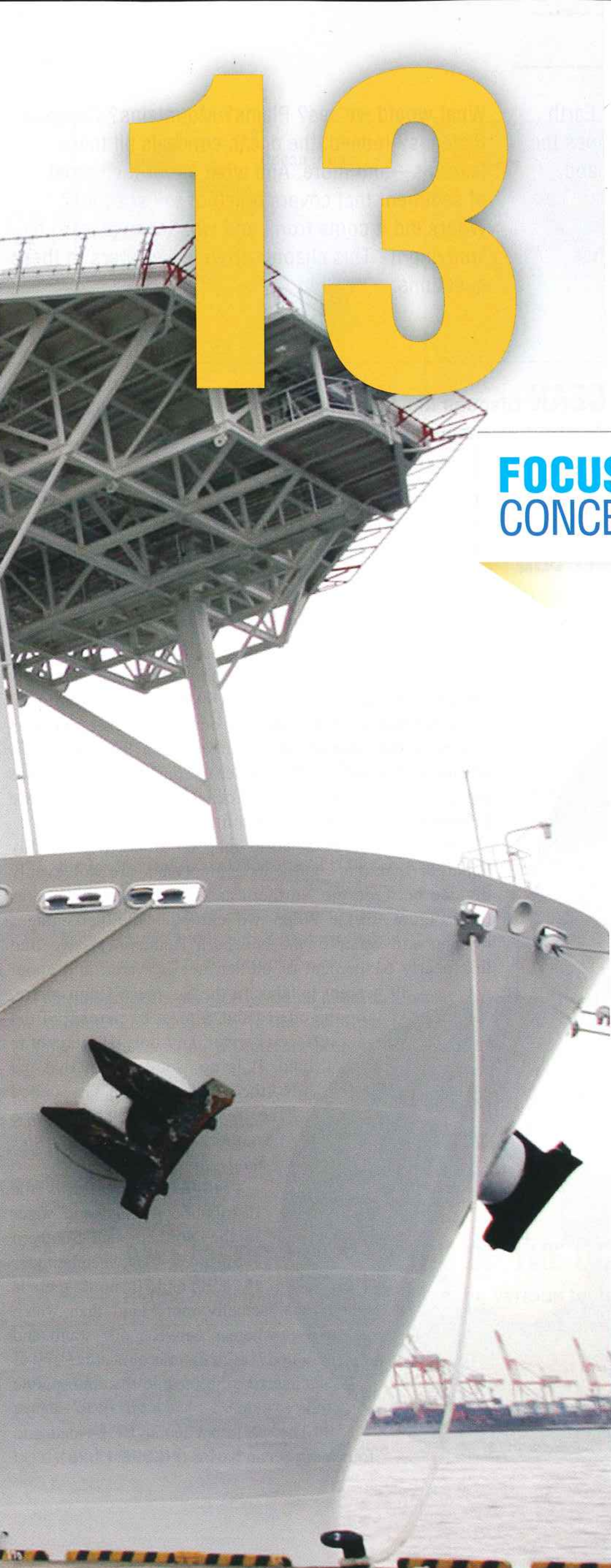


13 The Ocean Floor

FOCUS ON CONCEPTS

Each statement represents the primary **LEARNING OBJECTIVE** for the corresponding major heading within the chapter. After you complete the chapter, you should be able to:

13.1 Discuss the extent and distribution of oceans and continents on Earth. Identify Earth's four main ocean basins.

13.2 Define *bathymetry* and summarize the various techniques used to map the ocean floor.

13.3 Compare a passive continental margin with an active continental margin and list the major features of each.

13.4 List and describe the major features associated with deep-ocean basins.

13.5 Summarize the basic characteristics of oceanic ridges.

13.6 Distinguish among three categories of seafloor sediment and explain why some of these sediments can be used to study climate change.

13.7 Discuss some important resources and potential resources associated with the ocean floor.

The *Chikyu* (meaning "Earth" in Japanese) is one of the most advanced scientific drillings vessels. It is part of the Integrated Ocean Drilling Program (IODP). (Itsuo Inouye/AP Photo)

How deep is the ocean? How much of Earth is covered by the global sea? What does the seafloor look like? Answers to these and other questions about the oceans and the basins they occupy are sometimes elusive and often difficult to determine. Suppose that all the water were drained from the ocean. What would we see? Plains? Mountains? Canyons? Plateaus? Indeed, the ocean conceals all these features—and more. And what about the carpet of sediment that covers much of the seafloor? Where did it come from, and what can we learn by studying it? This chapter provides answers to these questions.

13.1 THE VAST WORLD OCEAN

Discuss the extent and distribution of oceans and continents on Earth. Identify Earth's four main ocean basins.

Oceans are a major part of our planet. In fact, Earth is frequently called the *water planet* or the *blue planet*. There is a good reason for these names: Nearly 71 percent of Earth's surface is covered by the global ocean (**FIGURE 13.1**). The focus of this chapter and Chapters 14 and 15 is oceanography. **Oceanography** is an interdisciplinary science that draws on the methods and knowledge of geology, chemistry, physics, and biology to study all aspects of the world ocean.

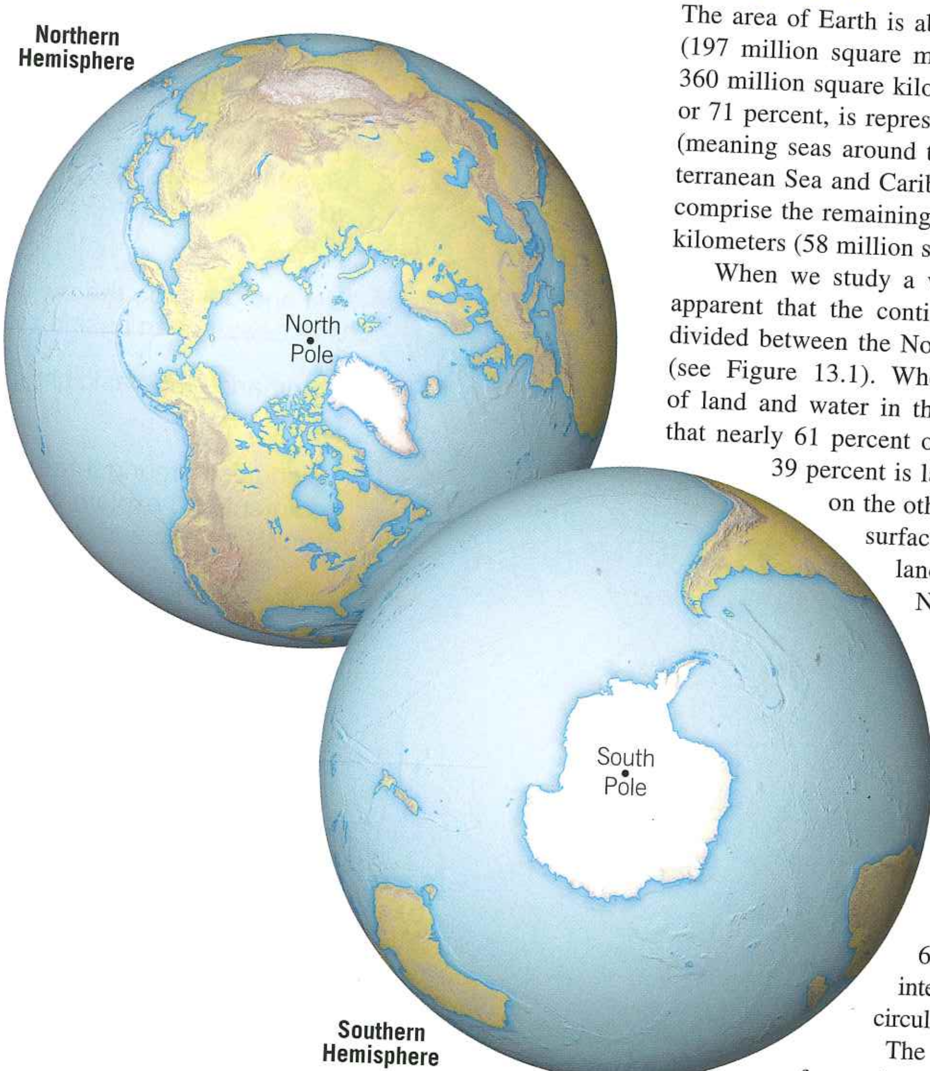


FIGURE 13.1 North Versus South These views of Earth show the uneven distribution of land and water between the Northern and Southern Hemispheres. Almost 81 percent of the Southern Hemisphere is covered by the oceans—20 percent more than the Northern Hemisphere.

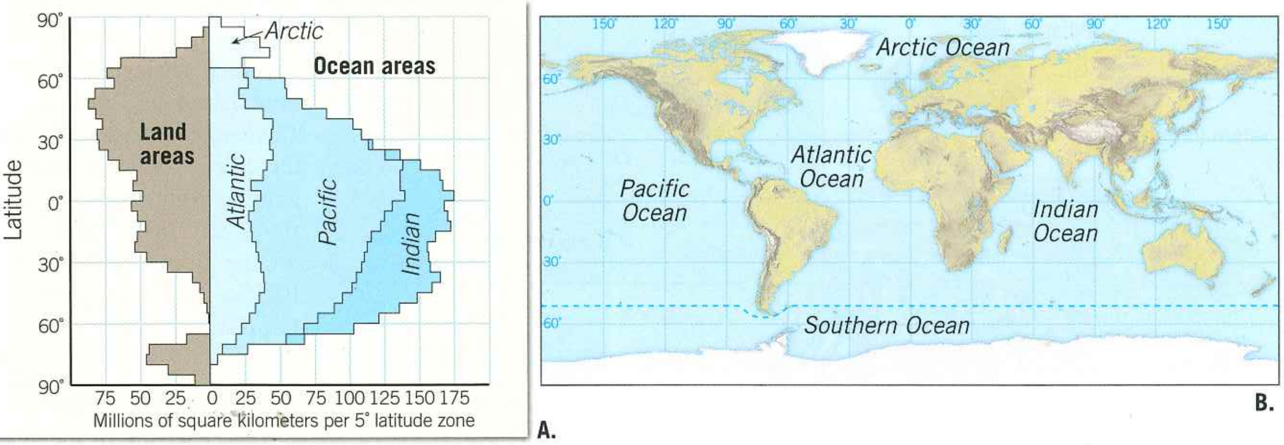
Geography of the Oceans

The area of Earth is about 510 million square kilometers (197 million square miles). Of this total, approximately 360 million square kilometers (140 million square miles), or 71 percent, is represented by oceans and marginal seas (meaning seas around the ocean's margin, like the Mediterranean Sea and Caribbean Sea). Continents and islands comprise the remaining 29 percent, or 150 million square kilometers (58 million square miles).

When we study a world map or globe, it is readily apparent that the continents and oceans are not evenly divided between the Northern and Southern Hemispheres (see Figure 13.1). When we compute the percentages of land and water in the Northern Hemisphere, we find that nearly 61 percent of the surface is water, and about 39 percent is land. In the Southern Hemisphere, on the other hand, almost 81 percent of the surface is water, and only 19 percent is land. It is no wonder then that the Northern Hemisphere is called the *land hemisphere* and the Southern Hemisphere the *water hemisphere.*

FIGURE 13.2A shows the distribution of land and water in the Northern and Southern Hemispheres. Between latitudes 45° north and 70° north, there is actually more land than water, whereas between 40° south and 65° south there is almost no land to interrupt the oceanic and atmospheric circulation.

The world ocean can be divided into four main ocean basins (**FIGURE 13.2B**):



SmartFigure 13.2 Distribution of Land and Water **A.** The graph shows the amount of land and water in each 5° latitude belt. **B.** The world map provides a more familiar view.

1. The *Pacific Ocean*, which is the largest ocean and the largest single geographic feature on the planet, accounts for over half of the ocean surface area of Earth. In fact, the Pacific Ocean is so large that all the continents could fit into the space occupied by it—and have room left over! It is also the world's deepest ocean, with an average depth of 3940 meters (12,927 feet, or about 2.5 miles).
2. The *Atlantic Ocean* is about half the size of the Pacific Ocean and not quite as deep. It is a relatively narrow ocean compared to the Pacific and is bounded by almost parallel continental margins.
3. The *Indian Ocean* is slightly smaller than the Atlantic Ocean but has about the same average depth. Unlike the Pacific and Atlantic Oceans, it is largely a Southern Hemisphere water body.
4. The *Arctic Ocean* is about 7 percent the size of the Pacific Ocean and is only a little more than one-quarter as deep as the rest of the oceans.

Oceanographers also recognize an additional ocean near e continent of Antarctica in the Southern Hemisphere. efined by the meeting of currents near Antarctica called e Antarctic Convergence, the *Southern Ocean*, or *Antarctic cean*, is actually those portions of the Pacific, Atlantic, and dian Oceans south of about 50° south latitude.

Comparing the Oceans to the Continents

A major difference between continents and ocean basins is their relative levels. The average elevation of the continents above sea level is about 840 meters (2756 feet), whereas the average depth of the oceans is nearly four and a half times this amount—3729 meters (12,234 feet). The volume of ocean water is so large that if Earth's solid mass were perfectly smooth (level) and spherical, the oceans would cover Earth's entire surface to a uniform depth of more than 2000 meters (1.2 miles)!

13.1 CONCEPT CHECKS

1. How does the area of Earth's surface covered by the oceans compare with that of the continents?
2. Contrast the distribution of land and water in the Northern Hemisphere and the Southern Hemisphere.
3. Excluding the Southern Ocean, name the four main ocean basins. Contrast them in terms of area and depth.
4. How does the average depth of the oceans compare to the average elevation of the continents?

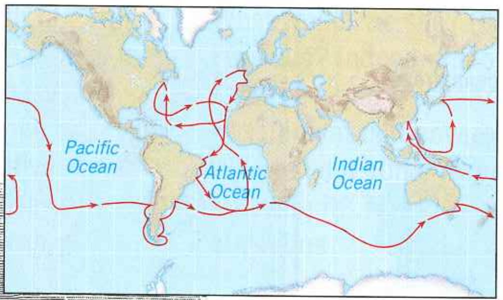
3.2 AN EMERGING PICTURE OF THE OCEAN FLOOR

Define *bathymetry* and summarize the various techniques used to map the ocean floor.

all water were removed from the ocean basins, a great ariety of features would be seen, including broad volcanic eaks, deep trenches, extensive plains, linear mountain hains, and large plateaus. In fact, the scenery would be early as diverse as that on the continents.

