

CALIFORNIA

Standards Preview

S 6.1 Plate tectonics accounts for important features of Earth's surface and major geologic events. As a basis for understanding this concept:

- a. Students know evidence of plate tectonics is derived from the fit of the continents; the location of earthquakes, volcanoes, and mid-ocean ridges; and the distribution of fossils, rock types, and ancient climatic zones.
- b. Students know Earth is composed of several layers: a cold, brittle lithosphere; a hot, convecting mantle; and a dense, metallic core.
- c. Students know lithospheric plates the size of continents and oceans move at rates of centimeters per year in response to movements in the mantle.
- e. Students know major geologic events, such as earthquakes, volcanic eruptions, and mountain building, result from plate motions.
- f. Students know how to explain major features of California geology (including mountains, faults, and volcanoes) in terms of plate tectonics.

S 6.4 Many phenomena on Earth's surface are affected by the transfer of energy through radiation and convection currents. As a basis for understanding this concept:

- c. Students know heat from Earth's interior reaches the surface primarily through convection.

The diagonal line in the photo marks California's San Andreas fault. Two large pieces of Earth's crust slide past each other along the fault. ►





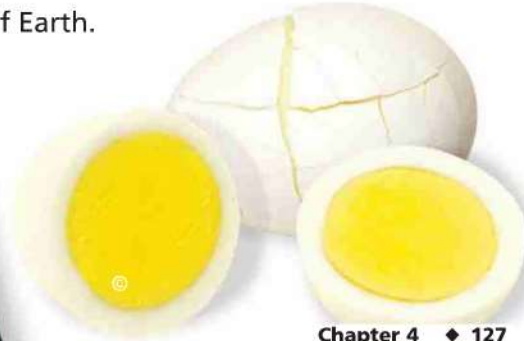
Focus on the
BIG Idea

S 6.1.c, S 6.1.d, S 6.1.e

What are Earth's plates, and how do their movements change our planet's surface?

Check What You Know

Imagine knocking a hardboiled egg against a table so that the shell cracks in several places. Then suppose that you slice the egg in half to make a cross section of the shell, egg white, and yolk. Explain how your sliced egg with the cracked shell can serve as a model of Earth.



Build Science Vocabulary

The images shown here represent some of the key terms in this chapter. You can use this vocabulary skill to help you understand the meaning of some key terms in this chapter.

Vocabulary Skill

Use Greek Word Origins

Many science words come to English from ancient Greek. In this chapter you will learn the word *lithosphere*. You probably know the meaning of *sphere*, a globe or ball. The Greek word *litho* means "stone." Therefore, the *lithosphere* is the stony outer shell, or sphere, that forms Earth's surface.

litho + **sphere** = **lithosphere**
stone globe the stony outer part of Earth

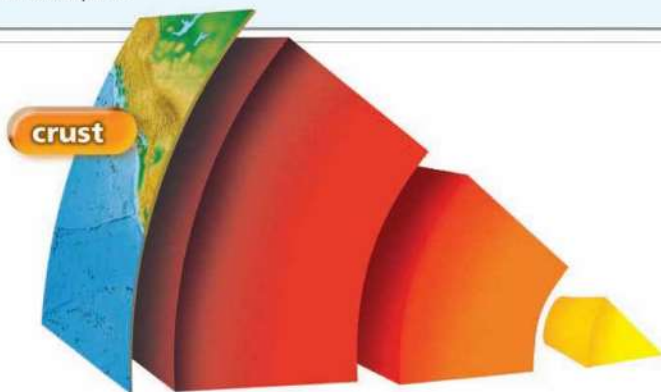
Learn these Greek words to help you remember the key terms.

Greek Root	Meaning	Examples
<i>asthenes</i>	weak	asthenosphere
<i>litho-</i>	stone	lithosphere
<i>seismos</i>	earthquake	seismic
<i>sphaira</i>	sphere	lithosphere
<i>tektón</i>	carpenter, builder	tectonics

Apply It!

Review the Greek roots and meanings in the chart. Then predict the meaning of seismic waves. As you read, revise your definition as needed.

Use these Greek words to help you figure out unfamiliar words in this chapter.



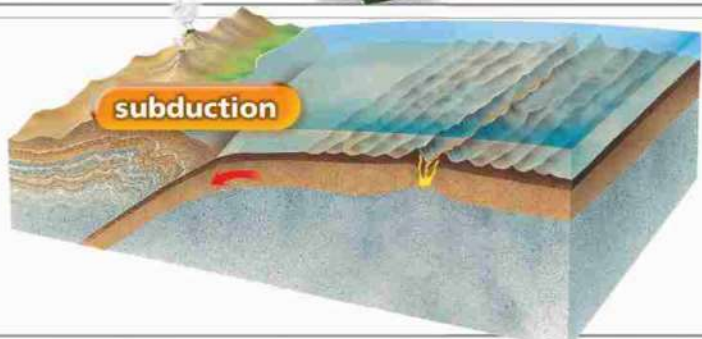
Chapter 4 Vocabulary



convection current



fossil



subduction



plate

Section 1 (page 132)

seismic waves
pressure
crust
basalt
granite
mantle
lithosphere
asthenosphere
outer core
inner core

Section 2 (page 140)

radiation
conduction
convection
density
convection current

Section 3 (page 144)

continental drift
Pangaea
fossil

Section 4 (page 149)

mid-ocean ridge
sonar
sea-floor spreading
deep-ocean trench
subduction

Section 5 (page 158)

plate
scientific theory
plate tectonics
fault
spreading boundary
rift valley
colliding boundary
sliding boundary



Build Science Vocabulary
Online

Use interactive flashcards

How to Read Science

Reading Skill



Identify Supporting Evidence

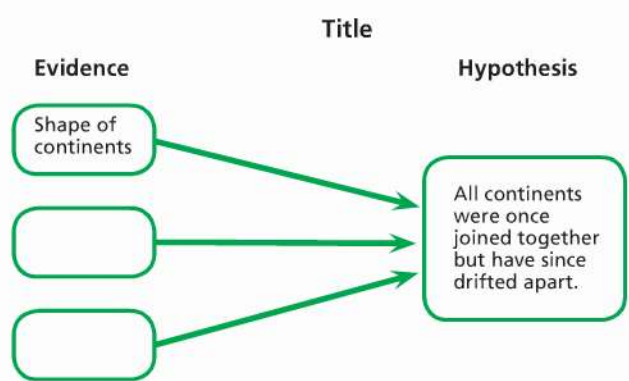
Science textbooks often describe the scientific evidence that supports a theory or hypothesis. Remember that scientific evidence includes data and facts that have been confirmed by observation or experiments.

You can use a graphic organizer like the one below to help you understand how supporting evidence is related to a theory.

Include

- a title
- supporting evidence on the left
- the hypothesis or theory on the right

This chapter discusses Wegener's hypothesis of continental drift.



Apply It!

Review the graphic organizer and answer the questions.

1. What is a good title for the graphic organizer?
2. What information should you include in the ovals on the left?

As you read Section 3, complete the graphic organizer on continental drift. In Section 4, create a graphic organizer to explain the theory of sea-floor spreading.

Make a Model of Earth

In this chapter, you will learn how movements deep within Earth help to form mountains and other surface features. As you read this chapter, you will build a model that shows Earth's interior.

Your Goal

To build a model that shows Earth's surface features, as well as a cutaway view of Earth's interior

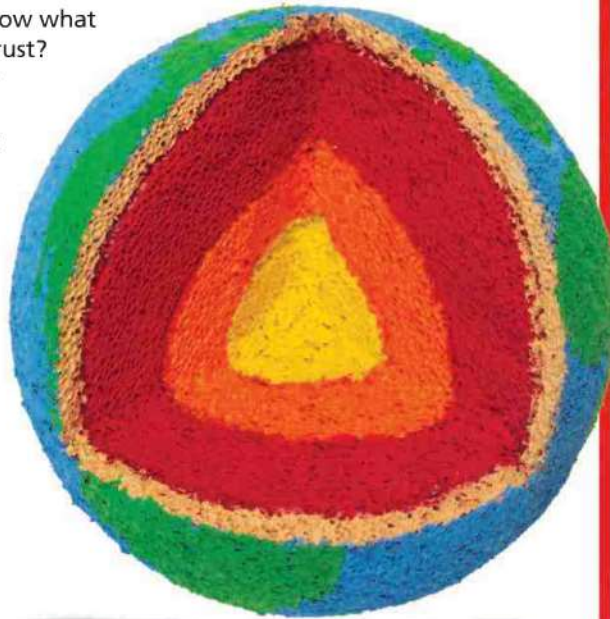
Your model must

- be built to scale to show the layers of Earth's interior
- include at least three of the plates that form Earth's surface, as well as two landmasses or continents
- show how the plates push together, pull apart, or slide past each other and indicate their direction of movement
- be built following the safety guidelines in Appendix A

Plan It!

Think about the materials you could use to make a three-dimensional model. How will you show what happens beneath the crust?

As you learn about sea-floor spreading and plate tectonics, add the appropriate features to your model.



Section 1

Earth's Interior

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Standards Focus

S 6.1.b. Students know Earth is composed of several layers: a cold, brittle lithosphere; a hot, convecting mantle; and a dense, metallic core.

- How have geologists learned about Earth's inner structure?
- What are the characteristics of Earth's crust, mantle, and core?

Key Terms

- seismic waves
- pressure
- crust
- mantle
- lithosphere
- asthenosphere
- outer core
- inner core

FIGURE 1

Lava From Inside Earth

A lava flow like this one on Mount Kilauea, Hawaii, transfers some of the heat of Earth's interior to the surface.

Lab
zone

Standards Warm-Up

How Do Scientists Find Out What's Inside Earth?

1. Your teacher will provide you with three closed film canisters. Each canister contains a different material. Your goal is to determine what is inside each canister—even though you can't directly observe what it contains.
2. Tape a paper label on each canister.
3. To gather evidence about what is in the canisters, you may tap, roll, shake, or weigh them. Record your observations.
4. What differences do you notice between the canisters? Apart from their appearance on the outside, are the canisters similar in any way? How did you obtain this evidence?

Think It Over

Inferring From your observations, what can you infer about the contents of the canisters? How is a canister like Earth?

Volcanic eruptions like those at Mount Kilauea in Hawaii make people wonder, What's inside Earth? Yet this question is very difficult to answer. Much as geologists would like to, they cannot dig a hole to the center of Earth. The extreme conditions in Earth's interior prevent exploration far below the surface.

The deepest mine in the world, a gold mine in South Africa, reaches a depth of 3.8 kilometers. But that mine only scratches the surface. You would have to travel more than 1,600 times that distance—over 6,000 kilometers—to reach Earth's center.



Exploring Inside Earth

👉 Geologists have used two main types of evidence to learn about Earth's interior: **direct evidence from rock samples** and **indirect evidence from seismic waves**. Geologists have used this evidence to build a picture of Earth's interior.

