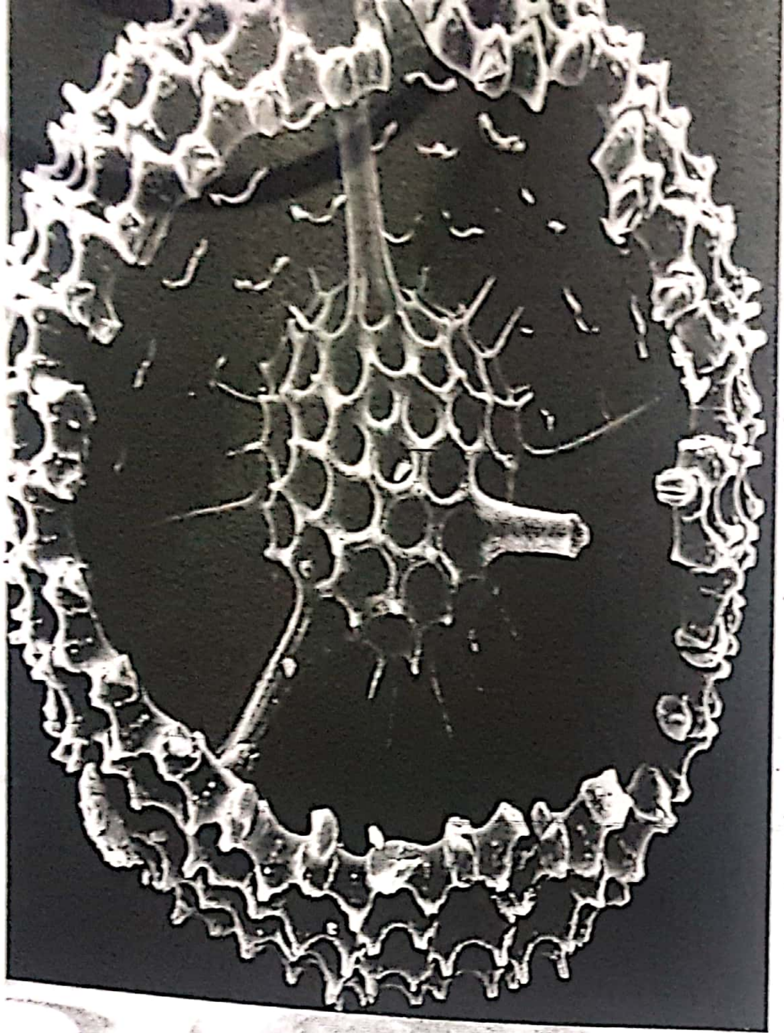


Colorized scanning electron micrograph
siliceous test (skeleton) of a radiolarian

Chapter 4

The Sea Floo

LEARNING OBJECTIVES

After reading this chapter, you should be able to

- Describe the divisions and features of the continental margin.
- Describe the formation of a submarine canyon.
- Describe the features of the ocean basin floor.
- Understand the use of echo sounding to map the sea floor.
- Compare ocean sediments by source, properties, and distribution.
- Relate sediment particle size and sinking rate.
- Describe the instruments used to sample seafloor sediments.
- Give examples of seafloor mineral resources.
- Understand the political, legal, and economic factors related to harvesting seafloor mineral resources.

The sea floor was an unknown environment to early mariners and the first curious scientists. They believed that the oceans were large basins or depressions in Earth's crust, but they did not conceive that these basins held features that were as magnificent as the mountain chains, deep valleys, and great canyons of the land. As maps were created in greater detail and as ocean travel and commerce increased, it became essential to map seafloor features in the shallower regions, but it was not until the 1950s that improvements in technology made it possible to sample the deep sea floor routinely and in detail.

The geography and the geology of the sea floor are the products of processes that occur on both human and geological time scales. The main features of the sea floor are compelling evidence for plate tectonics as discussed in chapter 3.

4.1 The Sea Floor

The mountain ranges under the sea are longer, the valley floors are wider and flatter, and the canyons are often deeper than those found on land. Land features are continually eroded by wind, rain, and ice, and are affected by changes in temperature and rock chemistry. The erosion of seafloor features is slow, and occurs only by way of waves and currents along the shore and on steep underwater slopes. Beneath the surface the water dissolves away certain materials, changing the rock chemistry, but the features retain their shape and are only slowly modified as they are covered by a constant rain of particles or **sediment** falling from above. Computer-drawn profiles of elevations across the United States and the Atlantic Ocean are compared in figure 4.1. Notice that the profiles of the mountain ranges on land and ridge systems of the sea floor are similar.

4.2 The Continental Margin

The region of the sea floor that is closest to land is called the **continental margin**. Continental margins are the edges of the landmasses at present below the ocean surface and their steep slopes that descend to the deep sea floor. The two different types of continental margins, passive and active, are discussed in section 3.10. Passive continental margins can be subdivided into four distinct regions: the continental shelf, shelf break, slope, and rise (fig. 4.2). Along active continental margins, the continental slope typically continues into a deep ocean trench except where large amounts of sediment carried off the continent have filled the trench.

The **continental shelf** is a nearly flat region of varying width that slopes very gently toward the ocean basins. Shelf widths average about 65 km (40 mi) and vary from only a few tens of kilometers to more than 1500 km (930 mi).

