A portion of the mid-Atlantic ridge above the sea surface in Iceland.

2

CHAPTER

The Sea Floor

The oceans are not just places where the land happens to be covered by water. The sea floor is geologically distinct from the continents. It is locked in a perpetual cycle of birth and destruction that shapes the oceans and controls much of the geology and geological history of the continents. Geological processes beneath the waters of the sea affect not only the oceans, but dry land as well.

Most of the processes that mold ocean basins occur slowly, over hundreds of millions of years. On this timescale, where a human lifetime is but the blink of an eye, solid rocks flow like liquid, entire continents move across the face of the earth, and mountains grow from flat plains. To understand the sea floor, we must learn to adopt the unfamiliar perspective of geological time.

At first glance geology might not seem to have much to do with marine biology, but, day to day and over aeons, geological processes profoundly influence marine **habitats,** the natural environments where marine organisms live. Geological processes sculpt the shoreline; determine the water depth; control whether the bottom is muddy, sandy, or rocky; create new islands and undersea mountains for organisms to colonize; and determine the nature of marine habitats in countless other ways. Indeed, much of the history of life in the oceans has been determined by geological events.

THE WATER PLANET

Our planet is very much a water planet, unique in having large amounts of liquid water—the oceans—on its surface. The oceans not only cover 71% of the globe, but also regulate its climate and atmosphere.

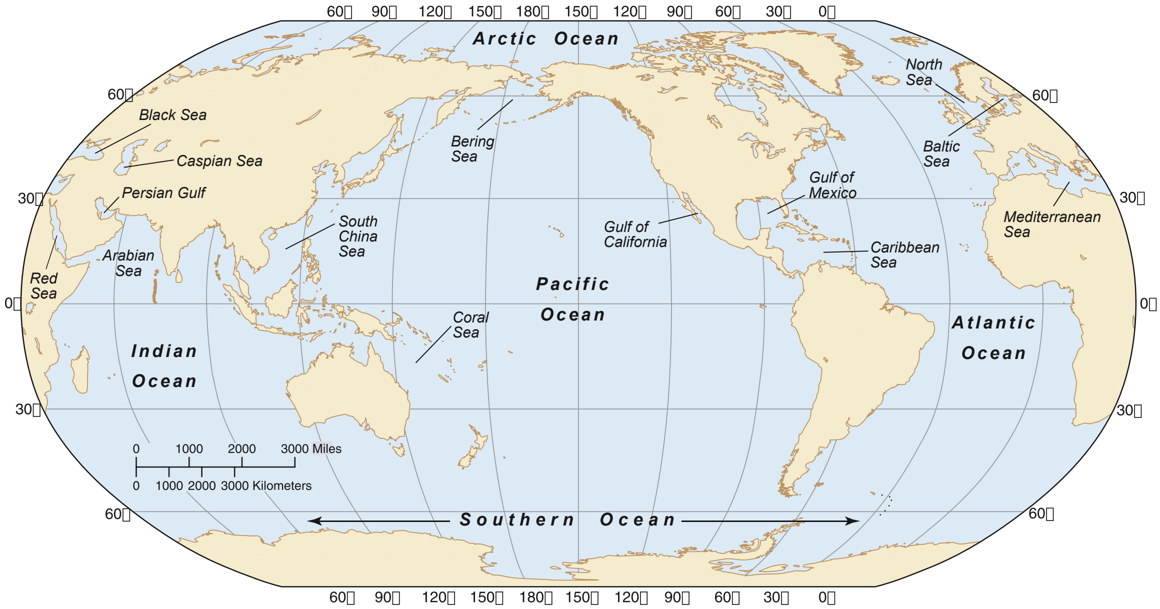

FIGURE 2.1 The major ocean basins and some of the marginal seas.

The Geography of the Ocean Basins

The oceans are not distributed equally with respect to the Equator. About two-thirds of the earth's land area is found in the Northern Hemisphere, which is only 61% ocean. About 80% of the Southern Hemisphere is ocean.

The oceans are traditionally classified into four large basins (Fig. 2.1). The **Pacific** is the deepest and largest ocean, almost as large as all the others combined (Table 2.1). The **Atlantic** Ocean is a little larger than the **Indian** Ocean, but the two are similar in average depth. The **Arctic** is the smallest and shallowest ocean. A number of shallow seas, such as the Mediterranean Sea, Gulf of Mexico, and South China Sea, are connected or marginal to the main ocean basins.