Mapping the Seafloor

The complex nature of ocean-floor topography did not unfold until the historic 3½-year voyage of the HMS *Challenger* (**FIGURE 13.3**). From December 1872 to May 1876, the



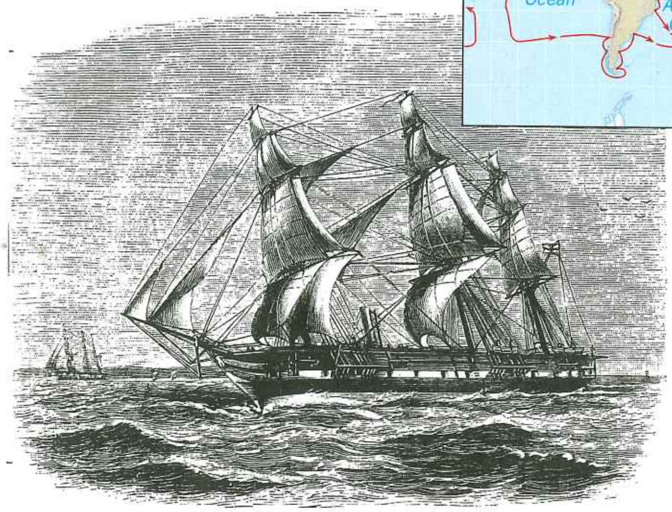


FIGURE 13.3 HMS *Challenger* The first systematic bathymetric measurements of the ocean were made aboard the HMS *Challenger*, which departed England in December 1872 and returned in May 1876. (Image courtesy of the Library of Congress)

Challenger expedition made the first comprehensive study of the global ocean ever attempted. During the 127,500-kilometer (79,200-mile) voyage, the ship and its crew of scientists traveled to every ocean except the Arctic. Throughout the voyage, they sampled a multitude of ocean properties, including water depth, which was accomplished by laboriously lowering a long, weighted line overboard and then retrieving it. Using this laborious process, the *Challenger* made the first recording of the deepest-known point on the ocean floor in 1875. This spot, on the floor of the western Pacific, was later named the *Challenger Deep*.

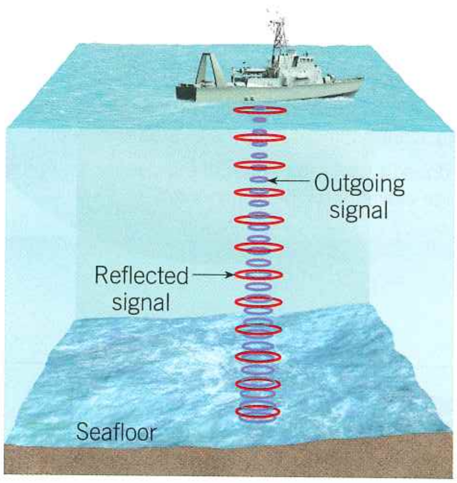


FIGURE 13.4 Echo Sounder An echo sounder determines water depth by measuring the time interval required for an acoustic wave to travel from a ship to the seafloor and back. The speed of sound in water is 1500 meters per second. Therefore, Depth = ½ (1500 m/sec × Echo travel time).

Modern Bathymetric Techniques The measurement of ocean depths and the charting of the shape (topography) of the ocean floor is known as **bathymetry** (*bathos* = depth, *metry* = measurement). Today, sound energy is used to measure water depths. The basic approach employs **sonar**, an acronym for *so*und *na*vigation and *r*anging. The first devices that used sound to measure water depth, called **echo sounders**, were developed early in the twentieth century. Echo sounders work by transmitting a sound wave (called a *ping*) into the water in order to produce an echo when it bounces off any object, such as a large marine organism or the ocean floor (**FIGURE 13.4**). A sensitive receiver intercepts the echo reflected from the bottom, and a clock precisely measures the travel time to fractions of a second. By knowing the speed of sound waves in water—about 1500 meters (4900 feet) per second—and the time required for the energy pulse to reach the ocean floor and return, depth can be calculated. Depths determined from continuous monitoring of these echoes are plotted to create a profile of the ocean floor. By laboriously combining profiles from several adjacent traverses, a chart of a portion of the seafloor is produced.

Following World War II, the U.S. Navy developed *sidescan sonar* to look for explosive devices that had been deployed in shipping lanes (**FIGURE 13.5A**). These torpedo-shaped instruments can be towed behind a ship, where they send out a fan of sound extending to either side of the ship's track. By combining swaths of sidescan sonar data, researchers produced the first photograph-like images of the seafloor. Although sidescan sonar provides valuable views of the seafloor, it does not provide bathymetric (water depth) data.

This drawback was resolved in the 1990s, with the development of *high-resolution multibeam sonar* instruments (see Figure 13.5A). These systems use hull-mounted sound sources that send out a fan of sound and then record reflections from the seafloor through a set of narrowly focused receivers aimed at different angles. Rather than obtain the depth of a single point every few seconds, this technique makes it possible for a survey ship to map the features of the ocean floor along a strip

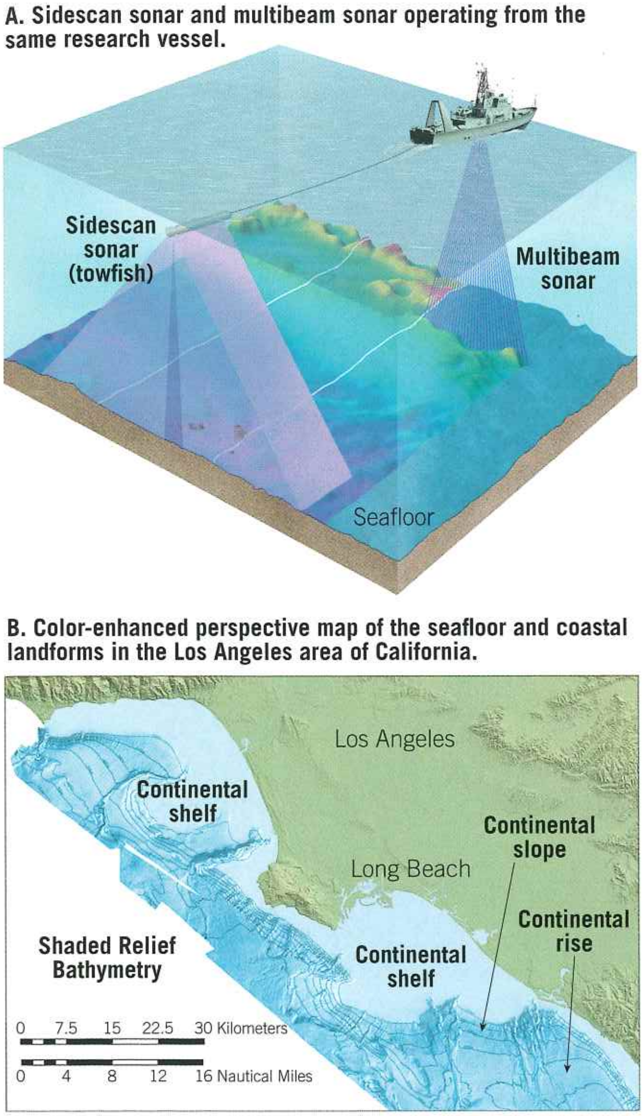
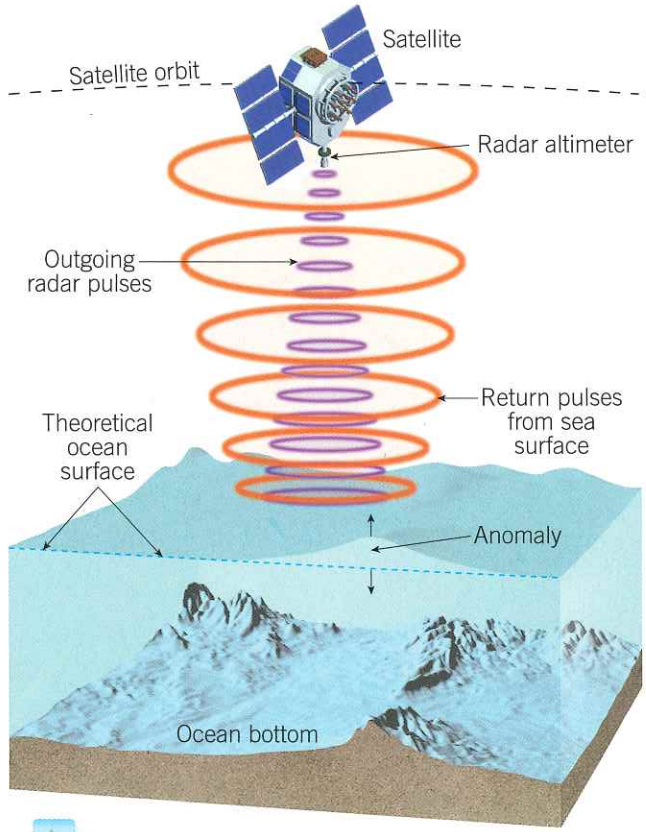


FIGURE 13.5 Sidescan and Multibeam Sonar



SmartFigure 13.6 Satellite Altimeter A satellite altimeter measures the variation in sea-surface elevation, which is caused by gravitational attraction and mimics the shape of the seafloor. The sea-surface anomaly is the difference between the measured and theoretical ocean surface.

tens of kilometers wide. These systems can collect bathymetric data of such high resolution that they can distinguish depths that differ by less than a meter (**FIGURE 13.5B**). When multibeam sonar is used to make a map of a section of seafloor, the ship travels through the area in a regularly spaced back-and-forth pattern known as "mowing the lawn."

Despite their greater efficiency and enhanced detail, research vessels equipped with multibeam sonar travel at a mere 10–20 kilometers (6 to 12 miles) per hour. It would take at least 100 vessels outfitted with this equipment hundreds of years to map the entire seafloor. This explains why only about 5 percent of the seafloor has been mapped in detail—and why large portions of the seafloor have not yet been mapped with sonar at all.

Mapping the Ocean Floor from Space Another technological breakthrough that has led to an enhanced understanding of the seafloor involves measuring the shape of the ocean surface from space. After compensating for waves, tides, currents, and atmospheric effects, it was discovered that the ocean surface is not perfectly "flat." Because massive seafloor features exert stronger-than-average gravitational attraction, they produce elevated areas on the ocean surface. Conversely, canyons and trenches create slight depressions.

Satellites equipped with *radar altimeters* are able to measure these subtle differences by bouncing microwaves off the sea surface (**FIGURE 13.6**). These devices can measure variations as small as a few centimeters. Such data have added greatly to the knowledge of ocean-floor topography. Combined with traditional sonar depth measurements, the data are used to produce detailed ocean-floor maps, such as the one shown in **FIGURE 13.7**.

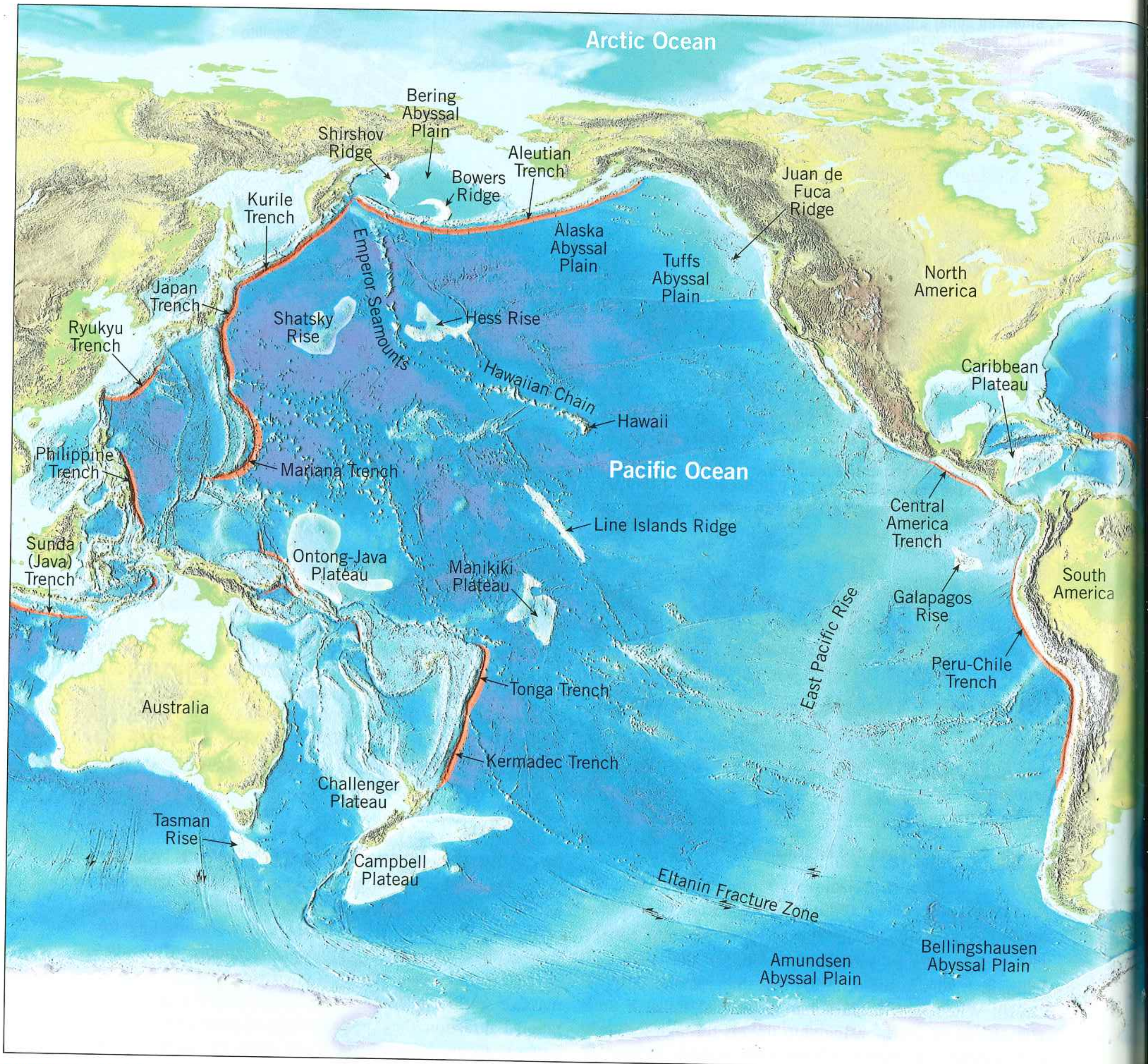
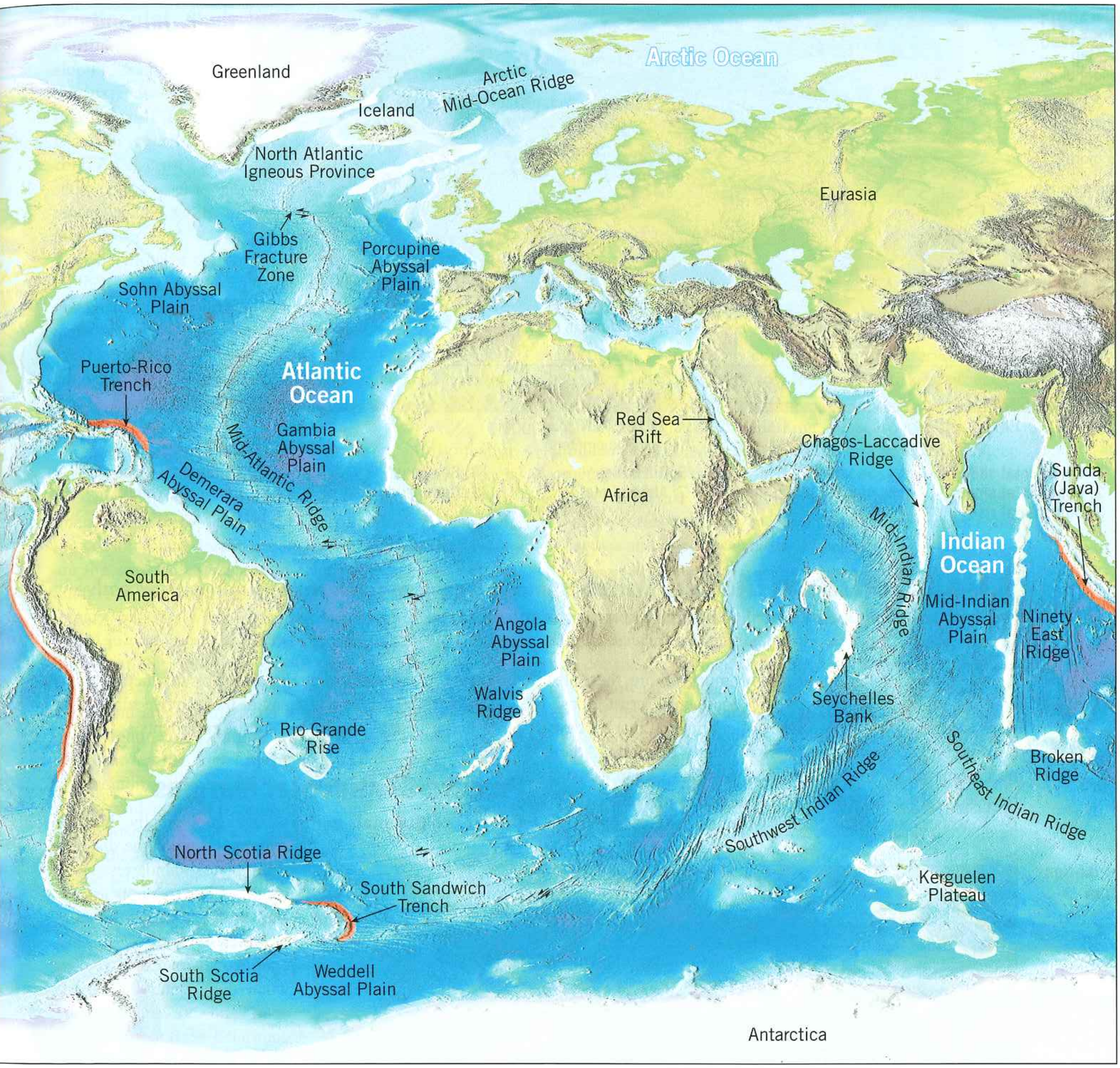


