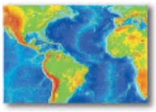
# Chapter 19
## Changing Earth



Earth is changing all the time, but some changes occur so slowly we don't even notice. Right now, the ground under our feet is moving as a separate layer over the interior of Earth. The theory of plate tectonics explains how and why the ground moves. By the end of this chapter, you will know more about the evidence for this theory than any scientist knew only forty years ago. Wow!

The continents of South America and Africa appear to fit together like puzzle pieces. Were they ever connected? If so, how did they get separated? These questions were asked by scientists for a long time before enough scientific evidence established the theory of plate tectonics.

Plate tectonics explains how and why Earth's surface has changed over millions and millions of years. The changes are due to the flow of solid rock, under great heat and pressure, deep within our planet. The motion of pieces of Earth's lithosphere caused by this flow leads to earthquakes and volcanoes; the building of mountain ranges, such as the Himalayas; the creation of trenches; and the melting of rocks as well as the formation of new ones.

### Key Questions

- ✔ *What does the interior of Earth look like?*
- ✔ *Why do South America and Africa seem to fit together like puzzle pieces?*
- ✔ *How are rocks made from other rocks?*

*Himalayan Mountains*
*Map: Courtesy of National Geophysical Data Center (NGDC).*

471

# 19.1 Inside Earth

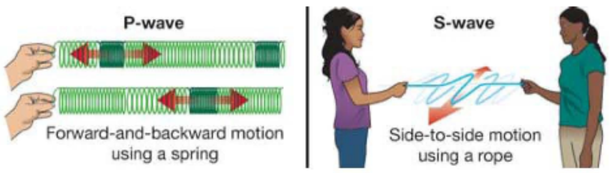
The center of Earth is about 6,400 kilometers below the surface. The deepest anyone has ever drilled is 13 kilometers—not even close to the center! Yet scientists know a lot about Earth's interior. This section is about the inside of Earth and how we know what it looks like.

## Waves inside Earth

**Special vibrations** Special vibrations that travel through Earth, called **seismic waves**, have revealed the structure of Earth's interior. Seismic waves, which are caused by events like earthquakes and human-made blasts, pass along the surface and through Earth. A **seismologist** is a scientist who studies earthquakes by detecting and interpreting seismic waves using sensors at different places on Earth's surface.

**Wave motion** Wave motion is the way that energy is transmitted though Earth as a result of a disturbance. Seismic waves transmit energy released by earthquakes, meteorite impacts, or human activities to other locations. Wave motion is a series of movements that progress through materials while the material remains in place. This is how waves transfer the energy from a disturbance from one location to a very distant location.

**P-waves and S-waves** Two types of seismic waves that are important for studying Earth's interior are primary and secondary waves, or P-waves and S-waves. **P-waves** travel faster than S-waves and move with a forward-and-backward motion. Slower **S-waves** travel with a side-to-side motion. S-waves cannot pass through liquids, but P-waves can pass through both solids and liquids.




### VOCABULARY

**seismic waves** - vibrations that travel through Earth and are caused by events like earthquakes or human-made blasts.

**seismologist** - a scientist who studies earthquakes.

**P-waves** - seismic waves that move with a forward-and-backward motion. They are faster than S-waves and can travel through both solids and liquids.

**S-waves** - seismic waves that move with a side-to-side motion, are slower than P-waves, and can only travel through solids.

### SCIENCE FACT

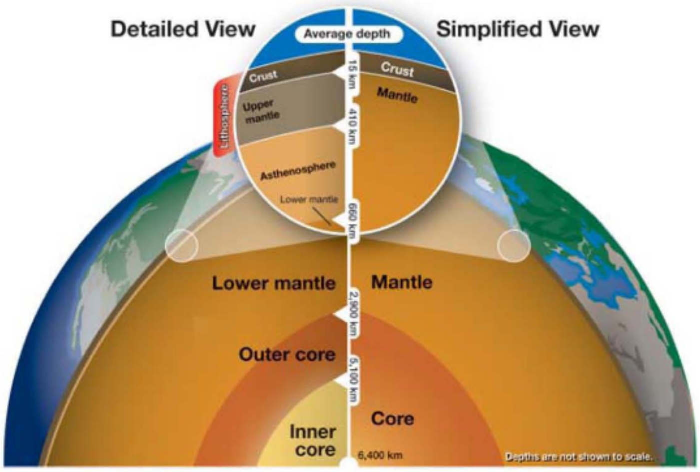
**Richter Magnitude Scale**

You have probably heard of the Richter scale which is used to identify the magnitude (size) of earthquakes. It was first presented to the world in 1936, in a publication by Charles F. Richter, a California seismologist and physicist. At first, Richter's scale only applied to Southern California. With the help of Dr. Beno Gutenberg, the scale was developed to apply worldwide to various types of instruments that measure and record seismic waves.