Though we usually treat the oceans as four separate entities, they are actually interconnected. This connection is most obvious when the world is viewed from the South Pole (Fig. 2.2). From this view it is clear that the Pacific, Atlantic, and Indian oceans are large branches of one vast system. The connections among the major basins allow seawater, materials, and some organisms to move from one ocean to another. Because the oceans are actually one great interconnected system, oceanographers often speak of a single **world ocean.** They also refer to the continuous body of water that surrounds Antarctica as the **Southern Ocean.**

The world ocean, which covers 71% of the planet, is divided into four major basins: the Pacific, Atlantic, Indian, and Arctic oceans.

The Structure of the Earth

The earth and the rest of the solar system are thought to have originated about 4.5 billion years ago from a cloud or clouds of dust. This dust is thought to be the debris remaining from a great cosmic explosion called the **big bang,** which astrophysicists estimate occurred about 13.7 billion years ago. The dust particles collided with each other, clumping into larger particles. These larger particles collided in turn, joining into pebble-sized rocks that collided to form larger rocks, and so on. The process eventually built up the earth and other planets.

Table 2.1 Average Depths and Total Areas of the Four Major Ocean Basins

	AREA		AVERAGE DEPTH		
Ocean	**Millions of km^2**	**Millions of mi^2**	**Meters**	**Feet**	**Deepest Place**
Pacific	166.2	64.2	4,188	13,741	Mariana Trench, 11,022 m (36,163 ft)
Atlantic	86.5	33.4	3,736	12,258	Puerto Rico Trench, 8,605 m (28,233 ft)
Indian	73.4	28.3	3,872	12,704	Java Trench, 7,725 m (25,344 ft)
Arctic	9.5	3.7	1,330	4,364	Molloy Deep, 5,608 m (18,400 ft)

FIGURE 2.2 South polar view of the world. The major ocean basins can be seen as extensions of one interconnected world ocean. The ocean that surrounds Antarctica is often called the Southern Ocean.

So much heat was generated as the early earth formed that the planet was probably molten. This allowed materials to settle within the planet according to their **density.** Density is the mass of a given volume of a substance. Obviously, a pound of styrofoam weighs more than an ounce of lead, but most people think of lead as "heavier" than styrofoam. This is because lead weighs more than styrofoam if *equal volumes* of the two are compared. In other words, lead is denser than styrofoam. The density of a substance is calculated by dividing its mass by its volume. If two substances are mixed, the denser material tends to sink and the less dense to float.

> Density is the mass of a substance per unit volume. Substances of low density will float on substances of higher density.
>
> $$\text{density} = \frac{\text{mass}}{\text{volume}}$$

While the young earth was molten, the densest material tended to flow toward the center of the planet, while lighter materials floated toward the surface. The light surface material cooled into a thin crust. Eventually, the atmosphere and oceans began to form. If the earth had settled into orbit too far away from or too close to the sun, or our atmosphere had formed differently, the earth would be either so hot that all the water would have evaporated into space or so cold that all water on earth would be perpetually frozen. Fortunately for us, both our planet's orbit and its atmosphere are such that liquid water, and therefore life as we know it, can exist.

Internal Structure The internal structure of the earth reflects the planet's early beginnings. As materials sank or floated according to their density, they formed concentric layers like those of an onion (Fig. 2.3). The innermost layer, the **core,** is composed mostly of iron. The pressure in the core is more than a million times that at the earth's surface, and the temperature is estimated to be over 4,000°C (7,200°F). The core is made up of a solid inner core and a liquid outer core. It is thought that swirling motions of the liquid material in the iron-rich outer core produce the earth's magnetic field.

The layer outside the earth's core is the **mantle.** Though most of the mantle is thought to be solid, it is very hot—near the melting point of the rocks. Because of this, much of the mantle slowly flows almost like a liquid, swirling and mixing over hundreds of millions of years.

The **crust** is the outermost, and therefore best-known, layer of the earth. Compared with the deeper layers, it is extremely thin, like a rigid skin floating on top of the mantle. The composition and characteristics of the crust differ greatly between the oceans and the continents.

> The earth is composed of three main layers: the iron-rich core, the semiplastic mantle, and the thin outer crust.

