Chapter 25

Movements of the Ocean

Chapter Outline

1 Ocean Currents

Factors That Affect Surface Currents

Major Surface Currents

Deep Currents

2 Ocean Waves

Wave Energy

Waves and the Coastline

Tsunamis

3 Tides

The Causes of Tides

Behavior of Tides

Tidal Variations

Tidal Currents

Why It Matters

Both surface currents and deep currents move heat around Earth. This affects climates worldwide.

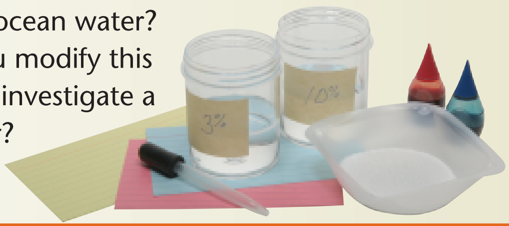
Inquiry Lab **Creating Currents**

15 min

Fill a **clear cup** half full with **3% salt solution,** which is dyed red using **food coloring.** Fill a **second cup** half full with **10% salt solution,** which is dyed blue. Using a **dropper,** slowly add some of the 10% salt solution to the cup containing the 3% salt solution. Hold the end of the dropper near the edge of the cup, right at the water level. You will need to refill the dropper several times. Observe and record what happens. Repeat the experiment, this time adding some of the 3% salt solution to the cup containing the 10% salt solution.

Questions to Get You Started

1. What is density? Explain how adding salt to water changes the density of the water.
2. Explain your observations. How are your observations related to the movement of ocean water?
3. What other factors might affect the density and movement of ocean water? How could you modify this experiment to investigate a different factor?



READING TOOLBOX

These reading tools will help you learn the material in this chapter.

Word Families

Tide You will soon learn many new terms that contain the word *tide* or *tidal*. Both *tide* and *tidal* come from *tid,* the Old English word for "time." The suffix *-al,* meaning "of" or "like," makes *tidal* an adjective. As you read this chapter, you will see some familiar words combined with *tide* or *tidal*, along with their definitions.

Your Turn As you read Section 3, start a table like the one below. Add all the key terms and italicized words that include either *tide* or *tidal,* and write down the definitions of these terms and words, and compare them to each other.

Term	Definition
tidal current	a horizontal movement of water with the tide, toward and away from the coastline

Cause and Effect

Signal Words Certain words and phrases, called markers, can signal cause-and-effect relationships.

Cause markers	Effect markers
cause	therefore
affect	thus
as a result of	as a result
due to	is an effect of
because	consequently

Sentences can also express cause-and-effect relationships, without using markers.

Your Turn As you read Sections 1 and 2, create a table like the one below. When you find a cause-and-effect relationship, add it to your table.

Cause	Effect	Marker
the uneven heating of the atmosphere	winds	caused by

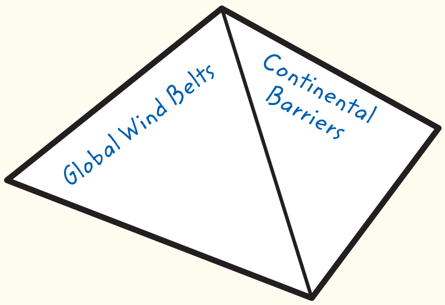
FoldNotes

Pyramid A pyramid can be used to summarize information in three categories, on the three sides of the pyramid.

Your Turn Create a pyramid, as described in Appendix A.

1. Along one edge of one side of the FoldNote, write "Global Wind Belts."
2. On one edge of another side, write "Continental Barriers."
3. On one edge of the third side, write "The Coriolis Effect."

As you read Section 1, fill in details about the three factors that influence surface currents.



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

SECTION 1 Ocean Currents

Key Ideas	Key Terms	Why It Matters
❯ Describe how wind patterns, the rotation of Earth, and continental barriers affect surface currents in the ocean. ❯ Identify the major factor that determines the direction in which a surface current circulates. ❯ Explain how differences in the density of ocean water affect the flow of deep currents.	**current** **surface current** **Coriolis effect** **gyre** **Gulf Stream** **deep current**	Spending time near the coast would let you experience the effects of ocean currents on the local climate. Ocean currents have a large impact on climates around the world.

The water in the ocean moves in giant streams called **currents.** Many ocean currents are complex and difficult to trace. Oceanographers identify ocean currents by studying the physical and chemical characteristics of the ocean water. They also identify currents by mapping the path of debris that is dumped or washed overboard from ships, as shown in **Figure 1.** From these data, scientists have mapped a detailed pattern of ocean currents around the world. Scientists place ocean currents into two major categories: surface currents and deep currents.

Factors That Affect Surface Currents

Currents that move at or near the surface of the ocean and are driven by wind are called **surface currents.** Surface currents are controlled by three factors: air currents, Earth's rotation, and the location of the continents.

All surface currents are affected by wind. Wind is caused by the uneven heating of the atmosphere. Variations in air temperature lead to variations in air density and pressure. Colder, denser air sinks and forms areas of high pressure. Air moves away from high-pressure areas to lower pressure areas. This movement gives rise to wind.

Because *wind* is moving air, wind has kinetic energy. The wind passes this energy to the ocean as the air moves across the ocean surface. As energy is transferred from the air to the ocean, the water at the ocean's surface begins to move.

current a horizontal movement of water in a well-defined pattern, such as a river or stream

surface current a horizontal movement of ocean water that is caused by wind and that occurs at or near the ocean's surface

Figure 1 Glass floats, which are used to hold up Japanese fishing nets, have been carried by surface currents from off the coast of Japan to this beach in northwest Hawaii.

Global Wind Belts

Global wind belts, such as the trade winds and westerlies shown in **Figure 2**, are a major factor affecting the flow of ocean surface water. The *trade winds* are located just north and south of the equator. In the Northern Hemisphere, the trade winds blow from the northeast. In the Southern Hemisphere, they blow from the southeast. In both hemispheres, trade-wind belts push currents westward across the tropical latitudes of all three major oceans.

The *westerlies* are located in the middle latitudes. In the Northern Hemisphere, westerlies blow from the southwest. In the Southern Hemisphere, they blow from the northwest. Westerlies push ocean currents eastward in the higher latitudes of the Northern and Southern Hemispheres.

Coriolis effect the curving of the path of a moving object from an otherwise straight path due to Earth's rotation

gyre a huge circle of moving ocean water found above and below the equator

Continental Barriers

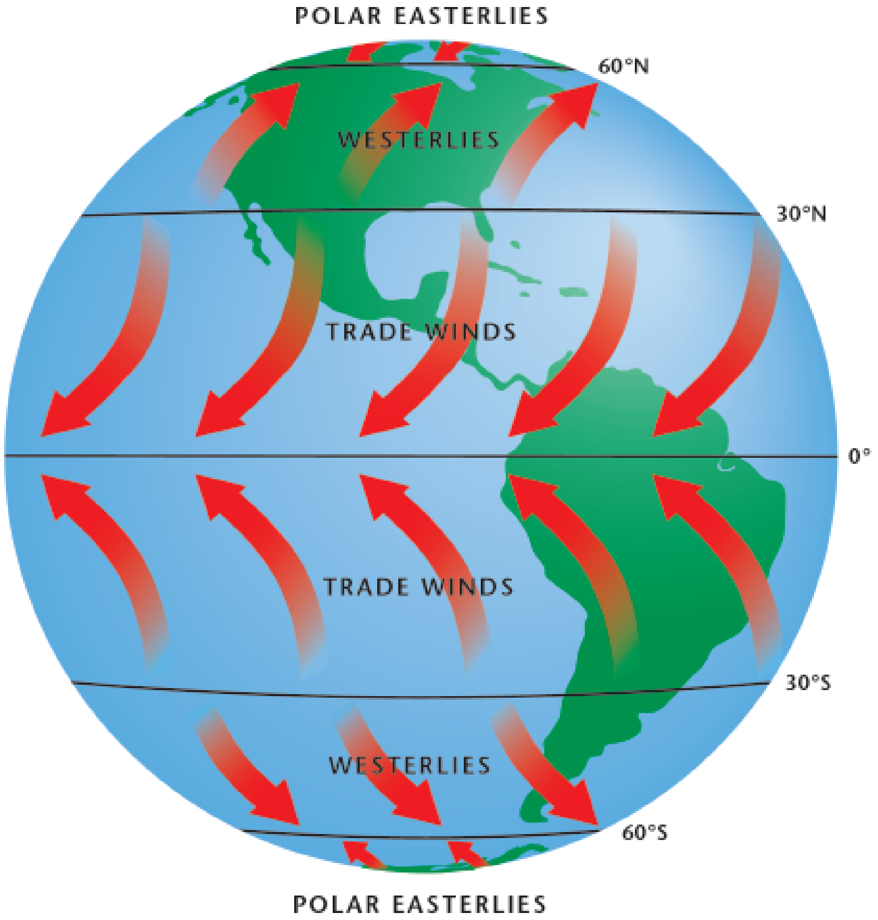
The continents are another major influence on surface currents. The continents act as barriers to surface currents. When a surface current flows against a continent, the current is deflected and divided.

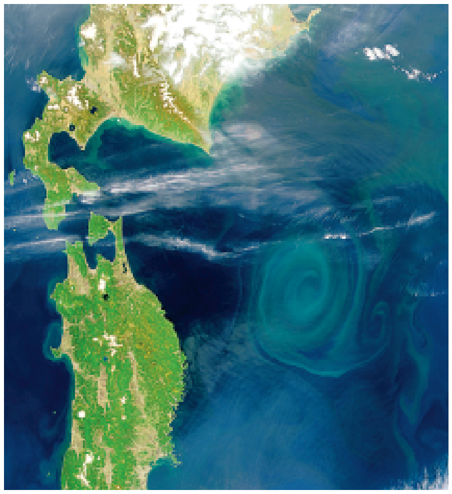
The Coriolis Effect

As Earth spins on its axis, ocean currents and wind belts curve. The curving of the paths of ocean currents and winds due to Earth's rotation is called the **Coriolis effect.** The wind belts and the Coriolis effect cause huge circles of moving water, called **gyres,** to form.

Figure 3 shows the five main gyres in the ocean. In the Northern Hemisphere, water in the main gyres flows clockwise. In the Southern Hemisphere, water in the main gyres flows counterclockwise.

Figure 2 Global winds and the Coriolis effect together drive the surface currents of the oceans in great circular patterns. The photo at the right shows a small gyre in the Pacific Ocean, off the east coast of Japan.





