

Pearson New International Edition

Foundations of Earth Science
F.K. Lutgens E.J. Tarbuck D.G. Tasa
Seventh Edition



Pearson New International Edition

Foundations of Earth Science
F.K. Lutgens E.J. Tarbuck D.G. Tasa
Seventh Edition

PEARSON

Did You Know?

A group of scientists proposed an interesting although incorrect explanation for the cause of continental drift. Their proposal suggested that early in Earth's history, our planet was only about half its current diameter and completely covered by continental crust. Through time, Earth expanded, causing the continents to split into their current configurations, while new sea-floor "filled in" the spaces as they drifted apart.

3 The Great Debate

Discuss the two main objections to the continental drift hypothesis.

Wegener's proposal did not attract much open criticism until 1924, when his book was translated into English, French, Spanish, and Russian. From that point until his death in 1930, the drift hypothesis encountered a great deal of hostile criticism. The respected American geologist R. T. Chamberlain stated, "Wegener's hypothesis in general is of the foot-loose type, in that it takes considerable liberty with our globe, and is less bound by restrictions or tied down by awkward, ugly facts than most of its rival theories."

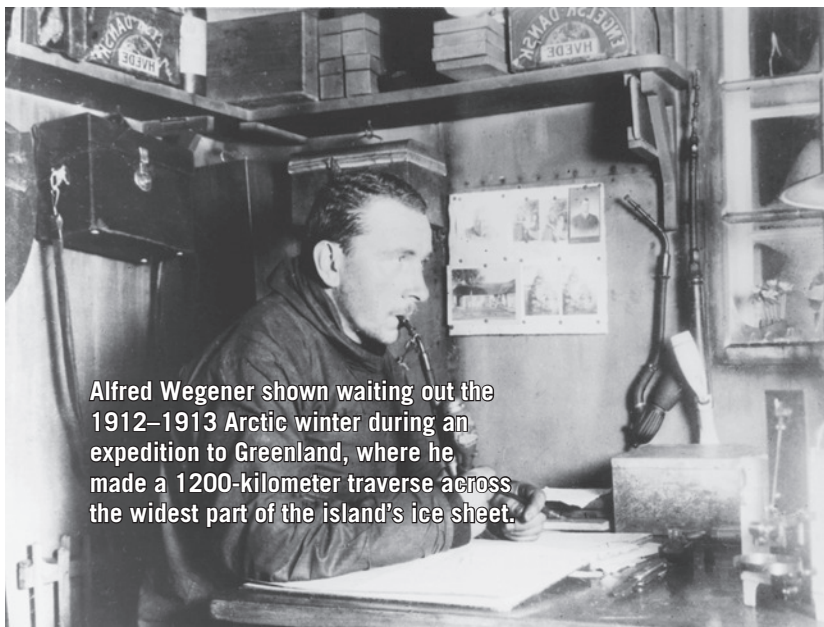
Rejection of the Drift Hypothesis

One of the main objections to Wegener's hypothesis stemmed from his inability to identify a credible mechanism for continental drift. Wegener proposed that gravitational forces of the Moon and Sun that produce Earth's tides were also capable of gradually moving the continents across the globe. However, the prominent physicist Harold Jeffreys correctly countered that tidal forces strong enough to move Earth's continents would have resulted in halting our planet's rotation, which, of course, has not happened.

Wegener also incorrectly suggested that the larger and sturdier continents broke through thinner oceanic crust, much as ice breakers cut through ice. However, no evidence existed to suggest that the ocean floor was weak enough to permit passage of the continents without the continents being appreciably deformed in the process.

In 1930 Wegener made his fourth and final trip to the Greenland Ice Sheet (Figure 8). Although the primary focus of this expedition was to study this great ice cap and its climate, Wegener continued to test his continental drift hypothesis. While returning from Eismitte, an experimental station located in the center of Greenland, Wegener perished along with his Greenland companion. His intriguing idea, however, did not die.

