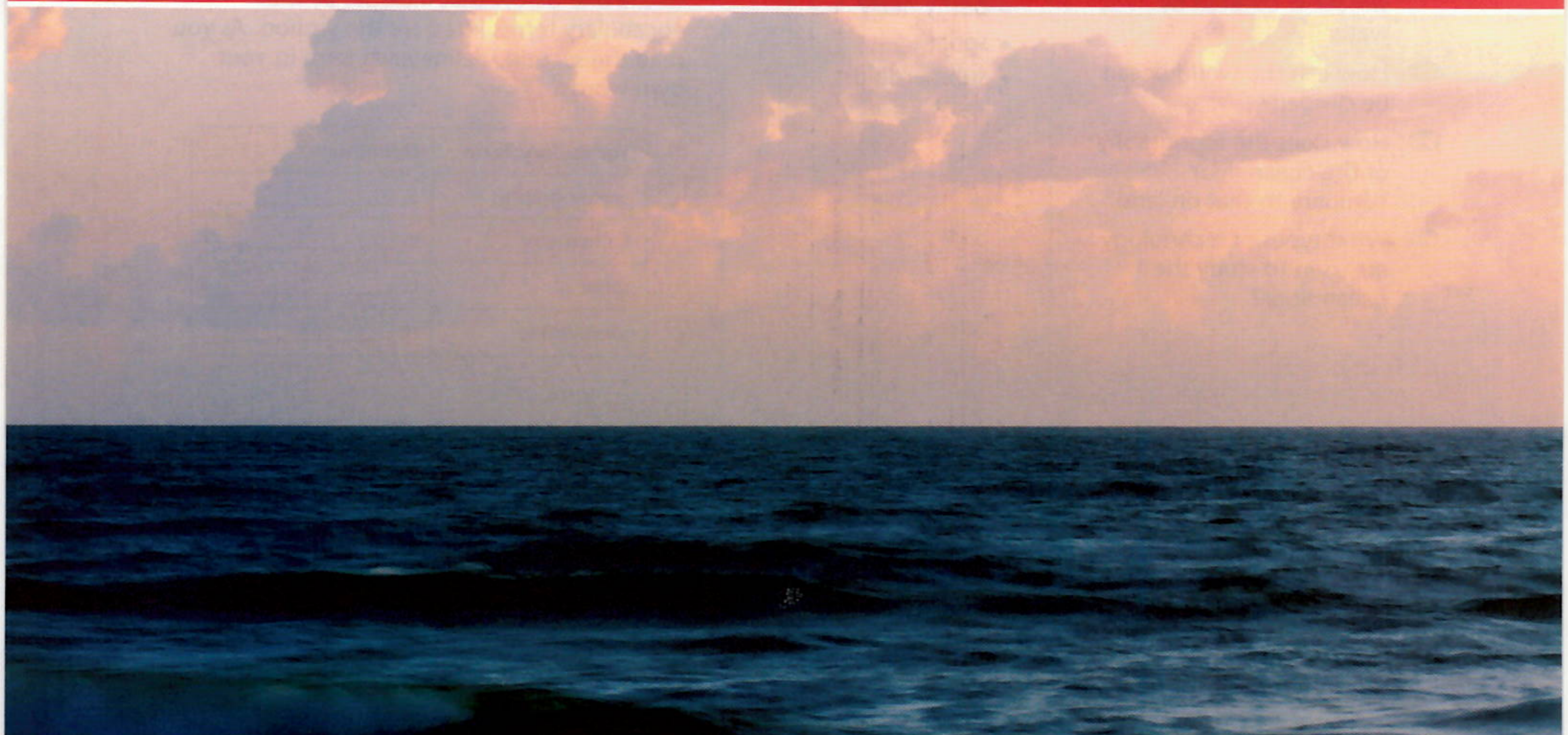
Chapter Preview



Inquiry Activity

How Does Particle Size Affect Settling Rates?

Procedure

1. Fill two large transparent containers with water. Place two samples of sediment, one clay and one sand, on separate sheets of white paper. Examine the sediments with a hand lens. Determine which sediment sample has larger-sized particles. Record your observations.
2. Carefully measure 1 tbsp of the clay sample. Hold the spoon directly above the first container and pour the clay into the water. Using a stopwatch, time how long it takes for the entire clay sample to reach the bottom of the container and settle. Record the time.
3. Repeat Step 2 using the second container and the sand sample. Be sure to hold the spoon the same distance from the container as you did in the clay sample.

Think About It

1. **Drawing Conclusions** Which sample had smaller particles? Which sample took longer to settle in the water? Explain the general relationship between sediment size and settling rates.
2. **Predicting** Both of these sediments enter ocean water from rivers. Predict which type of sediment would be found closest to the coast. Which will be found father away? Explain.

14.1 The Vast World Ocean

Reading Focus

Key Concepts

- How much of Earth's surface is covered by water?
- How can the world ocean be divided?
- How does the topography of the ocean floor compare to that on land?
- What types of technology are used to study the ocean floor?

Vocabulary

- oceanography
- bathymetry
- sonar
- submersible

Reading Strategy

Building Vocabulary Draw a table similar to the one below that includes all the vocabulary terms listed for the section. As you read the section, define each term in your own words.

Vocabulary Term	Definition
oceanography	a. ___?___
bathymetry	b. ___?___
sonar	c. ___?___
submersible	d. ___?___

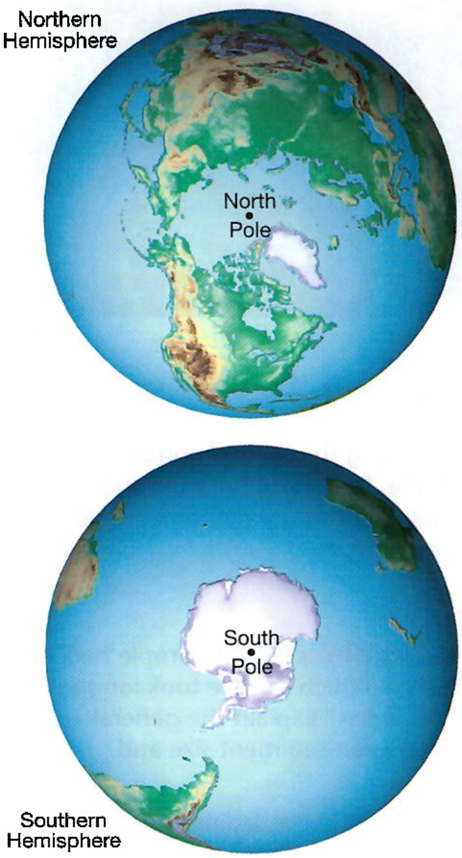


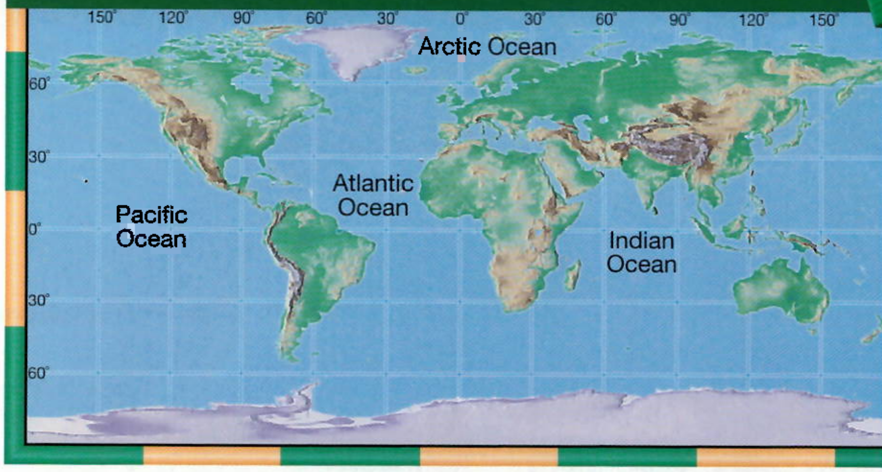
Figure 1 The World Ocean These views of Earth show the planet is dominated by a single interconnected world ocean.

How deep is the ocean? How much of Earth is covered by the global ocean? What does the ocean floor look like? Humans have long been interested in finding answers to these questions. However, it was not until relatively recently that these simple questions could be answered. Suppose, for example, that all of the water were drained from the ocean. What would we see? Plains? Mountains? Canyons? Plateaus? You may be surprised to find that the ocean conceals all of these features, and more.

The Blue Planet

Look at Figure 1. You can see why the "blue planet" or the "water planet" are appropriate nicknames for Earth. **Nearly 71 percent of Earth's surface is covered by the global ocean.** Although the ocean makes up a much greater percentage of Earth's surface than the continents, it has only been since the late 1800s that the ocean became an important focus of study. New technologies have allowed scientists to collect large amounts of data about the oceans. As technology has advanced, the field of oceanography has grown. **Oceanography** is a science that draws on the methods and knowledge of geology, chemistry, physics, and biology to study all aspects of the world ocean.

Distribution of Land and Water



MAP MASTER™ Skills Activity

Figure 2

Location The four main ocean basins are the Pacific Ocean, the Atlantic Ocean, the Indian Ocean, and the Arctic Ocean.

Predicting What is the longitude of the easternmost point of the Pacific Ocean? What is the longitude of the westernmost point of the Atlantic Ocean?

Geography of the Oceans

The area of Earth is about 510 million square kilometers. Of this total, approximately 360 million square kilometers, or 71 percent, is represented by oceans and smaller seas such as the Mediterranean Sea and the Caribbean Sea. Continents and islands comprise the remaining 29 percent, or 150 million square kilometers. **The world ocean can be divided into four main ocean basins—the Pacific Ocean, the Atlantic Ocean, the Indian Ocean, and the Arctic Ocean.** These ocean basins are shown in Figure 2.

The Pacific Ocean is the largest ocean. In fact, it is the largest single geographic feature on Earth. It covers more than half of the ocean surface area on Earth. It is also the world's deepest ocean, with an average depth of 3940 meters.

The Atlantic Ocean is about half the size of the Pacific Ocean, and is not quite as deep. It is a relatively narrow ocean compared to the Pacific. The Atlantic and Pacific Oceans are bounded to the east and west by continents.

The Indian Ocean is slightly smaller than the Atlantic Ocean, but it has about the same average depth. Unlike the Pacific and Atlantic oceans, the Indian Ocean is located almost entirely in the southern hemisphere.

The Arctic Ocean is about 7 percent of the size of the Pacific Ocean. It is only a little more than one-quarter as deep as the rest of the oceans.

Reading Checkpoint *What are the four main ocean basins?*

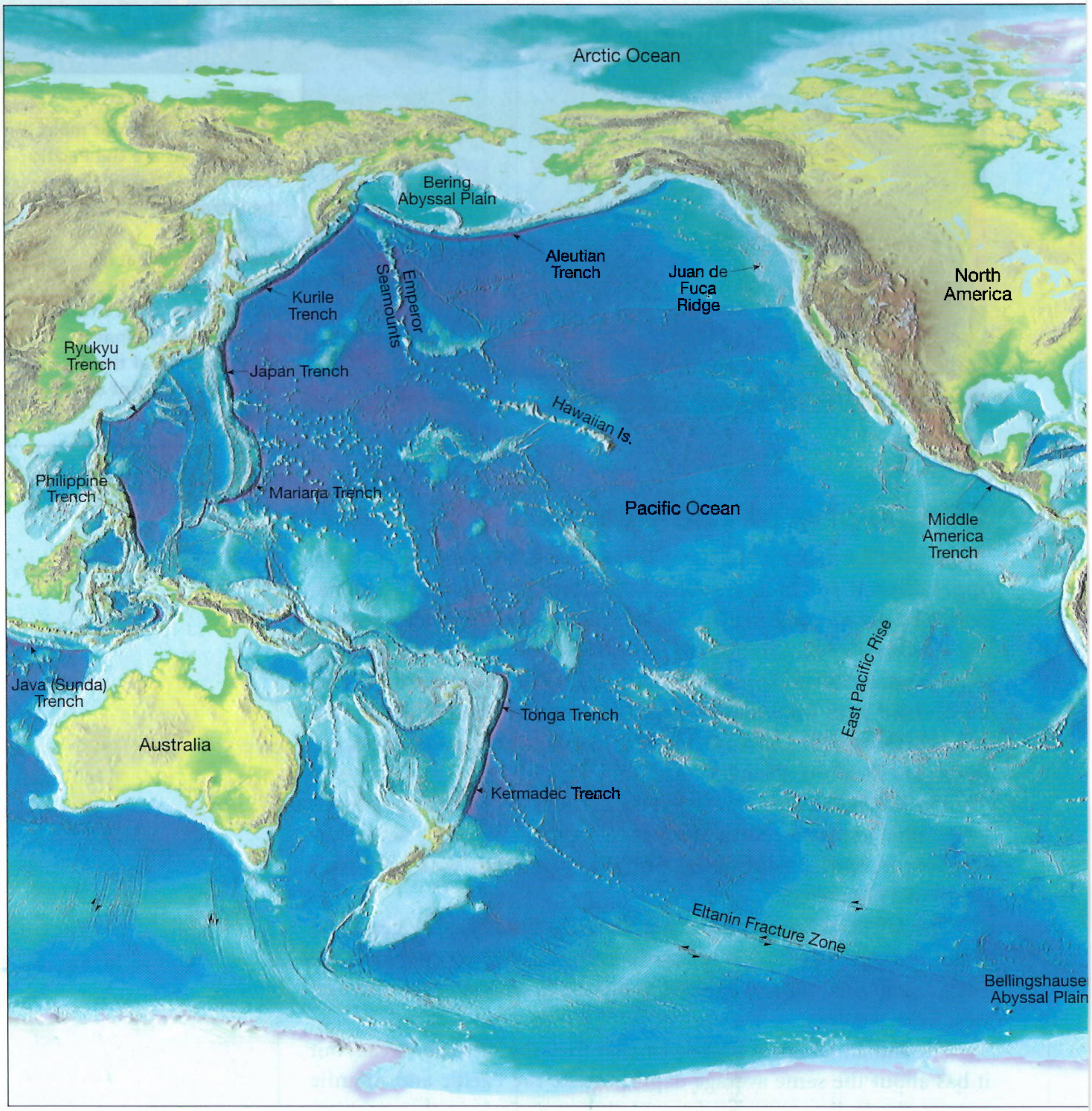
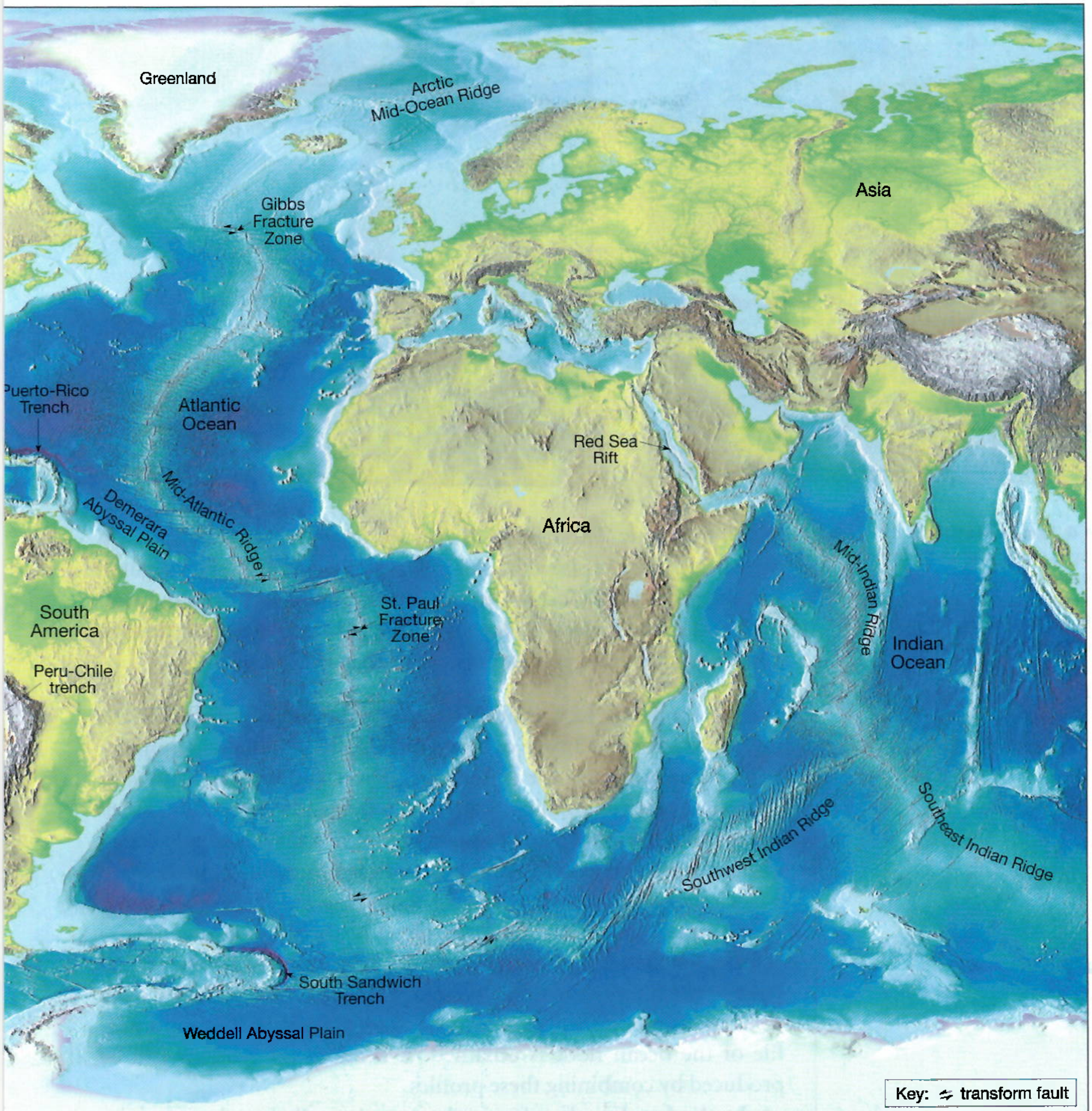


Figure 3 The topography of the ocean floor is as varied as the topography of the continents. The ocean floor contains mountain ranges, trenches, and flat regions called abyssal plains.
Interpreting Diagrams ***List all of the features you can identify in the figure.***

Mapping the Ocean Floor

If all the water were drained from the ocean basins, a variety of features would be seen. These features include chains of volcanoes, tall mountain ranges, trenches, and large submarine plateaus. **The topography of the ocean floor is as diverse as that of continents.** The topographic features of the ocean floor are shown in Figure 3.

An understanding of ocean-floor features came with the development of techniques to measure the depth of the oceans. **Bathymetry**



(*bathos* = depth, *metry* = measurement) is the measurement of ocean depths and the charting of the shape or topography of the ocean floor.

The first understanding of the ocean floor's varied topography did not unfold until the historic three-and-a-half-year voyage of the HMS *Challenger*. From December 1872 to May 1876, the *Challenger* expedition made the first—and perhaps still the most comprehensive—study of the global ocean ever attempted by one agency. The 127,500 kilometer trip took the ship and its crew of scientists to every ocean

Go Online
SCILINKS NSTA

For: Links on oceans
Visit: www.SciLinks.org
Web Code: cjn-5141

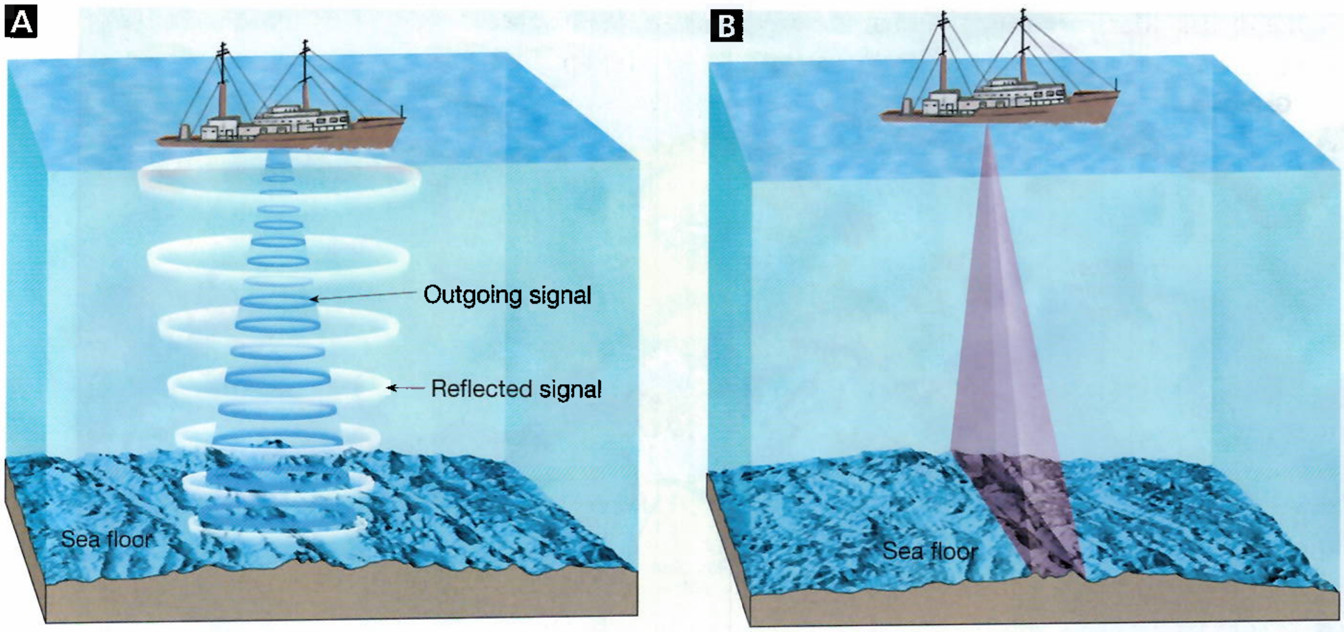


Figure 4 Sonar Methods
A By using sonar, oceanographers can determine the depth of the ocean floor in a particular area.
B Modern multibeam sonar obtains a profile of a narrow swath of seafloor every few seconds.

except the Arctic. Throughout the voyage, they sampled various ocean properties. They measured water depth by lowering a long, weighted line overboard. **Today's technology—particularly sonar, satellites, and submersibles—allows scientists to study the ocean floor in a more efficient and precise manner than ever before.**

Sonar In the 1920s, a technological breakthrough occurred with the invention of sonar, a type of electronic depth-sounding equipment. Sonar is an acronym for **so**und **n**avigation **a**nd **r**anging. It is also referred to as echo sounding. Sonar works by transmitting sound waves toward the ocean bottom, as shown in Figure 4A. With simple sonar, a sensitive receiver intercepts the echo reflected from the bottom. Then a clock precisely measures the time interval to fractions of a second. Depth can be calculated from the speed of sound waves in water—about 1500 meters per second—and the time required for the energy pulse to reach the ocean floor and return. The depths determined from continuous monitoring of these echoes are plotted. In this way a profile of the ocean floor is obtained. A chart of the seafloor can be produced by combining these profiles.

In the last few decades, researchers have designed even more sophisticated sonar to map the ocean floor. In contrast to simple sonar, multibeam sonar uses more than one sound source and listening device. As you can see from Figure 4B, this technique obtains a profile of a narrow strip of ocean floor rather than obtaining the depth of a single point every few seconds. These profiles are recorded every few seconds as the research vessel advances. When a ship uses multibeam sonar to make a map of a section of ocean floor, the ship travels through the area in a regularly spaced back-and-forth pattern. Not surprisingly, this method is known as "mowing the lawn."

Satellites Measuring the shape of the ocean surface from space is another technological breakthrough that has led to a better understanding of the ocean floor. After compensating for waves, tides, currents, and atmospheric effects, scientists discovered that the ocean surface is not perfectly flat. This is because gravity attracts water toward regions where massive ocean floor features occur. Therefore, mountains and ridges produce elevated areas on the ocean surface. Features such as canyons and trenches cause slight depressions.

The differences in ocean-surface height caused by ocean floor features are not visible to the human eye. However, satellites are able to measure these small differences by bouncing microwaves off the ocean surface. Figure 5 shows how the outgoing radar pulses are reflected back to a satellite. The height of the ocean surface can be calculated by knowing the satellite's exact position. Devices on satellites can measure variations in sea-surface height as small as 3 to 6 centimeters. This type of data has added greatly to the knowledge of ocean-floor topography. Cross-checked with traditional sonar depth measurements, the data are used to produce detailed ocean-floor maps, such as the one previously shown in Figure 3.

Reading Checkpoint ***How do satellites help us learn about the shape of the seafloor?***

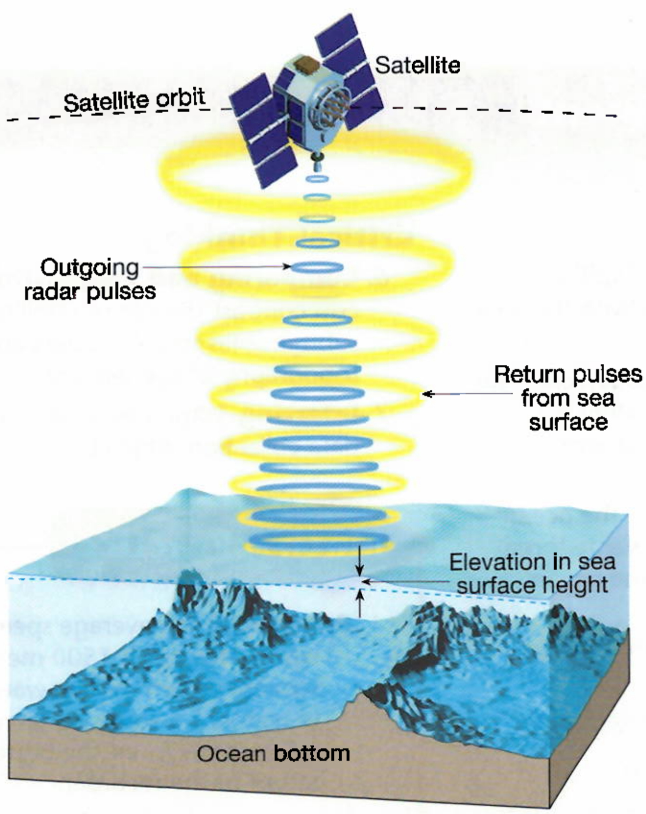


Figure 5 Satellite Method Satellites can be used to measure sea-surface height. The data collected by satellites can be used to predict the location of large features on the seafloor. This method of data collection is much faster than using sonar.

Submersibles A **submersible** is a small underwater craft used for deep-sea research. Submersibles are used to collect data about areas of the ocean that were previously unreachable by humans. Submersibles are equipped with a number of instruments ranging from thermometers to cameras to pressure gauges. The operators of submersibles can record video and photos of previously unknown creatures that live in the abyss. They can collect water samples and sediment samples for analysis.

The first submersible was used in 1934 by William Beebe. He descended to a depth of 923 meters off of Bermuda in a steel sphere that was tethered to a ship. Since that time, submersibles have become more sophisticated. In 1960, Jacques Piccard descended in the untethered submersible *Trieste* to 10,912 meters below the ocean surface into the Mariana Trench. *Alvin* and *Sea Cliff II* are two other manned submersibles used for deep-sea research. *Alvin* can reach depths of 4000 meters, and *Sea Cliff II* can reach 6000 meters.

Today, many submersibles are unmanned and operated remotely by computers. These remotely operated vehicles (ROVs) can remain under water for long periods. They collect data, record video, use sonar, and collect sample organisms with remotely operated arms. Another type of submersible, the autonomous underwater vehicle (AUV), is under development. Its goal is to collect long-term data without interruption.

Section 14.1 Assessment

Reviewing Concepts

1. How does the area of Earth's surface covered by the oceans compare with the area covered by land?
2. Name the four ocean basins. Which of the four ocean basins is the largest? Which is located almost entirely in the southern hemisphere?
3. How does the topography of the ocean floor compare to that on land? Name three topographic features found on the ocean floor.
4. What types of technology are used to study the ocean floor?
5. Describe how sonar is used to determine seafloor depth.

Critical Thinking

6. **Comparing and Contrasting** Compare and contrast the use of satellites and submersibles to collect data about the topography of the seafloor.
7. **Inferring** Why is deep-sea exploration and data collection difficult?

Math Practice

8. Assuming the average speed of sound waves in water is 1500 meters per second, determine the water depth in meters if a sonar signal requires 4.5 seconds to hit the bottom and return to the recorder.

14.2 Ocean Floor Features

Reading Focus

Key Concepts

- What are the three main regions of the ocean floor?
- How do continental margins in the Atlantic Ocean differ from those in the Pacific Ocean?
- How are deep-ocean trenches formed?
- How are abyssal plains formed?
- What is formed at mid-ocean ridges?

