2

OCEAN BASINS

Objectives

1. Distribution of continents and ocean basins;
2. Major features of each ocean basin;
3. Principal features of the ocean floor; and
4. Major features of submerged continental margins.

From: M. Grant Gross
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The ocean basins are a primary feature of the earth's surface (see Plate 1). But our vision of the ocean bottom is obscured by the ocean waters. Thus the ocean bottom remains among the least known features of our planet. For example, the largest mountain range on earth (see Plate 5), the midocean ridge, was not discovered until the late nineteenth century, and its origins were finally understood in the 1960s.

Ocean basin exploration continues today, with new findings coming every few months. Our improved understanding of the ocean basins has changed our view of the earth as much as the exploration of the New World changed human perspectives in the fifteenth and sixteenth centuries.

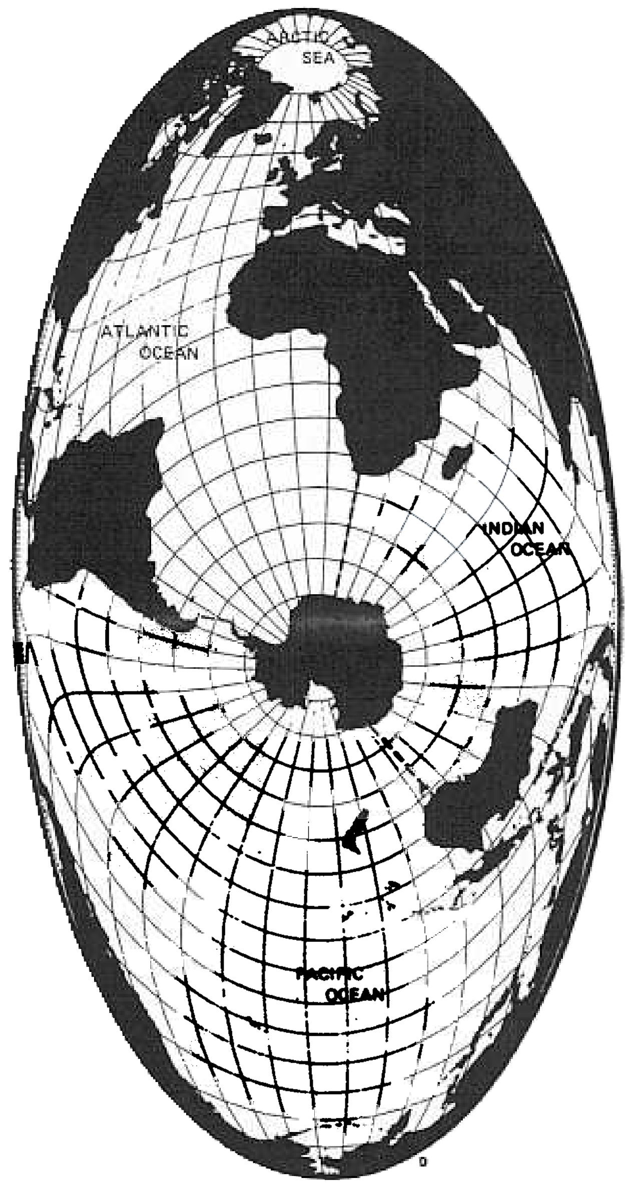
In this chapter we examine the ocean basins, their individual features and those common to all the major basins:

Distribution of continents and ocean basins;
Major features of each ocean basin;
Principal features of the ocean floor; and
Major features of submerged continental margins.

DISTRIBUTION OF LAND AND WATER

Land and water are unevenly distributed on the earth. The continents, which cover 29.2% of the earth's surface, break up the ocean into the three basins, which we call the Atlantic, Pacific, and Indian oceans. The ocean basins, which cover 70.8% of the earth's surface, can be viewed as northward-projecting gulfs of the world-circling ocean around Antarctica (Fig. 2-1). Because of the connections of the ocean basins around Antarctica, the Southern Hemisphere (see Plate 1) is dominated by ocean (80.9%). The Northern Hemisphere contains most of the land but is still dominated by ocean (60.7%).

FIGURE 2-1
The ocean is centered on Antarctica. For our convenience it is considered to be three separate ocean basins, separated as shown.



HYPSOGRAPHIC CURVE

Relationships between oceanic depths and land elevations can be shown in a **hypsographic curve** (Fig. 2-2), which indicates that earth's surface has two distinct levels. On the average, the land projects about 840 meters (2755 feet) above sea level and ocean basins have an average depth of 3800 meters (12,500 feet) below sea level. Despite the great oceanic depths (11 kilometers, or 7 miles, in the Marianas Trench) and the enormous height of the mountains (8.8 kilometers, or 5 miles, at Mount Everest), these numbers are truly insignificant when compared with the dimensions of the earth (radius 6371 kilometers, or 3823 miles). If the earth were a smooth sphere with the continents planed off to fill the ocean basins, it would be covered with water 2430 meters (7970 feet) deep. In short, the ocean is a thin film of water on a nearly smooth globe, interrupted here and there by continents.

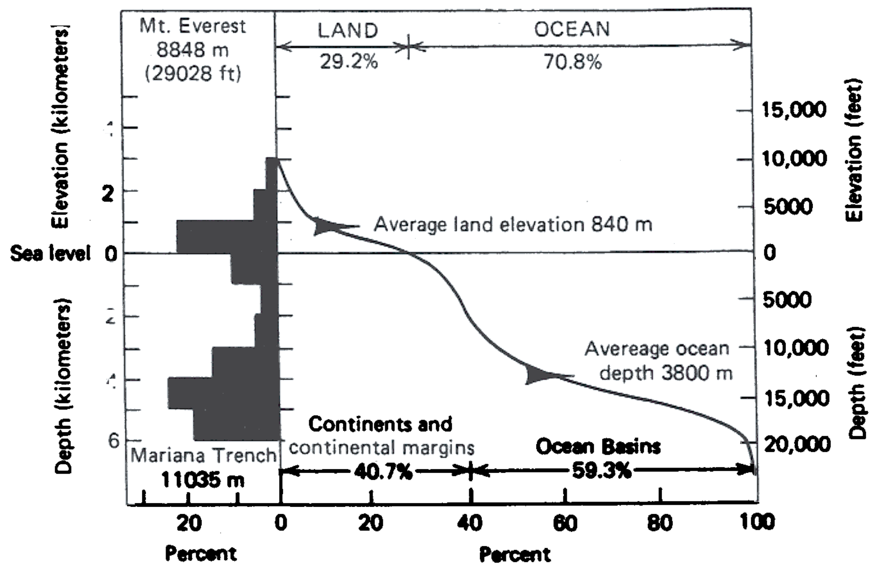


FIGURE 2-2
A hypsographic diagram shows the fraction of the earth's surface in elevation or depth zones of one kilometer (left side). The right side shows the cumulative fraction of earth's surface shallower than a given depth. Note that the earth's surface has two dominant levels—one representing the land and the other the ocean bottom.

PACIFIC OCEAN

The **Pacific** is the deepest and by far the largest ocean basin (Fig. 2-3). Bordered by the Americas, Asia, and Australia, the Pacific occupies more than one-third of the earth's surface (Fig. 2-4) and contains more than one-half of the earth's free water (see Fig. 2-3). Mountain building dominates Pacific shorelines. Along the Pacific's entire eastern margin (the western coasts of the Americas from Alaska to Peru), rugged, young mountains parallel the coastlines.

These young mountains block rivers flowing into the ocean along most of its margins, especially on the west coast of North and South

FIGURE 2-3
Distribution (in percent) of water on the earth's surface. Note the minute fraction of the total amount of water that occurs as freshwater lakes, rivers, or atmospheric water vapor.