Why was Wegener unable to overturn the established scientific views of his day? Foremost was the fact that, although the central theme of Wegener's drift hypothesis was correct, it contained some incorrect details. For example, continents do not break through the ocean floor, and tidal energy is much too weak to cause continents to be displaced. Moreover, in order for any comprehensive scientific theory to gain wide acceptance, it must withstand critical testing from all areas of science. Despite Wegener's great contribution to our understanding



Alfred Wegener shown waiting out the 1912–1913 Arctic winter during an expedition to Greenland, where he made a 1200-kilometer traverse across the widest part of the island's ice sheet.

Figure 8 Alfred Wegener (Photo courtesy of Archive of Alfred Wegener Institute)

Figure 9 Plate movement causes destructive earthquakes Pisco, Peru, following a powerful earthquake on August 16, 2007. (Sergio Erday/epa/Corbis)



of Earth, not *all* of the evidence supported the continental drift hypothesis as he had proposed it.

Although many of Wegener's contemporaries opposed his views, even to the point of open ridicule, some considered his ideas plausible. For those geologists who continued the search, the exciting concept of continents adrift held their interest. Others viewed continental drift as a solution to previously unexplainable observations (Figure 9). Nevertheless, most of the scientific community,

particularly in North America, either categorically rejected continental drift or treated it with considerable skepticism.

3 CONCEPT CHECK

1. What two aspects of Wegener's continental drift hypothesis were objectionable to most Earth scientists?

4 The Theory of Plate Tectonics

List the major differences between Earth's lithosphere and asthenosphere and explain the importance of each in the plate tectonics theory.

Following World War II, oceanographers equipped with new marine tools and ample funding from the U.S. Office of Naval Research embarked on an unprecedented period of oceanographic exploration. Over the next two decades, a much better picture of large expanses of the seafloor slowly and painstakingly began to emerge. From this work came the discovery of a global **oceanic ridge system** that winds through all the major oceans in a manner similar to the seams on a baseball.

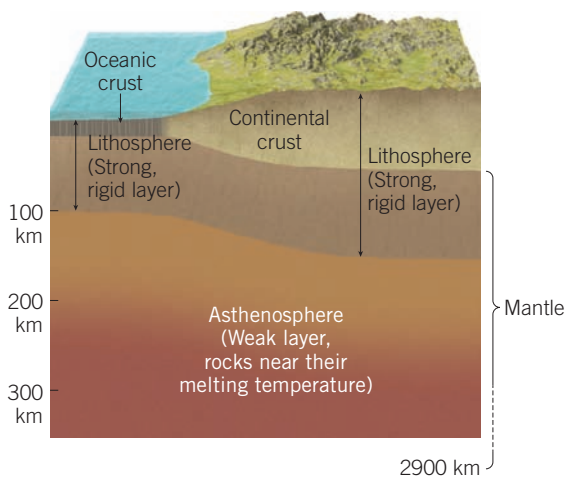
In other parts of the ocean, more new discoveries were being made. Studies conducted in the western Pacific demonstrated that earthquakes were occurring at great depths beneath deep-ocean trenches. Of equal importance was the fact that dredging of the seafloor did not bring up any oceanic crust that was older than 180 million years. Further, sediment accumulations in the deep-ocean basins were found to be thin, not the thousands of meters that were predicted. By 1968

these developments, among others, had led to the unfolding of a far more encompassing theory than continental drift, known as the **theory of plate tectonics** (*tekto* = to build).