Vocabulary

- continental margin
- continental shelf
- continental slope
- submarine canyon
- turbidity current
- continental rise
- ocean basin floor
- abyssal plains
- seamounts
- mid-ocean ridge
- seafloor spreading

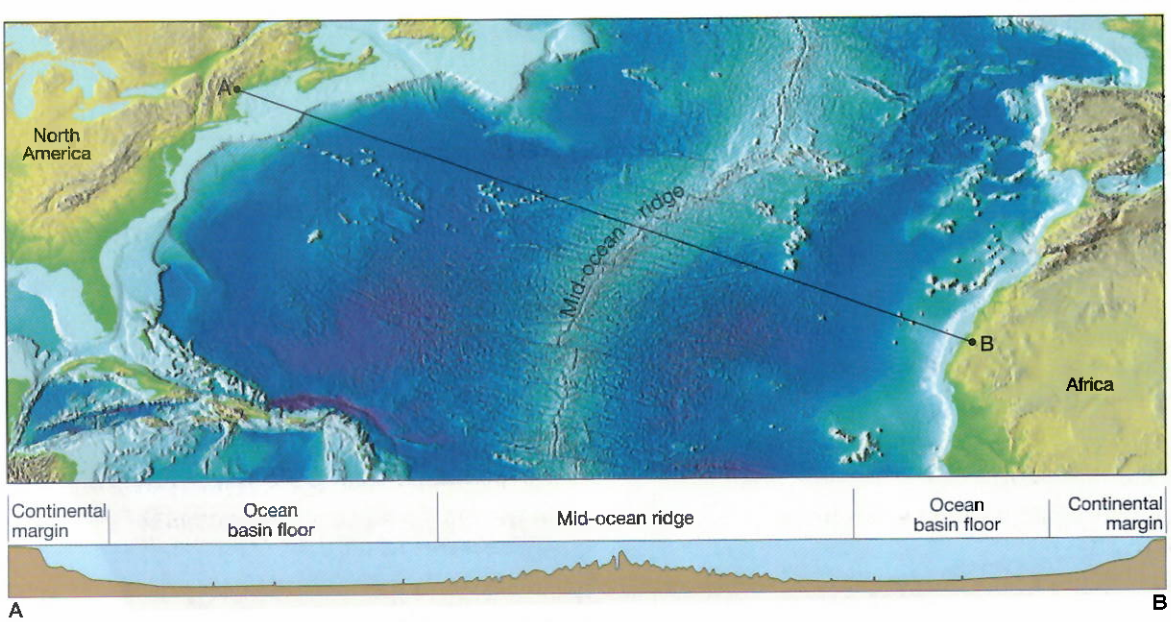
Reading Strategy

Outlining Before you read, make an outline of this section. Use the green headings as the main topics and the blue headings as subtopics. As you read, add supporting details.

I. Continental Margins
  A. Continental Shelf
  B. Continental Slope
  C. ____?____
II. ____?____
  A. ____?____

Oceanographers studying the topography of the ocean floor have divided it into three major regions. **The ocean floor regions are the continental margins, the ocean basin floor, and the mid-ocean ridge.** The map in Figure 6 outlines these regions for the North Atlantic Ocean. The profile at the bottom of the illustration shows the varied topography. Scientists have discovered that each of these regions has its own unique characteristics and features.

Figure 6 Topography of the North Atlantic Ocean Basin Beneath the map is a profile of the area between points A and B. The profile has been exaggerated 40 times to make the topographic features more distinct.



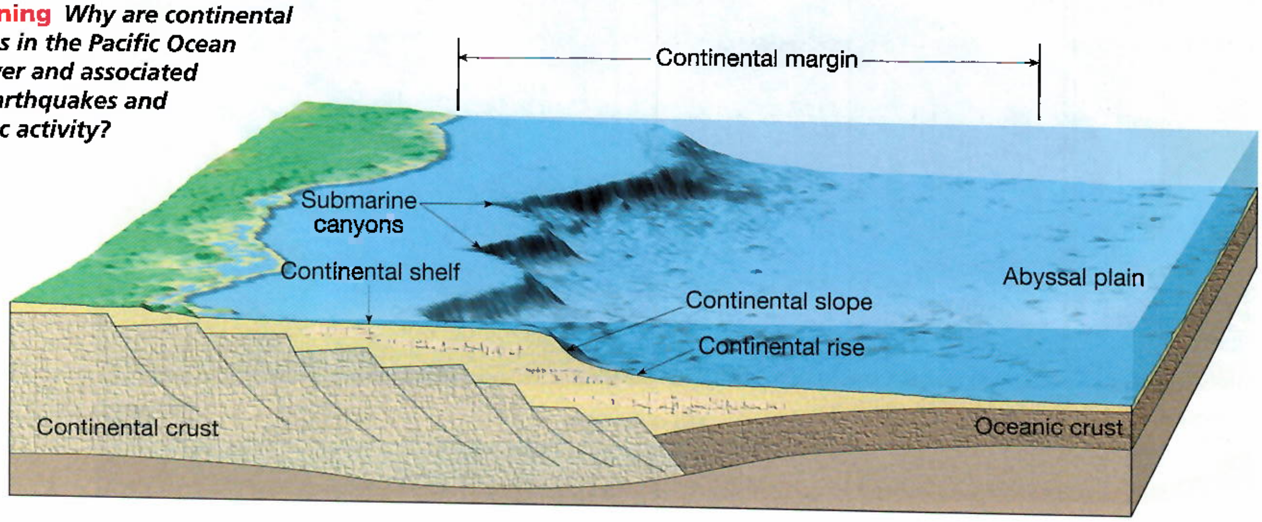
Continental Margins

The zone of transition between a continent and the adjacent ocean basin floor is known as the **continental margin.** **In the Atlantic Ocean, thick layers of undisturbed sediment cover the continental margin. This region has very little volcanic or earthquake activity.** This is because the continental margins in the Atlantic Ocean are not associated with plate boundaries, unlike the continental margins of the Pacific Ocean. **In the Pacific Ocean, oceanic crust is plunging beneath continental crust. This force results in a narrow continental margin that experiences both volcanic activity and earthquakes.** Figure 7 shows the features of a continental margin found along the Atlantic coast.

Continental Shelf What if you were to begin an underwater journey eastward across the Atlantic Ocean? The first area of ocean floor you would encounter is the continental shelf. The **continental shelf** is the gently sloping submerged surface extending from the shoreline. The shelf is almost nonexistent along some coastlines. However, the shelf may extend seaward as far as 1500 kilometers along other coastlines. On average, the continental shelf is about 80 kilometers wide and 130 meters deep at its seaward edge. The average steepness of the shelf is equal to a drop of only about 2 meters per kilometer. The slope is so slight that to the human eye it appears to be a horizontal surface.

Continental shelves have economic and political significance. **Continental shelves contain important mineral deposits, large reservoirs of oil and natural gas, and huge sand and gravel deposits.** The waters of the continental shelf also contain important fishing grounds, which are significant sources of food.

Figure 7 Atlantic Continental Margin The continental margins in the Atlantic Ocean are wider than in the Pacific Ocean and are covered in a thick layer of sediment.
Explaining ***Why are continental margins in the Pacific Ocean narrower and associated with earthquakes and volcanic activity?***



Continental Slope Marking the seaward edge of the continental shelf is the **continental slope.** This slope is steeper than the shelf, and it marks the boundary between continental crust and oceanic crust. The continental slope can be seen in Figure 7 on page 402. Although the steepness of the continental slope varies greatly from place to place, it averages about 5 degrees. In some places the slope may exceed 25 degrees. The continental slope is a relatively narrow feature, averaging only about 20 kilometers in width.

Deep, steep-sided valleys known as **submarine canyons** are cut into the continental slope. These canyons may extend to the ocean basin floor. Figure 8 shows how submarine canyons are formed. Most information suggests that submarine canyons have been eroded, at least in part, by turbidity currents. **Turbidity currents** are occasional movements of dense, sediment-rich water down the continental slope. They are created when sand and mud on the continental shelf and slope are disturbed—perhaps by an earthquake—and become suspended in the water. Because such muddy water is denser than normal seawater, it flows down the slope. As it flows down, it erodes and accumulates more sediment. Erosion from these muddy torrents is believed to be the major force in the formation of most submarine canyons. Narrow continental margins, such as the one located along the California coast, are marked with numerous submarine canyons.

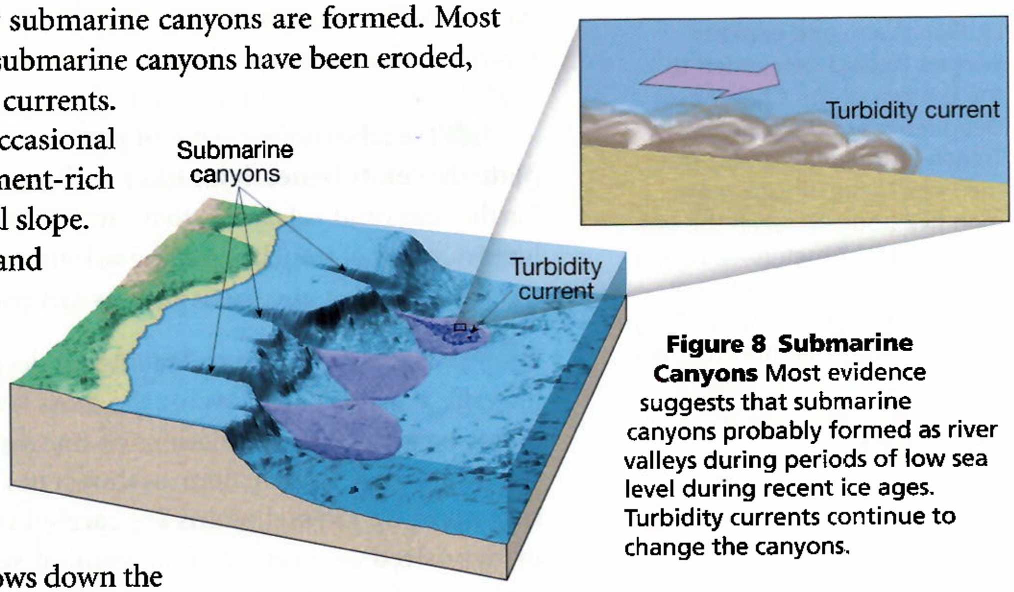


Figure 8 Submarine Canyons Most evidence suggests that submarine canyons probably formed as river valleys during periods of low sea level during recent ice ages. Turbidity currents continue to change the canyons.

Turbidity currents are known to be an important mechanism of sediment transport in the ocean. Turbidity currents erode submarine canyons and deposit sediments on the deep-ocean floor.

Continental Rise In regions where trenches do not exist, the steep continental slope merges into a more gradual incline known as the **continental rise.** Here the steepness of the slope drops to about 6 meters per kilometer. Whereas the width of the continental slope averages about 20 kilometers, the continental rise may be hundreds of kilometers wide.

Reading Checkpoint ***Compare and contrast the continental slope and continental rise.***

Go Online
SCI LINKS NSTA

For: Links on ocean floor features
Visit: www.SciLinks.org
Web Code: cjn-5142

![Q&A]

Q *Have humans ever explored the deepest ocean trenches? Could anything live there?*

A Humans have indeed visited the deepest part of the oceans—where there is crushing high pressure, complete darkness, and near-freezing water temperatures. In January 1960, U.S. Navy Lt. Don Walsh and explorer Jacques Piccard descended to the bottom of the Challenger Deep region of the Mariana Trench in the deep-diving submersible *Trieste*. It took more than five hours to reach the bottom at 10,912 meters—a record depth of human descent that has not been broken since. They did see some organisms that are adapted to life in the deep: a small flatfish, a shrimp, and some jellyfish.

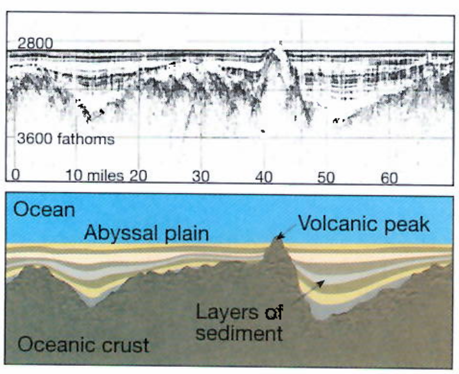


Figure 9 Abyssal Plain Cross Section This seismic cross section and matching sketch of a portion of the Madeira abyssal plain in the eastern Atlantic Ocean shows how the irregular oceanic crust is buried by sediments.

Ocean Basin Floor

Between the continental margin and mid-ocean ridge lies the **ocean basin floor.** The size of this region—almost 30 percent of Earth's surface—is comparable to the percentage of land above sea level. This region includes deep-ocean trenches, very flat areas known as abyssal plains, and tall volcanic peaks called seamounts and guyots.

Deep-Ocean Trenches Deep-ocean trenches are long, narrow creases in the ocean floor that form the deepest parts of the ocean. Most trenches are located along the margins of the Pacific Ocean, and many exceed 10,000 meters in depth. A portion of one trench—the Challenger Deep in the Mariana Trench—has been measured at a record 11,022 meters below sea level. It is the deepest known place on Earth.

Trenches form at sites of plate convergence where one moving plate descends beneath another and plunges back into the mantle. Earthquakes and volcanic activity are associated with these regions. The large number of trenches and the volcanic activity along the margins of the Pacific Ocean give the region its nickname as the *Ring of Fire.*

Abyssal Plains **Abyssal plains** are deep, extremely flat features. In fact, these regions are possibly the most level places on Earth. Abyssal plains have thick accumulations of fine sediment that have buried an otherwise rugged ocean floor, as shown in Figure 9. **The sediments that make up abyssal plains are carried there by turbidity currents or deposited as a result of suspended sediments settling.** Abyssal plains are found in all oceans of the world. However, the Atlantic Ocean has the most extensive abyssal plains because it has few trenches to catch sediment carried down the continental slope.

Seamounts and Guyots The submerged volcanic peaks that dot the ocean floor are called **seamounts.** They are volcanoes that have not reached the ocean surface. These steep-sided cone-shaped peaks are found on the floors of all the oceans. However, the greatest number have been identified in the Pacific. Some seamounts form at volcanic hot spots. An example is the Hawaiian-Emperor Seamount chain, shown in Figure 3 on page 396. This chain stretches from the Hawaiian Islands to the Aleutian trench.

Once underwater volcanoes reach the surface, they form islands. Over time, running water and wave action erode these volcanic islands to near sea level. Over millions of years, the islands gradually sink and may disappear below the water surface. This process occurs as the moving plate slowly carries the islands away from the elevated oceanic ridge or hot spot where they originated. These once-active, now-submerged, flat-topped structures are called guyots.

Reading Checkpoint *What are abyssal plains?*

Mid-Ocean Ridges

The **mid-ocean ridge** is found near the center of most ocean basins. It is an interconnected system of underwater mountains that have developed on newly formed ocean crust. This system is the longest topographic feature on Earth's surface. It exceeds 70,000 kilometers in length. The mid-ocean ridge winds through all major oceans similar to the way a seam winds over the surface of a baseball.

The term *ridge* may be misleading because the mid-ocean ridge is not narrow. It has widths from 1000 to 4000 kilometers and may occupy as much as one half of the total area of the ocean floor. Another look at Figure 3 shows that the mid-ocean ridge is broken into segments. These are offset by large transform faults where plates slide past each other horizontally, resulting in shallow earthquakes.

Seafloor Spreading A high amount of volcanic activity takes place along the crest of the mid-ocean ridge. This activity is associated with seafloor spreading. **Seafloor spreading** occurs at divergent plate boundaries where two lithospheric plates are moving apart. **New ocean floor is formed at mid-ocean ridges as magma rises between the diverging plates and cools.**

Hydrothermal Vents Hydrothermal vents form along mid-ocean ridges. These are zones where mineral-rich water, heated by the hot, newly-formed oceanic crust, escapes through cracks in oceanic crust into surrounding water. As the super-heated, mineral-rich water comes in contact with the surrounding cold water, minerals and metals such as sulfur, iron, copper, and zinc precipitate out and are deposited.

Section 14.2 Assessment

Reviewing Concepts

1. What are the three main regions of the ocean floor?
2. How do continental margins in the Atlantic Ocean differ from those in the Pacific Ocean?
3. What are trenches? How are deep-ocean trenches formed?
4. What are abyssal plains? How are abyssal plains formed?
5. What is formed at mid-ocean ridges?

Critical Thinking

6. **Comparing and Contrasting** Compare and contrast seamounts and guyots.
7. **Applying Concepts** Explain how turbidity currents are related to submarine canyons.

Writing in Science

Descriptive Paragraph Imagine you are about to take an underwater journey in a submersible across the Atlantic Ocean. Your journey begins at the coast, and you travel out toward the mid-ocean ridge. Write a paragraph describing the ocean floor features you will likely see on your journey.

understanding EARTH

Explaining Coral Atolls—Darwin's Hypothesis

Coral atolls are ring-shaped structures that often extend several thousand meters below sea level. Corals are colonial animals about the size of an ant. They are related to jellyfish and feed with stinging tentacles. Most corals protect themselves by precipitating a hard external skeleton made of calcium carbonate. Coral reefs occur where corals reproduce and grow over many centuries. Their skeletons fuse into large structures called coral reefs.

The Problem with Corals

Corals require specific environmental conditions to grow. For example, reef-building corals grow best in waters with an average annual temperature of about 24°C. They cannot survive prolonged exposure to temperatures below 18°C or above 30°C. Reef-building corals also need clear sunlit water. As a result, the limiting depth of most active reef growth is only about 45 meters.

Gathering Data

How can corals—which require warm, shallow, sunlit water no deeper than a few dozen meters to live—create thick structures like coral atolls that extend into deep water? The naturalist Charles Darwin was one of the first to formulate a hypothesis on the origin of atolls. From 1831 to 1836, he sailed aboard the British ship HMS *Beagle* during its famous voyage around the world. In various places Darwin noticed a series of stages in coral-reef development. Development begins with a fringing reef, like the one shown in Figure 10A. The fringing reef forms along the sides of a volcanic island. As the volcanic island slowly sinks, the fringing reef becomes a barrier reef, as shown in Figure 10B. Figure 10C shows the final stage of development of the atoll. The volcano sinks completely underwater but the coral reef remains near the surface.

Darwin's Hypothesis

Figure 10 is a drawing that summarizes Darwin's hypothesis about atoll formation. As a volcanic island slowly sinks, the corals continue to build the reef upward. This explained how living coral reefs, which are restricted to shallow water, can build structures that now exist in much deeper water. The theory of plate tectonics supports Darwin's hypothesis.Plate tectonics explains how a volcanic island can become extinct and experience a change in elevation over long periods of time. As the hot ocean seafloor moves away from the mid-ocean ridge, it becomes denser and sinks. This is why islands also sink. Darwin's hypothesis is also supported by evidence from drilling that shows volcanic rock is beneath the oldest and deepest coral reef structures. Atolls owe their existence to the gradual sinking of volcanic islands containing coral reefs that build upward through time.

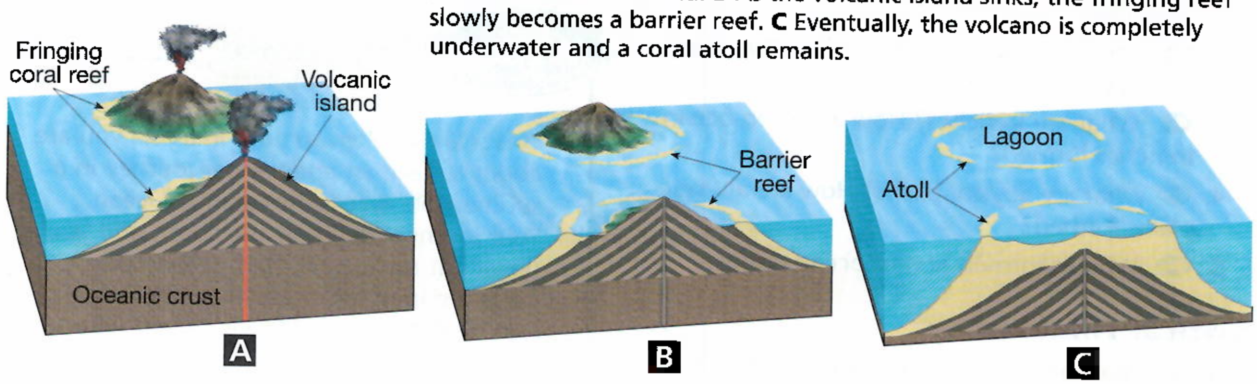


Figure 10 Formation of a Coral Atoll A A fringing coral reef forms around a volcanic island. **B** As the volcanic island sinks, the fringing reef slowly becomes a barrier reef. **C** Eventually, the volcano is completely underwater and a coral atoll remains.

14.3 Seafloor Sediments

Reading Focus

Key Concepts

- What are the three types of ocean-floor sediments?
- What does terrigenous sediment consist of?
- What is the composition of biogenous sediment?
- How is hydrogenous sediment formed?

Vocabulary

- terrigenous sediment
- biogenous sediment
- calcareous ooze
- siliceous ooze
- hydrogenous sediment

Reading Strategy

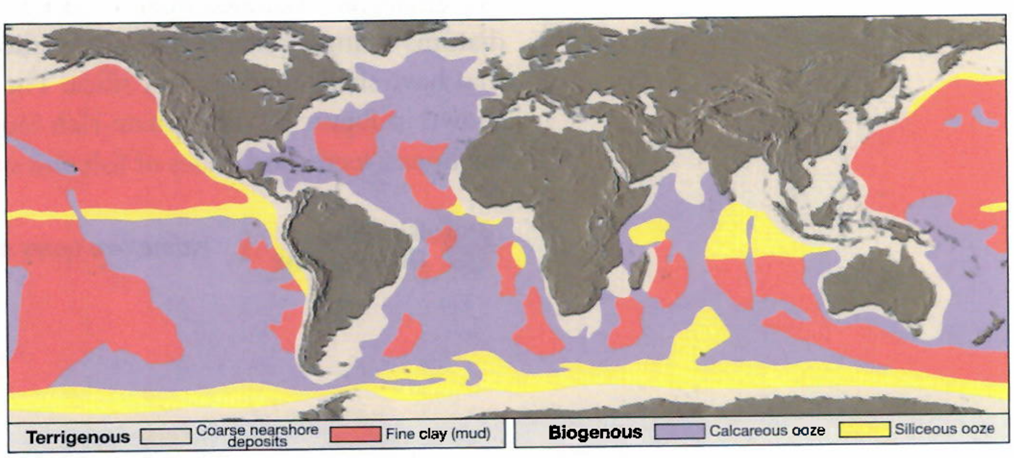
Summarizing Make a table like the one below that includes all the headings for the section. Write a brief summary of the text for each heading.

Actions at Boundaries
I. Types of Seafloor Sediments • Terrigenous sediments originated on land. • Biogenous sediments are biological in origin. • ______?______

Except for steep areas of the continental slope and the crest of the mid-ocean ridge, most of the ocean floor is covered with sediment. Some of this sediment has been deposited by turbidity currents. The rest has slowly settled onto the seafloor from above. The thickness of ocean-floor sediments varies. Some trenches act as traps for sediment originating on the continental margin. The accumulation may approach 10 kilometers in thickness. In general, however, accumulations of sediment are much less—about 500 to 1000 meters.

Generally, coarser sediments, such as sand, cover the continental shelf and slope while finer sediments, such as clay, cover the deep-ocean floor. Figure 11 shows the distribution of the different types of ocean-floor sediments. Various types of sediment accumulate on nearly all areas of the ocean floor in the same way dust accumulates in all parts of your home. Even the deep-ocean floor, far from land, receives small amounts of windblown material and microscopic parts of organisms.

Figure 11 Distribution of Ocean-Floor Sediments Coarse-grained terrigenous deposits dominate continental margin areas. Fine-grained clay, or mud, is more common in the deepest areas of the ocean basins. **Infer** ***Why is it more common to find fine-grained sediments in the deepest areas of the ocean basins?***



Q&A

Q *Do we use diatoms in any products?*

A Diatoms are used in filters for refining sugar, straining yeast from beer, and cleaning swimming pool water. They also are mild abrasives in household cleaning and polishing products and facial scrubs; and absorbents for chemical spills. You use diatoms in a variety of household products such as toothpaste, facial scrubs, and cleaning solutions.

Types of Seafloor Sediments

Ocean-floor sediments can be classified according to their origin into three broad categories: terrigenous sediments, biogenous sediments, and hydrogenous sediments. Ocean-floor sediments are usually mixtures of the various sediment types.

Terrigenous Sediment

Terrigenous sediment is sediment that originates on land. **Terrigenous sediments consist primarily of mineral grains that were eroded from continental rocks and transported to the ocean.** Larger particles such as gravel and sand usually settle rapidly near shore. Finer particles such as clay can take years to settle to the ocean floor and may be carried thousands of kilometers by ocean currents. Clay accumulates very slowly on the deep-ocean floor. To form a 1-centimeter abyssal clay layer, for example, requires as much as 50,000 years. In contrast, on the continental margins near the mouths of large rivers, terrigenous sediment accumulates rapidly and forms thick deposits. In the Gulf of Mexico, for instance, the sediment is many kilometers thick.

Biogenous Sediment

Biogenous sediment is sediment that is biological in origin. **Biogenous sediments consist of shells and skeletons of marine animals and algae.** This debris is produced mostly by microscopic organisms living in surface waters. Once these organisms die, their hard shells sink, accumulating on the seafloor.

The most common biogenous sediment is calcareous ooze. **Calcareous ooze** is produced from the calcium carbonate shells of organisms. Calcareous ooze has the consistency of thick mud. When calcium carbonate shells slowly sink into deeper parts of the ocean, they begin to dissolve. In ocean water deeper than about 4500 meters, these shells completely dissolve before they reach the bottom. As a result, calcareous ooze does not accumulate in the deeper areas of ocean basins.

Other biogenous sediments include siliceous ooze and phosphate-rich material. **Siliceous ooze** is composed primarily of the shells of diatoms—single-celled algae—and radiolarians—single-celled animals that have shells made out of silica. The shells of these organisms are shown in Figure 12. Phosphate-rich biogenous sediments come from the bones, teeth, and scales of fish and other marine organisms.

Reading Checkpoint *Name two types of biogenous sediments.*

Hydrogenous Sediment **Hydrogenous sediment consists of minerals that crystallize directly from ocean water through various chemical reactions.** Hydrogenous sediments make up only a small portion of the overall sediment in the ocean. They do, however, have many different compositions and are distributed in many different environments. Some of the most common types of hydrogenous sediment are listed below.

- Manganese nodules are rounded, hard lumps of manganese, iron, and other metals. These metals precipitate around an object such as a grain of sand. The nodules can be up to 20 centimeters in diameter and are often scattered across large areas of the deep ocean floor.
- Calcium carbonates form by precipitation directly from ocean water in warm climates. If this material is buried and hardens, a type of limestone forms. Most limestone, however, is composed of biogenous sediment.
- Evaporites form where evaporation rates are high and there is restricted open-ocean circulation. As water evaporates from such areas, the remaining ocean water becomes saturated with dissolved minerals that then begin to precipitate. Collectively termed "salts," some evaporite minerals do taste salty, such as halite, or common table salt. Other salts do not taste salty, such as the calcium sulfate minerals anhydrite ($CaSO_4$) and gypsum.

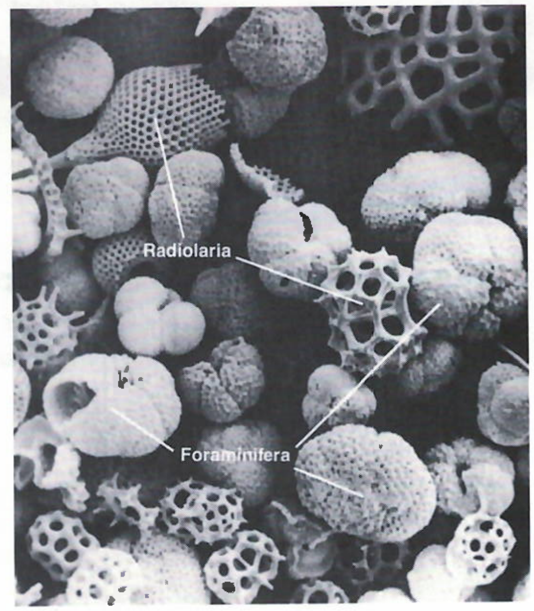


Figure 12 Biogenous Sediments The microscopic shells of radiolarians and foraminifers are examples of biogenous sediments. This photomicrograph has been enlarged hundreds of times.

Section 14.3 Assessment

Reviewing Concepts

1. What are the three types of ocean floor sediments?
2. What does terrigenous sediment consist of?
3. What is the composition of biogenous sediment?
4. How is hydrogenous sediment formed?

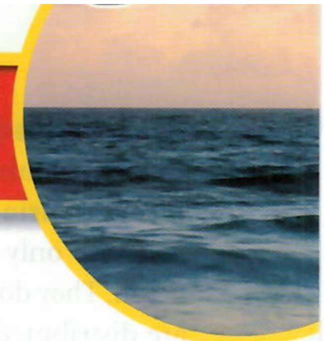
Critical Thinking

5. **Comparing and Contrasting** Compare and contrast calcareous ooze and siliceous ooze.
6. **Predicting** Would you expect to find more evaporites in an area of warm water that receives large amounts of sunlight such as the Red Sea or in an area of cold water that receives less sunlight such as the Greenland Sea?

Connecting Concepts

Origin of Sediments An oceanographer is studying sediment samples from the Bahama Banks. The sediments have a high amount of calcium carbonate. They are labeled biogenous but are later found to contain no shells from organisms that typically make up calcareous ooze. What other explanation is there for the origin of these sediments?

14.4 Resources from the Seafloor



Reading Focus

Key Concepts

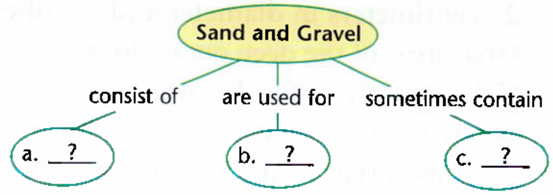
- Which ocean resources are used for energy production?
- How are gas hydrates formed?
- What other resources are derived from the ocean?

Vocabulary

- gas hydrates
- manganese nodule

Reading Strategy

Identifying Details Copy the concept map below. As you read, complete it to identify details about resources from the ocean.



The ocean floor is rich in mineral and organic resources. Recovering them, however, involves technological challenges and high costs. As technology improves we are able to access some of these resources more efficiently. However, other resources, such as manganese nodules, remain untouched.