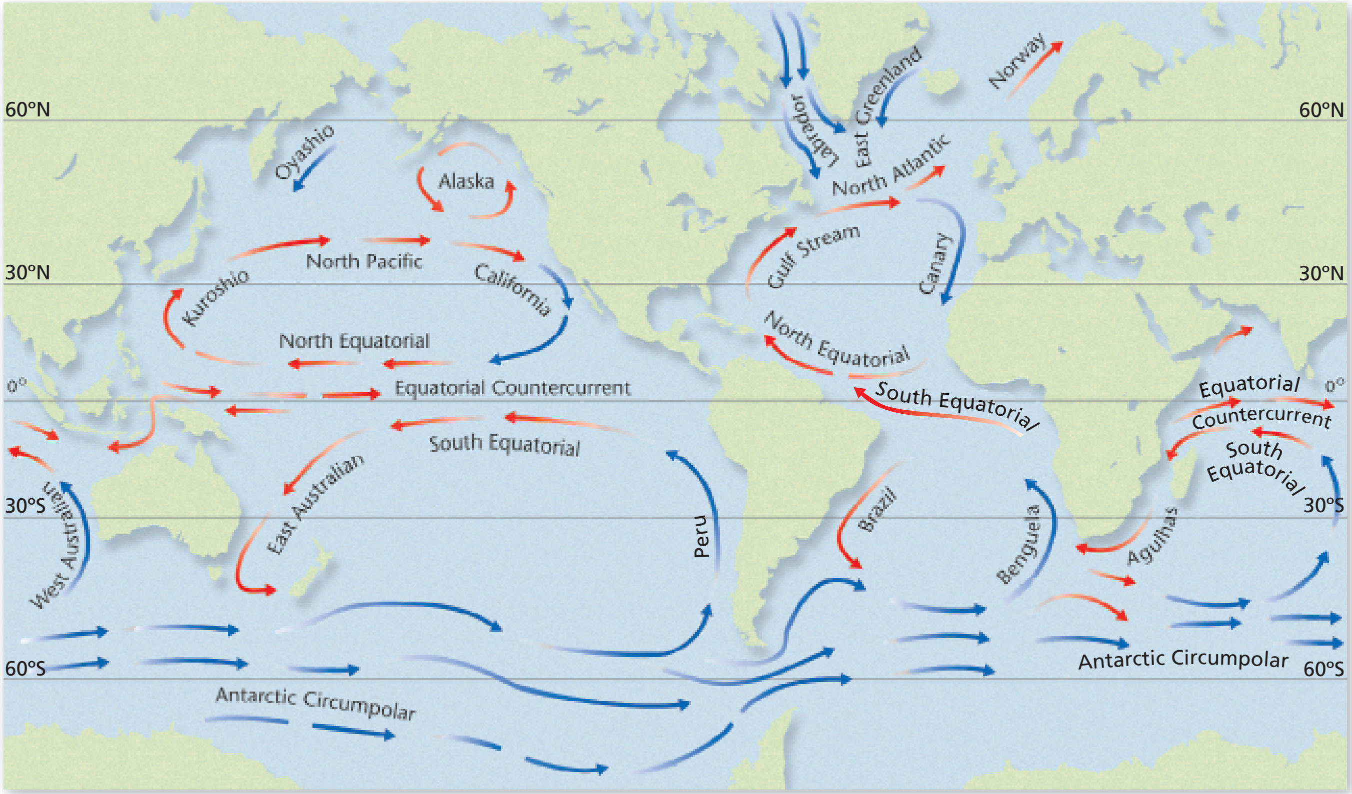


Figure 3 This map shows the major surface currents in the oceans of the world. Warm-water currents are shown in red; cold-water currents are shown in blue.

Major Surface Currents

The major surface currents of the world are shown in **Figure 3.** The major currents in the equatorial region and in the Northern and Southern Hemispheres are described below.

Equatorial Currents

Warm equatorial currents are located in the Atlantic, Pacific, and Indian Oceans. Each of these oceans has two warm-water equatorial currents that move in a westward direction. Between these westward-flowing currents lies a weaker, eastward-flowing current called the *Equatorial Countercurrent*.

Currents in the Southern Hemisphere

In the Southern Hemisphere, the currents in the main gyres move counterclockwise. In the most southerly regions of the oceans, constant westward winds produce the world's largest current, the *Antarctic Circumpolar Current*, also known as *West Wind Drift*. No continents interrupt the movement of this current, which completely circles Antartica and crosses all three major oceans.

The Indian Ocean surface currents follow two patterns. Currents in the southern Indian Ocean follow a circular, counterclockwise gyre. Currents in the northern Indian Ocean are governed by *monsoons*, winds whose directions change seasonally.

Reading Check **What is the world's largest ocean current?** (See Appendix G for answers to Reading Checks.)

Academic Vocabulary

major (MAY juhr) of great importance; large scale

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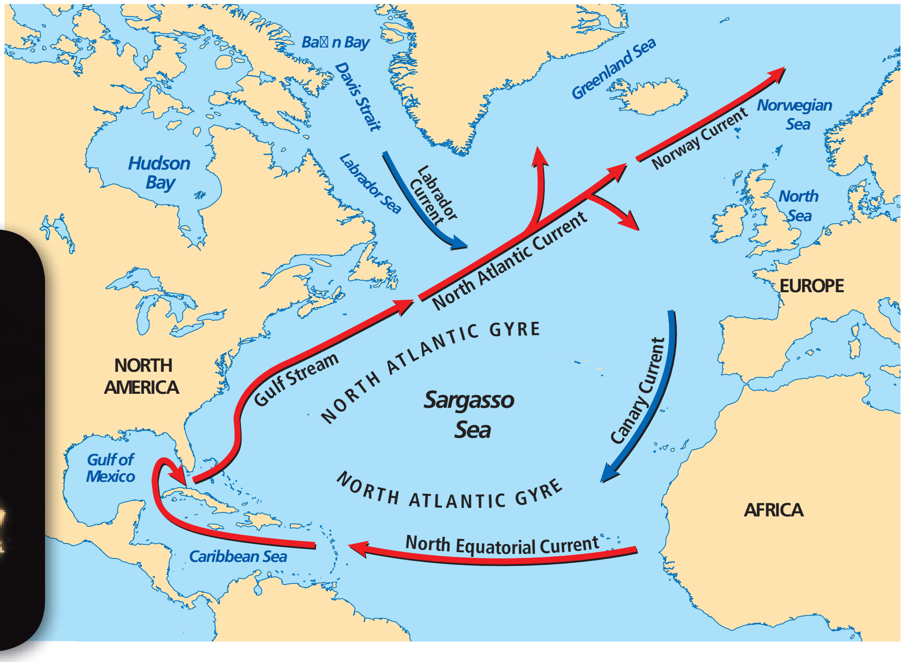
Figure 4 Surface currents in the Atlantic Ocean form the North Atlantic Gyre. The Sargasso Sea results from this pattern of currents. The organisms below are commonly found in the Sargasso Sea.



Gulf Stream the swift, deep, and warm Atlantic current that flows along the eastern coast of the United States toward the northeast

Quick Lab

10 min

Ocean Currents

Procedure

1. Fill a shallow pan with water.
2. Sprinkle paper confetti on the surface of the water.
3. Blow across the surface of the water through a drinking straw to produce a clockwise current.
4. Blow through the straw to make a counterclockwise current. Try to make two currents at the same time.

Analysis

1. Draw a diagram of the currents. Draw the straw's positions, and use arrows to show air and water direction.
2. How does this activity relate to what happens in ocean currents?

Currents in the North Atlantic

In the North Atlantic Ocean, warm water moves through the Caribbean Sea and Gulf of Mexico and then north along the east coast of North America in a swift, warm current called the **Gulf Stream.** Farther north, the cold-water Labrador Current, which flows south, joins the Gulf Stream. South of Greenland, the Gulf Stream widens and slows until it becomes a vast, slow-moving warm current known as the *North Atlantic Current*. Near western Europe, the North Atlantic Current splits. One part becomes the Norway Current, which flows northward along the coast of Norway and keeps that coast ice-free all year. The other part is deflected southward and becomes the cool Canary Current, which eventually warms and rejoins the North Equatorial Current.

As **Figure 4** shows, the Gulf Stream, the North Atlantic Current, the Canary Current, and the North Equatorial Current form the North Atlantic Gyre. At the center of this gyre lies a vast area of calm, warm water called the *Sargasso Sea*. The Sargasso Sea is named after *sargassum*, the brown seaweed that floats on the surface of the water in this area. The pattern of winds and currents around the Sargasso Sea concentrates all kinds of floating debris, such as orange peels and plastic cups, in this area.

Currents in the North Pacific

The pattern of currents in the North Pacific is similar to that in the North Atlantic. The warm Kuroshio Current, the Pacific equivalent of the Gulf Stream, flows northward along the east coast of Asia. This current then flows toward North America as the North Pacific Drift. It eventually flows southward along the California coast as the cool California Current.

Deep Currents

In addition to having wind-driven surface currents, the ocean has **deep currents,** cold, dense currents far below the surface. Deep currents move much more slowly than surface currents do. Deep currents form as cold, dense water of the polar regions sinks and flows beneath warmer ocean water.

The movement of polar waters is a result of differences in density. When water cools, it contracts and the water molecules move closer together. This contraction makes the water denser, and the water sinks. When water warms, it expands and the water molecules move farther apart. The warm water is less dense, so it rises above the cold water. Temperature helps determine density.

Salinity, too, helps determine the density of water. The water in polar regions has high salinity because of the large amount of water frozen in icebergs and sea ice. When water freezes, the salt in the water does not freeze but stays in the unfrozen water. So, unfrozen polar water has a high salt concentration and is denser than water that has a lower salinity. This dense polar water sinks and forms a deep current that flows beneath less dense surface currents, as shown in **Figure 5.**

deep current a streamlike movement of ocean water far below the surface

Antarctic Bottom Water

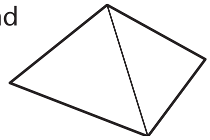
The temperature of the water near Antarctica is very cold, –2°C. The water's salinity is high. These two factors make the water off the coast of Antarctica the densest and coldest ocean water in the world. This dense, cold water sinks to the ocean bottom and forms a deep current called the *Antarctic Bottom Water*. The Antarctic Bottom Water moves slowly northward along the ocean bottom for thousands of kilometers to a latitude of about 40°N. It takes hundreds of years for the current to make the trip.

Reading Check **Why is Antarctic Bottom Water the densest ocean water in the world?**

READING TOOLBOX

Pyramid

Create a pyramid to compare three examples of currents in the deep ocean: Antarctic Bottom Water, North Atlantic Deep Water, and Turbidity Currents. Be sure to note the similarities and differences among the currents.