Rigid Lithosphere Overlies Weak Asthenosphere

According to the plate tectonics model, the crust and the uppermost, and therefore coolest, part of the mantle constitute Earth's strong outer layer, known as the **lithosphere** (*lithos* = stone, *sphere* = ball). The lithosphere varies in both thickness and density, depending on whether it is oceanic lithosphere or continental lithosphere (Figure 10). Oceanic lithosphere is about 100 kilometers (60 miles) thick in the deep-ocean basins but is considerably thinner along the crest of the oceanic ridge system—a topic we will consider later. By contrast, continental lithosphere averages about 150 kilometers (90 miles) thick but may extend to depths of 200 kilometers (125 miles) or more beneath the stable interiors of the continents. Further, the composition of both the oceanic and continental crusts affects their respective densities. Oceanic crust is composed of rocks that have a mafic (basaltic) composition, and therefore oceanic lithosphere has a greater density than continental lithosphere. Continental crust is composed largely of less dense felsic (granitic) rocks, making continental lithosphere less dense than its oceanic counterpart.

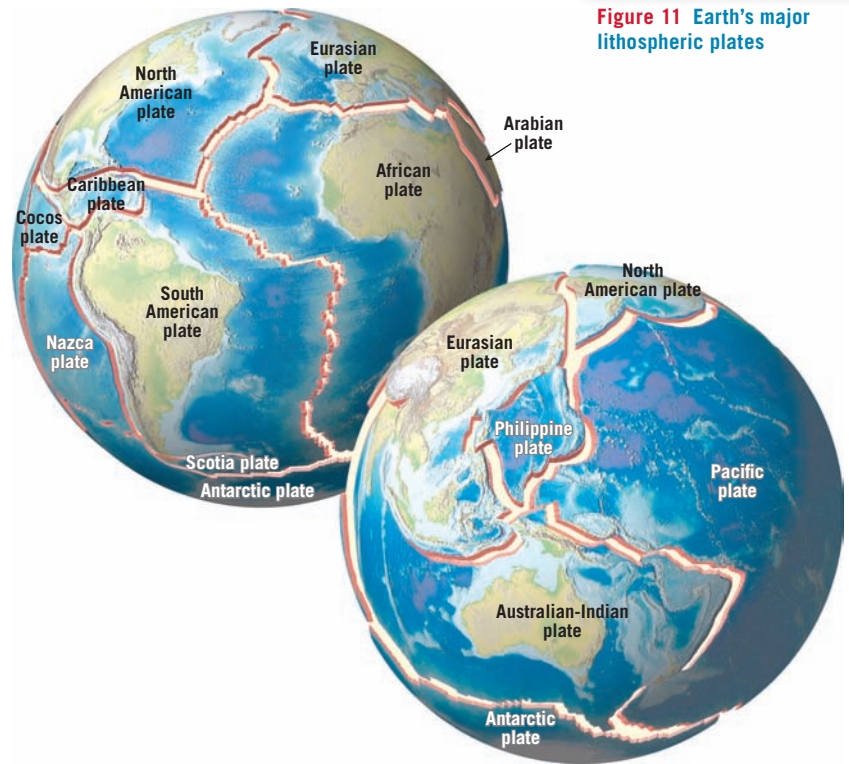
The **asthenosphere** (*asthenos* = weak, *sphere* = ball) is a hotter, weaker region in the mantle that lies



SmartFigure 10 Rigid Lithosphere overlies the weak asthenosphere



Figure 11 Earth's major lithospheric plates



below the lithosphere (see Figure 10). The temperatures and pressures in the upper asthenosphere (100 to 200 kilometers in depth) are such that rocks at this depth are very near their melting temperatures and, hence, respond to forces by *flowing*, similarly to the way a thick liquid would flow. By contrast, the relatively cool and rigid lithosphere tends to respond to forces acting on it by *bending or breaking but not flowing*. Because of these differences, Earth's rigid outer shell is effectively detached from the asthenosphere, which allows these layers to move independently.