Energy Resources

Most of the value of nonliving resources in the ocean comes from their use as energy products. **Oil and natural gas are the main energy products currently being obtained from the ocean floor.** Other resources have the potential to be used as a source of energy in the future.

Oil and Natural Gas The ancient remains of microscopic organisms are the source of today's deposits of oil and natural gas. These organisms were buried within marine sediments before they could decompose. After millions of years of exposure to heat from Earth's interior and pressure from overlying rock, the remains were transformed into oil and natural gas. The percentage of world oil produced from offshore regions has increased from trace amounts in the 1930s to more than 30 percent today. Most of this increase is due to the continual update of the technology used by offshore drilling platforms such as the one shown in Figure 13.

Major offshore reserves exist in the Persian Gulf, in the Gulf of Mexico, off the coast of southern California, in the North Sea, and in the East Indies. Additional reserves are probably located off the north coast of Alaska and in the Canadian Arctic, Asian seas, Africa, and Brazil. One

Figure 13 Offshore drilling rigs tap the oil and natural gas reserves of the continental shelf. These platforms are near Santa Barbara, California.
Inferring ***What changes to the marine environment may occur as a result of drilling for oil?***

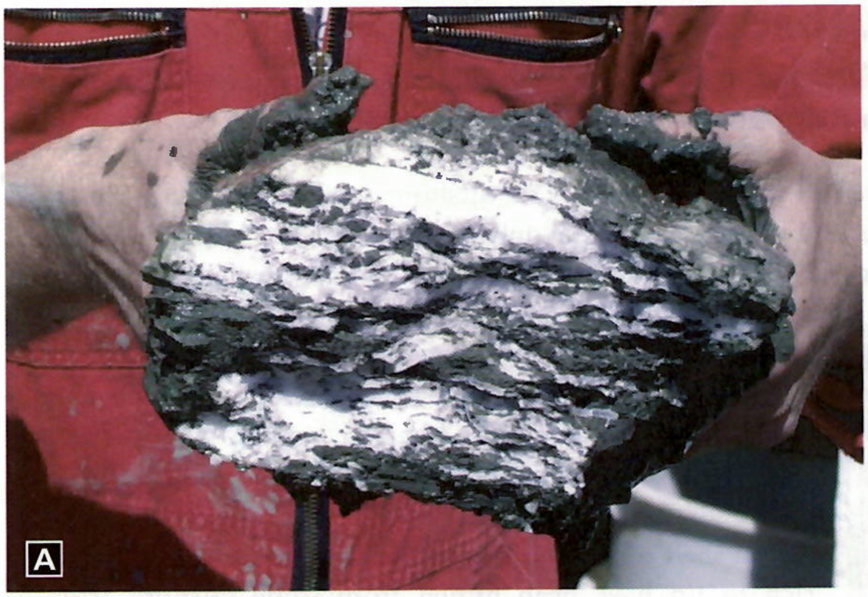


Figure 14 Gas Hydrates
A A sample from the ocean floor has layers of white, ice-like gas hydrate mixed with mud.
B Gas hydrates evaporate when exposed to surface conditions, releasing natural gas that can be burned.

environmental concern about offshore petroleum exploration is the possibility of oil spills caused by accidental leaks during the drilling process.

Gas Hydrates **Gas hydrates** are compact chemical structures made of water and natural gas. The most common type of natural gas is methane, which produces methane hydrate. Gas hydrates occur beneath permafrost areas on land and under the ocean floor at depths below 525 meters.

Most oceanic gas hydrates are created when bacteria break down organic matter trapped in ocean-floor sediments. The bacteria produce methane gas along with small amounts of ethane and propane. These gases combine with water in deep-ocean sediments in such a way that the gas is trapped inside a lattice-like cage of water molecules.

Vessels that have drilled into gas hydrates have brought up samples of mud mixed with chunks of gas hydrates like the one shown in Figure 14A. These chunks evaporate quickly when they are exposed to the relatively warm, low-pressure conditions at the ocean surface. Gas hydrates resemble chunks of ice but ignite when lit by a flame, as shown in Figure 14B. The hydrates burn because methane and other flammable gases are released as gas hydrates evaporate.

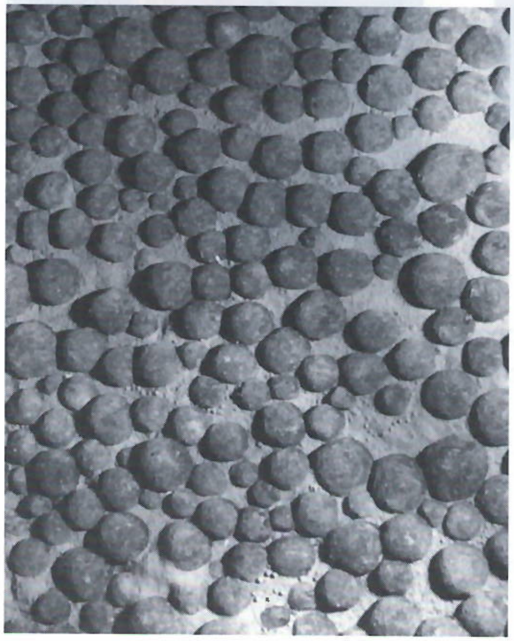
An estimated 20 quadrillion cubic meters of methane are locked up in sediments containing gas hydrates. This amount is double the amount of Earth's known coal, oil, and natural gas reserves combined. One drawback to using gas hydrates as an energy source is that they rapidly break down at surface temperatures and pressures. In the future, however, these ocean-floor reserves of energy may help provide our energy needs.

Reading Checkpoint *What happens when gas hydrates are brought to the surface?*

Go Online SCI LINKS NSTA

For: Links on ocean resources
Visit: www.SciLinks.org
Web Code: cjn-5144

Figure 15 These manganese nodules lie 5323 meters on the Pacific Ocean floor south of the island of Tahiti.
Applying Concepts *How do manganese nodules form?*



Other Resources

Other major resources from the ocean floor include sand and gravel, evaporative salts, and manganese nodules.

Sand and Gravel The offshore sand-and-gravel industry is second in economic value only to the petroleum industry. Sand and gravel, which include rock fragments that are washed out to sea and shells of marine organisms, are mined by offshore barges using suction devices. Sand and gravel are used for landfill, to fill in recreational beaches, and to make concrete.

In some cases, materials of high economic value are associated with offshore sand and gravel deposits. Gem-quality diamonds, for example, are recovered from gravels on the continental shelf offshore of South Africa and Australia. Sediments rich in tin have been mined from some offshore areas of Southeast Asia. Platinum and gold have been found in deposits in gold-mining areas throughout the world. Some Florida beach sands are rich in titanium.

Manganese Nodules As described earlier, **manganese nodules** are hard lumps of manganese and other metals that precipitate around a smaller object. Figure 15 shows manganese nodules on the deep-ocean floor. They contain high concentrations of manganese, iron, and smaller concentrations of copper,

Quick Lab

Evaporative Salts

Materials

400 mL beaker, table salt, tablespoon, balance, glass stirrer

Procedure

1. Place the empty beaker on the balance and add between 3 and 5 tablespoons of the salt. Measure the combined mass of the balance and the salt. Record the measurement and remove the beaker from the balance.
2. Add 100 mL of water to the beaker and stir until the salt is dissolved.
3. Place the beaker in a warm, sunny area and allow the water to evaporate.
4. When all of the water has evaporated, place the beaker and its remaining contents on the balance and record the measurement.

Analyze and Conclude

1. **Comparing** How did the mass of the beaker and salt before the water was added compare to the mass of the beaker and salt after the water evaporated?
2. **Drawing Conclusions** What happened to the salt when the water evaporated?
3. **Predicting** How could the oceans be used as a source of salt?

nickel, and cobalt, all of which have a variety of economic uses. Cobalt, for example, is important because it is required to produce strong alloys with other metals. These alloys are used in high-speed cutting tools, powerful permanent magnets, and jet engine parts. With current technology, mining the deep-ocean floor for manganese nodules is possible but not economically profitable.

Manganese nodules are widely distributed along the ocean floor, but not all regions have the same potential for mining. Good locations for mining must have a large amount of nodules that contain an optimal mix of copper, nickel, and cobalt. Sites like this are limited. In addition, it is difficult to establish mining rights far from land. Also, there are environmental concerns about disturbing large portions of the deep-ocean floor.

Figure 16 Common table salt, or halite, is harvested from the salt left behind when ocean water evaporates. About 30 percent of the world's salt is produced by evaporating seawater.

Evaporative Salts When seawater evaporates, the salts increase in concentration until they can no longer remain dissolved. When the concentration becomes high enough, the salts precipitate out of solution and form salt deposits. These deposits can then be harvested, as shown in Figure 16. The most economically important salt is halite—common table salt. Halite is widely used for seasoning, curing, and preserving foods. It is also used in agriculture, in the clothing industry for dying fabric, and to de-ice roads.

Section 14.4 Assessment

Reviewing Concepts

1. What are the main energy resources from the ocean?
2. How are gas hydrates formed?
3. What drawbacks are associated with harvesting ocean resources for energy use?
4. What other resources are derived from the ocean?
5. What are the uses of evaporative salts?
6. What are manganese nodules? Why is it difficult to recover them from the ocean?

Critical Thinking

7. **Making Generalizations** How does technology influence the availability of resources from the ocean?
8. **Inferring** Near-shore mining of sand and gravel can result in large amounts of sediments being suspended in water. How might this affect marine organisms living in the area?

Connecting Concepts

Sand and Gravel Why are most sand and gravel deposits found on the continental shelf? What type of sediment is sand and gravel?

Exploration Lab

Modeling Seafloor Depth Transects

Oceanographers use a number of methods to determine the depth and topography of the ocean floor. Technology, such as sonar, satellites, and submersibles, have allowed scientists to produce detailed maps of the ocean floor in each ocean basin. In this lab, you will model a seafloor depth transect to determine the topography of an ocean basin created by your classmates.

Problem How can the topography of an ocean basin be determined?

Materials

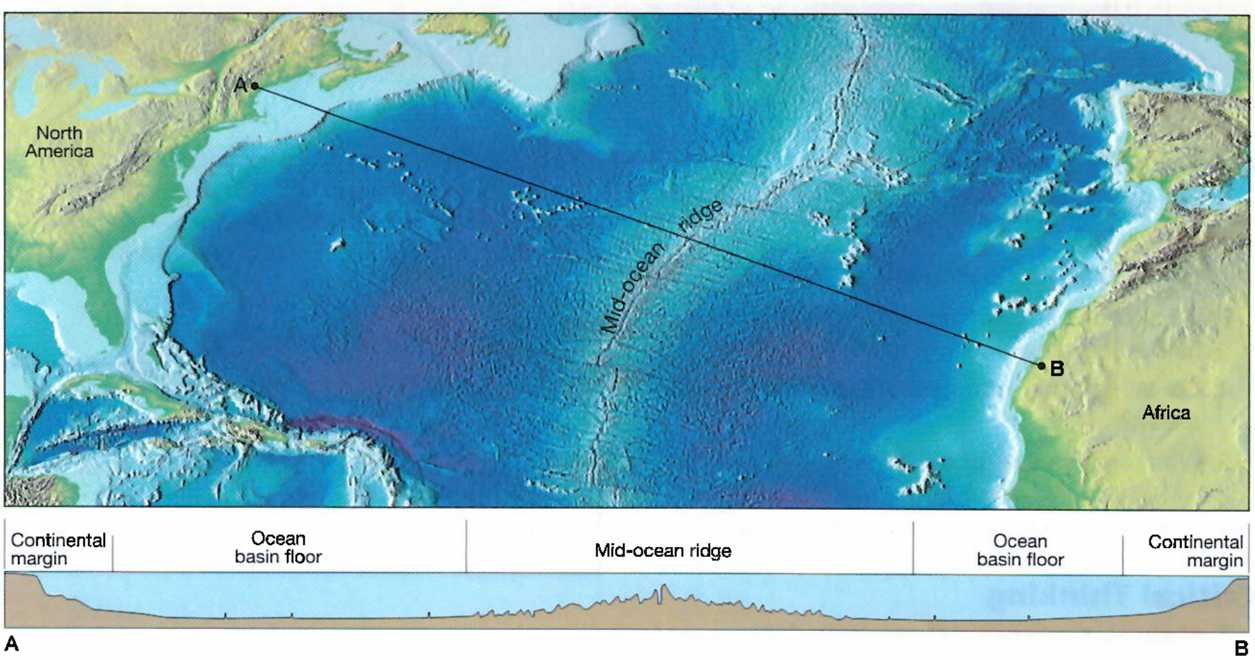
- shoe box
- modeling clay
- aluminum foil
- pencil
- scalpel
- graph paper
- ruler

Skills Measuring, Graphing, Inferring, Drawing Conclusions

Procedure

Part A: Making a Model of the Seafloor

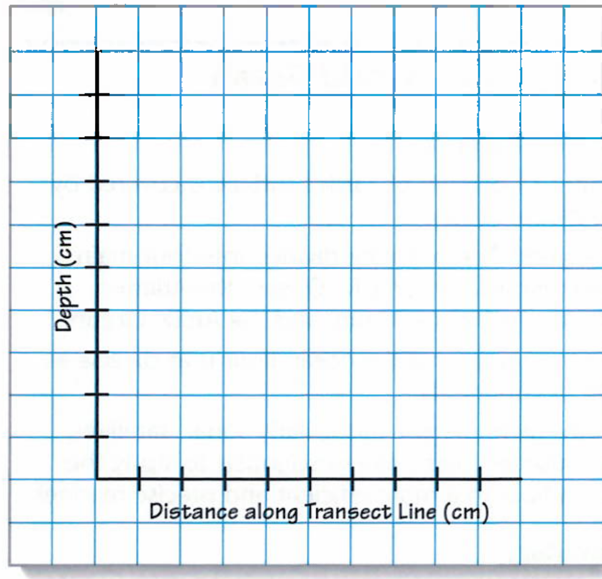
1. Reexamine Figure 3, Figure 7, and the figure below to determine which area of the ocean floor you will model. Be sure to identify the specific features that would be found in the area you choose to model. For example, if you were to model the continental margin you would want to include the continental shelf, continental slope, continental rise, and maybe some submarine canyons in your model. If you were to model the ocean basin floor you would want to include abyssal plains, trenches, seamounts, and guyots. Do not discuss the plan for your model with students outside your group.
2. Once you have determined which area of the ocean floor you will model, use the clay to make a contoured model of the seafloor inside the shoebox.



3. Cover the box with its top and exchange boxes with another group from your class. Do not remove the top of the box that you receive from another group.

Part B: Completing a Depth Transect

4. Obtain a piece of aluminum foil that is large enough to cover the top of the shoebox and fold over the sides of the box about an inch all the way around.
5. Spread the foil flat on your lab table. Place the ruler lengthwise on the foil, parallel to the edge of the foil. The ruler can be in the middle of the foil or off to the side. The line formed by the edge of the ruler will be your transect line.
6. Use a pencil to make tick marks on the foil piece every centimeter along the entire length of the foil.
7. Hold the foil in place over the top of the box. Quickly and carefully remove the top of the box and set the foil piece down in place of the top. Do not look in the box. Secure the foil in place on top of the box by turning down the foil over the sides of the box. Be sure the foil is taut across the top.
8. Label your graph paper. The x-axis will be "Distance along Transect Line" in centimeters, and the y-axis will be "Depth" in centimeters. Make tick marks along the x-axis once every centimeter. Make tick marks along the y-axis every half of a centimeter.
9. Use the scalpel to carefully make a slit in the foil along the first centimeter mark. **CAUTION** *The scalpel is extremely sharp. Handle it carefully.* After cutting the foil, gently place the ruler through the slit until it makes contact with the clay in the box. Be sure to hold the ruler straight and take the depth measurement. Record your data on the graph.
10. Repeat Step 9 for each point along the foil. When you are done, you should have a depth profile for the entire length of the box along your transect line.
11. Remove the foil from the box and examine the contour of the model.



Analyze and Conclude

1. **Inferring** Based on your contour profile, what part of the ocean floor was being modeled? Check your answer with the group that created the model. Were you correct? Why or why not?
2. **Comparing** How does the profile on your graph compare with the contour of the model? Are there any major features in the model that did not appear on your graph? Why or why not?
3. **Analyzing Data** What could you have done to make your profile match the contour more accurately?
4. **Explaining** Before sonar was used to measure ocean depth, a less sophisticated method was used. A long line of rope with a lead weight on the end was tossed over the side of a ship and lowered until the weight hit the bottom. How is this method similar to what you did in the lab? How can the rope method lead to inaccuracies when trying to build an ocean floor profile?

CHAPTER 14

Study Guide

14.1 The Vast World Ocean

Key Concepts

- Nearly 71 percent of Earth's surface is covered by the global ocean.
- The world ocean can be divided into four main ocean basins—the Pacific Ocean, the Atlantic Ocean, the Indian Ocean, and the Arctic Ocean.
- The topography of the ocean floor is as diverse as that of continents.
- Today, technology—particularly sonar, satellites, and submersibles—allows scientists to study the ocean floor in a more efficient and precise manner.

Vocabulary

oceanography, *p. 394*; bathymetry, *p. 396*; sonar, *p. 398*; submersible, *p. 400*

14.2 Ocean Floor Features

Key Concepts

- The ocean floor regions are the continental margins, the ocean basin floor, and the mid-ocean ridge.
- In the Atlantic Ocean thick layers of undisturbed sediment cover the continental margin. This region has very little volcanic or earthquake activity.
- In the Pacific Ocean oceanic crust is plunging beneath continental crust. This force results in a narrow continental margin that experiences both volcanic activity and earthquakes.
- Continental shelves contain important mineral deposits, large reservoirs of oil and natural gas, and huge sand and gravel deposits.
- Trenches form at sites of plate convergence where one moving plate descends beneath another and plunges back into the mantle.
- The sediments that make up abyssal plains are carried there by turbidity currents or are deposited as a result of suspended sediments settling.
- New ocean floor is formed at mid-ocean ridges as magma rises between the diverging plates and cools.

Vocabulary

continental margin, *p. 402*; continental shelf, *p. 402*; continental slope, *p. 403* submarine canyon, *p. 403*; turbidity current, *p. 403*; continental rise, *p. 403*; ocean basin floor, *p. 404*; abyssal plains, *p. 404*; seamounts, *p. 404*; mid-ocean ridge, *p. 405*; seafloor spreading, *p. 405*

14.3 Seafloor Sediments

Key Concepts

- Ocean-floor sediments can be classified according to their origin into three broad categories: terrigenous sediments, biogenous sediments, and hydrogenous sediments.
- Terrigenous sediments consist primarily of mineral grains that were eroded from continental rocks and transported to the ocean.
- Biogenous sediments consist of shells and skeletons of marine animals and algae.
- Hydrogenous sediments consist of minerals that crystallize directly from ocean water through various chemical reactions.

Vocabulary

terrigenous sediment, *p. 408*; biogenous sediment, *p. 408*; calcareous ooze, *p. 408*; siliceous ooze, *p. 408*; hydrogenous sediment, *p. 409*

14.4 Resources from the Seafloor

Key Concepts

- Oil and natural gas are the main energy products currently being obtained from the ocean floor.
- Most oceanic gas hydrates are created when bacteria break down organic matter trapped in ocean-floor sediments.
- Other major resources from the seafloor include sand and gravel, evaporative salts, and manganese nodules.

Vocabulary

gas hydrates, *p. 411*; manganese nodule, *p. 412*

CHAPTER 14

Assessment

Interactive textbook with assessment at PHSchool.com

Reviewing Content

Choose the letter that best answers the question or completes the statement.

1. Approximately what percentage of Earth's surface is covered by oceans?
   a. 40 **b.** 50
   c. 60 **d.** 70

2. Which ocean basin is the largest?
   a. the Atlantic **b.** the Indian
   c. the Pacific **d.** the Arctic

3. The use of sound waves to determine the depth of the ocean is called
   a. submarine sounding.
   b. sonar.
   c. satellite altimetry.
   d. submersible sounding.

4. The gently sloping submerged surface that extends from the shoreline toward the ocean basin floor is the continental
   a. shelf. **b.** slope.
   c. rise. **d.** margin.

5. Submarine canyons are believed to have been created by
   a. rivers during the ice age.
   b. earthquakes.
   c. lost ships.
   d. subduction.

6. Important mineral deposits, including large reservoirs of oil and natural gas, are associated with
   a. the ocean basin floor.
   b. the continental shelf.
   c. abyssal plains.
   d. the continental rise.

7. Calcareous ooze is an example of
   a. terrigenous sediment.
   b. biogenous sediment.
   c. hydrogenous sediment.
   d. a combination of hydrogenous and terrigenous sediment.

8. Sediments that consist of mineral grains that were eroded from continental rocks are called
   a. terrigenous. **b.** biogenous.
   c. hydrogenous. **d.** hydrates.

9. What could gas hydrates be used for?
   a. as landfill
   b. to make concrete
   c. as a source of energy
   d. as a source of cobalt and copper

10. Economically valuable materials such as diamonds, tin, and platinum are associated with which ocean floor resource?
    a. oil and natural gas
    b. sand and gravel
    c. evaporative salts
    d. manganese nodules

Understanding Concepts

11. Why is Earth called the "blue planet"?

12. What is bathymetry? What techniques do scientists use to discover more about the bathymetry of ocean basins?

13. Why is multibeam sonar more efficient than simple sonar at collecting data from the ocean floor?

14. Compare and contrast the size and topography of the Atlantic Ocean basin to that of the Pacific Ocean basin.

15. What is a continental shelf? What economic significance do continental shelves have?

16. Compare and contrast deep-ocean trenches and mid-oceanic ridges.

17. In which ocean basin are most trenches found? Why?

18. What is the difference between terrigenous sediments and biogenous sediments?

19. Explain the process by which hydrogenous sediments are formed.

20. Why is it uncommon to find calcareous ooze in deep-ocean basins?

21. From which area of the ocean basin are the resources of oil and natural gas harvested?

22. What current disadvantages exist to using gas hydrates as a form of energy?

23. What are the uses for sand and gravel harvested from the continental shelf?

CHAPTER 14

Assessment *continued*

Critical Thinking

24. **Interpreting Diagrams** Reexamine Figure 1. Why do you think that the Northern Hemisphere is called the "land hemisphere" and the Southern Hemisphere is called the "water hemisphere"?

25. **Making Generalizations** A friend says that because of gravity we can learn about the topography of the ocean floor. Explain why this is true.

26. **Inferring** The continental margin of the Atlantic Ocean is often referred to as a "passive" continental margin whereas Pacific Ocean continental margins are referred to as "active." Infer what the characteristics of passive and active continental margins would be.

27. **Inferring** There is usually very little sediment accumulation found at mid-ocean ridges. Why do you think this is true?

28. **Applying Concepts** Imagine you have been asked to invent a device that would be used to retrieve manganese nodules. What characteristics would the device have in order to successfully achieve this goal?

Math Skills

29. **Calculating** Assuming the average speed of sound waves in water is 1500 meters per second, determine, in seconds, how long it would take a sonar signal to hit the bottom and return to the recorder if the water depth is 7500 meters.

30. **Calculating** The rate of seafloor spreading in the Atlantic Ocean has been estimated to be about 2.5 centimeters per year. By how many centimeters will the Atlantic Ocean basin increase over a period of 7 years?

31. **Calculating** If the settling rate of very fine sand in the open ocean is 360 meters per day, how many days will it take for the sediment to reach the ocean floor at a depth of 4 kilometers?

Concepts in Action

Use the table below to answer Questions 32 and 33.

The table shows the kind of data that a simple sonar echo sounder would provide. The sonar is taken along a transect line in the Pacific Ocean. The stations are approximately 500 meters apart from each other.

Sonar Data

Station Number	Depth (in meters)	Station Number	Depth (in meters)
1	5500	7	3110
2	5550	8	3285
3	4540	9	3490
4	4000	10	4000
5	3675	11	4675
6	3355	12	5000

32. **Making Graphs** Plot these points on a sheet of graph paper.

33. **Interpreting Data** The data recorded in the table was taken over a portion of the ocean basin floor in the Pacific Ocean. What ocean basin feature could be between stations 2 and 12?

Performance-Based Assessment

Researching Choose a resource that is harvested from the ocean. Research information about how the resource is formed, where in the ocean it is harvested, what methods and equipment are used in the harvesting of the resource, what it is used for, and if there are any negative impacts on the marine environment as a result of harvesting the resource. Present the results of your research to your class in the form of an oral presentation.

Standardized Test Prep

Test-Taking Tip

Avoiding Careless Mistakes
Students often make mistakes when they fail to examine a test question and possible answers thoroughly. Read the question carefully and underline key words that may change the meaning of the question, such as *not, except, excluding,* and so on. After choosing an answer, reread the question to check your selection.

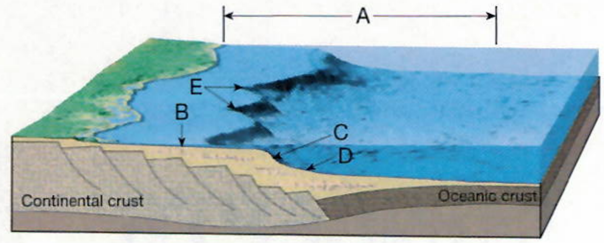
Which of the following is NOT one of the four major topographic features of the ocean basin floor?
(A) deep-ocean trench
(B) abyssal plain
(C) submarine canyon
(D) seamount

(Answer: C)

Choose the letter that best answers the question or completes the statement.

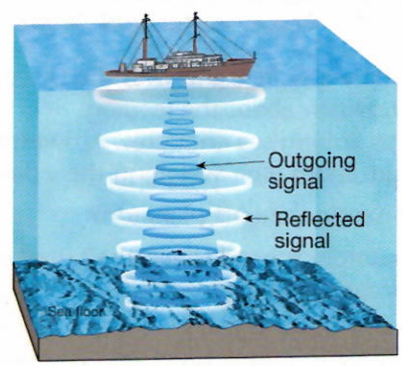
1. Which of the following is NOT true of deep ocean trenches?
   (A) They are long and narrow depressions in the ocean floor.
   (B) They are sites where plates plunge back into the mantle.
   (C) They are geologically very stable.
   (D) They may act as sediment traps.
2. Movements of sediment-rich water down the continental slope are known as
   (A) streaming currents.
   (B) longshore currents.
   (C) turbidity currents.
   (D) avalanches.

Use the diagram below to answer Questions 3 and 4.



3. Which portion of the ocean floor is represented by the letter A? Describe its physical features.
4. Which ocean floor area is represented by the letter D? What are its characteristics?
5. What is the most economically important salt? Why is it important?
6. What are abyssal plains? What is underneath the plains, and how do they form?

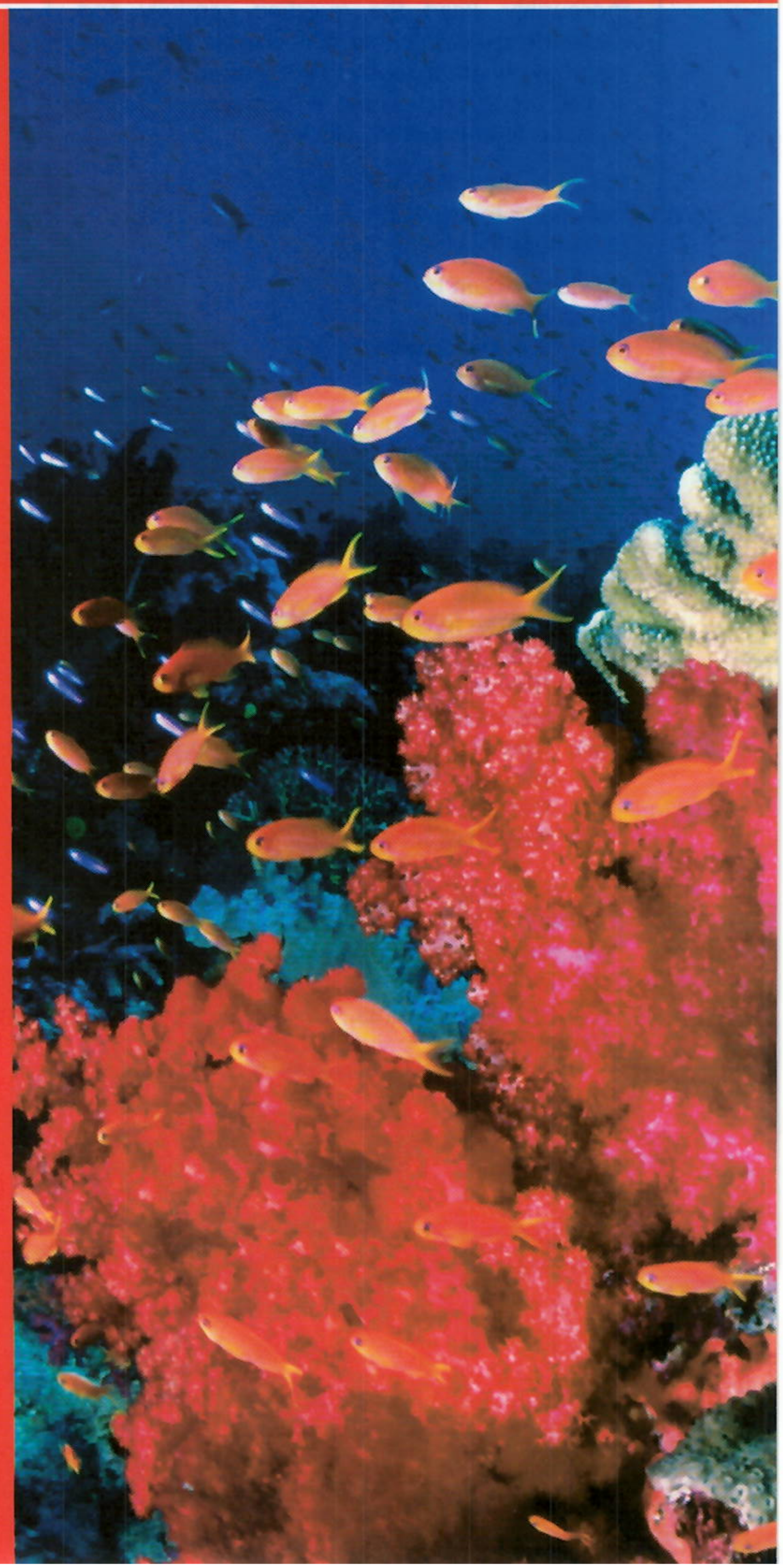
Use the diagram below to answer Question 7.