FIGURE 13.7 Major Features of the Seafloor

Provinces of the Ocean Floor

Oceanographers studying the topography of the ocean floor recognize three major units: *continental margins*, the *deep-ocean basin*, and the *oceanic (mid-ocean) ridge*.

The map in **FIGURE 13.8** outlines these provinces for the North Atlantic Ocean, and the profile at the bottom of the illustration shows the varied topography. Such profiles usually have their vertical dimension exaggerated many times—40 times in this case—to make topographic



features more conspicuous. Vertical exaggeration, however, makes slopes shown in seafloor profiles appear to be *much* steeper than they actually are.

13.2 CONCEPT CHECKS

1. Define *bathymetry*.
2. Describe how satellites orbiting Earth can determine features on the seafloor without being able to directly observe them beneath several kilometers of seawater.
3. List the three major provinces of the ocean floor.

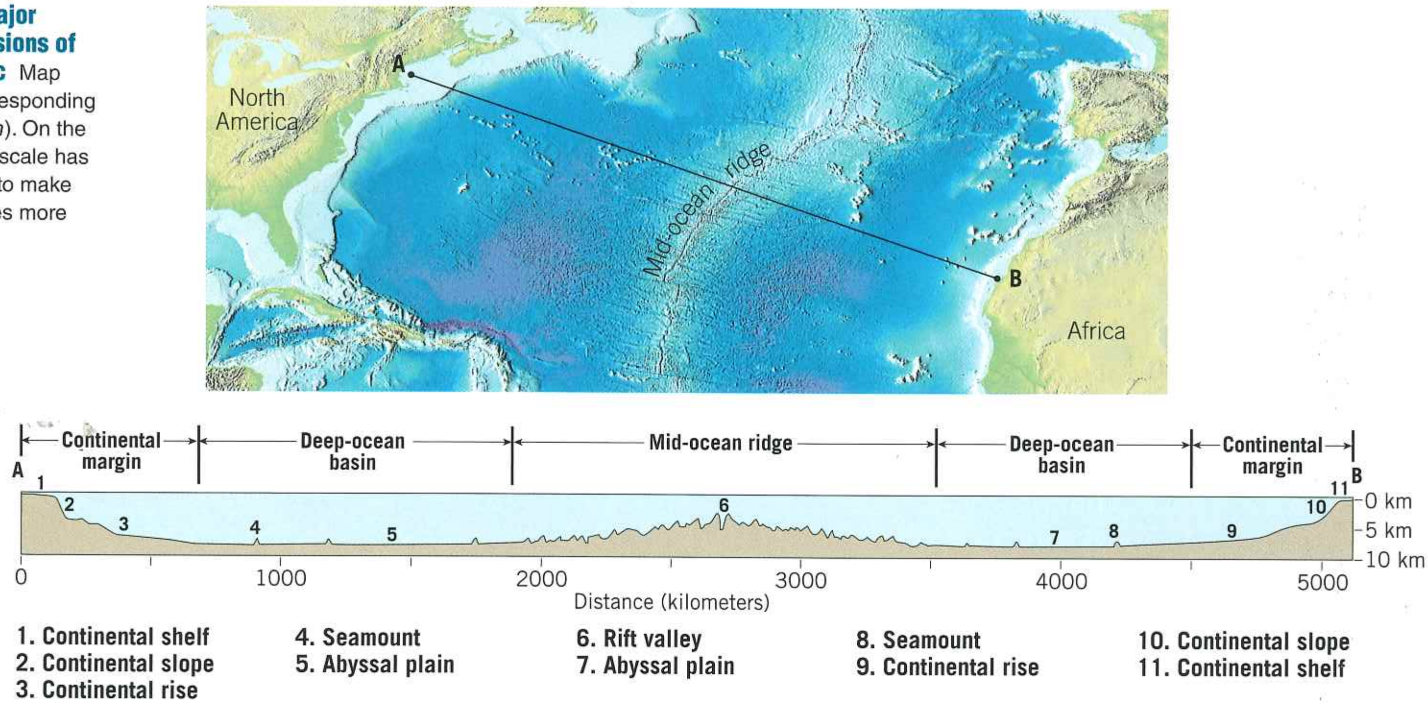


FIGURE 13.8 Major Topographic Divisions of the North Atlantic Map view (*top*) and corresponding profile view (*bottom*). On the profile, the vertical scale has been exaggerated to make topographic features more conspicuous.

13.3 CONTINENTAL MARGINS Compare a passive continental margin with an active continental margin and list the major features of each.

As the name implies, **continental margins** are the outer margins of the continents where continental crust transitions to oceanic crust. Two types of continental margin have been identified: *passive* and *active*. Nearly the entire Atlantic Ocean and a large portion of the Indian Ocean are surrounded by passive continental margins (see Figure 13.7). By contrast, most of the Pacific Ocean is bordered by active continental margins that are represented by subduction zones in **FIGURE 13.9**. Notice that many of those active subduction zones lie far beyond the margins of the continents.

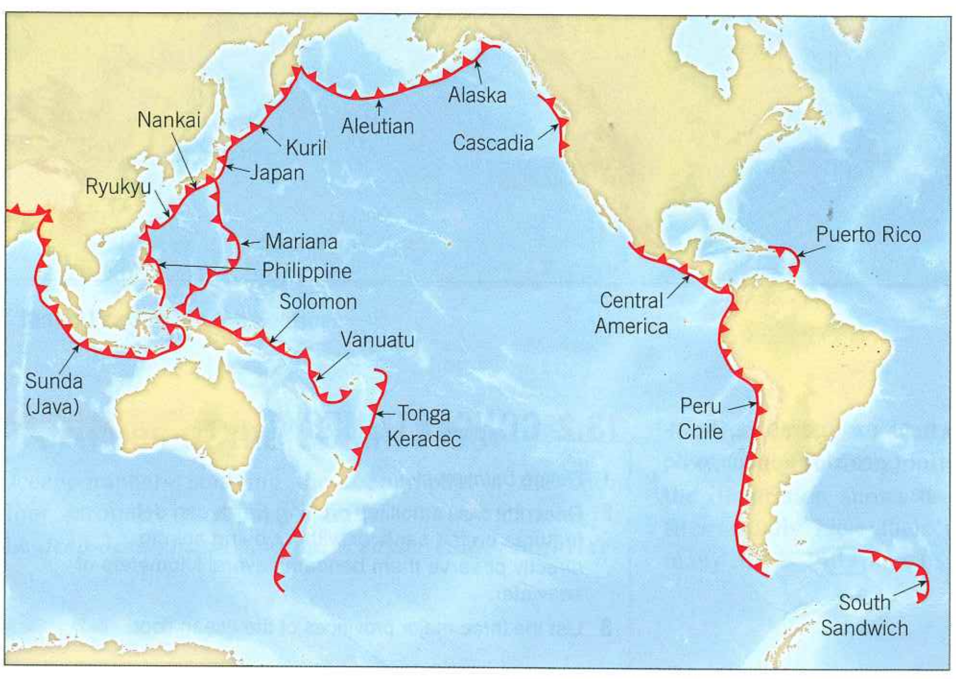


FIGURE 13.9 Distribution of Earth's Subduction Zones Most of the active subduction zones surround the Pacific basin.

Passive Continental Margins

Passive continental margins are geologically inactive regions located some distance from plate boundaries. As a result, they are not associated with strong earthquakes or volcanic activity. Passive continental margins develop when continental blocks rift apart and are separated by continued seafloor spreading. As a result, the continental blocks are firmly attached to the adjacent oceanic crust.

Most passive margins are relatively wide and are sites where large quantities of sediments are deposited. The features comprising passive continental margins include the continental shelf, the continental slope, and the continental rise (**FIGURE 13.10**).

Continental Shelf

The **continental shelf** is a gently sloping, submerged surface that extends from the shoreline toward the deep-ocean basin. It consists mainly of continental crust capped with sedimentary rocks and sediments eroded from adjacent landmasses.

The width of the continental shelf varies greatly. The shelf is almost nonexistent along portions of some continents, and it extends seaward more than 1500 kilometers (930 miles) along others. The average inclination of the continental shelf is only about one-tenth of 1 degree, a slope so slight that it would appear to an observer to be a horizontal surface.

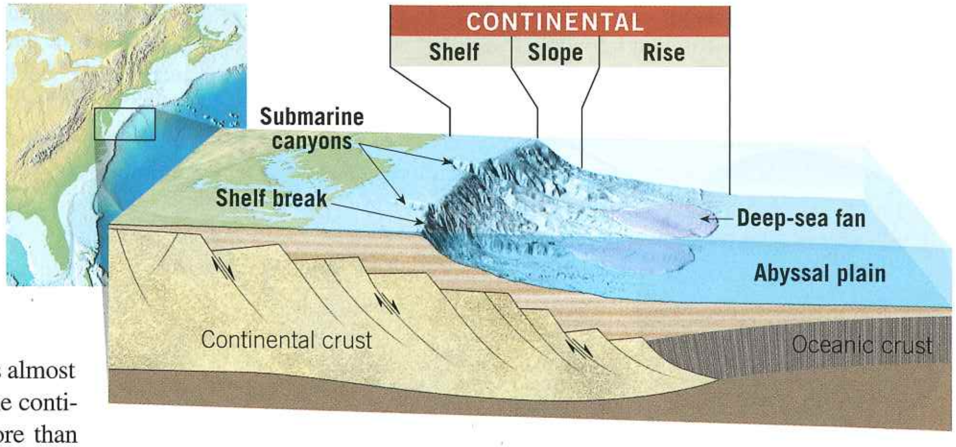


FIGURE 13.10 Continental Ma
that the slopes s
the continental s
continental slope
exaggerated. Th
shelf has an ave
of one-tenth of 1
whereas the con
slope has an ave
of about 5 degre

The continental shelf tends to be relatively featureless; however, some areas are mantled by extensive glacial deposits and thus are quite rugged. In addition, some continental shelves are dissected by large valleys that run from the coastline into deeper waters. Many of these *shelf valleys* are the seaward extensions of river valleys on the adjacent landmass. They were eroded during the last Ice Age (Quaternary period), when enormous quantities of water were stored in vast ice sheets on the continents, causing sea level to drop at least 100 meters (330 feet). Because of this sea-level drop, rivers extended their valleys, and land-dwelling plants and animals migrated to the newly exposed portions of the continents. Dredging off the coast of North America has retrieved the ancient remains of numerous land dwellers, including mammoths, mastodons, and horses, providing further evidence that portions of the continental shelves were once above sea level.

Although continental shelves represent only 7.5 percent of the total ocean area, they have economic and political significance because they contain important reservoirs of oil and natural gas, and they support important fishing grounds.

Continental Slope

Marking the seaward edge of the continental shelf is the **continental slope**, a relatively steep structure that marks the boundary between continental crust and oceanic crust. Although the inclination of the continental slope varies greatly from place to place, it averages about 5 degrees and in places exceeds 25 degrees.

Continental Rise

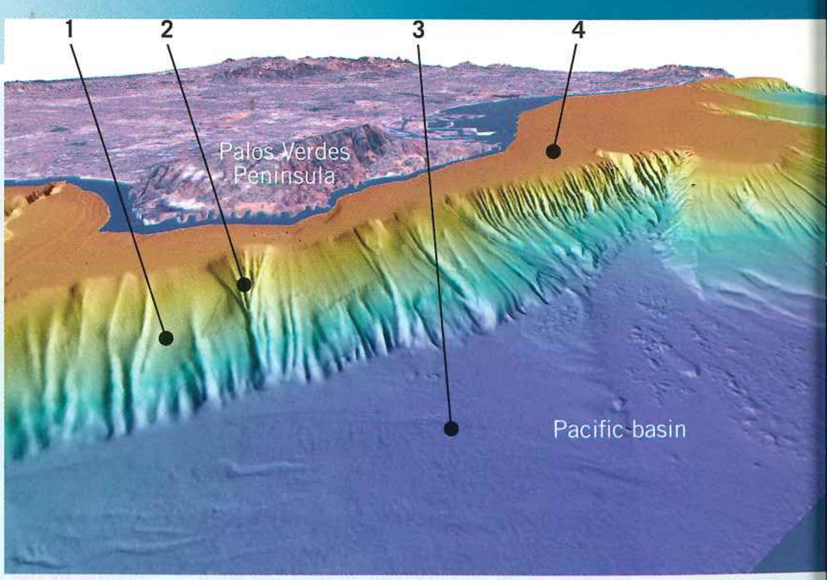
The continental slope merges into a more gradual incline known as the **continental rise** that may extend seaward for hundreds of kilometers. The continental rise consists of a thick accumulation of sediment that has moved down the continental slope and onto deep-ocean floor. Most of the sediments are delivered to the seafloor by *turbidity currents* that periodically flow down *submarine canyons*. (We will discuss these shortly.) When these muddy slurries emerge from the mouth of a canyon onto the relatively flat ocean floor, they deposit sediment that forms a **deep-sea fan**. As fans from adjacent submarine canyons grow, they merge to produce a continuous wedge of sediment at the base of the continental slope, forming the continental rise.