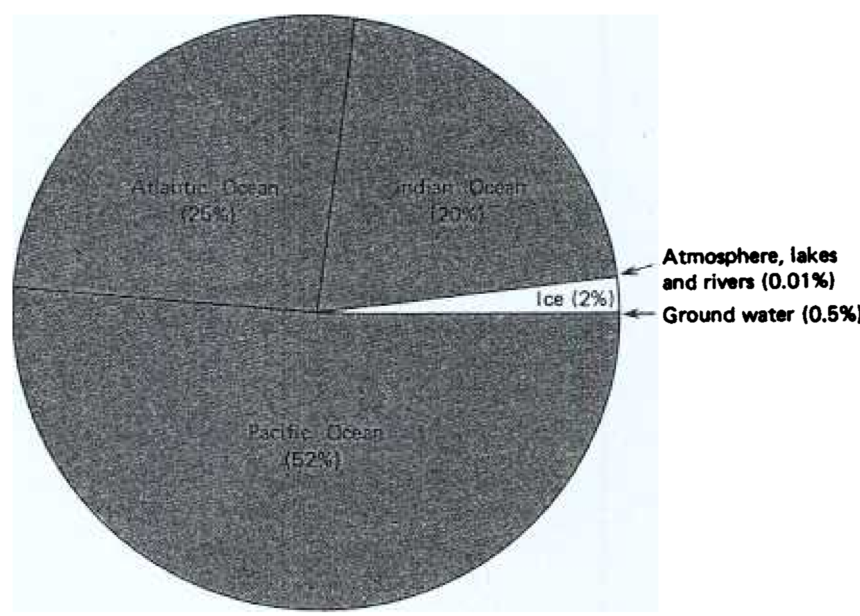
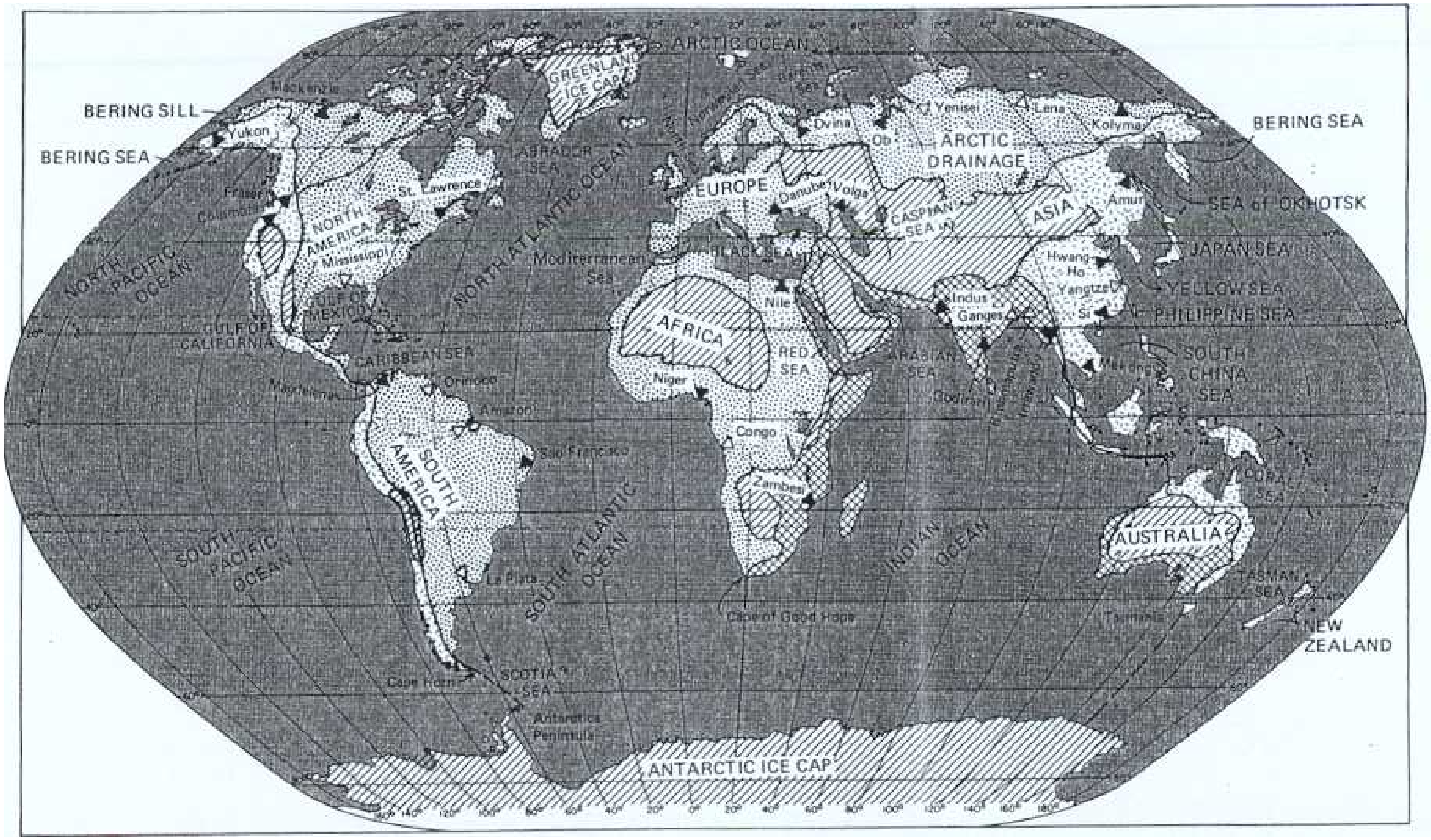


FIGURE 2-4 Map of the earth's surface showing the boundaries between the major ocean basins. Areas of the continents whose rivers drain into each of the ocean basins are shown, as well as the mouths of some major rivers. Note the large land area that drains into the Atlantic and Arctic oceans.



▽ Rivers discharging more than 15,000 cubic meters (525,000 cubic feet) per second

▼ Rivers discharging more than 3000 cubic meters (100,000 cubic feet) per second

Runoff to Atlantic Ocean and Arctic Sea

Runoff to Pacific Ocean

Runoff to Indian Ocean

No runoff to oceans

America. Consequently, freshwater and sediment flowing into the Pacific come primarily from Asia. Submerged continental margins are narrow because the steep slopes of the young mountain ranges continue below sea level. The net result is that the Pacific is less affected by the continents than either the Atlantic or Indian oceans.

Islands are abundant in the Pacific, especially in the southern and western portions. As previously mentioned, these islands served as stepping stones for human migrations across the Pacific. The smallest islands are low-lying sand islands, many of them associated with coral reefs. (Reefs are discussed in Chapter 14.)

Most of the larger islands are volcanoes, many still active. The inactive volcanoes are deeply eroded by waves and rivers. The Hawaiian Islands are good examples of volcanic islands (see Plate 6). They are the tops of a chain of enormous volcanoes (up to 10,600 meters or 35,000 feet above the sea floor) that extends 3000 kilometers (1800 miles) from Hawaii, with two active volcanoes, to Kure Island, a small sand island on top of a deeply submerged volcano that is more than 20 million years old. Most of the large islands in the western Pacific are actually pieces of continents that were separated from Australia and Asia millions of years ago. (More about this in the next chapter.)

ATLANTIC OCEAN

The **Atlantic Ocean** is a narrow, S-shaped basin that connects the two polar ocean areas to the north and south (see Fig. 2-1). The boundary between the Atlantic and Indian oceans is usually drawn from South Africa's Cape of Good Hope along longitude 20°E to Antarctica. (Remember that longitude lines run north-south and measure angular distance east and west from the prime meridian, which runs through Greenwich, England. Latitude and longitude lines are shown in Fig. 2-4. Both are discussed further in Appendix 3.) The boundary between the Atlantic and Pacific oceans is drawn between Cape Horn at the southern tip of South America and the northern end of the Antarctic Peninsula. When the Arctic Ocean is included as part of the Atlantic Ocean, it meets the Pacific at the Bering Strait between Alaska and Siberia. Defined in this way, the Atlantic Ocean stretches from the shores of Antarctica northward across the North Pole to about 65°N, where it borders the North Pacific.

The Atlantic is relatively shallow, averaging 3310 meters (10,800 feet) in depth, as a result of the large areas of submerged continental margins, several shallow marginal seas, and the presence of the large, relatively shallow Mid-Atlantic Ridge. There are relatively few islands in the Atlantic. Greenland, the world's largest island, is a piece of the North American continent that was separated many millions of years ago. Most other islands are tops of volcanoes, including several on the Mid-Atlantic Ridge.

The Atlantic Ocean receives large amounts of river discharge, both water and sediment. The Amazon and Congo (Zaire) rivers flow into the equatorial Atlantic. Together they discharge about one-quarter of the world's river flow into the ocean. Other large rivers flow into marginal seas. Freshwater from several large Asian rivers flowing into the Arctic Ocean eventually enters the Atlantic.

The **Arctic Ocean** is an arm of the Atlantic (see Fig. 2-1). It is unique in several respects: Submerged continental margins form one-third of its floor. It is almost completely surrounded by land. And—especially important—much of it is covered by sea ice. During much of the year, its surface is covered by **pack ice** (sea ice in thick chunks that freeze together, break apart, and freeze again) to a thickness of 3 to 4 meters (10 to 12 feet). In the central Arctic this ice cover is permanent, although it partially melts, thinning to about 2 meters (6 feet) by late August.

Being almost entirely surrounded by land, the Arctic Ocean is greatly influenced by rivers that discharge considerable amounts of sediment onto the continental shelves. Large amounts of sediment deposited on the bottom of the Arctic basins came from extensive erosion of the surrounding lands by glaciers during the ice ages of the past several million years.

INDIAN OCEAN

The **Indian Ocean** is primarily a Southern Hemisphere ocean (see Fig. 2-4). Its Pacific boundary runs through Indonesia and extends from Australia southward to Antarctica along longitude 150°E. It is the smallest of the major ocean basins. Continental shelves around the Indian Ocean are relatively narrow. The large amount of sediment deposited in the northern Indian Ocean makes the basin intermediate in depth.

Three of the world's largest rivers (Ganges, Brahmaputra, Indus) discharge large amounts of sediments and water into the northern Indian Ocean (see Fig. 2-4). The Red Sea and the Arabian Gulf influence the waters of the entire Indian Ocean because they are areas of intensive evaporation and produce large quantities of warm, salty water that flow out into the main ocean basin as subsurface currents.

There are relatively few islands in the Indian Ocean. Madagascar, the largest, was once part of the African continent, as were several shallowly submerged banks. There are a few volcanic islands and groups of carbonate islands, including **atolls**—groups of islands that ring a shallow lagoon, usually located on top of a submerged volcano (see Plate 7). Most atolls are in the Pacific and Indian oceans because of the abundant volcanic seamounts in these two ocean basins. (Atolls are discussed further in Chapter 14 when we discuss coral reefs.)