7. How is sonar used to determine the topography of ocean basins?
8. Sediment on the seafloor often leaves clues about various conditions that existed during deposition. What do the following layers in a seafloor sample tell about the environment in which each layer was deposited?
   Layer 5 (top): Fine clay
   Layer 4: Siliceous ooze
   Layer 3: Calcareous ooze
   Layer 2: Fragments of coral reef
   Layer 1 (bottom): Volcanic rock

CHAPTER

15 Ocean Water and Ocean Life



CONCEPTS in Action

Exploration Lab
How Does Temperature Affect Water Density?

How the Earth Works
Ocean Life

Discovery Channel School **Video Field Trip**
Ocean Water and Ocean Life

Take an underwater field trip with the Discovery Channel and learn about the feeding relationships among sea creatures. Answer the following questions after watching the video.

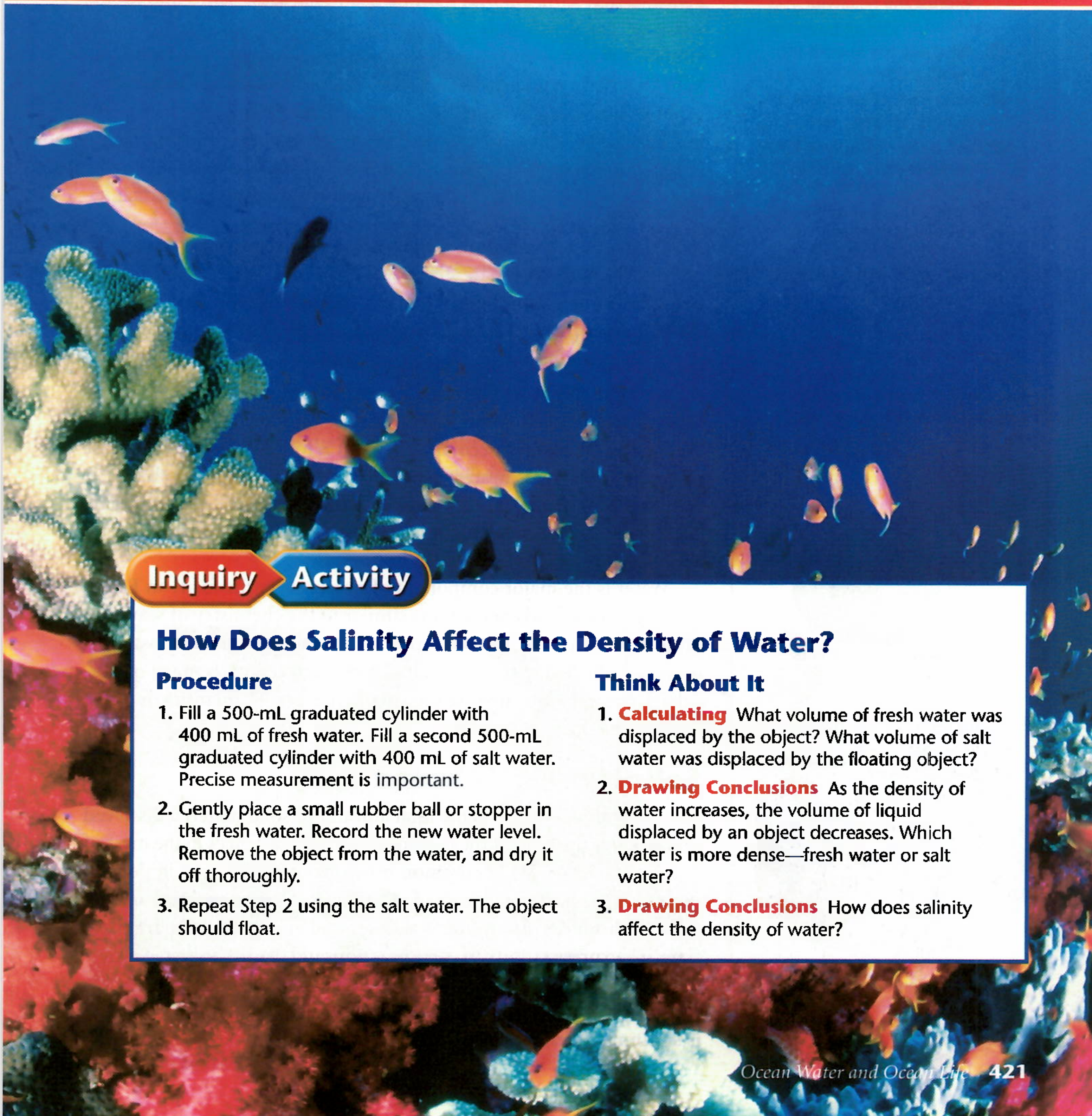
1. How do sardines ingest plankton?
2. Why do dolphins need to pin their prey close to the ocean surface?

Go Online PHSchool.com

For: Chapter 15 Resources
Visit: PHSchool.com
Web Code: cjk-9999

The marine environment is a habitat for ▶ thousands of species of organisms, including the damselfish and corals shown here in the south Pacific near Fiji.

Chapter Preview



Inquiry Activity

How Does Salinity Affect the Density of Water?

Procedure

1. Fill a 500-mL graduated cylinder with 400 mL of fresh water. Fill a second 500-mL graduated cylinder with 400 mL of salt water. Precise measurement is important.
2. Gently place a small rubber ball or stopper in the fresh water. Record the new water level. Remove the object from the water, and dry it off thoroughly.
3. Repeat Step 2 using the salt water. The object should float.

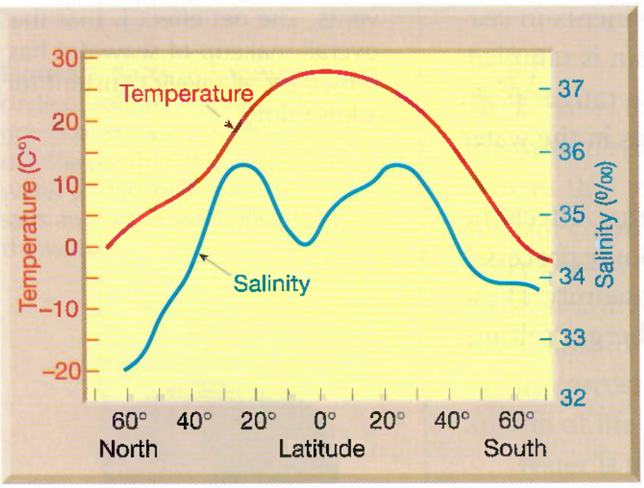
Think About It

1. **Calculating** What volume of fresh water was displaced by the object? What volume of salt water was displaced by the floating object?
2. **Drawing Conclusions** As the density of water increases, the volume of liquid displaced by an object decreases. Which water is more dense—fresh water or salt water?
3. **Drawing Conclusions** How does salinity affect the density of water?

Other processes remove large amounts of fresh water from seawater, increasing salinity. These processes include evaporation and the formation of sea ice. High salinities, for example, are found where evaporation rates are high, as is the case in the dry subtropical regions. In areas where large amounts of precipitation dilute ocean waters, as in the mid-latitudes and near the equator, salinity is lower. Both of these examples are shown on the graph in Figure 3.

Surface salinity in polar regions varies seasonally due to the formation and melting of sea ice. When seawater freezes in winter, salts do not become part of the ice. Therefore, the salinity of the remaining seawater increases. In summer when sea ice melts, the addition of relatively fresh water dilutes the solution and salinity decreases.

Figure 3 This graph shows the variations in ocean surface temperature (top curve) and surface salinity (lower curve). **Interpreting Diagrams** ***At which latitudes is sea surface temperature highest? Why?***



Ocean Temperature Variation

The ocean's surface water temperature varies with the amount of solar radiation received, which is primarily a function of latitude. The graph in Figure 3 shows this relationship. The intensity of solar radiation in high latitudes is much less than the intensity of solar radiation received in tropical latitudes. Therefore, lower sea surface temperatures are found in high-latitude regions. Higher sea surface temperatures are found in low-latitude regions.

Temperature Variation with Depth If you lowered a thermometer from the surface of the ocean into deeper water, what temperature pattern do you think you would find? Surface waters are warmed by the sun, so they generally have higher temperatures than deeper waters. However, the observed temperature pattern depends on the latitude.

Figure 4 on page 425 shows two graphs of temperature versus depth: one for low-latitude regions and one for high-latitude regions. The low-latitude curve begins with high temperature at the surface. However, the temperature decreases rapidly with depth because of the inability of the sun's rays to penetrate very far into the ocean. At a depth of about 1000 meters, the temperature remains just a few degrees above freezing and is relatively constant from this level down to the ocean floor. The **thermocline** (*thermo* = heat, *cline* = slope) is the layer of ocean water between about 300 meters and 1000 meters, where there is a rapid change of temperature with depth. The thermocline is a very important structure in the ocean because it creates a vertical barrier to many types of marine life.

The high-latitude curve in Figure 4 shows a very different pattern from the low-latitude curve. Surface water temperatures in high latitudes are much cooler than in low latitudes, so the curve begins at the surface with a low temperature. Deeper in the ocean, the temperature of the water is similar to that at the surface, so the curve remains vertical. There is no rapid change of temperature with depth. A thermocline is not present in high latitudes. Instead, the water column is isothermal (*iso* = same, *thermo* = heat).

Reading Checkpoint ***What is the thermocline?***

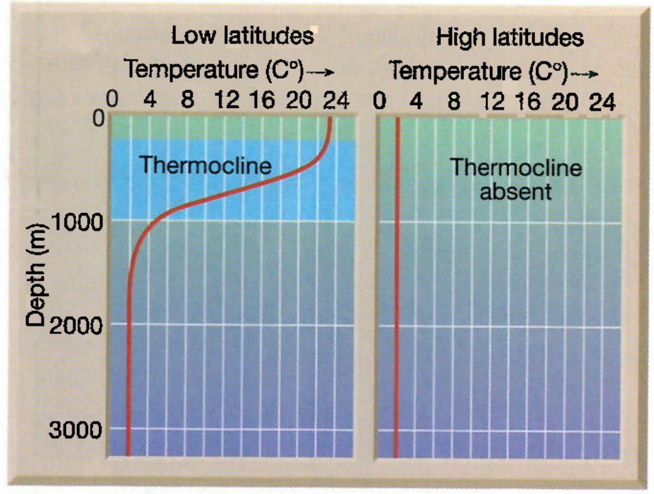


Figure 4 These graphs show the variations in ocean water temperature with depth for low-latitude and high-latitude regions. **Applying Concepts** ***Why is the thermocline absent in the high latitudes?***

Ocean Density Variation

Density is defined as mass per unit volume. It can be thought of as a measure of how heavy something is for its size. For example, an object that has low density is lightweight for its size, such as a dry sponge, foam packing, or a surfboard. An object that has high density is heavy for its size, such as cement, most metals, or a large container full of water.

Density is an important property of ocean water because it determines the water's vertical position in the ocean. Density differences cause large areas of ocean water to sink or float. When high-density seawater is added to low-density fresh water, the denser seawater sinks below the fresh water.

Factors Affecting Seawater Density

Seawater density is influenced by two main factors: salinity and temperature. An increase in salinity adds dissolved substances and results in an increase in seawater density. An increase in temperature results in a decrease in seawater density. Temperature has the greatest influence on surface seawater density because variations in surface seawater temperature are greater than salinity variations. In fact, only in the extreme polar areas of the ocean—where temperatures are low and remain relatively constant—does salinity significantly affect density. Cold water that also has high salinity is some of the highest-density water in the world.

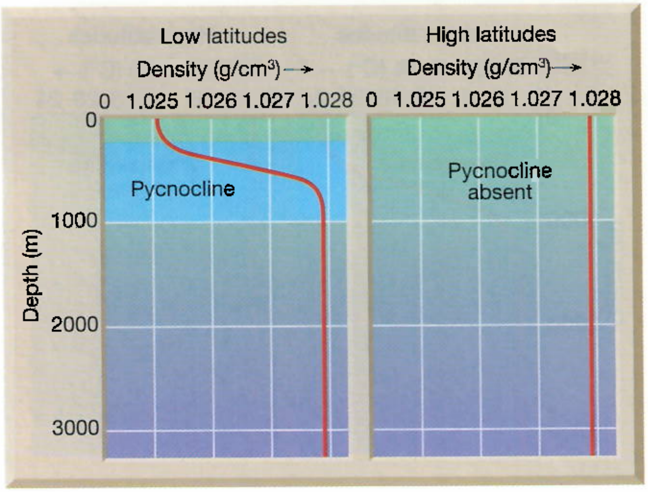


Figure 5 The graphs show variations in ocean water density with depth for low-latitude and high-latitude regions.
Interpreting Diagrams
What is the difference between the low-latitude graph and the high-latitude graph? Why does this difference occur?

Density Variation with Depth By sampling ocean waters, oceanographers have learned that temperature and salinity—and the water's resulting density—vary with depth. Figure 5 shows two graphs of density versus depth. One graph shows the density for low-latitude regions and the other for high-latitude regions. Compare the density curves in Figure 5 to the temperature curves in Figure 4. They are similar. This similarity demonstrates that temperature is the most important factor affecting seawater density. It also shows that temperature is inversely proportional to density. When two quantities are inversely proportional, they can be multiplied together to equal a constant. Therefore, if the value of one quantity increases, the value of the other quantity decreases proportionately. When water temperature increases, its density decreases.

Reading Checkpoint ***How does temperature affect the density of seawater?***

The **pycnocline** (*pycno* = density, *cline* = slope) is the layer of ocean water between about 300 meters and 1000 meters where there is a rapid change of density with depth. A pycnocline presents a significant barrier to mixing between low-density water above and high-density water below. A pycnocline is not present in high latitudes; instead, the water column is about the same density throughout.

Ocean Layering

The ocean, like Earth's interior, is layered according to density. Low-density water exists near the surface, and higher-density water occurs below. Except for some shallow inland seas with a high rate of evaporation, the highest-density water is found at the greatest ocean depths. **Oceanographers generally recognize a three-layered structure in most parts of the open ocean: a shallow surface mixed zone, a transition zone, and a deep zone.** These zones are shown in Figure 6.

Surface Zone Because solar energy is received at the ocean surface, it is here that water temperatures are warmest. The **mixed zone** is the area of the surface created by the mixing of water by waves, currents, and tides. The mixed zone has nearly uniform temperatures. The depth and temperature of this layer vary, depending on latitude and season. The zone usually extends to about 300 meters, but it may extend to a depth of 450 meters. The surface mixed zone accounts for only about 2 percent of ocean water.

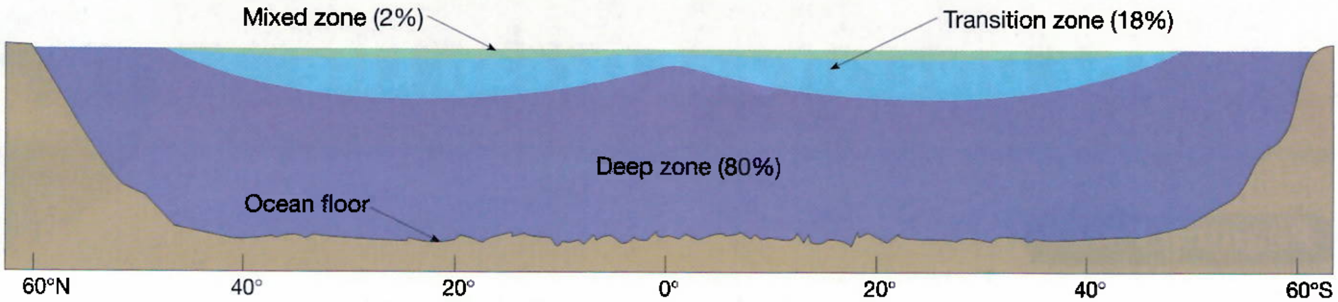


Figure 6 Ocean Zones Oceanographers recognize three main zones of the ocean based on water density, which varies with temperature and salinity.

Transition Zone Below the sun-warmed zone of mixing, the temperature falls abruptly with depth as was seen in Figure 4. Here, a distinct layer called the transition zone exists between the warm surface layer above and the deep zone of cold water below. The transition zone includes a thermocline and associated pycnocline. This zone accounts for about 18 percent of ocean water.

Deep Zone Below the transition zone is the deep zone. Sunlight never reaches this zone, and water temperatures are just a few degrees above freezing. As a result, water density remains constant and high. The deep zone includes about 80 percent of ocean water.

In high latitudes, this three-layered structure of the open ocean does not exist as seen in Figure 6. The three layers do not exist because there is no rapid change in temperature or density with depth. Therefore, good vertical mixing between surface and deep waters can occur in high-latitude regions. Here, cold high-density water forms at the surface, sinks, and initiates deep-ocean currents, which are discussed in Chapter 16.

Section 15.1 Assessment

Reviewing Concepts

1. What is salinity? What units are used to express the salinity of ocean water?
2. What are the six most abundant elements in seawater?
3. What are the sources of salt in ocean water?
4. Explain the relationship between latitude and sea surface temperature.
5. What factors affect the density of ocean water?
6. What are the three main zones of the open ocean?

Critical Thinking

7. **Inferring** Why does the salinity of seawater remain relatively constant over time?
8. **Summarizing** Explain the general pattern of temperature variation with depth in low-latitude oceans.

Writing in Science

Descriptive Paragraph Write a paragraph that describes the different characteristics of the three zones of the open ocean. Include an explanation of why polar regions do not exhibit the same pattern of water stratification.

15.2 The Diversity of Ocean Life

Reading Focus

Key Concepts

- How can marine organisms be classified?
- What is the difference between plankton and nekton?
- In which area of the ocean can most benthos organisms be found living?
- What factors are used to divide the ocean into marine life zones?

Vocabulary

- plankton
- phytoplankton
- zooplankton
- nekton
- benthos
- photic zone
- intertidal zone
- neritic zone
- oceanic zone
- pelagic zone
- benthic zone
- abyssal zone

Reading Strategy

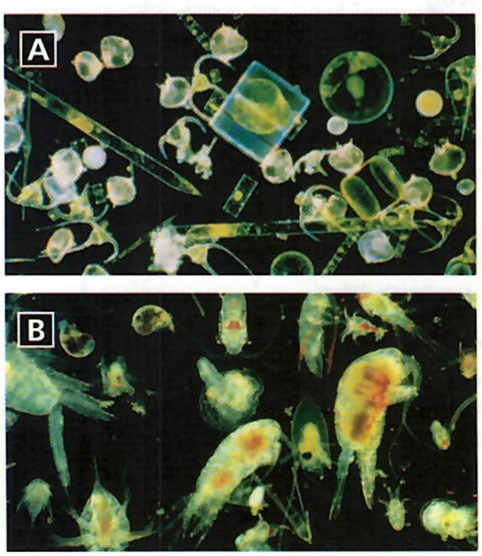
Building Vocabulary Copy the table below. As you read, add definitions and examples to complete the table.

Definitions	Examples
Plankton: organisms that drift with ocean currents	bacteria
Phytoplankton: a. ___?___	b. ___?___
Zooplankton: c. ___?___	d. ___?___
Nekton: e. ___?___	f. ___?___
Benthos: g. ___?___	h. ___?___

A wide variety of organisms inhabit the marine environment. These organisms range in size from microscopic bacteria and algae to the largest organisms alive today—blue whales, which are as long as three buses lined up end to end. Marine biologists have identified over 250,000 marine species. This number is constantly increasing as new organisms are discovered.

Most marine organisms live within the sunlit surface waters. Strong sunlight supports photosynthesis by marine algae. Algae either directly or indirectly provide food for the majority of organisms. All marine algae live near the surface because they need sunlight to survive. Most marine animals also live near the surface because this is where they can find food.

Figure 7 Plankton are organisms that drift with ocean currents. **A** This photo shows a variety of phytoplankton from the Atlantic Ocean. **B** The zooplankton shown here include copepods and the larval stages of other common marine organisms.



Classification of Marine Organisms

Marine organisms can be classified according to where they live and how they move. They can be classified as either plankton (floaters) or nekton (swimmers). All other organisms are benthos, or bottom dwellers.

Plankton

Plankton (*planktos* = wandering) **include all organisms—algae, animals, and bacteria—that drift with ocean currents.** Just because plankton drift does not mean they are unable to swim. Many plankton can swim but either move very weakly or move only vertically.

Among plankton, the algae that undergo photosynthesis are called **phytoplankton.** Most phytoplankton, such as diatoms, are microscopic. Animal plankton, are called **zooplankton.** Zooplankton include the larval stages of many marine organisms such as fish, sea stars, lobsters, and crabs. Figure 7 shows members of each group.

Nekton

Nekton (*nektos* = swimming) **include all animals capable of moving independently of the ocean currents, by swimming or other means of propulsion.** Nekton are able to determine their position within the ocean and in many cases complete long migrations. Nekton include most adult fish and squid, marine mammals, and marine reptiles. Figure 8 shows examples of nekton.

Fish may appear to exist everywhere in the oceans, but they are more abundant near continents and islands and in colder waters. Some fish, such as salmon, swim upstream in fresh water rivers to spawn. Many eels do just the reverse, growing to maturity in fresh water and then swimming out of the streams to breed in the depths of the ocean.

Benthos

The **term *benthos*** (*benthos* = bottom) **describes organisms living on or in the ocean bottom.** Figure 9 shows some examples of benthos organisms. The shallow coastal ocean floor contains a wide variety of physical conditions and nutrient levels. Most benthos organisms can be found living in this area. Shallow coastal areas are the only locations where large marine algae, often called seaweeds, are found attached to the bottom. These are the only areas of the seafloor that receive enough sunlight for the algae to survive.

Throughout most of the deeper parts of the seafloor, animals live in perpetual darkness, where photosynthesis cannot occur. They must feed on each other or on whatever nutrients fall from the productive surface waters. The deep-sea bottom is an environment of coldness, stillness, and darkness. Under these conditions, life progresses slowly. Organisms that live in the deep sea usually are widely distributed because physical conditions vary little on the deep-ocean floor.

Figure 8 Nekton includes all animals capable of moving independently of ocean currents. **A** This squid can use propulsion to move through the water. **B** This school of grunts swims through the water with ease.
Inferring ***Why do you think some organisms, such as fish, are classified as plankton during some stages of their lives and nekton during other stages?***

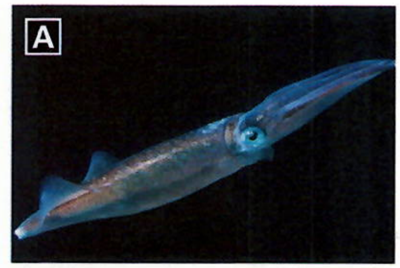
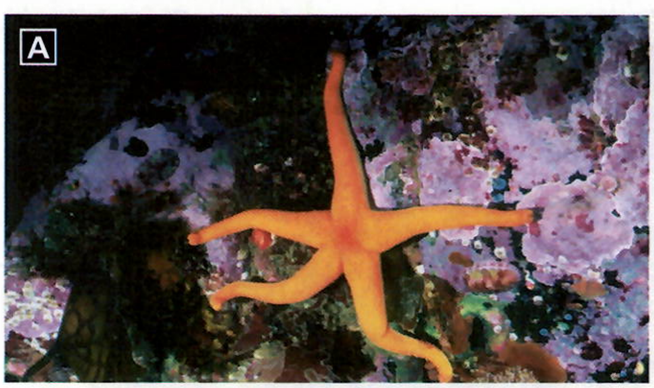


Figure 9 Benthos describes organisms living on or in the ocean bottom. **A** Sea star **B** Coral crab



Go Online
SCI LINKS NSTA

For: Links on marine ecosystems
Visit: www.SciLinks.org
Web Code: cjn-5152

Marine Life Zones

The distribution of marine organisms is affected by the chemistry, physics, and geology of the oceans. Marine organisms are influenced by a variety of physical factors. **Three factors are used to divide the ocean into distinct marine life zones: the availability of sunlight, the distance from shore, and the water depth.** Figure 10 shows the different zones in which marine life can be found.

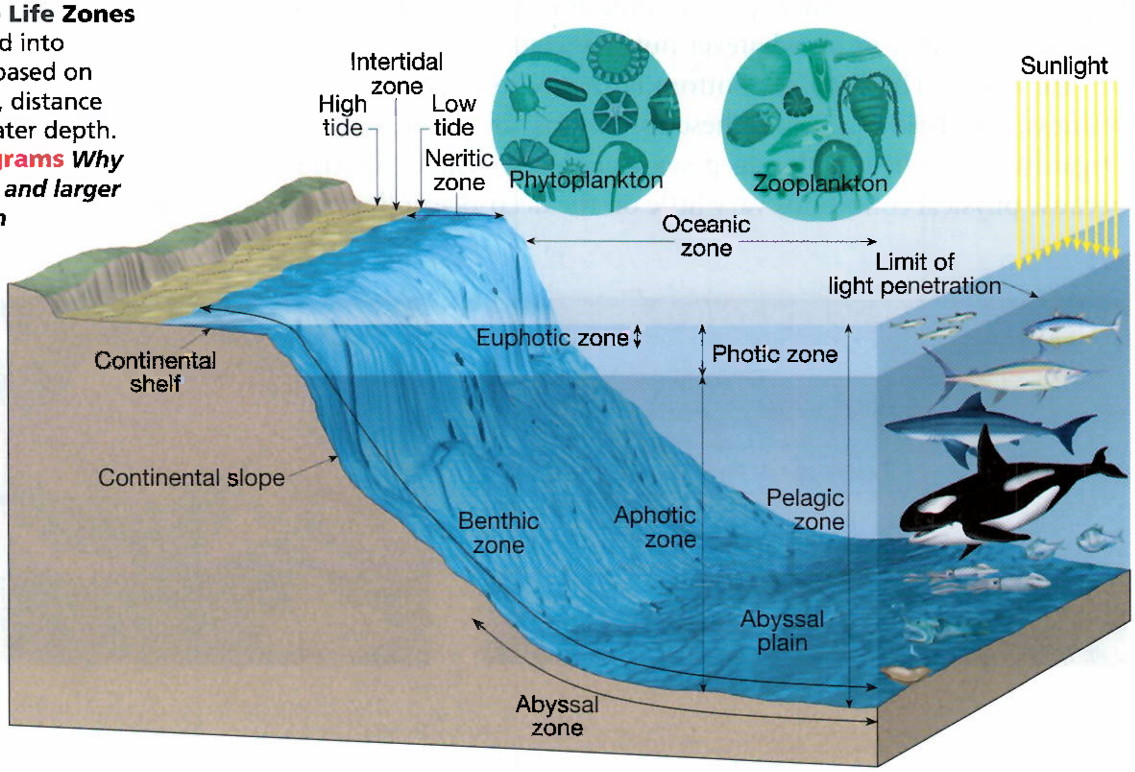
Availability of Sunlight The upper part of the ocean into which sunlight penetrates is called the **photic zone** (*photos* = light). The clarity of seawater is affected by many factors, such as the amount of plankton, suspended sediment, and decaying organic particles in the water. In addition, the amount of sunlight varies with atmospheric conditions, time of day, season of the year, and latitude.

The euphotic zone is the portion of the photic zone near the surface where light is strong enough for photosynthesis to occur. In the open ocean, this zone can reach a depth of 100 meters, but the zone will be much shallower close to shore where water clarity is typically reduced. In the euphotic zone, phytoplankton use sunlight to produce food and become the basis of most oceanic food webs.

Although photosynthesis cannot occur much below 100 meters, there is enough light in the lower photic zone for marine animals to avoid predators, find food, recognize their species, and locate mates. Below this zone is the aphotic zone, where there is no sunlight.

Reading Checkpoint ***What is the difference between the photic zone and the aphotic zone?***

Figure 10 Marine Life Zones The ocean is divided into marine life zones, based on availability of light, distance from shore, and water depth. **Interpreting Diagrams** ***Why are phytoplankton and larger algae found only in surface waters?***



Distance from Shore Marine life zones can also be subdivided based on distance from shore. The area where the land and ocean meet and overlap is the **intertidal zone.** This narrow strip of land between high and low tides is alternately covered and uncovered by seawater with each tidal change. It appears to be a harsh place to live with crashing waves, periodic drying out, and rapid changes in temperature, salinity, and oxygen concentrations. However, the species that live here are well adapted to the constant environmental changes.

Seaward from the low-tide line is the **neritic zone.** This zone covers the gently sloping continental shelf. The neritic zone can be very narrow or may extend hundreds of kilometers from shore. It is often shallow enough for sunlight to reach all the way to the ocean floor, putting it entirely within the photic zone.

Although the neritic zone covers only about 5 percent of the world ocean, it is rich in both biomass and number of species. Many organisms find the conditions here ideal because photosynthesis occurs readily, nutrients wash in from the land, and the bottom provides shelter and habitat. This zone is so rich that it supports 90 percent of the world's commercial fisheries.

Beyond the continental shelf is the **oceanic zone.** The open ocean reaches great depths. As a result, surface waters typically have lower nutrient concentrations because nutrients tend to sink out of the photic zone to the deep-ocean floor. This low nutrient concentration usually results in smaller populations than the more productive neritic zone.

