19.2 Plate Tectonics

A map of the world illustrates that the continents look like pieces of a puzzle. In fact, if all the continents were moved closer together across the Atlantic Ocean, they would fit together to form a giant landmass. In the first part of this section, you will learn about Alfred Wegener, who collected evidence that the continents had once fit together. Based on this evidence, Wegener proposed that the continents formed a supercontinent long ago. Wegener's idea eventually led to one of the most important discoveries of the twentieth century—plate tectonics.

Movement of continents

Pangaea and continental drift

In 1915, Alfred Wegener, a German scientist and arctic explorer, published *Origins of the Continents and Oceans.* In this book, Wegener hypothesized that the continents we know today had once been part of an earlier supercontinent which he called **Pangaea** (Greek for "all land"). Calling his idea **continental drift**, Wegener proposed that Pangaea broke apart and the pieces moved to their present places, becoming today's continents.

Continental drift was rejected

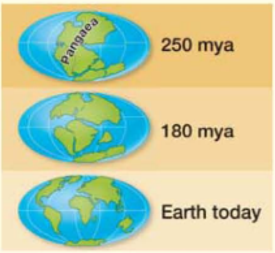
Continental drift was a scientific hypothesis based on observations and collected evidence (see next page). A key part of Wegener's hypothesis was that some unknown force had caused the continents to slide over, or push through, the rocky bottoms of the oceans. Yet, neither he nor anyone else could identify the source of the force needed to move continents. Continental drift helped explain issues in geology—like why South America and Africa seem to fit together. However, continental drift could not be accepted by scientists because there was no evidence to explain how the continents moved. For this reason, no one paid much attention to continental drift as a valid hypothesis until the 1950s and 1960s. The sidebar at the right illustrates our current understanding of the time line for the breakup of Pangaea.

VOCABULARY

Pangaea - an ancient, huge landmass composed of earlier forms of today's continents; an ancient supercontinent.

continental drift - the idea that continents move around on Earth's surface.

From Pangaea to Today



About 250 million years ago (mya), all land on Earth was part of the supercontinent Pangaea. About 180 mya, this huge landmass began to split apart into many sections. Seven of the largest sections form our continents. Before Pangaea existed, there were other earlier configurations of oceans and continents, and, over a very long period of time, forces related to plate tectonics brought them together to form Pangaea.

Evidence on Earth's surface

Matching coal beds, mountains, and fossils

Wegener was not the only scientist to suggest that continents move. His idea stood out because of the evidence that he gathered to support his idea of continental drift. Wegener's evidence is presented in the graphic below and listed in Figure 19.7.

Undersea mountains discovered

During World War II, the United States Navy needed to locate enemy submarines hiding on the bottom of shallow seas. Because of this, large areas of the ocean floor were mapped for the first time. American geophysicist and naval officer Harry Hess did some of the mapping. The naval maps showed huge mountain ranges that formed a continuous chain along the ocean floors. These mountain ranges are now called *mid-ocean ridges*.

Wegener's evidence for continental drift

- Coal beds stretch across the eastern United States and continue across parts of Europe.
- Matching plant fossils are found in South America, Africa, India, Australia, and Antarctica.
- Matching reptile fossils are found in South America and Africa.
- Matching early mammal fossils are found in South America and Africa.
- Fossils in South America and Africa are found in rocks of identical age and type.
- Matching rock types and mountain belts occur in North America and the British Isles.
- Evidence of glaciers is present in regions with warm, dry climates. This indicates that continents that are close to the equator today were once closer to the South Pole in the distant past.

