pressure, humidity, wind speed, and wind direction from high in the atmosphere. Weather radar locates precipitation, while Doppler radar measures wind speed. Weather satellites use visible light and infrared imagery to record weather. Symbols are used with station models to record weather for a given place and time. Isobars and isotherms are used on weather maps to connect lines of equal pressure and equal temperature, respectively.

Most modern forecasts use digital forecasting methods. Analog forecasting compares current and past weather patterns.

The Nature of Storms

Severe Weather Abundant moisture in the lower atmosphere, a mechanism to lift the moisture, and unstable air are necessary for a thunderstorm to form. The way in which the air rises—whether by the unequal heating of Earth’s surface or by the push of an advancing front—determines the type of storm that develops. The three stages of a thunderstorm are the cumulus stage, the mature stage, and the dissipation stage. Thunderstorm hazards include lightning, violent winds, hail, floods, and tornadoes. The Fujita tornado intensity scale classifies tornadoes. The Saffir-Simpson hurricane scale rates hurricane intensity.

Climate

Climatic Basics Climate is the long-term weather pattern of a region and includes annual variations of temperature, precipitation, and wind. Data covering at least 30 years are averaged on a monthly or yearly basis to determine a region’s normals. Latitude, topography, bodies of water, moisture, wind patterns, ocean currents, and air masses are factors that influence climate. The tropical latitudes are always warm. The temperate zones have moderate climates. Polar zones are always cold.



Time lapse photo of a hurricane

Climatic Changes Climatic changes are indicated by fossils, ice cores, and other evidence. Ice ages, or periods of extensive glacial coverage, are examples of long-term climatic changes. Seasons are examples of short-term climatic changes. Climatic changes may be caused by changes in solar activity, the tilt of Earth’s axis, Earth’s orbit, and volcanic eruptions. Some human activities may cause climatic change. Global warming may be caused by a rise in atmospheric carbon dioxide. The burning of fossil fuels and deforestation may contribute to global warming, but scientists are still investigating its causes.

Vital Statistics

Deadliest Hurricanes of the Twentieth Century (Western Hemisphere)

Location	Year	Lives Lost
Hurricane Mitch, Central America	1998	11 000
Galveston, Texas	1900	8000
Hurricane Fifi, Honduras	1974	8000
Dominican Republic	1930	8000
Hurricane Flora, Haiti and Cuba	1963	7200



British Virgin Islands

Physical Oceanography

The Oceans The first oceans probably formed more than 4 billion years ago. The water may have come from impacting comets or from volcanic eruptions which released water from Earth's interior. About 71 percent of Earth's surface is covered by oceans. Seawater is 96.5 percent water and 3.5 percent dissolved salts, which are added and removed from the ocean at the same rate. Seawater density changes with temperature and salinity. Water temperature decreases with depth, forming three layers. Ocean waves are generated by wind. Water in a wave moves in a circular motion but does not move forward. When waves reach shallow water they become breakers. Tides are caused by the gravitational attraction of the Sun and the Moon. Density currents are deep currents caused by differences in temperature and salinity. Upwelling occurs when winds push surface water aside and it is replaced by cold, deep water.

The Marine Environment

Shoreline and Seafloor Wave erosion and refraction shape shorelines. Beaches are made of loose sediment deposited along shorelines. Longshore currents move sediment along the shore, building barrier islands and other depositional

features. Sea level has changed over time. The submerged part of a continent is the continental margin. The oceans cover thinner, oceanic crust. The flat part of the seafloor is the abyssal plains. Deep-sea trenches are found mainly in the Pacific Ocean. Mid-ocean ridges extend through all ocean basins. Active and inactive volcanoes are found on mid-ocean ridges and the seafloor. Deep-sea sediments are fine-grained and accumulate slowly. They may be derived from land or living organisms or may precipitate out of seawater.

FOCUS ON CAREERS

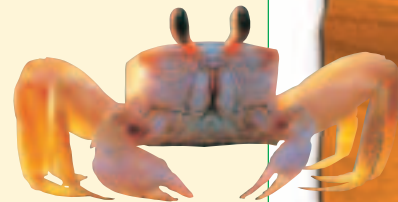
Mariculturist

Mariculturists farm marine organisms such as salmon, oysters, mussels, clams, scallops, shrimp, crayfish, prawns, and seaweed. Marine organisms may be sold as food or they may be raised for research purposes. Many mariculturists have a degree in fisheries. Some mariculturists receive advanced training in field techniques and biology of the species that they plan to raise.

ASSESSMENT

Understanding Main Ideas

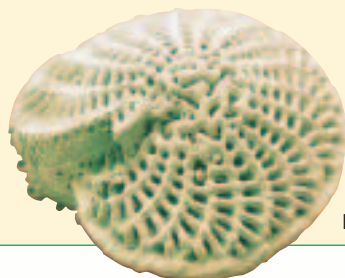
1. What forms when warm, moist air is forced upward, expands, and cools?
 - a. clouds
 - b. density currents
 - c. atmospheric pressure
 - d. altitude
2. What happens to atmospheric pressure in the troposphere with increasing altitude?
 - a. It gets thicker.
 - b. It gets warmer.
 - c. It increases.
 - d. It decreases.
3. What do we call the average weather patterns for an area over a long period of time?
 - a. the Coriolis effect
 - b. meteorology
 - c. climate
 - d. pressure systems
4. What kind of imagery do satellites use to record weather from space?
 - a. analog
 - b. infrared
 - c. symbolic
 - d. directional
5. What helps shape the shoreline?
 - a. waves
 - b. reflection
 - c. atmospheric pressure
 - d. solar energy
6. Which scale is used to classify tornadoes?
 - a. the Fujita intensity scale
 - b. the Saffir-Simpson scale
 - c. the Richter scale
 - d. the heat index
7. How many years of weather are usually averaged together to determine a region's normals?
 - a. 3
 - b. 30
 - c. 300
 - d. 3000
8. Which of the following provides evidence of climatic change?
 - a. deforestation
 - b. fossil fuels
 - c. tilt of Earth's orbit
 - d. ice cores
9. What percentage of Earth is covered by water?
 - a. 3.5 percent
 - b. 7.1 percent
 - c. 35 percent
 - d. 71 percent
10. What is the flat part of the seafloor called?
 - a. abyssal plain
 - b. deep-sea trench
 - c. continental margin
 - d. mid-ocean ridge



Fiddler crab

Thinking Critically

1. If a meteorologist wanted to know how fast a storm was moving, would he or she use traditional weather radar or Doppler radar? Why?
2. You watch a wave approach the shore. Is the water that breaks onshore the same water that you observed offshore? Explain your answer.
3. Suppose you collected a sample of deep-sea sediments. How could you determine the derivation of these sediments?



Foraminifera