Water Depth A third method of classifying marine habitats is based on water depth. Open ocean of any depth is called the **pelagic zone.** Animals in this zone swim or float freely. The photic part of the pelagic zone is home to phytoplankton, zooplankton, and nekton, such as tuna, sea turtles, and dolphins. The aphotic part of this zone has giant squid and other species that are adapted to life in deep water.

Benthos organisms such as giant kelp, sponges, crabs, sea anemones, sea stars, and marine worms that attach to, crawl upon, or burrow into the seafloor occupy parts of the benthic zone. The **benthic zone** includes any sea-bottom surface regardless of its distance from shore and is mostly inhabited by benthos organisms.

The **abyssal zone** is a subdivision of the benthic zone. The abyssal zone includes the deep-ocean floor, such as abyssal plains. This zone is characterized by extremely high water pressure, consistently low temperature, no sunlight, and sparse life. Food sources at abyssal depths typically come from the surface. Some food is in the form of tiny decaying particles that steadily "rain" down from the surface. These particles provide food for filter-feeders, brittle stars, and burrowing worms. Other food arrives as large fragments or entire carcasses of organisms that sink from the surface. These pieces supply meals for actively searching fish, such as the grenadier, tripodfish, and hagfish.

Q&A

Q *Do any deep-sea organisms produce light themselves?*

A Over half of deep-sea organisms—including fish, jellies, crustaceans, and deep-sea squid—can bioluminesce, which means they can produce light organically. These organisms produce light through a chemical reaction in specially designed structures or cells called photophores. Some of these cells contain luminescent bacteria that live symbiotically within the organism. In a world of darkness, the ability to produce light can be used to attract prey, define territory, communicate with others, or avoid predators.

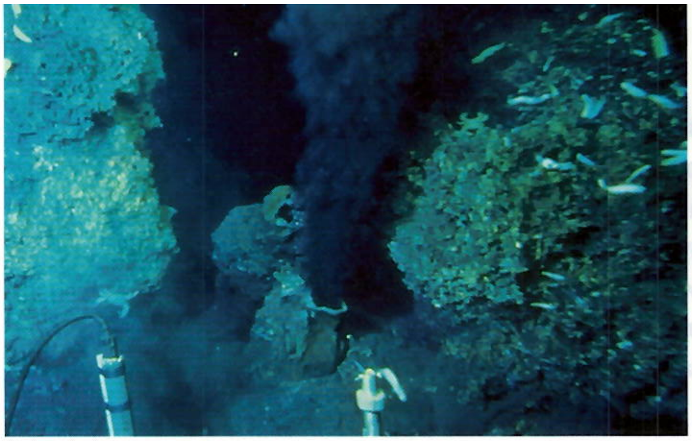


Figure 11 When super-heated water meets cold seawater, minerals and metals precipitate out of the water to form this black smoker.

Hydrothermal Vents

Among the most unusual seafloor discoveries of the past 30 years have been the hydrothermal vents along the oceanic ridge. Here seawater seeps into the ocean floor through cracks in the crust.

The water becomes super-heated and saturated with minerals. Eventually the heated water escapes back into the ocean. When the hot water comes in contact with the surrounding cold water, the minerals precipitate out, giving the water the appearance of black smoke. These geysers of hot water are referred to as black smokers, like the one shown in Figure 11.

At some vents water temperatures of 100°C or higher support communities of organisms found nowhere else in the world. In fact, hundreds of new species have been discovered surrounding these deep-sea habitats since scientists found some vents along the Galápagos Rift in 1977. Chemicals from the vents become food for bacteria. The bacteria produce sugars and other foods that enable them and many other organisms to live in this very unusual and extreme environment. Look at Figure 12 for another example of organisms found along hydrothermal vents.

Figure 12 Tube worms up to 3 meters in length are among the organisms found along hydrothermal vents.

Section 15.2 Assessment

Reviewing Concepts

1. How can marine organisms be classified?
2. What is the difference between plankton and nekton?
3. In which area of the ocean do most benthos organisms live?
4. What factors are used to divide the ocean into marine life zones?
5. Why is the neritic zone rich in life?

Critical Thinking

6. **Inferring** Why do many fish in the abyssal zone locate food through chemical sensing?
7. **Inferring** Organisms that live in the intertidal zone must deal with harsh and changing conditions. What types of adaptations would benefit organisms living in this zone?

Writing in Science

Making Tables Make a table to organize the information about marine life zones presented in this section. Include the basis by which the zone is classified, any subdivisions of the zone, and the characteristics of each zone within the table.

15.3 Oceanic Productivity

Reading Focus

Key Concepts

- What factors influence a region's photosynthetic productivity?
- Describe the transfer efficiency between trophic levels.
- What advantage do organisms in a food web have over those in a food chain?

Vocabulary

- primary productivity
- photosynthesis
- chemosynthesis
- trophic level
- food chain
- food web

Reading Strategy

Identifying Main Ideas Copy the table below. As you read, write the main idea of each topic.

Topic	Main Idea
Productivity in polar oceans	a. ___?___
Productivity in tropical oceans	b. ___?___
Productivity in temperate oceans	c. ___?___

Like other ecosystems on Earth, organisms in the marine environment are interconnected through the web of food production and consumption. Marine producers include phytoplankton, larger algae such as seaweeds, and bacteria. Consumers include crabs, clams, sea stars, fish, dolphins, and whales. Why are some regions of the ocean teeming with life, while other areas seem barren? The answer is related to the amount of primary productivity in various parts of the ocean.

Primary Productivity

Primary productivity is the production of organic compounds from inorganic substances through photosynthesis or chemosynthesis. **Photosynthesis** is the use of light energy to convert water and carbon dioxide into energy-rich glucose molecules. **Chemosynthesis** is the process by which certain microorganisms create organic molecules from inorganic nutrients using chemical energy. Bacteria in hydrothermal vents use hydrogen sulfide as an energy source. Acting as producers, these bacteria support the hydrothermal vent communities.

Two factors influence a region's photosynthetic productivity: the availability of nutrients and the amount of solar radiation, or sunlight. Primary producers need nutrients such as nitrogen, phosphorus, and iron. Lack of nutrients can be a limiting factor in productivity. Thus, the most abundant marine life exists where there are ample nutrients and good sunlight. Oceanic productivity, however, varies dramatically because of the uneven distribution of nutrients throughout the photosynthetic zone and the availability of solar energy due to seasonal changes.

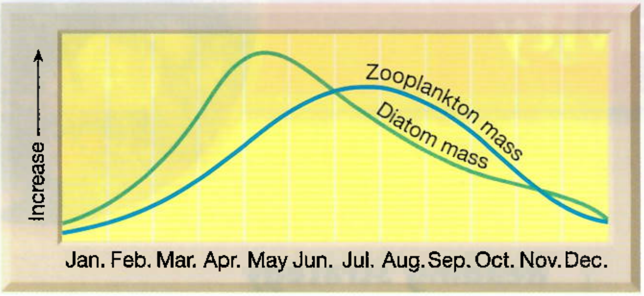


Figure 13 One example of productivity in polar oceans is illustrated by the Barents Sea. **Interpreting Diagrams** ***Describe the relationship between the zooplankton and phytoplankton populations.***

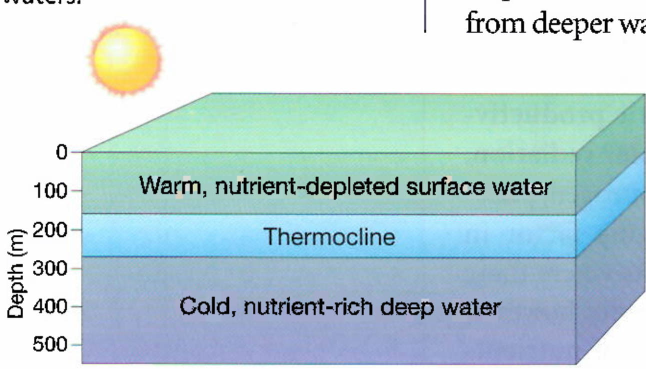
Productivity in Polar Oceans Polar regions such as the Arctic Ocean's Barents Sea, off the northern coast of Europe, experience continuous darkness for about three months of winter and continuous illumination for about three months during summer. Productivity of phytoplankton, mostly single-celled algae called diatoms, peaks there during May. This trend is shown in the graph in Figure 13. During May the sun rises high enough in the sky so that sunlight penetrates deep into the water. As soon as the diatoms develop, zooplankton begin feeding on them. As Figure 13 shows, the zooplankton biomass peaks in June and continues at a relatively high level until winter darkness begins in October.

Recall that density and temperature change very little with depth in polar regions and mixing occurs between surface waters and deeper, nutrient-rich waters. In the summer, however, melting ice creates a thin, low-salinity layer that does not readily mix with the deeper waters. This lack of mixing between water masses is crucial to summer production, because it helps prevent phytoplankton from being carried into deeper, darker waters. Instead, they are concentrated in the sunlit surface waters where they reproduce continuously.

Because of the constant supply of nutrients rising from deeper waters below, high-latitude surface waters typically have high nutrient concentrations. **The availability of solar energy, however, is what limits photosynthetic productivity in polar areas.**

Productivity in Tropical Oceans You may be surprised to learn that productivity is low in tropical regions of the open ocean. Because the sun is more directly overhead, light penetrates much deeper into tropical oceans than in temperate and polar waters. Solar energy also is available year-round. However, productivity is low because a permanent thermocline prevents mixing between surface waters and nutrient-rich deeper waters. Figure 14 shows how water masses are separated in the tropics. The thermocline is a barrier that cuts off the supply of nutrients from deeper waters below. **Productivity in tropical regions is limited by the lack of nutrients.** These areas have so few organisms that they are considered biological deserts.

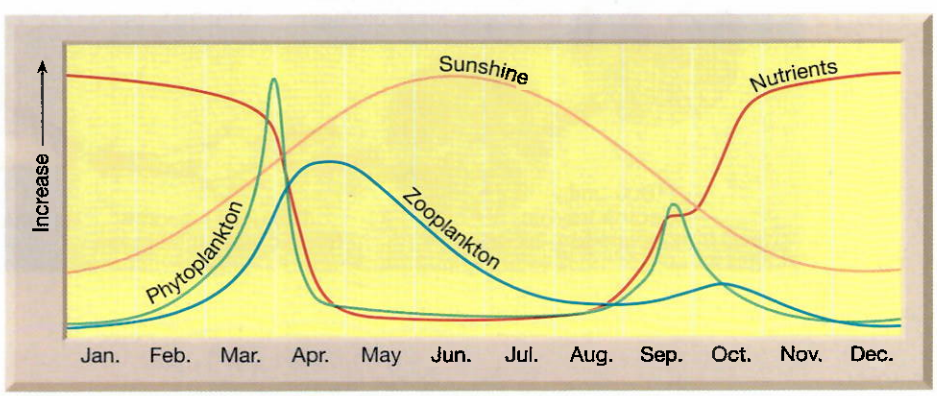
Figure 14 Water Layers in the Tropics The permanent thermocline in tropical oceans prevents the mixing of surface and deep water masses. Productivity is limited by the amount of nutrients in surface waters.



Productivity in Temperate Oceans Productivity is limited by available sunlight in polar regions and by nutrient supply in the tropics. **In temperate regions, which are found at mid-latitudes, a combination of these two limiting factors, sunlight and nutrient supply, controls productivity.** These relationships are shown in Figure 15.

- **Winter** Productivity in temperate oceans is very low during winter, even though nutrient concentration is highest at this time. The reason is that solar energy is limited because days are short, and the sun angle is low. As a result, the depth at which photosynthesis can occur is so shallow that phytoplankton do not grow much.
- **Spring** The sun rises higher in the sky during spring, creating a greater depth at which photosynthesis can occur. A spring bloom of phytoplankton occurs because solar energy and nutrients are available, and a seasonal thermocline develops. The thermocline traps algae in the euphotic zone. This creates a tremendous demand for nutrients in the euphotic zone, so the supply is quickly depleted, causing productivity to decrease sharply. Even though the days are lengthening and sunlight is increasing, productivity during the spring bloom is limited by the lack of nutrients.
- **Summer** The sun rises even higher in the summer, so surface waters in temperate parts of the ocean continue to warm. A strong seasonal thermocline is created that prevents the mixing of surface and deeper waters. So nutrients depleted from surface waters cannot be replaced by those from deeper waters. Throughout summer, the phytoplankton population remains relatively low.
- **Fall** Solar radiation decreases in the fall as the sun moves lower in the sky. Surface temperatures drop and the summer thermocline breaks down. Nutrients return to the surface layer as increased wind strength mixes surface waters with deeper waters. These conditions create a fall bloom of phytoplankton, which is much less dramatic than the spring bloom. The fall bloom is very short-lived because sunlight becomes the limiting factor as winter approaches to repeat the seasonal cycle.

Figure 15 Productivity in Northern Hemisphere, Temperate Oceans The graph shows the relationship among phytoplankton, zooplankton, amount of sunshine, and nutrient levels for surface waters. **Analyzing** ***What happens to phytoplankton in the spring and in the fall?***



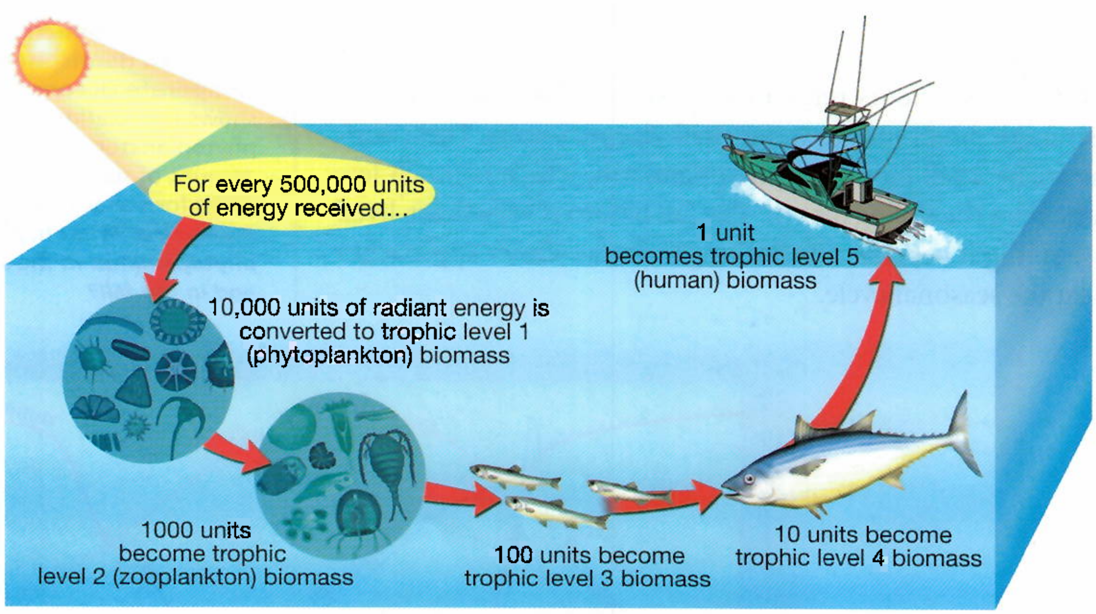
Oceanic Feeding Relationships

Marine algae, plants, bacteria, and bacteria-like organisms are the main oceanic producers. As producers make food available to the consuming animals of the ocean, energy passes from one feeding population to the next. Only a small percentage of the energy taken in at any level is passed on to the next because energy is consumed and lost at each level. As a result, the producers' biomass in the ocean is many times greater than the mass of top consumers, such as sharks or whales.

Trophic Levels Chemical energy stored in the mass of the ocean's algae is transferred to the animal community mostly through feeding. Zooplankton are herbivores (*herba* = grass, *vora* = eat), so they eat algae. Larger herbivores feed on the larger algae and marine plants that grow attached to the ocean bottom near shore. The herbivores are then eaten by carnivores (*carni* = meat, *vora* = eat). Smaller carnivores are eaten by another population of larger carnivores, and so on. Each of these feeding stages is called a **trophic level.**

Transfer Efficiency **The transfer of energy between trophic levels is very inefficient.** The efficiencies of different algal species vary, but the average is only about 2 percent. This means that 2 percent of the light energy absorbed by algae is ultimately changed into food and made available to herbivores. Figure 16 shows the passage of energy between trophic levels through an entire ecosystem—from the solar energy used by phytoplankton to a top-level carnivore, humans.

Figure 16 Energy Flow and Transfer Efficiency in an Ecosystem For every 500,000 units of radiant energy input available to the producers, only one unit of mass is added to the fifth trophic level.
Analyzing ***What is the average transfer efficiency for phytoplankton? What is it for all of the other trophic levels?***



Food Chains and Food Webs A **food chain** is a sequence of organisms through which energy is transferred, starting with the primary producer. A herbivore eats the producer, then one or more carnivores eats the herbivore. The chain finally culminates with the "top carnivore," which is not usually preyed upon by any other organism.

Figure 17A shows a simple food chain. Feeding relationships are rarely as simple as this food chain suggests. More often, top carnivores in a food chain feed on a number of different animals, each of which feeds on a variety of organisms. These feeding relationships form a **food web,** as shown in Figure 17B for North Sea herring.

Animals that feed through a food web rather than a food chain are more likely to survive because they have alternative foods to eat should one of their food sources diminish or disappear. Newfoundland herring, on the other hand, eat only copepods, so the disappearance of copepods would greatly affect their population.

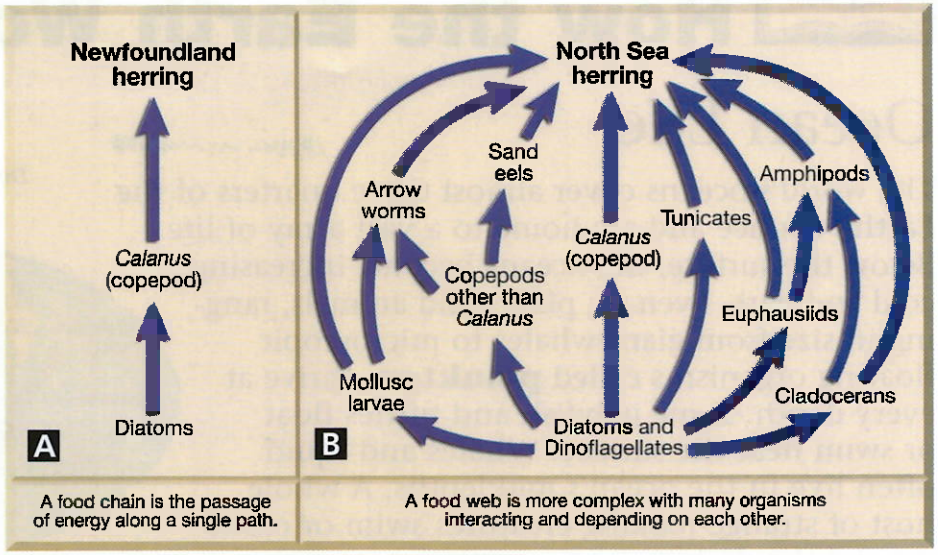


Figure 17 A A food chain is the passage of energy along a single path. **B** A food web is a complex series of feeding relationships with many organisms interacting and depending on each other.

Section 15.3 Assessment

Reviewing Concepts

1. What factors influence a region's photosynthetic productivity?
2. Describe the transfer efficiency between trophic levels.
3. What advantage do organisms in a food web have over those in a food chain?
4. What limits primary productivity in tropical oceans? Why?

Critical Thinking

5. **Comparing and Contrasting** Compare and contrast photosynthesis and chemosynthesis. Give examples of organisms that undergo each process.
6. **Drawing Conclusions** Explain why producers are always the first tropic level in a food chain or food web.

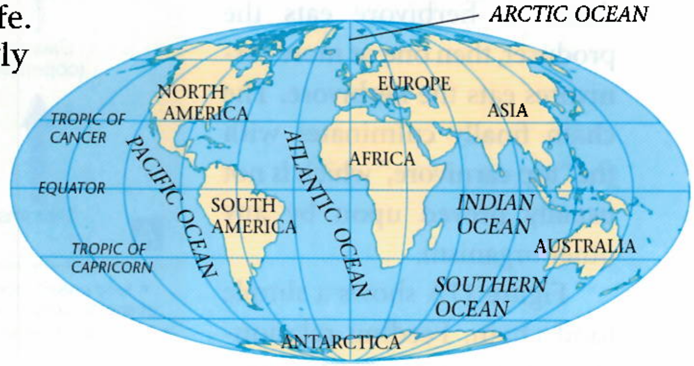
Math Practice

7. If 700,000 energy units are received by phytoplankton in the ocean surface, how many energy units will reach a consumer that is on the fourth trophic level of a food chain?

Ocean Life

The world's oceans cover almost three quarters of the Earth's surface and are home to a vast array of life. Below the surface, the oceans become increasingly cold and dark. Even so, plants and animals, ranging in size from giant whales to microscopic floating organisms called **plankton,** thrive at every depth. Some jellyfish and turtles float or swim near the surface. Whales and squid often live in the ocean's middepths. A whole host of strange-looking creatures swim or crawl around the darkest ocean depths.

Distribution of world's major oceans

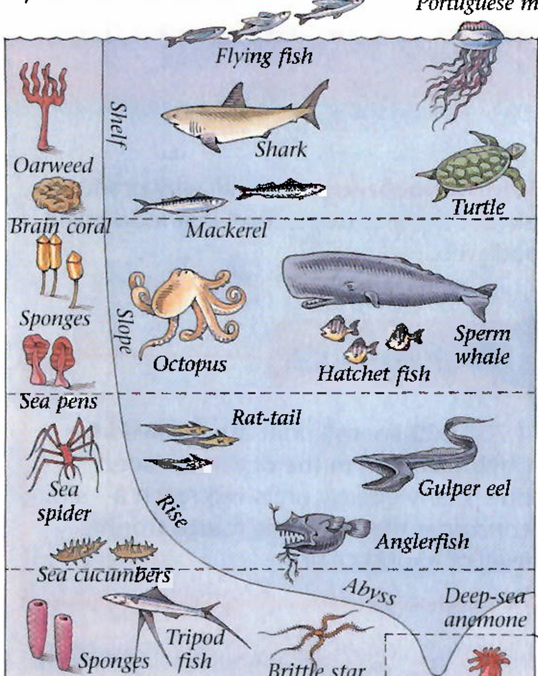


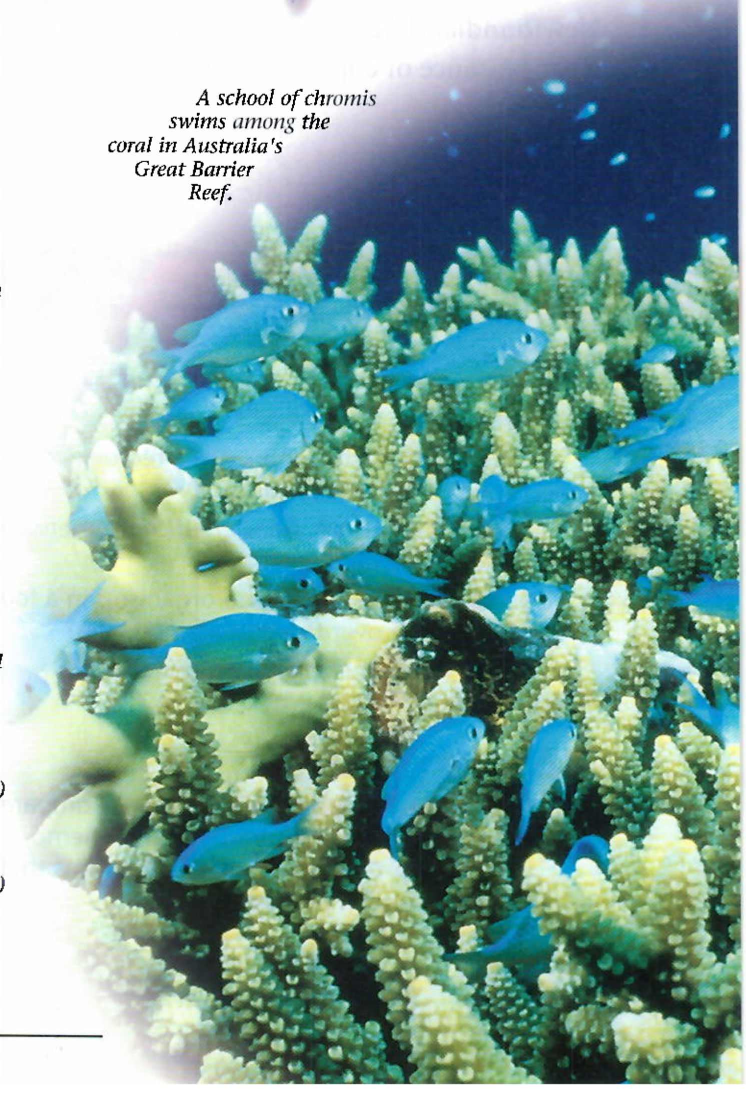
BIOLUMINESCENCE
Some fish have special organs called photophores that give off a glow. In this process, called **bioluminescence,** fish use the light to recognize members of their own species or as lures for attracting prey.


Black snaggletooth fish

VERTICAL ZONES
Oceanographers divide the oceans into zones based on depth. Each zone is home to living things that are adapted to survive at that depth. For example, deep-water animals cope with darkness, very cold temperatures, and pressures that would crush a human. Some creatures can survive in more than one zone.

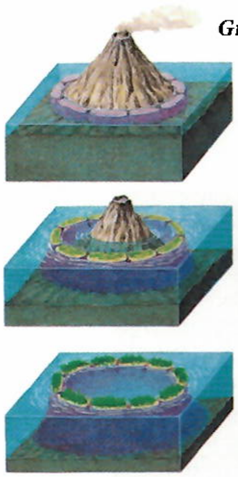
Life in the ocean zones




A school of chromis swims among the coral in Australia's Great Barrier Reef.

CORAL REEFS
A coral is a tubular animal with tentacles. Most corals attach to a surface and build reefs that can rise above sea level around islands and continents. Other reefs are ring-shaped **atolls** around a lagoon of shallow water. Atolls grow over millions of years.

Growth of a coral atoll



1. Coral starts to grow around a volcanic island.

2. The island sinks. Sand collects on the growing coral reef and forms land.

3. The island disappears. Vegetation grows on the atoll that remains.

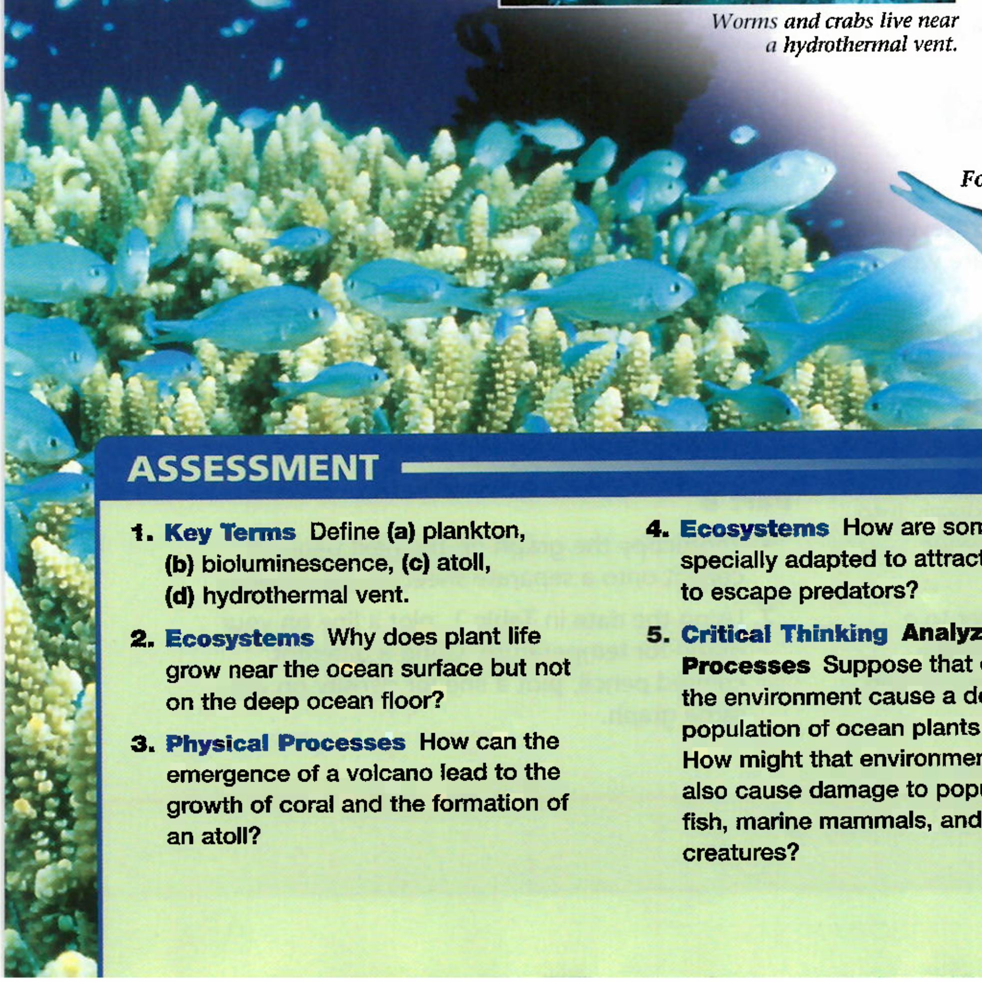
Australian sea lions are marine mammals that breathe air, feed at sea, and breed on land.

