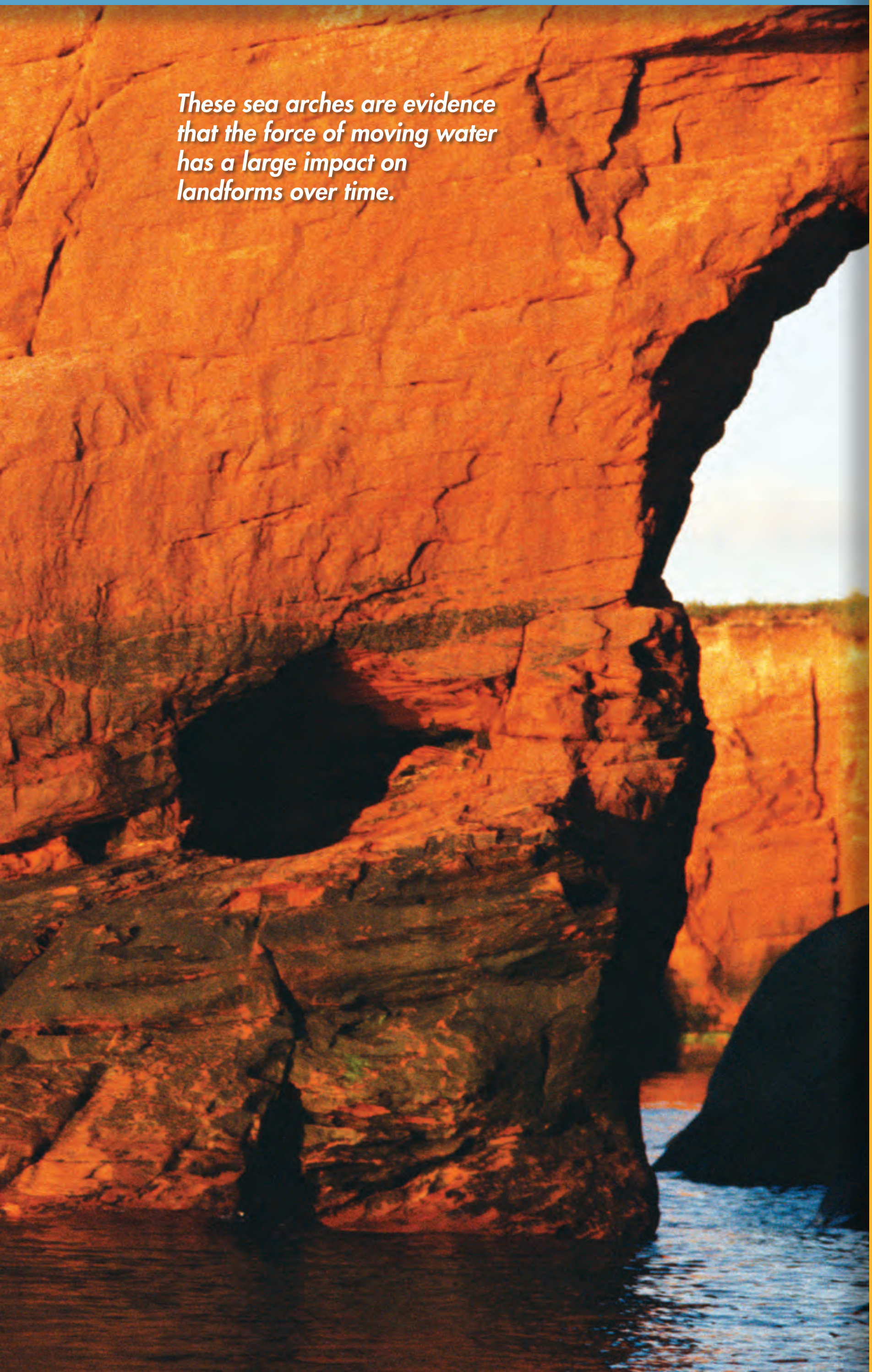
# 16 The Dynamic Ocean

**Big idea**

## Water Planet

**Q:** How does ocean movement affect land?



*These sea arches are evidence that the force of moving water has a large impact on landforms over time.*

**VIRGINIA SCIENCE STANDARDS OF LEARNING**

ES.1.c, ES.1.f, ES.2.c, ES.3.b, ES.10.a, ES.10.b.
**See lessons for details.**

# INQUIRY
## TRY IT!

## HOW DO OCEAN WAVES FORM?

### Procedure

1. Fill a rectangular, clear, plastic container with water to within about 3 cm of the top of the container.
2. Place a fan next to the container, aiming the flow of air toward the water. **CAUTION:** *Make sure the cord and the fan do not come in contact with the water in the container.*
3. Turn the fan on low power for 2 to 3 minutes. Observe what effect blowing air has on the water in the container. Using a ruler, measure the size of the waves produced. Record your observations and data.
4. Turn the fan off and allow the water in the container to settle. Repeat Step 3 with the fan on high power.

### Think About It

1. **Infer** Where does the energy to produce most ocean waves come from?
2. **Draw Conclusions** What is the relationship between the speed of the wind and the size of a wave?

# 16.1 Ocean Circulation

**ES.10** The student will investigate and understand that oceans are complex, interactive physical, chemical, and biological systems and are subject to long- and short-term variations. Key concepts include **a.** physical and chemical changes related to tides, waves, currents, sea level and ice cap variations, upwelling, and salinity variations; and **b.** importance of environmental and geologic implications.

## Key Questions

***How do surface currents develop?***

***How do ocean currents affect climate?***

***Why is upwelling important?***

***How are density currents formed?***

## Vocabulary

- ocean current
- surface current
- gyre • Coriolis effect
- upwelling • density current

## Reading Strategy

**Identify Main Ideas**
Copy the table below into your notebook. Leave space to expand the table. As you read, write the main idea of each topic.

| Topic | Main Idea |
|---|---|
| Surface currents | a. ___?___ |
| Gyres | b. ___?___ |
| Ocean currents and climate | c. ___?___ |
| Upwelling | d. ___?___ |

**OCEAN WATER IS** constantly in motion, powered by many different forces. Winds, for example, produce waves such as the ones shown in **Figure 1.** Masses of ocean water move horizontally from one area to another. Masses of ocean water also move vertically as denser masses sink below masses that are less dense.

## Surface Circulation

**Ocean currents** are masses of ocean water that flow from one place to another. The amount of water can be large or small. Ocean currents can be at the surface or deep below the surface. The formation of currents can be simple or complex. In all cases, however, the currents involve water masses in motion. Anyone who navigates the ocean needs to be aware of currents. By understanding the direction and strength of ocean currents, sailors soon realize that their voyage time can be reduced if they travel with a current.

### Surface Currents

**Surface currents** are movements of water that flow horizontally in the upper part of the ocean's surface. **Surface currents develop from friction between the ocean and the wind that blows across its surface.** Some of these currents do not last long, and they affect only small areas.

**FIGURE 1 Wind's Effects**
Wind not only produces waves, it also provides the force that drives the ocean's surface circulation.

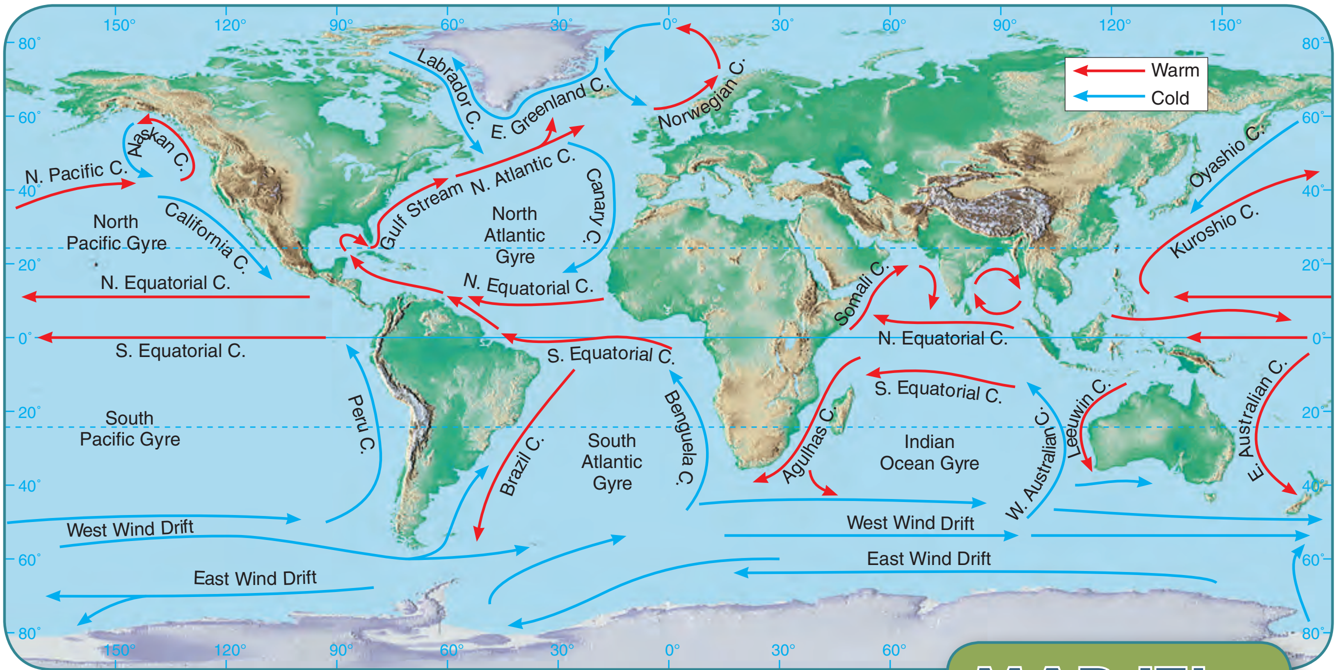



**FIGURE 2 Ocean Surface Currents** This map shows average surface ocean currents from February to March.

## MAP IT! ACTIVITY

**Figure 2** shows that the ocean's circulation is organized into five huge currents called gyres.

**Interpret Maps** Which currents make up the Indian Ocean Gyre?

**Draw Conclusions** Find the West Wind Drift on the map. Explain why the West Wind Drift is the only current that completely encircles Earth.

Such water movements are responses to local or seasonal influences. Other surface currents, such as those shown in **Figure 2,** are more permanent and extend over large portions of the oceans. These major horizontal movements of surface waters are closely related to the general circulation pattern of the atmosphere.

**Gyres** Huge circular-moving current systems dominate the surfaces of the oceans. These large whirls of water within an ocean basin are called **gyres** (gyros = a circle). There are five main ocean gyres: the North Pacific Gyre, the South Pacific Gyre, the North Atlantic Gyre, the South Atlantic Gyre, and the Indian Ocean Gyre.

Although wind is the force that generates surface currents, other factors also influence the movement of ocean waters. The most significant of these is the Coriolis effect. The **Coriolis effec** is the deflection of currents away from their original course as a result of Earth's rotation. **Because of Earth's rotation, currents are deflected to the right in the Northern Hemisphere and the left in the Southern Hemisphere.** As a consequence, gyres flow in opposite directions in the two hemispheres.