MIDOCEAN RIDGES AND RISES

Midocean ridges and rises (Fig. 2-5) stand conspicuously above the deep-ocean floor (see Plate 5). They constitute 23.1% of the earth's surface. The midocean ridge and rise system includes low-relief rises in the Pacific (shown schematically in Fig. 2-6) and high-relief ridges in the Atlantic (shown schematically in Fig. 2-7).

The rugged, high-relief **Mid-Atlantic Ridge** stands 1 to 3 kilometers (0.6 to 1.9 miles) above the deep-ocean floor. It is 1500 to 2000 kilometers (900 to 1200 miles) across and has a prominent steep-sided central valley (Fig. 2-8), 25 to 50 kilometers (15 to 30 miles) wide and 1 to 2 kilometers (0.6 to 1.2 miles) deep. It is bordered by rugged mountains whose shallowest peaks come to within 2 kilometers (1.2 miles) of the sea surface. The closest analogues on land to the Mid-Atlantic Ridge are the mountains and the long, narrow, lake-filled East African valleys (see Fig. 2-7). The East Pacific Rise is much less rugged (see Fig. 2-5).

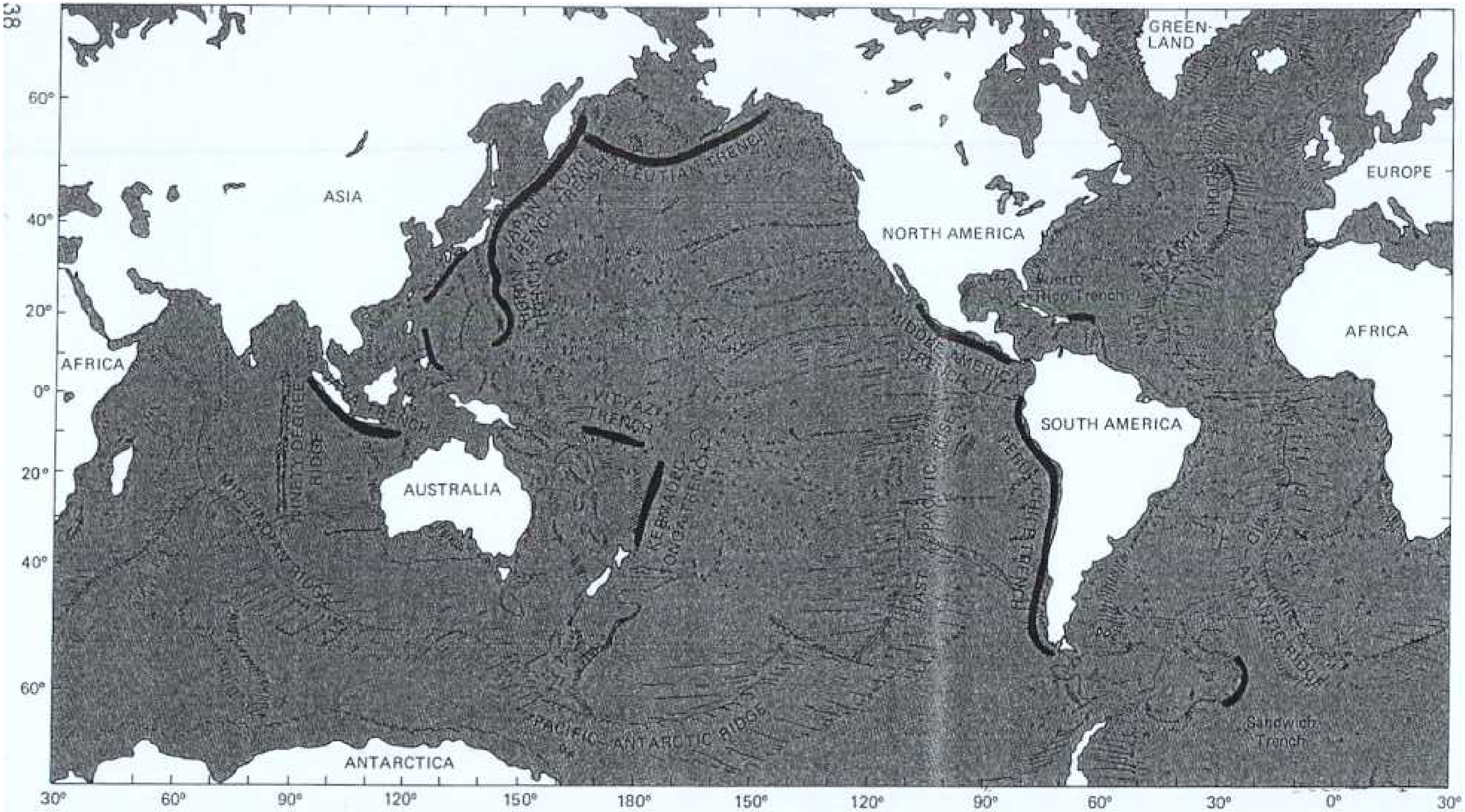


FIGURE 2-5 Map of the ocean bottom, showing the major topographic features.

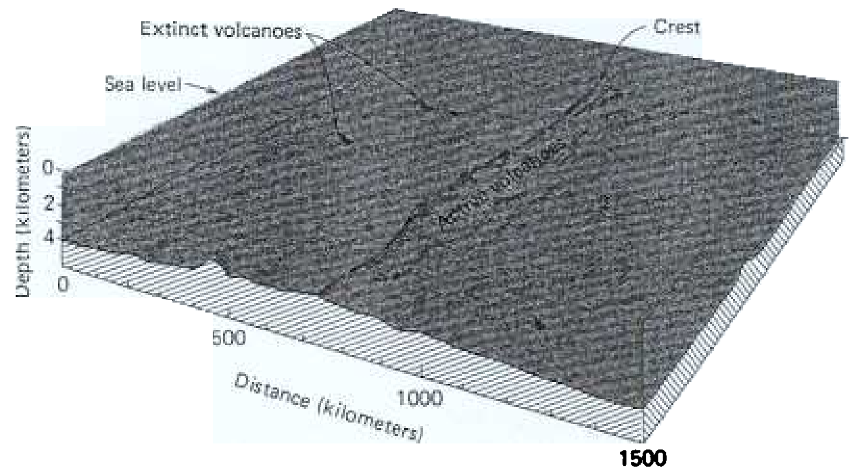


FIGURE 2-6
Schematic representation of the ocean-bottom topography along the East Pacific Rise, a broad, low rise of the ocean bottom with many volcanoes. Note that there is no central rift valley as in the Mid-Atlantic Ridge (see Fig. 2-7).

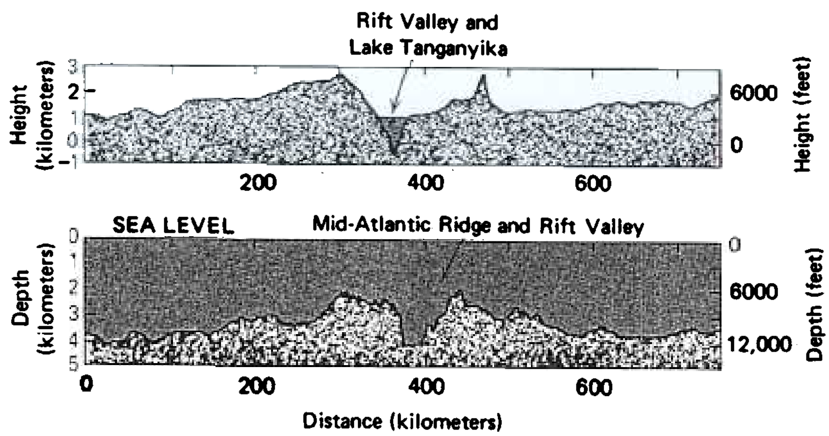


FIGURE 2-7
Profiles of the rift valley of the Mid-Atlantic Ridge and the Tanganyika rift in East Africa. Note the similarity in form and size of the two features.

Faults (fractures where two pieces of the crust have moved past each other) cut across the ridges and offset them, forming segments of the ridges, as seen in Fig. 2-8. Earthquakes occur when crustal segments move past each other along faults (see Fig. 2-9). There are numerous and frequent shallow-focus earthquakes [occurring within 70 kilometers (42 miles) of the earth's surface] along the Mid-Atlantic Ridge (Fig. 2-9) as well as volcanoes and volcanic islands, including Iceland.

The **East Pacific Rise** lies near the eastern margin of the Pacific basin. Unlike the Mid-Atlantic Ridge, it is a vast, low bulge on the ocean floor, approximately equal in size to North and South America combined. The rise stands about 2 to 4 kilometers (1.2 to 2.4 miles) above the adjacent ocean bottom. Intersecting the North American continent in the Gulf of California, its continuation, the Juan de Fuca and Gorda ridges, reappears off the Oregon coast and extends into the Gulf of Alaska.

In the Indian Ocean, the high-relief **Mid-Indian Ridge** (similar to the Mid-Atlantic Ridge) intersects Africa–Asia in the Red Sea area (see Fig. 2-5). On the south, the Mid-Indian Ridge system branches to join the system of active ridges and rises that circle Antarctica. Near Madagascar, a low section of the ridge system permits deep waters to move between the deeper parts of the Indian and the Atlantic oceans.