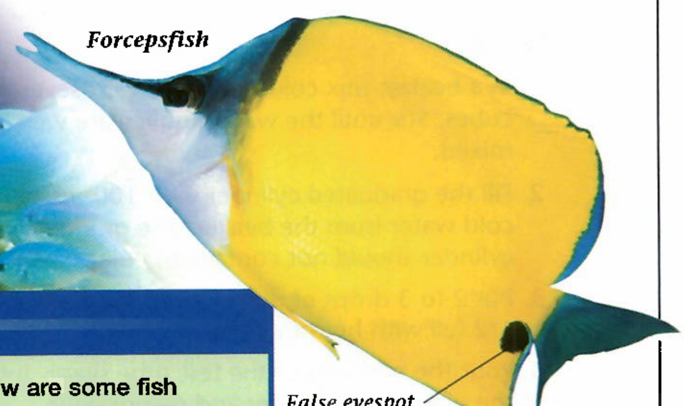
PHOTIC ZONE
Sunlight supports the growth of algae, sea grasses, and other plants on which some sea creatures feed. Marine mammals, squid, fish, and other animals have to be strong swimmers to move in the surface currents. Sea grasses and coral reefs provide food, shelter, and breeding sites for a variety of creatures.

HYDROTHERMAL VENTS
On the deep ocean floor, hot, mineral-rich water gushes from cracks, called **hydrothermal vents.** Bacteria feed on chemicals in this water, forming the basis of a food chain that does not rely on sunlight and plants. Giant tube worms, clams, and blind white crabs live around these vents.

Worms and crabs live near a hydrothermal vent.

Jellyfish can swim, but they are also influenced by ocean currents.





Forcepsfish

False eyespot

BRIGHT COLORS
Many fish have bright colors that attract mates and confuse predators. Complex coloration makes it hard to detect the outline of a fish. Some fish have eyespots, or false eyes. As a predator attacks the false head, the fish darts off in the opposite direction.

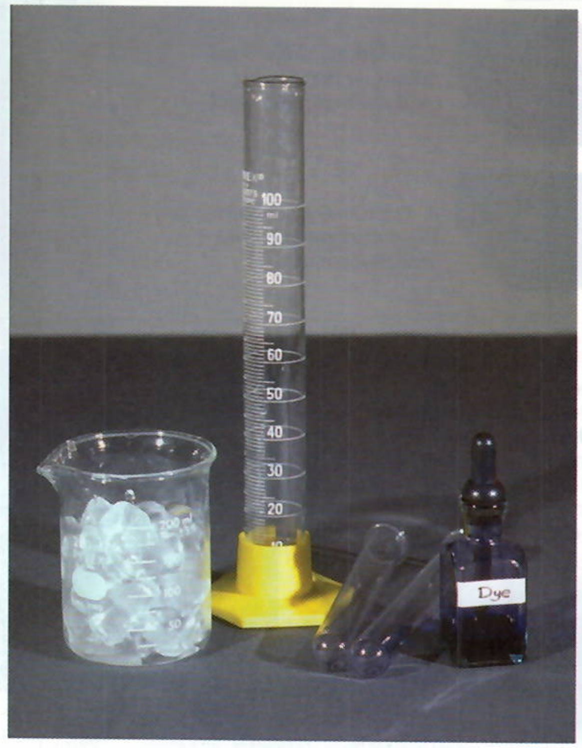
ASSESSMENT

1. **Key Terms** Define **(a)** plankton, **(b)** bioluminescence, **(c)** atoll, **(d)** hydrothermal vent.
2. **Ecosystems** Why does plant life grow near the ocean surface but not on the deep ocean floor?
3. **Physical Processes** How can the emergence of a volcano lead to the growth of coral and the formation of an atoll?
4. **Ecosystems** How are some fish specially adapted to attract prey or to escape predators?
5. **Critical Thinking Analyzing Processes** Suppose that changes in the environment cause a decline in the population of ocean plants and corals. How might that environmental change also cause damage to populations of fish, marine mammals, and other sea creatures?

Exploration Lab

How Does Temperature Affect Water Density?

Ocean water temperatures vary from equator to pole and change with depth. Temperature, like salinity, affects the density of seawater. However, the density of seawater is more sensitive to temperature fluctuations than salinity. Cool surface water, which has a greater density than warm surface water, forms in the polar regions, sinks, and moves toward the tropics.



Problem

How can you determine the effects of temperature on water density?

Materials

- 100 mL graduated cylinders (2)
- test tubes (2)
- beakers (2)
- food coloring or dye
- stirrer
- ice
- tap water
- graph paper
- colored pencils

Skills

Observing, Graphing, Inferring, Drawing Conclusions

Procedure

Part A

1. In a beaker, mix cold tap water with several ice cubes. Stir until the water and ice are well mixed.
2. Fill the graduated cylinder with 100 mL of the cold water from the beaker. The graduated cylinder should not contain any pieces of ice.
3. Put 2 to 3 drops of dye in a test tube and fill it 1/2 full with hot tap water.
4. Pour the contents of the test tube slowly into the graduated cylinder and record your observations.
5. Add a test tube full of cold tap water to a beaker. Mix in 2 to 3 drops of dye and a handful of ice to the beaker. Stir the solution thoroughly.
6. Fill the test tube 1/2 full of the solution from Step 5. Do not allow any ice into the test tube.
7. Fill the second graduated cylinder with 100 mL of hot tap water.
8. Pour the test tube of cold liquid slowly into the cylinder of hot water. Record your observations.
9. Clean the glassware and return it along with other materials to your teacher.

Part B

1. Photocopy the graph on the next page or copy it onto a separate sheet of graph paper.
2. Using the data in Table 1, plot a line on your graph for temperature. Using a different colored pencil, plot a line for density on the same graph.

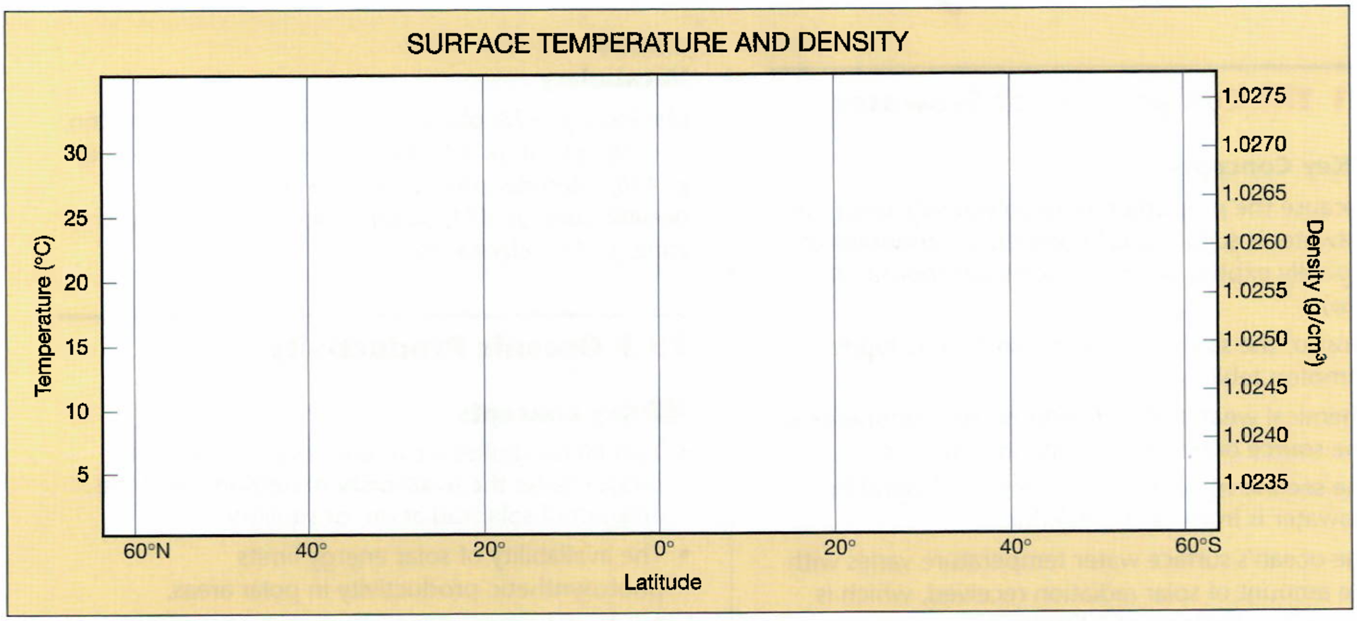


Table 1 Idealized Ocean Surface Water Temperatures and Densities at Various Latitudes

Latitude	Surface Temperature (C°)	Surface Density (g/cm³)
60°N	5	1.0258
40°N	13	1.0259
20°N	24	1.0237
0°	27	1.0238
20°S	24	1.0241
40°S	15	1.0261
60°S	2	1.0272

Analyze and Conclude

1. **Observing** What differences did you observe in the behavior of the water samples from Part A and Part B? Which water sample was the most dense in each experiment?
2. **Inferring** How does temperature affect the density of water?
3. **Drawing Conclusions** If two water samples of equal mass had equal salinities, which sample would be more dense: Water Sample A, which has a temperature of 25°C or water Sample B, which has a temperature of 14°C?
4. **Interpreting Diagrams** Describe the density and temperature characteristics of water in equatorial regions. Compare these characteristics to water found in polar regions.
5. **Inferring** What is the reason that higher average surface densities are found in the Southern Hemisphere?

CHAPTER 15

Study Guide

15.1 The Composition of Seawater

Key Concepts

- Because the proportion of dissolved substances in seawater is such a small number, oceanographers typically express salinity in parts per thousand (‰).
- Most of the salt in seawater is sodium chloride—common table salt.
- Chemical weathering of rocks on the continents is one source of elements found in seawater.
- The second major source of elements found in seawater is from Earth's interior.
- The ocean's surface water temperature varies with the amount of solar radiation received, which is primarily a function of latitude.
- Seawater density is influenced by two main factors: salinity and temperature.
- Oceanographers generally recognize a three-layered structure in most parts of the open ocean: a shallow surface mixed zone, a transition zone, and a deep zone.

Vocabulary

salinity, *p. 422*; thermocline, *p. 424*; density, *p. 425*; pycnocline, *p. 426*; mixed zone, *p. 426*

15.2 The Diversity of Ocean Life

Key Concepts

- Marine organisms can be classified according to where they live and how they move.
- Plankton include all organisms—algae, animals, and bacteria—that drift with ocean currents.
- Nekton include all animals capable of moving independently of the ocean currents, by swimming or other means of propulsion.
- The term *benthos* describes organisms living on or in the ocean bottom.
- Three factors are used to divide the ocean into distinct marine life zones: the availability of sunlight, the distance from shore, and the water depth.

Vocabulary

plankton, *p. 428*; phytoplankton, *p. 429*; zooplankton, *p. 429*; nekton, *p. 429*; benthos, *p. 429*; photic zone, *p. 430*; intertidal zone, *p. 431*; neritic zone, *p. 431*; oceanic zone, *p. 431*; pelagic zone, *p. 431*; benthic zone, *p. 431*; abyssal zone, *p. 431*

15.3 Oceanic Productivity

Key Concepts

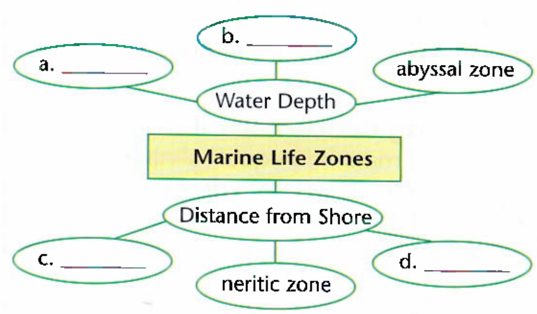
- Two factors influence a region's photosynthetic productivity: the availability of nutrients and the amount of solar radiation, or sunlight.
- The availability of solar energy limits photosynthetic productivity in polar areas.
- Productivity in tropical regions is limited by the lack of nutrients.
- In temperate regions, which are found at mid-latitudes, a combination of these two limiting factors, sunlight and nutrient supply, controls productivity.
- The transfer of energy between trophic levels is very inefficient.
- Animals that feed through a food web rather than a food chain are more likely to survive because they have alternative foods to eat should one of their food sources diminish in quantity or even disappear.

Vocabulary

primary productivity, *p. 433*, photosynthesis, *p. 433*, chemosynthesis, *p. 433*, trophic level, *p. 436*, food chain, *p. 437*, food web, *p. 437*

Thinking Visually

Web Diagram Use the information in the chapter to complete the web diagram on marine life zones.



CHAPTER 15 Assessment

Interactive textbook with assessment at PHSchool.com

Reviewing Content

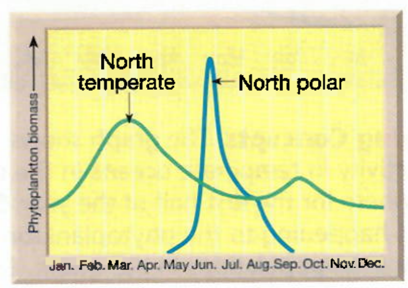
Choose the letter that best answers the question or completes the statement.

1. The most abundant salt in seawater is
   a. calcium chloride. b. magnesium chloride.
   c. sodium chloride. d. sodium fluoride.
2. Which process does NOT lead to a decrease in the salinity of seawater?
   a. runoff from land b. precipitation
   c. evaporation d. sea ice melting
3. Which term refers to the layer of water in which there is a rapid change of temperature with depth in the ocean?
   a. pycnocline b. abyssal zone
   c. thermocline d. isothermal line
4. Which is NOT a zone in the three-layered structure of the ocean according to density?
   a. mixed zone b. deep zone
   c. transition zone d. intertidal zone
5. Organisms that drift with ocean currents are
   a. nekton. b. plankton.
   c. neritic. d. pelagic.
6. Which term describes the upper part of the ocean into which sunlight penetrates?
   a. neritic zone b. intertidal zone
   c. oceanic zone d. photic zone
7. Phytoplankton are usually found in the
   a. benthic zone. b. photic zone.
   c. abyssal zone. d. aphotic zone.
8. The use of light energy by organisms to convert water and carbon dioxide into organic molecules is
   a. chemosynthesis. b. decomposition.
   c. photosynthesis. d. consumption.
9. During which season does primary productivity reach its peak in polar oceans?
   a. spring b. summer
   c. fall d. winter
10. In temperate oceans, primary productivity is limited by
    a. nutrients and oxygen concentration.
    b. nutrients and water temperature.
    c. sunlight and oxygen concentration.
    d. sunlight and nutrients.

Understanding Concepts

11. Why is salinity expressed in parts per thousand instead of percent?
12. What is the principal source of water in oceans? Why do scientists reach this conclusion?
13. Explain how the salinity of water in polar regions varies seasonally.
14. What is the range of salinity for surface waters in the open ocean?
15. Is there a thermocline present in high-latitude ocean waters? Why or why not?
16. Compare and contrast phytoplankton and zooplankton.
17. What factors may affect the depth of the photic zone in any given area of the ocean?
18. What is the oceanic zone? What limits the amount of production in the oceanic zone?
19. What is the difference between the pelagic zone and the benthic zone?
20. How does the permanent thermocline in tropical oceans affect primary productivity in those areas?

Copy the diagram onto a separate sheet of paper and use it to answer Questions 21 and 22.



21. Draw a line on the graph that correctly represents the productivity of tropical oceans year-round.
22. Draw a line on the graph that represents the changes in zooplankton population in north temperate oceans throughout the course of a year.
23. What is the difference between a food chain and a food web?

Assessment *continued*

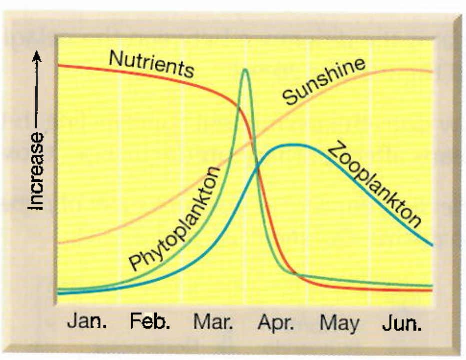
Critical Thinking

24. **Analyzing** In the Red Sea, evaporation values are higher than the values of precipitation and river runoff, particularly in summer months. Do you think that the salinity of the water here is higher or lower than average ocean water salinity? Why?

25. **Drawing Conclusions** Water Mass A is 2°C with a salinity of 34.50‰. Water Mass B is 2°C with a salinity of 34.00‰. Water Mass C is 2°C with a salinity of 34.78‰. Order the water masses from lowest density to highest density. Which water mass will be nearest the surface? Which will be closest to the bottom?

26. **Relating Cause and Effect** Explain how the phytoplankton productivity in polar waters is related to the fact that density and temperature change very little with depth in polar waters.

Use the figure below to answer Questions 27–29.



27. **Applying Concepts** The graph shows the productivity in temperate oceans in the northern hemisphere for the first half of the year. Describe what is happening to the phytoplankton and zooplankton populations in the graph. Explain what factors are affecting productivity.

28. **Inferring** Describe what the graph would look like if it were extended through December. How is it different than the January through June portion?

29. **Drawing Conclusions** How would this graph be different if it were for a temperate ocean in the southern hemisphere?

Concepts in Action

Use the table below to answer Questions 30 and 31.

Depth (m)	Temperature (°C)
0	23
200	22.5
400	20
600	14
800	8
1000	5
1200	4.5
1400	4.5
1600	4

30. **Interpreting Data** An oceanographer records the following temperature data for an area of ocean water. Graph the data on a sheet of graph paper. What feature exists between 400 and 1200 meters?

31. **Applying Concepts** For which area of the world oceans would this temperature variation with depth be present? What processes cause this to occur?

32. **Formulating Hypotheses** It has been observed that some species of zooplankton migrate vertically in ocean water. They spend the daylight hours at deeper depths of about 200 meters and at night move to the surface. Formulate a hypothesis that might explain this behavior.

Performance-Based Assessment

Designing Equipment Imagine you have been asked to collect marine plankton samples from surface waters near the coast. Recall that many plankton are microscopic or nearly so and that by definition, plankton drift with currents. Design a piece of equipment that will allow you to collect the plankton so that they can be brought to the lab and examined under a microscope. Include the materials you will use to construct the equipment, a drawing of it, and an explanation of how it should be used in the field.

Standardized Test Prep

Test-Taking Tip

Watch for Qualifiers
The words *best*, *least*, and *greatest* are examples of qualifiers. If a question contains a qualifier, more than one answer will contain correct information. However, only one answer will be complete and correct for the question asked. Look at the question below. Eliminate any answers that are clearly incorrect. Then choose the remaining answer that offers the best explanation for the question asked.

Which factor has the *greatest* influence on the density of surface water in the ocean?
(A) temperature
(B) pressure
(C) salinity
(D) oxygen

(Answer: A)

Choose the letter that best answers the question or completes the statement.

1. The total amount of solid material dissolved in water is known as
   (A) sediment load.
   (B) salinity.
   (C) total dissolved solids.
   (D) density.

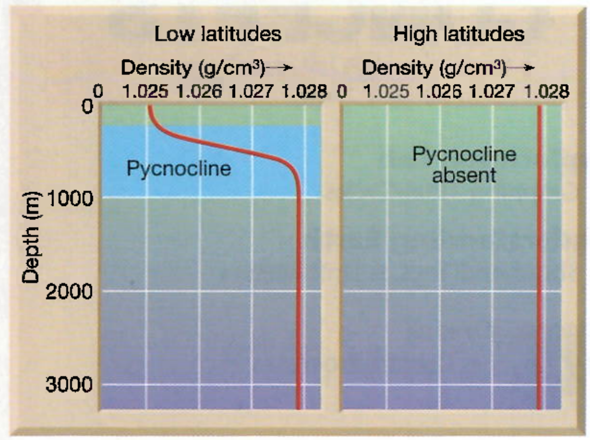
2. Thermoclines in oceans are *best* developed at
   (A) lower latitudes.
   (B) higher latitudes.
   (C) both high and low latitudes.
   (D) regions close to continents.

3. Which term describes a rapid change in density with depth?
   (A) thermocline
   (B) halocline
   (C) isocline
   (D) pycnocline

4. Animals capable of moving independently of ocean currents, by swimming or other means of propulsion are called
   (A) benthos.
   (B) plankton.
   (C) nekton.
   (D) pelagic.

5. During which season is productivity the *greatest* in temperate waters?
   (A) spring
   (B) summer
   (C) fall
   (D) winter

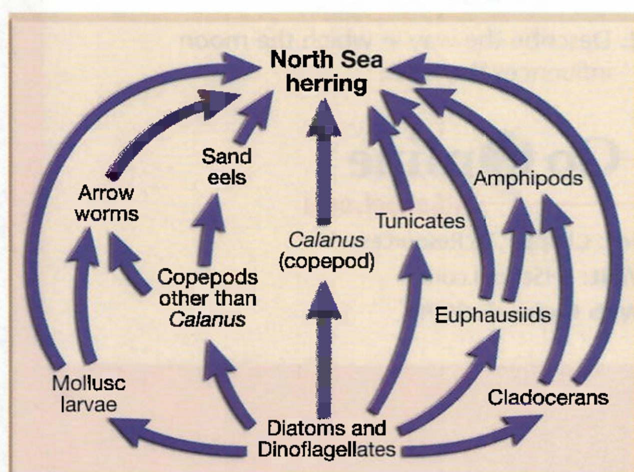
Use the diagram below to answer Questions 6 and 7.



6. Explain what influences the formation of the pycnocline at low latitudes.

7. Why is the pycnocline absent at high latitudes?

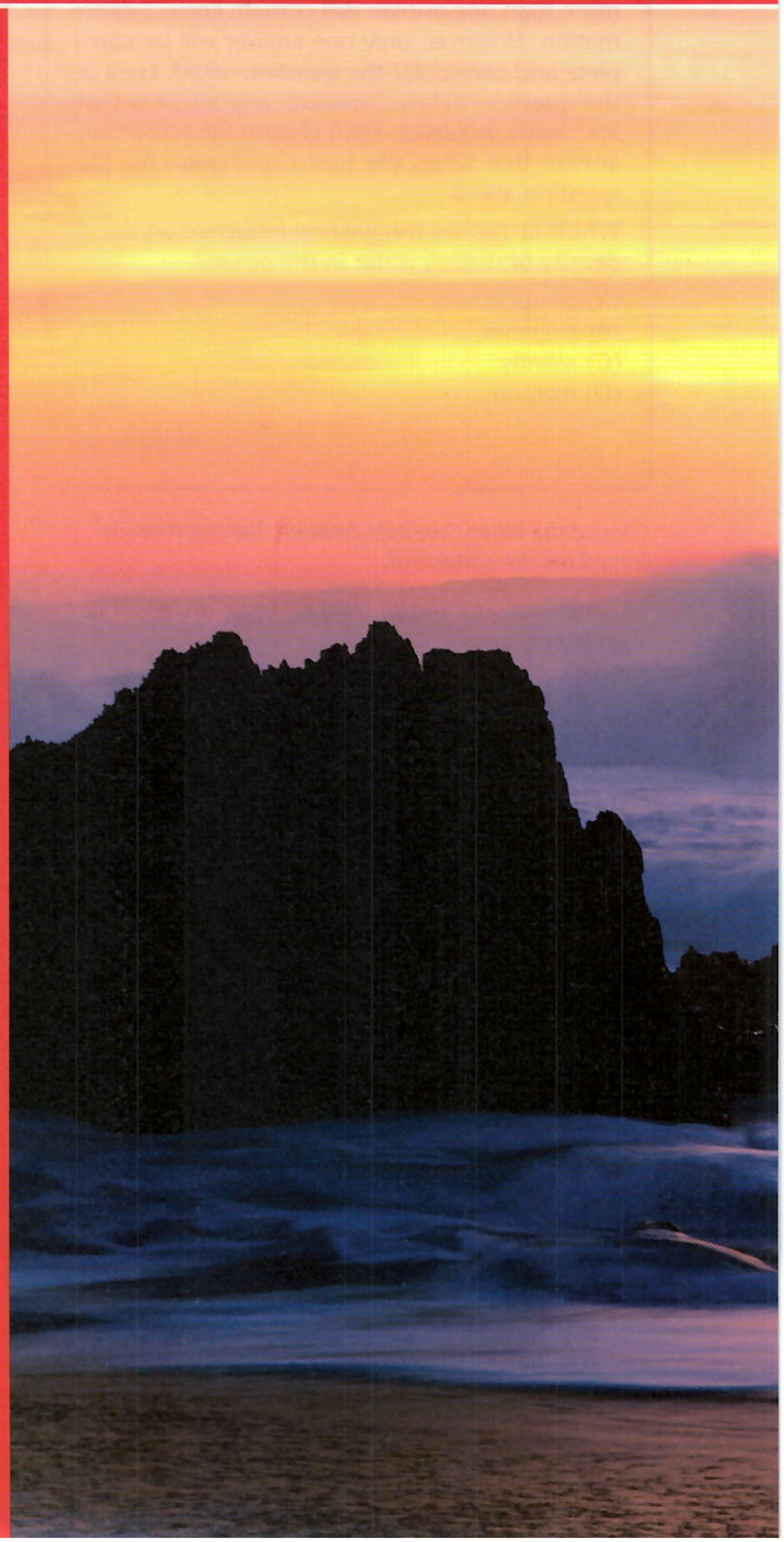
8. What changes would occur to the food web below if the population of copepods was killed by a bacterial disease?



A food web is more complex with many organisms interacting and depending on each other.

CHAPTER

16 The Dynamic Ocean



CONCEPTS in Action

Exploration Lab
Graphing Tidal Cycles

Understanding Earth
Shoes and Toys as Drift Meters

GEODe EARTH SCIENCE
Oceans
↳ Coastal Processes

Discovery Channel School **Video Field Trip**
Waves and Tides

Take a surfing field trip with Discovery Channel and learn about waves, swells, and tides. Answer the following questions after watching the video.

1. How are waves created?
2. Describe the way in which the moon influences the tides.

Go Online PHSchool.com

For: Chapter 16 Resources
Visit: PHSchool.com
Web Code: cjk-9999

Waves break along California's rocky Big Sur coast. ▶

Chapter Preview

Inquiry Activity

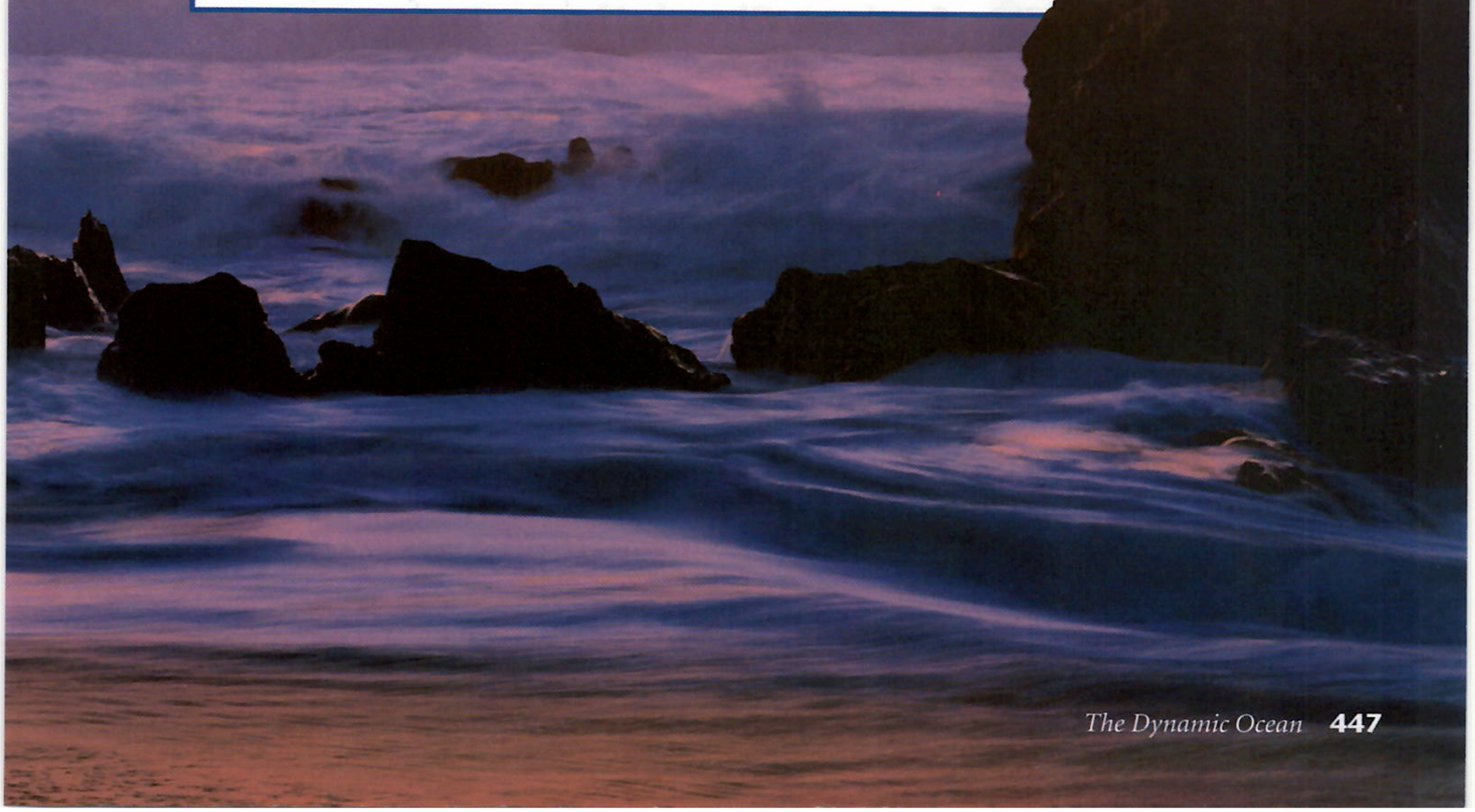
How Do Ocean Waves Form?