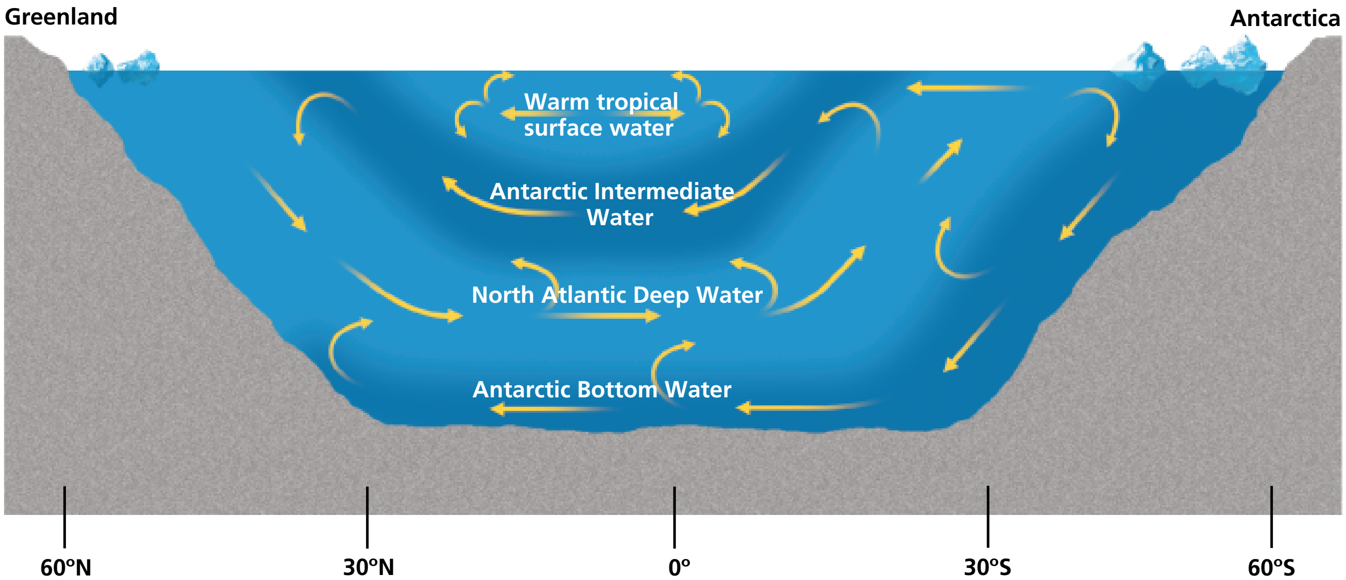


Figure 5 The very dense and highly saline Antarctic Bottom Water travels beneath less dense North Atlantic Deep Water.

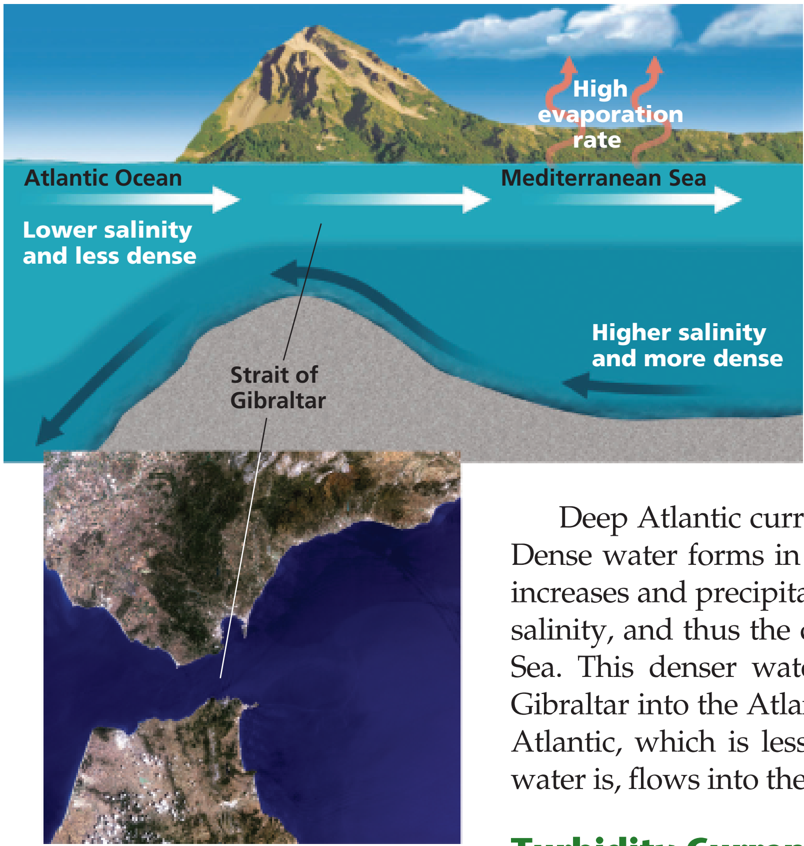


Figure 6 The dense, highly saline water of the Mediterranean Sea forms a deep current as it flows through the Strait of Gibraltar and into the less dense Atlantic Ocean.

North Atlantic Deep Water

In the North Atlantic, south of Greenland, the water is very cold and has a high salinity. This cold, salty water forms a deep current that moves southward under the northward-flowing Gulf Stream. Near the equator, this deep current divides. One part begins to rise, reverse direction, and flow northward again. The rest of the current continues southward toward Antarctica and flows over the colder, denser Antarctic Bottom Water.

Deep Atlantic currents exist near the Mediterranean Sea, too. Dense water forms in the Mediterranean Sea when evaporation increases and precipitation decreases. These changes increase the salinity, and thus the density, of the water of the Mediterranean Sea. This denser water sinks and flows through the Strait of Gibraltar into the Atlantic Ocean. In turn, surface water from the Atlantic, which is less saline and less dense than deep current water is, flows into the Mediterranean Sea, as shown in **Figure 6.**

Turbidity Currents

A turbidity current is a strong current caused by an underwater landslide. Turbidity currents occur when large masses of sediment that have accumulated along a continental shelf or continental slope suddenly break loose and slide downhill. The landslide mixes the nearby water with sediment. The sediment causes the water to become cloudy, or turbid, and denser than the surrounding water. The dense water of the turbidity current moves beneath the less dense, clear water.

Section 1 Review

Key Ideas

1. **Describe** the force that drives most surface currents.
2. **Identify** the winds that affect the surface currents on both sides of the equator.
3. **Identify** the winds that affect the surface currents in the middle latitudes.
4. **Describe** how density affects the flow of deep currents.
5. **List** the factors that affect the density of ocean water.
6. **List** three major surface currents and two major deep currents.

Critical Thinking

7. **Predicting Consequences** Describe how surface currents would be affected if Earth did not rotate.
8. **Identifying Relationships** Explain how the distribution of solar energy around Earth affects ocean surface currents.

Concept Mapping

9. Use the following terms to create a concept map: *ocean currents, surface currents, deep currents, Gulf Stream, North Atlantic Current, Antarctic Bottom Water, gyres,* and *Coriolis effect.*

SECTION 2

Ocean Waves

Key Ideas	Key Terms	Why It Matters
❯ Describe the formation of waves and the factors that affect wave size. ❯ Explain how waves interact with the coastline. ❯ Identify the cause of destructive ocean waves.	**wave** **wave period** **fetch** **refraction**	Ocean waves, whether small or large, have similar characteristics, which sometimes can cause trouble for people.

A **wave** is a periodic disturbance in a solid, liquid, or gas as energy is transmitted through the medium. One kind of wave is described as the periodic up-and-down movement of water. Such a wave has two basic parts—a *crest* and a *trough*—as shown in **Figure 1.** The crest is the highest point of a wave. The trough is the lowest point between two crests. The *wave height* is the vertical distance between the crest and the trough of a wave. The *wavelength* is the horizontal distance between two consecutive crests or between two consecutive troughs. The **wave period** is the time required for two consecutive wave crests to pass a given point. The speed at which a wave moves is calculated by dividing the wave's wavelength by its period.

$$\textit{wave speed} = \frac{\textit{wavelength}}{\textit{wave period}}$$

wave a periodic disturbance in a solid, liquid, or gas as energy is transmitted through a medium

wave period the time required for identical points on consecutive waves to pass a given point

Wave Energy

The uneven heating of Earth's atmosphere causes pressure differences that make air move. This moving air is called *wind*. Wind then transfers the energy received from the sun to the ocean and forms waves. Small waves, or ripples, form as a result of friction between the moving air and the water. As a ripple receives more energy from the wind, the ripple grows into a larger wave. The longer that the wind blows from a given direction, the more energy that is transferred from the wind to the water and the larger the wave becomes.

The smoothness of the ocean's surface is generally disrupted by many small waves moving in different directions. Because of their large surface area, larger waves receive more energy from the wind than smaller waves do. Thus, larger waves grow larger, and smaller waves die out.

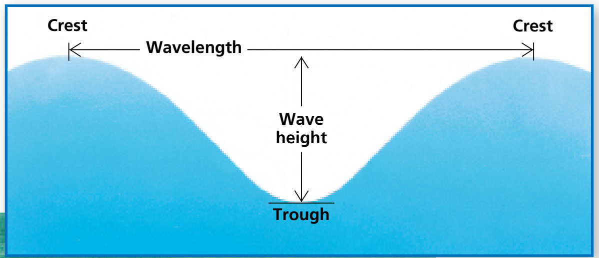


Figure 1 The vertical distance between the crest and the trough of a wave is the wave height.

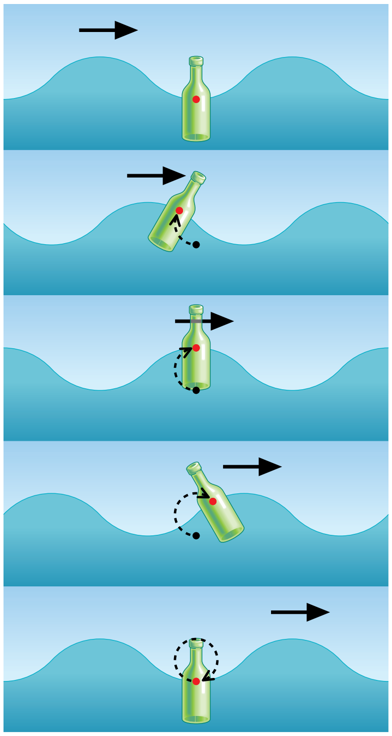


Figure 2 Like the bottle in this diagram, water molecules do not travel horizontally through the water with the wave.

Water Movement in a Wave

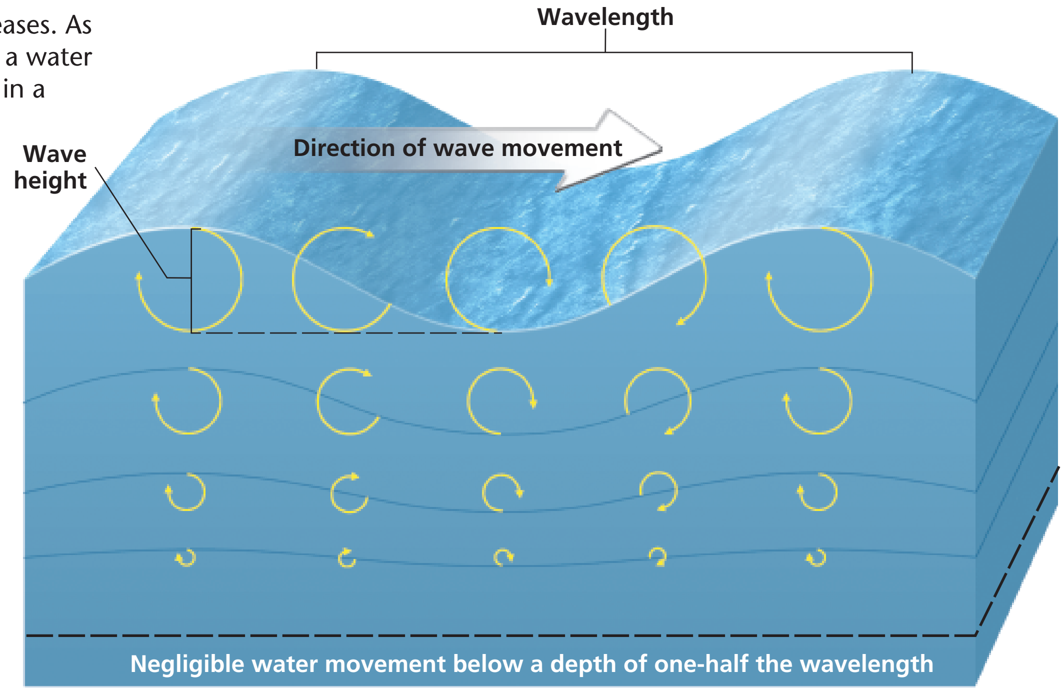
Although the energy of a wave moves from water molecule to water molecule in the direction of the wave, the water itself moves very little. This fact can be demonstrated by observing the movement of a bottle floating on the water as a wave passes. The bottle appears to move up and down, but it moves in a circular path, as shown in **Figure 2.** As the wave passes, the bottle moves only a small distance.