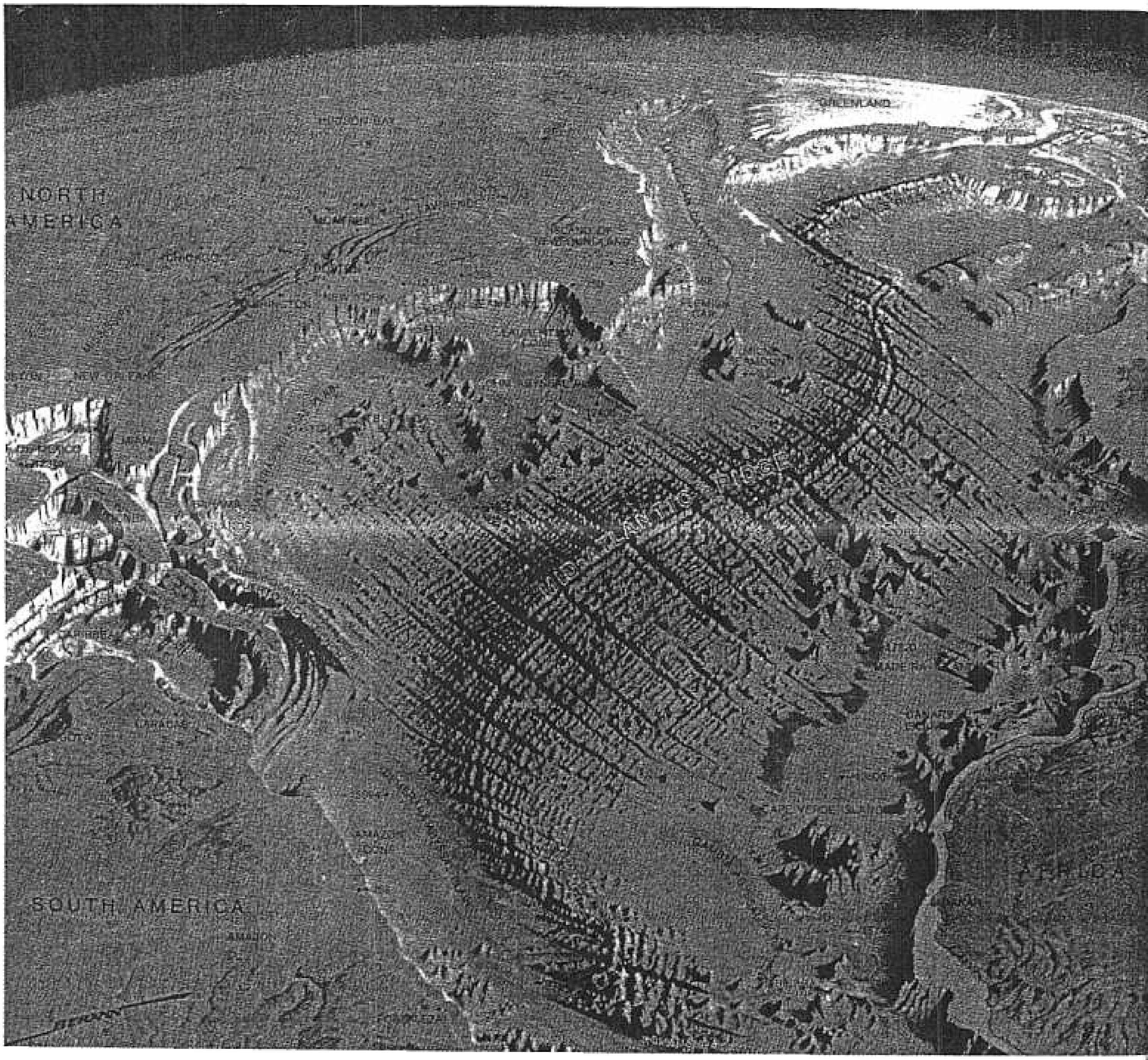


FIGURE 2-8
Artist's rendition showing the topography of the bottom of the North Atlantic Ocean depicted with all the water removed. Depths are noted in feet.

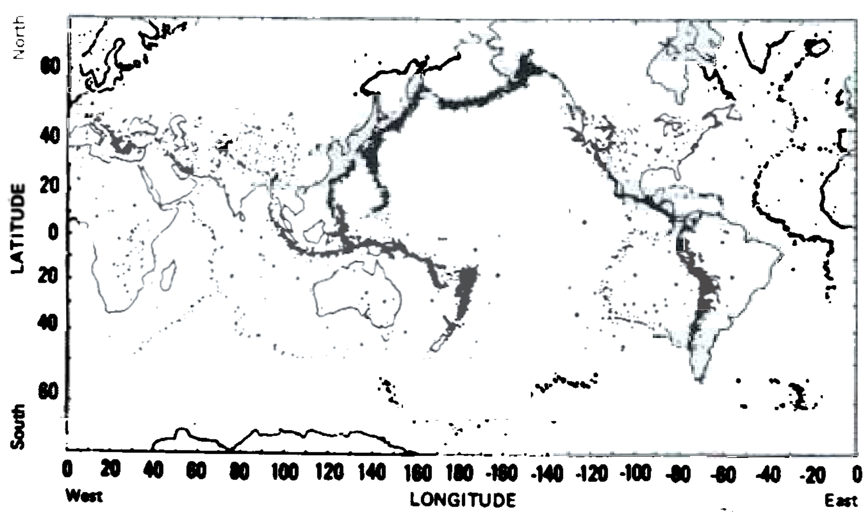


FIGURE 2-9
Earthquakes mark the locations of midocean ridges and trenches.

Narrow belts of frequent shallow-focus earthquakes run along the crests of oceanic rises (Fig. 2-9). These earthquakes coincide closely with the axis of the rift valley. Indeed, earthquakes have been used to pinpoint active ridge systems in little-known ocean areas.

Midoceanic ridge systems are also sites of high heat flow. Areas of unusually high heat flow occur in narrow bands in rift valleys, caused by intrusions of molten rocks. Hydrothermal vents discharge hot waters in areas of recent volcanic eruptions.

FRACTURE ZONES

The ocean floor is cut by hundreds of **fracture zones**. These zones are long, narrow (10- to 100-kilometer, or 6- to 60-mile) belts of irregular topography with many rugged ridges; some are nearly 4000 kilometers (2400 miles) long. Fracture zones displace segments of midocean ridges (see Fig. 2-8).

Fracture zones continue into the continents. The Mendocino Fracture Zone comes onto land at Cape Mendocino, California, where it extends southeastward as the **San Andreas Fault** to connect with the East Pacific Rise in the Gulf of California. Most of the earthquakes in California occur on or near the San Andreas Fault.

One of the earth's largest fracture zones is the **Romanche Fracture Zone** (see Fig. 2-8) which offsets the Mid-Atlantic Ridge by 950 kilometers (600 miles) near the equator. It is part of a group of large faults; the entire zone consists of deep valleys about 100 kilometers (60 miles) wide, separated by ridges, one of which comes to the sea surface.

The Romanche Fracture Zone contains one of the deepest parts of the Atlantic, which reaches a depth of 7960 meters (26,100 feet). The gap in the Mid-Atlantic Ridge is an important pathway for bottom waters from the western Atlantic flowing into the nearly isolated deep basins of the eastern Atlantic Ocean. (We learn about movements of deep-water masses in Chapter 8.)

ABYSSAL HILLS AND PLAINS

The **deep-ocean floor** (deeper than 4000 meters, or 13,000 feet) occupies about 29.5% of the earth's surface. Low **abyssal hills** [less than 1000 meters (3300 feet) above the surrounding ocean bottom] cover about 80% of the Pacific deep-ocean bottom, about 50% of the Atlantic, and are abundant in the Indian Ocean. These hills—probably the most common feature on the earth's surface—are typically about 200 meters (600 feet) high and about 6 kilometers (4 miles) across. Most appear to be extinct small volcanoes.

Immense areas of exceedingly flat ocean bottom, called **abyssal plains**, occur near continents. These areas are the flattest portions of the earth's surface. They have slopes of less than 1 in 1000, comparable to the flattest parts of the continents. Abyssal plains commonly occur at the seaward margins of the deep-sea fans that make up the continental rises. Most abyssal plains are covered with thick sediment deposits which have buried any rough topography. Abyssal plains are especially common in marginal seas, such as the Gulf of Mexico, the Caribbean, and the many small ocean basins around the Pacific Ocean margin.