Procedure

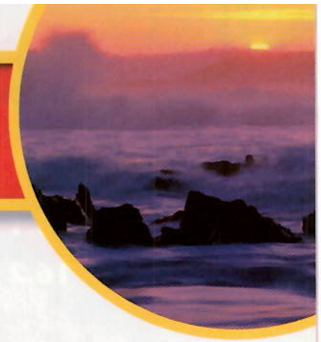
1. Fill a rectangular, clear, plastic container with water to within about 3 cm of the top of the container.
2. Place a fan next to the container, aiming the flow of air toward the water. **CAUTION:** *Make sure the cord and the fan do not come in contact with the water in the container.*
3. Turn the fan on low power for 2–3 minutes. Observe what effect this 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. **Inferring** Where does the energy to produce most ocean waves come from?
2. **Drawing Conclusions** What is the relationship between the speed of the wind and the size of a wave?



16.1 Ocean Circulation



Reading Focus

Key Concepts

- 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

Identifying Main Ideas Copy and expand the table below. 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. ___?___

Figure 1 Wind not only creates waves, but it also provides the force that drives the ocean's surface circulation.

Ocean water is constantly in motion, powered by many different forces. Winds, for example, generate surface currents, which influence coastal climate. Winds also produce waves like the ones shown in Figure 1. Some waves carry energy from powerful storms to distant shores, where their impact erodes the land. In some areas, density differences create deep-ocean circulation. This circulation is important for ocean mixing and recycling nutrients.

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 creation of these currents can be simple or complex. In all cases, however, the currents that are generated involve water masses in motion.

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. Such water movements are responses to local or seasonal influences. Other surface currents 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.

Ocean Surface Currents

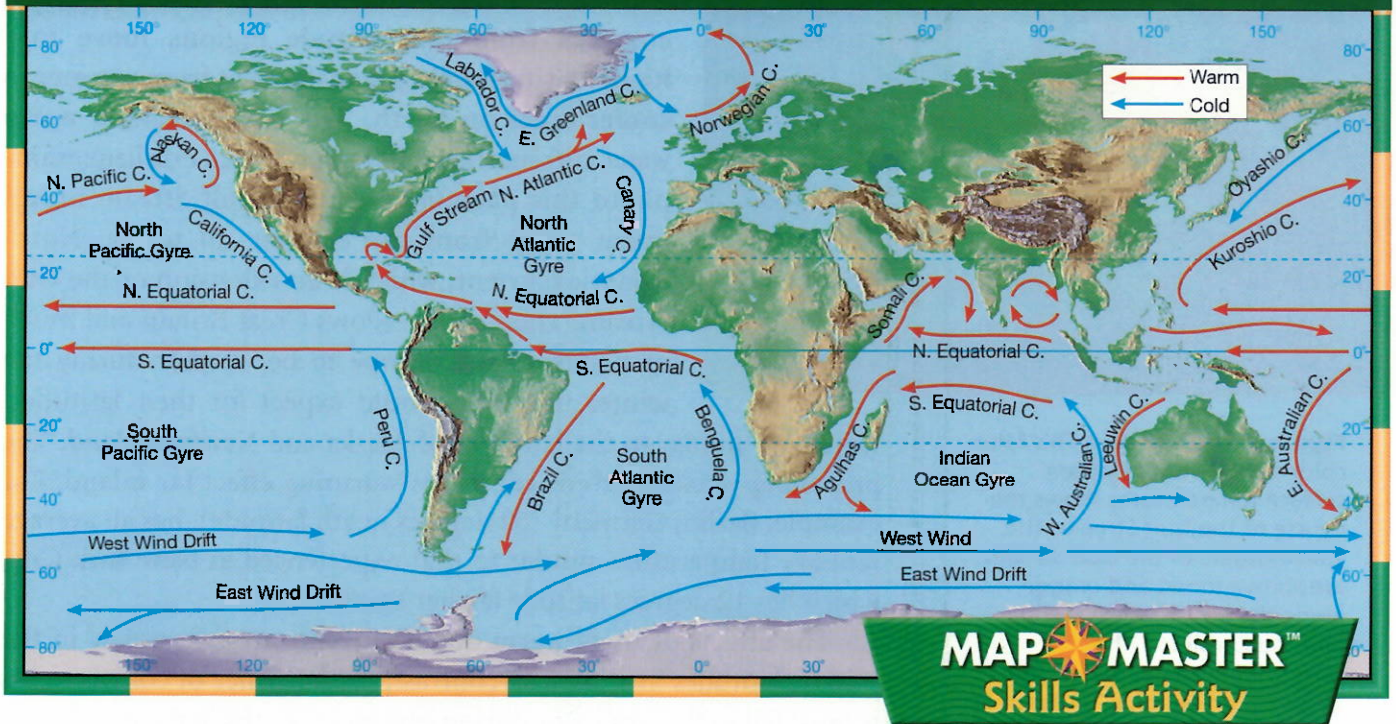


Figure 2
The ocean's circulation is organized into five major gyres, or circular current systems. The West Wind Drift flows around the continent of Antarctica.

Movement

Locate Which currents make up the North Atlantic Gyre?

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

Drawing Conclusions Why is there not another comparable current that encircles Earth at the same latitude in the Northern Hemisphere?

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. Find these gyres in Figure 2.

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 effect** 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 to the left in the Southern Hemisphere.** As a consequence, gyres flow in opposite directions in the two different hemispheres.

Four main currents generally exist within each gyre. For example, the North Pacific Gyre consists of the North Equatorial Current, the Kuroshio Current, the North Pacific Current, and the California Current. The tracking of floating objects that are released into the ocean reveals that it takes about six years for the objects to go all the way around the loop.

Reading Checkpoint ***Why do gyres in the Northern Hemisphere flow in the opposite direction of gyres in the Southern Hemisphere?***

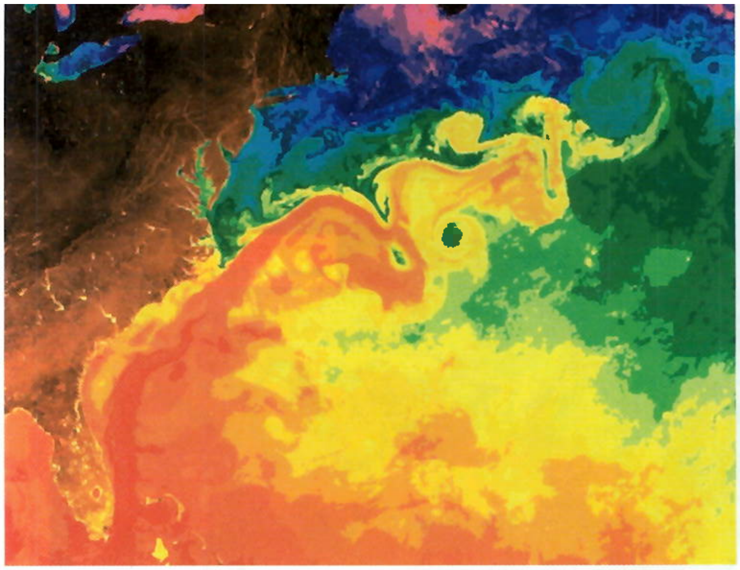


Figure 3 **Gulf Stream** This false-color satellite image of sea surface temperatures shows the course of the Gulf Stream. The warm waters of the Gulf Stream are shown in red and orange along the east coast of Florida and the Carolinas. The surrounding colder waters are shown in green, blue, and purple. 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. **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 up to the North Atlantic Current, which is an extension of the Gulf Stream. This current allows Great Britain and much of northwestern Europe to be warmer during the winter than one would expect for their latitudes, which are similar to the latitudes of 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 at New York City, which lies 12 degrees latitude farther south.

The effects of these warm ocean currents are felt mostly in the middle latitudes in 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 also 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 less heat exists. Ocean water movement accounts for about a quarter of this heat transport. Winds transport the remaining three-quarters.

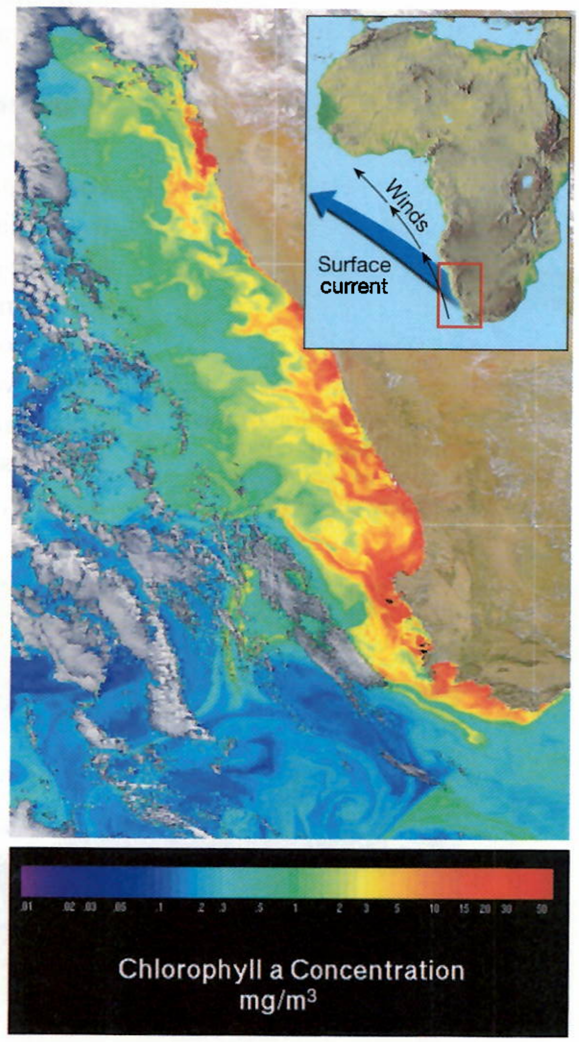
Upwelling In addition to producing surface currents, winds can also cause vertical water movements. **Upwelling** is the rising of cold water from deeper layers to replace warmer surface water. Upwelling is a common wind-induced vertical movement. One type of upwelling, called coastal upwelling, is most characteristic along the west coasts of continents, most notably along California, western South America, and West Africa.

Coastal 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 surface layer moves away from the coast, it is replaced by water that "upwells" from below the surface. This slow upward movement of water from depths of 50 to 300 meters brings water that is cooler than the original surface water and results in lower surface water temperatures near the shore.

Upwelling brings greater concentrations of 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 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.

Density Currents **Density currents** are vertical currents of ocean water that result from density differences among water masses. 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 water include evaporation and the formation of sea ice. Processes that decrease the salinity of water include precipitation, runoff from 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.

High Latitudes Most water involved in deep-ocean density currents begins in high latitudes at the surface. In these regions, surface water becomes cold, and its salinity increases as sea ice forms. When this water becomes dense enough, it sinks, initiating deep-ocean density currents. Once this water sinks, it is removed from the physical processes that increased its density in the first 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 5 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.
Drawing Conclusions ***How does this process lead to the formation of a density current?***

Near Antarctica, surface conditions create the highest density water in the world. This cold, salty water slowly sinks to the sea floor, where it 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.

Evaporation Density currents can also result from increased salinity of ocean water due to evaporation. In the Mediterranean Sea conditions exist that lead to the formation of a dense water mass at the surface that sinks and eventually flows into the Atlantic Ocean. Climate conditions in the eastern Mediterranean include a dry northwest wind and sunny days. These conditions lead to an annual excess of evaporation compared to the amount of precipitation. When seawater evaporates, salt is left behind, and the salinity of the remaining water increases. The surface waters of the eastern 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

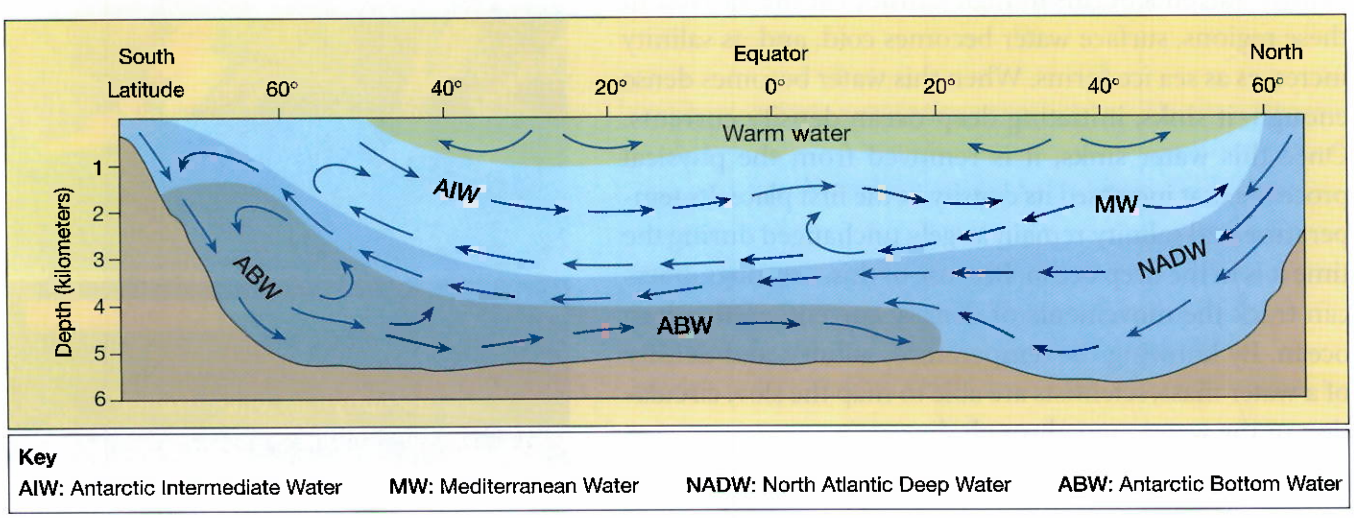


Figure 6 This cross section of the Atlantic Ocean shows the deep-water circulation of water masses formed by density currents.

Ocean. At 38‰, this water is more dense than the Atlantic Ocean surface water at 35‰, so it sinks. This Mediterranean water mass can be tracked as far south as Antarctica. Figure 6 shows some of the different water masses created by density currents in the Atlantic Ocean.

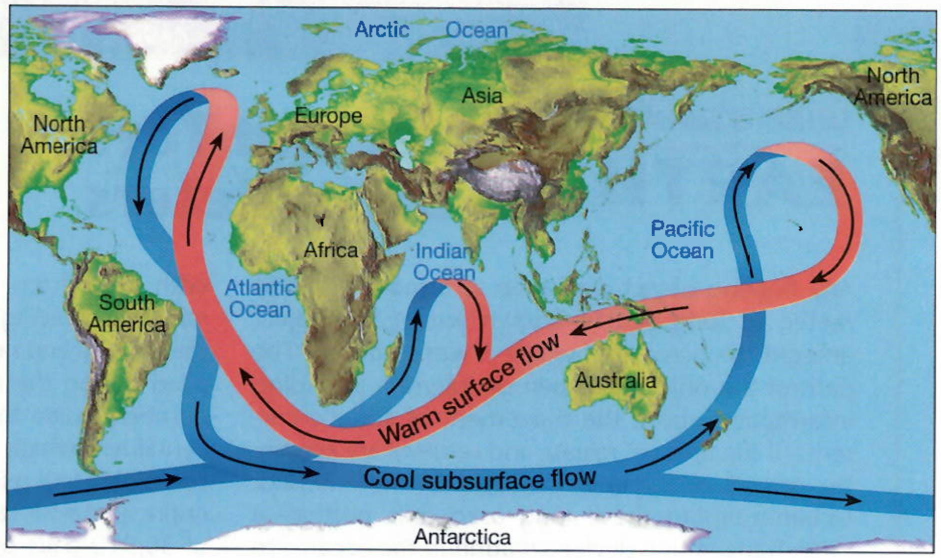


Figure 7 This "conveyor belt" model of ocean circulation shows a warm surface current with an underlying cool current.

A Conveyor Belt A simplified model of ocean circulation is similar to a conveyor belt that travels from the Atlantic Ocean through the Indian and Pacific oceans and back again. Figure 7 shows this conveyor belt model. In this model, 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 to complete the circuit. As this "conveyor belt" moves around the globe, it influences global climate by converting warm water to cold water and releasing heat to the atmosphere.

Section 16.1 Assessment

Reviewing 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?

Thinking Critically

6. **Applying 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. **Inferring** 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

Explanatory Paragraph 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.

understanding EARTH

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 have helped oceanographers advance the understanding of surface circulation in the North Pacific Ocean. In May 1990, the container vessel *Hansa Carrier* was traveling from 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 8. 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.

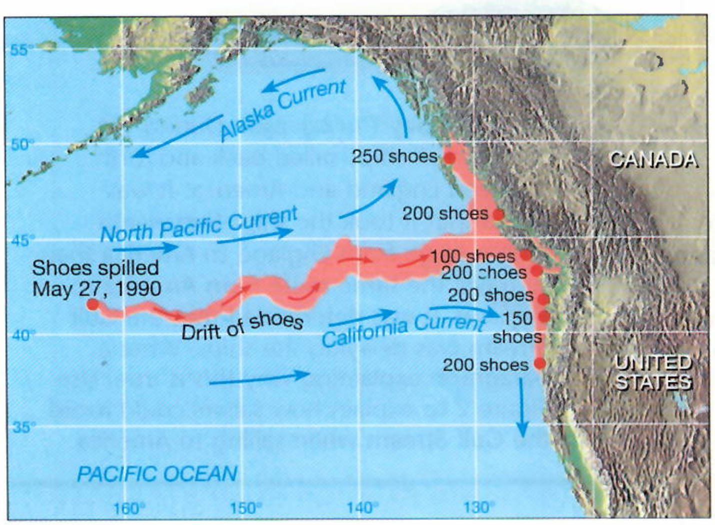


Figure 8 The map shows the path of drifting shoes and recovery locations from a spill in 1990.

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 Lego pieces, and an unidentified number of small plastic doll parts.

16.2 Waves and Tides

Reading Focus

Key Concepts

- 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 force produces tides?

Vocabulary

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

Reading Strategy

Building 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. ___?___

The movement of ocean water is a powerful thing. Waves created by storms release energy when they crash along the shoreline. Sometimes the energy of water movement can be harnessed and used to generate electricity.

Waves

Ocean waves are energy traveling along the boundary between ocean and atmosphere. Waves often transfer energy from a storm far out at sea over distances of several thousand kilometers. That's why even on calm days the ocean still has waves that travel across its surface. The power of waves is most noticeable along the shore, the area between land and sea where waves are constantly rolling in and breaking. Sometimes the waves are low and gentle. Other times waves, like the ones shown in Figure 9, are powerful as they pound the shore. If you make waves by tossing a pebble into a pond, or by splashing in a pool, or by blowing across the surface of a cup of coffee, you are giving 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. In Chapter 24, you will study waves of the electromagnetic spectrum (which includes light). These waves transfer energy without matter as a medium.

Figure 9 The Force of Breaking Waves These waves are slamming into a seawall that has been built at Sea Bright, New Jersey, to protect the nearby electrical lines and houses from the force of the waves.

Q & A

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 10. 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 the **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 fixed 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 where 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, waves generated near Antarctica were tracked as they traveled through the Pacific Ocean basin. After more than 10,000 kilometers, the waves finally expended their energy a week later along the shoreline of the Aleutian Islands of Alaska. The water itself does not travel the entire distance, but the wave does. As a wave travels, the water particles pass the energy along by moving in a circle. This movement, shown in Figure 10, is called circular orbital motion.

Observations of a floating object reveals that it moves not only up and down but also slightly forward and backward with each successive wave.

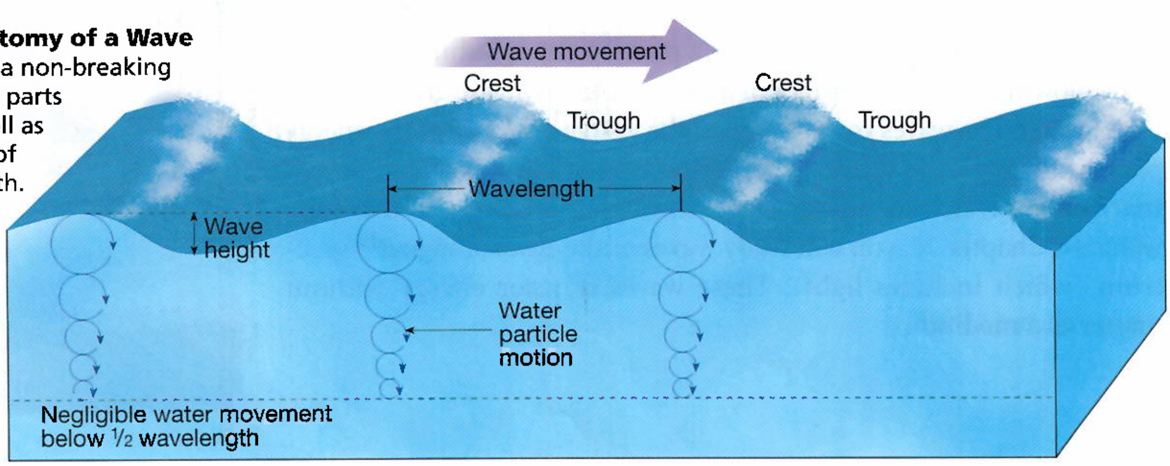


Figure 10 Anatomy of a Wave The diagram of a non-breaking wave shows the parts of a wave as well as the movement of particles at depth.

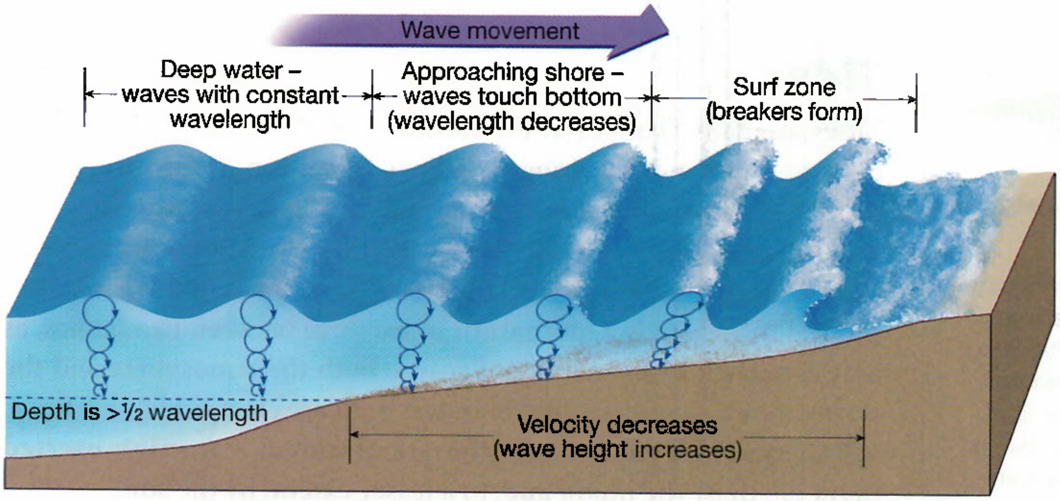


Figure 11 Breaking Waves Changes occur as a wave moves onto shore. As the waves touch bottom, wave speed decreases. The decrease in wave speed results in a decrease in wavelength and an increase in wave height.

This movement results in a circle that returns the object to essentially the same place in the water. **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.**

The energy contributed 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 negligible. The dramatic decrease of wave energy with depth is shown by the rapidly decreasing diameters of water-particle orbits in Figure 10.

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 11 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 the wavelength. As the speed and length of the wave decrease, the wave steadily 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 turbulent 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?*

Go Online SCI LINKS NSTA

For: Links on ocean waves
Visit: www.SciLinks.org
Web Code: cjn-5162

Q&A

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 northern end of Minas Basin, the maximum spring tidal range is about 17 meters. This extreme tidal range leaves boats high and dry during low tide.

Tides

Tides are daily changes in the elevation of the ocean surface. Their rhythmic rise and fall along coastlines have been noted throughout history. Other than waves, they are the easiest ocean movements to observe. Although known for centuries, tides were not well explained until Sir Isaac Newton applied the law of gravitation to them. Newton showed that there is a mutual attractive force between two bodies, as between Earth and the moon. Because both the atmosphere and the ocean are fluids and are free to move, both are changed by this force. **Ocean tides result from the gravitational attraction exerted upon Earth by the moon and, to a lesser extent, by the sun.**

Tide-Causing Force 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.

To illustrate how tides are produced, consider the Earth as a rotating sphere covered to a uniform depth with water. Think about the tide-generating forces that result from the Earth-moon system, ignoring the influence of the sun for now. **The force that produces tides is gravity.** Gravity is the force that attracts Earth and the moon to each other. On the side of Earth closest to the moon, the force of the moon's gravity is greater. At this time, water is pulled in the direction of the moon and produces a tidal bulge. On the side of Earth furthest from the moon, water is pulled away from the direction of the moon and produces an equally large tidal bulge on the side of Earth directly opposite the moon. These idealized tidal bulges are shown in Figure 12.

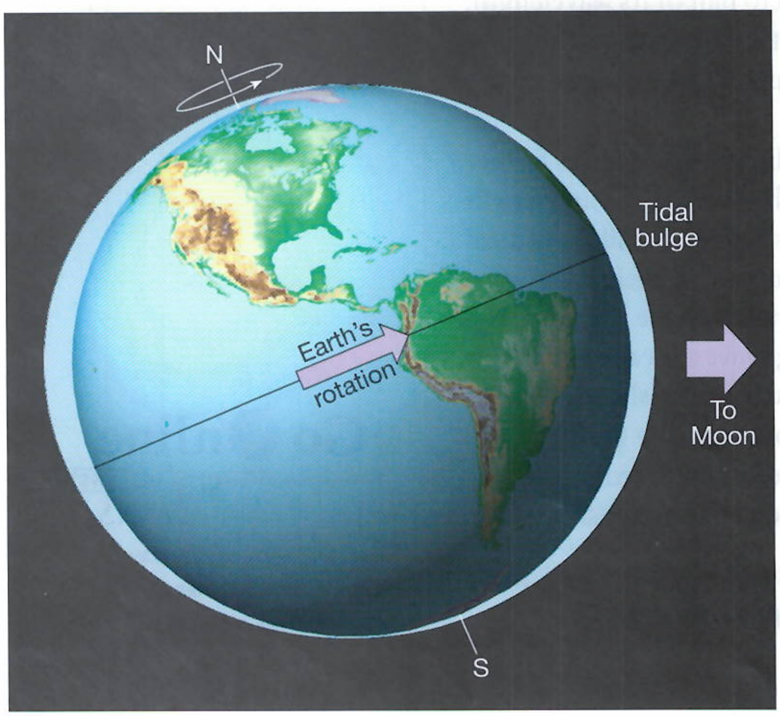


Figure 12 Tidal Bulges on Earth Caused by the Moon **Analyzing** ***What force is involved in causing the tidal bulges?***

Because the position of the moon 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 the 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 intervening troughs between the tidal bulges, the tide falls. Therefore, most places on Earth experience two high tides and two low tides each day.

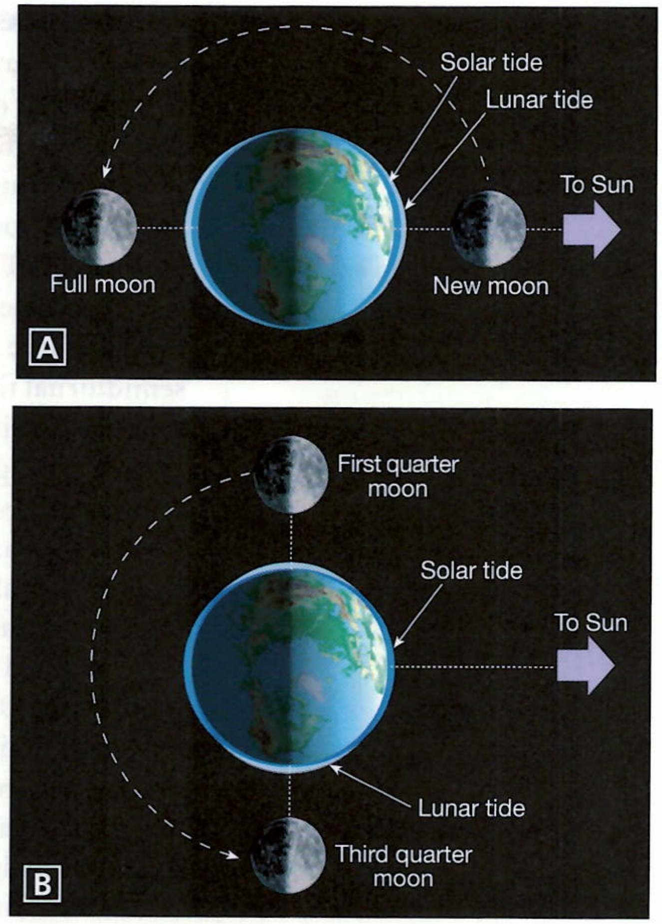


Figure 13 Earth-Moon-Sun Positions and the Tides
A When Earth, moon, and sun are aligned, spring tides are experienced. **B** When Earth, moon, and sun are at right angles to each other, neap tides are experienced.
Describing ***How does the sun influence the formation of spring and neap tides?***

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 on Earth. 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 added together, as shown in Figure 13A. The combined gravity of these two tide-producing bodies causes larger tidal bulges (higher high tides) and larger tidal troughs (lower low tides). This combined gravity produces a large tidal range. The **tidal range** 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 the Earth–moon–sun system. They are experienced during new and full moons. Conversely, at about the time of the first and third quarters of the moon, the gravitational forces of the moon and sun act on Earth at right angles. The sun and moon partially offset the influence of the other, as shown in Figure 13B. 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?***

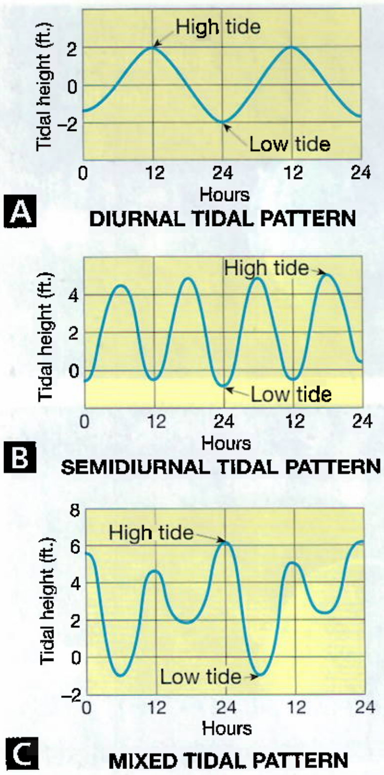


Figure 14 **Tidal patterns**

Tidal Patterns You now know the basic causes and types of tides. However, many factors—including the shape of the coastline, the configuration 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.