As a wave moves across the surface of the ocean, only the energy of the wave, not the water, moves in the direction of the wave. The water molecules within the wave move in a circular motion. During a single wave period, each water particle moves in one complete circle. At the end of the wave period, a circling water particle ends up almost exactly where it started.

As a wave passes a given point, the circle traced by a water particle initially on the surface of the ocean has a diameter that is equal to the height of the wave. Because waves receive their energy from wind pushing against the surface of the ocean, the energy received decreases as the depth of the water increases. As a result, water at various depths receives varying amounts of energy. Thus, the diameter of a water molecule's circular path decreases as the depth of the water increases, as shown in **Figure 3.** Below a depth of about one-half the wavelength, there is almost no circular motion of water molecules.

Reading Check **Why does the diameter of a water molecule's circular path in a wave decrease as depth increases?**

Figure 3 Wave energy decreases as depth increases. As a result, the diameter of a water molecule's circular path in a wave also decreases.



Wave Size

Three factors determine the size of a wave. These factors are the speed of the wind, the length of time that the wind blows, and fetch. **Fetch** is the distance that the wind can blow across open water. Very large waves are produced by strong, steady winds blowing across a long fetch.

During a storm, steady high winds can cause some waves to gather enough energy to become very large. Strong, gusty winds, on the other hand, produce choppy water that has waves of various heights and lengths, which may come from various directions. Nevertheless, the size of a wave will increase to only a certain height-to-length ratio before the wave collapses.

On calm days, small, smooth waves move steadily across the ocean's surface. One of a group of long, rolling waves that are of similar size is called a *swell*. Swells move in groups in which one wave follows another. Swells that reach the shore may have formed thousands of kilometers out in the ocean.

Figure 4 Whitecaps, such as the ones shown here off the coast of North Carolina, may form during storms.

fetch the distance that wind blows across an area of the sea to generate waves

Academic Vocabulary

collapse (kuh LAPS) fall or cave in

Whitecaps

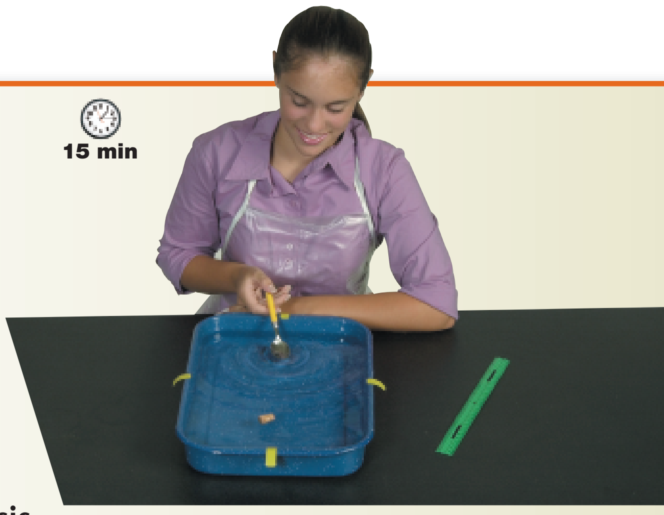
When winds blow the crest of a wave off, *whitecaps* form, as shown in **Figure 4.** Because whitecaps reflect solar radiation, they allow less radiation to reach the ocean. Scientists have been studying how this characteristic may affect climate.

Quick Lab — Waves

15 min

Procedure

1. Fill a rectangular pan (40 cm × 30 cm × 10 cm) with water to a depth of 7 cm.
2. Float a cork near the center of the pan. On each side of the pan, mark the location of the cork with a small piece of tape.
3. Hold a spoon in the water at one end of the pan. Carefully move the spoon up and down in the water to make a slow, regular pattern of waves.
4. Observe the movement of the cork for 1 min. Sketch how the cork moves in relation to the waves.
5. Remove the cork from the pan.
6. Use the spoon to make a strong, steady series of waves.
7. Remove the spoon from the pan. Observe what happens when the waves reach the edges of the pan. Write down or sketch what you observe.



Analysis

1. Describe the motion of the cork when a wave passes.
2. How does the cork move relative to the tape on the sides of the pan? Explain your answer.
3. When a wave breaks on the shore, the water is carried in the direction of the wave. Based on your observations in step 4, does this statement contradict your model? Explain your answer.

READING TOOLBOX

Word Families
In this section are several terms that belong to the word family of the key term *wave*. Create a table for these terms, similar to the table described at the beginning of the chapter. Complete your table by writing definitions for these terms in your own words.

Waves and the Coastline

In shallow water near the coastline, the bottom of a wave touches the ocean floor. A wave touches the ocean floor where the depth of the water is about half the wavelength. Contact with the ocean floor causes the wave to slow and eventually break, as shown in **Figure 5.**

Breakers

The height of a wave changes as the wave approaches the coastline. The water involved in the motion of a wave extends to a depth of one-half the wavelength. As the wave moves into shallow water, the bottom of the wave is slowed. The top of the wave, however, continues to move at its original speed. The top of the wave gets farther and farther ahead of the bottom of the wave. Finally, the top of the wave topples over and forms a *breaker*, a foamy mass of water that washes onto the shore. The height of the wave when the wave topples over is one to two times the height of the original wave.

Breaking waves scrape sediments off the ocean floor and move the sediments along the coastline. The waves also erode rocky coastlines. The size and force of breakers are determined by the original wave height, the wavelength, and the steepness of the ocean floor close to the coastline. If the slope of the ocean floor is steep, the height of the wave increases rapidly and the wave breaks with great force. If the coastline slopes gently, the wave rises slowly. The wave spills forward with a rolling motion that continues as the wave advances up the coastline.

Reading Check **As a wave moves into shallow water, what causes the top of the wave to break and topple over?**

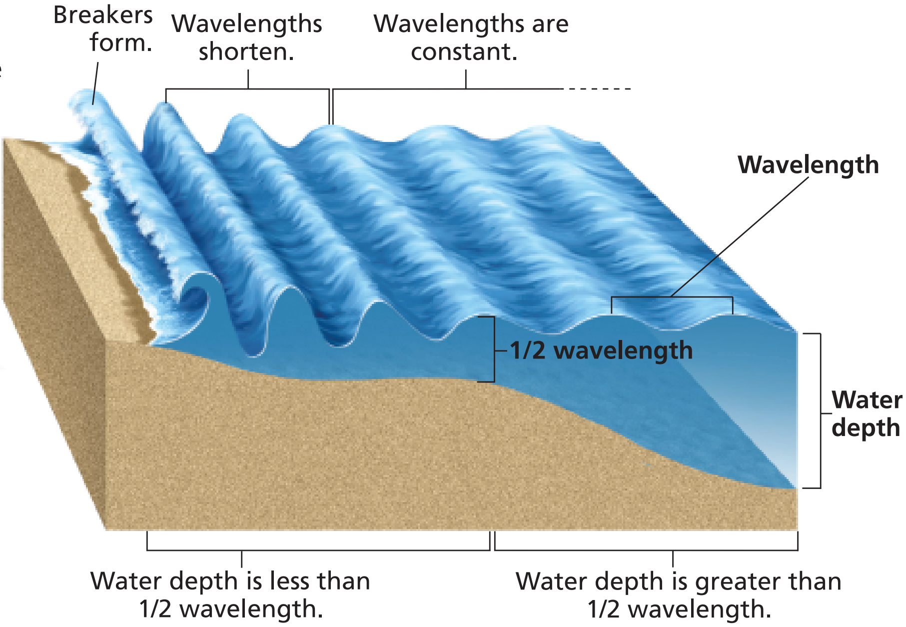


Figure 5 Breakers begin to form as a wave approaches a coastline. As the wave nears the coastline, wave height increases and wavelength decreases.

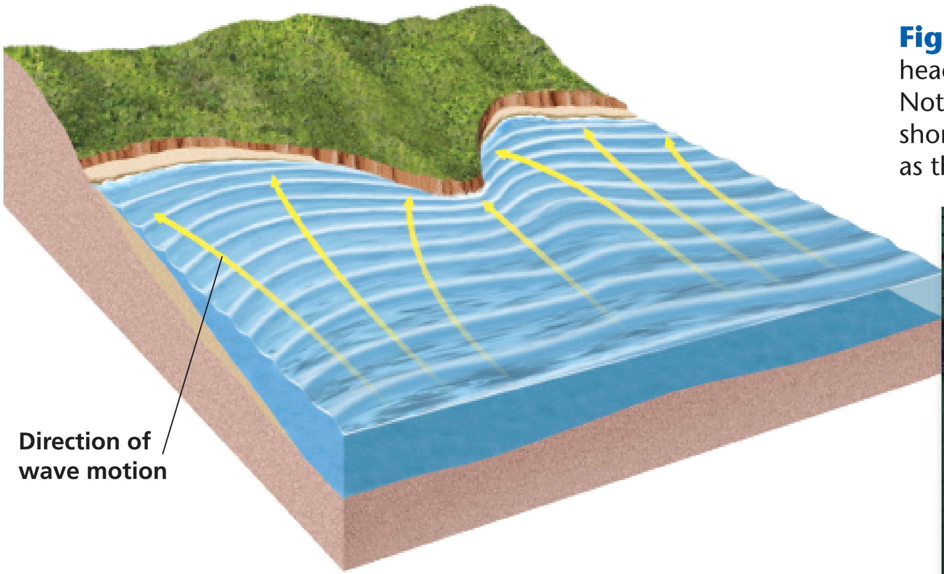
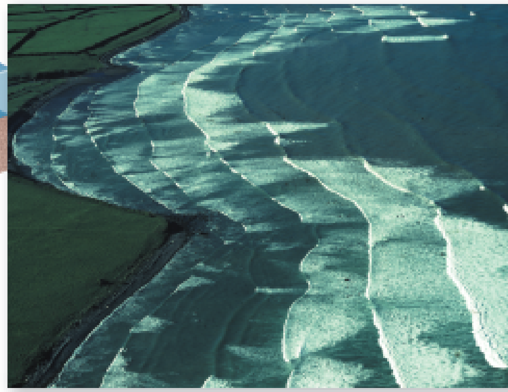


Figure 6 Waves strike the shore head-on as a result of refraction. Notice the waves approaching the shore at an angle. These waves bend as they draw closer to the shore.