Continental and Oceanic Crusts The geological distinction between ocean and continents results from physical and chemical differences in the rock that makes up the crust (Table 2.2). The

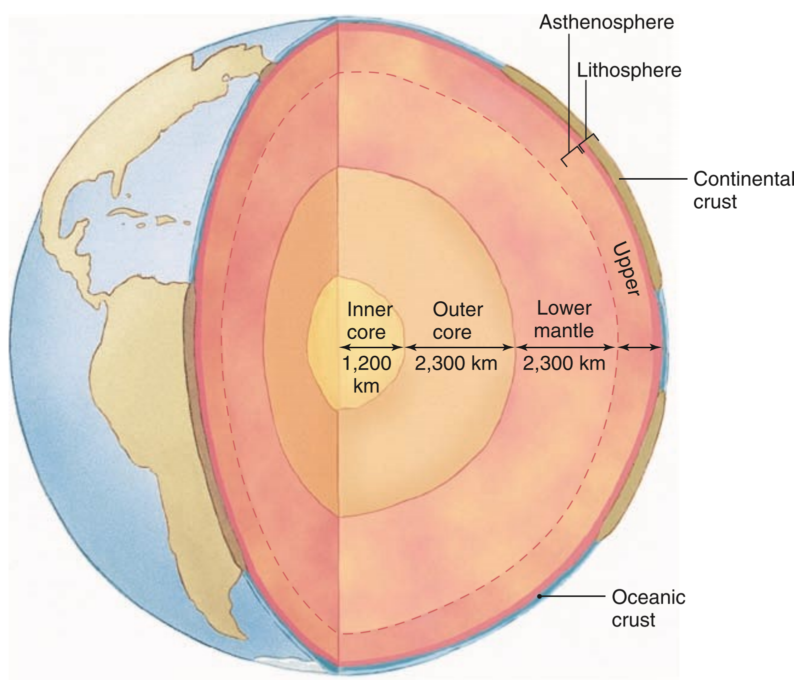

FIGURE 2.3 The interior of the earth is divided into the core, mantle, and crust. The core is subdivided into the solid inner core and the liquid outer core. The mantle is also subdivided into upper and lower layers. The very upper layer of the upper mantle is solid, and together with the crust forms the lithosphere. The upper mantle below the lithosphere is relatively fluid and is called the asthenosphere. The thickness of the crust and lithosphere is exaggerated here, and the thicknesses of all layers vary from place to place.

Table 2.2
Comparison of Continental and Oceanic Crusts

Oceanic Crust (Basalt)	Continental Crust (Granite)
Density about 3.0 g/cm^3	Density about 2.7 g/cm^3
Only about 5 km (3 mi) thick	20 to 50 km (12 to 30 mi) thick
Geologically young	Can be very old
Dark in color	Light in color
Rich in iron and magnesium	Rich in sodium, potassium, calcium, and aluminum

nature of the rock determines the elevation of a particular area of the earth's crust, and therefore whether or not it is covered by water.

Oceanic crust, which makes up the sea floor, consists of a type of mineral called **basalt** that has a dark color. Most continental rocks are of a general type called **granite,** which has a different chemical composition than basalt and is lighter in color. Oceanic crust is denser than continental crust, though both are less dense than the underlying mantle. The continents can be thought of as thick blocks of relatively light crust floating on the mantle, much as icebergs float in water. Oceanic crust floats on the mantle, too, but because it is denser it doesn't float as high.