For example, trace the path of water in the North Atlantic Gyre in Figure 2. As water moves north from Florida in the Gulf Stream and North Atlantic Current, it is deflected to the right, or eastward. Water moving south in the Canary Current is deflected westward into the North Equatorial Current. This gyre moves in a clockwise direction. Now look at the South Atlantic Gyre. Because the Coriolis effect deflects its current to the left, this gyre flows counterclockwise.

**Reading Checkpoint** *What is a gyre?*

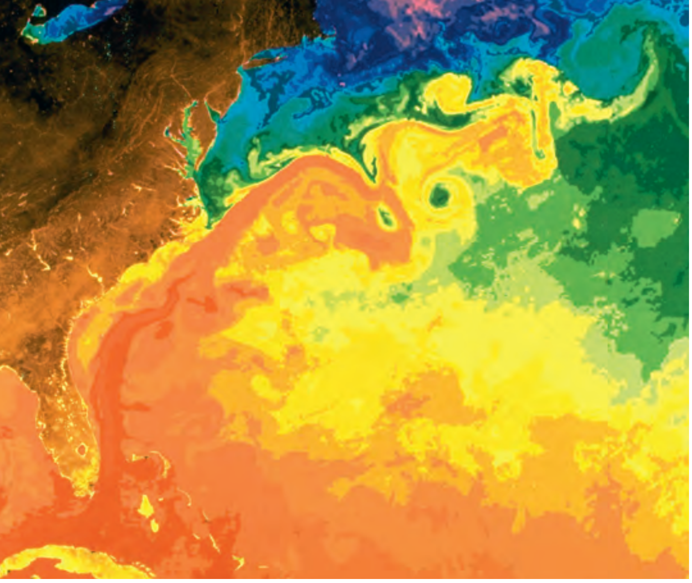


**FIGURE 3 Gulf Stream** This false-color satellite image of sea-surface temperatures shows the course of the Gulf Stream. The warm waters of the Gulf Stream are shown in red and orange along the east coast of Florida and the Carolinas. The surrounding colder waters are shown in green, blue, and purple. Compare this image to the map of the Gulf Stream in Figure 2.

**Ocean Currents and Climate** Ocean currents have an important effect on climates. Ocean water in areas closer to the equator absorbs more energy from the sun than does water farther from the equator. **When currents from low-latitude regions move into higher latitudes, they transfer heat from warmer to cooler areas on Earth.** The Gulf Stream, a warm water current shown in **Figure 3,** is an excellent example of this phenomenon. The Gulf Stream brings warm water from the equator northward to the North Atlantic Current. This current allows Great Britain and much of northwestern Europe to be warmer during the winter than areas of similar latitudes such as Alaska and Newfoundland. The prevailing westerly winds carry this warming effect far inland. For example, Berlin, Germany (52 degrees north latitude), has an average January temperature similar to that experienced in New York City, which lies 12 degrees to the south.

The effects of these warm ocean currents are felt in the middle latitudes mostly in the winter. In contrast, the influence of cold currents is most felt in the tropics or during summer months in the middle latitudes. Cold currents begin in cold high-latitude regions. **As cold water currents travel toward the equator, they help moderate the warm temperatures of adjacent land areas.** Such is the case for the Benguela Current along western Africa, the Peru Current along the west coast of South America, and the California Current. These currents are shown in Figure 2.

Ocean currents play a major role in maintaining Earth's heat balance. They do this by transferring heat from the tropics, where there is an excess of heat, to the polar regions, where there is less heat. Ocean water movement accounts for about a quarter of this heat transport. Winds transport the remaining three-quarters.

**Upwelling** In addition to producing horizontal surface currents, winds can also cause vertical water movements. A common wind-induced vertical movement is called **upwelling,** which is the rising of cold water to replace warmer surface water that has been displaced by wind. Upwelling is most characteristic along the west coasts of continents, most notably along California, western South America, and West Africa. When upwelling occurs along coasts, it may be referred to as coastal upwelling.

Upwelling occurs in these areas when winds blow toward the equator and parallel to the coast. Coastal winds combined with the Coriolis effect cause surface water to move away from shore. As the warm surface layer moves away from the coast, it is replaced by colder water that upwells from below the surface. This slow upward movement of water from depths of 50 to 300 meters brings up water that is cooler than the original surface water and results in lower surface water temperatures near the shore.

**Upwelling brings dissolved nutrients, such as nitrates and phosphates, to the ocean surface.** These nutrient-enriched waters from below promote the growth of microscopic plankton, which in turn support extensive populations of fish and other marine organisms. **Figure 4** is a satellite image that shows high levels of productivity due to coastal upwelling off the southwest coast of Africa.

**Reading Checkpoint** *What is upwelling?*

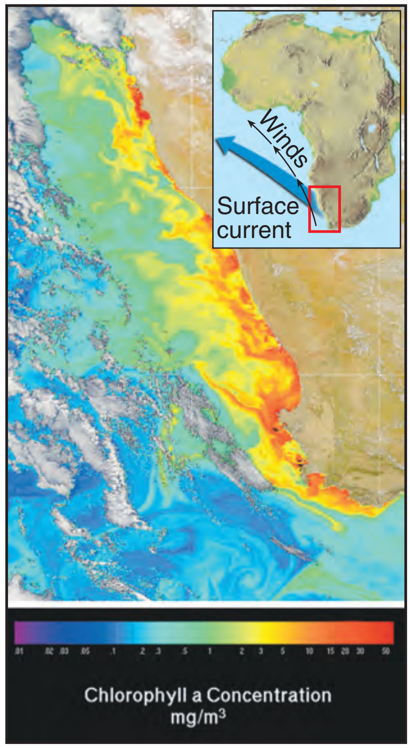



**FIGURE 4 Effects of Upwelling** This image from the SeaStar satellite shows chlorophyll concentration along the southwest coast of Africa. High chlorophyll concentrations, in red, indicate high amounts of photosynthesis, which is linked to upwelling nutrients.

# Deep-Ocean Circulation

In contrast to the largely horizontal movements of surface currents, deep-ocean circulation has a significant vertical component. It accounts for the thorough mixing of deep-water masses. Vertical currents of ocean water that result from density differences among water masses are called **density currents.** Denser water sinks and slowly spreads out beneath the surface. **An increase in seawater density can be caused by a decrease in temperature or an increase in salinity.** Processes that increase the salinity of surface water include evaporation and the formation of sea ice. Processes that decrease the salinity of water include precipitation, runoff rom land, icebergs melting, and sea ice melting. Density changes due to salinity variations are important in very high latitudes, where water temperature remains low and relatively constant.

**Evaporation** Density currents can result from increased salinity of ocean water due to evaporation. For example, climate conditions in the Mediterranean Sea include a dry northwest wind and sunny days. Due to these factors water evaporates from the Mediterranean Sea faster than it is replaced by precipitation. When seawater evaporates, salt is left ehind, and the salinity of the remaining water increases. The surface waters of the Mediterranean Sea have a salinity of about 38‰ (parts per thousand). In the winter months, this water flows out of the Mediterranean Sea into the Atlantic Ocean. At 38‰, this water sinks because it is more dense than the Atlantic Ocean surface water at 35‰. This Mediterranean water mass can be tracked as far south as Antarctica.

**FIGURE 5 A Scene in the Mediterranean** A sunny day, such as the one shown here in Loutro on the south coast of Crete, contributes to the salinity of the Mediterranean Sea.

**FIGURE 6 Sea Ice in the Arctic Ocean** When seawater freezes, sea salts do not become part of the ice, leading to an increase in the salinity of the surrounding water.
**Draw Conclusions** *How does this process lead to the formation of a density current?*

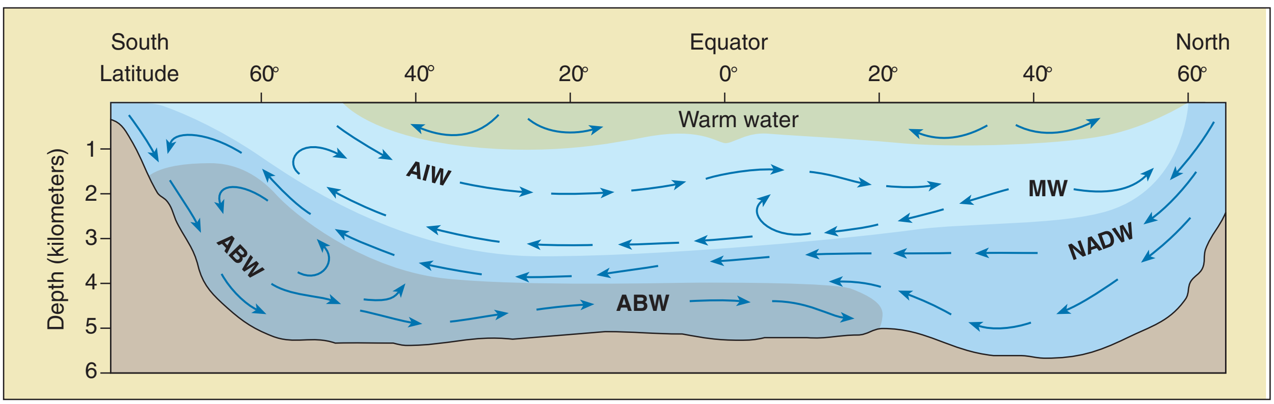
## PLANET DIARY

For links about **Deep-Ocean Currents,** visit PlanetDiary.com/HSES.

**Sea Ice** Most water involved in density currents begins in high latitudes at the surface. In these regions, surface water becomes cold, sea ice forms, and the water's salinity increases. Eventually, the surface water mass becomes denser than the masses beneath it and it sinks. Once this water sinks, it is removed from the physical processes that increased its density in the fi st place. Its temperature and salinity remain largely unchanged during the time it is in the deep ocean. Because of this, oceanographers can track the movements of density currents in the deep ocean. By knowing the temperature, salinity, and density of a water mass, scientists are able to map the slow circulation of the water mass through the ocean.

**Figure 7** shows some of the different water masses created by density currents in the Atlantic Ocean. Near Antarctica, surface conditions produce the highest density water in the world. This cold, salty water slowly sinks to the sea floor, then moves throughout the ocean basins in slow currents. After sinking from the surface of the ocean, deep waters will not reappear at the surface for an average of 500 to 2000 years.

**FIGURE 7 Deep-Ocean Circulation** This cross section of the Atlantic Ocean shows the deep-water circulation of water masses formed by density currents.