Figure 19.7: *A summary of Wegener's evidence for continental drift.*

Evidence for sea-floor spreading

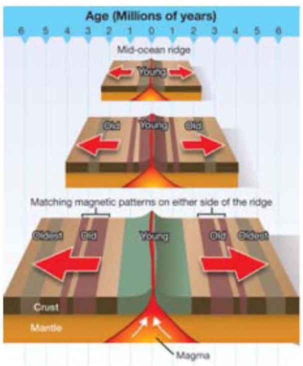
A new hypothesis is born

Harry Hess wondered if it was possible that new ocean floor was created at the site of **mid-ocean ridges**. Hess knew about continental drift and thought that Wegener was partly right. The continents had separated from a supercontinent, but not by plowing through the sea floor. Instead, Hess realized that if new ocean floor formed at these undersea mountains, then continents on either side would get separated apart during the process (Figure 19.8). Hess proposed that continents moved along as part of the growing sea floor. Hess called his hypothesis **sea-floor spreading**.

A good idea needs more evidence

Sea-floor spreading was an intriguing hypothesis. But for many years scientists had viewed the continents as permanently fixed in place. Sea-floor spreading would need strong evidence to support it before it would ever be more than just a hypothesis. And so, a time of tremendously rapid scientific research and progress followed Hess's sea-floor spreading hypothesis. Many scientists added to each other's work and found the evidence needed to explain sea-floor spreading.

Magnetic patterns and the age of rocks



The discovery of magnetic reversal patterns in the rocks on both sides of the mid-ocean ridges was a key piece of evidence. These striped patterns are formed as iron-bearing minerals in newly formed basalt align to Earth's magnetic field as the rock cools. Scientists noticed that the magnetic patterns were symmetrical on either side of a ridge. They also noticed that the oldest rocks were farthest from the ridge. These observations showed that sea-floor spreading was occurring—the new ocean floor that forms at mid-ocean ridges moves away from the ridges as time passes.

VOCABULARY

mid-ocean ridge - a long chain of undersea mountains.

sea-floor spreading - a hypothesis that new sea floor is created at mid-ocean ridges and that, in the process, the continents are separated from each other.

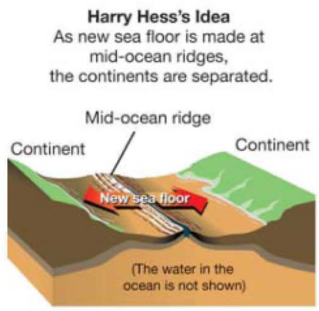
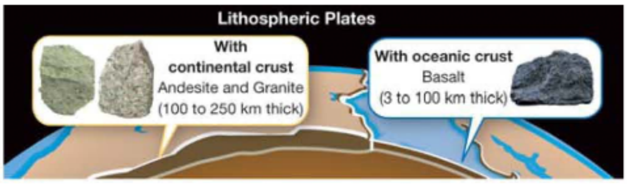


Figure 19.8: *Harry Hess wondered if it was possible that new ocean floor was created at the mid-ocean ridges. After more scientific evidence was collected, Hess's idea was supported. New ocean floor is formed at mid-ocean ridges.*

Moving pieces of the lithosphere

Lithospheric plates After the breakthrough discovery of magnetic patterns, there was a lot of interest in the idea of sea-floor spreading. Scientists realized that large pieces of Earth's surface moved about like rafts on a river. Today, we know these "rafts" are pieces of lithosphere called **lithospheric plates** that move over the asthenosphere. Recall that the lithosphere, and therefore each plate, includes Earth's crust and a portion of the upper mantle. A lithospheric plate can be composed of both oceanic and continental crust. As you have learned, oceanic crust is relatively thin and mostly made of dense basalt. Continental crust is thicker, less dense, and made of mostly andesite and granite. The graphic below shows the relative thickness of the lithosphere depending on whether it is associated with oceanic or continental crust.



Major plates Earth's lithosphere is broken up into many small plates and seven major plates. These are the Pacific, North American, South American, African, Eurasian, Indo-Australian, and Antarctic plates. Each of these plates moves as a unit and relative to the other plates. The speed at which a plate moves is very slow and ranges from 1 to 10 centimeters per year.