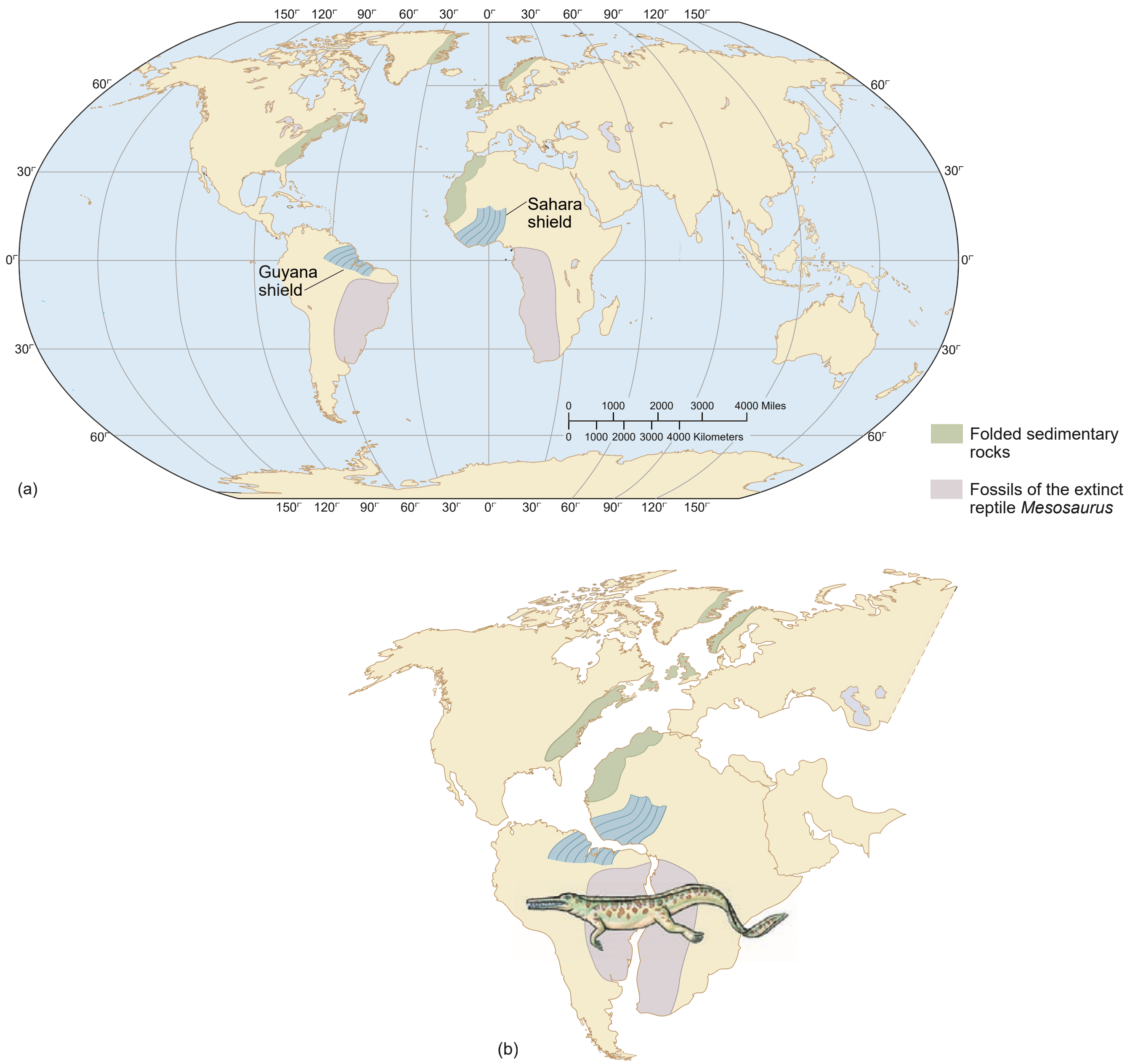

FIGURE 2.4 (*a*) The landmasses on opposite sides of the Atlantic have coastlines and geological features that (*b*) fit together like pieces of a puzzle.

This is why the continents lie high and dry above sea level and oceanic crust lies below sea level, covered with water. Oceanic crust is also much thinner than continental crust.

Oceanic and continental crusts also differ in age. The oldest oceanic rocks are less than 200 million years old, quite young by geological standards. Continental rocks, on the other hand, can be as much as 3.8 billion years old.

THE ORIGIN AND STRUCTURE OF THE OCEAN BASINS

For centuries people viewed the world as static and unchanging. Evidence of geological change is all around, however, from catastrophic earthquakes and volcanic eruptions to the slow erosion of river valleys. People eventually understood that the face of the planet does indeed change. Today scientists recognize the earth as a world of constant transformation where even the continents move.

Early Evidence of Continental Drift

As early as 1620 the English philosopher, writer, and statesman Sir Francis Bacon noted that the coasts of the continents on opposite sides of the Atlantic fit together like pieces of a puzzle (Fig. 2.4). It was later suggested that the Western Hemisphere might once have been joined to Europe and Africa, and evidence for this slowly accumulated. Coal deposits and other geological formations, for example, match up on opposite sides of the Atlantic. Fossils collected on opposing coasts are also similar.