**Key**
**AIW**: Antarctic Intermediate Water **MW**: Mediterranean Water **NADW**: North Atlantic Deep Water **ABW**: Antarctic Bottom Water

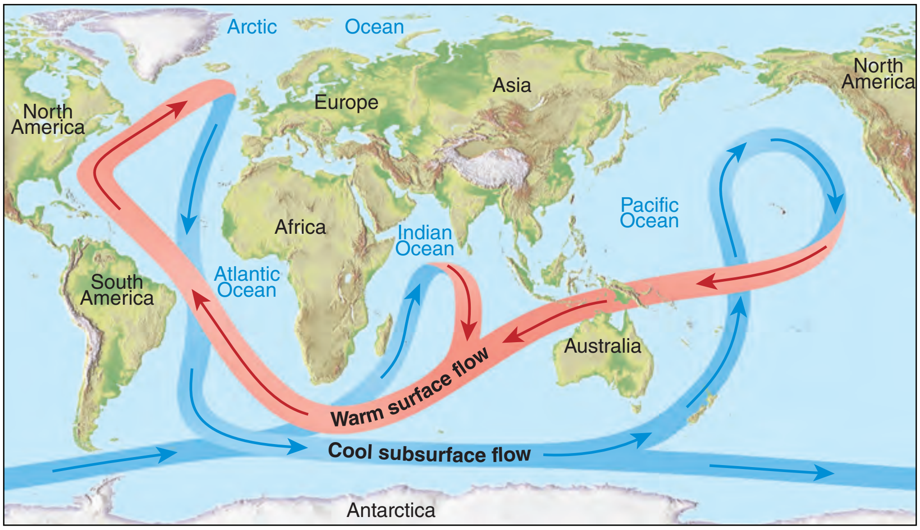
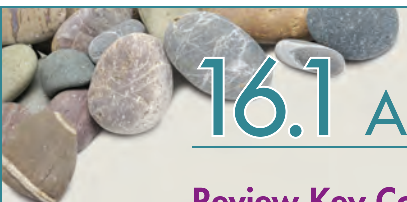



**FIGURE 8 A Continuous Current** This "conveyor belt" model of ocean circulation shows a warm surface current with an underlying cool current.

**A Conveyor Belt** A simplified model of ocean circulation is similar to a conveyor belt that travels throughout the world. **Figure 8** shows this conveyor belt model in which warm water in the ocean's upper layers flows toward the poles. When the water reaches the poles, its temperature drops and salinity increases, making it more dense. Because the water is dense, it sinks and moves toward the equator. It returns to the equator as cold, deep water that eventually upwells along a coast, or another ocean feature such as a seamount, and completes the circuit. As this "conveyor belt" current moves around the globe, it influences global climate by converting warm water to cold water and releasing heat to the atmosphere.



# 16.1 Assessment

## Review Key Concepts

1. How do surface currents develop?
2. What is the Coriolis effect? How does it influence the direction of surface currents flowing in the ocean?
3. How do ocean currents affect climate?
4. Why is upwelling important?
5. How are density currents formed?

## Think Critically

6. **Apply Concepts** The average surface water temperature off of the coast of Ecuador is 21°C. The average surface water temperature off of the coast of Brazil at the same latitude is about 27°C. Explain why there is such a difference in water temperature between these areas at the same latitude.
7. **Infer** During an El Niño event, the upwelling of cold, nutrient-rich water stops in areas off the coast of Peru. How might this affect the food web in this area?

**WRITING IN SCIENCE**

8. **Explain** During the 1700s, mail ships sailed back and forth between England and America. It was noted that it took the ships two weeks longer to go from England to America than to travel the same route from America to England. It was determined that the Gulf Stream was delaying the ships. Write a paragraph explaining why this is true. Use Figure 2 to explain how sailors could avoid the Gulf Stream when sailing to America.

EARTH & ITS SYSTEMS

# Shoes and Toys as Drift Meters

Any floating object can serve as a makeshift drift meter, as long as it is known where the object entered the ocean and where it was retrieved. The path of the object can then be inferred, providing information about the movement of surface currents. If the times of release and retrieval are known, the speed of currents can also be determined. Oceanographers have long used drift bottles—a radio-transmitting device set adrift in the ocean—to track the movement of currents and, more recently, to refine computer models of ocean circulation.

Many objects have accidentally become drift meters when ships have lost some (or all) of their cargo at sea. In this way, athletic shoes helped oceanographers advance the understanding of surface circulation in the North Pacific Ocean. In May 1990, the container vessel *Hansa Carrier* was traveling from South Korea to Seattle, Washington, when it encountered a severe North Pacific storm. During the storm the ship lost 21 deck containers overboard, including five that held athletic shoes. The shoes that were released from their containers floated and were carried east by the North Pacific Current. Within six months, thousands of the shoes began to wash up along the beaches of Alaska, Canada, Washington, and Oregon—over 2400 kilometers from the site of the spill. The inferred course of the shoes is shown in **Figure 9.** A few shoes were found on beaches in northern California, and over two years later shoes from the spill were even recovered from the north end of the main island of Hawaii.

With help from the beachcombing public and remotely based lighthouse operators, information on the location and number of shoes collected was compiled during the months following the spill. Serial numbers inside the shoes were traced to individual containers, which indicated that only four of the five containers had released their shoes. Most likely, one entire container sank without opening. A maximum of 30,910 pairs of shoes (61,820 individual shoes) were released. Before the shoe spill, the largest number of drift bottles purposefully released at one time by oceanographers was about 30,000. Although only 2.6 percent of the shoes were recovered, this compares favorably with the 2.4 percent recovery rate of drift bottles released by oceanographers conducting research.

In January 1992, another cargo ship lost 12 containers overboard during a storm to the north of where the shoes had previously spilled. One of these containers held 29,000 packages of small, floatable, colorful plastic bathtub toys in the shapes of blue turtles, yellow ducks, red beavers, and green frogs. Even though the toys were housed in plastic packaging glued to a cardboard backing, studies showed that after 24 hours in seawater, the glue deteriorated, thereby releasing over 100,000 individual floating toys.

The floating bathtub toys began to come ashore in southeast Alaska 10 months later, which verified computer models of North Pacific circulation. The models indicate that many of the bathtub toys will continue to be carried by the Alaska Current and will eventually disperse throughout the North Pacific Ocean.

Since 1992, oceanographers have continued to study ocean currents by tracking other floating items spilled from cargo ships, including 34,000 hockey gloves, 5 million plastic building blocks, and an unidentified number of small plastic doll parts.

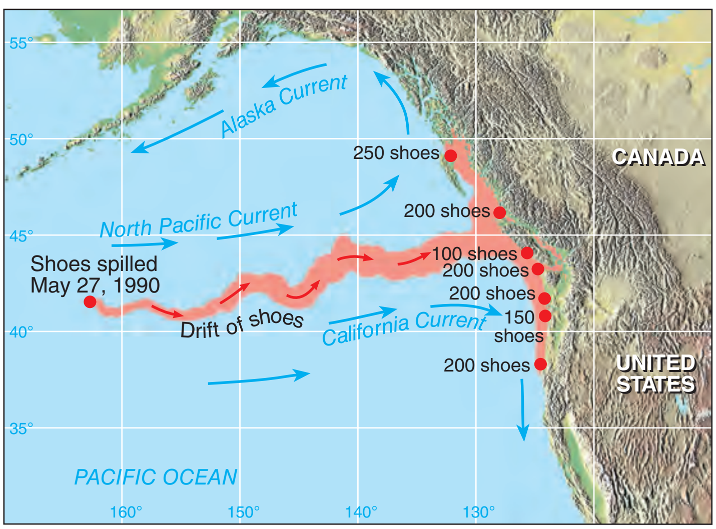



**FIGURE 9** The map shows the path of drifting shoes and recovery locations from a spill in 1990.

# 16.2 Waves and Tides

**ES.3** The student will investigate and understand the characteristics of Earth and the solar system. Key concepts include **b.** sun-Earth-moon relationships; (seasons, tides, and eclipses). **ES.10** The student will investigate and understand that oceans are complex, interactive physical, chemical, and biological systems and are subject to long- and short-term variations. Key concepts include **a.** physical and chemical changes related to tides, waves, currents, sea level and ice cap variations, upwelling, and salinity variations.

**MOST OCEAN** currents are not visible to the human eye, but waves and tides are the easiest ocean movements to observe. The movement of ocean water can be a powerful thing. Waves created by storms release energy when they crash along the shoreline. Wind-generated waves provide much of the energy that shapes and changes shorelines over time.

## Key Questions

***From where do ocean waves obtain their energy?***

***What three factors affect the characteristics of a wave?***

***How does energy move through a wave?***

***What causes tides?***

## Vocabulary

- wave height • wavelength
- wave period • fetch
- tide • tidal range
- spring tide • neap tide

## Reading Strategy

**Build Vocabulary** Copy the table below. As you read the section, define in your own words each vocabulary word listed in the table.

| Vocabulary Term | Definition |
|---|---|
| Wave height | a. ___?___ |
| Wavelength | b. ___?___ |
| Wave period | c. ___?___ |
| Fetch | d. ___?___ |

## Waves

Waves can transfer energy from a storm far out at sea over distances of several thousand kilometers. That's why even on calm days waves travel across the ocean surface. The power of waves is most noticeable along the shore, the area where land and sea meet and waves are constantly rolling in and breaking. Sometimes the waves are low and gentle. Other times waves, such as the ones shown in **Figure 10,** are powerful as they pound the shore.

If you make waves by tossing a pebble into a pond, splashing in a pool, or blowing across the surface of a glass of water, you are transferring energy to the water. The waves you see are just the visible evidence of the energy passing through the water. When observing ocean waves, remember that you are watching energy travel through a medium, in this case, water.

**FIGURE 10 The Force of Breaking Waves** These waves are slamming into a seawall that was built at Sea Bright, New Jersey, to protect the nearby electrical lines and houses from the force of the waves.

## INQUIRY
### APPLY IT!

**Q:** *Do waves always travel in the same directions as currents?*

**A:** Not in all cases. Most surface waves travel in the same direction as the wind blows, but waves radiate outward in all directions from the disturbance that creates them. In addition, as waves move away from the sea area where they were generated, they enter areas where other currents exist. As a result, the direction of wave movement is often unrelated to that of currents. In fact, waves can even travel in a direction completely opposite to that of a current. A rip current, for example, moves away from the shoreline, opposite to the direction of incoming waves.

**Wave Characteristics** **Most ocean waves obtain their energy and motion from the wind.** When a breeze is less than 3 kilometers per hour, only small waves appear. At greater wind speeds, more stable waves gradually form and advance with the wind.

Characteristics of ocean waves are illustrated in **Figure 11.** The tops of the waves are the crests, which are separated by troughs. Halfway between the crests and troughs is the still water level, which is the level that the water would occupy if there were no waves. The vertical distance between trough and crest is called **wave height.** The horizontal distance between two successive crests or two successive troughs is the **wavelength.** The time it takes one full wave—one wavelength—to pass a fi ed position is the **wave period.**

**The height, length, and period that are eventually achieved by a wave depend on three factors: (1) wind speed; (2) length of time the wind has blown; and (3) fetch.** **Fetch** is the distance that the wind has traveled across open water. As the quantity of energy transferred from the wind to the water increases, both the height and steepness of the waves also increase. Eventually, a critical point is reached at which waves grow so tall that they topple over, forming ocean breakers called whitecaps.

**Wave Motion** Waves can travel great distances across ocean basins. In one study, researchers tracked waves generated near Antarctica as they traveled through the Pacific Ocean basin. After traveling for a week and more than 10,000 kilometers, the waves fi ally expended their energy along the shoreline of the Aleutian Islands of Alaska.