Refraction

Most waves approach the coastline at an angle. When a wave reaches shallow water, however, the wave bends. This bending is called refraction. **Refraction** is the process by which ocean waves bend toward the coastline as they approach shallow water. As a wave approaches the coastline, the part of the wave that is in shallower water slows, and the part of the wave that is in deeper water maintains its speed. The wave gradually bends toward the beach and strikes the shore head-on, as shown in **Figure 6.**

refraction the process by which ocean waves bend directly toward the coastline as they approach shallow water

Undertows and Rip Currents

Water carried onto a beach by breaking waves is pulled back into deeper water by gravity. This motion forms an irregular current called an *undertow*. An undertow is seldom strong, and only along shorelines that have steep drop-offs do undertows create problems for swimmers.

The generally weak undertow is often confused with the more dangerous *rip current*. Rip currents form when water from large breakers returns to the ocean through channels that cut through underwater sandbars that are parallel to the beach. Rip currents flow perpendicular to the shore through those channels and may be strong enough to carry a swimmer away from the shore quickly. The presence of rip currents can usually be detected by a gap in a line of breakers or by turbid water—water in which sand has been stirred up by the current.

Longshore Currents

Longshore currents form when waves approach the beach at an angle. Longshore currents flow parallel to the shore. Great quantities of sand are carried by longshore currents. If there is a bay or inlet along the coastline where waves refract, sand will be deposited as the energy of the waves decreases. These sand deposits form low ridges of sand called *sandbars*.

Figure 7 The tsunami of 2004 left coastal communities of Sri Lanka in ruins. The tsunami was triggered by an earthquake that had a moment magnitude of 9.0.

Tsunamis

The most destructive waves in the ocean are not powered by the wind. *Tsunamis* are giant seismic ocean waves. Most tsunamis are caused by earthquakes on the ocean floor, but some can be caused by volcanic eruptions and underwater landslides. Tsunamis are commonly called *tidal waves*, which is misleading because tsunamis are not caused by tides.

Tsunamis have long wavelengths. In deep water, the wave height of a tsunami is usually less than 1 m, but the wavelength may be as long as 500 km. A tsunami commonly has a wave period of about 1 h and may travel at speeds of up to 890 km/h (as fast as a jet airplane). Because the wave height of a tsunami is so low in the open ocean, a tsunami cannot be felt by people aboard ships.

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Code: **HQX1561**

A Tsunami as a Destructive Force

A tsunami has a tremendous amount of energy. Because its wavelength is so long, the entire depth of the water is involved in the wave motion of a tsunami. All the energy of this mass of water is released against the shore and causes a great deal of destruction, as shown in **Figure 7.** Near the shore, the height of a tsunami greatly increases as the tsunami's speed decreases. As a tsunami approaches the shore, it may reach a height of 30 to 40 m. The arrival of a tsunami may be signaled by the sudden pulling back of the water along the shore. This pulling back occurs when the trough of the tsunami arrives before the crest. If the crest arrives first, a sudden, rapid rise in the water level occurs.

The tsunamis generated by the earthquakes in Chile in 1960 and in the Indian Ocean in 2004 caused widespread destruction. The Chilean tsunami struck the coast of South America and then Hawaii and crossed 17,000 km of ocean to strike Japan.

Section 2 Review

Key Ideas

1. **Explain** how wavelength and wave period can be used to calculate wave speed.
2. **Describe** the formation of waves.
3. **List** three factors that determine the size of a wave.
4. **Explain** why incoming waves refract toward the beach until they strike the shore head-on.
5. **Describe** what factors cause tsunamis.
6. **Explain** why waves slow down in shallow water.

Critical Thinking

7. **Analyzing Processes** Would the breakers on a specific beach always form at the same distance from the shore? Explain your answer.
8. **Predicting Consequences** Explain how whitecaps could affect climate.

Concept Mapping

9. Use the following terms to create a concept map: *wave, wave height, whitecap, trough, crest, fetch, swell,* and *tsunami.*

SECTION 3

Tides

Key Ideas	Key Terms	Why It Matters
❯ Describe how the gravitational pull of the moon causes tides. ❯ Compare spring tides and neap tides. ❯ Describe how tidal oscillations affect tidal patterns. ❯ Explain how the coastline affects tidal currents.	**tide** **tidal range** **tidal oscillation** **tidal current**	Tides are cyclical and predictable changes in sea level that are important not only to the plants and animals that live along the coast, but to people using the ocean as well.

The periodic rise and fall of the water level in the oceans is called the **tide.** *High tide* is when the water level is highest. *Low tide* is when the water level is lowest. The tide change is most noticeable on the coastline. If you stand on a beach long enough, you can see how the ocean retreats and returns with the tides.

The Causes of Tides

In the late 1600s, Isaac Newton identified the force that causes the rise and fall of tides along coastlines. According to Newton's law of gravitation, the gravitational pull of the moon on Earth and Earth's waters is the major cause of tides. The sun also causes tides, but they are smaller because the sun is so much farther from Earth than the moon is.

As the moon revolves around Earth, the moon exerts a gravitational pull on the entire Earth. However, because the force of the moon's gravity decreases with distance from the moon, the gravitational pull of the moon is stronger on the side of Earth that is nearer the moon. As a result, the ocean on Earth's near side bulges slightly, which causes a high tide within the area of the bulge.

tide the periodic rise and fall of the water level in the oceans and other large bodies of water

At the same time, another tidal bulge forms on the opposite side of Earth. This tidal bulge forms because the solid Earth, which acts as though all its mass were at Earth's center, is pulled more strongly toward the moon than the ocean water on Earth's far side is. The result is a smaller tidal bulge on Earth's far side. **Figure 1** shows the Earth-moon system and the position of the moon in relation to the tidal bulges.

Low tides form halfway between the two high tides. Low tides form because as ocean water flows toward the areas of high tide, the water level in other areas of the ocean drops.

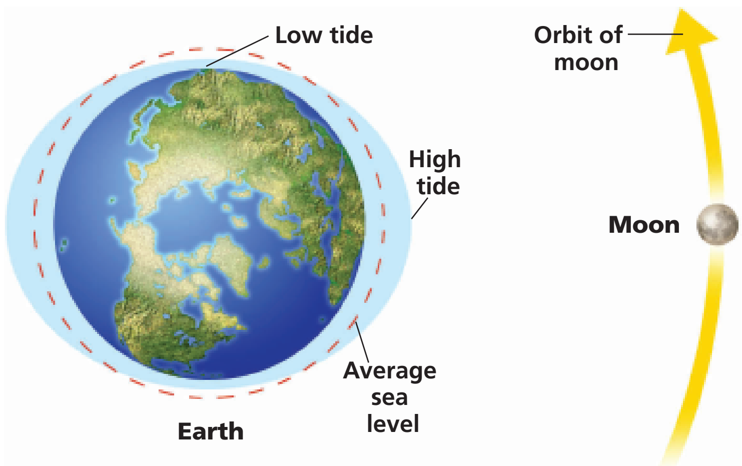


Figure 1 Because of Earth's rotation, most locations in the ocean have two high tides and two low tides daily.

Behavior of Tides

Earth rotates on its axis once every 24 h. In that 24 h, the moon moves through about 1/29 of its orbit. Because the moon orbits Earth in the same direction that Earth rotates, all areas of the ocean pass under the moon every 24 h 50 min. As seen from above the North Pole, Earth rotates counterclockwise and the tidal bulges appear to move westward around Earth.

Because there are two tidal bulges, most locations in the ocean have two high tides and two low tides daily. The difference in the levels of the ocean water at high tide and low tide is called the **tidal range.** The tidal range can vary widely from place to place. Because the moon rises about 50 min later each day, the times of high and low tides are also about 50 min later each day.

Spring Tides

The sun's gravitational pull can add to or subtract from the moon's influence on the tides. During the new moon and the full moon, Earth, the sun, and the moon are aligned, as shown in **Figure 2.** The combined gravitational pull of the sun and the moon results in higher high tides and lower low tides. So, the daily tidal range is greatest during the new moon and the full moon. During these two monthly periods, the tides are called *spring tides*.

Neap Tides

During the first-quarter and third-quarter phases of the moon, the moon and the sun are at right angles to each other in relation to Earth, also shown in **Figure 2.** The gravitational forces of the sun and the moon work against each other. As a result, the daily tidal range is small. The tides that occur during this time are called *neap tides*.

Reading Check **Describe the location of the sun and the moon in relation to Earth when the tidal range is small.**

Math Skills

Tidal Friction As the tidal bulges move around Earth, friction between the water and the ocean floor slows Earth's rotation slightly. Scientists estimate that the average length of a day has increased by 10.8 min in the last 65 million years. How many years does it take for Earth's rotation to slow by 1 s?

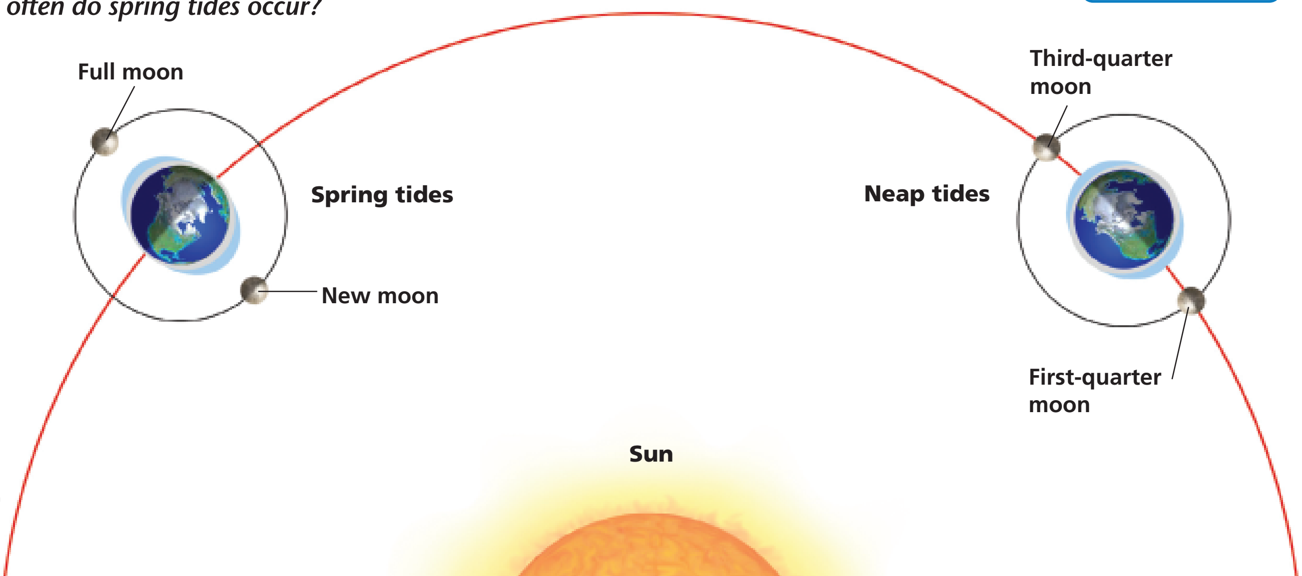
tidal range the difference in levels of ocean water at high tide and low tide

READING TOOLBOX

Cause and Effect
As you read this section, add the sentences that describe the multiple causes and effects of tides, tidal variations, and tidal currents to the table that you started at the beginning of the chapter.