EYE ON EARTH

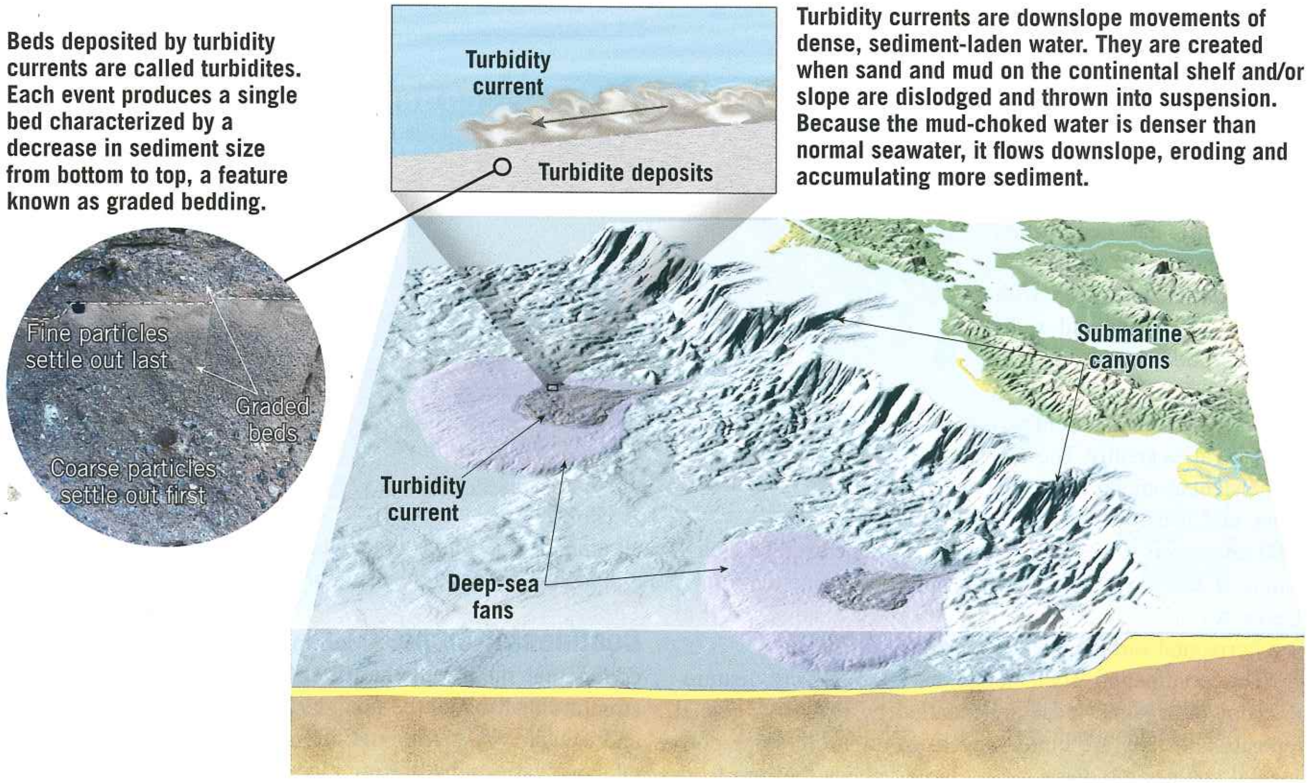
This image shows a perspective view of the continental margin, looking southwest toward the Palos Verdes Peninsula near Los Angeles.

QUESTION 1 *Match the features labeled 1 through 4 with the following terms: continental shelf, continental slope, continental rise, and submarine canyon.*

QUESTION 2 *Based on the features in this image, what type of continental margin is shown here?*



URE 13.11 Turbidity rrents and Submarine nyons Turbidity currents an important factor in formation of submarine yons. (Photo by Marli Miller)



SmartFigure 13.12 tive Continental rgins

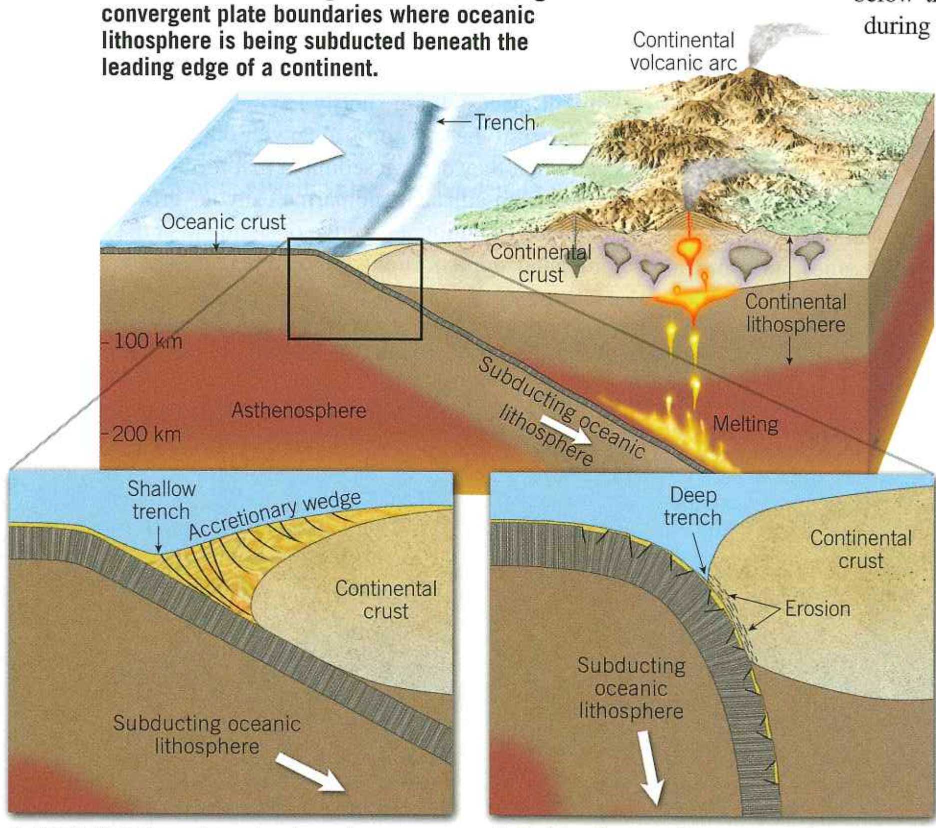
Submarine Canyons and Turbidity Currents

Deep, steep-sided valleys known as **submarine canyons** are cut into the continental slope and may extend across the entire continental rise to the deep-ocean basin (**FIGURE 13.11**). Although some of these canyons appear to be the seaward extensions of river valleys, many others do not line up in this manner. Furthermore, submarine canyons extend to depths far below the maximum lowering of sea level during the Ice Age, so we cannot attribute their formation to stream erosion.

These submarine canyons have probably been excavated by turbidity currents. **Turbidity currents** are downslope movements of dense, sediment-laden water. They are created when sand and mud on the continental shelf and slope are dislodged and thrown into suspension. Because the mud-choked water is denser than normal seawater, it moves downslope as a mass, eroding and accumulating more sediment as it goes. The erosional work repeatedly carried on by these muddy torrents is thought to be the major force in the excavation of most submarine canyons.

Turbidity currents usually originate along the continental slope and continue across the continental rise, still cutting channels. Eventually, they lose momentum and come to rest along the

Active continental margins are located along convergent plate boundaries where oceanic lithosphere is being subducted beneath the leading edge of a continent.



A. Accretionary wedges develop along subduction zones where sediments from the ocean floor are scraped from the descending oceanic plate and pressed against the edge of the overriding plate.

B. Subduction erosion occurs where sediment and rock scraped off the bottom of the overriding plate is carried into the mantle by the subducting plate.

floor of the deep-ocean basin. As these currents slow, suspended sediments begin to settle out. First, the coarser sand is dropped, followed by successively finer accumulations of silt and then clay. These deposits, called *turbidites*, display a decrease in sediment grain size from bottom to top, a feature known as *graded bedding*. Turbidity currents are an important mechanism of sediment transport in the ocean. By the action of turbidity currents, submarine canyons are excavated, and sediments are carried to the deep-ocean floor.

Active Continental Margins

Active continental margins are located along convergent plate boundaries where oceanic lithosphere is being subducted beneath the leading edge of a continent (**FIGURE 13.12**). Deep-ocean trenches are the major topographic expression at convergent plate boundaries. These deep, narrow furrows surround most of the Pacific Rim.

Along some subduction zones, sediments from the ocean floor and pieces of oceanic crust are scraped from the descending oceanic plate and plastered against the edge of the overriding plate. This chaotic accumulation of deformed sediment and scraps of oceanic crust is called an **accretionary wedge** (*ad* = toward, *crescere* = to grow). Prolonged plate subduction can produce massive accumulations of sediment along active continental margins.

The opposite process, known as **subduction erosion**, characterizes many other active continental margins. Rather than sediment accumulating along the front of the overriding plate, sediment and rock are scraped off the bottom of the overriding plate and transported into the mantle by the subducting plate. Subduction erosion is particularly effective when the angle of descent is steep. Sharp bending of the subducting plate causes faulting in the ocean crust and a rough surface, as shown in Figure 13.12.

13.3 CONCEPT CHECKS

1. List the three major features of a passive continental margin. Which of these features is considered a flooded extension of the continent? Which one has the steepest slope?
2. Describe the differences between active and passive continental margins. Where is each type found?
3. Discuss the process that is responsible for creating most submarine canyons.
4. How are active continental margins related to plate tectonics?
5. Briefly explain how an accretionary wedge forms. What is meant by *subduction erosion*?

13.4 FEATURES OF DEEP-OCEAN BASINS

List and describe the major features associated with deep-ocean basins.

Between the continental margin and the oceanic ridge lies the **deep-ocean basin** (see Figure 13.8). The size of this region—almost 30 percent of Earth's surface—is roughly comparable to the percentage of land that presently projects above sea level. This region includes *deep-ocean trenches*, which are extremely deep linear depressions in the ocean floor; remarkably flat areas known as *abyssal plains*; tall volcanic peaks called *seamounts* and *guyots*; and extensive areas of lava flows piled one atop the other called *oceanic plateaus*.

Deep-Ocean Trenches

Deep-ocean trenches are long, relatively narrow troughs that are the deepest parts of the ocean. Most trenches are located along the margins of the Pacific Ocean, where many exceed 10 kilometers (6 miles) in depth (see Figure 13.7). A portion of one—the Challenger Deep in the Mariana Trench—has been measured at a record 10,994 meters (36,069 feet) below sea level, making it the deepest-known part of the world ocean (**FIGURE 13.13**). Only two trenches are located in the Atlantic: the Puerto Rico Trench and the South Sandwich Trench.

Although deep-ocean trenches represent only a very small portion of the area of the ocean floor, they are nevertheless significant geologic features. Trenches are sites of plate convergence where slabs of oceanic lithosphere subduct and plunge back into the mantle. In addition to earthquakes being

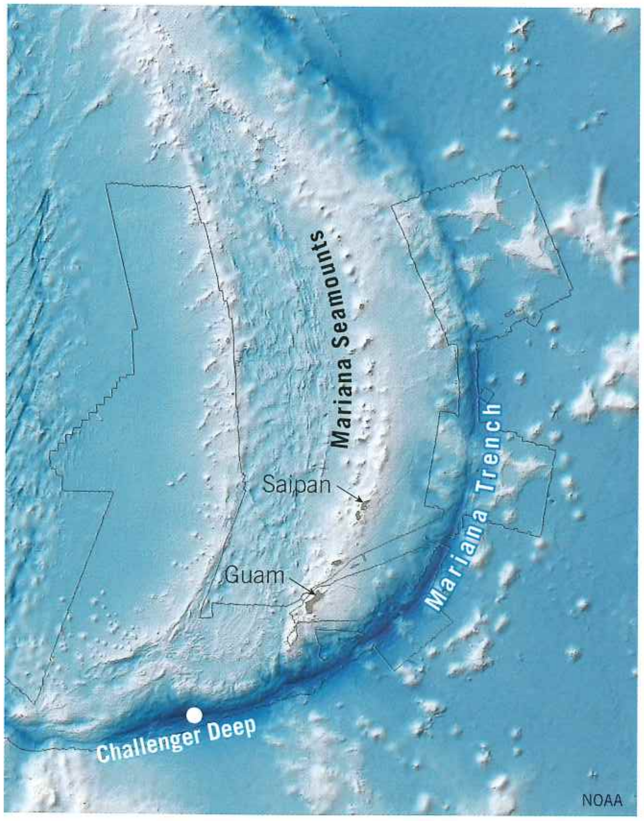
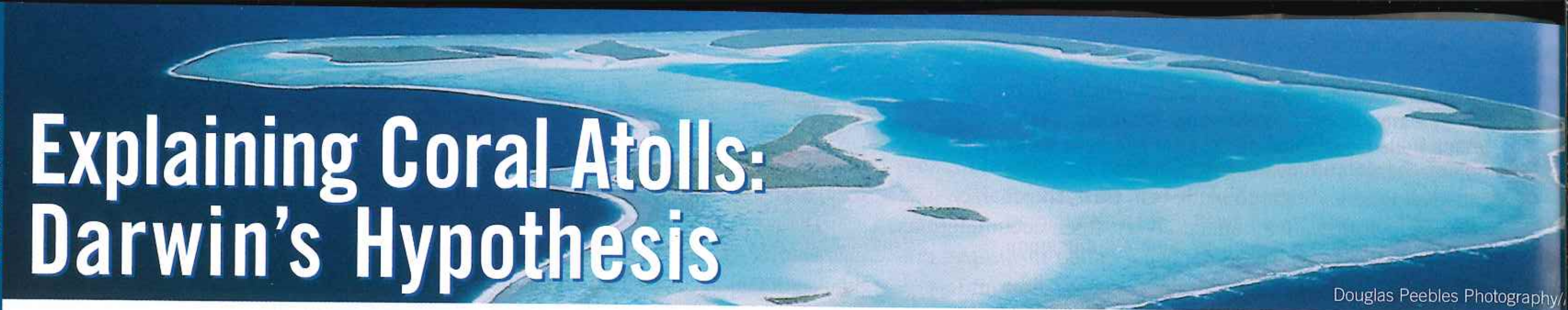


FIGURE 13.13 The Challenger Deep Located near the southern end of the Mariana Trench, the Challenger Deep is the deepest place in the global ocean, about 10,994 meters (36,069 feet) deep. Film director James Cameron (*Titanic* and *Avatar*) made news in March 2012 as the first person to take a deep-diving submersible to the bottom of the Challenger Deep in more than 50 years.