Water itself does not travel the entire distance of a wave. As a wave travels, the water particles pass the energy along by moving in a circle. This movement, shown in Figure 11, is called *circular orbital motion.* **Circular orbital motion allows energy to move forward through the water while the water particles that transmit the wave move around in a circle.**

**ACTIVE ART**

**For:** Water Motion activity
**Visit:** PearsonSchool.com
**Web Code:** czp-5162

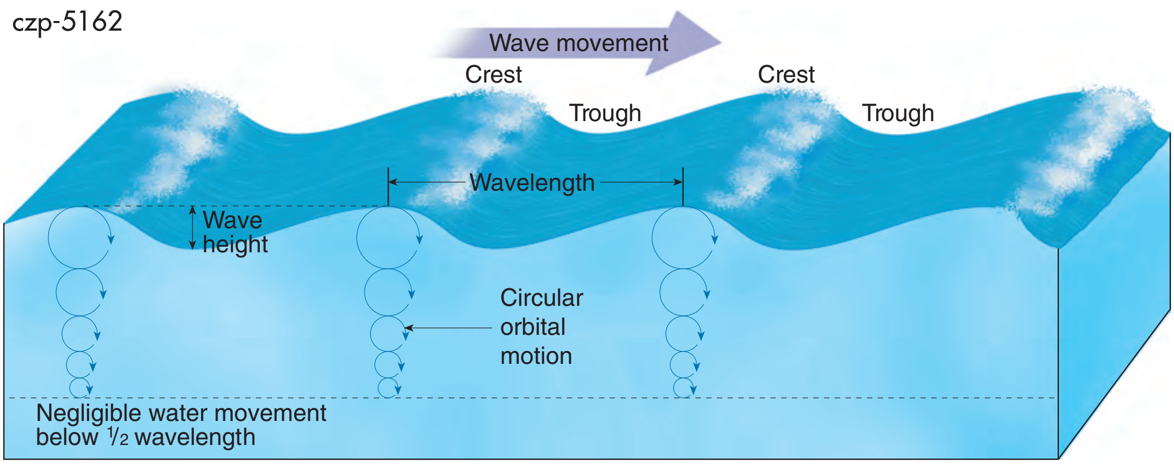



**FIGURE 11** **Anatomy of a Wave** The diagram shows the parts of a non-breaking wave and the movement of particles under the surface.

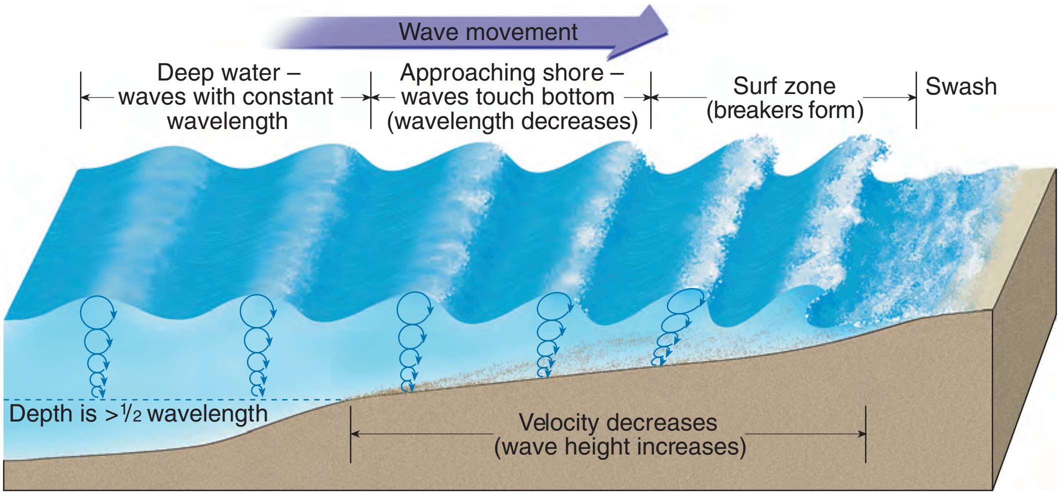



**FIGURE 12 Breaking Waves** Changes occur as a wave moves onto shore. As the waves touch bottom, wave speed decreases. The decrease in wave speed results in a decrease in wavelength and an increase in wave height.

Observations of a floating object, such as a toy boat, reveal that it moves not only up and down but also slightly forward and backward with each successive wave. This movement results in a circle that returns the object to essentially the same place in the water.

The energy transferred by the wind to the water is transmitted not only along the surface of the sea but also downward. However, beneath the surface, the circular motion rapidly diminishes until—at a depth equal to one-half the wavelength measured from still water level—the movement of water particles becomes very slight. In Figure 11, the dramatic decrease of wave energy with depth is shown by the rapidly decreasing diameters of water-particle orbits.

**Breaking Waves** As long as a wave is in deep water, it is unaffected by water depth. However, when a wave approaches the shore, the water becomes shallower and influences wave behavior. The wave begins to "feel bottom" at a water depth equal to half of its wavelength. Such depths interfere with water movement at the base of the wave and slow its advance. **Figure 12** shows the changes that occur as a wave moves onto shore.

As a wave advances toward the shore, the slightly faster waves farther out to sea catch up and decrease its wavelength. As the speed and length of the wave decrease, the wave grows higher. Finally, a critical point is reached when the wave is too steep to support itself, and the wave front collapses, or breaks, causing water to advance up the shore.

The turbulent water created by breaking waves is called surf. On the landward margin of the surf zone, the sheet of water from collapsing breakers, called *swash,* moves up the slope of the beach. When the energy of the swash has been expended, the water flows back down the beach toward the surf zone as backwash.

**Reading Checkpoint** *At what depth do the characteristics of a wave begin to change as it approaches the shore?*

**INQUIRY**
**APPLY IT!**

**Q:** *Where is the world's largest tidal range?*

**A:** The world's largest tidal range is found in the northern end of Nova Scotia's 258-kilometer-long Bay of Fundy. During maximum spring tide conditions, the tidal range at the mouth of the bay is only about 2 meters. However, the tidal range progressively increases from the mouth of the bay inward because the natural geometry of the bay concentrates tidal energy. In the eastern end of the bay, the maximum spring tidal range is about 17 meters. This extreme tidal range leaves boats high and dry during low tide.

# Tides

**Tides** are regular changes in the elevation of the ocean surface. Their rhythmic rise and fall along coastlines has been noted throughout history. But the cause of tides was not well understood until Sir Isaac Newton applied the law of universal gravitation to them. Newton showed that there is a mutually attractive force—gravity—between any two bodies, such as between Earth and the moon. The strength of gravity between two objects decreases as the distance between the objects increases. At any given time, different areas of Earth's surface are different distances from the moon. The pull of the moon's gravity is greater at parts of Earth's surface that are closer to the moon and less at parts that are farther from the moon.

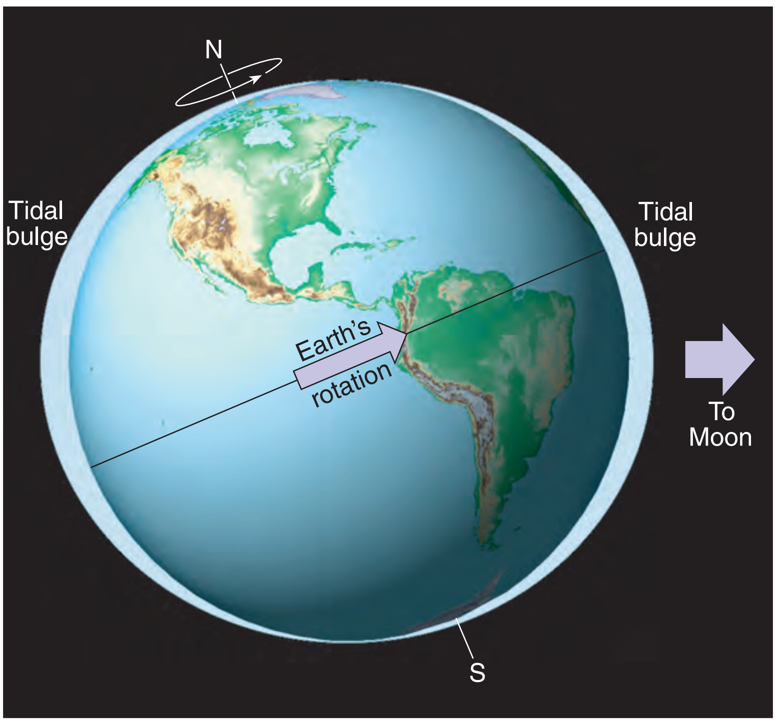
## The Cause of Tides

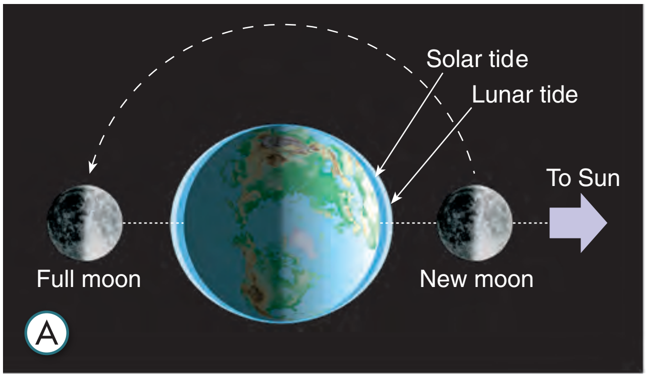
**Ocean tides result from differences in the gravitational attraction exerted upon different parts of Earth's surface by the moon and, to a lesser extent, by the sun.** The primary body that influences the tides is the moon, which makes one complete revolution around Earth every 29 and a half days. The sun, however, also influences the tides. It is far larger than the moon, but because it is much farther away, its effect is considerably less. In fact, the sun's tide-generating effect is only about 46 percent that of the moon's.

Think about the gravitational forces between the moon and Earth. This gravitational pull is strongest on the side of Earth closest to the moon and weakest on the far side of Earth from the moon. This difference causes Earth to be stretched slightly. The shape of the solid Earth is not affected much by this pull. However, the world ocean is much more mobile than the solid portions of Earth and a *tidal bulge* is produced as water is pulled toward the moon, as shown in **Figure 13.** A second tidal bulge is produced on the other side of Earth due to inertia—the tendency of an object, in this case water, to move in a straight line.

Because the position of the moon in relation to Earth changes only moderately in a single day, the tidal bulges remain in place while Earth rotates "through" them. For this reason, if you stand on a seashore for 24 hours, Earth will rotate you through alternating areas of higher and lower water. As you are carried into each tidal bulge, the tide rises. As you are carried into the troughs between the tidal bulges, the tide falls. Most coastal locations experience two high tides and two low tides each day.