Earth's Major Plates

The lithosphere is broken into about two dozen segments of irregular size and shape called **lithospheric plates**, or simply **plates**, that are in constant motion with respect to one another (Figure 11). Seven major lithospheric plates are recognized and account for 94 percent of Earth's surface area: the *North American*, *South American*, *Pacific*, *African*, *Eurasian*, *Australian-Indian*, and *Antarctic* plates. The largest is the Pacific plate, which encompasses a significant portion of the Pacific basin. The six other large plates include an entire continent plus a significant amount of ocean floor. Notice in Figure 12 that the South American plate encompasses almost all of South America and about one-half of the floor of the South Atlantic. This is a major departure from Wegener's

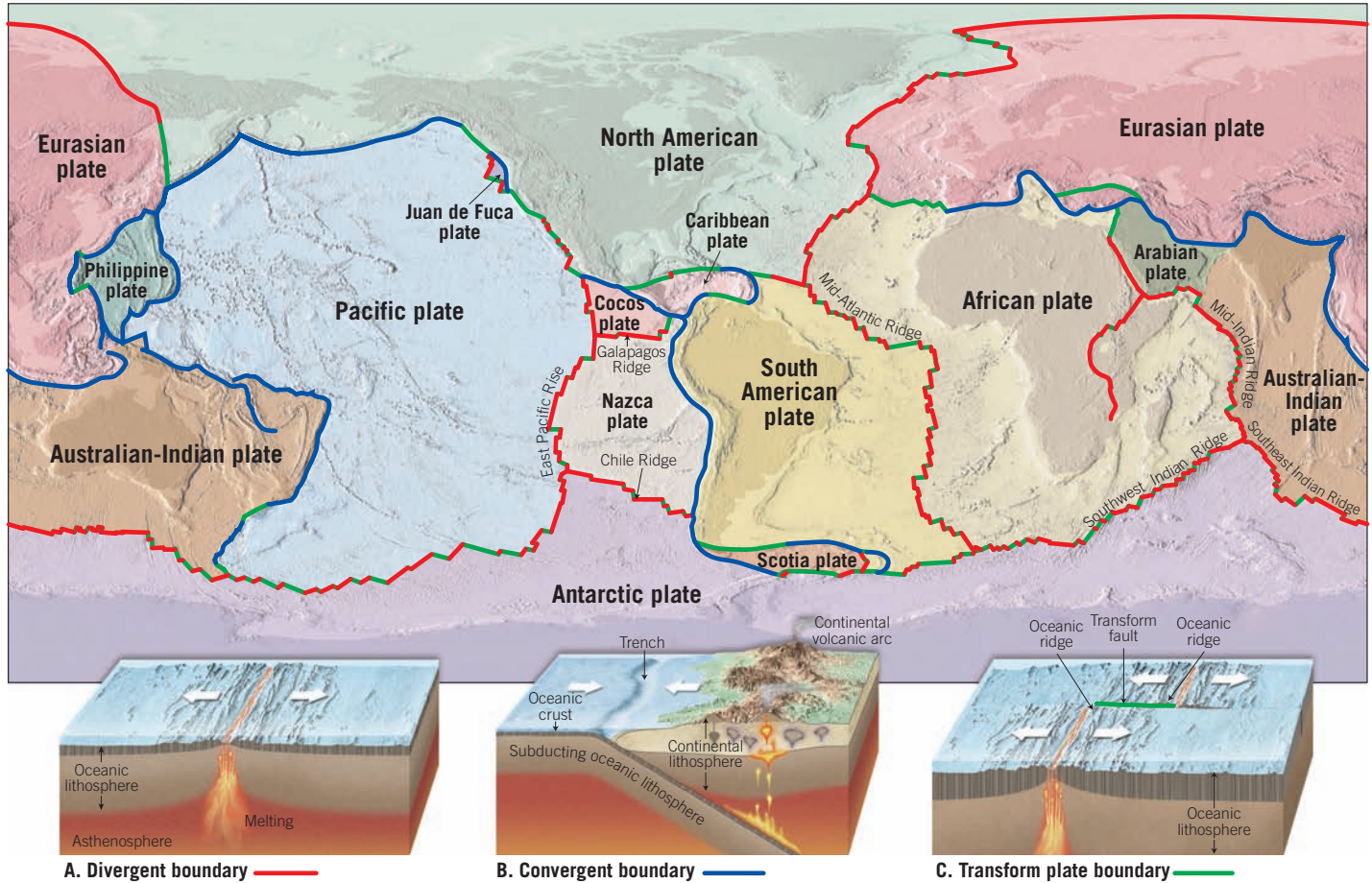


Figure 12 Divergent, convergent, and transform plate boundaries

continental drift hypothesis, which proposed that the continents move through the ocean floor, not with it. Note also that none of the plates are defined entirely by the margins of a single continent.