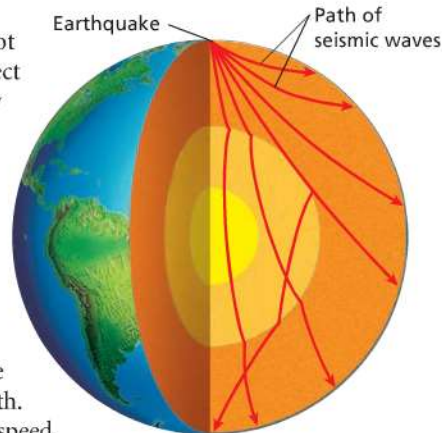
Evidence From Rock Samples Rocks from inside Earth give geologists clues about Earth's structure. Geologists have drilled holes as much as 12 kilometers into Earth. The drills bring up samples of rock. From these samples, geologists can learn about conditions deep inside Earth, where these rocks formed. In addition, forces inside Earth sometimes blast rock to the surface from depths of more than 100 kilometers. These rocks provide clues about the interior.

Evidence From Seismic Waves Geologists cannot look inside Earth. Instead, they must rely on indirect methods of observation. Have you ever hung a heavy picture on a wall? If you have, you know that you can knock on the wall to locate the wooden beam underneath the plaster that will support the picture. When you knock on the wall, you listen carefully for a change in the sound.

To study Earth's interior, geologists also use an indirect method. But instead of knocking on walls, they use seismic waves. When earthquakes occur, they produce **seismic waves** (SYZ mik). Geologists record the seismic waves and study how they travel through Earth. Different types of seismic waves behave differently. The speed of the waves and the paths they take reveal the structure of the planet. You will learn about the different types of seismic waves in Chapter 5, Earthquakes.

Using data from seismic waves, geologists have learned that Earth's interior is made up of layers. Each layer surrounds the layers beneath it, much like the layers of an onion. In Figure 2, you can see how seismic waves travel through the layers that make up Earth.

FIGURE 2
Seismic Waves
Scientists infer Earth's inner structure by recording and studying how seismic waves travel through Earth.




Reading Checkpoint What causes seismic waves?





A Journey to the Center of Earth

 The three main layers of Earth are the crust, the mantle, and the core. These layers vary greatly in size, composition, temperature, and pressure. If you could travel through these layers to the center of Earth, what would your trip be like? To begin, you will need a vehicle that can travel through solid rock. The vehicle will carry scientific instruments to record changes in temperature and pressure as you descend.

Temperature As you start to tunnel beneath the surface, the surrounding rock is cool. Then at about 20 meters down, your instruments report that the rock is getting warmer. For every 40 meters that you descend from that point, the temperature rises 1 Celsius degree. This rapid rise in temperature continues for several tens of kilometers. After that, the temperature increases more slowly, but steadily. The high temperatures inside Earth are the result of heat left over from the formation of the planet. In addition, radioactive substances inside Earth release energy. This further heats the interior.

Pressure During your journey to the center of Earth, your instruments record an increase in pressure in the surrounding rock. **Pressure** results from a force pressing on an area. Because of the weight of the rock above, pressure inside Earth increases as you go deeper. The deeper you go, the greater the pressure. Pressure inside Earth increases much as it does in the swimming pool in Figure 3.

FIGURE 3

Pressure and Depth

The deeper this swimmer goes, the greater the pressure from the surrounding water.

Comparing and Contrasting How is the water in the swimming pool similar to Earth's interior? How is it different?





The Crust

Your journey to the center of Earth begins in the crust. The **crust** is the layer of rock that forms Earth's outer skin. 🌍 **The crust is a layer of solid rock that includes both dry land and the ocean floor.** On the crust you find rocks and mountains. The crust also includes the soil and water on Earth's surface.

This outer layer of rock is much thinner than the layer that lies beneath it. In fact, you can think of Earth's crust as being similar to the paper-thin skin of an onion. The crust is thickest under high mountains and thinnest beneath the ocean. In most places, the crust is between 5 and 40 kilometers thick. But it can be up to 70 kilometers thick beneath mountains.

The crust beneath the ocean is called oceanic crust. Oceanic crust consists mostly of rocks such as basalt. Recall that basalt (buh SAWLT) is a dark igneous rock with a fine texture. Continental crust, the crust that forms the continents, consists mainly of rocks such as granite. Recall that granite is an igneous rock that usually is a light color and has a coarse texture.



What is the main type of rock in oceanic crust?

FIGURE 4

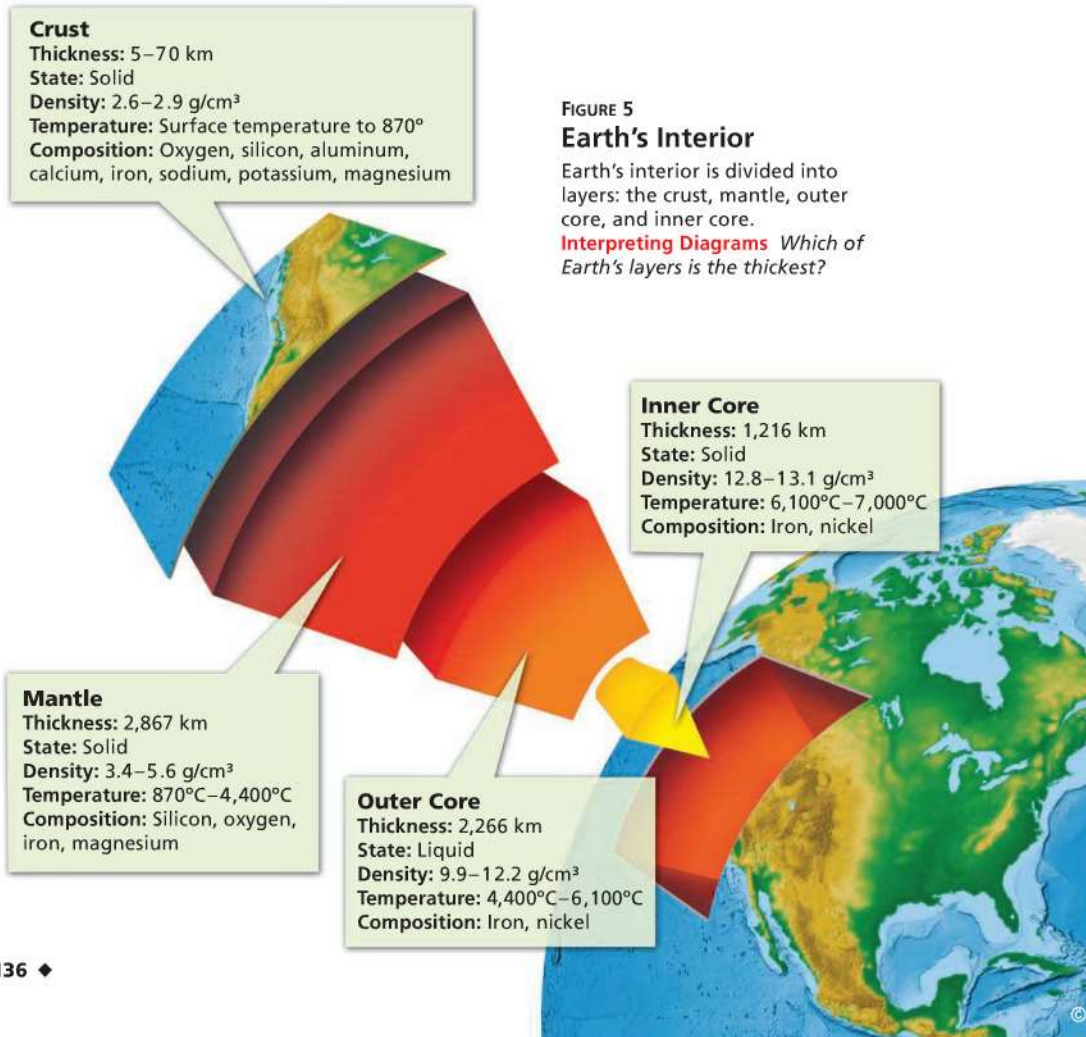
Earth's Crust

Half Dome in Yosemite National Park forms part of Earth's continental crust. Soil and plants cover much of the crust.

The Mantle

Your journey downward continues. About 40 kilometers beneath the surface, you cross a boundary. Below the boundary is the solid material of the **mantle**, a layer of hot rock. 🇺🇸 **Earth's mantle is made up of rock that is very hot, but solid. Different layers of the mantle have different physical characteristics.** Overall, the mantle is nearly 3,000 kilometers thick.

The Lithosphere The uppermost part of the mantle and the crust together form a rigid layer called the **lithosphere** (LITH uh sfeeer). In Greek, *lithos* means "stone." As you can see in Figure 5, the lithosphere averages about 100 kilometers thick.



The Asthenosphere Below the cold, brittle lithosphere, your vehicle encounters material that is hotter and under increasing pressure. As a result, the part of the mantle just beneath the lithosphere is less rigid than the rock above. Like road tar softened by the heat of the sun, this part of the mantle is somewhat soft—it can bend like plastic. This soft layer is called the **asthenosphere** (as THEN uh sfer). In Greek, *asthenes* means “weak.” Although the asthenosphere is softer than the rest of the mantle, it’s still solid. If you kicked it, you would stub your toe.

The Lower Mantle Beneath the asthenosphere, the mantle is solid. This solid material extends all the way to Earth’s core.



What is the asthenosphere?

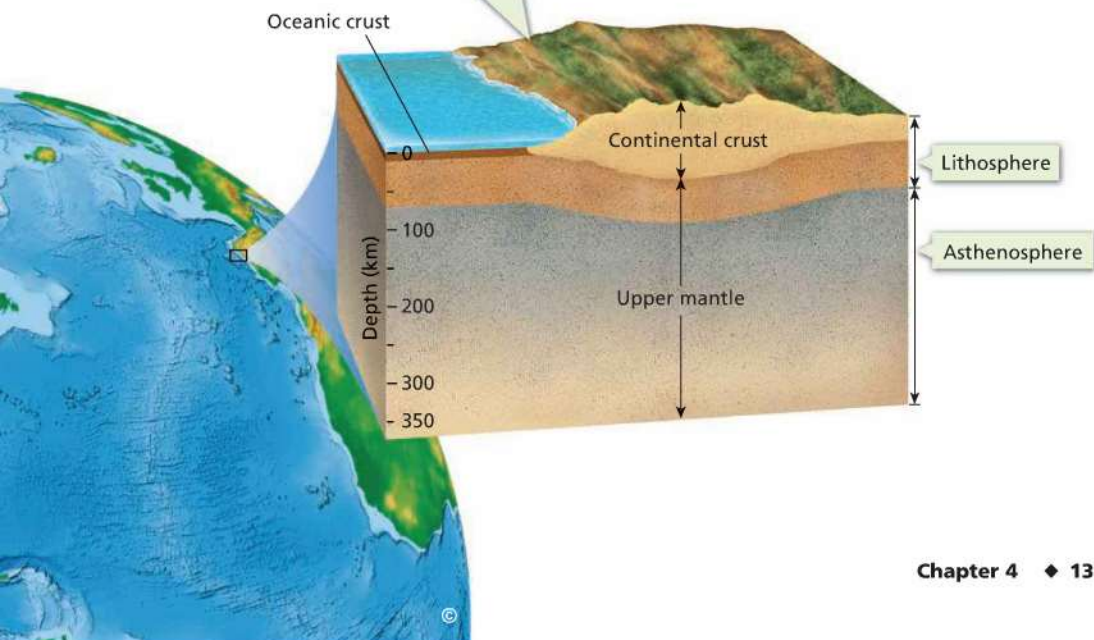
Lab zone Skills Activity

Creating Data Tables
Imagine that you are in a super-strong vehicle that is tunneling deep into Earth’s interior. You stop several times on your trip to collect data. Copy the data table. For each depth, identify the layer and what that layer is made of. Then complete the table.