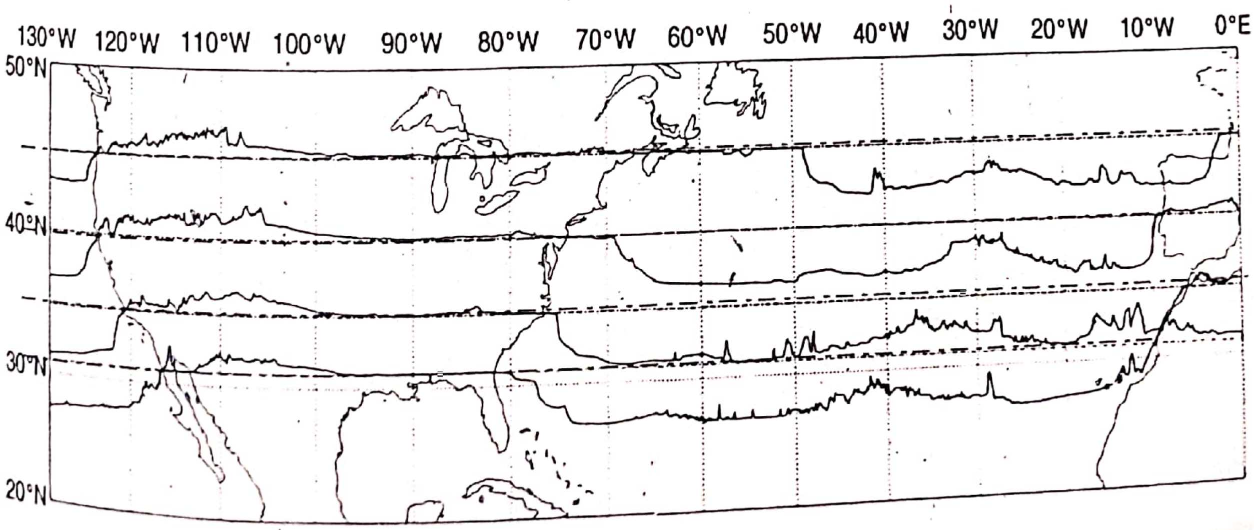


Figure 4.1 Computer-drawn topographic profiles from the west coast of Europe and Africa to the Pacific Ocean. The elevations and depths above and below 0 meters are shown along a line of latitude by using the latitude line as zero elevation. For example, the ocean depth at 40°N and 60°W is 5040 m (16,500 ft). The vertical scale has been exaggerated about one hundred times the horizontal scale. If both the horizontal and vertical scales were kept the same, a vertical elevation change of 5000 m would measure only 0.05 millimeters (0.002 inches).

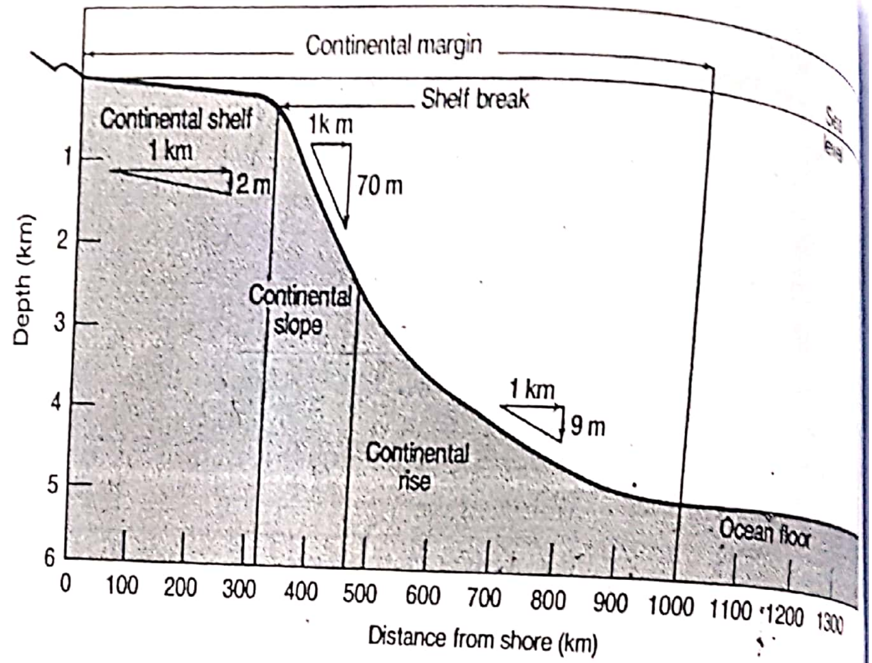
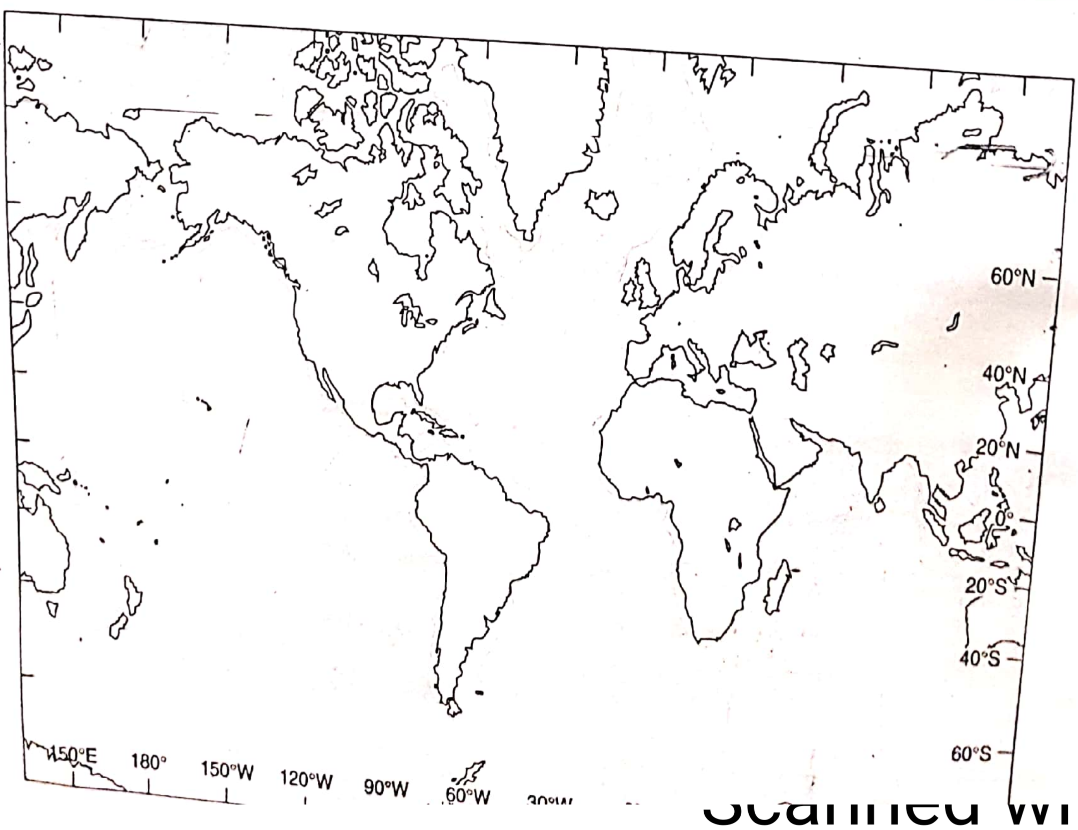


Figure 4.2 A typical profile of a passive continental margin. Notice both the vertical and horizontal extent of each subdivision. The average slope is indicated for the continental shelf, slope, and rise. The vertical scale is one hundred times greater than the horizontal scale.