Douglas Peebles Photography/

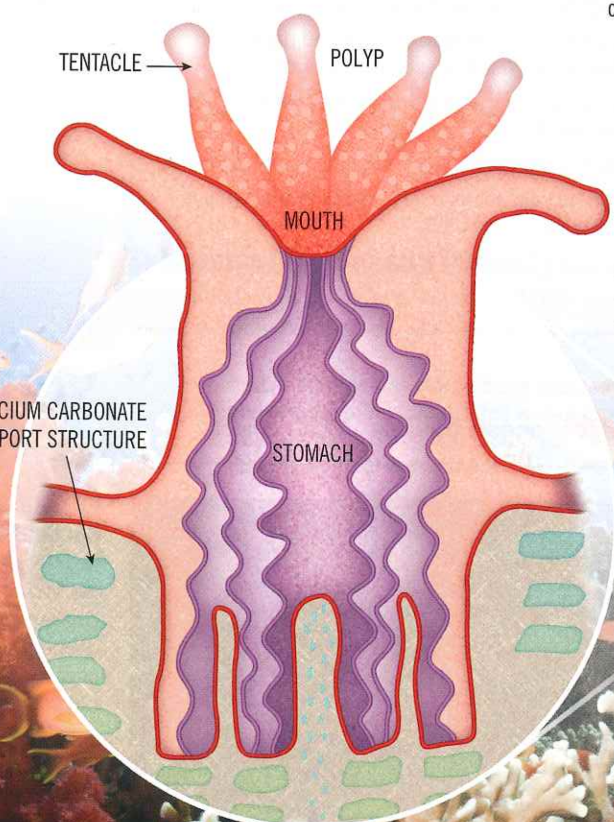
Explaining Coral Atolls: Darwin's Hypothesis

Coral atolls are ring-shaped structures that often extend from slightly above sea level to depths of several thousand meters. What causes atolls to form, and how do they attain such great thicknesses?

Reef-building corals only grow in warm, clear sunlit water. The depth of most active reef growth is limited to warm tropical water no more than about 45 meters (150 feet) deep. The strict environmental conditions required for coral growth create an interesting paradox: How can corals—which require warm, shallow, sunlit water no deeper than a few dozen meters—create massive structures such as coral atolls that extend to great depths?

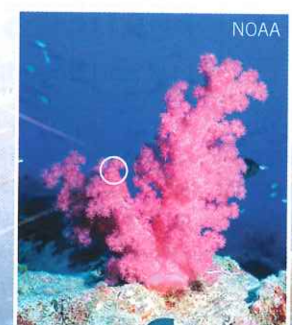
Most corals secrete a hard external skeleton made of calcium carbonate. Colonies of these corals build large calcium carbonate structures, called reefs, where new colonies grow atop the strong skeletons of previous colonies. Sponges and algae may attach to the reef, further enlarging the structure.

Mark A. Wilson



Corals: Tiny colonial animals
Corals are marine animals that typically live in compact colonies of many identical organisms called polyps.


NOAA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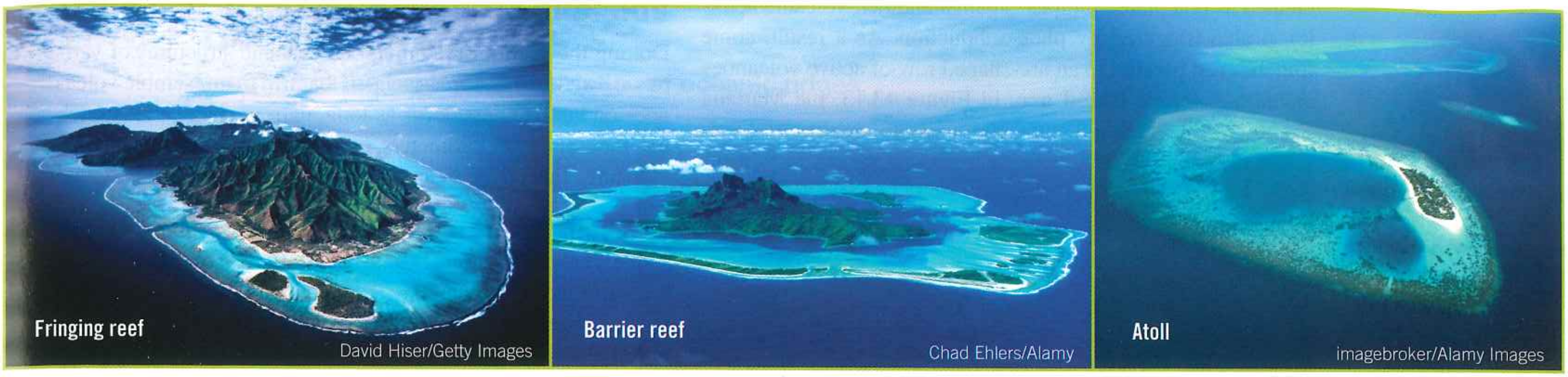
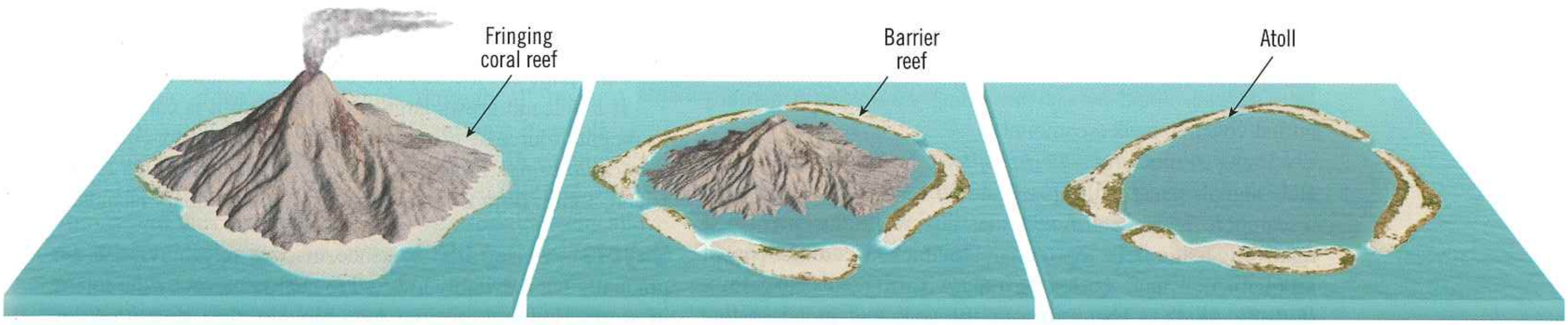
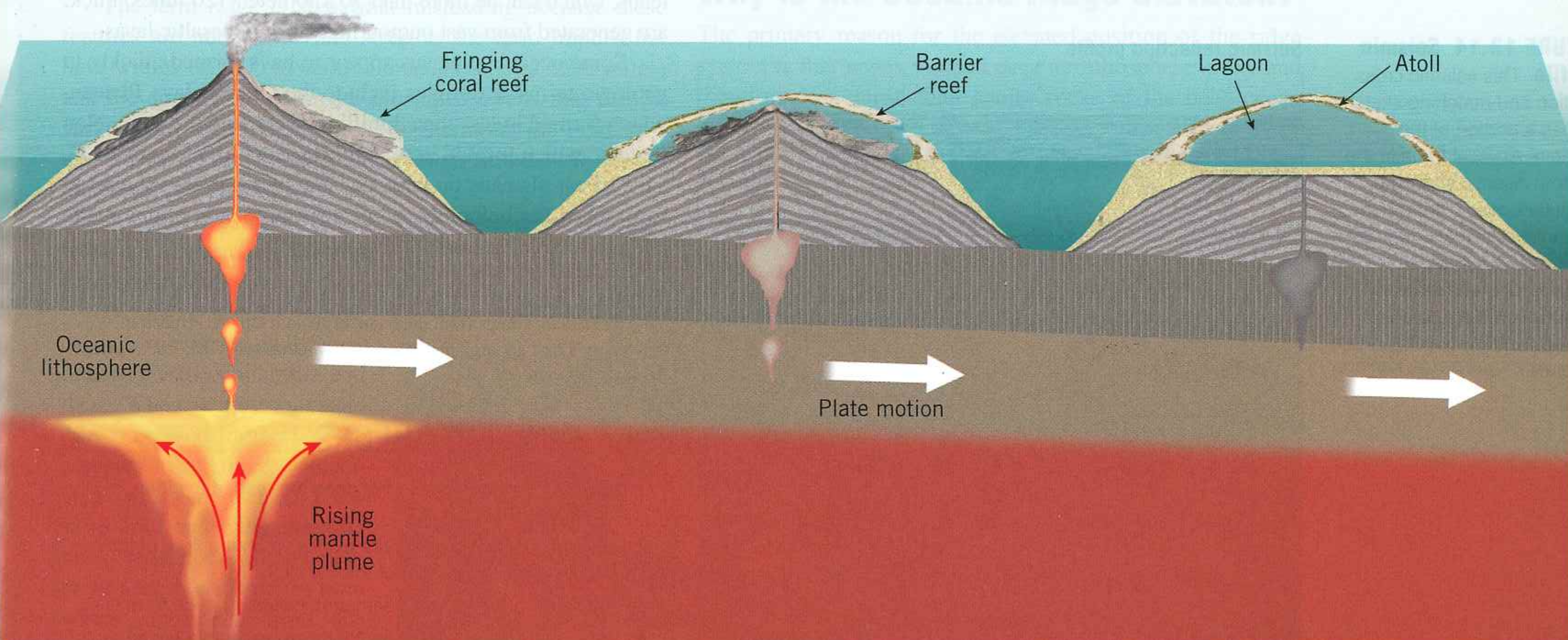


What Darwin observed Naturalist Charles Darwin was one of the first to formulate a hypothesis on the origin of these ringed-shaped atolls. Aboard the British ship HMS *Beagle* during its famous global circumnavigation, Darwin noticed a progression of stages in coral reef development from (1) a fringing reef along the margins of a volcano to (2) a barrier reef with a volcano in the middle to (3) an atoll, consisting of a continuous or broken ring of coral reef surrounding a central lagoon.



Darwin's hypothesis Darwin's hypothesis asserts that, in addition to being lowered by erosional forces, many volcanic islands gradually sink. Darwin also suggested that corals respond to the gradual change in water depth caused by the subsiding volcano by building the reef complex upward. During Darwin's time, however, there was no plausible mechanism to account for how, or why so many volcanic islands sink.

Plate tectonics and coral atolls The plate tectonics theory provides the most current scientific explanation regarding how volcanic islands become extinct and sink to great depths over long periods of time. Some volcanic islands form over relatively stationary mantle plumes, causing the lithosphere to be buoyantly uplifted. Over spans of millions of years, these volcanic islands gradually sink as moving plates carry them away from the region of hot-spot volcanism because the oceanic lithosphere cools, becomes denser, and sinks.



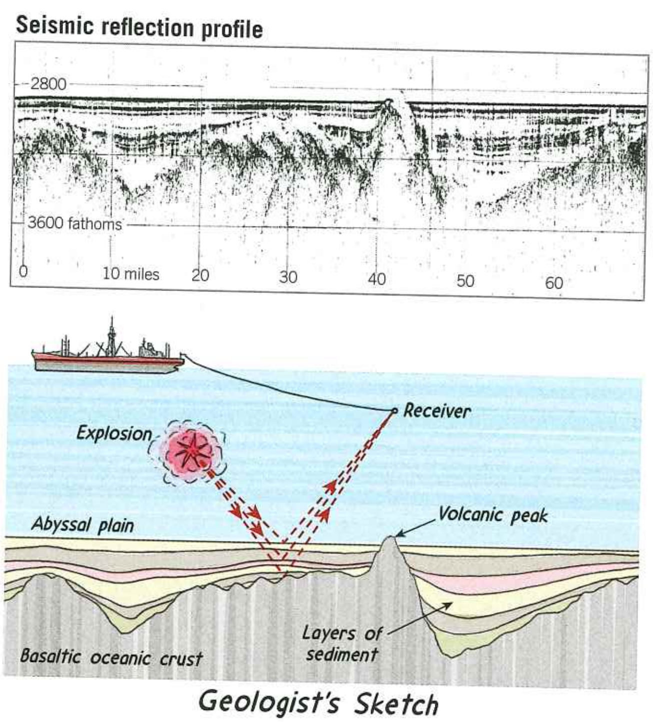
created as one plate "scrapes" against another, volcanic activity is also triggered by plate subduction. As a result, some trenches run parallel to an arc-shaped row of active volcanoes called a **volcanic island arc**. In Figure 13.13, the Mariana Seamounts are such a feature. Furthermore, **continental volcanic arcs**, such as those making up portions of the Andes and Cascades, are located parallel to trenches that lie adjacent to continental margins. The volcanic activity associated with the trenches that surround the Pacific Ocean explains why the region is called the *Ring of Fire*.

Abyssal Plains

Abyssal (*a* = without, *byssus* = bottom) **plains** are deep, incredibly flat features; in fact, these regions are likely the most level places on Earth. The abyssal plain found off the coast of Argentina, for example, has less than 3 meters (10 feet) of relief over a distance exceeding 1300 kilometers (800 miles). The monotonous topography of abyssal plains is occasionally interrupted by the protruding summit of a partially buried volcanic peak (seamount).

Using *seismic reflection profilers*, instruments that generate signals designed to penetrate far below the ocean floor, researchers have determined that abyssal plains owe their relatively featureless topography to thick accumulations of sediment that have buried an otherwise rugged ocean floor (**FIGURE 13.14**). The nature of the sediment indicates that these plains consist primarily of three types of sediment: (1) fine sediments transported far out to sea by turbidity currents, (2) mineral matter that has precipitated out of seawater, and (3) shells and skeletons of microscopic marine organisms.

Abyssal plains occur in all oceans. However, the floor of the Atlantic has the most extensive abyssal plains because it has few trenches to act as traps for sediment carried down the continental slope.



13.14 Seismic This seismic cross nd matching sketch portion of the byssal Plain in the tlantic show the oceanic crust buried ents. (Image courtesy Oceanographic harles Hollister, Jsed with permission s Hole Oceanographic

Volcanic Structures on the Ocean Floor

Dotting the seafloor are numerous volcanic structures of various sizes. Many occur as isolated features that resemble volcanoes on land. Others occur as long, narrow chains that stretch for thousands of kilometers, while still others are massive structures that cover an area the size of Texas.

Seamounts and Volcanic Islands

Submarine volcanoes, called **seamounts**, may rise hundreds of meters above the surrounding topography. It is estimated that more than 1 million seamounts exist. Some grow large enough to become oceanic islands, but most do not have a sufficiently long eruptive history to build a structure above sea level. Although seamounts are found on the floors of all the oceans, they are most common in the Pacific.

Some, like the Hawaiian Island–Emperor seamount chain, which stretches from the Hawaiian islands to the Aleutian trench, form over volcanic hot spots (see Figure 13.7 and Figure 7.28, page 231). Others are born near oceanic ridges.