On the basis of such evidence Alfred Wegner, a German geophysicist, proposed the first detailed hypothesis of **continental drift** in 1912. Wegener suggested that all the continents had once been joined in a single "supercontinent," which he named **Pangaea.** He thought Pangaea began breaking up into the continents we know today about 180 million years ago.

The Theory of Plate Tectonics

Wegener's hypothesis was not widely accepted because he could not explain *how* the continents moved. Later proposals of continental drift also failed to provide a workable mechanism, but evidence continued to accumulate. In the late 1950s and the 1960s scientists were able to put all the evidence together. They concluded that the continents *did* drift, as part of **plate tectonics,** a process that involves the entire surface of our planet.

Discovery of the Mid-Ocean Ridge In the years after World War II, sonar allowed the first detailed surveys of large areas of the sea floor. These surveys resulted in the discovery of the **mid-ocean ridge** system, a continuous chain of submarine volcanic mountains that encircles the globe like the seams on a baseball (Figs. 2.5 and 2.6). The mid-ocean ridge system is the largest geological feature on earth. At regular intervals the mid-ocean ridge is displaced to one side or the other by cracks, or **faults,** in the earth's crust known as **transform faults.** Occasionally the submarine mountains of the ridge rise so high that they break the surface to form islands, such as Iceland and the Azores.

The mid-ocean ridge in the Atlantic, called the **Mid-Atlantic Ridge,** runs right down the center of the Atlantic Ocean, closely following the curves of the opposing coastlines. The ridge forms an inverted Y in the Indian Ocean and runs up the eastern side of the Pacific (Fig. 2.5). The main section of ridge in the Eastern Pacific is called the **East Pacific Rise.**

The mid-ocean ridge system is a continuous, submarine range of volcanic mountains that runs through all the ocean basins.

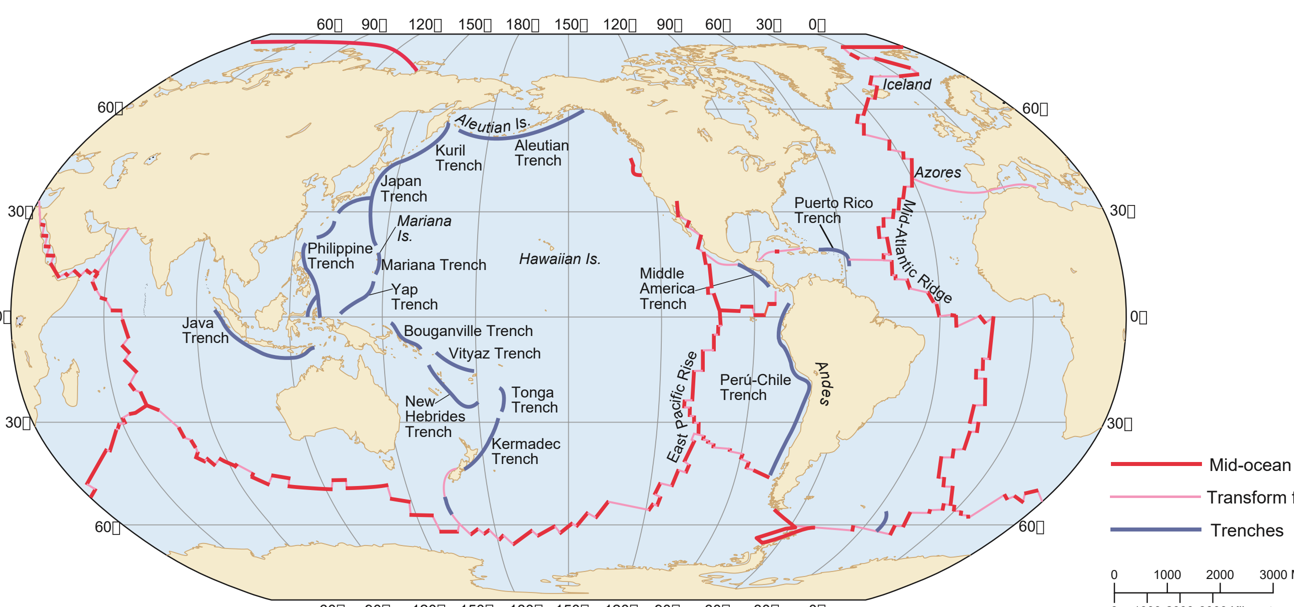

FIGURE 2.5 The major features of the sea floor. Compare this map with Figure 2.6.