TRENCHES

Trenches—the deepest parts of the ocean floor—occur near the ocean basin margins. They are relatively narrow (see Fig. 2-10) and steep-sided features, typically several tens of kilometers wide and about 3

TABLE 2-1
Characteristics of Trenches*

TRENCH	DEPTH (kilometers)	LENGTH (kilometers)	AVERAGE WIDTH (kilometers)
Pacific Ocean			
Kurile–Kamchatka Trench	10.5	2200	120
Japan Trench	8.4	800	100
Bonin Trench	9.8	800	90
Mariana Trench	11.0	2550	70
Philippine Trench	10.5	1400	60
Tonga Trench	10.8	1400	55
Kermadec Trench	10.0	1500	40
Aleutian Trench	7.7	3700	50
Middle America Trench	6.7	2800	40
Peru–Chile Trench	8.1	5900	100
Indian Ocean			
Java Trench	7.5	4500	80
Atlantic Ocean			
Puerto Rico Trench	8.4	1550	120
South Sandwich Trench	8.4	1450	90

* After R. W. Fairbridge, 1966. Trenches and related deep sea troughs. In R. W. Fairbridge (Ed.), *The Encyclopedia of Oceanography*, pp. 929–938. Reinhold Publishing Corporation, New York.

to 4 kilometers (1.9 to 2.5 miles) deeper than the surrounding ocean floor (Table 2-1). Most occur in the Pacific, although there are two in the Atlantic Ocean and one in the Indian Ocean (see Fig. 2-5). Trenches are always associated with active volcanoes and earthquake activity; most are associated with chains of volcanic islands (called **island arcs**) or volcanoes on nearby land (see Fig. 2-11). They are conspicuous manifestations of mountain building (which we discuss in the next chapter). The greatest depth in the ocean is 11,035 meters (39,195 feet), measured in the Challenger Deep, in the Mariana Trench, southeast of Japan (see Fig. 2-5).

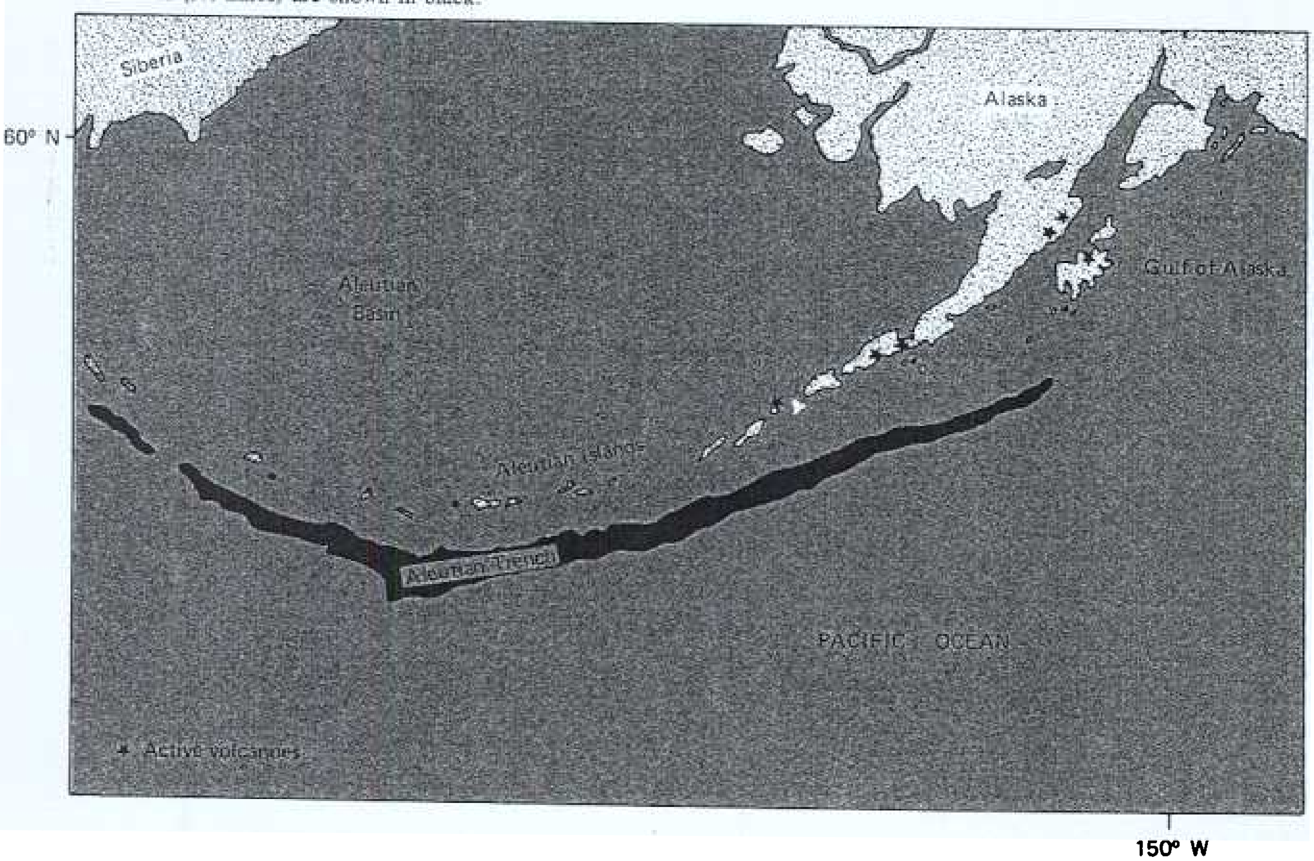


FIGURE 2-10
The Aleutian Islands, a simple island-arc system with a trench on the convex seaward side. These islands are built of volcanic rock. Many of the volcanoes are active. Depths greater than 6 kilometers (3.6 miles) are shown in black.

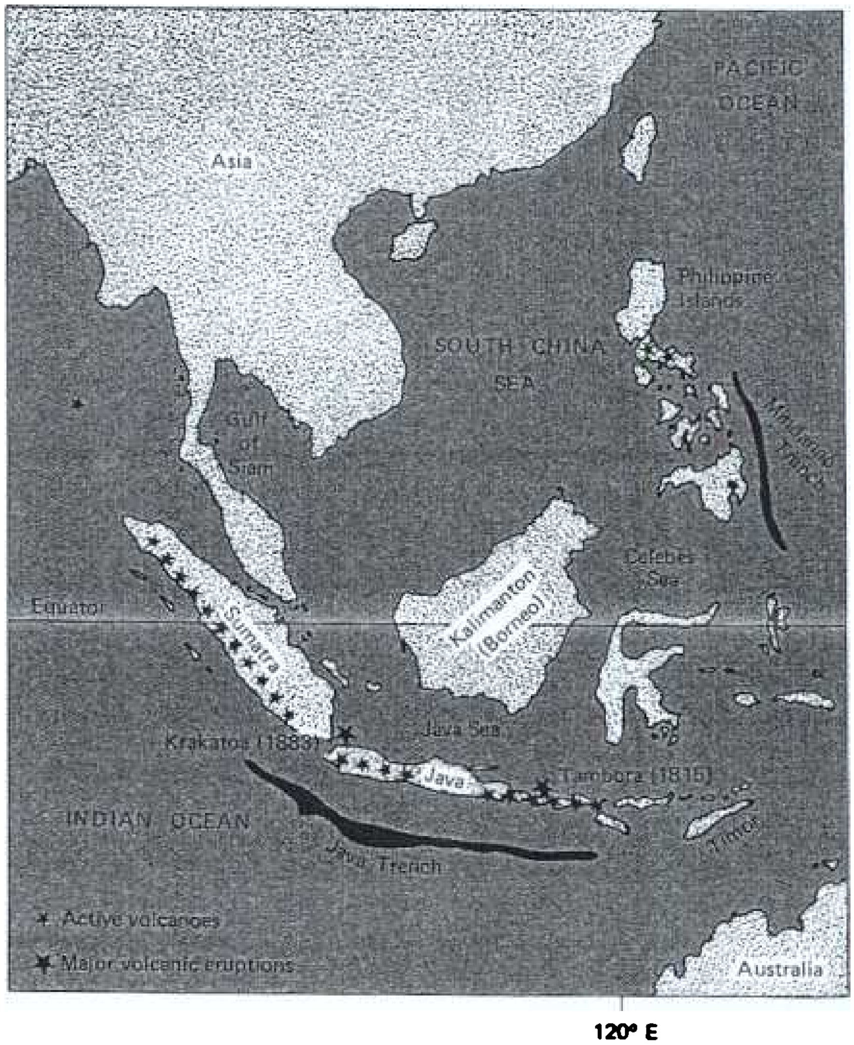


FIGURE 2-11
Indonesia, a complex island-arc system. Active volcanoes occur on the larger islands. Some of the smaller islands near the trench are built of deformed sediment deposits. Depths greater than 6 kilometers (3.6 miles) are shown in black.

VOLCANOES

Volcanoes and volcanic islands are common features on the ocean floor, usually projecting 1 kilometer (0.6 mile) or more above the surrounding ocean floor. There are tens of thousands of volcanoes on the Pacific floor. Most volcanic activity on land occurs near the edges of the ocean basin, especially around the Pacific.

Many active volcanoes occur in the middle of ocean basins, far from midocean ridges or island arcs. Such volcanoes form chains of volcanic peaks, such as the Hawaiian Islands (see Plate 6). These oceanic volcanoes are called **shield volcanoes**. As mentioned earlier, these are among the largest mountains on earth. (Origins of such volcanoes are discussed in the next chapter.)

Submerged volcanoes persist in the ocean for millions of years. A volcano builds a cone while it is active, and then eventually becomes dormant, often millions of years later. Over millions of years, volcanoes subside and are eroded. Eventually they become submerged banks or the foundation for coral reefs and atolls (Plate 7).

Volcanic island arcs are associated with active mountain building and trenches. The Aleutian Islands southwest of Alaska, for instance, are a single chain with a trench on the seaward side, as shown in Fig.