If a volcano grows large enough before it is carried from its magma source by plate motion, the structure may emerge as a *volcanic island*. Examples of volcanic islands include Easter Island, Tahiti, Bora Bora, Galapagos, and the Canary islands.

Guyots

During their existence, inactive volcanic islands are gradually but inevitably lowered to near sea level by the forces of weathering and erosion. As a moving plate slowly carries inactive volcanic islands away from the elevated oceanic ridge or hot spot over which they formed, they gradually sink and disappear below the water surface. Submerged, flat-topped seamounts that formed in this manner are called **guyots**.*

Oceanic Plateaus

The ocean floor contains several massive **oceanic plateaus**, which resemble lava plateaus composed of flood basalts found on the continents. Oceanic plateaus, which can be more than 30 kilometers (20 miles) thick, are generated from vast outpourings of fluid basaltic lavas.

Some oceanic plateaus appear to have formed quickly in geologic terms. Examples include the Ontong Java Plateau, which formed in less than 3 million years, and the Kerguelen Plateau, which formed in 4.5 million years (see Figure 13.7). Like basalt plateaus on land, oceanic plateaus are thought to form when the bulbous head of a rising mantle plume melts and produces a vast outpouring of basalt.

*The term *guyot* comes from the name of Arnold Guyot, Princeton University's first geology professor. It is pronounced "GEE-oh," with a hard *g*, as in *give*.

13.4 CONCEPT CHECKS

1. Explain how deep-ocean trenches are related to plate boundaries.
2. Why are abyssal plains more extensive on the floor of the Atlantic than on the floor of the Pacific?
3. How does a flat-topped seamount, called a *guyot*, form?
4. What features on the ocean floor most resemble basalt plateaus on the continents?

13.5 THE OCEANIC RIDGE

Summarize the basic characteristics of oceanic ridges.

Along well-developed divergent plate boundaries, the seafloor is elevated, forming a broad linear swell called the or **rise**, or **mid-ocean ridge**. Our knowledge of the oceanic ridge system comes from soundings of the ocean floor, core samples from deep-sea drilling, visual inspection using deep-diving submersibles (**FIGURE 13.15**), and firsthand inspection of slices of ocean floor that have been thrust onto dry land during continental collisions. At oceanic ridges we find extensive normal and strike-slip faulting, earthquakes, high heat flow, and volcanism.

FIGURE 13.15 The Deep-Diving Submersible *Alvin* This submersible is 7.6 meters (25 feet) long, weighs 16 tons, has a cruising speed of 1 knot, and can reach depths of 4000 meters (more than 13,000 feet). A pilot and two scientific observers are along during a normal 6- to 10-hour dive. (Photo by Rod Catanach KRT/Newscom)

Anatomy of the Oceanic Ridge

The oceanic ridge system winds through all major oceans in a manner similar to the seam on a baseball and is the longest topographic feature on Earth, at more than 70,000 kilometers (43,000 miles) in length (**FIGURE 13.16**). The crest of the ridge typically stands 2 to 3 kilometers above the adjacent deep-ocean basins and marks the plate boundary where new oceanic crust is created.

Notice in Figure 13.16 that large sections of the oceanic ridge system have been named based on their locations within the various ocean basins. Some ridges run through the middle of ocean basins, where they are appropriately called *mid-ocean* ridges. The Mid-Atlantic Ridge and the Mid-Indian Ridge are examples. By contrast, the East Pacific Rise is *not* a "mid-ocean" feature. Rather, as its name implies, it is located in the eastern Pacific, far from the center of the ocean.

The term *ridge* is somewhat misleading because these features are not narrow and steep as the term implies but have widths of 1000 to 4000 kilometers (600 to 2500 miles) and the appearance of broad, elongated swells that exhibit varying degrees of ruggedness. Furthermore, the ridge system is broken into segments that range from a few tens to hundreds of kilometers in length. Each segment is offset from the adjacent segment by a transform fault.

Oceanic ridges are as high as some mountains on the continents; but the similarities end there. Whereas most mountain ranges on land form when the compressional forces associated with continental collisions fold and metamorphose thick sequences of sedimentary rocks, oceanic ridges form where upwelling from the mantle generates new oceanic crust. Oceanic ridges consist of layers and piles of newly formed basaltic rocks that are buoyantly uplifted by the hot mantle rocks from which they formed.

Along the axes of some segments of the oceanic ridge system are deep, down-faulted structures that are called **rift valleys** because of their striking similarity to the continental rift valleys found in East Africa (**FIGURE 13.17**). Some rift valleys, including those along the rugged Mid-Atlantic Ridge, are typically 30 to 50 kilometers (20 to 30 miles) wide and have walls that tower 500 to 2500 meters (1640 to 8200 feet) above the valley floor. This makes them comparable to the deepest and widest part of Arizona's Grand Canyon.

Why Is the Oceanic Ridge Elevated?

The primary reason for the elevated position of the ridge system is that newly created oceanic lithosphere is hot and therefore less dense than cooler rocks of the deep-ocean basin. As the newly formed basaltic crust travels away from the ridge crest, it is cooled from above as seawater

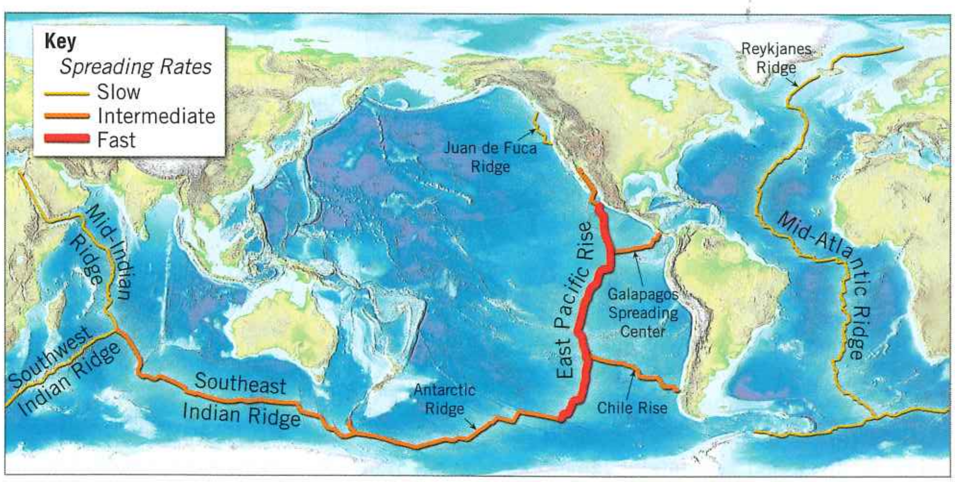


FIGURE 13.16 Distribution of the Oceanic Ridge System The map shows ridge segments that exhibit slow, intermediate, and fast spreading rates.

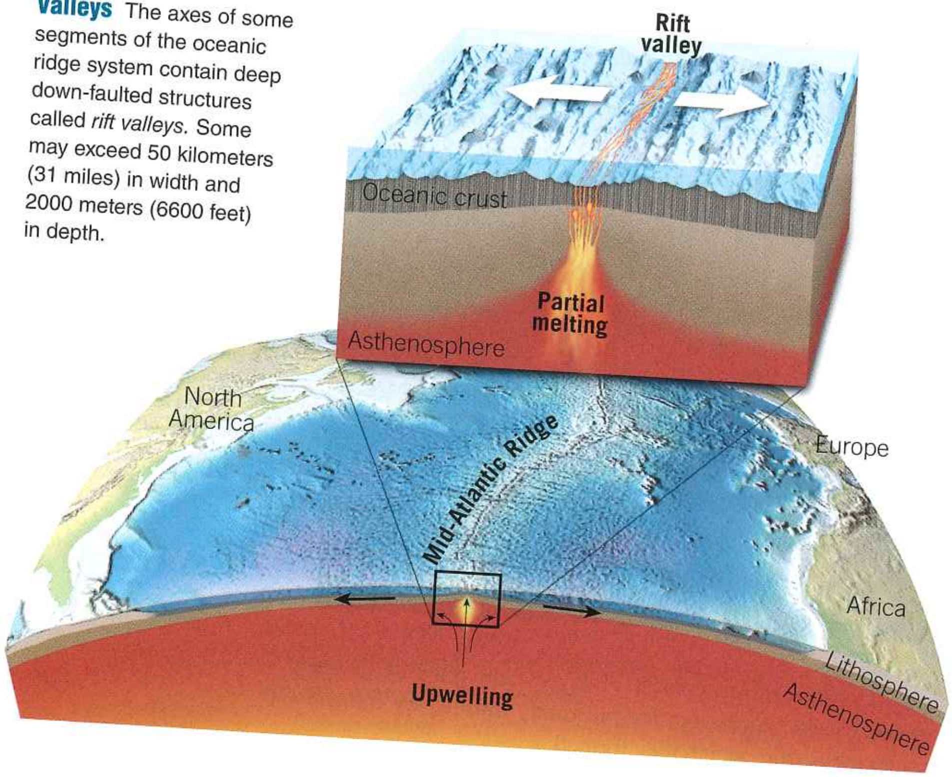


FIGURE 13.17 Rift Valleys The axes of some segments of the oceanic ridge system contain deep down-faulted structures called *rift valleys*. Some may exceed 50 kilometers (31 miles) in width and 2000 meters (6600 feet) in depth.

circulates through the pore spaces and fractures in the rock. In addition, it cools because it gets farther and farther from the zone of hot mantle upwelling. As a result, the lithosphere gradually cools, contracts, and becomes denser. This thermal contraction accounts for the greater ocean depths that occur away from the ridge. It takes almost 80 million years of cooling and contraction for rock that was once part of an elevated ocean ridge system to relocate to the deep-ocean basin.

As lithosphere is displaced away from the ridge crest, cooling also causes a gradual increase in lithospheric thickness. This happens because the boundary between the lithosphere and asthenosphere is a thermal (temperature) boundary. Recall that the lithosphere is Earth's cool, stiff outer layer, whereas the asthenosphere is a comparatively hot and weak layer. As material in the uppermost asthenosphere ages (cools), it becomes stiff and rigid. Thus, the upper portion of the asthenosphere is gradually converted to lithosphere simply by cooling. Oceanic lithosphere continues to thicken until it is about 80 to 100 kilometers (50 to 60 miles) thick. Thereafter, its thickness remains relatively unchanged until it is subducted.

13.5 CONCEPT CHECKS

1. Briefly describe oceanic ridges.
2. Although oceanic ridges can be as tall as some mountains on the continents, list some ways that oceanic ridges are different from mountains.
3. Where do rift valleys form along the oceanic ridge system?
4. What is the primary reason for the elevated position of the oceanic ridge system?

13.6 SEAFLOOR SEDIMENTS

Distinguish among three categories of seafloor sediment and explain why some of these sediments can be used to study climate change.

Except for steep areas of the continental slope and areas near the crest of the mid-ocean ridge, the ocean floor is covered with sediment. Part of this material has been deposited by turbidity currents, and the rest has slowly settled to the seafloor from above. The thickness of this carpet of debris varies greatly. In some trenches, which act as traps for sediments originating on the continental margin, accumulations may approach 10 kilometers (6 miles). In general, however, sediment accumulations are considerably less. In the Pacific Ocean, for example, uncompacted sediment measures about 600 meters (2000 feet) or less, whereas on the floor of the Atlantic, the thickness varies from 500 to 1000 meters (1600 to 3300 feet).

Types of Seafloor Sediments

Seafloor sediments can be classified according to their origin into three broad categories: **terrigenous** ("derived from land"), **biogenous** ("derived from organisms"), and **hydrogenous** ("derived from water"). Although each category is discussed separately, remember that all seafloor sediments are mixtures. No body of sediment comes entirely from a single source.

Terrigenous Sediment Terrigenous sediment consists primarily of mineral grains that were weathered from continental rocks and transported to the ocean. Larger particles (sand and gravel) usually settle rapidly near shore, whereas the very smallest particles take years to settle to the ocean floor and may be carried thousands of kilometers by ocean currents. As a result, virtually every area of the ocean receives some terrigenous sediment. The rate at which this sediment accumulates on the deep-ocean floor, though, is very slow. Forming a 1-centimeter (0.4-inch) abyssal clay layer, for example, requires as much as 50,000 years. Conversely, on the continental margins near the mouths of large rivers, terrigenous sediment accumulates rapidly and forms thick deposits.

Biogenous Sediment Biogenous sediment consists of shells and skeletons of marine animals and algae (**FIGURE 13.18**).

This debris is produced mostly by microscopic organisms living in the sunlit waters near the ocean surface. Once these organisms die, their hard *tests* (*testa* = shell) continually "rain" down and accumulate on the seafloor.

The most common biogenous sediment is *calcareous* ($CaCO_3$) *ooze*, which, as the name implies, has the consistency of thick mud. This sediment is produced from the tests of organisms that inhabit warm surface waters. When calcareous hard parts slowly sink through a cool layer of water, they begin to dissolve. This occurs because the deeper cold seawater is richer in carbon dioxide and is thus more acidic than warm water. In seawater deeper than about 4500 meters (15,000 feet), calcareous tests completely dissolve before they reach bottom. Consequently, calcareous ooze does not accumulate at these greater depths.

Other biogenous sediments include *siliceous* (SiO_2) *ooze* and phosphate-rich material. The former is composed primarily of tests of diatoms (single-celled algae) and radiolaria (single-celled animals), whereas the latter is derived from the bones, teeth, and scales of fish and other marine organisms.

Hydrogenous Sediment Hydrogenous sediment consists of minerals that crystallize directly from seawater through various chemical reactions. For example, some limestones are formed when calcium carbonate precipitates directly from the water; however, most limestone is composed of biogenous sediment.

Some of the most common types of hydrogenous sediment include the following:

- *Manganese nodules* are rounded, hard lumps of manganese, iron, and other metals that precipitate in concentric layers around a central object (such as a volcanic pebble or a grain of sand). The nodules can be up to 20 centimeters (8 inches) in diameter and are often littered across large areas of the deep seafloor (**FIGURE 13.19A**).
- *Calcium carbonates* form by precipitating directly from seawater in warm climates. If this material is buried and hardened, it forms limestone. Most limestone, however, is composed of biogenous sediment.
- *Metal sulfides* are usually precipitated as coatings on rocks near black smokers associated with the crest of a mid-ocean ridge (**FIGURE 13.19B**). These deposits contain iron, nickel, copper, zinc, silver, and other metals in varying proportions.
- *Evaporites* form where evaporation rates are high and there is restricted open-ocean circulation. As water evaporates from such areas, the remaining seawater becomes saturated with dissolved minerals, which then begin to precipitate. Heavier than seawater, they sink to the bottom or form a characteristic white crust of evaporite minerals around the edges of these areas. Evaporites are collectively termed *salts*; some evaporite minerals taste salty, such as *halite* (common table salt, NaCl), and some do not, such as the calcium sulfate minerals *anhydrite* ($CaSO_4$) and *gypsum* ($CaSO_4 \cdot 2H_2O$).