Data Table		
Depth	Name of Layer	What Layer Is Made Of
20 km		
150 km		
2,000 km		
4,000 km		
6,000 km		

Lithosphere and Asthenosphere

The rigid lithosphere, which includes the crust, rests on the softer material of the asthenosphere.

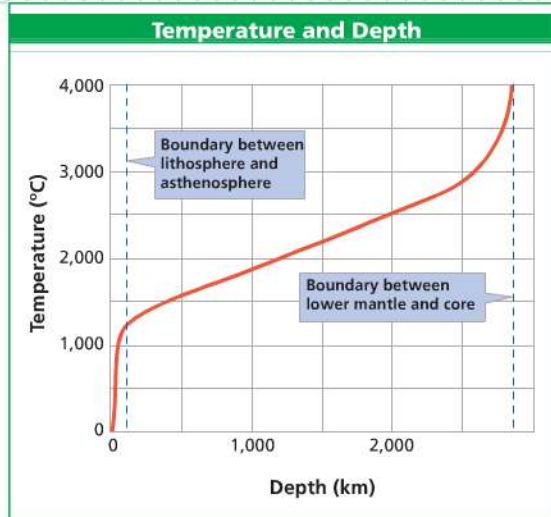


Math Analyzing Data

Temperature Inside Earth

The graph shows how temperatures change between Earth's surface and the bottom of the mantle. On this graph, the temperature at Earth's surface is 0°C. Study the graph carefully and then answer the questions.

- Reading Graphs** As you move from left to right on the x -axis, how does depth inside Earth change?
- Estimating** What is the temperature at the boundary between the lithosphere and the asthenosphere?
- Estimating** What is the temperature at the boundary between the lower mantle and the core?
- Interpreting Data** How does temperature change with depth in Earth's interior?



The Core

After traveling through the mantle, you reach Earth's dense, metallic core. 🌍 **The core is made mostly of the metals iron and nickel. It consists of two parts—a liquid outer core and a solid inner core.** Together, the inner and outer core are 3,486 kilometers thick.

Outer Core and Inner Core The **outer core** is a layer of molten metal that surrounds the inner core. Despite enormous pressure, the outer core is liquid. The **inner core** is a dense ball of solid metal. In the inner core, extreme pressure squeezes the atoms of iron and nickel so much that they cannot spread out and become liquid.

Most of the current evidence suggests that both parts of the core are made of iron and nickel. But scientists have found data showing that the core also contains substances such as oxygen, sulfur, and silicon. Scientists must seek more data before they decide which of these other substances is most abundant.

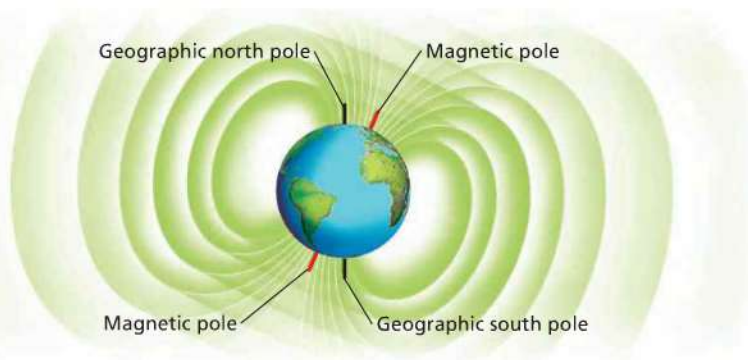


Reading Checkpoint

What is the main difference between the outer core and the inner core?



Bar Magnet's Magnetic Field
The pattern of iron filings was made by sprinkling them on paper placed under a bar magnet.



Earth's Magnetic Field
Like a magnet, Earth's magnetic field has north and south poles.

The Core and Earth's Magnetic Field Consider an ordinary bar magnet. If you place it on a piece of paper and sprinkle iron filings on the paper, the iron filings line up with the bar's magnetic field. Earth also has a magnetic field. If you could cover the entire planet with iron filings, they would form a similar pattern. In fact, the planet acts like a giant bar magnet. When you use a compass, the compass needle aligns with the lines of force in Earth's magnetic field.

Scientists think that movements in the liquid outer core create Earth's magnetic field. As you can see in Figure 6, the magnetic field affects the whole Earth.

FIGURE 6
Earth's Magnetic Field
Just as a bar magnet is surrounded by its own magnetic field, Earth's magnetic field surrounds the planet.

Relating Cause and Effect *If you shifted the magnet beneath the paper, what would happen to the iron filings?*

Section 1 Assessment

S 6.1.b, E-LA: Reading 6.1.0, Writing 6.2.1

Vocabulary Skill Use Greek Word Origins
Use what you know about the Greek words *asthenes* and *sphaira* to write the definition of *asthenosphere*.

c. Classifying Classify each of the following layers as liquid, rigid, or solid but able to flow slowly: lithosphere, asthenosphere, lower mantle, outer core, inner core.

HINT

Reviewing Key Concepts

1. a. **Explaining** Why is it difficult to determine Earth's inner structure?
b. **Inferring** How are seismic waves used to provide evidence about Earth's interior?
2. a. **Listing** List Earth's three main layers.
b. **Comparing and Contrasting** How are the lithosphere and the asthenosphere similar? How are they different?

Writing in Science

Narrative Write a narrative of your own imaginary journey to the center of Earth. Your narrative should describe the layers of Earth through which you travel and how temperature and pressure change beneath the surface.



Section 2

Convection in the Mantle

CALIFORNIA Standards Focus

S 6.4.c. Students know heat from Earth's interior reaches the surface primarily through convection.

- How is heat transferred?
- What causes convection currents?
- What causes convection currents in Earth's mantle?

Key Terms

- radiation
- conduction
- convection
- density
- convection current

Lab zone Standards Warm-Up

How Can Heat Cause Motion in a Liquid?

- Carefully pour some hot water into a small, shallow pan. Fill a clear, plastic cup about half full with cold water. Place the cup in the pan.
- Allow the water to stand for two minutes until all motion stops.
- Fill a plastic dropper with some food coloring. Then, holding the dropper under the water's surface and slightly away from the edge of the cup, gently squeeze a small droplet of the food coloring into the water.
- Observe the water for one minute.
- Add another droplet at the water's surface in the middle of the cup and observe again.



Think It Over

Inferring How do you explain what happened to the droplets of food coloring? Why do you think the second droplet moved in a way that was different from the way the first droplet moved?

Earth's molten outer core is nearly as hot as the surface of the sun. What makes an object become hotter? Whether the object is Earth's core or a cooking pot, the cause is the same. When an object is heated, the particles that make up the object move faster. The faster-moving particles have more energy.

Have you ever touched a hot pot accidentally? If so, you have learned for yourself (in a painful way) that heat moves. In this case, it moved from the hot pot to your hand. The movement of energy from a warmer object to a cooler object is called heat transfer. To explain how heat moves from Earth's core through the mantle, you need to know how heat is transferred.



Types of Heat Transfer

Heat always moves from a warmer substance to a cooler substance. For example, holding an ice cube will make your hand begin to feel cold in a few seconds. But is the coldness in the ice cube moving to your hand? No! Cold is the absence of heat. It's the heat in your hand that moves to the ice cube. This is one of the ways that heat is transferred. 🌟 **There are three types of heat transfer: radiation, conduction, and convection.**

Radiation The transfer of energy through space is called **radiation**. Heat transfer by radiation takes place with no direct contact between a heat source and an object. Sunlight is radiation that warms Earth's surface. Other familiar forms of radiation include the heat you feel around a flame or open fire.

Conduction Heat transfer within a material or between materials that are touching is called **conduction**. For example, a spoon in a pot of soup heats up by conduction, as shown in Figure 7. Heat moves from the hot soup and the pot to the particles that make up the spoon. The particles near the bottom of the spoon vibrate faster as they are heated, so they bump into other particles and heat them, too. Gradually the entire spoon heats up. When your hand touches the spoon, conduction transfers heat from the spoon directly to your skin. Then you feel the heat. Conduction also causes an ice cube in your hand to melt. Conduction is responsible for some of the heat transfer inside Earth.



What is conduction?

FIGURE 7

Conduction

In conduction, the heated particles of a substance transfer heat through contact with other particles in the substance.

Conduction heats the spoon and the pot itself. That's why you need a mitt to protect your hand from the hot handle.

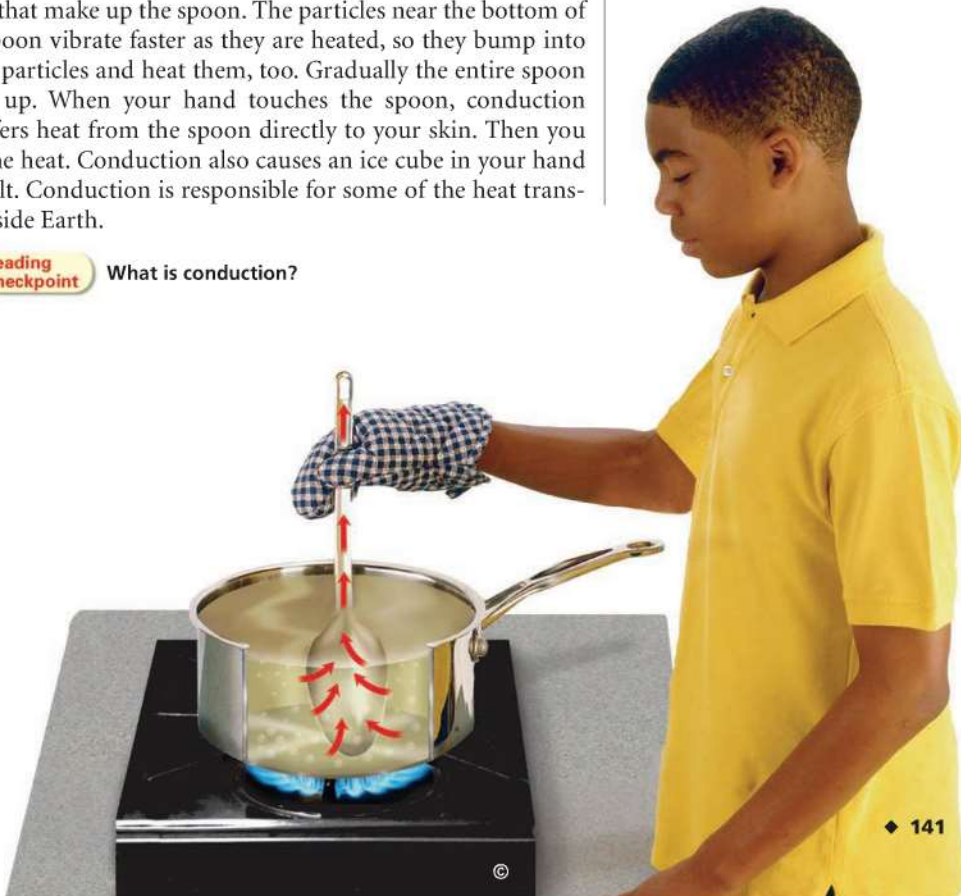




FIGURE 8

Convection Currents

Differences in temperature and density cause convection currents. In the pot, convection currents arise because the soup close to the heat source is hotter and less dense than the soup near the surface.