Figure 2 The alignment of the sun, the moon, and Earth during spring tides differs from their alignment during neap tides. *How often do spring tides occur?*

THINK central
INTERACT ONLINE
Keyword: HQXMOVF2



Tidal Variations

Although the global ocean is one body of water, continents and irregularities in the ocean floor divide the ocean into several basins. The tidal pattern in an area is greatly influenced by the size, shape, depth, and location of the ocean basin in which the tides occur.

Along the Atlantic coast of the United States, two high tides and two low tides occur each day and have a fairly regular tidal range. Along the shore of the Gulf of Mexico, however, only one high tide and one low tide occur each day. Along the Pacific coast, the tides follow a mixed pattern of tidal ranges. Pacific coast tides commonly have a very high tide followed by a very low tide and then a lower high tide, followed by a higher low tide.

Tidal Oscillations

Tidal patterns are also affected by tidal oscillations. **Tidal oscillations** (TIE duhl AHS uh LAY shunz) are slow, rocking motions of ocean water that occur as the tidal bulges move around the ocean basins. Along straight coastlines and in the open ocean, the effects of tidal oscillations are not very obvious. In some enclosed seas, such as the Baltic and Mediterranean Seas, tidal oscillations reduce the effects of the tidal bulges. As a result, these seas have a very small tidal range. In small basins and narrow bays located off major ocean basins, however, tidal oscillations may amplify the effects of the tidal bulges. An example of the effects of tidal oscillations is shown in **Figure 3.**

Figure 3 A great tidal range of as much as 15 m in the V-shaped Bay of Fundy in Canada is caused by tidal oscillations.

tidal oscillation the slow, rocking motion of ocean water that occurs as the tidal bulges move around the ocean basins

Why It Matters

Spring Spawn

EYE ON THE ENVIRONMENT

Some marine organisms have spawning cycles that coincide with spring tides. Spawning when the moon is new or full allows marine life to take advantage of the high waters and stronger tidal currents that occur during spring tides. These conditions are good for the dispersal of eggs and larvae.

Littorina snails, also known as periwinkles, live near the high-water mark of spring tides. Periwinkles release their larvae only when they are immersed in the sea.

The gulf killifish lives in the Atlantic Ocean, near Florida. These fish spawn during spring tides, depositing their eggs when water levels are the highest.

YOUR TURN

CRITICAL THINKING

Why have some marine mammals evolved to breed during spring tides?

Figure 4 The photo to the right shows a tidal bore in early spring at Turnagain Arm of Cook Inlet, Alaska.

SCILINKS
www.scilinks.org
Topic: Tides
Code: HQX1525

tidal current the movement of water toward and away from the coast as a result of the rise and fall of the tides

Tidal Currents

As ocean water rises and falls with the tides, it flows toward and away from the coast. This movement of the water is called a **tidal current.** When the tidal current flows toward the coast, it is called *flood tide*. When the tidal current flows toward the ocean, it is called *ebb tide*. When there are no tidal currents, the time period between flood tide and ebb tide is called *slack water*.

Tidal currents in the open ocean are much smaller than those at the coastline. Tidal currents are strongest between two adjacent coastal regions that have large differences in the height of the tides. In bays and along other narrow coastlines, tides may create rapid currents. Some tidal currents may reach speeds of 20 km/h.

Where a river enters the ocean through a long bay, the tide may enter the river mouth and create a *tidal bore*, a surge of water that rushes upstream, such as the one shown in **Figure 4.** In some areas, the tidal bore rushes upstream in the form of a large wave, up to 5 m high, that eventually loses energy. The tidal bores in the River Severn in England travel almost 20 km/h and reach as far as 33 km inland.

Academic Vocabulary

energy (EN uhr jee) the capacity to do work

Section 3 Review

Key Ideas

1. **Describe** how the moon causes tides.
2. **Explain** how the sun can influence the moon's effect on tides.
3. **Compare** spring tides and neap tides.
4. **Describe** how ocean basins affect tidal patterns.
5. **Explain** how tidal oscillations in an enclosed sea would affect tidal patterns in that sea.
6. **Compare** the movement of ocean water in the open ocean with the movement of ocean water in narrow bays.
7. **Describe** how a tidal bore forms.

Critical Thinking

8. **Predicting Consequences** Predict where tidal currents may be a concern to ships that are approaching the land.
9. **Identifying Relationships** Describe ways in which tides could be affected if Earth had two moons.

Concept Mapping

10. Use the following terms to create a concept map: *tide, tidal range, spring tide, neap tide, tidal oscillation, tidal current, flood tide,* and *ebb tide.*

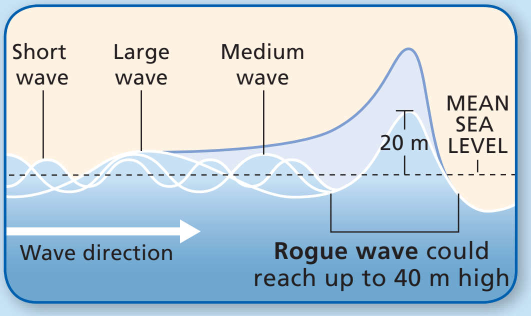
Why It Matters

Monster Waves: Myth or Fact?

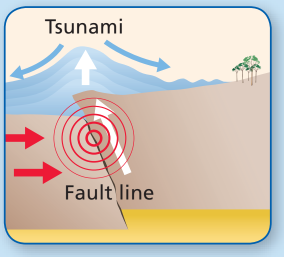
REAL WORLD

Imagine standing on the deck of a ship, watching the approach of a wave taller than a 10-storey building. Such waves do exist. Called rogue waves, they can reach heights of over 30 m and rise out of otherwise steady wave patterns in deep water. Also known as monster waves, freak waves, and extreme waves, they pose a serious threat to even the largest ships.

Rogue wave or tsunami?



Rogue waves form when two or more waves combine. They can also form when a strong current runs in the opposite direction of waves.



Tsunamis are massive movements of water that are not noticeable in deep water and present no threat to ships at sea. They become dangerous when they gain height as they approach shore.

YOUR TURN

UNDERSTANDING CONCEPTS

Why is the deep, open ocean a safe place to be sailing during an earthquake?

CRITICAL THINKING

Why can scientists warn people about tsunamis, but not yet predict with accuracy where and when rogue waves will form?

Making Models Lab

45 min

Wave Motion

The source of wave motion in water is energy, which is generated primarily from wind. Waves of water appear to move horizontally. However, only the energy of the waves moves horizontally; the water moves horizontally very little. In this lab, you will work with two classmates to simulate wave motion and to observe how energy generates wave motion in water. You will also observe the properties of waves.

What You'll Do

- **Model** the movement of waves.
- **Compare** the characteristics of waves when wave speed changes.

What You'll Need

cloth ties, about 50 cm in length (2)
marker
meterstick
paper, 2 m × 1 m
paper, graph
pen or pencil, colored (3)
rope, thin, 2.5 m in length

Procedure

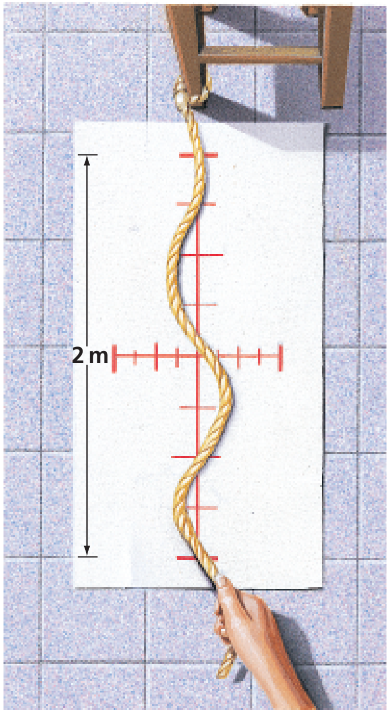
1. Tie one end of the rope securely to the leg of a chair or table.
2. On the large sheet of paper, use the meterstick to draw a grid like the one shown in the illustration on the next page. The vertical axis should be 2 m long, with marks at intervals of 0.25 m. The horizontal axis should be 1 m long, with marks at intervals of 0.125 m.
3. Place the sheet of paper on the floor, and line up the rope along the 2 m line of the grid.
4. To make waves, move the free end of the rope from side to side. (Note: Be sure to maintain a constant motion with the rope.)
5. While one person moves the rope, another person marks the paper where a crest of a wave hits. The third person marks the paper where a trough of a wave hits.
6. On the graph paper, make a diagram to display your results, with an *x* axis that has wavelength (in meters) and a *y* axis that has wave height (in meters).
7. Plot a wave that represents the wave you observed in step 5. Plot the wave height and the wavelength. Indicate the direction of the wave motion.

Step 5

8. Move the rope at a fast speed. Do not change the side-to-side distance that you move the free end of the rope.
9. As soon as a constant motion has been established, repeat step 5. On your diagram, plot a wave that represents the wave you observed when repeating step 5. Use a pen or pencil that is a different color from the color of the first wave plot.
10. Next, generate very small waves. Repeat step 5 and plot the wave, using a third color of pen or pencil.
11. On your diagram, label a crest and a trough on each of the waves you plotted.
12. Use the following formula to calculate the wave speeds of the three waves you plotted, if each wave period is 6 s:

$$\textit{wave speed} = \frac{\textit{wavelength}}{\textit{wave period}}$$

13. Tie the two pieces of cloth around the middle of the rope, about 15 cm apart.
14. Make waves by moving the end of the rope from side to side. Observe and record the motion of the cloth relative to the motion of the waves.