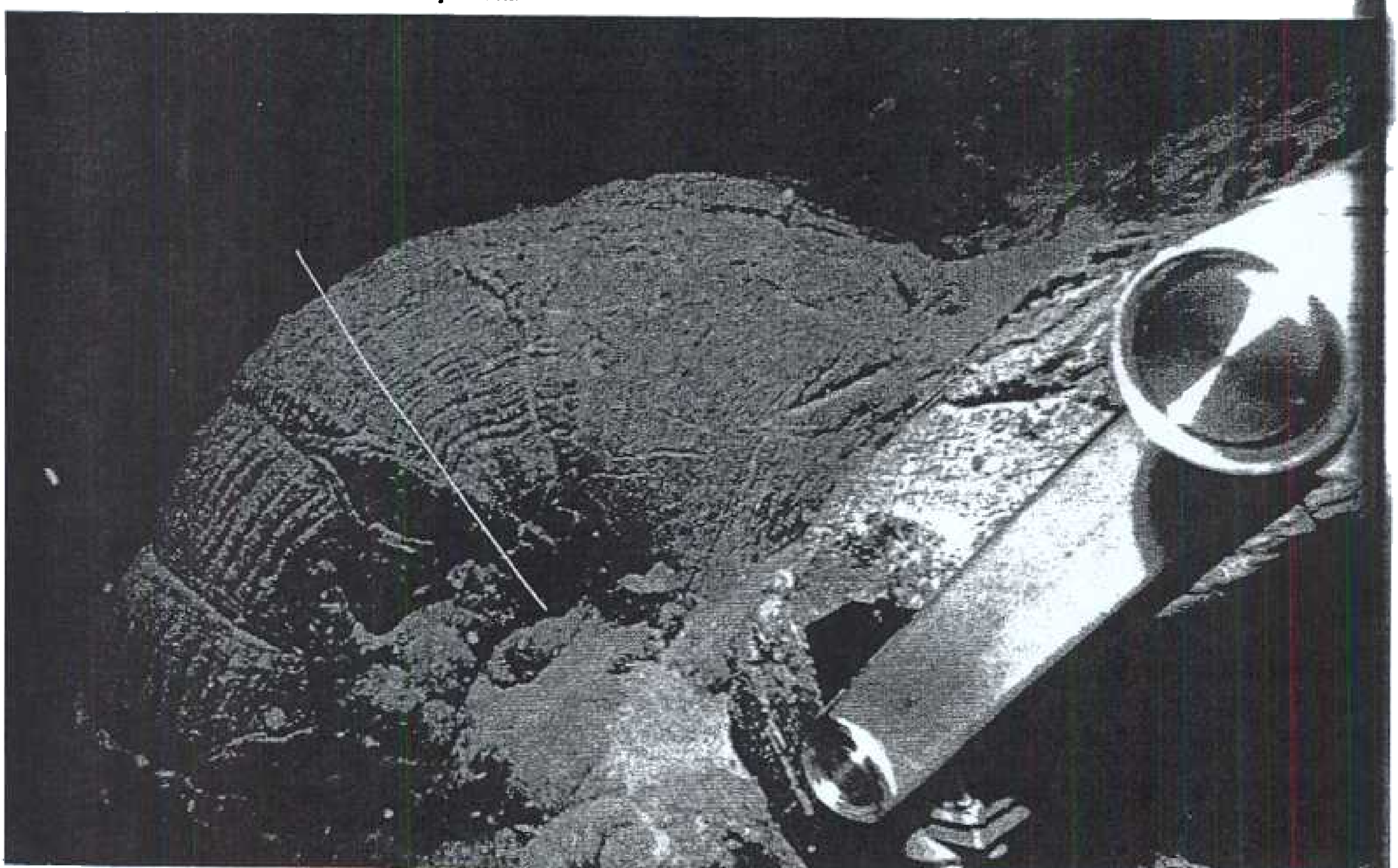
2-10. The Indonesian–Philippine area has two trenches (see Fig. 2-11) with many active volcanoes. Some of the largest recorded and most destructive eruptions occurred in Indonesia. Tambora on Sumbawa erupted in 1815, killing 92,000 people and caused an unusually cold summer in 1816. Snow fell in New England on July 4. In 1883, Krakatoa, between Java and Sumatra, killed 36,000 people when it erupted.

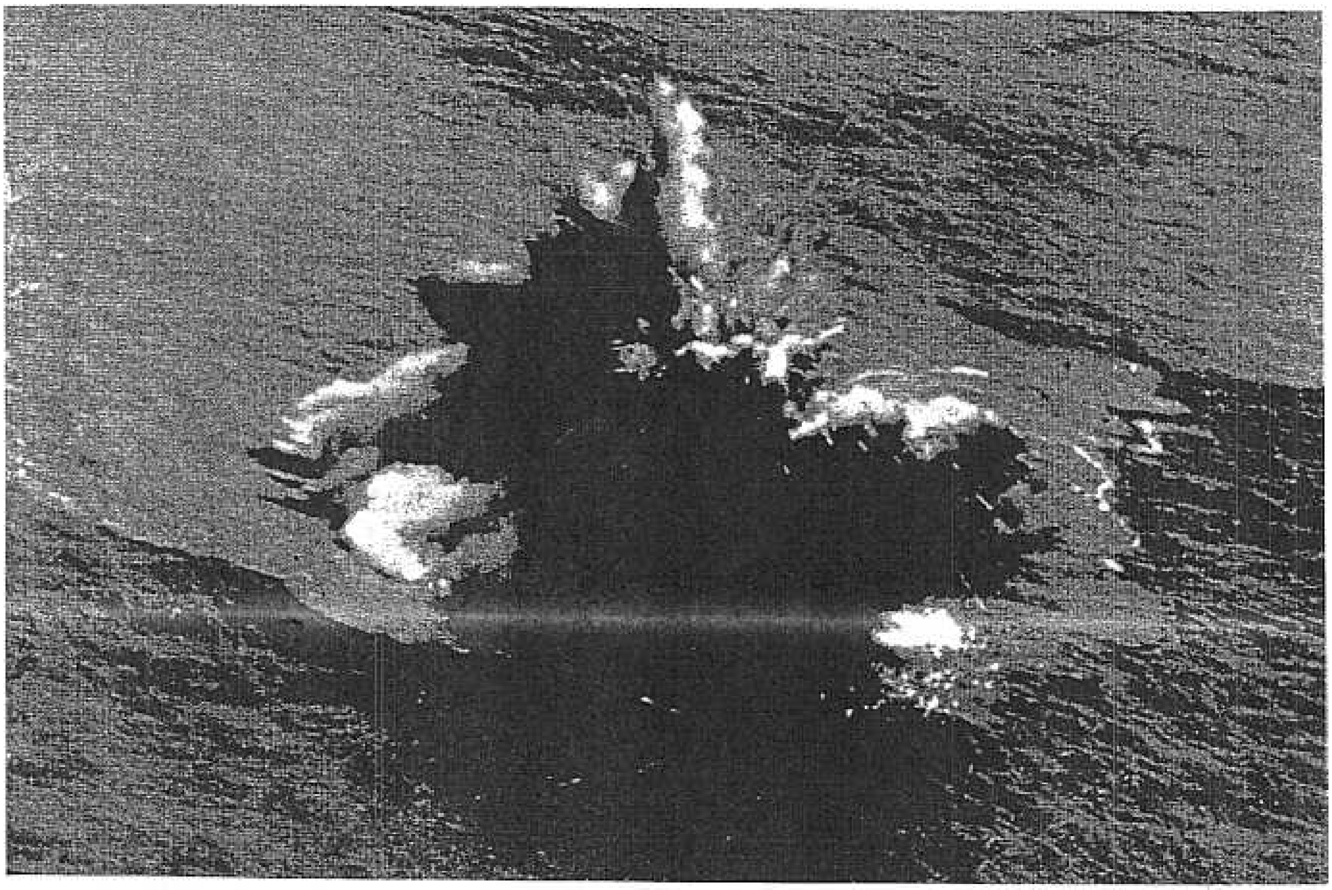
Volcanic eruptions are well known on land. Exploration of the ocean bottom shows that volcanic eruptions are especially common on mid-ocean ridges. On land and on the ocean bottom, volcanic lava (molten rock) erupts at temperatures between 900 and 1200°C. It flows for a while and then solidifies, first at the surface and finally throughout the flow. Further cooling turns the lava into volcanic rock.

There are two modes of oceanic volcanic eruptions. Some lavas form tranquil flows in which the surface cools first, forming an insulated cover for the still-molten material in the interior of the flow. When this type of lava flows into the ocean, it forms **pillow lavas** (Fig. 2-12), rounded masses of volcanic rock. Oceanic depths seem to favor such tranquil flows, for they are quite common features of the deep ocean. The other type of marine volcanic eruption [usually in relatively shallow waters (see Fig. 2-13)] is explosive, producing large amounts of volcanic ash, small pieces of volcanic rock, and glass formed by quenching of molten rock.

Not all volcanic activity forms volcanoes. Large areas of ocean bottom are smooth plains of volcanic rock. Apparently lava flowed out in large volumes, covering previous topography over extensive areas of the ocean bottom. These **archipelagic plains** (or **aprons**) surround volcanic groups or islands and extend tens or hundreds of kilometers from the volcanoes themselves. As we shall see in the next chapter, volcanic eruptions on the ocean floor are common at midocean ridges.