## Seeing Earth's interior with waves

**Waves tell us about Earth's interior** P-waves and S-waves might be bent, reflected, sped up, slowed down, or stopped depending on the nature of the material they encounter. By studying what happens to the waves as they travel through Earth, scientists are able to make a detailed model of Earth's interior (see below).

**A clue from S-waves** The discovery that Earth has a liquid outer core was determined by following the path of S-waves. Scientists observed that when an earthquake produced S-waves on one side of Earth, there was a large area on the other side where the waves couldn't be detected (Figure 19.1). They called this area the *S-wave shadow zone*. Since secondary waves cannot pass through liquids, scientists realized that the outer core of Earth must be liquid, blocking the path of the S-waves through Earth.



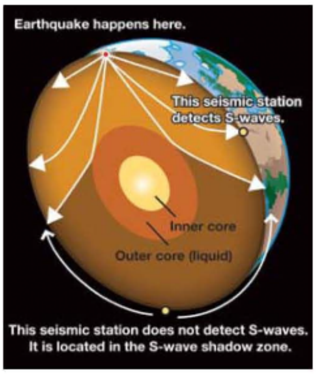




**Figure 19.1:** *S-waves are unable to penetrate the liquid outer core of Earth. An S-wave shadow zone occurs on the side of Earth opposite the earthquake.*

### STUDY SKILLS

Use flash cards to help you practice using new terms.

## Layers inside Earth

**Crust** Earth's outermost layer is called the **crust**. Oceanic crust is made of basalt, lies under the oceans, and is about 7 to 10 kilometers thick. Continental crust is made of granite, forms continents, and has an average thickness of 35 to 40 kilometers (Figure 19.2). The rock in the crust is brittle because it is cool. The crust breaks easily—like a cracker— when forces are applied to it.

**Mantle** Earth's crust floats on the **mantle**, which lies between the crust and Earth's core. The mantle is the thickest layer and makes up almost half of Earth's diameter. Temperature and pressure increase with depth in the mantle. Due to high heat and pressure, the rock of the mantle is solid, but it flows in huge, heat-driven, slow currents that have been in motion for millions of years.

**Asthenosphere** Earth's mantle is divided into the upper and lower mantle. Just below the upper mantle is a zone where the combination of high heat and pressure cause rock to be softest and weakest. This zone, called the **asthenosphere**, divides the upper mantle and the much larger lower mantle. Geologists compare the harder upper and lower mantle separated by the softer asthenosphere to a jelly sandwich, the asthenosphere being the jelly.

**Lithosphere** It is a common mistake to think that Earth's lithosphere is the same as the crust. It's not! The **lithosphere** is Earth's moving outer shell that includes *both* the crust and the upper mantle. Pieces of the lithosphere, called lithospheric plates, move slowly around Earth's surface. These plates are like the top piece of bread of the geologists' jelly sandwich. The movement of the lithosphere shapes our oceans and continents.

**Core** Earth's **core** is divided into two layers, the outer and inner core. Both the outer and inner layers are composed mostly of iron. The outer core is hot enough to melt and is liquid. You might think that the inner core would also be liquid, but the greater pressure at this depth prevents it from melting. The pressure causes the inner core to be solid. Rotation of the solid inner core and convection in the liquid outer core cause powerful electric currents that create Earth's magnetic field. This magnetic field protects the atmosphere and planet from harmful solar radiation. For this reason, life on Earth would be in danger if core movement stopped.