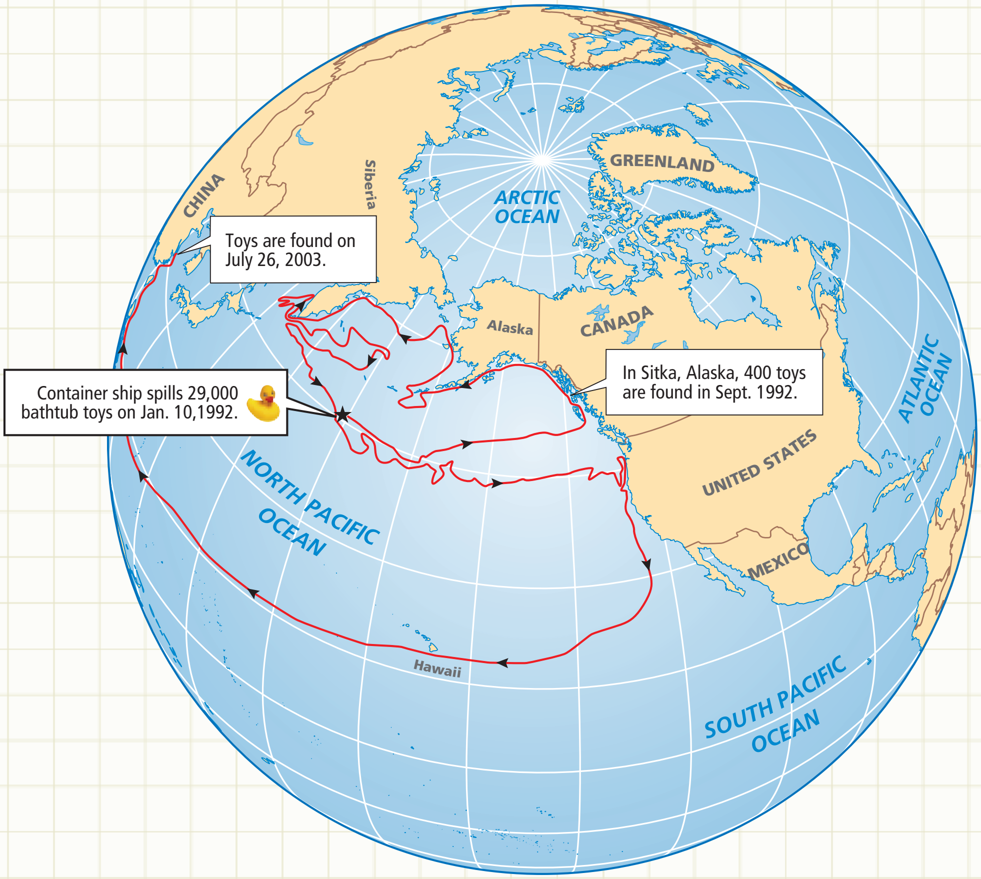
Analysis

1. **Examining Data** How do the waves you plotted differ from each other? If these waves were real water waves, what might be the cause(s) of the differences?
2. **Recognizing Relationships** How is the motion of the rope similar to wave motion in water?
3. **Analyzing Relationships** How does the motion of the cloth differ from the motion of the wave?
4. **Drawing Conclusions** What does the motion of the cloth tell you about wave motion in water?

Extension

Making Comparisons Use a 4 m rope to repeat the investigation. Construct a diagram similar to your first diagram, but extend the *x*-axis to provide room to plot a 4 m length. Observe and plot five waves of varying speeds and heights. Compare waves generated on a 2 m rope with those generated on a 4 m rope. Describe your results. Using 6 s as the wave period for each wave you plot, calculate wave speeds.

Roaming Rubber Duckies



Map Skills Activity

This map shows the estimated route taken by bathtub toys spilled from a cargo ship in the North Pacific Ocean. Use the map to answer the questions below.

1. **Analyzing Data** Describe where the toys started their journey.
2. **Evaluating Data** How long did it take the toys to travel to Sitka, Alaska, by the most direct route?
3. **Identifying Relationships** Compare the map above with the map of the major surface currents in the section entitled "Ocean Currents." Then, name the current that carried the toys past Hawaii.
4. **Evaluating Sources** Is the current that carried the toys along the coast of the western United States cold or warm? Explain your answer.
5. **Predicting Consequences** Predict where the toys might have been located in December 2003 if tracking data were plotted on the map.
6. **Identifying Relationships** What is the name of the current that carried the toys south along the coast of Siberia?
7. **Evaluating Data** How long did it take the toys to travel from the location where they were spilled to their location on the coast of China on July 26, 2003?

Chapter 25

Summary

THINK central SUPER SUMMARY Keyword: HQXMOVS

Key Ideas | **Key Terms**

Section 1

Ocean Currents

- As wind blows, it moves surface water in the ocean in the same direction. Continents deflect and divide surface currents. The Coriolis effect causes surface currents to curve as they flow.
- Surface currents are wind-driven currents.
- Deep currents are produced as dense water near the North and South Poles sinks and moves toward the equator beneath less dense water.

Key Terms

current, p. 689
surface current, p. 689
Coriolis effect, p. 690
gyre, p. 690
Gulf Stream, p. 692
deep current, p. 693

Section 2

Ocean Waves

- Wind is the primary source of wave energy. Wave size is determined by wind speed, by the length of time that wind blows, and fetch.
- As a wave comes into contact with the ocean floor, the wave may undergo refraction or form breakers. Waves near the shoreline can cause currents, such as an undertow and a rip current.
- Tsunamis, which are caused by earthquakes on the ocean floor, volcanic eruptions, and underwater landslides, are giant, destructive waves.

Key Terms

wave, p. 695
wave period, p. 695
fetch, p. 697
refraction, p. 699

Section 3

Tides

- The gravitational pull of the moon is strongest on the side of Earth that is nearer the moon. As a result, the ocean on this side bulges slightly, which causes a high tide within the area of the bulge. At the same time, a smaller tidal bulge forms on the opposite side of Earth.
- Tidal ranges are greatest during spring tides and smallest during neap tides.
- In some enclosed seas, tidal oscillations reduce the effects of tidal bulges, resulting in a very small tidal range. In small basins and narrow bays located off major ocean basins, tidal oscillations may amplify the effects of the tidal bulges.
- Tidal currents are generally small in the open ocean but may create rapid currents in narrow bays along the coastline.

Key Terms

tide, p. 701
tidal range, p. 702
tidal oscillation, p. 703
tidal current, p. 704

Chapter 25 Review

1. **Word Families** Create a table for key terms and italicized words that belong to the word family of the key term *current*. Add the words that are combined with *current* (such as *surface, deep, rip, longshore,* and *tidal*) and their definitions to your table. Combine these words with *current,* and write your own definitions of the new terms. Then compare your definitions with the definitions given in the chapter.

READING TOOLBOX

USING KEY TERMS

Use each of the following terms in a separate sentence.

2. *current*
3. *gyre*
4. *tide*
5. *wave*

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

6. *surface current* and *deep current*
7. *Coriolis effect* and *gyre*
8. *fetch* and *refraction*
9. *tidal range* and *tidal oscillation*

UNDERSTANDING KEY IDEAS

10. The water in the ocean moves in giant streams called
    a. currents.
    b. westerlies.
    c. waves.
    d. tides.
11. The effect of Earth's rotation on winds and ocean currents is called the
    a. neap-tide effect.
    b. refraction effect.
    c. Coriolis effect.
    d. tsunami effect.
12. Which of the following currents is the westward warm-water current in the North Atlantic Gyre?
    a. Canary Current
    b. North Atlantic Current
    c. North Equatorial Current
    d. Gulf Stream
13. Deep currents are the result of
    a. the Coriolis effect.
    b. changes in the density of ocean water.
    c. the trade winds.
    d. neap tides.
14. The periodic disturbance in water as energy is transmitted through the water is a
    a. current. **c.** fetch.
    b. breaker. **d.** wave.
15. The highest point of a wave is the
    a. trough. **c.** crest.
    b. period. **d.** length.
16. The distance that a wind blows across an area of the ocean to generate waves is the
    a. trough. **c.** fetch.
    b. sargassum. **d.** wave period.
17. The movement of water toward and away from the coast due to tidal forces is called a
    a. tidal bore.
    b. tidal current.
    c. tidal range.
    d. tidal oscillation.

SHORT ANSWER

18. Describe how a breaker forms.
19. Define *tide*, and explain why tides form.
20. What factors control most ocean surface currents?
21. How does the depth of the ocean affect the shape and speed of a wave?
22. How do deep currents form?
23. Explain how wind is the primary source of wave energy.
24. What is a tidal bore?

CRITICAL THINKING

25. Determining Cause and Effect During winter in the northern Indian Ocean, winds called *monsoons* blow in a direction opposite to the direction that they blow during summer. What effect do these winds have on surface currents?

26. Analyzing Processes Suppose that a retaining wall is built along a shoreline. What will happen to waves as they pass over the retaining wall?

27. Making Inferences Imagine that you are fishing from a small boat anchored off the shore in the Gulf of Mexico. You are lulled to sleep by the gently rocking boat but wake up to find your boat on wet sand. What happened?

28. Making Predictions If Earth rotated in the direction opposite to the direction that it now rotates, what effect would this have on the movement of ocean currents?

CONCEPT MAPPING

29. Use the following terms to create a concept map: *currents, surface currents, trade winds, deep currents, Coriolis effect, wave, breaker, rip current, tide, Antarctic Bottom Water,* and *tidal current.*

MATH SKILLS

30. Applying Quantities The Gulf Stream can move 100 million cubic meters of water per second. The Mississippi River moves 15,400 m^3 of water per second. How many times more water per second does the Gulf Stream move than the Mississippi River does?

31. Making Calculations If a wave has a wavelength of 216 m and a period of 12 s, what is the speed of the wave?

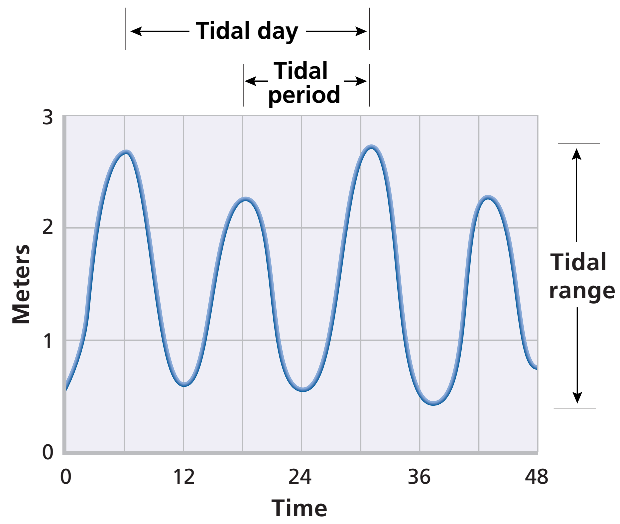
WRITING SKILLS

32. Writing from Research Write a report on the tidal power plant project at La Rance, France. Describe the amount of electricity provided by the project and the impact the project has on the environment of the area.

33. Outlining Topics Create an outline that shows the steps of tide formation. Provide diagrams as needed to illustrate the steps.

INTERPRETING GRAPHICS

The graph below shows the measurements of tides in one location on the Atlantic coast of North America. Use this graph to answer the questions that follow.