FIGURE 2-12
Toothpaste and pillow lavas are formed by submarine volcanic eruptions in the axial valley of the Mid-Atlantic Ridge. These features are probably less than 10,000 years old. The submersible's remote-controlled arm is picking up a rock.





(a)

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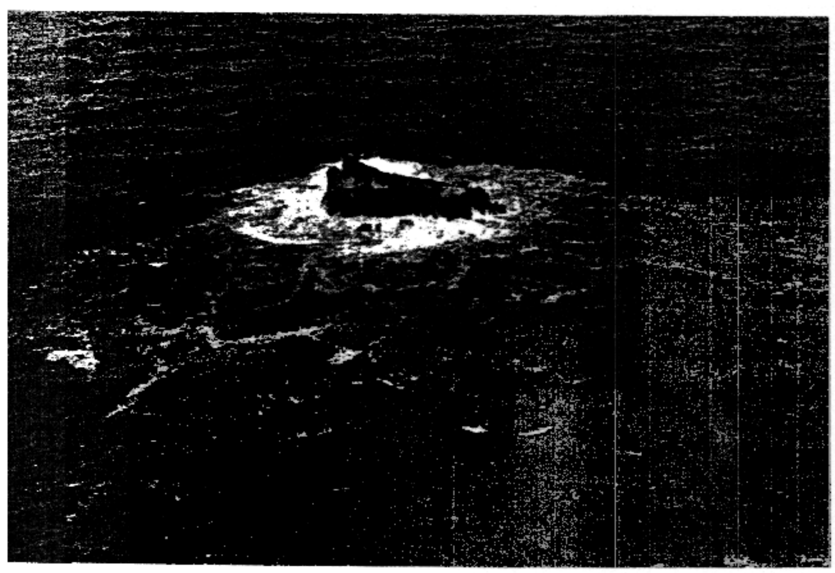


FIGURE 2-13
Eruption of Kovachi, a submarine volcano in the Solomon Islands, South Pacific, in October 1968. (a) Eruptions and explosions ejected water and steam 60 to 90 meters (200 to 300 feet) into the air and discolored surface waters for 130 kilometers (80 miles). (b) An island formed by an eruption in 1961 has since been eroded away to form a submerged bank.

MARGINAL OCEAN BASINS

Marginal ocean basins are large ocean bottom depressions lying near continents. They are separated from the open ocean by submarine ridges, islands, or parts of continents. Marginal basins are usually more than 2 kilometers (1.2 miles) deep and so their bottom waters are partially isolated from ocean waters at comparable depths outside the basin.

These small seas are transitional between continents and deep-ocean basins. They commonly have an oceanic crust overlain by thick sediment deposits. Being near coasts, they receive the discharge of many large rivers. The sediment brought by these rivers accumulates in the basins, resulting in deposits many kilometers thick. These deposits contain about one-sixth of all known ocean sediments. Nearly all marginal ocean basins are located in areas where crustal deformation or mountain building is active.

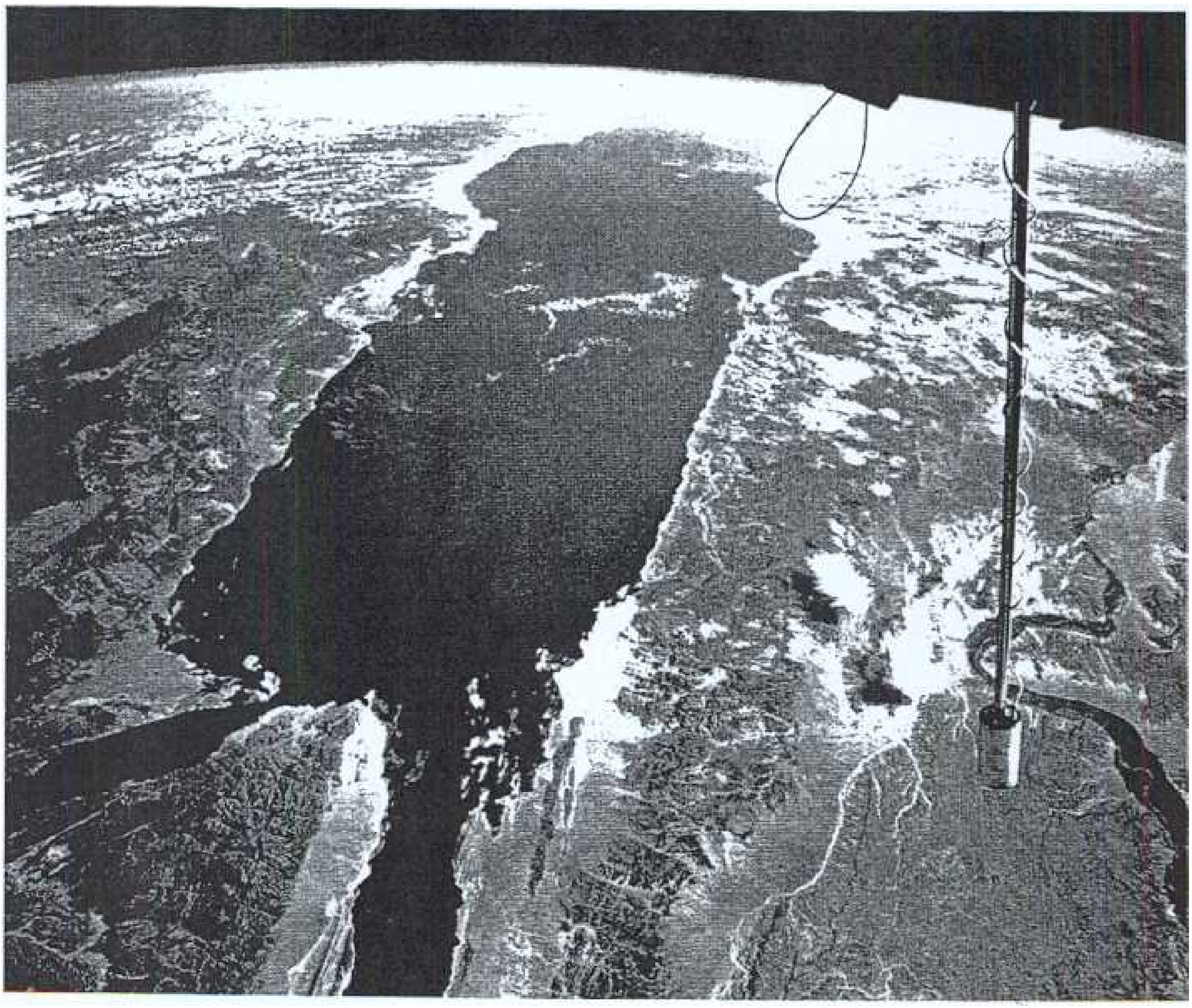
Three kinds of associations are typical of marginal ocean basins. The most common is that of a basin associated with island arcs and submarine volcanic ridges that partially isolate surface waters and may completely isolate the subsurface waters. The many small basins around Indonesia and along the Pacific margin of Asia are examples.

A second type of marginal sea lies between continents—for instance, the Mediterranean Sea between Europe and Africa, the Black Sea (now almost completely landlocked), and the Gulf of Mexico and Caribbean Sea between North and South America (see Fig. 2-4).

The third type is the long, narrow marginal sea surrounded by continents. The Red Sea (shown in Fig. 2-14) and the Gulf of California are examples of such basins.

Because of their proximity to large landmasses, marginal seas are subjected to greater extremes in climate than occur in the open

FIGURE 2-14
The Red Sea (upper center) with the Gulf of Aqaba (left) and the Gulf of Suez (lower right). The dark band on the right is the Nile Valley; the river is the light meandering line in the dark band. Note the straight sides of the Red Sea.



ocean. In high latitudes marginal seas are cold enough during winter to freeze over. In midlatitudes, where the world's deserts are located, marginal seas like the Mediterranean Sea and Arabian Gulf are also exposed to much evaporation and little rainfall, so their waters are much warmer and saltier than average seawater. Because of their marked response to regional and seasonal weather conditions, waters circulating through marginal seas have a recognizable influence on adjacent open waters.

Around Europe and North America shallow seas occupy depressed areas at the edge of continental blocks, such as Hudson Bay in Canada. The North Sea of northern Europe is another such flooded continental area, leaving only the British Isles above sea level at present.