**FIGURE 13 Tidal Bulges on Earth Caused by the Moon**
Interpret Visuals *When Earth is in this position, is North America experiencing low tide or high tide?*





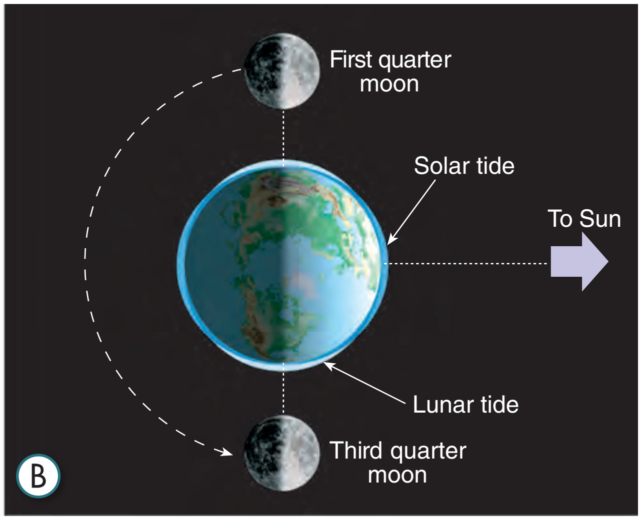




**FIGURE 14 Earth-Moon-Sun Positions and the Tides**
**A** When Earth, moon, and sun are aligned, spring tides are experienced. **B** When Earth, moon, and sun are at right angles to each other, neap tides are experienced.
**Describe** *How does the sun influence the formation of spring and neap tides?*

**Tidal Cycle** Although the sun is farther away from Earth than the moon, the gravitational attraction between the sun and Earth does play a role in producing tides. The sun's influence produces smaller tidal bulges. These tidal bulges are the result of the same forces involved in the bulges created by the moon. The influence of the sun on tides is most noticeable near the times of new and full moons. During these times, the sun and moon are aligned, and their forces are combined, as shown in **Figure 14A.** The combined gravity of these two tide-producing bodies causes larger tidal bulges (higher high tides) and larger tidal troughs (lower low tides). The result is a larger than normal **tidal range,** which is the difference in height between successive high and low tides.

**Spring tides** are tides that have the greatest tidal range due to the alignment of Earth, the moon, and the sun. They are experienced during new and full moons. Conversely, at about the time of the fi st and third quarters of the moon, the gravitational forces of the moon and sun act on Earth at a right angle, as shown in **Figure 14B.** The sun and moon partially offset the influence of the other. As a result, the daily tidal range is less. These tides are called **neap tides.** Each month there are two spring tides and two neap tides, each about one week apart.

**Reading Checkpoint** *What is the tidal range?*

**FIGURE 15 High Tide and Low Tide in a Village in Nova Scotia**

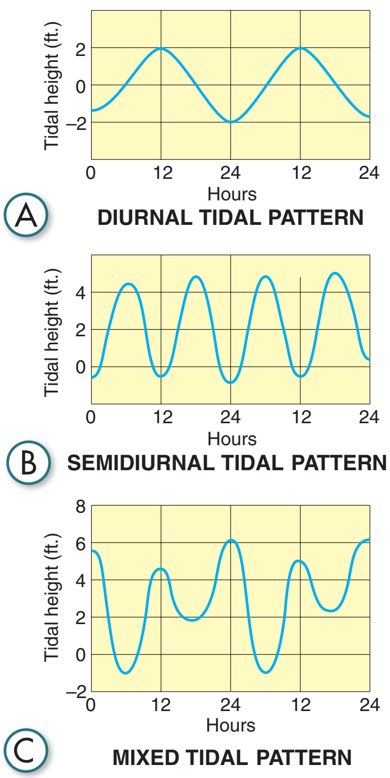



**FIGURE 16 Tidal Patterns**
The high points in these graphs represent high tides and the low points represent low tides.

**Tidal Patterns** You now know the basic causes and types of tides. However, many factors—including the shape of the coastline, the confi uration of ocean basins, and water depth—greatly influence the tides. Consequently, tides at various locations respond differently to the tide-producing forces. This being the case, the nature of the tide at any coastal location can be determined most accurately by actual observation. The predictions in tidal tables and tidal data on nautical charts are based on such observations.

**Th ee main tidal patterns exist worldwide: diurnal tides, semidiurnal tides, and mixed tides.** A *diurnal* tidal pattern is characterized by a single high tide and a single low tide each tidal day, as shown in the graph in **Figure 16A.** Tides of this type occur along the northern shore of the Gulf of Mexico.

A *semidiurnal* tidal pattern exhibits two high tides and two low tides each tidal day. The two highs are about the same height, and the two lows are about the same height. **Figure 16B** shows a semidiurnal tide pattern. This type of tidal pattern is common along the Atlantic Coast of the United States.

A *mixed* tidal pattern, shown in **Figure 16C,** is similar to a semidiurnal pattern except that it is characterized by a large inequality in high water heights, low water heights, or both. There are usually two high and two low tides each day. However, the high tides are of different heights, and the low tides are of different heights. Such tides are found along the Pacific Coast of the United States and in many other parts of the world.

# 16.2 Assessment

## Review Key Concepts

1. From where do ocean waves obtain their energy?
2. What three factors determine the height, length, and period of a wave?
3. How does energy move by means of a wave?
4. What changes occur in a wave as it approaches shore?
5. Which celestial bodies influence Earth tides?
6. What force produces tides?
7. What are the three types of tidal patterns?

## Think Critically

8. **Infer** Two waves have the same fetch and were created by winds of equal speed. Why might one wave be higher than the other?
9. **Relate Cause and Effect** Explain how gravity leads to tides in Earth's oceans.
10. **Compare and Contrast** Compare and contrast spring tides and neap tides.

**MATH PRACTICE**

11. **Calculate** Wavelength, wave period, and wave speed can be related to each other in the equation:

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

If wavelength = 187 meters, and wave speed = 16.8 meters per second, what is the period of this wave?

# 16.3 Shoreline Processes and Features

**ES.3** The student will investigate and understand the characteristics of Earth and the solar system. Key concepts include **b.** sun-Earth-moon relationships; (seasons, tides, and eclipses). **ES.10** The student will investigate and understand that oceans are complex, interactive physical, chemical, and biological systems and are subject to long- and short-term variations. Key concepts include **a.** physical and chemical changes related to tides, waves, currents, sea level and ice cap variations, upwelling, and salinity variations; and **b.** importance of environmental and geologic implications.

**BEACHES AND SHORELINES** are constantly undergoing changes as the force of waves and currents act on them. During calm weather, wave action is minimal. During storms, however, waves are capable of causing much erosion—the movement of material from one place to another. The pressure exerted by Altantic waves in wintertime, for example, averages 10,000 kilograms per square meter. The force during storms is even greater. These forces contribute to the fascinating assortment of shoreline features found along the world's coastal regions.

## Forces Acting on the Shoreline

When people think of beaches, they think of sandy areas where people lie in the sun and stroll along the water's edge. Technically, a **beach** is the accumulation of sediment found along the shore of a lake or ocean. Beaches are composed of whatever sediment is locally available. They may be made of mineral particles from the erosion of beach cliffs or nearby coastal mountains. Some beaches have a significant biological component. For example, most beaches in southern Florida are composed of shell fragments and the remains of coastal marine organisms. Beaches can be thought of as material in transit along the shoreline. The action of waves and abrasion greatly changes the shape of beaches and shorelines over time.

**Wave Impact** Waves that crash along the beach are constantly moving sediment. **Waves along the shoreline are constantly eroding, transporting, and depositing sediment. Many types of shoreline features can result from this activity.** During calm weather, wave action is minimal. During storms, however, waves are capable of causing much erosion. The impact of large, high-energy waves against the shore can be awesome in its violence. Each breaking wave may hurl thousands of tons of water against the land, sometimes causing the ground to tremble.

It is no wonder that cracks and crevices are quickly opened in cliffs, coastal structures, and anything else that is subjected to these enormous impacts. Water is forced into every opening, causing air in the cracks to become highly compressed by the thrust of crashing waves. When the wave subsides, the air expands rapidly. This expanding air dislodges rock fragments and enlarges and extends preexisting fractures.

### Key Questions

***How are sediments along the shoreline moved?***

***How does refraction affect wave action along the shore?***

***What do longshore currents do?***

***By which processes do shoreline features form?***

***What structures can be built to protect a shoreline?***

***What is beach nourishment?***

### Vocabulary

- beach
- wave refraction
- longshore current
- barrier island

### Reading Strategy

**Summarize** Read the section on wave refraction. Then copy and complete the concept map below to organize what you know about refraction.

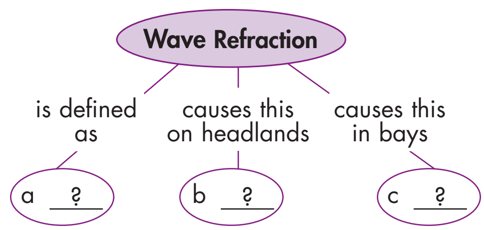


**FIGURE 17 Erosion** Abrasion has undercut this sandstone cliff at Gabriola Island, British Columbia, Canada.

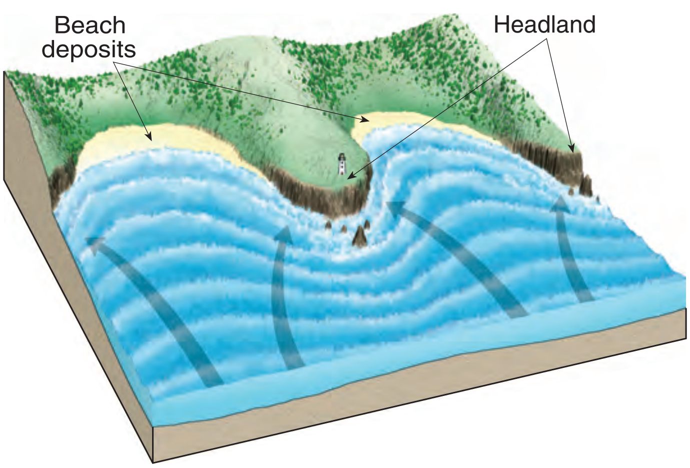
**Abrasion** In addition to the erosion caused by wave impact and pressure, erosion caused by abrasion is also important. In fact, abrasion is probably more intense in the surf zone than in any other environment. Abrasion is the sawing and grinding action of rock fragments in the water. Smooth, rounded stones and pebbles along the shore are evidence of the continual grinding action of rock against rock in the surf zone. Such fragments are also used as "tools" by waves as they cut horizontally into the land, as shown in the sandstone in **Figure 17.**

**Wave Refraction** The bending of waves, called **wave refraction,** plays an important part in shoreline processes. Wave refraction affects the distribution of energy along the shore. It strongly influences where and to what degree erosion, sediment transport, and deposition will take place.

Most waves move toward the shore at a slight angle, rather than straight on. However, when they reach the shallow water of a smoothly sloping bottom, the wave crests are refracted, or bent, and tend to line up nearly parallel to the shore. Such bending occurs because the part of the wave nearest the shore touches bottom and slows fi st, whereas the part of the wave that is still in deep water continues forward at its full speed. The change in speed causes wave crests to become nearly parallel to the shore.

**Because of refraction, wave energy is concentrated against the sides and ends of headlands that project into the water, whereas wave action is weakened in bays.** A *bay* is an indentation in a shoreline. This type of wave action along irregular coastlines is illustrated in **Figure 18.** Waves reach the shallow water in front of the headland sooner than they do in the bays. Therefore, wave energy is concentrated in this area, leading to erosion. By contrast, refraction in the bays causes waves to spread out and expend less energy. This refraction leads to deposition and the formation of sandy beaches.