34. How many high tides occur every day in this location?

35. How many hours is the tidal period?

36. How many hours apart are the low tides?

37. What is the average tidal range, in meters?

38. What is the difference in height, in meters, between the first high tide and the second high tide?

Chapter 25 Standardized Test Prep

Understanding Concepts

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

1. Which of the following factors affects the movement of surface currents?
   A. Earth's rotation on its axis
   B. water salinity
   C. human activity
   D. sea-floor spreading

2. What is the speed of an ocean wave that has 12 s between crests and a wavelength of 216 m?
   F. 6 m/s
   G. 3 km
   H. 18 m/s
   I. 12 m

3. When an ocean wave travels 100 m west, which of the following also travels 100 m west?
   A. the energy in the wave
   B. the water molecules in the wave
   C. both the water molecules and the energy
   D. neither the water molecules nor the energy

4. What role do convection currents in the ocean and atmosphere have in regulating climate?
   F. They set up atmospheric circulation.
   G. They prevent deep-water currents.
   H. They restrict energy to local use.
   I. They ensure a balance of precipitation.

5. The vertical distance from the trough of a wave to the crest of the wave is called the
   A. wave height.
   B. wavelength.
   C. wave speed.
   D. wave distance.

Directions (6–8): For each question, write a short response.

6. What is a main factor that causes the movements of deep-water currents?

7. What happens to the height of a wave as the wave approaches the shore?

8. Most waves are generated by energy that is transferred to water from what?

Reading Skills

Directions (9–11): Read the passage below. Then, answer the questions.

Tsunamis

Tsunamis are the most destructive waves in the ocean. Most tsunamis are caused by earthquakes on the ocean floor, but some can be caused by volcanic eruptions and underwater landslides. Tsunamis are sometimes called *tidal waves*, which is misleading because tsunamis have no connection to tides.

Tsunamis commonly have a wave period of about 1 h and a wave speed of about 890 km/h, which is about as fast as a commercial airplane. By the time a tsunami reaches the shore, the tsunami's height may be 40 m.

Tsunamis can travel thousands of kilometers. One tsunami was triggered by an earthquake off the coast of South America in 1960. The tsunami was so powerful that it crossed the Pacific Ocean and hit the city of Hilo, on the coast of Hawaii, approximately 10,000 km away. The same tsunami then continued and struck Japan.

9. Why is the word "misleading" used to describe the term *tidal waves* in the reading passage?
   F. Tsunamis are really large tides.
   G. Tsunamis can cause extensive damage to coastal areas.
   H. Tsunamis are related to earthquakes.
   I. Tsunamis are not related to tides.

10. Which of the following statements is a fact from the passage?
   A. All tsunamis are caused by earthquakes.
   B. A tsunami can travel as fast as an airplane.
   C. The tsunami of 1960 only struck Japan.
   D. Tsunamis are caused by surface currents.

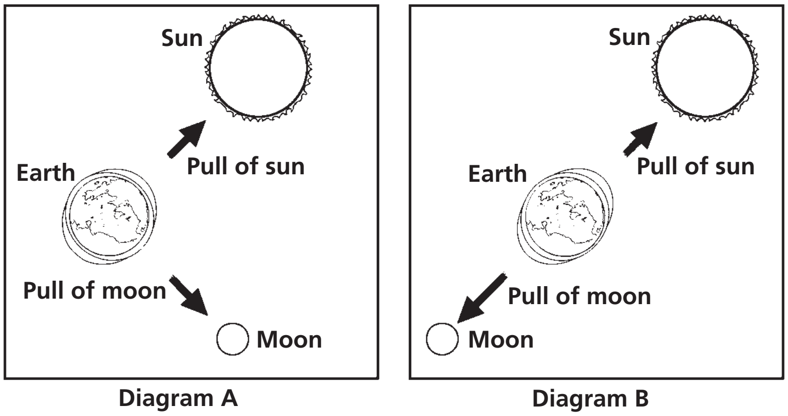
11. Once triggered, how far can a tsunami travel?
   F. Tsunamis are short-lived and usually dissipate within just a few kilometers.
   G. Tsunamis travel about 100 km before dissipating in the ocean.
   H. Tsunamis travel about 1,000 km before dissipating in the ocean.
   I. Tsunamis can travel thousands of kilometers before dissipating or striking land.

Interpreting Graphics

Directions (12–15): For each question below, record the correct answer on a separate sheet of paper.

The diagrams below show the Earth, moon, and sun system. Use these diagrams to answer questions 12 and 13.

Effect of Sun and Moon on Earth's Tides

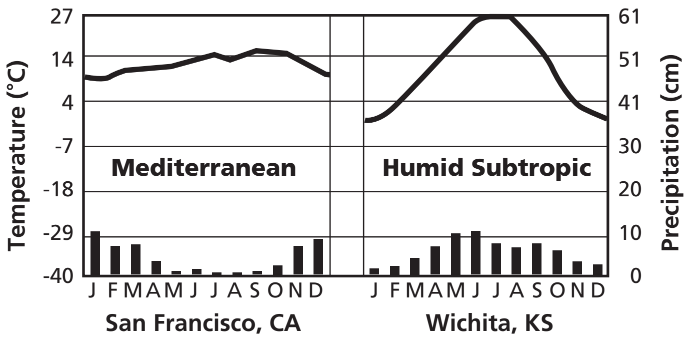


12. What type of tide is produced by the arrangement in Diagram B?
- **A.** spring tide
- **B.** neap tide
- **C.** winter tide
- **D.** weak tide

13. Using the diagrams above, explain how the gravitational effects of astronomical bodies cause tides on Earth.

The climate graphs below combine temperature and precipitation data for San Francisco, California, and Wichita, Kansas. Use these graphs to answer questions 14 and 15.

Average Yearly Weather Data for San Francisco and Wichita



14. Which location shows the most extreme climate variation?
- **F.** Wichita, Kansas shows the most extreme climate variation.
- **G.** San Francisco, California shows the most extreme climate variation.
- **H.** Both climates are equally mild.
- **I.** Both climates are equally variable.

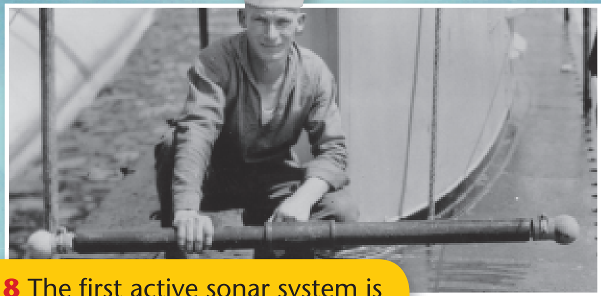
15. How do the locations of these cities and the nearby currents help to explain the differences in their climates?

Test Tip

Allow a few minutes at the end of the test-taking period to check for careless mistakes, such as marking two answers for a single question.

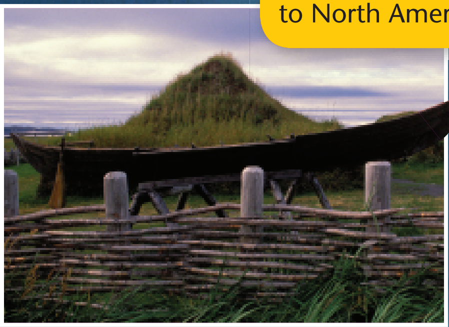
Oceanography Connections

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



1918 The first active sonar system is constructed and used.

1000 C.E. Vikings migrated to North America.

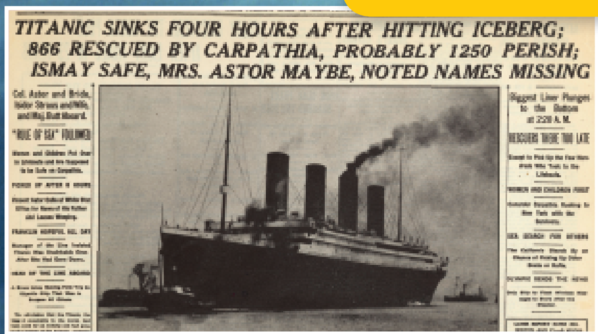


1620 Cornelius Drebbel invents first practical submarine.

1859 The first ocean-going ironclad ships are employed by the French.

1519 Magellan and his crew leave Spain to circumnavigate the world.

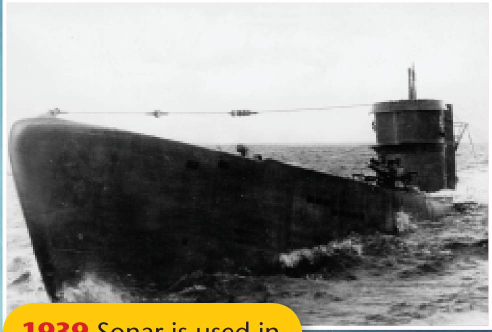
1912 The RMS *Titanic* strikes an iceberg and sinks.



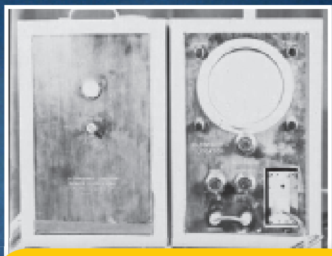
TITANIC SINKS FOUR HOURS AFTER HITTING ICEBERG; 866 RESCUED BY CARPATHIA, PROBABLY 1250 PERISH; ISMAY SAFE, MRS. ASTOR MAYBE, NOTED NAMES MISSING

1913 The International Convention for Safety of Life at Sea establishes main shipping routes.

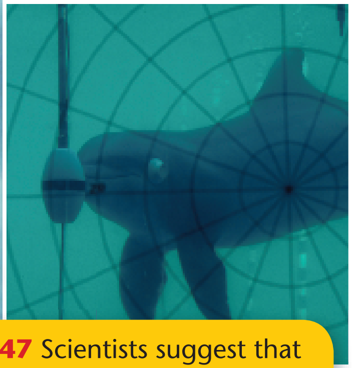
HISTORY IN SCIENCE



1939 Sonar is used in World War II to find enemy submarines.

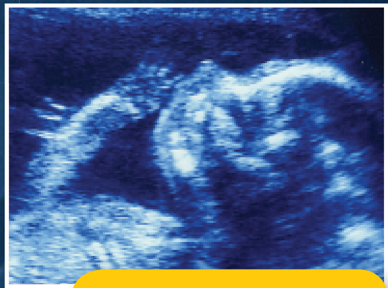


1949 American scientists investigate the use of sonar for medical purposes.

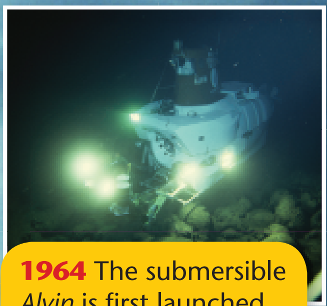


1947 Scientists suggest that dolphins echolocate.

1939–1945 During WWII, whales are mistakenly identified as submarines.



1956 Obstetricians begin to use ultrasound technology.



1964 The submersible *Alvin* is first launched.

2000 Sixteen whales beach themselves in the Bahamas after military low- and mid-frequency sonar tests.

1986 Scientists use *Alvin* to explore the wreckage of the RMS *Titanic*.

2003 North Atlantic shipping lanes are shifted to prevent collisions with Right whales off Canada's coast.

2008 About 90% of all international goods travel some distance by ship.

YOUR TURN

UNDERSTANDING CONCEPTS

When were modern shipping lanes established?

CRITICAL THINKING

Why might human use of sonar be harmful to animals such as dolphins and whales?