Intermediate-sized plates include the *Caribbean*, *Nazca*, *Philippine*, *Arabian*, *Cocos*, *Scotia*, and *Juan de Fuca* plates. These plates, with the exception of the Arabian plate, are composed mostly of oceanic lithosphere. In addition, several smaller plates (*microplates*) have been identified but are not shown in Figure 11.

Plate Boundaries

One of the main tenets of the plate tectonics theory is that plates move as somewhat rigid units relative to all other plates. As plates move, the distance between two locations on different plates, such as New York and London, gradually changes, whereas the distance between sites on the same plate—New York and Denver, for example—remains relatively constant. However, parts of some plates are comparatively “soft,” such as southern

China, which is literally being squeezed as the Indian subcontinent rams into Asia proper.

Because plates are in constant motion relative to each other, most major interactions among them (and, therefore, most deformation) occur along their *boundaries*. In fact, plate boundaries were first established by plotting the locations of earthquakes and volcanoes. Plates are bounded by three distinct types of boundaries, which are differentiated by the type of movement they exhibit. These boundaries are depicted in Figure 12 and are briefly described here:

1. Divergent plate boundaries (*constructive margins*)—where two plates move apart, resulting in upwelling of hot material from the mantle to create new sea-floor (**Figure 12A**).
2. Convergent plate boundaries (*destructive margins*)—where two plates move together, resulting in oceanic lithosphere descending beneath an overriding plate, eventually to be reabsorbed into the mantle or possibly in the collision of two continental blocks to create a mountain belt (**Figure 12B**).

3. Transform plate boundaries (*conservative margins*)—where two plates grind past each other without the production or destruction of lithosphere (Figure 12C).

Divergent and convergent plate boundaries each account for about 40 percent of all plate boundaries. Transform faults account for the remaining 20 percent. In the following sections we will summarize the nature of the three types of plate boundaries.

4 CONCEPT CHECKS

1. What major ocean floor feature did oceanographers discover after World War II?
2. Compare and contrast the lithosphere and the asthenosphere.
3. List the seven largest lithospheric plates.
4. List the three types of plate boundaries and describe the relative motion at each of them.

Did You Know?

An observer on another planet would notice, after only a few million years, that all of the continents and ocean basins on Earth are indeed moving. The Moon, on the other hand, is tectonically dead, so it would look virtually unchanged millions of years in the future.

5 Divergent Plate Boundaries and Seafloor Spreading

Sketch and describe the movement along a divergent plate boundary that results in the formation of new oceanic lithosphere.

Most **divergent plate boundaries** (*di* = apart, *vergere* = to move) are located along the crests of oceanic ridges and can be thought of as *constructive plate margins* because this is where new ocean floor is generated (Figure 13). Here, two adjacent plates move away from each other, producing long, narrow fractures in the ocean crust. As a result, hot rock from the mantle below migrates upward to fill the voids left as the crust is being ripped apart. This molten material gradually cools, producing new slivers of seafloor. In a slow and unending manner, adjacent plates spread apart, and

new oceanic lithosphere forms between them. For this reason divergent plate boundaries are also referred to as **spreading centers**.

Oceanic Ridges and Seafloor Spreading

The majority of, but not all, divergent plate boundaries are associated with *oceanic ridges*: elevated areas of the seafloor characterized by high heat flow and volcanism.