Plate tectonics The theory of how these lithospheric plates move on Earth's surface is called **plate tectonics**. The word *tectonics* is derived from the Greek word for "builder." The evidence that Alfred Wegener collected to support an ancient supercontinent is valid today as scientists continue to refine the theory of plate tectonics. The movement of lithospheric plates—especially at plate boundaries, the subject of the next section— influences the formation of mountains, trenches, and rocks, and the occurrence of volcanic eruptions and earthquakes. On the next page you will learn how the plates move.

VOCABULARY

lithospheric plates - large pieces of Earth's lithosphere that move over the asthenosphere.

plate tectonics - a theory explaining how lithospheric plates move on Earth's surface.

SOLVE IT!

Faster than a Moving Plate

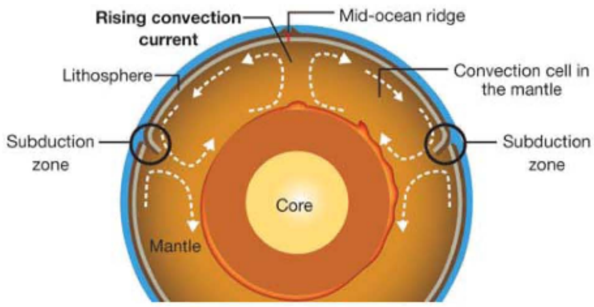
Are you faster than the speed of a moving plate on Earth's surface?

The speed of a moving plate ranges from 1 to 10 centimeters each year. On average, that's about as fast as your fingernails grow! So, even if you are walking slowly, you are moving quickly compared to a plate moving on Earth's surface. Plates move so slowly that scientists measure their movement in millions of years.

If a lithospheric plate moved 5 centimeters per year for 1,000 years, how far would it have traveled during this time?

What drives lithospheric plates?

Convection cells As you read in Section 19.1, convection cells are present in Earth's lower mantle. These convection cells help drive the lithospheric plates on the surface. Recall that as Earth's core heats the rock material of the lower mantle, it expands, becomes less dense, and rises.



What happens at mid-ocean ridges? The lower-mantle rock material then rises toward Earth's surface. Lithospheric plates move apart over the rising part of a convection cell. Basaltic material from the mantle, called *magma*, is extruded as *lava* between the plates along a mid-ocean ridge. This material adds to the plates so that they grow in size. Over time, as newly formed plate material moves away from the mid-ocean ridge, it ages, cools, and becomes denser.

Subduction By the process of **subduction**, the cooler, denser edge of a lithospheric plate eventually sinks below another lithospheric plate and enters the mantle (Figure 19.9). The sinking edge pulls the rest of the plate along in the same way that pulling the edge of a tablecloth drags the rest of the cloth off a table. As the subducting plate enters the mantle, it cools the adjacent mantle material, making it denser. As a result, the plate sinks deeper, completing the mantle convection cell. Subduction also happens when a denser oceanic plate encounters a continental plate. The oceanic plate subducts under the less dense continental plate.

VOCABULARY

subduction - a process that involves a lithospheric plate sinking into the mantle.

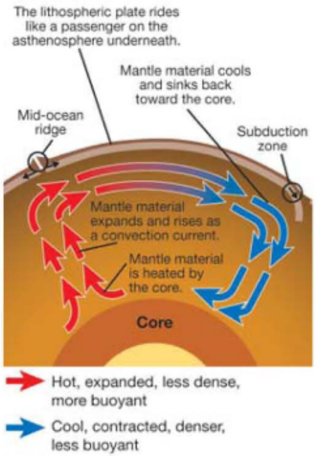


Figure 19.9: *A convection cell in the lower mantle.*

How do scientists measure the motion of plates?

A chain of islands One way that scientists measure the motion of plates is by studying a chain of islands such as the Hawaiian Islands on the Pacific Plate. These islands are formed by a mantle plume hot spot. The biggest and youngest island, Hawaii, has been on top of this hot spot for the last 700,000 years.