**FIGURE 18 Wave Refraction** Waves are refracted as they come into shore. Wave energy is concentrated at the headlands and dispersed in the bays.
**Infer** ***What processes occur as a result of wave refraction on this shoreline?***



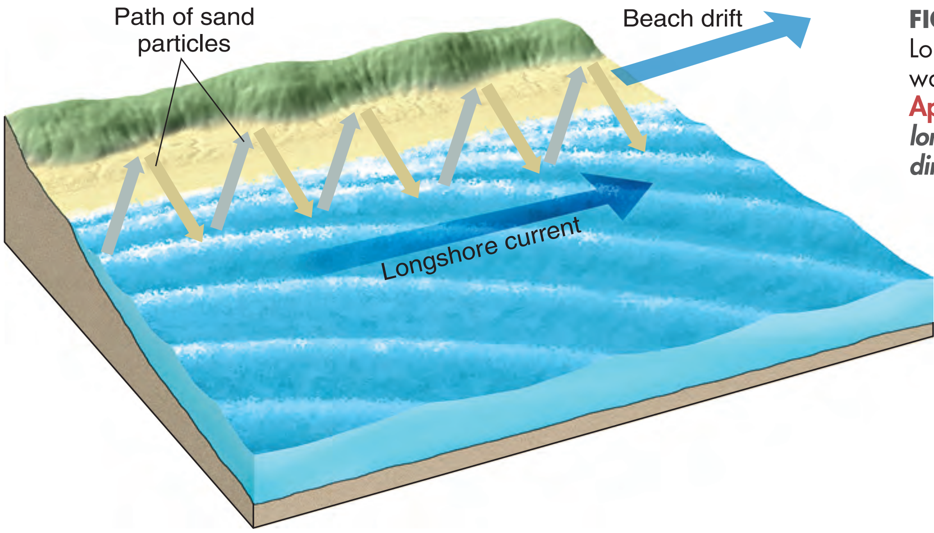



**FIGURE 19 Longshore Transport** Longshore currents are created by waves breaking at an angle. **Apply Concepts** ***Explain how longshore currents can change direction.***

**Longshore Transport** Although waves are refracted, most still reach the shore at a slight angle. As a result, the uprush of water, or swash, from each breaking wave is at an slight angle to the shoreline. However, the backwash is straight down the slope of the beach. The effect is a zigzag pattern along the beach face. This movement, called *beach drift,* can transport sand and pebbles hundreds or even thousands of meters daily. These angled waves also produce currents within the surf zone. The currents flow parallel to the shore and move large amounts of sediment along the shore. **Figure 19** shows this type of current, which is called a **longshore current.**

The water in the surf zone is turbulent, which means there is a lot of movement. **Turbulence allows longshore currents to easily move the fi  e suspended sand and to roll larger sand and gravel particles along the bottom.** Longshore currents can change direction when the direction that waves approach the beach changes with the seasons. Generally, longshore currents flow southward along both the Atlantic and Pacific shores of the United States.

**Reading Checkpoint** *What causes longshore currents?*

## Erosional Features

Shoreline features vary depending on the type of rocks exposed along the shore, the intensity of waves, coastal currents, and whether the coast is stable, sinking, or rising. **Shoreline features that originate primarily from erosion are called erosional features. Sediment that is transported along the shore and deposited in areas where energy is low produce depositional features.**

Erosional features are common along the rugged and irregular New England coast and along the steep shorelines of the West Coast of the United States.Wave erosion is steadily wearing away the California coast. Where the coast is made up of sedimentary rock, average erosion is 15 to 30 centimeters per year. But where the coast consists of soil and sand, erosion can be as high as 2 to 3 meters per year. Coastal erosion is a hazard to structures built on cliffs and bluffs along the shore.

**FIGURE 20 Sea Arch** In time, the sea arch will collapse and form a sea stack similar to the sea stack on the left side of the photograph.

The cliffs along California's coast form as tectonic processes slowly uplift oastal land. At the same time, the energy of ocean waves undercuts the cliffs. Over time, this process produces features such as wave-cut cliffs, wave-cut platforms, sea arches, and sea stacks.

### Wave-Cut Cliffs and Platforms

Wave-cut cliffs result from the cutting action of the surf against the base of coastal land. As erosion progresses, rocks that overhang the notch at the base of the cliff crumble into the surf, and the cliff etreats. A relatively flat, benchlike surface, called a wave-cut platform, is left ehind by the receding cliff. The platform broadens as the wave attack continues. Some debris produced by the breaking waves remains along the water's edge as sediment on the beach. The rest of the sediment is transported farther seaward.

**Sea Arches and Sea Stacks** Headlands that extend into the sea are vigorously attacked by waves because of refraction. The surf erodes the rock selectively and wears away the softer or more highly fractured rock at the fastest rate. At fi st, sea caves may form. When two caves on opposite sides of a headland unite, a sea arch such as the one in **Figure 20** results. Eventually, the sea arch may fall in, leaving an isolated remnant, or sea stack, on the wave-cut platform.

☑ **Reading Checkpoint** *How does a sea arch form?*

## Depositional Features

Sediment eroded from beaches is transported along the shore and deposited in areas where wave energy is low. Such processes produce many depositional features.

**FIGURE 21 Baymouth Bar** This high-altitude image shows a baymouth bar along the coast of Martha's Vineyard, Massachusetts.


**Spits, Bars, and Tombolos** Where longshore currents and other surf zone currents are active, several features may develop. A *spit* is an elongated ridge of sand that projects from the land into the mouth of an adjacent bay. Often the end in the water hooks landward in response to the dominant direction of the longshore current. The term *baymouth bar* is applied to a sandbar that completely crosses a bay, sealing it off from the open ocean. Find the baymouth bar in **Figure 21.** Such a feature tends to form across bays in which currents are weak and spits extend across. A *tombolo* is a ridge of sand that connects an island to the mainland or to another island. A tombolo forms in much the same way as a spit. **Figure 22** shows how tomobolos and other features form as a shoreline changes over time.

# VISUAL SUMMARY

## EVOLUTION OF SHORELINE FEATURES

**FIGURE 22** Over time erosion and deposition transform an irregular coastline into one that is smooth and straight.

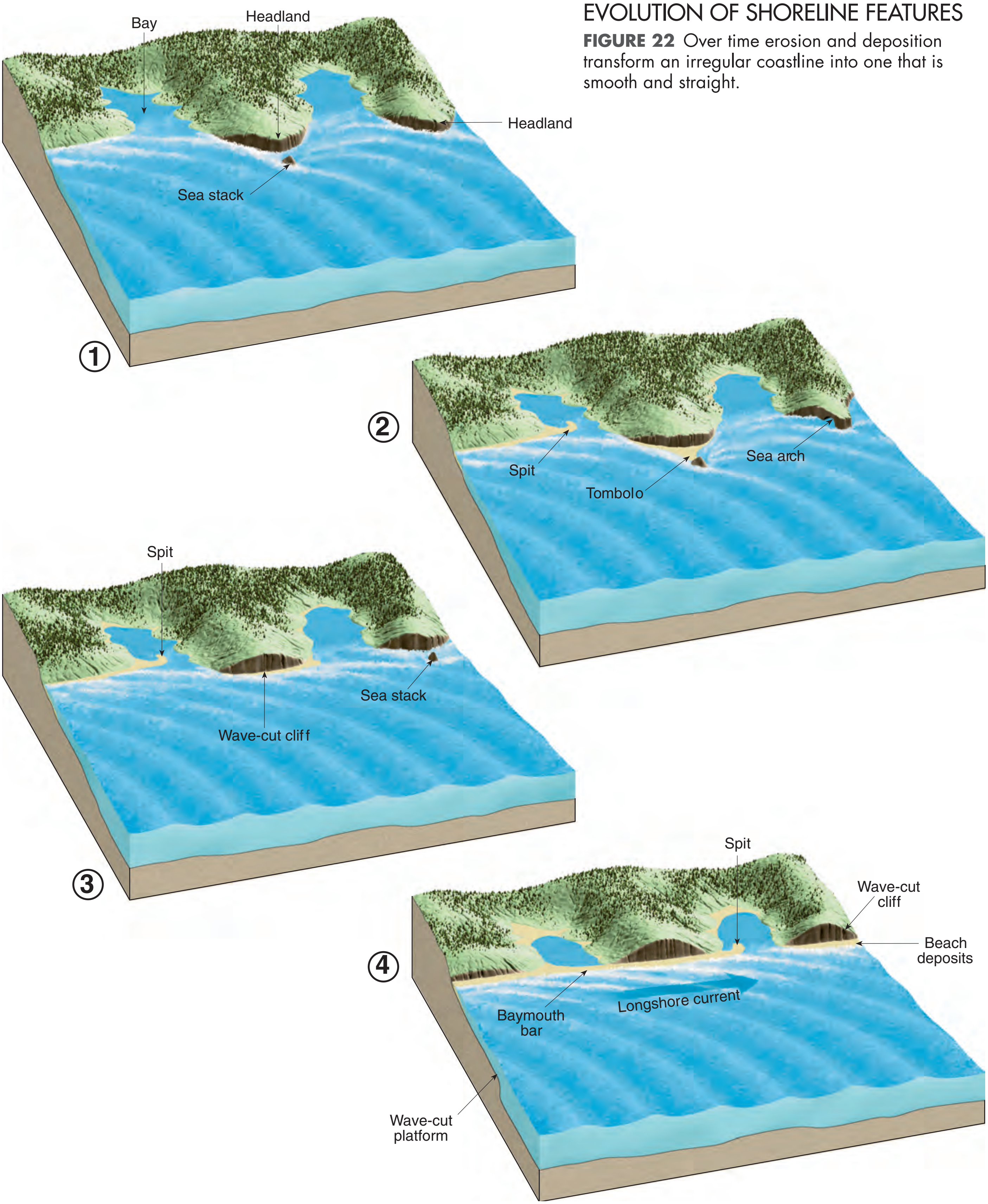



**FIGURE 23 Barrier Islands** The islands along the coast of North Carolina are examples of barrier islands.

**Barrier Islands** The Atlantic and Gulf Coastal Plains are relatively flat and slope gently seaward. The shore zone in these areas is characterized by barrier islands. **Barrier islands** are narrow sandbars parallel to, but separated from, the coast at distances from 3 to 30 kilometers offshore. From Cape Cod, Massachusetts, to Padre Island, Texas, nearly 300 barrier islands rim the coast. The barrier islands along the coast of North Carolina are shown in **Figure 23.**

Barrier islands may have formed in several ways. Some began as spits that were later cut off rom the mainland by wave erosion or by the general rise in sea level following the last glacial period. Others were created when turbulent waters in the line of breakers heaped up sand that had been scoured from the bottom. Finally, some barrier islands may be former sand-dune ridges that began along the shore during the last glacial period, when sea level was lower. As the ice sheets melted, sea level rose and flooded the area behind the beach-dune complex.

**Reading Checkpoint** *What is a barrier island?*

# Stabilizing the Shore

Shorelines are among Earth's most dynamic places. They change rapidly in response to natural forces. Storms are capable of eroding beaches and cliffs at rates that far exceed the long-term average erosion. Such bursts of accelerated erosion not only affect the natural evolution of a coast but can also have a profound impact on people who live in the coastal zone. Erosion along the coast causes significant property damage. Huge sums of money are spent annually to repair damage and to prevent or control erosion.

**Protective Structures** **Groins, breakwaters, and seawalls are some structures built to protect a coast from erosion or to prevent the movement of sand along a beach.** *Groins* are sometimes constructed to maintain or widen beaches that are losing sand. A groin is a barrier built at a right angle to the beach to trap sand that is moving parallel to the shore.