Convection Heat can also be transferred by the movement within fluids—liquids and gases. **Convection** is heat transfer by the movement of currents within a fluid. During convection, heated particles of fluid begin to flow. This flow transfers heat from one part of the fluid to another.

Heat transfer by convection is caused by differences of temperature and density within a fluid. **Density** is a measure of how much mass there is in a volume of a substance. For example, rock is more dense than water because a given volume of rock has more mass than the same volume of water.

When a liquid or gas is heated, the particles move faster and spread apart. As a result, the particles of the heated fluid occupy more space. The fluid's density decreases. But when a fluid cools, its particles move more slowly and settle together more closely. As the fluid becomes cooler, its density increases.

Convection Currents

When you heat soup on a stove, changes in density cause convection in the soup, as shown in Figure 8. As the soup at the bottom of the pot gets hot, it expands and therefore becomes less dense. The warm, less dense soup moves upward and floats over the cooler, denser soup. At the surface, the warm soup cools, becoming denser. Then gravity pulls this cooler, denser soup back down to the bottom of the pot, where it is heated again.

A constant flow begins as the cooler, denser soup sinks to the bottom of the pot and the warmer, less dense soup rises. A **convection current** is the flow that transfers heat within a fluid. **Heating and cooling of the fluid, changes in the fluid's density, and the force of gravity combine to set convection currents in motion.** Convection currents continue as long as heat is added. Without heat, convection currents eventually stop.

**Reading Checkpoint**

What is the role of gravity in creating convection currents?





Convection Currents in Earth

In Earth's mantle, large amounts of heat are transferred by convection currents, as shown in Figure 9.

Heat from the core and the mantle itself causes convection currents in the mantle.

How can mantle rock flow? Recall that temperature increases steadily as you go deeper in the mantle. Rock in the lower mantle is hotter and therefore less dense than the rock above it. As a result, solid mantle rock rises slowly from the bottom of the mantle toward the top. The hot rock eventually cools and sinks back through the mantle. These cycles of rising and sinking take place over millions of years. Convection currents like these have been moving inside Earth for most of Earth's history.

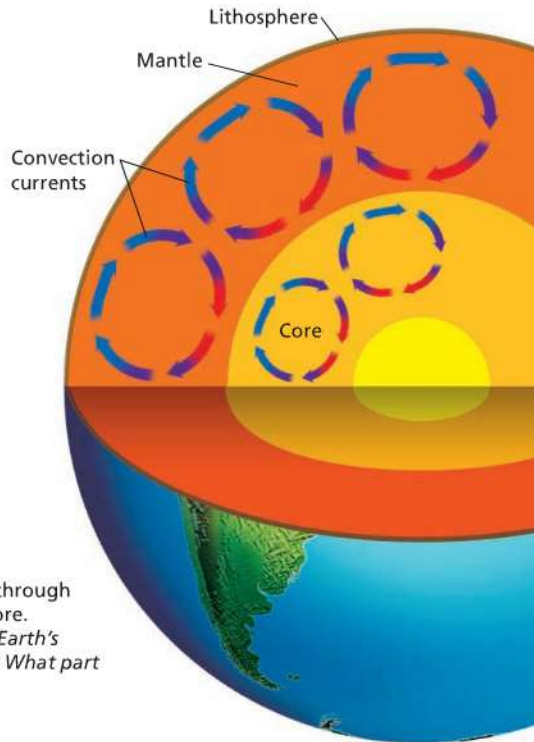


FIGURE 9

Mantle Convection

Convection currents rise and sink through the mantle and the liquid outer core.

Applying Concepts *What part of Earth's interior is like the soup in the pot? What part is like the burner on the stove?*

Section 2 Assessment

S 6.4.c; E-LA: Reading 6.1.0

Vocabulary Skill **Use Greek Word Origins** Use what you know about the Greek words *litho* and *sphaira* to write the definition of *lithosphere*.

Lab zone

At-Home Activity

Tracing Heat Flow Convection currents may keep the air inside your home at a comfortable temperature. Air is made up of gases, so it is a fluid. Regardless of the type of home heating system, heated air circulates through a room by convection. You may have tried to adjust the flow of air in a stuffy room by opening a window. When you did so, you were making use of convection currents. With an adult family member, study how your home is heated. Look for evidence of convection currents.

Reviewing Key Concepts

- a. Listing** What are the three types of heat transfer?

b. Explaining How is heat transferred through space?
- a. Defining** What is a convection current?

b. Relating Cause and Effect In general, what happens to the density of a fluid as it becomes hotter?

c. Summarizing Describe how convection currents form.
- a. Identifying** Name two layers of Earth in which convection currents take place.

b. Relating Cause and Effect What causes convection currents in the mantle?

c. Predicting What will happen to the convection currents in the mantle if Earth's interior eventually cools down? Explain.

HINT

HINT

HINT

HINT

HINT

HINT



Section 3

Drifting Continents

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Standards Focus

S 6.1.a Students know evidence of plate tectonics is derived from the fit of the continents; the location of earthquakes, volcanoes, and mid-ocean ridges; and the distribution of fossils, rock types, and ancient climatic zones.

- ➡ What was Alfred Wegener's hypothesis about the continents?
- ➡ What evidence supported Wegener's hypothesis?
- ➡ Why was Wegener's hypothesis rejected by most scientists of his day?

Key Terms

- continental drift
- Pangaea
- fossil

Lab zone

Standards Warm-Up

How Are Earth's Continents Linked Together?

1. Find the oceans and the seven continents on a globe showing Earth's physical features.
2. How much of the globe is occupied by the Pacific Ocean? Does most of Earth's dry land lie in the Northern or Southern Hemisphere?
3. Find the points or areas where most of the continents are connected. Find the points at which several of the continents almost touch, but are not connected.
4. Examine the globe more closely. Find the great belt of mountains running from north to south along the western side of North and South America. Can you find another great belt of mountains on the globe?

Think It Over

Posing Questions What questions can you pose about how oceans, continents, and mountains are distributed on Earth's surface?



Five hundred years ago, the sea voyages of Columbus and other explorers changed the map of the world. The continents of Europe, Asia, and Africa were already known to mapmakers. Soon mapmakers were also showing the outlines of the continents of North and South America. Looking at these world maps, many people wondered why the coasts of several continents matched so neatly. For example, the coasts of Africa and South America look as if they could fit together like jigsaw-puzzle pieces. In the 1700s, geologists thought that the continents had always remained in the same place. But early in the 1900s, one scientist became curious about the matching shapes of the continents.

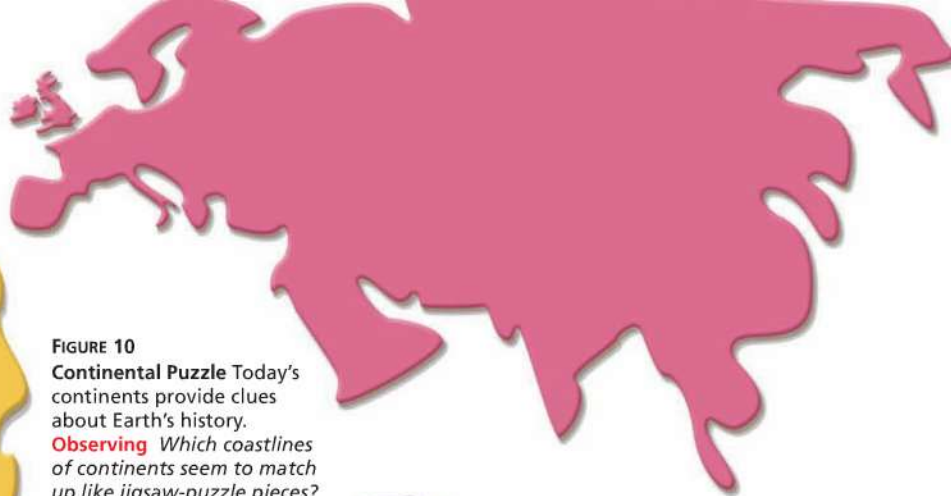




FIGURE 10
Continental Puzzle Today's continents provide clues about Earth's history.
Observing Which coastlines of continents seem to match up like jigsaw-puzzle pieces? (Hint: Refer to the map in Figure 11.)

Continental Drift

In 1910, a young German scientist named Alfred Wegener (VAY guh nur) attempted to solve the jigsaw puzzle of the continents. He hypothesized that Earth's continents had moved!  **Wegener's hypothesis was that all the continents were once joined together in a single landmass and have since drifted apart.** Wegener's idea that the continents slowly moved over Earth's surface became known as **continental drift**.

According to Wegener, the continents drifted together to form the supercontinent **Pangaea** (pan JEE uh). *Pangaea* means "all lands." According to Wegener, Pangaea existed about 300 million years ago. This was the time when reptiles and winged insects first appeared. Tropical forests, which later formed coal deposits, covered large parts of Earth's surface.

Over tens of millions of years, Pangaea began to break apart. The pieces of Pangaea slowly moved toward their present-day locations. These pieces became the continents as they are today.

How did Wegener attempt to prove his amazing idea?  **Wegener gathered evidence from different scientific fields to support his ideas about continental drift. He studied land features, fossils, and evidence of climate change.** In 1915, Wegener published his evidence for continental drift in a book called *The Origin of Continents and Oceans*.