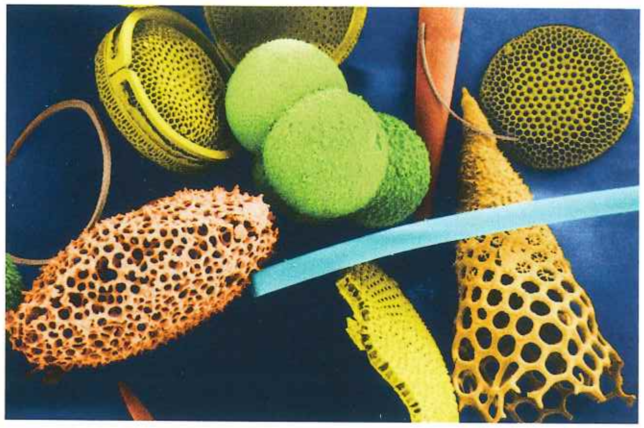


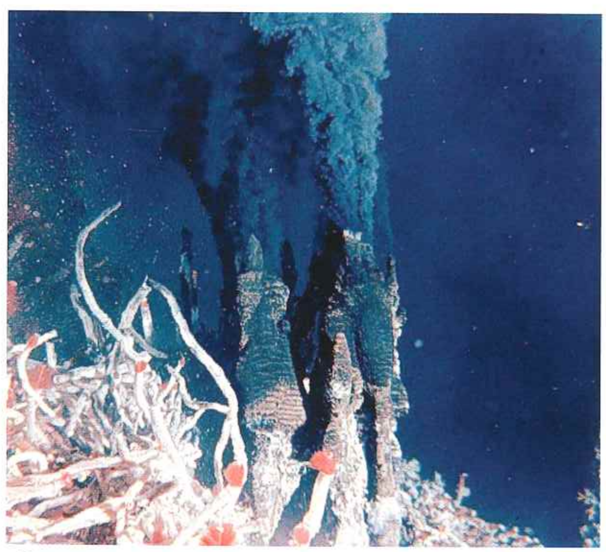
FIGURE 13.18 Marine Microfossils: An Example of Biogenous Sediment These tiny, single-celled organisms are sensitive to even small fluctuations in temperature. Seafloor sediments containing these fossils are useful sources of data on climate change. (Photo by Mary Martin/Science Source)

Seafloor Sediment—A Storehouse of Climate Data

Reliable climate records go back only a couple hundred years, at best. How do scientists learn about climates and climate change prior to that time? They must reconstruct past climates from *indirect evidence*; that is, they must analyze phenomena that respond to and reflect changing atmospheric conditions. An interesting and important technique for analyzing Earth's climate history is the study of biogenous seafloor sediments.

We know that the parts of the Earth system are linked so that a change in one part can produce changes in any or all of the other parts. For example, changes in atmospheric and oceanic temperatures are reflected in the nature of life in the sea.

A.



B.

SmartFigure 13.19 Examples of Hydrogenous Sediment **A.** Manganese nodules. (Photo by Charles A. Winter/Science Source) **B.** This black smoker is spewing hot, mineral-rich water. When the heated solutions meet cold seawater, metal sulfides precipitate and form mounds of minerals around these hydrothermal vents. (Photo by Fisheries and Oceans Canada/Uvic—Verena Tunnicliffe/Newscom)

FIGURE 13.20 Data from the Seafloor This scientist is holding a sediment core obtained by an oceanographic research vessel. Cores of sediment provide data that allow for a more complete understanding of past climates. Notice the "library" of sediment cores in the background. (Photo by INGO WAGNER/EPA/Newscom)

Most seafloor sediments contain the remains of organisms that once lived near the sea surface (the ocean–atmosphere interface). When such near-surface organisms die, their shells slowly settle to the floor of the ocean, where they become part of the sedimentary record. These seafloor sediments are useful recorders of worldwide climate change because the numbers and types of organisms living near the sea surface change with the climate.

Thus, in seeking to understand climate change as well as other environmental transformations, scientists are tapping the huge reservoir of data in seafloor sediments (**FIGURE 13.20**). The sediment cores gathered by drilling ships such as the one in the chapter-opening photo and other research vessels have provided invaluable data that have significantly expanded our knowledge and understanding of past climates.

One notable example of the importance of seafloor sediments to our understanding of climate change relates to unraveling the fluctuating atmospheric conditions of the Ice Age. The records of temperature changes contained in cores of sediment from the ocean floor have been critical to our present understanding of this recent span of Earth history.

13.6 CONCEPT CHECKS

1. Distinguish among the three basic types of seafloor sediments. Give an example of each.
2. Why are seafloor sediments useful in studying past climates?

13.7 RESOURCES FROM THE SEAFLOOR

Discuss some important resources and potential resources associated with the ocean floor.

The seafloor is rich in mineral and organic resources. Most, however, are not easily accessible, and recovery involves technological challenges and high cost. Nevertheless, certain resources have high value and thus make appealing exploration targets.

Energy Resources

Among the nonliving resources extracted from the oceans, more than 95 percent of the economic value comes from energy products. The main energy products are oil and natural gas, which are currently being extracted, and gas hydrates, which are not yet being utilized but have significant potential.

Oil and Natural Gas The ancient remains of microscopic organisms, buried within marine sediments before they could completely decompose, are the source of today's deposits of 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 results from continuing technological advancements employed by offshore drilling platforms.

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 located off the northern coast of Alaska and in the Canadian Arctic, Asian seas, Africa, and Brazil. Because the likelihood of finding major new reserves on land is small, future offshore exploration will continue to be important, especially in deeper waters of the continental margins. A major environmental concern about offshore petroleum exploration is the possibility of oil spills caused by inadvertent leaks or blowouts during the drilling process (**FIGURE 13.21**).

Gas Hydrates **Gas hydrates** are unusually 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 (1720 feet).

Most oceanic gas hydrates are created when bacteria break down organic matter trapped in seafloor sediments, producing methane gas with minor amounts of ethane and propane. These gases combine with water in deep-ocean sediments (where pressures are high and temperatures are low) 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 retrieved cores of mud mixed with chunks or layers of gas hydrates (**FIGURE 13.22**) that fizzle and 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 because methane and other flammable gases are released as gas hydrates vaporize.

Some estimates indicate that as much as 20 quadrillion cubic meters (700 quadrillion cubic feet) of methane are locked up in sediments containing gas hydrates. This is equivalent to about *twice* as much carbon as Earth's coal, oil, and conventional gas reserves combined, so gas hydrates have great potential. A major drawback in exploiting reserves of gas hydrates is that they rapidly decompose at surface temperatures and pressures. In the future, however, these vast seafloor reserves of energy may help power modern society.

Other Resources

Other major resources from the seafloor 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 includes rock fragments that are washed out to sea and shells of marine organisms, are mined by offshore barges using suction dredges. Sand and gravel are primarily used as an aggregate in concrete, as a fill material in grading projects, and on recreational beaches.

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, and some Florida beach sands are rich in titanium.

FIGURE 13.21 Disaster in the Gulf of Mexico On April 20, 2010, the mobile floating drilling platform named *Deepwater Horizon* exploded while working on a 10,680-meter (35,000-foot) well in approximately 1600 meters (5200 feet) of water, causing a devastating oil spill. (Photo by John Mosier/ZUMA Press/Newscom)

Evaporative Salts When seawater evaporates, the salts increase in concentration until they can no longer remain dissolved, so they precipitate out of solution and form salt deposits, which can then be harvested. 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 water conditioners, in agriculture, in the clothing industry for dying fabric, and to de-ice roads. Since ancient times, the ocean has been an important source of salt for human consumption, and the sea remains a significant supplier (**FIGURE 13.23**).

FIGURE 13.22 Gas Hydrates This sample was retrieved from the deep-ocean floor and shows white ice-like gas hydrate mixed with mud. Gas hydrates evaporate when exposed to surface conditions and release natural gas, which can be ignited. (Photo courtesy USGS National Center)

EYE ON EARTH

Gas hydrates are natural gas reservoirs in ice-like crystalline solids found in sediments on the deep-ocean floor and in Arctic permafrost areas deeper than 200 meters (660 feet). Gas hydrates contain methane molecules—the main ingredient of most natural gas—which is trapped within a lattice-like cage of water molecules. These deposits, called "ice that burns" are stable only at relatively high pressures and/or low temperatures. (Photo by Yonhap News/Newscom)

QUESTION 1 *At surface temperatures and pressures, in what state of matter is methane? With this in mind, what problems exist for the extraction of gas hydrate deposits?*

QUESTION 2 *Explain why gas hydrates are not found in sediments at shallow depths such as those found on the continental shelf.*

FIGURE 13.23 Solar Salt Seawater is one important source of common salt (sodium chloride). Saltwater is held in shallow ponds, where solar energy evaporates the water. The nearly pure salt deposits that eventually form are essentially artificial evaporate deposits. (Photo by Geof Kirb/Alamy Images)

Manganese Nodules Manganese nodules contain significant concentrations of manganese and iron, and they contain smaller concentrations of copper, nickel, and cobalt, all of which have a variety of economic uses. Cobalt, for example, is deemed "strategic" (essential to U.S. national security) because it is required to produce dense, strong alloys with other metals and is used in high-speed cutting tools, powerful permanent magnets, and jet engine parts. Technologically, mining the deep-ocean floor for manganese nodules is possible but economically not profitable.

Nodules are widely distributed, but not all regions have the same potential for mining. Good locations have abundant nodules that contain the economically optimum mix of copper, nickel, and cobalt. Sites meeting these criteria, however, are relatively limited. In addition, there are political problems of establishing mining rights far from land and environmental concerns about disturbing large portions of the deep-ocean floor.

13.7 CONCEPT CHECKS

1. Which seafloor resource is presently most valuable?
2. What are gas hydrates? Will they likely be a significant energy source in the next 10 years?
3. What nonenergy seafloor resource is most valuable?

13 CONCEPTS IN REVIEW — The Ocean Floor

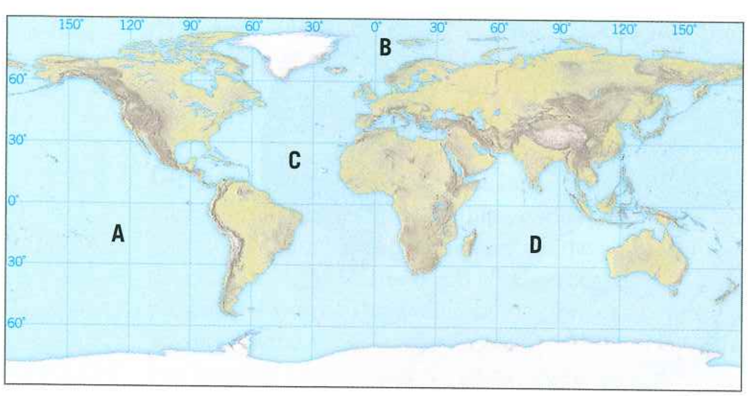
13.1 THE VAST WORLD OCEAN

Discuss the extent and distribution of oceans and continents on Earth. Identify Earth's four main ocean basins.

KEY TERM: oceanography

- Oceanography is an interdisciplinary science that draws on the methods and knowledge of biology, chemistry, physics, and geology to study all aspects of the world ocean.
- Earth's surface is dominated by oceans. Nearly 71 percent of the planet's surface area is oceans and marginal seas. In the Southern Hemisphere, about 81 percent of the surface is water.
- Of the three major oceans—the Pacific, Atlantic, and Indian—the Pacific Ocean is the largest, contains slightly more than half of the water in the world ocean, and has the greatest average depth—3940 meters (12,927 feet).

Q Name the four principal oceans identified with letters on this world map.



13.2 AN EMERGING PICTURE OF THE OCEAN FLOOR

Define *bathymetry* and summarize the various techniques used to map the ocean floor.

KEY TERMS: bathymetry, sonar, echo sounder

- Seafloor mapping is done with sonar—shipboard instruments that emit pulses of sound that "echo" off the bottom. Satellites are also used to map the ocean floor. Their instruments measure slight variations in sea level that result from differences in the gravitational pull of features on the seafloor. Accurate maps of seafloor topography can be made using these data.
- Mapping efforts have revealed three major areas of the ocean floor: continental margins, deep-ocean basins, and oceanic ridges.

Q Do the math: How many seconds would it take an echo sounder's ping to make the trip from a ship to the Challenger Deep (10,994 meters [36,069 feet]) and back? Recall that Depth = ½ (1500 m/sec × Echo travel time).

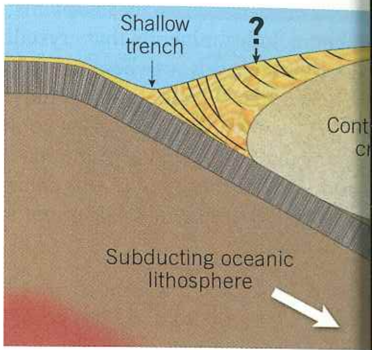
13.3 CONTINENTAL MARGINS

Compare a passive continental margin with an active continental margin and list the major features of each.

KEY TERMS: continental margin, passive continental margin, continental shelf, continental slope, continental rise, deep-sea fan, submarine canyon, turb[...] current, active continental margin, accretionary wedge, subduction erosion

- Continental margins are transition zones between continental and oceanic crust. Active continental margins occur where a plate boundary and the e[...] a continent coincide, usually on the leading edge of a plate. Passive continental margins are on the trailing edges of continents, far from plate bound[...]
- Heading offshore from the shoreline of a passive margin, a submarine traveler would first encounter the gently sloping continental shelf and then the steeper continental slope, which marks the end of the continental crust and the beginning of the oceanic crust. Beyond the continental slope is another gently sloping section, the continental rise: It is made of sediment transported by turbidity currents through submarine canyons and piled up in deep-sea fans atop the oceanic crust.
- Submarine canyons are deep, steep-sided valleys that originate on the continental slope and may extend to the deep-ocean basin. Many submarine canyons have been excavated by turbidity currents (downslope movements of dense, sediment-laden water).
- At an active continental margin, material may be added to the leading edge of a continent in the form of an accretionary wedge (common at shallow-angle subduction zones), or material may be scraped off the edge of a continent by subduction erosion (common at steeply dipping subduction zones).

Q What type of continental margin is depicted by this diagram? Be as specific as possible. Name the feature indicated by the question mark.



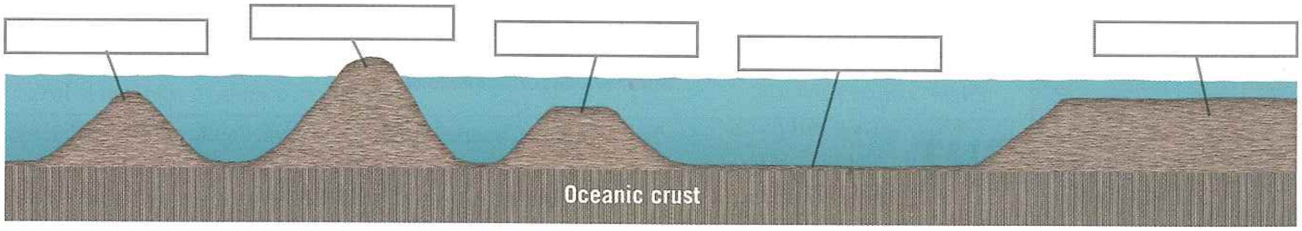
13.4 FEATURES OF DEEP-OCEAN BASINS

List and describe the major features associated with deep-ocean basins.