**FIGURE 24 Breakwater** These breakwaters, built along a Chesapeake Bay shoreline, should help protect the shoreline from erosion by absorbing force from strong waves.

Protective structures, such as the *breakwaters* shown in **Figure 24,** can also be built parallel to the shoreline. Their purpose is to protect boats or eroding shorelines from the force of large breaking waves by creating a quiet water zone near the shore. A *seawall* is another protective structure built parallel to the shore. A seawall is designed to shield the coast and defend property from breaking waves. Waves expend much of their energy as they move across an open beach. Seawalls reduce this process by reflecting the force of unspent waves seaward.

Protective structures often only offer temporary solutions to shoreline problems. The structures themselves interfere with the natural processes of erosion and deposition. Then more structures may need to be built in order to counteract the new problems that arise. Many scientists feel that using protective structures to divert the ocean's energy causes more harm than good.

**Beach Nourishment** **Beach nourishment is the artificial addition of large quantities of sand to the beach system.** It is an attempt to stabilize shoreline sands without building protective structures. Examine the before and after photographs shown in **Figure 25.** By building the beaches seaward, both beach quality and storm protection are improved. However, the same processes that removed the sand in the first place will eventually wash away the replacement sand as well.

Beach nourishment can be very expensive because huge volumes of sand must be transported to the beach from offshore areas, nearby rivers, or other source areas for sand. Beach nourishment can also have detrimental effects on local marine life. For example, beach nourishment at Waikiki Beach, Hawaii, involved replacing the natural coarse beach sand with softer, muddier sand. Destruction of the softer sand by breaking waves increased the water's turbidity, or "cloudiness," and killed offshore coral reefs.


**FIGURE 25 Miami Beach A** Before beach nourishment **B** After beach nourishment
**Explain** *What are the advantages and disadvantages of beach nourishment?*

# 16.3 Assessment

## Review Key Concepts

1. How are sediments along the shoreline moved?
2. What effect does wave impact have on shorelines?
3. How does refraction affect wave action along the shore?
4. What do longshore currents do?
5. By which processes do shoreline features form?
6. Name three examples of shoreline features formed by erosion.
7. How do barrier islands form?
8. What structures can be built to protect a shoreline?
9. What is beach nourishment?

## Think Critically

10. **Explain** How can beach nourishment be helpful? How can it be harmful?
11. **Compare and Contrast** Compare and contrast a tombolo and a barrier island.
12. **Relate Cause and Effect** A breakwater is built to reduce wave action in near-shore areas. How might the reduced wave action along the shore behind the breakwater affect sediment deposition? What problems might this cause?

**BIG IDEA** WATER PLANET

13. **Summarize** Examine Figure 22. In your own words summarize how waves and currents changed this shoreline over time.

INQUIRY

EXPLORATION LAB

# Graphing Tidal Cycles

**Problem** How can you determine the tidal pattern an area experiences?

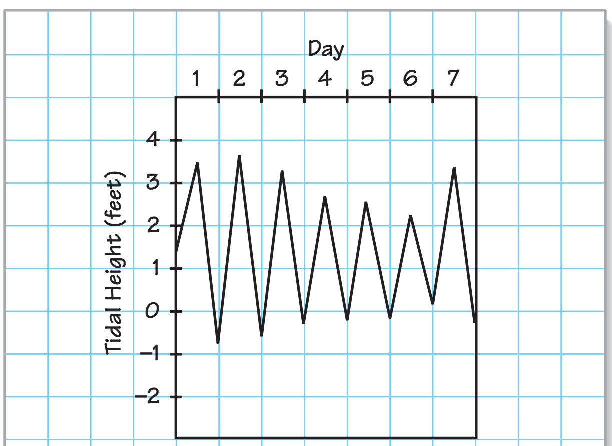
**Materials** graph paper, pencil

**Skills** Graph, Interpret Data, Infer, Draw Conclusions

**Connect to the Big idea** Tides are the cyclical rise and fall of sea level caused by the gravitational attraction between Earth and the moon and, to a lesser extent, between Earth and the sun. Gravitational pull creates a bulge in the ocean on the side of Earth nearest the moon. A similar bulge forms on the other side of Earth due to inertia. Tides develop as the rotating Earth moves through these bulges, causing periods of high and low water. In this lab, you will graph tidal data to determine whether an area has diurnal, semidiurnal, or mixed tides.

## Procedure

1. Label the graph paper as below to make a graph of the tidal cycle. The *x*-axis should be in days, and the *y*-axis should be in feet. As shown below, place the *x*-axis at the top of the graph, rather than at the bottom.
2. Use the data in **Table 1** to make a graph of the tidal cycle.



Sample Tidal Curve


High tide in Nova Scotia's Bay of Fundy


Low tide in the same area

## Analyze and Conclude

1. **Apply Concepts** What tidal pattern does this area experience? Explain how you determined this.
2. **Calculate** What is the greatest tidal range for the data you graphed? What is the least tidal range? What types of tides correspond to each of these tidal ranges?
3. **Draw Conclusions** Based on your graph, identify the days when each moon phase could have occurred: new moon, fi st quarter moon, full moon, last quarter moon. How do you know this?
4. **Apply Concepts** On January 5th (Day 5 on the table) at 9:00 a.m., Jarred anchored his boat in about 4 feet of water at the beach. When he returned at 3:30 that afternoon, the boat was in the sand. What had happened? How long did Jarred have to wait to leave the area in his boat?

| Table 1 Tidal Data for Long Beach, New York, January 2003 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| All times are listed in Local Standard Time (LST). All heights are in feet. | | | | | | | | |
| Day | Time | Height | Time | Height | Time | Height | Time | Height |
| 1 | 05:45 A.M. | 5.5 | 12:16 P.M. | −0.7 | 06:12 P.M. | 4.4 | ——— | – |
| 2 | 12:18 A.M. | −0.5 | 06:35 A.M. | 5.6 | 01:07 P.M. | −0.8 | 07:03 P.M. | 4.4 |
| 3 | 01:10 A.M. | −0.5 | 07:23 A.M. | 5.5 | 01:56 P.M. | −0.8 | 07:53 P.M. | 4.4 |
| 4 | 01:59 A.M. | −0.4 | 08:11 A.M. | 5.4 | 02:42 P.M. | −0.7 | 08:42 P.M. | 4.3 |
| 5 | 02:45 A.M. | −0.2 | 08:59 A.M. | 5.1 | 03:25 P.M. | −0.5 | 09:32 P.M. | 4.2 |
| 6 | 03:30 A.M. | 0.0 | 09:47 A.M. | 4.8 | 04:07 P.M. | −0.3 | 10:23 P.M. | 4.0 |
| 7 | 04:14 A.M. | 0.3 | 10:35 A.M. | 4.6 | 04:49 P.M. | −0.1 | 11:12 P.M. | 3.9 |
| 8 | 05:01 A.M. | 0.6 | 11:22 A.M. | 4.3 | 05:32 P.M. | 0.2 | 11:59 P.M. | 3.9 |
| 9 | 05:54 A.M. | 0.8 | 12:09 P.M. | 4.0 | 06:18 P.M. | 0.4 | ——— | – |
| 10 | 12:45 A.M. | 3.9 | 06:56 A.M. | 0.9 | 12:57 P.M. | 3.7 | 07:10 P.M. | 0.5 |
| 11 | 01:31 A.M. | 3.9 | 07:59 A.M. | 0.9 | 01:47 P.M. | 3.5 | 08:02 P.M. | 0.5 |
| 12 | 02:19 A.M. | 4.0 | 08:57 A.M. | 0.8 | 02:41 P.M. | 3.4 | 08:53 P.M. | 0.5 |
| 13 | 03:10 A.M. | 4.1 | 09:50 A.M. | 0.6 | 03:39 P.M. | 3.5 | 09:41 P.M. | 0.4 |
| 14 | 04:02 A.M. | 4.3 | 10:38 A.M. | 0.3 | 04:34 P.M. | 3.6 | 10:28 P.M. | 0.2 |
| 15 | 04:51 A.M. | 4.6 | 11:26 A.M. | 0.1 | 05:23 P.M. | 3.7 | 11:15 P.M. | 0.1 |
| 16 | 05:36 A.M. | 4.8 | 12:12 P.M. | −0.1 | 06:08 P.M. | 3.9 | ——— | – |
| 17 | 12:02 A.M. | −0.1 | 06:17 A.M. | 5.0 | 12:57 P.M. | −0.3 | 06:51 P.M. | 4.1 |
| 18 | 12:49 A.M. | −0.2 | 06:58 A.M. | 5.1 | 01:40 P.M. | −0.5 | 07:32 P.M. | 4.2 |
| 19 | 01:35 A.M. | −0.4 | 07:38 A.M. | 5.2 | 02:22 P.M. | −0.6 | 08:15 P.M. | 4.3 |
| 20 | 02:20 A.M. | −0.4 | 08:21 A.M. | 5.2 | 03:30 P.M. | −0.7 | 09:01 P.M. | 4.4 |
| 21 | 03:05 A.M. | −0.4 | 09:07 A.M. | 5.1 | 03:44 P.M. | −0.7 | 09:51 P.M. | 4.5 |
| 22 | 03:52 A.M. | −0.3 | 09:58 A.M. | 4.9 | 04:27 P.M. | −0.6 | 10:44 P.M. | 4.6 |
| 23 | 04:43 A.M. | −0.1 | 10:52 A.M. | 4.7 | 05:13 P.M. | −0.4 | 11:37 P.M. | 4.7 |
| 24 | 05:43 A.M. | 0.1 | 11:48 A.M. | 4.4 | 06:08 P.M. | −0.2 | ——— | – |
| 25 | 12:32 A.M. | 4.7 | 06:53 A.M. | 0.2 | 12:47 P.M. | 4.2 | 07:11 P.M. | −0.1 |
| 26 | 01:30 A.M. | 4.8 | 08:06 A.M. | 0.2 | 01:50 P.M. | 3.9 | 08:17 P.M. | 0.0 |
| 27 | 02:31 A.M. | 4.8 | 09:12 A.M. | 0.1 | 02:57 P.M. | 3.8 | 09:19 P.M. | 0.0 |
| 28 | 03:35 A.M. | 4.8 | 10:13 A.M. | −0.1 | 04:05 P.M. | 3.9 | 10:17 P.M. | −0.1 |
| 29 | 04:37 A.M. | 5.0 | 11:09 A.M. | −0.3 | 05:07 P.M. | 4.0 | 11:13 P.M. | −0.2 |
| 30 | 05:33 A.M. | 5.1 | 12:01 P.M. | −0.5 | 06:01 P.M. | 4.2 | ——— | – |
| 31 | 12:06 A.M. | −0.3 | 06:22 A.M. | 5.2 | 12:51 P.M. | −0.6 | 06:50 P.M. | 4.3 |

Source: Center for Operational Oceanographic Products and Services, National Oceanographic and Atmospheric Association, National Ocean Service.

**ES.1** The student will plan and conduct investigations in which **c.** scales, diagrams, charts, graphs, tables, imagery, models, and profiles are constructed and interpreted; and **f.** current applications are used to reinforce Earth science concepts. **ES.2** The student will demonstrate an understanding of the nature of science and scientific reasoning and logic. Key concepts include **c.** observation and logic are essential for reaching a conclusion. **ES.10** The student will investigate and understand that oceans are complex, interactive physical, chemical, and biological systems and are subject to long- and short-term variations. Key concepts include **a.** physical and chemical changes related to tides, waves, currents, sea level and ice cap variations, upwelling, and salinity variations.