Go Online

 For: Links on continental drift
 Visit: www.SciLinks.org
 Web Code: scn-1013



Evidence for Continental Drift

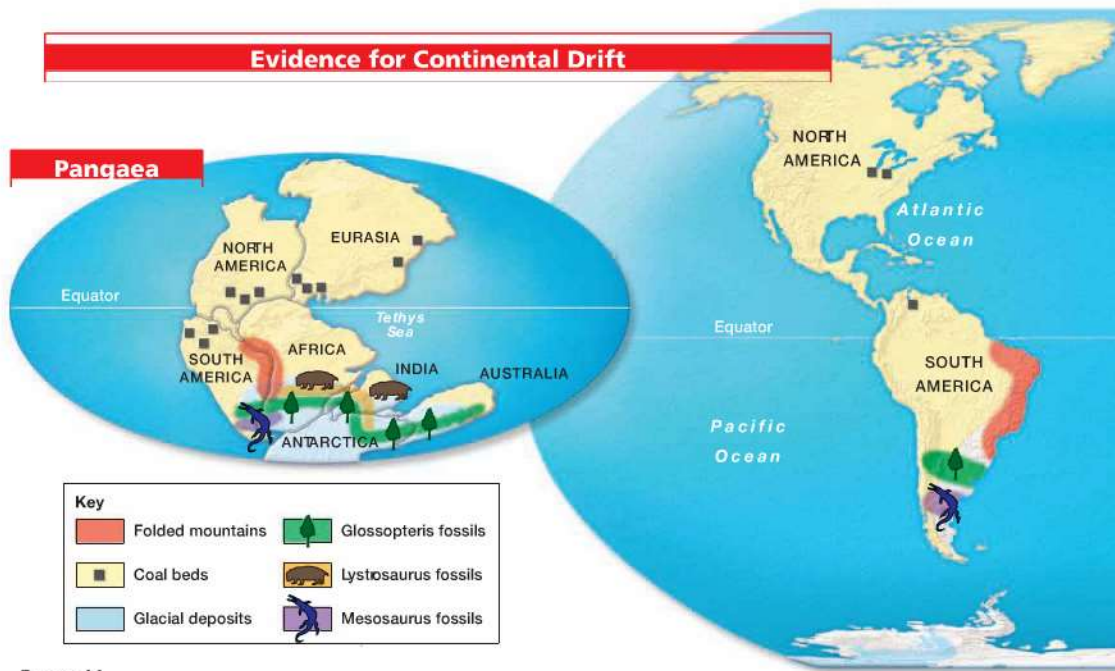


FIGURE 11

Fossils and rocks found on different continents provide evidence that Earth's landmasses once were joined together in the supercontinent Pangaea.

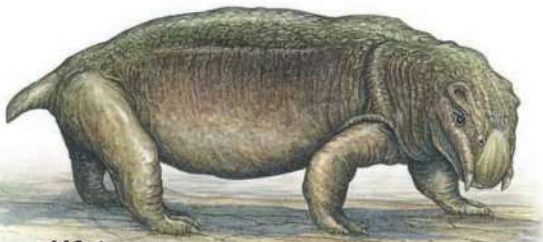
Inferring What do the matching mountain ranges in Africa and South America show, according to Wegener's hypothesis?

Evidence From Land Features As shown in Figure 11, mountains and other features on the continents provided evidence for continental drift. For example, when Wegener pieced together maps of Africa and South America, he noticed that mountain ranges on both continents line up. He noticed that European coal fields match up with coal fields in North America.

Evidence From Fossils Wegener also used fossils to support his argument for continental drift. A **fossil** is any trace of an ancient organism that has been preserved in rock. For example, *Glossopteris* (glaw SAHP tuh ris), was a fernlike plant that lived 250 million years ago. *Glossopteris* fossils have been found in rocks in Africa, South America, Australia, India, and Antarctica. The occurrence of *Glossopteris* on these widely separated landmasses convinced Wegener that Pangaea had existed.

Other examples include fossils of the fresh-water reptiles *Mesosaurus* and *Lystrosaurus*. These fossils have also been found in places now separated by oceans. Neither reptile could have swum great distances across salt water. Wegener inferred that these reptiles lived on a single landmass that has since split apart.

Lystrosaurus

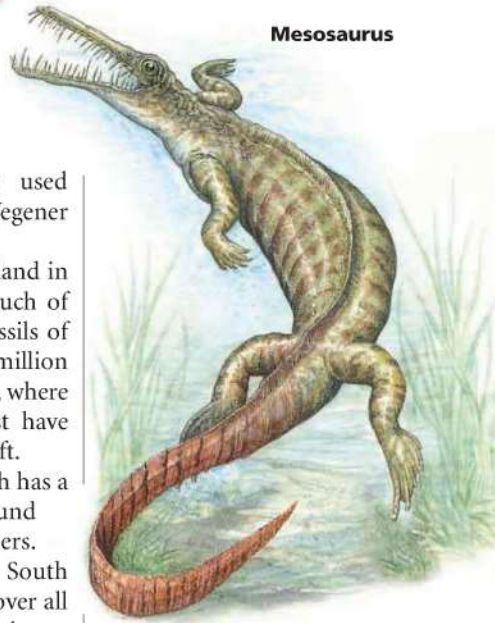




Glossopteris



Mesosaurus



Evidence From Ancient Climatic Zones Wegener used evidence of past climates to support his hypothesis. Wegener found this evidence by studying fossils and rocks.

Evidence from fossils showed that Spitsbergen, an island in the Arctic Ocean, once had a warm climate. Today, much of Spitsbergen is covered with ice. But scientists found fossils of tropical plants there. When these plants lived, about 300 million years ago, the island must have been closer to the equator, where it is warm. Wegener concluded that Spitsbergen must have reached its location in the Arctic through continental drift.

Evidence from rocks showed that South Africa, which has a warm climate today, was once very cold. Geologists found deep scratches in rocks and sediment left behind by glaciers. This showed that continental glaciers once covered South Africa. Continental glaciers are thick layers of ice that cover all or part of a continent. But the climate of South Africa is too mild today for continental glaciers to form. Wegener concluded that continental drift had moved South Africa away from the South Pole.



Reading Checkpoint How would continental drift affect a continent's climate?



FIGURE 12
Alfred Wegener
Although scientists rejected his theory, Wegener continued to collect evidence on continental drift and to update his book until his death in 1930.

Wegener's Hypothesis Rejected

Wegener attempted to explain how continental drift took place. He suggested that the continents plowed across the ocean floors. 🌍 Unfortunately, Wegener could not provide a **satisfactory explanation for the force that pushes or pulls the continents**. Because Wegener could not identify the cause of continental drift, most geologists rejected his idea. Geologists also rejected Wegener's idea because it contradicted their ideas about how mountains form.

More than 30 years would pass before geologists accepted new evidence that supported Wegener's ideas. In the early 1900s, many geologists thought that mountains formed because Earth was slowly cooling and shrinking. According to this hypothesis, mountains formed when the crust wrinkled like the skin of a dried-up apple.

Wegener said that if these geologists were correct, then mountains should be found all over Earth's surface. But mountains usually occur in narrow bands along the edges of continents. Wegener proposed that when continents collide, their edges crumple and fold. The folding continents push up huge mountains.

Section 3 Assessment

S 6.1.a; E-LA: Reading 6.2.0

🔄 **Target Reading Skill Identify Supporting Evidence** What supporting evidence did you include in your graphic organizer for the hypothesis of continental drift?

🌍 Reviewing Key Concepts

- HINT** 1. a. **Identifying** Who proposed the concept of continental drift?
- HINT** b. **Summarizing** According to the hypothesis of continental drift, how would a world map have changed over the last 250 million years?
- HINT** 2. a. **Reviewing** What evidence supported the hypothesis of continental drift?
- HINT** b. **Explaining** How did fossils provide evidence for continental drift?
- HINT** c. **Forming Hypotheses** Deposits of coal have been found beneath the ice of Antarctica. But coal only forms in warm swamps. Use Wegener's hypothesis to explain how coal could be found so near to the South Pole.

3. a. **Explaining** Why did most scientists reject Wegener's hypothesis of continental drift?
- b. **Making Judgments** Do you think the scientists of Wegener's time should have accepted his hypothesis? Why or why not?

HINT

HINT

Lab zone

At-Home Activity

Moving the Continents Using a world map and tracing paper, trace the outlines of the continents that border the Atlantic Ocean. Label the continents. Then use scissors to carefully cut your map along the edges of the continents. Throw away the Atlantic Ocean. Place the two remaining pieces on a dark surface and ask family members to try to fit the two halves together. Explain to them about continental drift and Pangaea.



Section 4

Sea-Floor Spreading

CALIFORNIA

Standards Focus

S 6.1.a Students know evidence of plate tectonics is derived from the fit of the continents; the location of earthquakes, volcanoes, and mid-ocean ridges; and the distribution of fossils, rock types, and ancient climatic zones.

- What is the process of sea-floor spreading?
- What is the evidence for sea-floor spreading?
- What happens at deep-ocean trenches?

Key Terms

- mid-ocean ridge
- sonar
- sea-floor spreading
- deep-ocean trench
- subduction

Lab
zone

Standards Warm-Up

What Is the Effect of a Change in Density?

1. Partially fill a sink or dishpan with water.
2. Open up a dry washcloth in your hand. Does the washcloth feel light or heavy?
3. Moisten one edge of the washcloth in the water. Then gently place the washcloth so that it floats on the water's surface. Observe the washcloth carefully (especially at its edges) as it starts to sink.
4. Remove the washcloth from the water and open it up in your hand. Is the mass of the washcloth the same as, less than, or greater than when it was dry?

Think It Over

Observing How did the washcloth's density change? What effect did this change in density have on the washcloth?

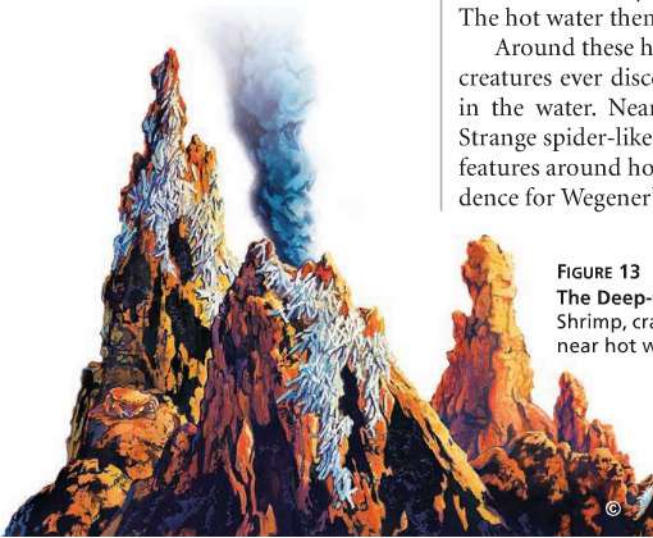
Deep in the ocean, the temperature is near freezing. There is no light, and living things are generally scarce. Yet some areas of the deep-ocean floor are teeming with life. One of these areas is the East Pacific Rise. This area forms part of the Pacific Ocean floor off the coasts of Mexico and South America. Here, ocean water sinks through cracks, or vents, in the crust. The water is heated by contact with hot material from the mantle. The hot water then spurts back into the ocean.