### VOCABULARY

**crust** - the outermost layer of Earth.

**mantle** - the hot, slow-flowing, solid layer of Earth between the crust and the core.

**lithosphere** - a layer of Earth that includes the crust and the upper mantle, above the asthenosphere.

**asthenosphere** - a zone in the mantle below the lithosphere where the combination of heat and pressure cause the mantle rock to be softest and weakest.

**core** - the center of Earth; it is divided into the solid inner core and the liquid outer core.

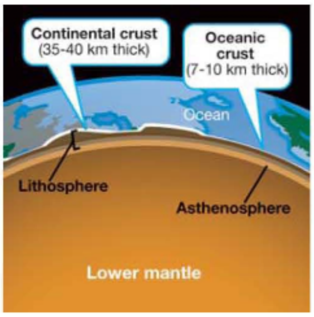



**Figure 19.2:** *The continental crust and the oceanic crust.*

## Density and Earth's materials

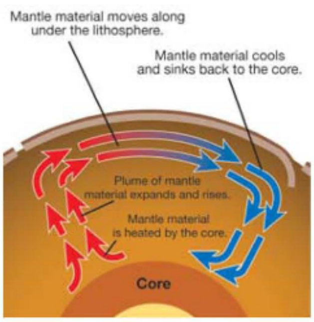
**How Earth's layers formed** Earth formed from the gas and dust that surrounded our young Sun. At first, Earth's surface was made of the same materials as its center. Later on, these materials melted. As the materials began to flow, less buoyant, denser materials settled toward the center, while more buoyant, less dense materials rose toward the surface. Aluminum and silicon, which have low densities, are common within Earth's crust. Earth's inner and outer cores are composed mostly of dense iron (Figure 19.3).

| Substance | Density (g/cm$^3$) |
|---|---|
| aluminum | 2.7 |
| silicon | 2.3 |
| iron | 7.9 |
| water | 1.0 |

**Figure 19.3:** *Density values for substances that make up Earth.*

**Earth's crust floats on the mantle** Earth's crust is made of various types of rock that are less dense than the mantle. Oceanic crust is made of basalt and is slightly denser than continental crust. The density of oceanic crust is 3.0 g/cm$^3$, whereas continental crust is made of andesite and granite and has a density of 2.7 g/cm$^3$(Figure 19.4).

**Convection in the lower mantle**




Convection is the transfer of heat as material circulates. Inside Earth, convection takes place in the lower mantle. Most of the heat left over from the formation of Earth lies in the core. This heat is constantly being transferred to lower mantle material, causing it to expand. Since the mass doesn't change but the volume increases, the heated material is less dense and rises from the core toward the lithosphere. Since less dense materials float on more dense materials, a convection current develops.

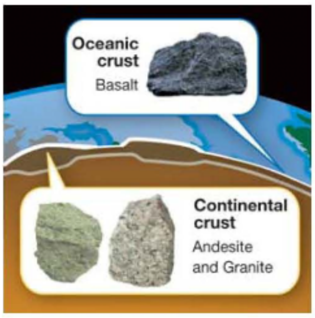
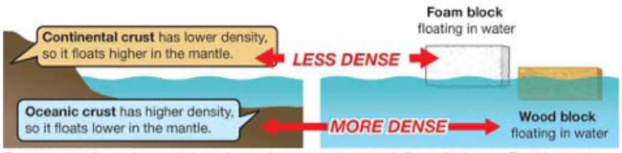



**Figure 19.4:** *The oceanic crust is made mostly of basalt. The continental crust is made mostly of andesite and granite.*

**Convection cells** As the convection current nears the lithosphere, it turns and runs along underneath. Eventually the convection current loses its heat and sinks back toward the core, creating a convection cell. In the next section, you will learn how lower-mantle convection helps drive the lithospheric plates across Earth's surface.

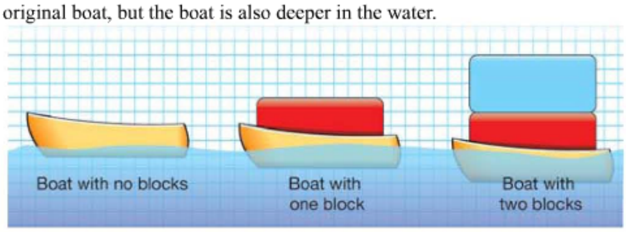
## Floating continents

**Rocks float on rocks** It's hard to imagine rocks floating on other rocks, but it happens inside Earth. The cold, brittle rock of the lithosphere floats on the hot, denser rock of the mantle below.