Mantle plumes A **mantle plume** is heated, lower mantle rock that rises toward Earth's surface. Sometimes a single plume causes a volcanic eruption in the plate above it. If the eruption is strong and lasts long enough, the volcanic eruption might form a large, volcanic island on the plate. After the island forms, the movement of the plate carries it away from the hot spot. Without the heat from the mantle plume underneath, the volcano that formed the island becomes dormant or extinct. In the meantime, a new, active volcano begins to form on the part of the plate that is now over the hot spot.

Measuring motion By studying the orientation, age, and length of a volcanic island chain, scientists can determine the direction and speed that a plate is moving. The Hawaiian Island chain shows that the Pacific Plate is moving to the northwest at about 9 centimeters per year.

VOCABULARY

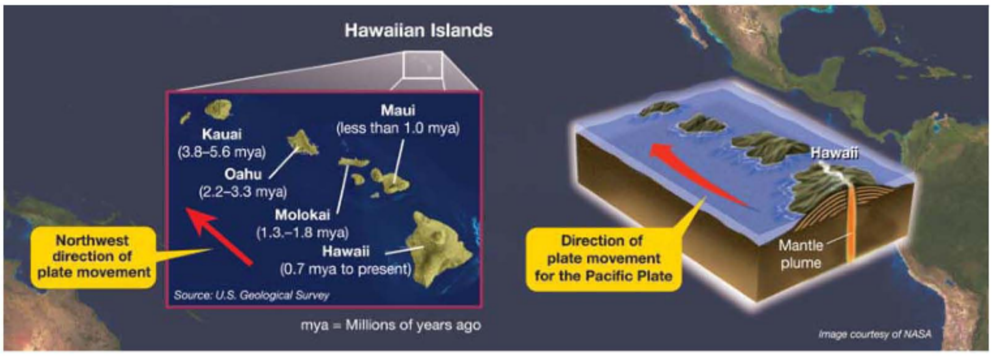
mantle plume - heated lower mantle rock that rises toward the lithosphere and forms a hot spot on the overlying lithospheric plate.

SOLVE IT!

Tracking a Moving Plate

The Pacific Plate is moving at 9 centimeters per year.

1. Draw a line on a piece of paper that is 9 centimeters long. What common objects are about this long?
2. How long will it take for this plate to travel 4.5 meters?
3. How far will the plate have traveled, in meters, after three years?



Section 19.2 Review

1. What is plate tectonics? Is it an old or a new field of science?
2. Alfred Wegener (Figure 19.10) is featured in this section. Who was he?
3. The development of the theory of plate tectonics is a good example of the scientific process.
   a. How did Wegener follow the scientific method?
   b. Were scientists applying the scientific method when they rejected continental drift? Why or why not?
   c. Would most scientists in 1900 have thought that Earth's surface was like a giant jigsaw puzzle? Why or why not?
4. List two pieces of evidence that illustrate that South America and Africa were once connected. How long ago were they connected to each other?
5. How were mid-ocean ridges discovered?
6. What was Harry Hess's hypothesis regarding the ocean floor and how it was made?
7. Explain why magnetic patterns are important evidence for plate tectonics.
8. Lithospheric plates move slowly over the _____, which is described as a zone of soft, weak rock between the upper mantle and lower mantle.
   a. crust
   b. outer core
   c. inner core
   d. asthenosphere
9. How is the process of convection related to plate tectonics?
10. Do lithospheric plates move quickly or slowly? Explain your answer.
11. Describe the process of subduction in your own words. What causes subduction to happen?
12. Describe the process of how an island chain is formed by a mantle plume. You might want to use a diagram in your answer.

Figure 19.10: *Alfred Wegener.*

CHALLENGE

Measuring Plate Motion

There are actually a number of ways to measure the motion of plates. One method was described in this section. Find out about another technique and write about it.