Around these hot-water vents live some of the most bizarre creatures ever discovered. Giant, red-tipped tube worms sway in the water. Nearby sit giant clams nearly a meter across. Strange spider-like crabs scuttle by. Surprisingly, the geological features around hot water vents provided some of the best evidence for Wegener's hypothesis of continental drift.

FIGURE 13

The Deep-Ocean Floor

Shrimp, crabs, and other organisms cluster near hot water vents in the ocean floor.



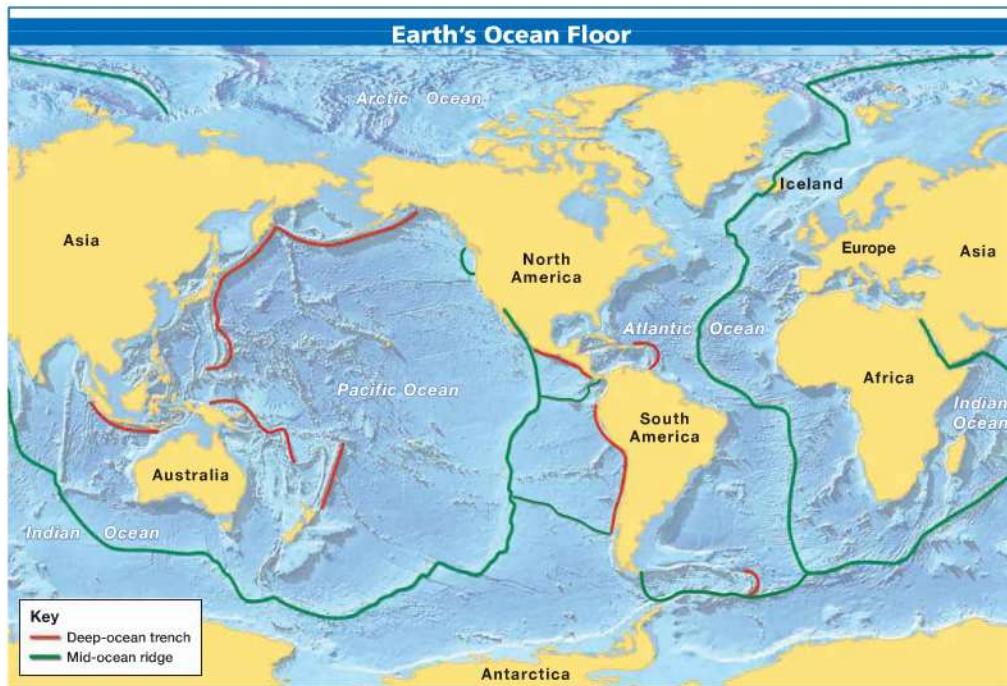


FIGURE 14
 The mid-ocean ridge system is more than 50,000 kilometers long.
Interpreting Maps What is unusual about Iceland?

Mid-Ocean Ridges

The East Pacific Rise is just one of many mid-ocean ridges. A **mid-ocean ridge** is an undersea mountain chain that is part of a long system of mountains that winds beneath Earth's oceans. In the mid-1900s, scientists mapped the mid-ocean ridges using sonar. **Sonar** is a device that bounces sound waves off underwater objects and then records the echoes of these sound waves. The time it takes for the echo to arrive indicates the distance to the object.

Mid-ocean ridges curve like the seam of a baseball along the sea floor. They extend into all of Earth's oceans. Figure 14 shows the location of these ridges. Most of the mountains in the mid-ocean ridge system lie hidden under hundreds of meters of water. But in a few places the ridge pokes above the surface. For example, the island of Iceland is a part of the mid-ocean ridge. Iceland rises above the surface in the North Atlantic Ocean. A steep-sided valley splits the top of some ridges.



**Reading
 Checkpoint**

What device is used to map the ocean floor?



What Is Sea-Floor Spreading?

The mapping of mid-ocean ridges made some scientists curious to know more about them. What are the ridges? How do they form? These scientists carefully examined maps of the mid-ocean ridge system. A few scientists began to think about the ocean floor in relation to the problem of continental drift. They began to think that maybe Wegener was right! Perhaps the continents do move.

In 1960, one geologist proposed a radical idea. He suggested that a process he called **sea-floor spreading** continually adds new material to the ocean floor. 🌊 **In sea-floor spreading, the sea floor spreads apart along both sides of a mid-ocean ridge as new crust is added. As a result, the ocean floors move like conveyor belts, carrying the continents along with them.** Look at Figure 15 to see the process of sea-floor spreading.

Sea-floor spreading begins at a mid-ocean ridge, which forms along a crack in the oceanic crust. Along the ridge, molten material that forms several kilometers beneath the surface rises and erupts. At the same time, older rock moves outward on both sides of the ridge. As the molten material cools, it forms a strip of solid rock in the center of the ridge. When more molten material flows into the crack, it forms a new strip of rock.

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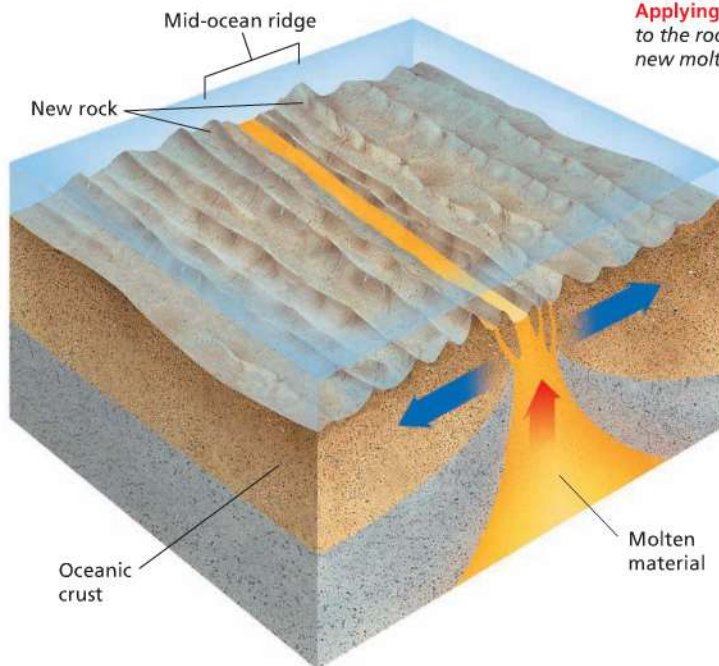
For: More on sea-floor spreading
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FIGURE 15

Sea-Floor Spreading

Molten material erupts through the center of a mid-ocean ridge. This material hardens to form the rock of the ocean floor.

Applying Concepts *What happens to the rock along the ridge when new molten material erupts?*



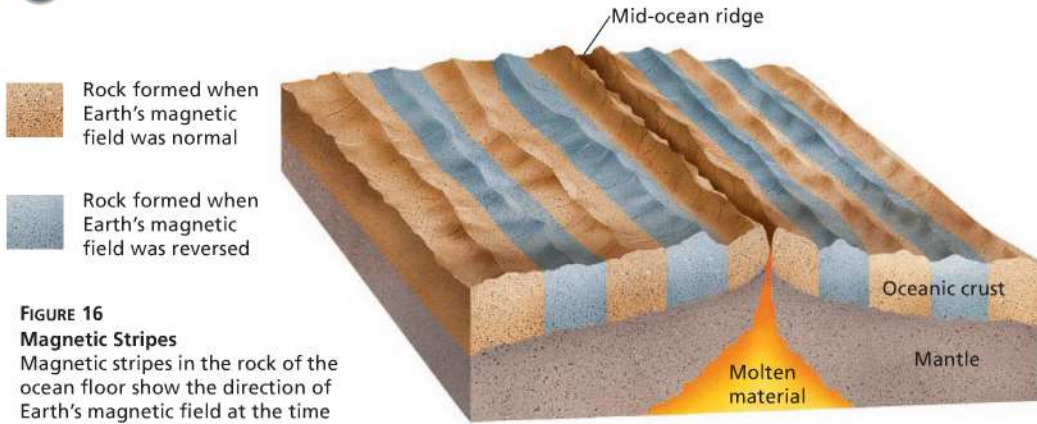


FIGURE 16

Magnetic Stripes

Magnetic stripes in the rock of the ocean floor show the direction of Earth's magnetic field at the time the rock hardened.

Interpreting Diagrams How are these matching stripes evidence of sea-floor spreading?

Evidence for Sea-Floor Spreading

Several types of evidence supported the theory of sea-floor spreading: eruptions of molten material, magnetic stripes in the rock of the ocean floor, and the ages of the rocks themselves. In the 1960s, this evidence led scientists to look again at Wegener's hypothesis of continental drift.

Evidence From Molten Material The scientists discovered evidence that new material is indeed erupting along mid-ocean ridges. The scientists dived to the ocean floor in *Alvin*, a small submarine. *Alvin* was built to withstand the crushing pressures four kilometers down in the ocean. In a ridge's central valley, *Alvin's* crew found strange rocks shaped like pillows. Other rocks looked like toothpaste squeezed from a tube. Such rocks form only when molten material hardens quickly under water. These rocks showed that molten material has erupted again and again along the mid-ocean ridges.

Evidence From Magnetic Stripes Patterns in the rocks of the ocean floor provided more support for sea-floor spreading. You read earlier that Earth behaves like a giant magnet, with a north pole and a south pole. Surprisingly, Earth's magnetic poles have reversed themselves many times during Earth's history. The last reversal happened 780,000 years ago. What if the magnetic poles suddenly reversed themselves today? You would find that your compass needle pointed south.



Scientists discovered that the rock that makes up the ocean floor lies in a pattern of magnetized “stripes,” shown in Figure 16. These stripes hold a record of reversals in Earth’s magnetic field. The rock of the ocean floor contains iron. The rock began as molten material that cooled and hardened. As the rock cooled, the iron bits inside lined up in the direction of Earth’s magnetic poles. This locked the iron bits in place, giving the rocks a permanent “magnetic memory.”

Scientists then used instruments to record the magnetic memory of rocks on both sides of a ridge. They found stripes of rock that formed when Earth’s magnetic field pointed north. These stripes alternate with stripes of rock that formed when the magnetic field pointed south. Look at Figure 16. Notice how the pattern is the same on both sides of the ridge.

Evidence From Drilling Samples The final proof of sea-floor spreading came from rock samples obtained by drilling into the ocean floor. The *Glomar Challenger*, a drilling ship built in 1968, gathered the samples. The *Glomar Challenger* sent drilling pipes through water six kilometers deep to drill holes in the ocean floor. This feat has been compared to digging a hole into the sidewalk from the top of the Empire State Building.

Samples from the sea floor were brought up through the pipes. Then the scientists determined the age of the rocks in the samples. They found that the farther away from a ridge the samples were taken, the older the rocks were. The youngest rocks were always in the center of the ridges. This showed that sea-floor spreading really has taken place.



Reading Checkpoint Why does the rock of the ocean floor have a pattern of magnetic stripes?