CONTINENTS AND CONTINENTAL MARGINS

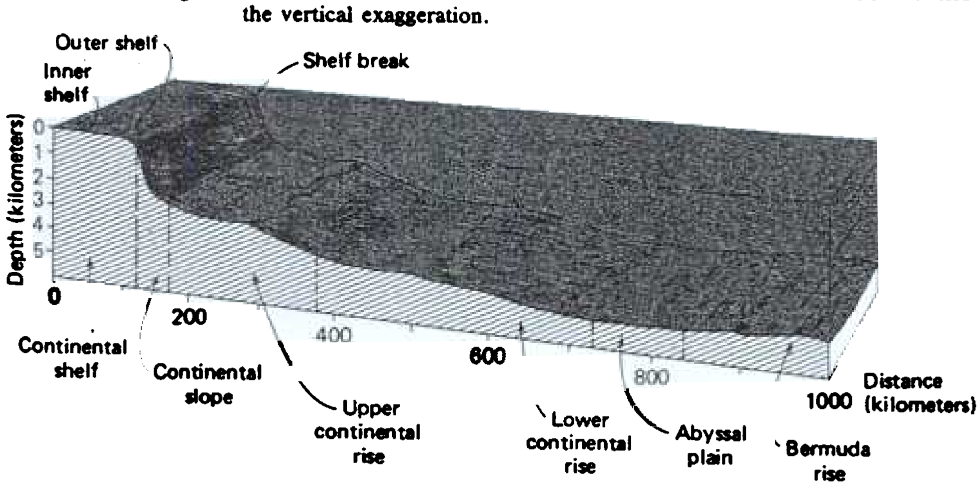
Four north-south-trending land masses—Eurasia-Africa, the Americas, Antarctica, and Australia—interrupt the ocean basins. As we shall see in later chapters, the locations of these land masses have an important effect on ocean currents.

Connections among continental land masses are rather narrow, usually low-lying and easily flooded, even by relatively small changes in sea level. As we shall see in Chapter 11, relatively recent changes in sea level have greatly modified the coastal features we see today. Large changes in sea level have opened up connections between ocean basins, such as the flooding of Central America, which connected the Atlantic and Pacific oceans, and the isolation of the Mediterranean Sea from the Atlantic (more about this in later chapters).

Continental margins consist of continental shelf, continental slope, and continental rise (Fig. 2-15). The **continental shelf** is the submerged top of the edge of the continental landmass. From the shoreline, the shelf slopes gently toward the **continental shelf break** (average depth about 130 meters, or 430 feet), where it joins the steeper **continental slope**. Off Antarctica the shelf break occurs at about 500 meters (1600 feet) because the weight of the Antarctic ice sheet has depressed the continental margin nearly 400 meters (1300 feet).

On the average, the continental shelf is about 70 kilometers (40 miles) across. Around much of the Pacific in areas of active mountain building, continental shelves are only a few tens of kilometers wide. Wide continental shelves generally occur where continental margins have not experienced mountain building for many millions of years. The widest shelves occur around the Arctic Sea.

FIGURE 2-15
Block diagram showing the North American continental margin in the Atlantic Ocean. Note the vertical exaggeration.



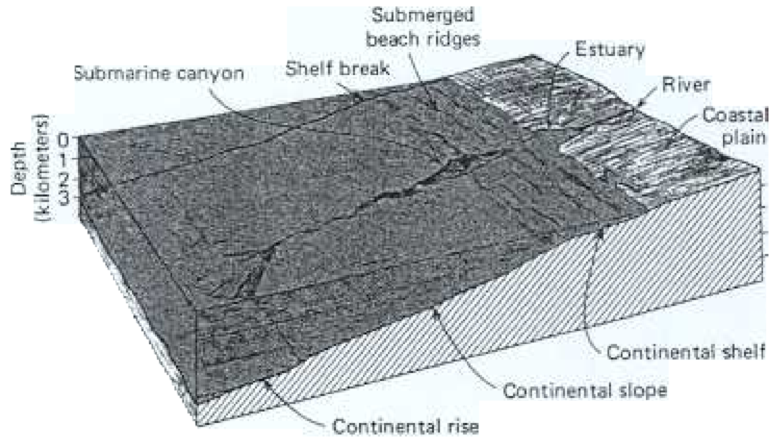


FIGURE 2-16
Schematic representation of the continental margin, showing the continental shelf, the coastal plain, the continental slope, and the continental rise. Note that a submarine canyon cuts across the shelf break and extends to the base of the continental slope, where it flows out onto the continental rise.

The **coastal plain** is an emergent continental shelf (Fig. 2-16). Where the coastal plain is absent and mountains form the coastline, as in southern California, the continental margin is rugged, broken by submarine ridges and basins. Continental shelves near high-latitude coasts tend to be rugged, another effect of the glaciers that have covered these areas several times in the last few million years.

Deep troughs, cut by glaciers, extend across high-latitude shelves and connect the deep, flooded indentations called **fjords** with the ocean. Nearby shelf areas were also substantially modified by the recent advance and retreat of the glaciers. As we shall see in Chapter 11, marine processes have not yet had enough time to completely alter such coastlines.

Continental slopes are the submerged outer edges of continental blocks. On an ocean-free earth, they would be the most conspicuous surface feature—cliffs several kilometers high. The most spectacular continental slopes occur where a range of coastal mountains borders a deep trench. On the western coast of South America, the peaks of the Andes Mountains reach elevations around 7 kilometers (4 miles), and the nearby Peru–Chile Trench is 8 kilometers (5 miles) deep—a total relief of 15 kilometers (9 miles) within a few hundred kilometers. Such slopes are common around the Pacific.

Submarine canyons (see Fig. 2-16) are common on continental shelves and slopes. Typically they follow curved paths and have tributary channels leading into them, much like river valleys on land. Some submarine canyons are as large as the Grand Canyon of the Colorado River. A few are obviously associated with the mouths of major rivers—for instance, Hudson Canyon or the Congo (Zaire) Canyon. In these cases, the upper parts of the canyons were apparently cut when sea level was much lower than its present level. Many submarine canyons have no obvious connection with large rivers.

Continental rises at the base of continental slopes are formed by accumulations of sediments eroded from the continents and deposited at the base of the slope. The thick deposits cover the transitions between continents and ocean basins.

SUMMARY

The ocean is centered around Antarctica, with three gulfs extending northward to form the Atlantic, Pacific, and Indian oceans. The solid earth surface has two primary levels—land and ocean bottom.

The Pacific Ocean is the largest, containing more than half the earth's free water. It is bordered by areas of active mountain building. The Atlantic Ocean is long and narrow, connecting the polar ocean regions. It is relatively shallow,

with many marginal seas, and receives about two-thirds of the world's river discharge. The Arctic Ocean is the nearly landlocked arm of the Atlantic. It is ice covered most of the year. The Indian Ocean is the smallest of the three major ocean basins, and lies primarily in the Southern Hemisphere.

Midocean ridges occur in all ocean basins. They form the longest mountain chain on earth. The Mid-Atlantic Ridge extends along the center of the basin. It is rugged and has a deep central rift valley. The Mid-Indian Ridge resembles the Mid-Atlantic Ridge. The East Pacific Rise has no central rift valley and is a broad, gentle rise on the ocean floor in contrast with the rugged mountains of the Mid-Atlantic and Mid-Indian ridges. Midocean ridges nearly surround Antarctica. Midocean ridges are offset by bands of rough topography called fracture zones.

The deep-ocean floor is mostly covered by sediment deposits, which smooth older topography and eventually form abyssal plains, the flattest parts of the earth's surface. Abyssal plains commonly occur near the continents at the edges of ocean basins. The greatest depths in the ocean basins occur in the trenches at the edges of the ocean basins; most occur in the Pacific and are associated with areas of active mountain building.

Smaller ocean basins occur around the margins of the major ocean basins. Many have been formed by mountain-building processes. Several are partially isolated from the adjoining ocean basins and are distinctly different from the rest of the ocean.

Continents separate the ocean basins, especially in the Northern Hemisphere. Continental margins (continental shelves and slope) are the submerged edges of the continents. The shelf break (average depth 130 meters, or 430 feet) marks the transition from continental shelf to continental slope. Continental slopes are cut by submarine canyons, especially near the mouths of major rivers. The continental rise at the base of the continental slope grades into the nearly flat abyssal plains.

Volcanoes are among the most common features on the ocean bottom; they are especially abundant on midocean ridges and are scattered across the ocean basins. Some long-extinct volcanoes have flat tops, apparently cut by waves when the volcanoes were exposed to wave action and weathering at the sea surface.

Marginal ocean basins are large, deep depressions near the continents. Most are formed by mountain building and contain thick sediment deposits. Many are structurally transitional between ocean and continent. Most marginal seas are associated with island arcs which cut them off from the open ocean. A second type, such as the Mediterranean Sea, lies between continents. The third type is the long, narrow ocean basin within a continent; the Red Sea is an example. Since the waters in these seas are partially isolated from the open ocean they sometimes form distinctive water masses. Shallow seas such as the North Sea or Hudson Bay occur on the continents.

Four north–south-trending continental masses interrupt the oceans. Connections between continental masses are often narrow and easily flooded by rises in sea level. Continental margins consist of continental shelves, continental slope, and continental rise. The continental shelf and associated coastal plain are the tops of the edges of continental blocks; they are separated by the shoreline. Continental slopes are the submerged edges of the continental blocks. Continental rises are thick sediment deposits at the base of the slopes, where they join the deep-ocean floor.

STUDY QUESTIONS

1. Draw a cross section showing the continental margin, the deep-ocean floor, and the adjacent continent. Label and indicate typical depths for each.
2. Draw a cross section of a rapidly spreading midocean ridge. Indicate where volcanic activity and hydrothermal vents are most likely to occur. Label significant features.
3. On an outline map of the world, sketch the locations of earthquake belts, active volcanoes, midocean ridges, and trenches.
4. Briefly describe the geographic relations of the three major ocean basins. Indicate how and where they connect and where and by what they are separated.
5. Discuss the origins and potential economic significance of marginal ocean basins.

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