Because continental crust is less dense than oceanic crust, it floats higher on Earth's mantle. Blocks of foam and wood floating in water demonstrate this phenomenon.

**How is a continent like a boat?** Imagine stacking blocks on a toy boat floating in a pool. As you add blocks, the stack gets higher and heavier. The extra weight presses more of the boat into the water to support the stack. The finished stack stands taller than the original boat, but the boat is also deeper in the water.




**Mountains on continents** Earth's crust floats on the mantle just like the boat. A mountain on land is just like the stack of blocks (Figure 19.5). Like the boat, the part of the crust with a mountain on it sticks down into the mantle. The average thickness of continental crust is 35 to 40 kilometers, but the combination of a mountain and its bulge underneath might make the crust as thick as 70 kilometers.

**Glaciers on continents** During an ice age, the weight of glacial ice presses the crust down just like a mountain. After the ice age ends and the glacier melts, the crust rises back up again (Figure 19.6).

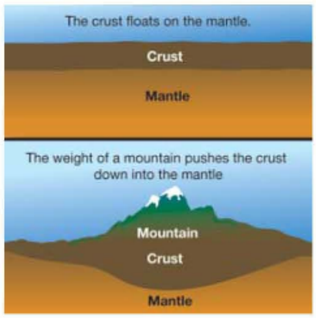



**Figure 19.5:** *How a mountain affects the crust.*

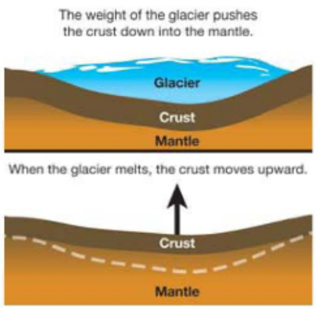



**Figure 19.6:** *How a glacier affects the crust. The effects have been exaggerated to show the changes.*

## Section 19.1 Review

1. What are seismic waves and what causes them? What have they revealed about Earth's interior?
2. List the two most important types of seismic waves used for studying Earth's interior. Give three facts about each type of wave.
3. Compare and contrast the two kinds of crust at Earth's surface.
4. What is the asthenosphere and how is it related to the lithosphere?
5. What factors increase as you go deeper toward Earth's core? Name two.
6. How is Earth's magnetic field generated? What role does Earth's magnetic field play in protecting our planet?
7. Explain how the young Earth separated into layers. Use the term *density* in your answer.
8. Using the density values in Figure 19.3, explain why water "floats" on Earth's surface.
9. Describe how convection works in the mantle. What is the source of heat?
10. How is a piece of continental crust like a boat?
11. What might happen to a mountain that would cause the crust to float higher in the mantle? What might happen to a glacier that would cause the crust to float higher in the mantle?
12. The table below lists details about the layers of Earth from its surface to its core. Imagine that you could travel to Earth's core (an impossible feat). What would you experience along the way?

| Layers of Earth | | Average Depth (km) | Appoximate Temperature (°C) | Description |
|---|---|---|---|---|
| Lithosphere | Crust | 15 | 0 | The uppermost layer |
| | Upper mantle | 410 | 870 | The lower part of the lithosphere |
| | Asthenosphere | 660 | | Zone where mantle rock is most fluid |
| | Lower mantle | 2900 | 3700 | Largest part of Earth's interior |
| Core | Outer core | 5100 | 3700 | Liquid iron |
| | Inner core | 6400 | 5000 | Solid iron |

Temperature increases with depth

### BIOGRAPHY

**Science Fiction and Jules Verne**

Jules Verne wrote science-fiction books in the mid-1800s. Verne was popular among readers because he researched his topics and wrote stories that could have been true. In 1864, he wrote *Journey to the Center of the Earth*. The main characters were three adventurers who explored a hollow Earth and lived to tell their tale. Along the way, they entered Earth through an opening in a volcano in Iceland, climbed down through many strange chambers, crossed an ocean at the center of Earth, and escaped to the surface by riding a volcanic eruption.

Wow! Are any parts of this story possible? Why or why not? Justify your answer.

*Image: NASA*