Lab zone Try This Activity

Reversing Poles

1. Cut six short pieces, each about 2.5 cm long, from a length of audiotape.
2. Tape one end of each piece of audiotape to a flat surface. The pieces should be spaced 1 cm apart and lined up lengthwise in a single row.
3. Touch a bar magnet’s north pole to the first piece of audiotape. Then reverse the magnet and touch its south pole to the next piece.
4. Repeat Step 3 until you have applied the magnet to each piece of audiotape.
5. Sweep one end of the magnet about 1 cm above the line of audiotape pieces. Observe what happens.

Making Models What characteristic of the ocean floor did you observe as you swept the magnet along the line of audiotape pieces?

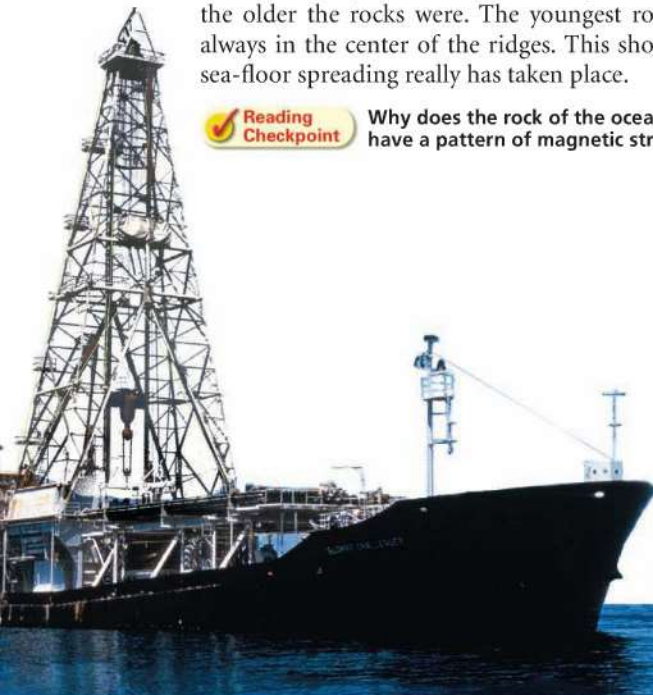


FIGURE 17
Sea-Floor Drilling
The *Glomar Challenger* was the first research ship designed to drill samples of rock from the deep-ocean floor.

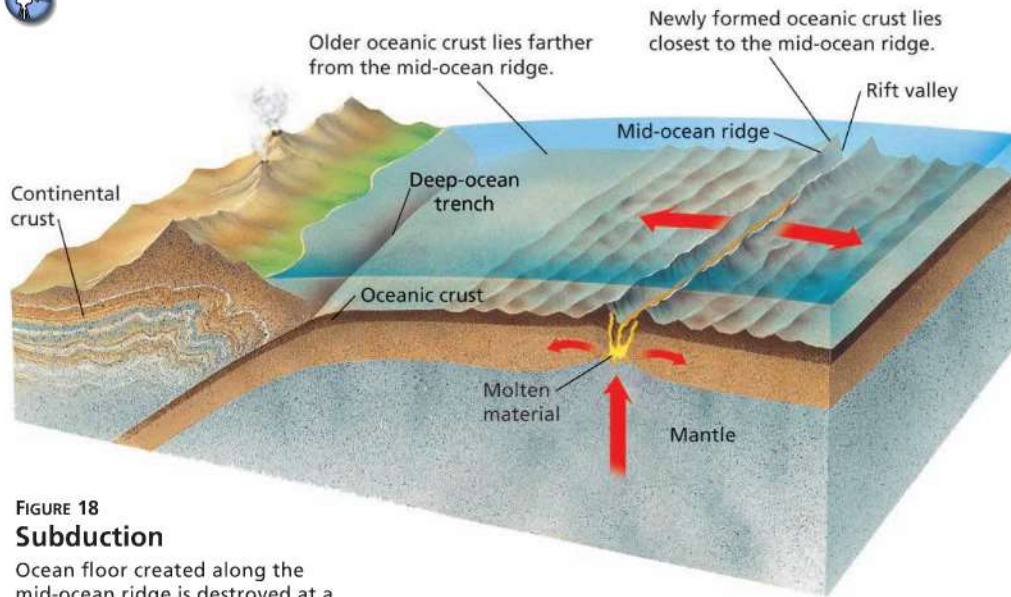


FIGURE 18

Subduction

Ocean floor created along the mid-ocean ridge is destroyed at a deep-ocean trench. In the process of subduction, ocean floor sinks down beneath the trench into the mantle.

Drawing Conclusions Where would the densest ocean floor be found?

Subduction at Trenches

How can the ocean floor keep getting wider and wider? The answer is that the ocean floor generally does not just keep spreading. Instead, the ocean floor sinks beneath deep underwater canyons called **deep-ocean trenches**. At a deep-ocean trench, the ocean floor bends downward. What occurs at trenches? 🌍 In a process taking tens of millions of years, part of the ocean floor sinks back into the mantle at deep-ocean trenches.

The Process of Subduction The process by which the ocean floor sinks beneath a deep-ocean trench and back into the mantle is called **subduction** (sub DUK shun). During subduction, ocean floor closer to a mid-ocean ridge moves away from the ridge and toward a trench. Sea-floor spreading and subduction work together. They move the ocean floor as if it were on a giant conveyor belt.

New ocean floor is hot. But as it moves away from the mid-ocean ridge, it cools and becomes more dense. Eventually, as shown in Figure 18, gravity pulls this older, denser ocean floor down beneath the trench. The sinking ocean floor is like the washcloth in the Standards Warm-Up at the beginning of this section. As the dry washcloth floating on the water gets wet, its density increases and it begins to sink.

 **Video Field Trip**
Discovery Channel School
Plate Tectonics

Subduction and Earth's Oceans Together, subduction and sea-floor spreading change the size and shape of the oceans. These processes renew the ocean floor about every 200 million years. That is the time it takes for new rock to form at a mid-ocean ridge, move across the ocean, and sink into a deep-ocean trench.

The vast Pacific Ocean covers almost one third of the planet. And yet it is shrinking. How can that be? The Pacific Ocean has many deep-ocean trenches around its edges. Subduction occurs through these trenches faster than new crust can be added. The result is that the width of the Pacific Ocean will gradually shrink over millions of years.

As you can see in Figure 19, the Atlantic Ocean is expanding. The main reason for this is that the Atlantic Ocean has only a few short trenches. As a result, most of the spreading ocean floor has nowhere to go. In most places, the oceanic crust of the Atlantic Ocean floor is attached to the continental crust of the continents around the ocean. So as the Atlantic's ocean floor spreads, the continents along its edges also move. Over time, the whole ocean gets wider.



FIGURE 19
Growing an Ocean
Because of sea-floor spreading, the distance between Europe and North America is increasing by a few centimeters per year.

Reading Checkpoint Why is the Pacific Ocean shrinking?

Section 4 Assessment

S 6.1.a, E-LA: Reading 6.2.0, Writing 6.2.2

Target Reading Skill Identify Supporting Evidence Create a graphic organizer for the theory of sea-floor spreading. What evidence did you include?

Reviewing Key Concepts

1. a. **Identifying** Along what feature of the ocean floor does sea-floor spreading begin?
b. **Describing** How is new rock added to the ocean floor?
c. **Sequencing** What are the steps in the process of sea-floor spreading?
2. a. **Reviewing** What three types of evidence provided support for the theory of sea-floor spreading?
b. **Applying Concepts** How do rocks along the central valley of the mid-ocean ridge provide evidence of sea-floor spreading?

- c. **Predicting** Where would you expect to find the oldest rock on the ocean floor?
3. a. **Defining** What is a deep-ocean trench?
b. **Relating Cause and Effect** What happens to oceanic crust at a deep-ocean trench?

HINT

HINT

HINT

Writing in Science

Description Write a description of what you might see if you could explore a mid-ocean ridge in a vessel like the *Alvin*. In your description, be sure to include the main features of the ocean floor along and near the ridge.



Modeling Sea-Floor Spreading



Materials



colored markers



2 sheets of
unlined paper



scissors



metric ruler

Problem How does sea-floor spreading add material to the ocean floor?

Skills Focus making models

Procedure  

1. Draw stripes across one sheet of paper, parallel to the short sides of the paper. The stripes should vary in spacing and thickness.
2. Fold the paper in half lengthwise and write the word "Start" at the top of both halves of the paper. Using the scissors, carefully cut the paper in half along the fold line to form two strips.

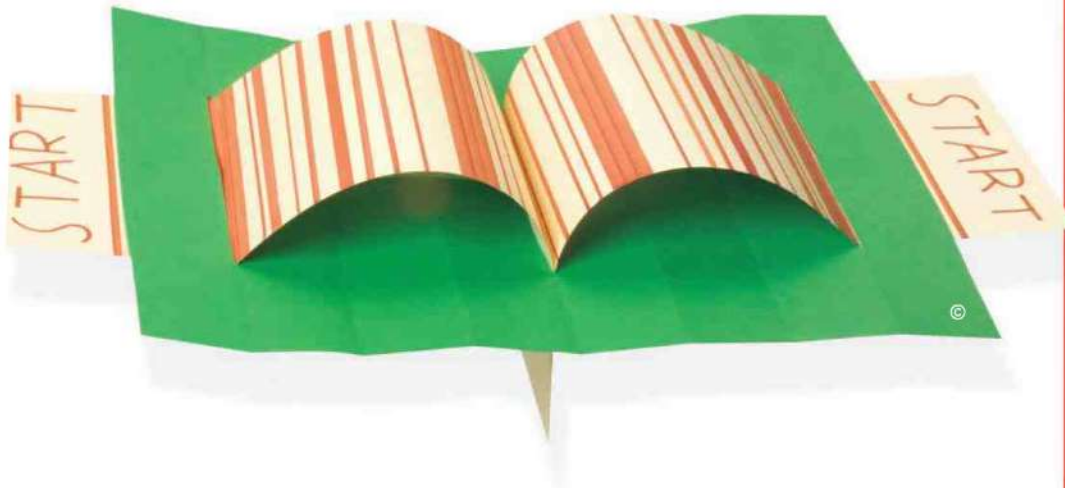


3. Lightly fold the second sheet of paper into eighths. Then unfold it, leaving creases in the paper. Fold this sheet in half lengthwise.
4. Starting at the fold, draw lines 5.5 cm long on the middle crease and the two creases closest to the ends of the paper.



5. Now carefully cut along the lines you drew. Unfold the paper. There should be three slits in the center of the paper.





6. Put the two striped strips of paper together so their Start labels touch one another. Insert the Start ends of the strips up through the center slit and then pull them toward the side slits.
 7. Insert the ends of the strips into the side slits. Pull the ends of the strips and watch what happens at the center slit.
 8. Practice pulling the strips until you can make the two strips come up through the center and go down through the sides at the same time.
4. **Making Models** What do the stripes on the strips stand for? Why is it important that your model have an identical pattern of stripes on both sides of the center slit?
 5. **Applying Concepts** Explain how differences in density and temperature provide some of the force needed to cause sea-floor spreading and subduction.
 6. **Communicating** Use your own words to describe the process of sea-floor spreading. What parts of the process were not shown by your model?