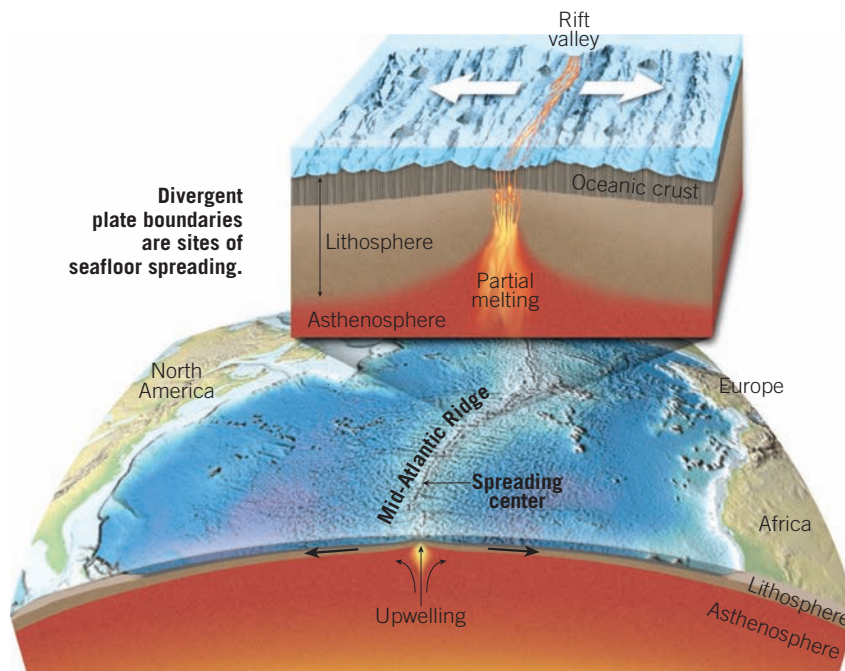


Figure 13 Seafloor spreading Most divergent plate boundaries are situated along the crests of oceanic ridges—the sites of seafloor spreading.

The global ridge system is the longest topographic feature on Earth's surface, exceeding 70,000 kilometers (43,000 miles) in length. As shown in Figure 12, various segments of the global ridge system have been named, including the Mid-Atlantic Ridge, East Pacific Rise, and Mid-Indian Ridge.

Representing 20 percent of Earth's surface, the oceanic ridge system winds through all major ocean basins like the seams on a baseball. Although the crest of the oceanic ridge is commonly 2 to 3 kilometers higher than the adjacent ocean basins, the term *ridge* may be misleading because it implies "narrow" when, in fact, ridges vary in width from 1000 kilometers (600 miles) to more than 4000 kilometers (2500 miles). Further, along the crest of some ridge segments is a deep canyonlike structure called a **rift valley** (Figure 14). This structure is evidence that tensional forces are actively pulling the ocean crust apart at the ridge crest.

The mechanism that operates along the oceanic ridge system to create new seafloor is appropriately called **seafloor spreading**. Typical rates of spreading average around 5 centimeters (2 inches) per year, roughly the same rate at which human fingernails grow. Comparatively slow spreading rates of 2 centimeters per year are found along the Mid-Atlantic Ridge, whereas spreading rates exceeding 15 centimeters (6 inches) per year have been measured along sections of the East Pacific Rise. Although these rates of seafloor production are slow on a human time scale, they are nevertheless rapid enough to have generated all of Earth's ocean basins within the past 200 million years.

The primary reason for the elevated position of the oceanic ridge is that newly created oceanic lithosphere is hot, which means it is less dense than cooler rocks found away from the ridge axis. (Geologists use the term *axis* to refer to a line that follows the general trend of the ridge crest.) As soon as new lithosphere forms, it is slowly yet



Figure 14 Rift valley Thingvellir National Park, Iceland, is located on the western margin of a rift valley that is roughly 30 kilometers (20 miles) wide in this region. This rift valley is connected to a similar feature that extends along the crest of the Mid-Atlantic Ridge. The cliff in the left half of the image approximates the eastern edge of the North American plate. (Photo by Ragnar Sigurdsson/Arctic/Alamy)