The distribution of the world's continental shelves is shown in figure 4.3. The shelf is narrow along the mountainous coasts of active continental margins and wide along low-lying land at passive continental margins. Passive margin continental shelves are often further modified by sea-level changes and storm waves that erode the edges of the continents, and, in some cases, natural dams on the shelves, such as reefs, trap sediments between the offshore dam and the coast. Notice the narrow shelf along the west coasts of North and South America and the wide shelves off the eastern and northern coasts of North America, Siberia, and Scandinavia.

The continental shelves are geologically part of the continents, and during past ages, they have been covered and uncovered by fluctuations in sea level. When the sea level was low during the ice ages (periods of increased ice on land), erosion deepened valleys, waves eroded previously submerged land, and rivers left their sediments far out on the shelf. When the ice melted and sea level rose, these areas were flooded and sediments built up in areas close to the new shore. Although presently submerged, these shelf areas still show the scars of old riverbeds and glaciers, features they acquired when exposed as part of the continent. Some continental shelves are covered with thick deposits of silt, sand, and mud derived from the land; for example, the Mississippi and Amazon Rivers deposit large amounts of sediments at their mouths. Other shelves are bare of sediments, such as where the



Florida Current sweeps the tip of Florida, carrying the shelf sediments northward to the deeper water of the Atlantic Ocean.

The boundary of the continental shelf on the ocean side is determined by an abrupt change in slope, leading to a more rapid increase in depth. This change in slope is referred to as the **continental shelf break**, while the steeper slope extending to the ocean basin floor is known as the **continental slope.**

The angle and extent of the slope vary from place to place. The slope may be short and steep—for example, the depth may increase rapidly from 200 m (650 ft) to 3000 m (10,000 ft), as in figure 4.2 or it may drop as far as 8000 m (26,000 ft) into a deep sea trench, as it does off the west coast of South America. The continental slope may show rocky outcroppings, and it is often relatively bare of sediments because of its steepness.

The most outstanding features found on the continental slopes are **submarine canyons.** These canyons sometimes extend up, into, and across the continental shelf. A submarine canyon is steep-sided and has a V-shaped cross section, with tributaries similar to those of river-cut canyons on land. Figure 4.4a shows the Monterey and Carmel canyons off the coast of California. Figure 4.4b compares a profile of the Monterey Canyon with a profile of the Grand Canyon of the Colorado River.

Many of these submarine canyons are associated with existing river systems on land and were apparently cut into the shelf during periods of low sea level, when the rivers flowed across the continental shelves. Ripple marks on the floors of canyons and sediments fanning out at the ends of these canyons suggest that they have been formed by moving flows of sediment and water called **turbidity currents.** Turbidity currents are fast-moving avalanches of mud, sand, and water caused by earthquakes or the overloading of sediments on steep slopes. They flow down the slope, eroding and picking up sediment as they gain speed, and over time they erode the slope and excavate the submarine canyon (fig. 4.5). As the turbidity current flow reaches the sea floor, it slows and spreads, and the sediments settle. During this settling process, coarse materials drop out and are overlaid by successive layers of decreasing particle size, and **turbidites** are formed; figure 4.6 shows a size-graded deposit preserved in a shore cliff. Turbidity currents have never been directly observed, although similar but smaller and more continuous flows, such as sand falls, have been observed and photographed. Compelling evidence of a large turbidity current in the ocean was observed in 1929 when a series of trans-Atlantic telephone cables south of Newfoundland along the Grand Banks were broken after an earthquake occurred beneath the continental slope (fig. 4.7). The cables closest to the earthquake broke when the earthquake occurred. The other cables broke in sequence with increasing distance from the earthquake. Scientists concluded that the earthquake triggered a turbidity current that moved down the continental slope at speeds of as much as 80 km (50 mi) per hour and across the less steep continental rise at about 24 km (15 mi) per hour, breaking cables as it reached them. This turbidity current traveled a total distance of about 650 km (400 mi).

At the base of the steep continental slope, there may be a gentle slope formed by the accumulation of sediment. This portion of the sea floor is the **continental rise** (fig. 4.2); it is a region of sediment deposition by turbidity currents, underwater landslides, and any other processes that carry sand, mud, and silt down the continental slope. The continental rise is a conspicuous feature in the Atlantic and Indian Oceans and around the Antarctic continent. Few continental rises occur in the Pacific Ocean; here great seafloor trenches are often at the