Three 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 14A. 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 14B 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 14C, is similar to a semidiurnal pattern except that it is characterized by a large inequality in high water heights, low water heights, or both. In this case, 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.

Section 16.2 Assessment

Reviewing Concepts

1. From where do ocean waves obtain their energy?
2. What three quantities are used to describe 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?

Thinking Critically

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

Math Practice

11. **Calculating** 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

Reading Focus

Key Concepts

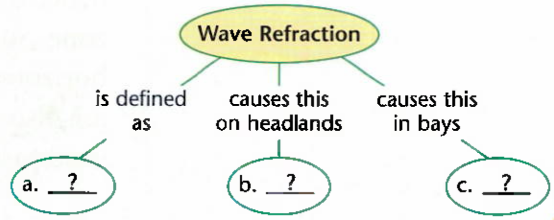
- How are sediments along the shoreline moved?
- How does refraction affect wave action along the shore?
- What do longshore currents do?
- By which processes do shoreline features form?
- What structures can be built to protect a shoreline?
- What is beach nourishment?

Vocabulary

- beach
- wave refraction
- longshore current
- barrier islands

Reading Strategy

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



Beaches and shorelines are constantly undergoing changes as the force of waves and currents act on them. 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. This sediment may be relatively coarse in texture. Some beaches have a significant biological component. For example, most beaches in southern Florida are composed of shell fragments and the remains of organisms that live in coastal waters. Regardless of the composition, the sediment that makes up the beach does not stay in one place. The waves that crash along the shoreline are constantly moving it. Beaches can be thought of as material in transit along the shoreline.

Figure 15 Erosion has undercut this sandstone cliff at Gabriola Island, British Columbia, Canada.

Forces Acting on the Shoreline

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

Wave Impact 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.

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 the waves as they cut horizontally into the land, like the sandstone shown in Figure 15. Waves are also very effective at breaking down rock material and supplying sand to beaches.

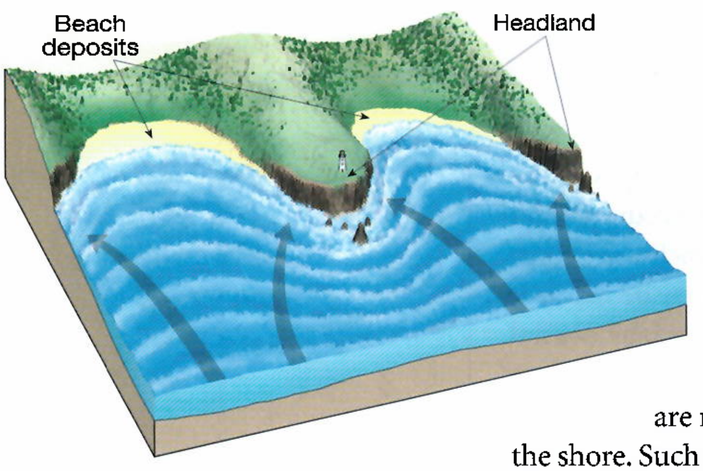


Figure 16 Wave Refraction Waves are refracted as they come into shore. Wave energy is concentrated at the headlands and dispersed in the bays. **Inferring** ***What processes occur as a result of wave refraction on this shoreline?***

Wave Refraction **Wave refraction** is the bending of waves, and it 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.

Waves seldom approach the shore straight on. Rather, most waves move toward the shore at a slight angle. 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 first, 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 regardless of their original orientation.

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. This type of wave action along irregular coastlines is illustrated in Figure 16. Waves reach the shallow water in front of the headland sooner than they do in adjacent 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 of sediments and the formation of sandy beaches.

Reading Checkpoint ***What is wave refraction?***

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 oblique angle to the shoreline. These angled waves produce currents within the surf zone. The currents flow parallel to the shore and move large amounts of sediment along the shore. This type of current is called a **longshore current,** shown in Figure 17.

The water in the surf zone is turbulent. **Turbulence allows longshore currents to easily move the fine suspended sand and to roll larger sand and gravel particles along the bottom.** At Sandy Hook, New Jersey, for example, the quantity of sand transported along the shore over a 48-year period averaged almost 680,000 metric tons annually. For a 10-year period at Oxnard, California, more than 1.4 million metric tons of sediment moved along the shore each year. Longshore currents can change direction because the direction that waves approach the beach changes with the seasons. Nevertheless, longshore currents generally flow southward along both the Atlantic and Pacific shores of the United States.

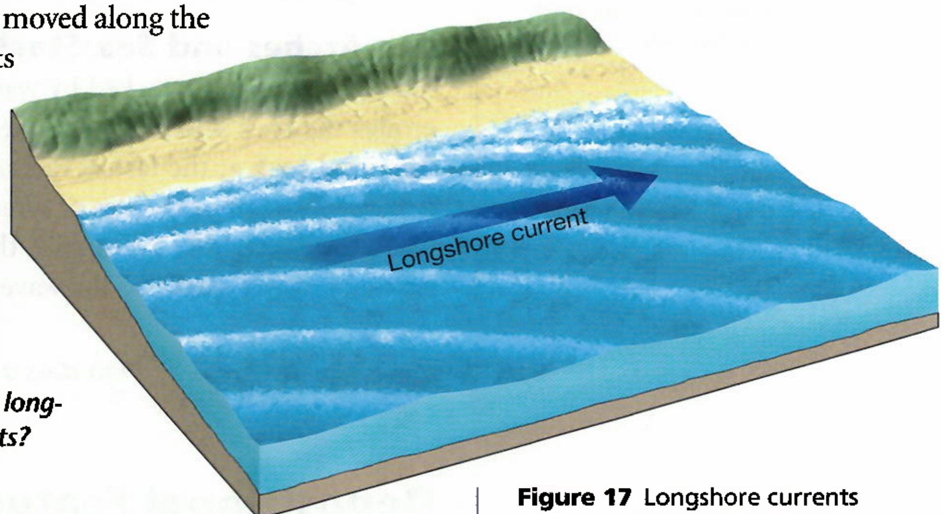


Figure 17 Longshore currents are created by waves breaking at an angle.
Applying Concepts ***Explain how longshore currents can change direction.***

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

Erosional Features

A fascinating assortment of shoreline features can be observed along the world's coastal regions. These shoreline features vary depending on the type of rocks exposed along the shore, the intensity of waves, the nature of coastal currents, and whether the coast is stable, sinking, or rising. **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.**

Many coastal landforms owe their origin to erosional processes. Such 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.

Figure 18 In time, the sea arch will collapse and form a sea stack like the one on the left.

Wave-Cut Cliffs and Platforms Wave-cut cliffs, like the one shown in Figure 20C, 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 retreats. A relatively flat, benchlike surface, called a wave-cut platform, is left behind 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 first, sea caves may form. When two caves on opposite sides of a headland unite, a sea arch like the one in Figure 18 results. Eventually, the arch falls in, leaving an isolated remnant, or sea stack, on the wave-cut platform.

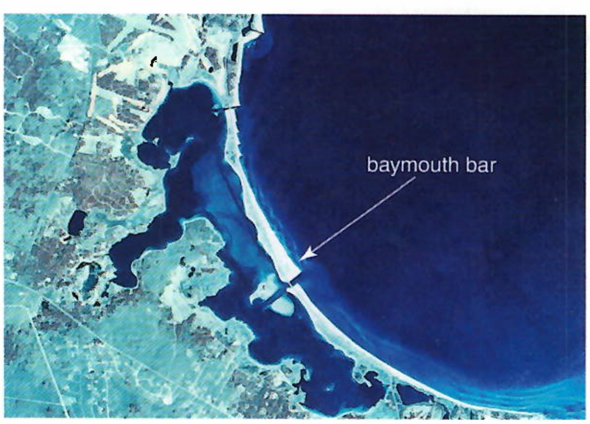
Reading Checkpoint *How does a sea arch form?*

Depositional Features

Recall that a beach is the shore of a body of water that is covered in sand, gravel, or other larger sediments. Sediment eroded from the beach is transported along the shore and deposited in areas where wave energy is low. Such processes produce a variety of depositional features.

Spits, Bars, and Tombolos Where longshore currents and other surf zone currents are active, several features related to the movement of sediment along the shore may develop. As shown in Figure 20B and C, 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 19. Such a feature tends to form across bays where currents are weak. The weak currents allow a spit to extend to the other side and form a baymouth bar. 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. Follow the formation of tombolos and other shoreline features in Figure 20.

Figure 19 This high-altitude image shows a baymouth bar along the coast of Martha's Vineyard, Massachusetts.



Evolution of Shoreline Features

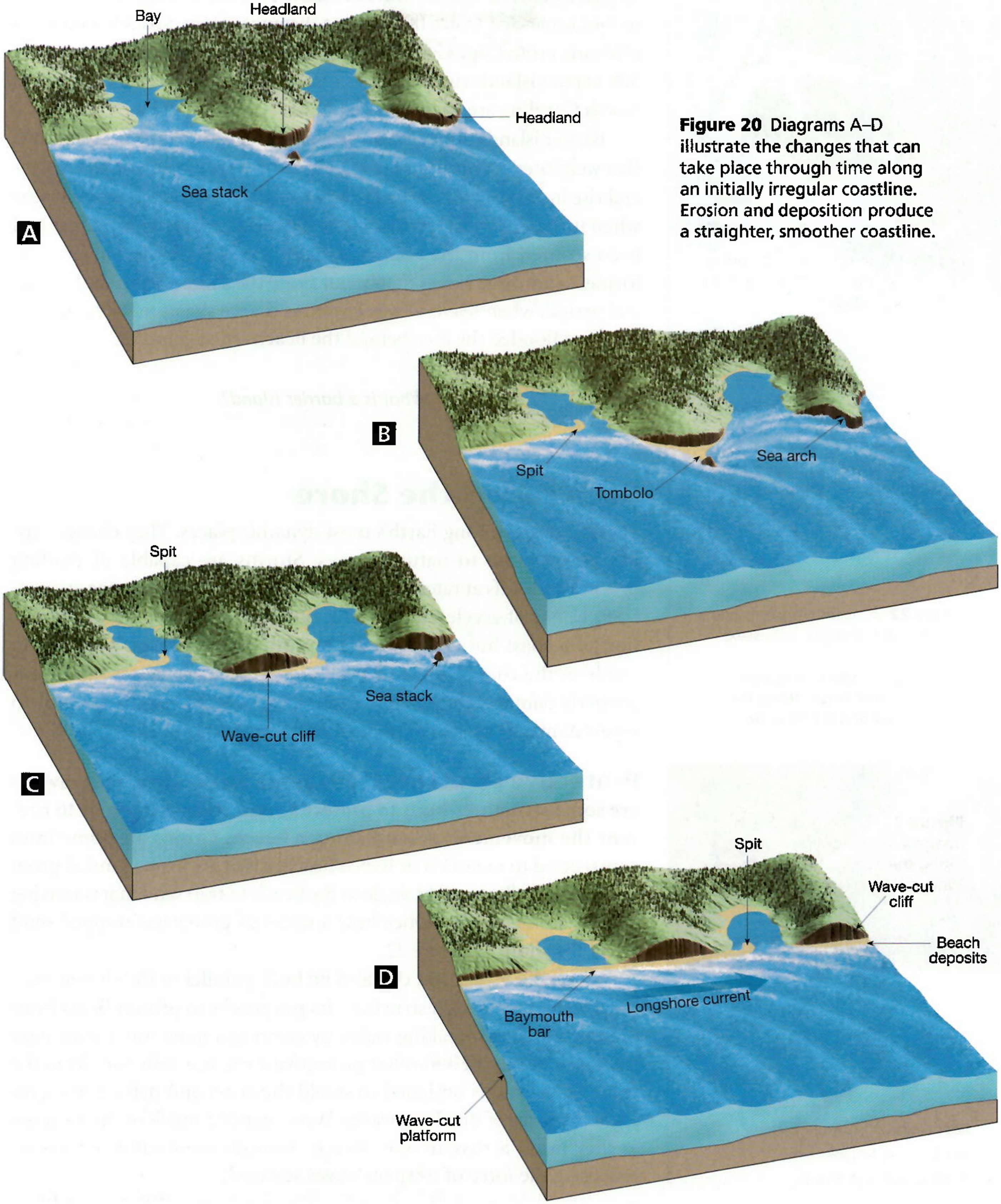


Figure 20 Diagrams A–D illustrate the changes that can take place through time along an initially irregular coastline. Erosion and deposition produce a straighter, smoother coastline.

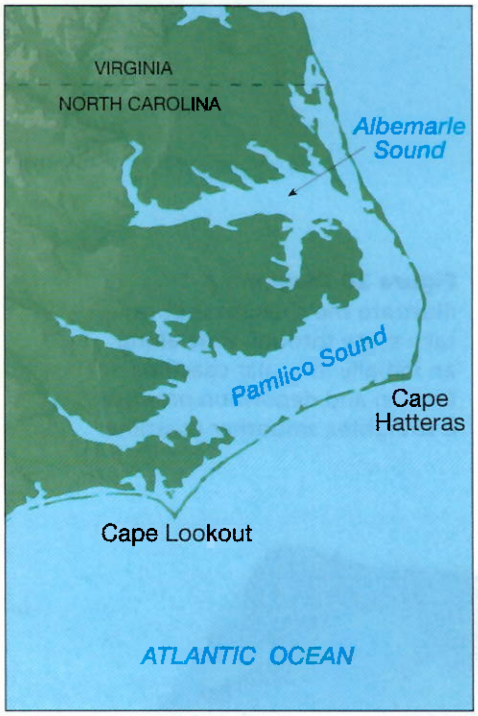


Figure 21 The islands along the coast of North Carolina are examples of barrier islands.

Figure 22 A series of groins traps sand along the shore in Sussex, England.
Inferring ***In which direction does the sand move along the coast in this photo? How do you know?***

Go Online SCI LINKS NSTA

For: Links on coastal changes
Visit: www.SciLinks.org
Web Code: cjn-5163

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 21.

Barrier islands probably formed in several ways. Some began as spits that were later cut off from 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 reside in the coastal zone. Erosion along the coast causes significant property damage. Huge sums of money are spent annually not only to repair damage but also 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. Notice how a series of groins has trapped sand along the shore in Figure 22.

Protective structures can also be built parallel to the shoreline. A breakwater is one such structure. Its purpose is to protect boats 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 the force of 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 often 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 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 photos shown in Figure 23. 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.

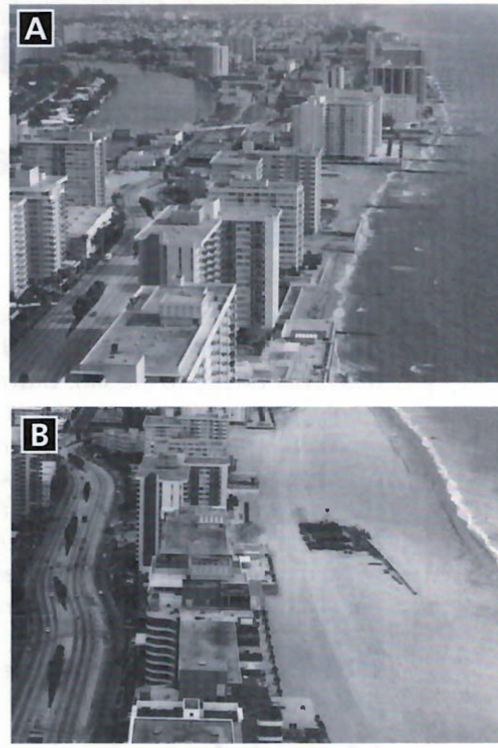


Figure 23 Miami Beach
A Before beach nourishment
B After beach nourishment
Analyzing ***What are the advantages and disadvantages of beach nourishment?***

Section 16.3 Assessment

Reviewing 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?

Thinking Critically

10. **Analyzing** How can beach nourishment be helpful? How can it be harmful?
11. **Comparing and Contrasting** Compare and contrast a tombolo and a barrier island.
12. **Relating 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?

Connecting Concepts

Wave Refraction Relate the concept of wave refraction to the changes that occur as a wave enters shallow water and goes into shore.

Exploration Lab

Graphing Tidal Cycles

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

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

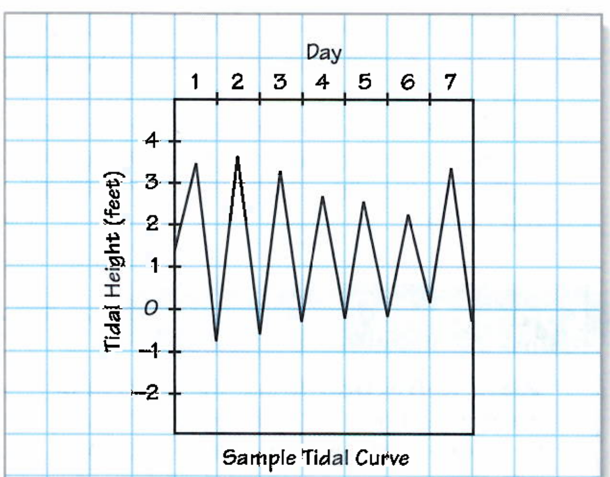
Materials

- graph paper
- pencil

Skills Graphing, Interpreting Data, Inferring, Drawing Conclusions

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. It is often easier to place the *x*-axis at the top of the graph, rather than at the bottom, when graphing a tidal cycle.
2. Use the data in Table 1 to make a graph of the tidal cycle.



High tide in Nova Scotia's Bay of Fundy

Low tide in the same area

Analyze and Conclude

1. **Applying Concepts** What tidal pattern does this area experience? Explain how you determined this.
2. **Calculating** 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, first quarter moon, full moon, last quarter moon. How do you know this?
4. **Applying 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 to his boat at 3:30 that afternoon, the boat was completely 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.

CHAPTER 16

Study Guide

16.1 Ocean Circulation

Key Concepts

- 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 greater concentrations of 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.

Vocabulary

ocean current, *p. 448;* surface current, *p. 448;* gyre, *p. 449;* Coriolis effect, *p. 449;* upwelling, *p. 450;* density current, *451*

16.2 Waves and Tides

Key Concepts

- 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 the gravitational attraction exerted upon Earth by the moon and, to a lesser extent, by the sun.
- The force that produces tides is gravity.
- Three main tidal patterns exist worldwide: diurnal tides, semidiurnal tides, and mixed tides.

Vocabulary

wave height, *p. 456;* wavelength, *p. 456;* wave period, *p. 456;* fetch, *p. 456;* tide, *p. 458;* tidal range, *p. 459;* spring tide, *p. 459;* neap tide, *p. 459*

16.3 Shoreline Processes and Features

Key Concepts

- Waves are responsible for the movement of sediment along the shoreline.
- 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 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 addition of large quantities of sand to the beach system.

Vocabulary

beach, *p. 461;* wave refraction, *p. 462;* longshore current, *p. 463;* barrier island, *p. 466*

CHAPTER 16

Assessment

Interactive textbook with assessment at PHSchool.com

Reviewing Content

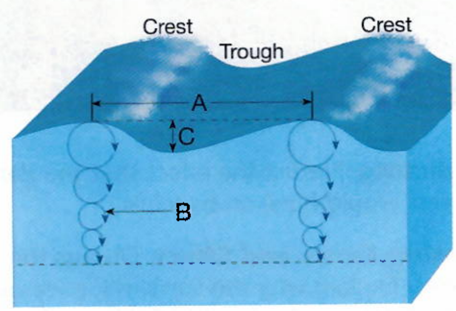
Choose the letter that best answers the questions or completes the statement.

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 Coriolos effect, surface currents in the Southern Hemisphere are deflected
   - **a.** to the left. **b.** to the right.
   - **c.** north. **d.** south.
3. Which term describes the rising of cold water from deeper layers to replace warmer surface water?
   - **a.** density current **b.** downwelling
   - **c.** surface current **d.** upwelling
4. The energy and motion of most waves is derived from
   - **a.** currents. **b.** tides.
   - **c.** wind. **d.** gravity.
5. The five huge circular-moving systems of ocean surface currents are called
   - **a.** density currents. **b.** fetches.
   - **c.** drifts. **d.** gyres.
6. Daily changes in the elevation of the ocean surface are called
   - **a.** surface currents. **b.** tides.
   - **c.** waves. **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. **b.** density current.
   - **c.** longshore current. **d.** surface current.
9. Which describes a ridge of sand that connects an island to the mainland or another island?
   - **a.** baymouth bar **b.** sea arch
   - **c.** sea stack **d.** tombolo
10. Which is created through the process of erosion?
    - **a.** baymouth bar **b.** sea arch
    - **c.** spit **d.** tombolo

Understanding 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?

Assessment *continued*

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?

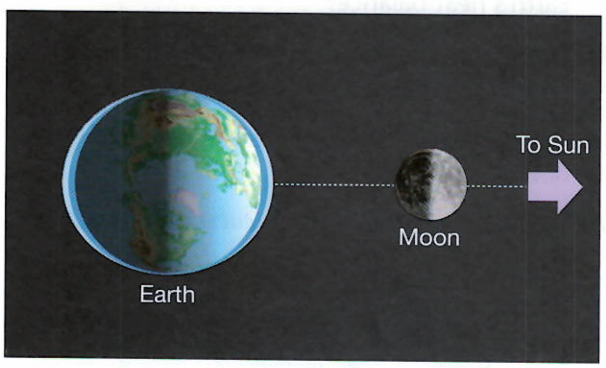
21. How are a wave-cut cliff and wave-cut platforms related?

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

Critical Thinking

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

24. **Applying Concepts** The figure below shows the Earth–moon–sun system. What type of tide is experienced when Earth, the moon, and the sun are in these positions? What is the phase of the moon in the diagram?



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

26. **Relating 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

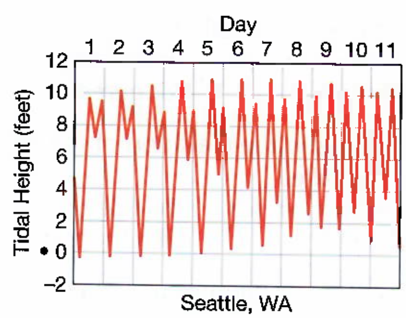
27. **Calculating** As waves enter shallow water and decrease in speed, wave height increases and eventually a wave will break. The point at which a wave will break can be calculated using the formula for wave steepness: steepness = wave height/wavelength. When the steepness of a wave reaches 1/7, the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

Concepts in Action

28. **Applying Concepts** Re-examine Figure 6. Describe the probable temperature and salinity characteristics for each water mass: Antarctic Bottom Water, North Atlantic Deep Water, and Mediterranean Water.

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

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



Performance-Based Assessment

Synthesizing 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.

Standardized Test Prep

Test-Taking Tip

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 tend to become 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 or completes the statement.

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.

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
   (A) seawall. (B) groin.
   (C) headland. (D) sea stack.

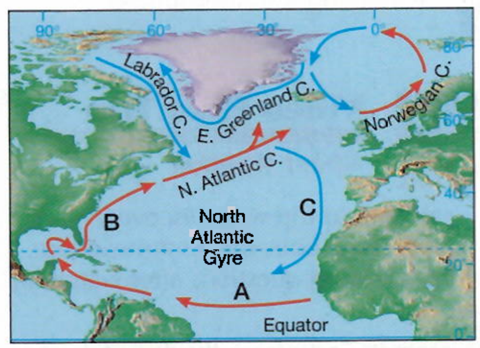
3. In the open sea, the movement of water particles in a wave becomes negligible at a depth equal to
   (A) one-fourth the wavelength.
   (B) one-third the wavelength.
   (C) one-half the wavelength.
   (D) three-fourths the wavelength.

4. Which term refers to the time interval between the passage of successive wave crests?
   (A) wave height
   (B) wavelength
   (C) wave period
   (D) wave speed

5. What happens as a wave approaches the shore?
   (A) wavelength decreases and wave height increases
   (B) wavelength increases and wave height increases
   (C) wave speed decreases and wave height decreases
   (D) wave period decreases and wave height decreases

Answer the following questions in complete sentences.

Use the figure below to answer Question 6.



6. Identify the currents in the North Atlantic Gyre represented by A, B, and C. Specify whether each current is a warm water current or a cold water current. How does the North Atlantic Current affect weather in northwestern Europe?

7. What is the primary driving force of surface currents in the ocean? How do the distribution of continents on Earth and the Coriolis effect influence these currents?

CHAPTER 17

The Atmosphere: Structure and Temperature

CONCEPTS in Action

Exploration Lab
Heating Land and Water

How the Earth Works
Earth's Atmosphere

GEODe EARTH SCIENCE
The Atmosphere
↳ Heating the Atmosphere

Discovery Channel School

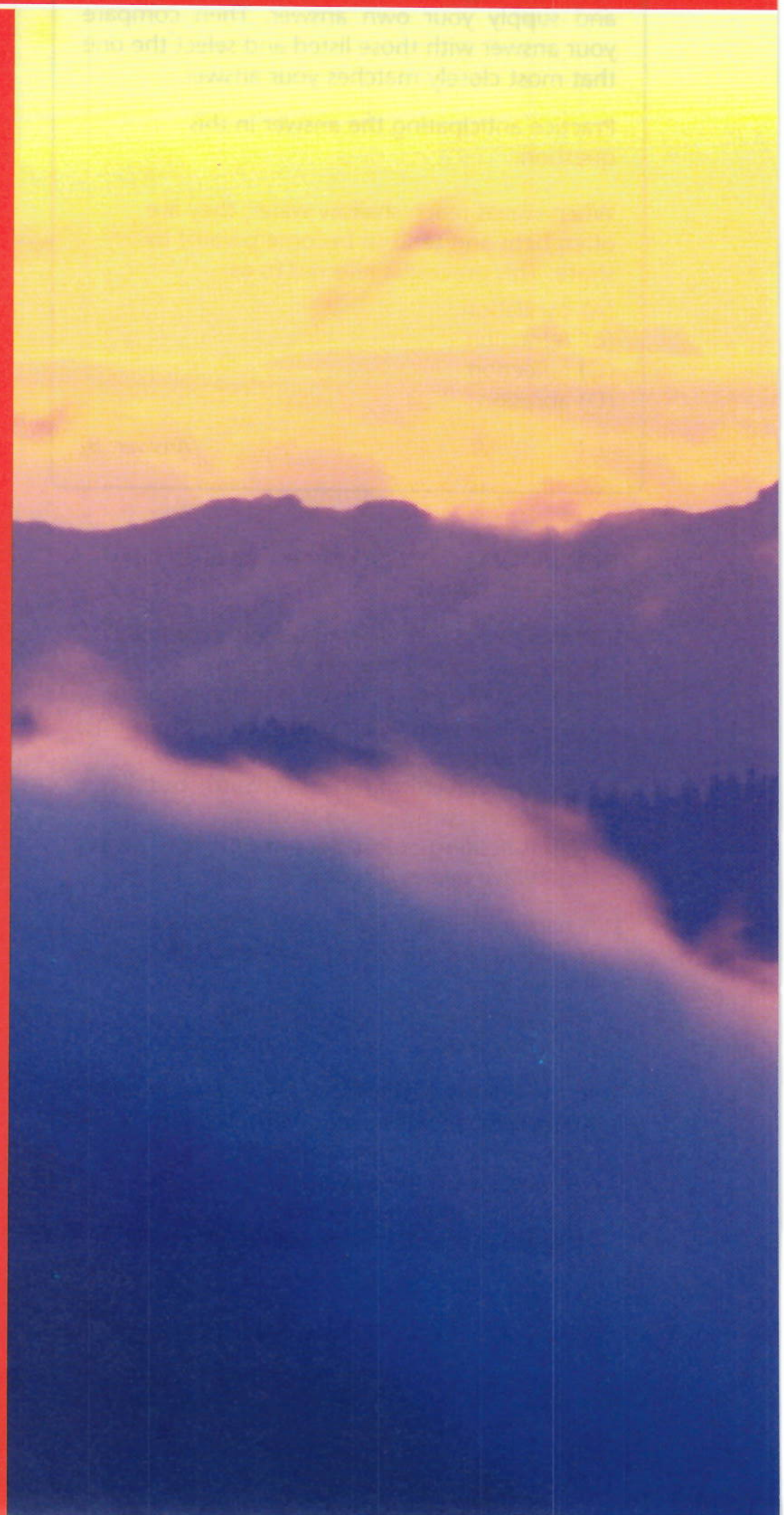
Video Field Trip
About Weather

Take a weather field trip with Discovery Channel and learn about Earth's atmosphere. Answer the following questions after watching the video.

1. What protects Earth from the hot and cold extremes of space?
2. How do clouds form?

Go Online PHSchool.com

For: Chapter 17 Resources
Visit: PHSchool.com
Web Code: cjk-9999



A bald eagle, found only in North America, ▶ soars over Mount Rainier National Park in Washington State.