KEY TERMS: deep-ocean basin, deep-ocean trench, volcanic island arc, continental volcanic arc, abyssal plain, seamount, guyot, oceanic plateau

- The deep-ocean basin makes up about half of the ocean floor's area. Much of it is abyssal plain (deep, featureless sediment-draped crust). Subducti[...] zones and deep-ocean trenches also occur in deep-ocean basins. Paralleling trenches are volcanic island arcs (if the subduction goes underneath oce[...] lithosphere) or continental volcanic arcs (if the overriding plate has continental lithosphere on its leading edge).
- There are a variety of volcanic structures on the deep-ocean floor. Seamounts are submarine volcanoes; if they pierce the surface of the ocean, we c[...] them volcanic islands. Guyots are old volcanic islands that have had their tops eroded off before they sink below sea level. Oceanic plateaus are unu[...] thick sections of oceanic crust formed by massive underwater eruptions of lava.

Q On this cross-sectional view of a deep-ocean basin, label the following features: a seamount, a guyot, a volcanic island, an oceanic plateau, [...] an abyssal plain.



13.5 THE OCEANIC RIDGE

Summarize the basic characteristics of oceanic ridges.

KEY TERMS: oceanic ridge or rise (mid-ocean ridge), rift valley

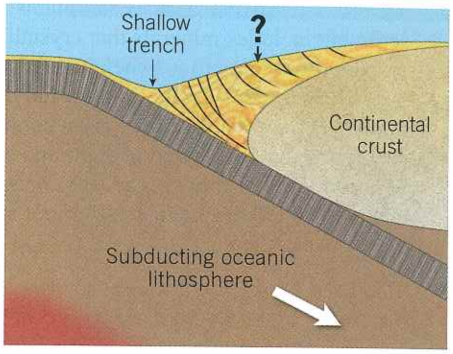
- The oceanic ridge system is the longest topographic feature on Earth, wrapping around the world through all major ocean basins. It is a few kilomet[...] tall, a few thousand kilometers wide, and a few tens of thousands of kilometers long. The summit is the place where new oceanic crust is generated, [...] marked by a rift valley.
- Oceanic ridges are elevated features because they are warm and therefore less dense than older, colder oceanic lithosphere. As oceanic crust moves a[...] from the ridge crest, heat loss causes the oceanic crust to become denser and subside. After 80 million years, crust that was once part of an oceanic r[...] in the deep-ocean basin, far from the ridge.

13.3 CONTINENTAL MARGINS

Compare a passive continental margin with an active continental margin and list the major features of each.

KEY TERMS: continental margin, passive continental margin, continental shelf, continental slope, continental rise, deep-sea fan, submarine canyon, turbidity current, active continental margin, accretionary wedge, subduction erosion

- Continental margins are transition zones between continental and oceanic crust. Active continental margins occur where a plate boundary and the edge of a continent coincide, usually on the leading edge of a plate. Passive continental margins are on the trailing edges of continents, far from plate boundaries.
- Heading offshore from the shoreline of a passive margin, a submarine traveler would first encounter the gently sloping continental shelf and then the steeper continental slope, which marks the end of the continental crust and the beginning of the oceanic crust. Beyond the continental slope is another gently sloping section, the continental rise: It is made of sediment transported by turbidity currents through submarine canyons and piled up in deep-sea fans atop the oceanic crust.
- Submarine canyons are deep, steep-sided valleys that originate on the continental slope and may extend to the deep-ocean basin. Many submarine canyons have been excavated by turbidity currents (downslope movements of dense, sediment-laden water).
- At an active continental margin, material may be added to the leading edge of a continent in the form of an accretionary wedge (common at shallow-angle subduction zones), or material may be scraped off the edge of a continent by subduction erosion (common at steeply dipping subduction zones).



Q What type of continental margin is depicted by this diagram? Be as specific as possible. Name the feature indicated by the question mark.

13.4 FEATURES OF DEEP-OCEAN BASINS

List and describe the major features associated with deep-ocean basins.

KEY TERMS: deep-ocean basin, deep-ocean trench, volcanic island arc, continental volcanic arc, abyssal plain, seamount, guyot, oceanic plateau

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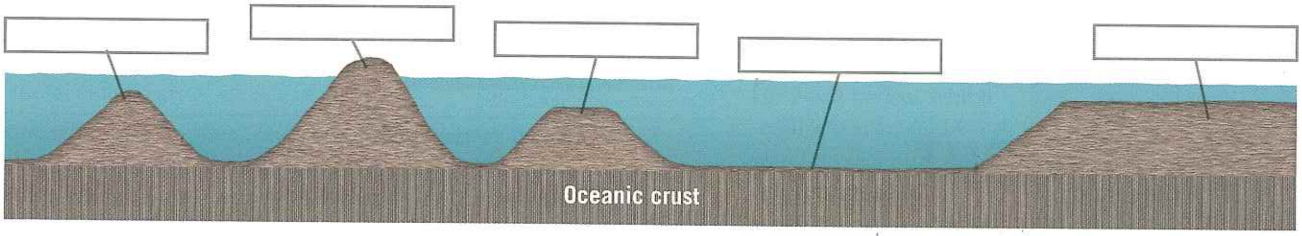
- There are a variety of volcanic structures on the deep-ocean floor. Seamounts are submarine volcanoes; if they pierce the surface of the ocean, we call them volcanic islands. Guyots are old volcanic islands that have had their tops eroded off before they sink below sea level. Oceanic plateaus are unusually thick sections of oceanic crust formed by massive underwater eruptions of lava.

Q On this cross-sectional view of a deep-ocean basin, label the following features: a seamount, a guyot, a volcanic island, an oceanic plateau, and an abyssal plain.



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KEY TERMS: oceanic ridge or rise (mid-ocean ridge), rift valley

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- Oceanic ridges are elevated features because they are warm and therefore less dense than older, colder oceanic lithosphere. As oceanic crust moves away from the ridge crest, heat loss causes the oceanic crust to become denser and subside. After 80 million years, crust that was once part of an oceanic ridge is in the deep-ocean basin, far from the ridge.

.6 SEAFLOOR SEDIMENTS

Distinguish among three categories of seafloor sediment and explain why some of these sediments can be used to study climate change.

TERMS: terrigenous sediment, biogenous sediment, hydrogenous sediment

here are three broad categories of seafloor sediments. errigenous sediment consists primarily of mineral grains hat were weathered from continental rocks and transported o the ocean; biogenous sediment consists of shells and keletons of marine animals and plants; and hydrogenous ediment includes minerals that crystallize directly from eawater through various chemical reactions.

eafloor sediments are helpful in studying worldwide limate change because they often contain the remains of rganisms that once lived near the sea surface. The numers and types of these organisms change as the climate hanges, and their remains in seafloor sediments record ese changes.

NASA

his satellite image from February 4, 2013, shows a lume of dust moving from the southern Arabian Peninula over the Arabian Sea, the name given to a portion the Indian Ocean. The wind will subside, and the dust ill settle onto the water and slowly sink, eventually aching the ocean floor. To which category of seafloor ediment will this material belong?

7 RESOURCES FROM THE SEAFLOOR

Discuss some important resources and potential resources associated with the ocean floor.

ERM: gas hydrate

l and natural gas represent more than 95 percent of the value of the nliving resources extracted from the oceans.

out 30 percent of world oil production is from offshore areas. Environntal concerns include leaks and blowouts.

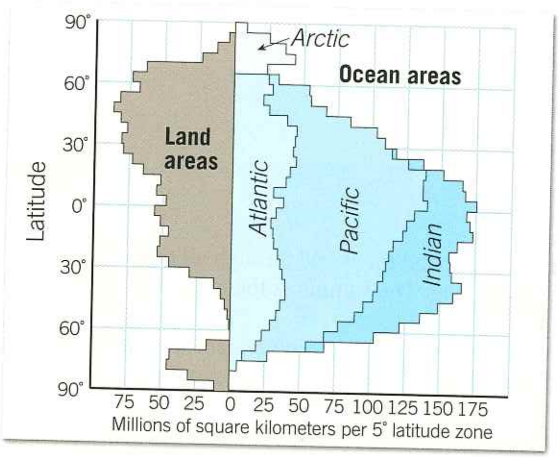
- Gas hydrates are complex molecules made of natural gas and water. Some form under high pressure and low temperature in marine sediments. Gas hydrates also form in permafrost environments. When brought to Earth's surface, they rapidly decompose into methane and water.
- Significant nonenergy resources and potential resources include sand and gravel, salt, and manganese nodules. About 30 percent of the world's supply of salt is extracted from seawater.

Q Name two *potential* resources from the seafloor—one energy and one nonenergy.

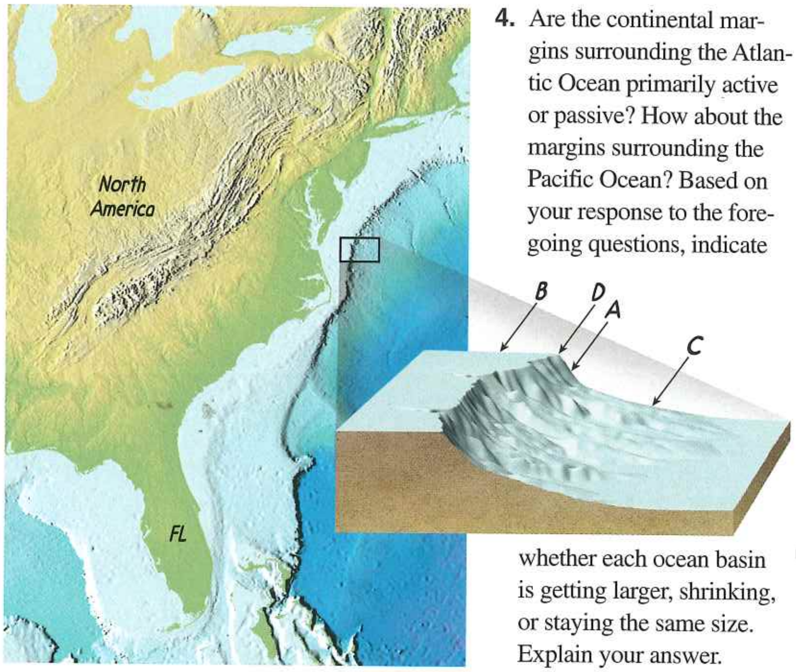
VE IT SOME **THOUGHT**

efer to the accomnying graph to swer the following estions:

Water dominates Earth's surface but not everywhere.
In what Northern Hemisphere latitude belt is there more land than water?
In what latitude belt is there no land at all?

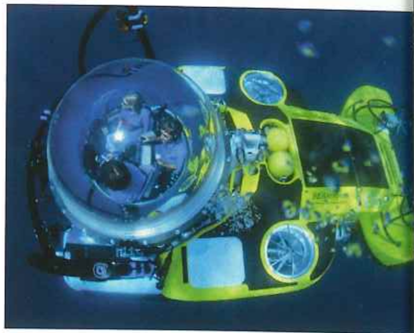


2. Assuming that the average speed of sound waves in water is 1500 meters per second, determine the water depth if a signal sent out by an echo sounder on a research vessel requires 6 seconds to strike bottom and return to the recorder aboard the ship.
3. Refer to the accompanying map on the top of the next page, which shows the eastern seaboard of the United States to complete the following:
   a. Associate each of the following with a letter on the map: continental rise, continental shelf, continental slope, and shelf-break.
   b. How does the size of the continental shelf surrounding Florida compare to the size of the Florida peninsula?
   c. Why are there no deep-ocean trenches on this map?

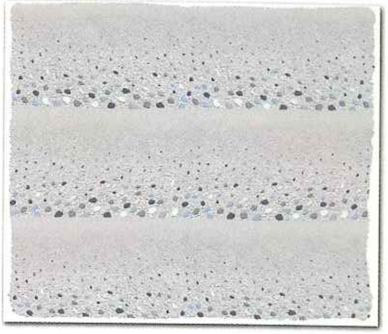


4. Are the continental margins surrounding the Atlantic Ocean primarily active or passive? How about the margins surrounding the Pacific Ocean? Based on your response to the foregoing questions, indicate whether each ocean basin is getting larger, shrinking, or staying the same size. Explain your answer.

5. Imagine that you and a passenger are in a deep-diving submersible such as the one shown here in the North Pacific Ocean near Alaska's Aleutian islands. During a typical 6- to 10-hour dive, you encounter a long, narrow depression on the ocean floor. Your passenger asks whether you think it is a submarine canyon, a rift valley, or a deep-ocean trench. How would you respond? Explain your choice.

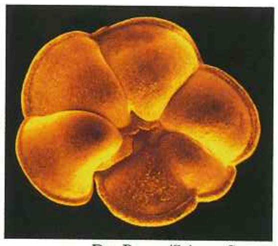

Jeff Rotman/Alamy

6. Examine the accompanying sketch, showing three sediment layers on the ocean floor. What term is applied to such layers? What process was responsible for creating these layers? Are these layers more likely part of a deep-sea fan or an accretionary wedge?



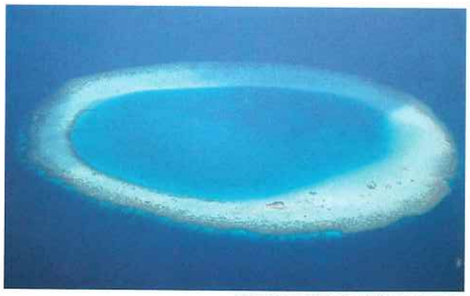
EXAMINING THE **EARTH SYSTEM**

1. Describe some of the material and energy exchanges that take place at the following interfaces:
   a. ocean surface and atmosphere
   b. ocean water and ocean floor
   c. ocean biosphere and ocean water
2. This image from a scanning electron microscope shows the shell (test) of a tiny organism called a foraminiferan that was collected from the ocean floor by a research vessel. When alive, the organism that created this shell lived in the shallow surface waters of the ocean. Relate this tiny shell to each of Earth's four major spheres. Why are microscopic fossils such as this one useful in the study of climate change?


Dee Breger/Science Source

3. Sediment on the seafloor often leaves clues about various conditions that existed during deposition. What do the following layers in a seafloor core indicate about the environment in which each layer was deposited?
   - Layer 5 (top): A layer of fine clays
   - Layer 4: Siliceous ooze
   - Layer 3: Calcareous ooze
   - Layer 2: Fragments of coral reef
   - Layer 1 (bottom): Rocks of basaltic composition with some metal sulfide coatings

   Explain how one area of the seafloor could experience such varied conditions of deposition.
4. Reef-building corals are responsible for creating atolls—ring-shaped structures that extend from the surface of the ocean to depths of thousands of meters. These corals, however, can only live in warm, sunlit water no more than about 45 meters (150 feet) deep. This presents a paradox: How can corals, which require warm, sunlit water, create structures that extend to great depths? Explain the apparent contradiction.


Reinlhard Dirscherl/Getty Images

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