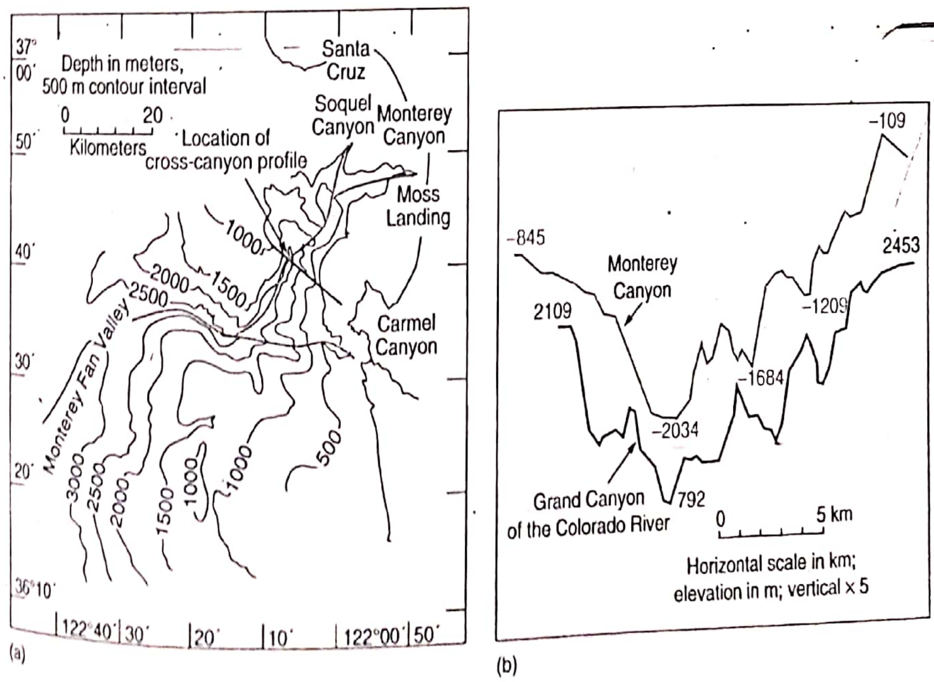


Figure 4.4 (a) Depth contours depict three submarine canyons off the California coast as they cut across the continental slope and continental shelf. The axes of the canyons, which merge seaward, are indicated by the *blue line*. (b) Cross-canyon profile, along the *red line* in (a), of the Monterey Canyon. Compare this profile to that of the Grand Canyon drawn to the same scale. *From* Submarine Geology. *Copyright © 1963 by Francis P. Shepard. Reprinted by permission of Addison-Wesley Educational Publishers.*

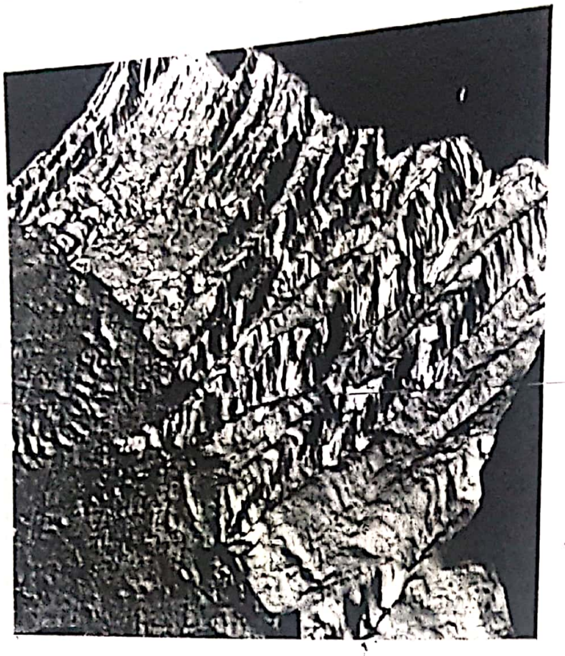


Figure 4.5 Image of the Continental Margin off the Coast of Delaware. Turbidity currents have cut deep canyons into the edge of the continental shelf and the continental slope. Some of these currents extend into the abyssal plains. The smooth plain at the base of the slope indicates where the sediments settled.

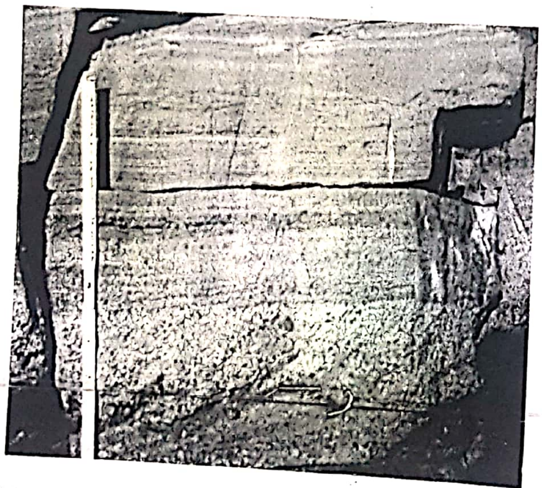


Figure 4.6 This beach cliff shows an ancient turbidite deposit that has been uplifted and then exposed by wave erosion. Turbidites are graded deposits, with the largest particles in the deposit at the bottom of the turbidite and the smallest particles at the top.

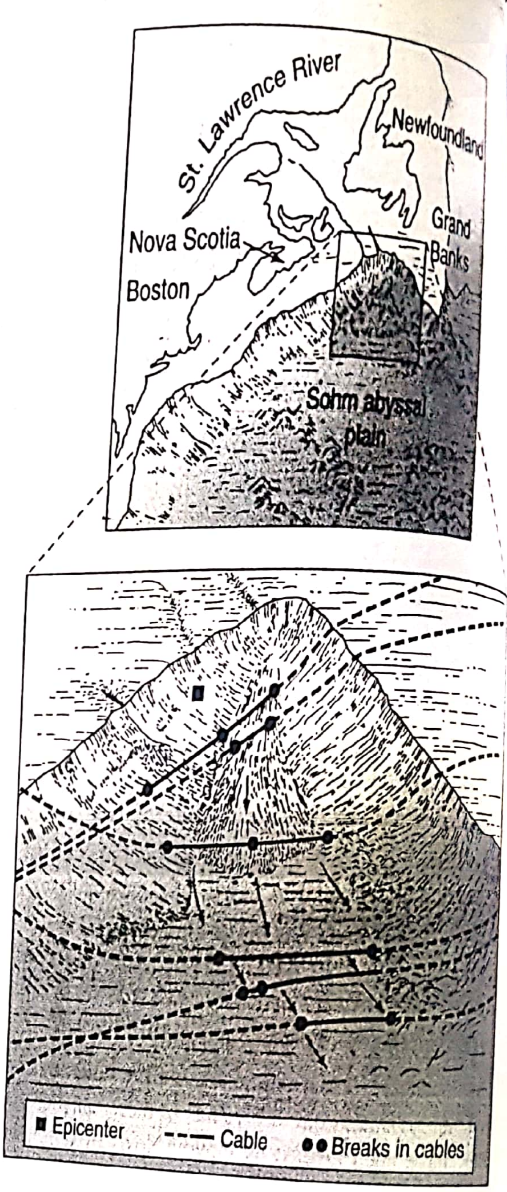


Figure 4.7 Failure of Cables Caused by Turbidity Currents. Cables lay across the continental shelf and the Grand Banks. A turbidity current formed as sediment at the edge of the continental shelf broke loose and flowed down the continental slope and rise, breaking the cables as it moved toward the abyssal plains.

base of the continental slope, where material from the active margin is being subducted.