# 16 Study Guide

**Big idea** **Water Planet**

## 16.1 Ocean Circulation

Surface currents develop from friction between the ocean and the wind that blows across its surface.

Because of Earth's rotation, currents are deflected to the right in the Northern Hemisphere and to the left in the Southern Hemisphere.

When currents from low-latitude regions move into higher latitudes, they transfer heat from warmer to cooler areas on Earth.

As cold water currents travel toward the equator, they help moderate the warm temperatures of adjacent land areas.

Upwelling brings dissolved nutrients, such as nitrates and phosphates, to the ocean surface.

An increase in seawater density can be caused by a decrease in temperature or an increase in salinity.

ocean current (448)
surface current (448)
gyre (449)
Coriolis effect (449)
upwelling (450)
density current (451)

## 16.2 Waves and Tides

Most ocean waves obtain their energy and motion from the wind.

The height, length, and period that are eventually achieved by a wave depend on three factors: (1) wind speed; (2) length of time the wind has blown; and (3) fetch.

Circular orbital motion allows energy to move forward through the water while the individual water particles that transmit the wave move around in a circle.

Ocean tides result from differences in the gravitational attraction exerted upon different parts of Earth's surface by the moon and, to a lesser extent, by the sun.

Three main tidal patterns exist worldwide: diurnal tides, semidiurnal tides, and mixed tides.

wave height (456)
wavelength (456)
wave period (456)
fetch (456)
tide (458)
tidal range (459)
spring tide (459)
neap tide (459

## 16.3 Shoreline Processes and Features

Waves along the shoreline are constantly eroding, transporting, and depositing sediment. Many types of shoreline features can result from this activity.

Because of refraction, wave energy is concentrated against the sides and ends of headlands that project into the water, whereas wave action is weakened in bays.

Turbulence allows longshore currents to easily move the fine suspended sand and to roll larger sand and gravel particles along the bottom.

Shoreline features that originate primarily from the work of erosion are called erosional features. Sediment that is transported along the shore and deposited in areas where energy is low produce depositional features.

Groins, breakwaters, and seawalls are some structures built to protect a coast from erosion or to prevent the movement of sand along a beach.

Beach nourishment is the artificial addition of large quantities of sand to the beach system.

beach (461)
wave refraction (462)
longshore current (463)
barrier island (466)

# 16 Assessment

## Review Content

*Choose the letter that best answers the questions or completes the statement.*

**1.** An ocean current moving from the equator toward a pole is
**a.** cold.
**b.** warm.
**c.** cold in the Northern Hemisphere and warm in the Southern Hemisphere.
**d.** warm in the Northern Hemisphere and cold in the Northern Hemisphere.

**2.** Because of the Coriolis effect, surface currents in the Southern Hemisphere are deflected
**a.** to the left. **c.** north.
**b.** to the right. **d.** south.

**3.** Which term describes the rising of cold water from deeper layers to replace warmer surface water?
**a.** density current **c.** surface current
**b.** downwelling **d.** upwelling

**4.** The energy and motion of most waves is derived from
**a.** currents. **c.** wind.
**b.** tides. **d.** gravity.

**5.** The five huge circular-moving systems of ocean surface currents are called
**a.** density currents. **c.** drifts
**b.** fetches. **d.** gyres.

**6.** Daily changes in the elevation of the ocean surface are called
**a.** surface currents. **c.** waves.
**b.** tides. **d.** density currents.

**7.** Which of the following results from wave refraction?
**a.** Wave energy is concentrated on headlands projecting into the water.
**b.** Wave energy is concentrated in the recessed areas between headlands.
**c.** Wave energy is largely dissipated before waves reach the shore.
**d.** Headlands are enlarged because sediment is deposited on their seaward side.

**8.** The movement of water within the surf zone that parallels the shore is called
**a.** tidal current. **c.** longshore current.
**b.** density current. **d.** surface current.

**9.** Which describes a ridge of sand that connects an island to the mainland or another island?
**a.** baymouth bar **c.** sea stack
**b.** sea arch **d.** tombolo

**10.** Which is created through the process of erosion?
**a.** baymouth bar **c.** spit
**b.** sea arch **d.** tombolo

## Understand Concepts

**11.** Describe the influence that the Coriolis effect has on the movement of ocean waters.

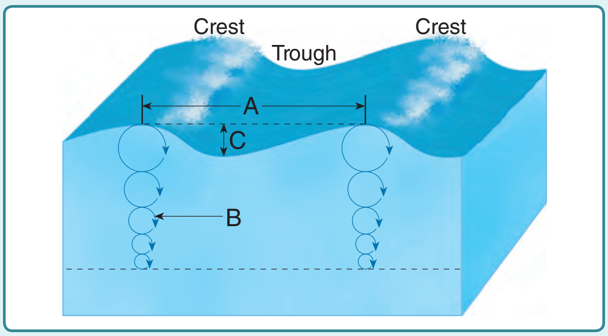
**12.** Describe the effect that cold ocean currents have on the climates of adjacent land areas.

**13.** What role do ocean currents play in maintaining Earth's heat balance?

**14.** Describe coastal upwelling and the effect it has on fish populations.

**15.** Where and how is the densest water in all the oceans formed?

*Use the figure below to answer Questions 16–18.*




**16.** Identify which wave characteristics are represented by A and C.

**17.** Explain what B represents. What happens to a floating object as a wave passes through the water?

**18.** What factors can lead to an increase in the height of this wave?

19. Compare and contrast a diurnal tidal pattern with a semidiurnal tidal pattern.

20. How does wave refraction result in sediment deposition in some shoreline areas?

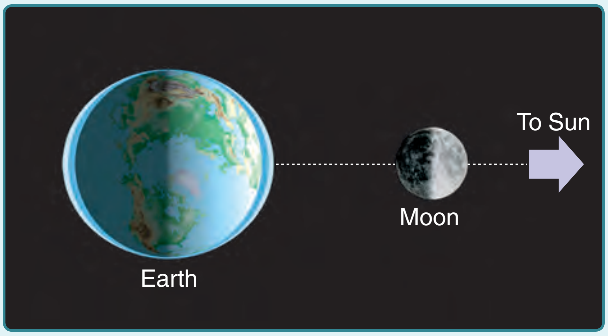
21. How are a wave-cut cliff  nd wave-cut platforms related?

22. What are two types of protective structures used to stop erosion on beaches?

## Think Critically

23. **Use Models** Create a diagram that models the steps involved in the process of upwelling.

24. **Apply Concepts** What type of tide is experienced when Earth, the moon, and the sun are in the positions shown in the fi  ure below? What is the phase of the moon in the diagram?




25. **Predict** Predict the effect that the damming of rivers would have on beaches.

26. **Relate Cause and Effect** Discuss the origin of tides. Explain why the sun's influence on Earth's tides is only about half that of the moon's, even though the sun is much more massive than the moon.

## Math Skills

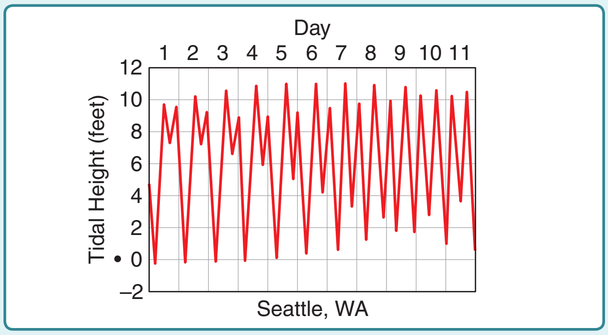
27. **Calculate** As waves enter shallow water and decrease in speed, wave height increases and eventually a wave will break. The point at which a wave will break can be calculated using the formula for wave steepness: steepness = wave height/wavelength. When the steepness of a wave reaches 1/7, the wave will break. If the wavelength of a wave is 50 m, at what height will the wave break?

## Concepts in Action

28. **Apply Concepts** Re-examine Figure 7. Describe the probable temperature and salinity characteristics for each water mass: Antarctic Bottom Water, North Atlantic Deep Water, and Mediterranean Water.

29. **Infer** How do you think an increase in Earth's surface temperature would affect the "conveyor belt" model of currents in the ocean?

30. **Interpret Graphs** The graph below shows a tidal curve for Seattle, Washington. What type of tidal pattern does Seattle experience?




## Performance-Based Assessment

**Synthesize** Investigate the problems associated with shoreline development. Choose a coastal area that is experiencing problems with shoreline erosion. What actions have been taken to try to resolve the problems? Have the actions been effective? Why or why not? What are the advantages and disadvantages to different methods of preventing shoreline erosion? Offer a solution for the area you investigated.

# Virginia SOL Test Prep

**Tips for** Success

**Anticipate the Answer** When answering a multiple-choice question, a useful strategy is to cover up the given answers and supply your own answer. Then compare your answer with those listed and select the one that most closely matches your answer.

Practice anticipating the answer in this question.

**When waves reach shallow water, they are often bent and may become almost parallel to shore. This process is referred to as—**

**A** oscillation
**B** refraction
**C** reflection
**D** abrasion

***(Answer: B)***

**Choose the letter that best answers the question.**

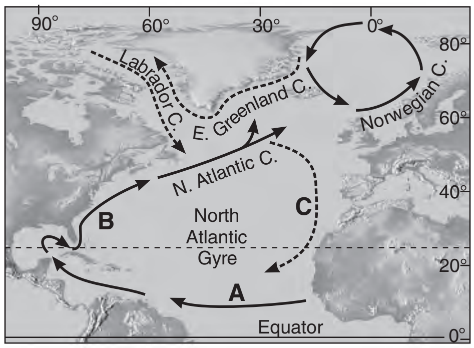
**1 Which of the following statements correctly explains a wave in the open ocean?**
**A** Water particles move in a circular path.
**B** Waves continue to move without change, regardless of depth.
**C** The waveform moves forward, and the water particles also advance.
**D** A floating object does not move at all as a wave passes through the water. ES.10.a

**2 A barrier built at a right angle to the beach to trap sand that is moving parallel to the shore is known as a—**
**F** seawall
**G** headland
**H** groin
**J** sea stack ES.10.b

**3 In the open sea, the movement of water particles in a wave becomes negligible at a depth equal to—**
**A** one-fourth the wavelength
**B** one-third the wavelength
**C** one-half the wavelength
**D** three-fourths the wavelength ES.10.a

**4 What happens as a wave approaches the shore?**
**F** wavelength decreases and wave height increases
**G** wavelength increases and wave height increases
**H** wave speed decreases and wave height decreases
**J** wave period decreases and wave height decreases ES.10.a

**Use the figure below to answer Question 5.**




**5 What current in the North Atlantic Gyre is represented by B? Is this current a warm water current or a cold water current?**
**A** Gulf Stream Current; warm
**B** Gulf Stream Current; cold
**C** North Equatorial Current; warm
**D** North Equatorial Current; cold ES.10.a

## If You Have Trouble With . . .

| **Question** | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| **See Lesson** | 16.2 | 16.3 | 16.2 | 16.2 | 16.1 |