Identify the divisions of the continental margin and distinguish between them.

How does the width of the continental shelf vary from place to place?

Explain the formation of a submarine canyon.

4.3 The Ocean Basin Floor

The deep sea floor, between 4000 and 6000 m (13,000–20,000 ft), covers more of Earth's surface (30%) than do the continents (29%). In many places, the ocean floor is a flat plain, known as an **abyssal plain.** Abyssal plains form as sediment deposits (from turbidity currents and the waters above) cover the irregular topography of the sea floor. Large wavelike undulations have been discovered in these sediment layers; these "mud waves" are formed by deep-ocean currents flowing across the abyssal plain. **Abyssal hills** and seamounts are scattered across the sea floor in all the oceans. Abyssal hills are volcanic features less than 1000 m (3300 ft) high, and seamounts are steep-sided volcanoes that are formed by local vulcanism and over hot spots; they rise abruptly toward the sea surface. Sometimes seamounts pierce the sea surface to become islands. These features are shown in figure 4.8. Abyssal hills are probably Earth's most common topographic feature. They are found over 50% of the Atlantic sea floor and about 80% of the Pacific floor; they are also abundant in the Indian Ocean.

In the warm waters of the Atlantic, Pacific, and Indian Oceans, coral reefs and coral islands are formed in association with seamounts. Reef-building coral is a warm-water animal that requires a place of attachment and grows in intimate association with a single-celled, plant-type organism. It is therefore confined to sunlit, shallow, warm waters. When a seamount pierces the sea surface to form an island, it provides a base on which the

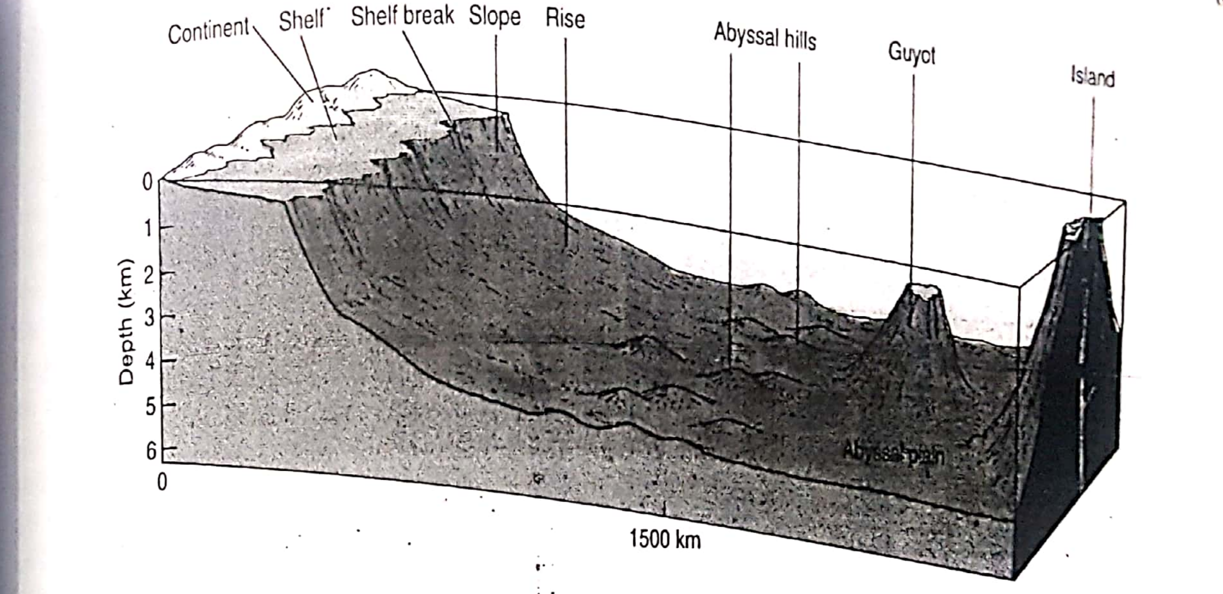


Figure 4.8 An idealized portion of ocean basin floor with abyssal hills (less than 1000 m of elevation), a guyot (a flat-topped seamount), and an island on the abyssal plain. The island was previously a seamount before it reached the surface. Seamounts and guyots are known to be volcanic in origin (vertical × 100).

coral can grow. The coral grows to form a **fringing reef** around the island. If the seamount sinks or subsides slowly enough, the coral continues to grow upward at the same rate as the rising water, and a **barrier reef** with a lagoon between the reef and the island is formed. If the process continues, eventually the seamount disappears below the surface and the coral reef is left as a ring, or **atoll.** This process is illustrated in figure 4.9.

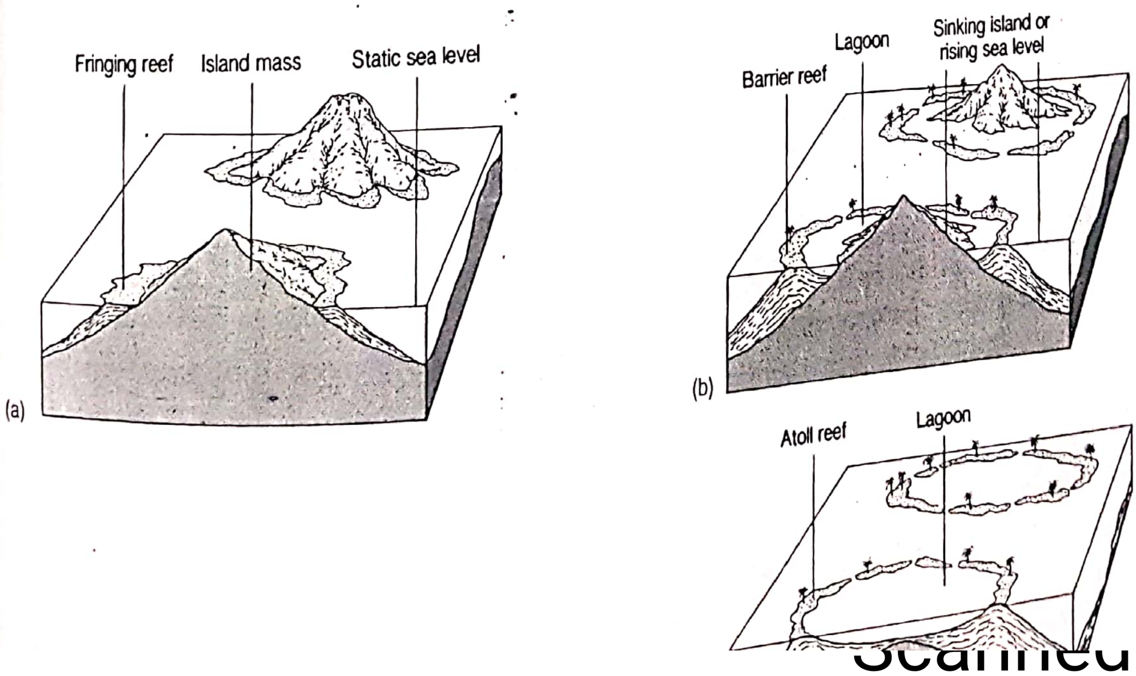
These steps required to form an atoll were suggested by Charles Darwin, based on his observations during the voyage of the *Beagle* in 1831–36. Darwin's ideas have been proved substantially correct by more recent expeditions that drilled through the coral debris of lagoon floors and found the basalt peak of the seamount that once protruded above the sea surface.

Submerged flat-topped seamounts, known as **guyots,** or **tablemounts** (fig. 4.8), are found most often in the Pacific Ocean. These guyots are 1000 to 1700 m (3300 to 5600 ft) below the surface, with many at the 1300 m (4300 ft) depth. Many guyots show the remains of shallow marine coral reefs and the evidence of wave erosion at their summits. This indicates that at one time they were surface features and that their flat tops are the result of rain and wave erosion, past coral reef growth, or both. Guyots have dropped far below sea level because their weight has helped depress the oceanic crust and because the plate supporting them has moved away from the hot spot or ridge where they were created; refer to section 3.11. They have also been submerged by rising sea level during periods in which the land ice has melted.

List the features of the ocean basin floor.

Explain the series of events that produce an atoll.

How are seamounts and guyots the same, and how are they different?



4.4 The Ridges and Rises

The most remarkable features of the ocean floor are the mid-ocean **ridge and rise systems** that form at the spreading boundaries of the lithospheric plates. This series of great continuous underwater volcanic mountain ranges stretches for 65,000 km (40,000 mi) around the world and runs through every ocean; see figure 4.10 and refer to figure 3.5. These ridge systems are about 1000 km (600 mi) wide and 1000 to 2000 m (3500 to 7000 ft) high. If the slopes of these mountain ranges are steep, they are referred to as ridges (such as the Mid-Atlantic Ridge and the Mid-Indian Ridge); if the slopes are more gentle, they are called rises (such as the East Pacific Rise). Along portions of the system's crest is a central **rift valley,** 15 to 50 km (9 to 30 mi) wide and 500 to 1500 m (1500 to 5000 ft) deep. The rift valley is volcanically very active and bordered by rugged rift mountains. Fracture zones with steep sides run perpendicular to the ridges and rises, connecting offset sections of the mid-ocean ridges to make a stair-step pattern. The faults between the offset sections of rift valley are the transform faults; refer to section 3.8. The mid-ocean ridge and rise systems and their smaller lateral extensions separate the ocean basins into sub-basins, in which bodies of deep water are isolated from each other. Refer back to figure 3.5.

Distinguish between a ridge and a rise.

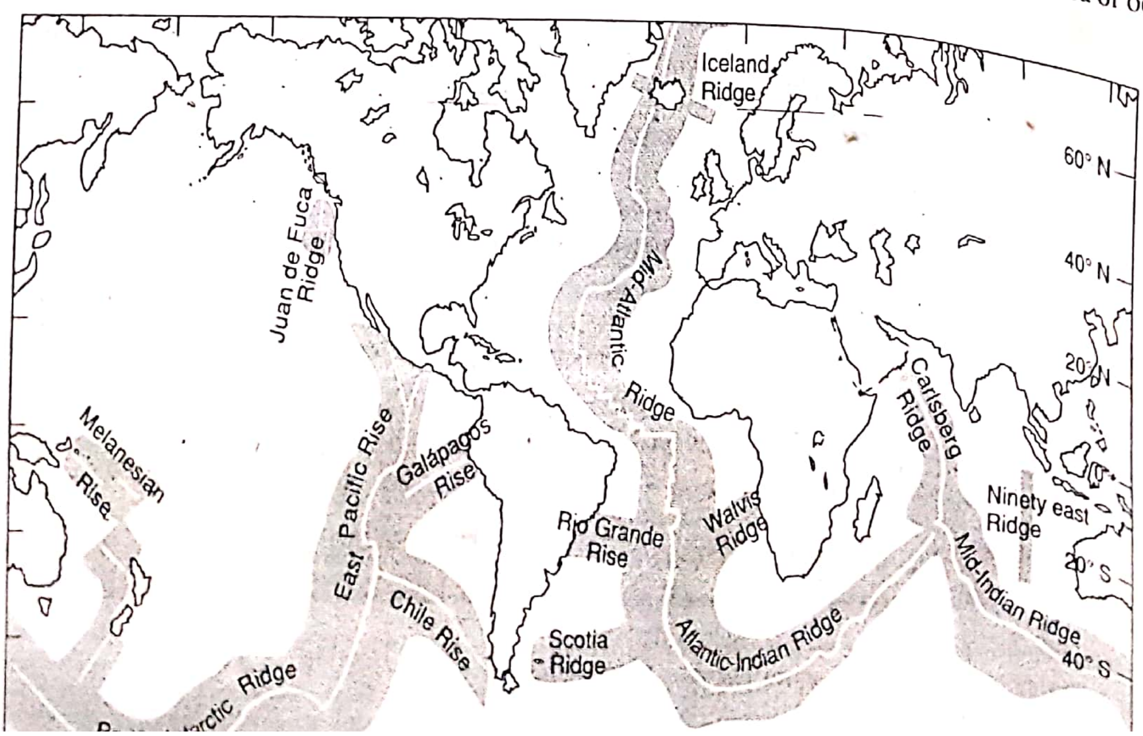
Where would you find examples of each? Use figure 3.5.

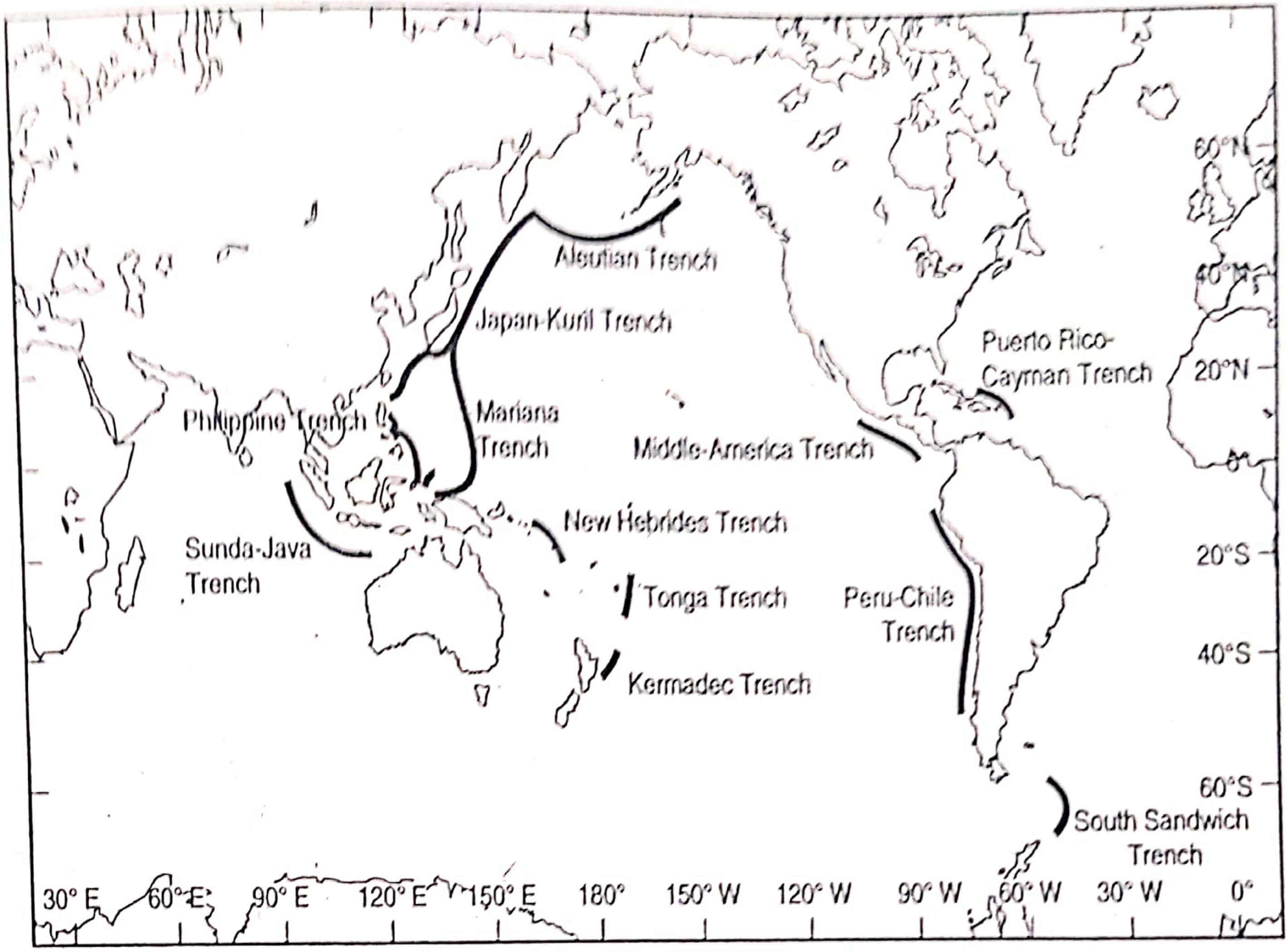
Use figures 3.5 and 4.10 to identify South Atlantic ocean basins formed by the Mid-Atlantic Ridge and its lateral extensions.

4.5 The Trenches

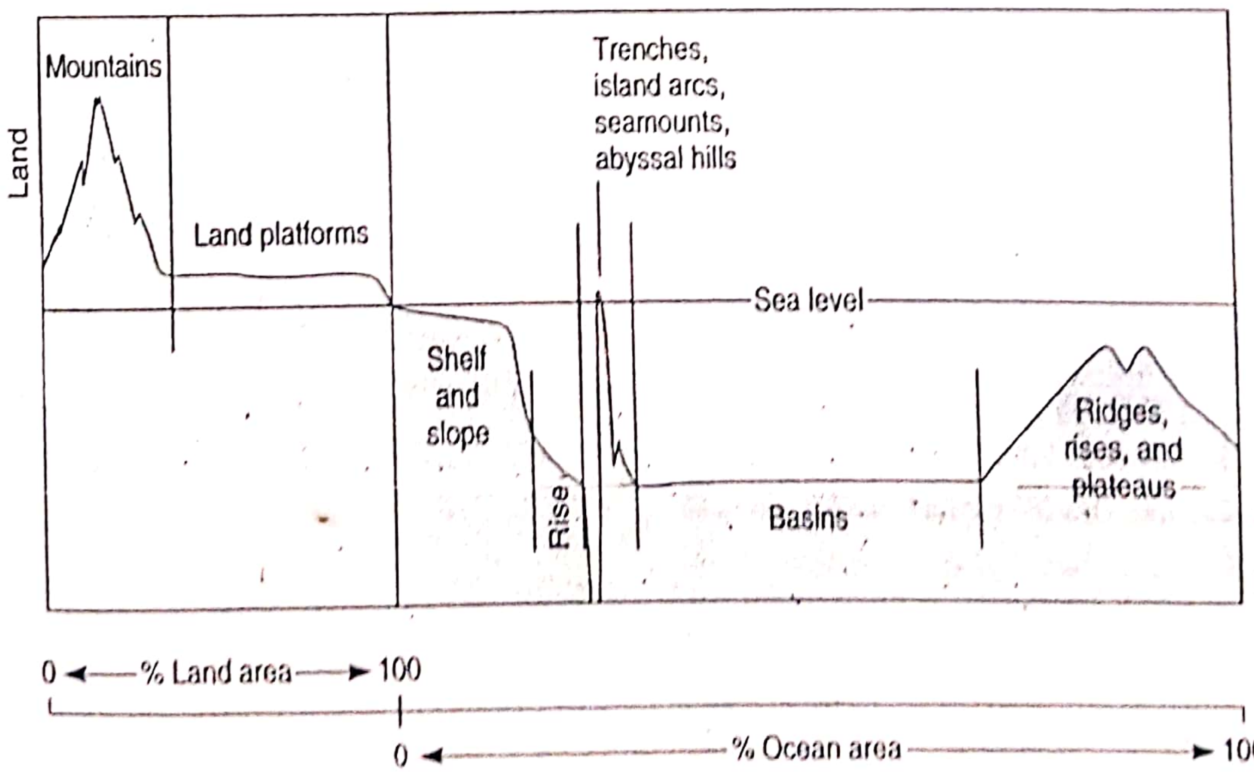
The Mid-Atlantic Ridge is the dominant feature of the floor of the Atlantic Ocean, but the narrow, steep-sided, deep-ocean trenches characterize the Pacific. Trenches occur at convergent plate boundaries; refer to section 3.9 to review their formation and see figures 4.11 and 3.5 for their locations. Some of these trenches are located on the seaward side of chains of volcanic islands known as **island arcs.** For example, the Japan-Kuril Trench, the Aleutian Trench, the Philippine Trench, and the deepest of all ocean trenches, the Mariana Trench, are all associated with island arc systems. The Challenger Deep, a portion of the Mariana Trench, has a depth of 11,020 m (36,150 ft), making it the deepest known spot in all the oceans. The longest of the trenches is the Peru-Chile Trench, stretching 5900 km (3700 mi) along the west side of South America. To the north, the Middle-America Trench borders Central America. The Peru-Chile and Middle-America Trenches are associated with active volcanoes on the western margins of South and Central America. These volcanoes lie above the subducted plate and along the edge of the upper plate. In the Indian Ocean the great Sunda-Java Trench runs for 4500 km (2800 mi) along Indonesia, while in the Atlantic there are two comparatively short trenches, the Puerto Rico-Cayman Trench and the South Sandwich Trench, both associated with chains of volcanic islands.

Figure 4.12 summarizes the topography of the land and the bathymetry of the sea floor as percents of Earth's surface area. Compare the tectonically active areas of ridges and trenches. Compare the area of land platforms to the area of ocean basins.





4.11 Major ocean trenches of the world. The deepest ocean depth is 11,020 m, east of the Philippines in the Mariana Tren
enger Deep.



3.10 Continental Margins

When a continent rifts and moves away from a spreading center, the resultant continental margin is known as a **trailing,** or **passive margin.** These are also frequently referred to as Atlantic-style margins since they are found on both sides of the Atlantic Ocean as well as around Antarctica, the Arctic Ocean, and in the Indian Ocean. Continental and oceanic lithosphere are joined along passive margins so there is no plate boundary at the margin. As passive margins move away from the ridge the oceanic lithosphere cools, increases its density, thickens, and subsides. This causes the edge of the continent to slowly subside as well. While passive margins begin at a divergent plate boundary, they end up in a midplate position as a result of seafloor spreading and the opening of the ocean basin. Old passive margins are not greatly modified by tectonic processes because of their distance from the ridge. These margins are often broad and shallow and have thick sedimentary deposits, as along the eastern coast of the United States.

When a plate boundary is located along a continental margin, the margin is called a **leading,** or **active margin.** Active continental margins are often marked by ocean trenches where oceanic lithosphere is subducted beneath the edge of the continent. These margins are typically narrow and steep with volcanic mountain ranges, as along the west coast of South America as well as Oregon and Washington. Active margins are found primarily in the Pacific Ocean.

Studies of the North American crust indicate that the core of the continent was assembled about 1.8 billion years ago by collisions with four or five large pieces of even older continental land. Crustal fragments with properties and histories distinct from adjoining crust and added by collisions are known as **terranes.** Terranes may be pieces of island arc systems, seamount volcanoes, seafloor plateaus, or parts of other continental landmasses. The terranes of Alaska and the West Coast of the United States and Canada appear to have arrived from the south about 70 million years ago. Fossils collected between Virginia and Georgia indicate that a long section up and down the East Coast was formed somewhere adjacent to an island arc system; the fossils point to a past European connection. It is estimated that 25% of North America was formed from terranes; see figure 3.27 for examples. The subcontinent of India is considered by some to be a single, giant terrane; it arrived from Antarctic latitudes and is now firmly attached to the continent of Asia. North of the Himalayas there appear to be terranes that became a part of the continent before the arrival of India.

What is the difference between "passive" and "active" continental margins?

Is the east coast of South America a passive or an active continental margin? What about the west coast?

What does the presence of terranes tell us about the past geological history of an area?