Analyze and Conclude

1. **Making Models** What feature of the ocean floor does the center slit stand for? What prominent feature of the ocean floor is missing from the model along the center slit?
2. **Making Models** What do the side slits stand for? What does the space under the paper stand for?
3. **Comparing and Contrasting** As shown by your model, how does the ocean floor close to the center slit differ from the ocean floor near a side slit? How does this difference affect the depth of the ocean?

More to Explore

How could you modify your model to show an island that formed where a large amount of molten rock erupted from the mid-ocean ridge? How could you show what would happen to the island over a long period of time?

Section 5

The Theory of Plate Tectonics

CALIFORNIA

Standards Focus

S 6.1.c. Students know lithospheric plates the size of continents and oceans move at rates of centimeters per year in response to movements in the mantle.

- What is the theory of plate tectonics?
- What are the three types of plate boundaries?

Key Terms

- plate
- plate tectonics
- fault
- spreading boundary
- rift valley
- colliding boundary
- sliding boundary

Lab zone

Standards Warm-Up

How Well Do the Continents Fit Together?

- Using a world map in an atlas, trace the shapes of the continents North America, South America, Africa, and Europe.
- Carefully cut apart the landmasses.
- Piece together these landmasses as they may have looked before Pangaea split apart, creating the Atlantic Ocean.
- Attach your partial reconstruction of Pangaea to a piece of paper.
- Obtain a map that shows the continental shelf. The continental shelf is the apron of continental crust that extends under water around the edges of the continents. Trace around the shelves of the same continents used in Step 1.
- Repeat steps 2 through 4 to compare the fit of the continents with and without their continental shelves.



Think It Over

Drawing Conclusions Do your observations support the idea that the continents were once joined together? When did they fit together better: when you cut them out along their coastlines or along their continental shelves? Explain.

▼ A cracked eggshell



Have you ever dropped a hard-boiled egg? If so, the eggshell probably cracked in many places. Earth's lithosphere, its solid outer shell, is not one unbroken layer. It is more like that cracked eggshell. It's broken into jagged pieces.

There are cracks in the continents similar to those on the ocean floor. In the 1960s, scientists proposed that these cracks break the lithosphere into separate sections called **plates**. The plates fit together along cracks in the lithosphere. As shown in Figure 20, the plates carry the continents or parts of the ocean floor, or both. One scientist combined what geologists knew about sea-floor spreading, Earth's plates, and continental drift into a single theory. Recall that a scientific theory is a well-tested concept that explains a wide range of observations.

How Plates Move

The theory of **plate tectonics** (tek TAHN icks) states that pieces of Earth's lithosphere are in slow, constant motion, driven by convection currents in the mantle. 🌍 The theory of plate tectonics explains the formation, movement, and subduction of Earth's plates.

What force is great enough to move Earth's heavy plates? Geologists think that movement of convection currents in the mantle is the major cause of plate motion. Mantle motion is transferred to the lithosphere at its boundary with the asthenosphere. The plates are carried along in much the same way that ice floats on slow-moving water. During subduction, gravity pulls one edge of a plate down into the mantle. The rest of the plate also moves. This slow movement is similar to what happens in a pot of soup when gravity causes the cooler, denser soup near the surface to sink.

As the plates move, they change Earth's surface. These changes include earthquakes, volcanoes, mountain ranges, and deep-ocean trenches.

FIGURE 20
Plate boundaries divide the lithosphere into large plates. **Interpreting Maps** Which plates include both continents and ocean floor?

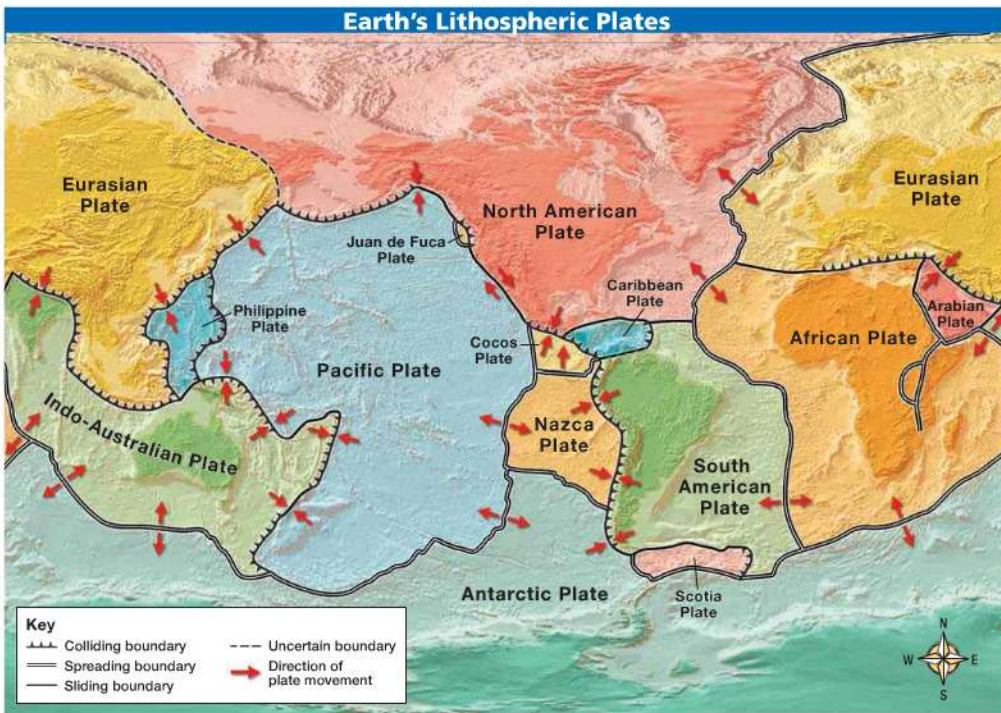


Plate Boundaries

The edges of Earth's plates meet at plate boundaries. Plate boundaries extend deep into the lithosphere. Faults form along these boundaries. **Faults** are breaks in Earth's crust where rocks have slipped past each other. 🌍 There are three kinds of plate boundaries: **spreading boundaries**, **colliding boundaries**, and **sliding boundaries**. A different type of plate movement occurs along each type of boundary.

Scientists have used instruments on satellites to measure plate motion. The plates move about 1 to 24 centimeters per year in response to movements in the mantle. The North American and Eurasian plates are moving apart at a rate of 2.5 centimeters per year. That's about as fast as your fingernails grow. But these plates have been moving for millions of years.

Spreading Boundaries The place where two plates move apart is called a **spreading boundary**. Most spreading boundaries occur along the mid-ocean ridges where sea-floor spreading occurs. Spreading boundaries are also called divergent boundaries.

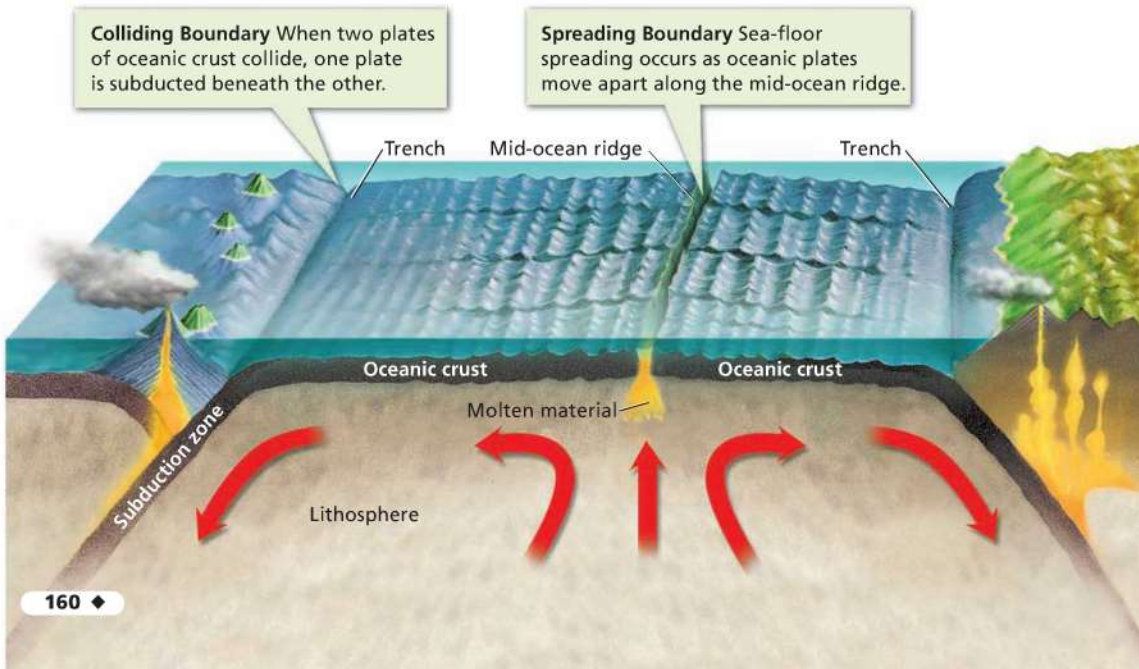
Spreading boundaries also occur on land. When a spreading boundary develops on land, two of Earth's plates slide apart. A deep valley called a **rift valley** forms along the spreading boundary. For example, the Great Rift Valley in East Africa marks a deep crack in the African continent.

FIGURE 21

Plate Tectonics

Plate movements have built many of the features of Earth's land surfaces and ocean floors.

Predicting What will eventually happen if a rift valley continues to pull apart?



Colliding Boundaries The place where two plates come together, or collide, is called a **colliding boundary**. Another term for colliding boundary is convergent boundary. When two plates collide, the density of the plates determines which one comes out on top. There are three types of collision between plates.

In the first type of collision, two plates made up of oceanic crust meet at a trench. The plate that is more dense sinks under the other plate. The reason for this is that oceanic crust becomes cooler and denser during sea-floor spreading.

In the second type of collision, an oceanic plate collides with a continental plate. Subduction occurs as the denser oceanic plate sinks beneath the less dense continental plate.

In the third type of collision, two plates carrying continental crust collide, but subduction does not take place. Neither piece of crust is dense enough to sink very far into the mantle. Instead, the collision squeezes the crust into mighty mountain ranges.

Sliding Boundaries A **sliding boundary** is a place where two plates slip past each other, moving in opposite directions. Along sliding boundaries, crust is neither created nor destroyed. Sliding boundaries can also be called transform boundaries.

Math Skills

Calculating a Rate

To calculate the rate of plate motion, divide the distance the plate moves by the time it takes to move that distance.

$$\text{Rate} = \frac{\text{Distance}}{\text{Time}}$$

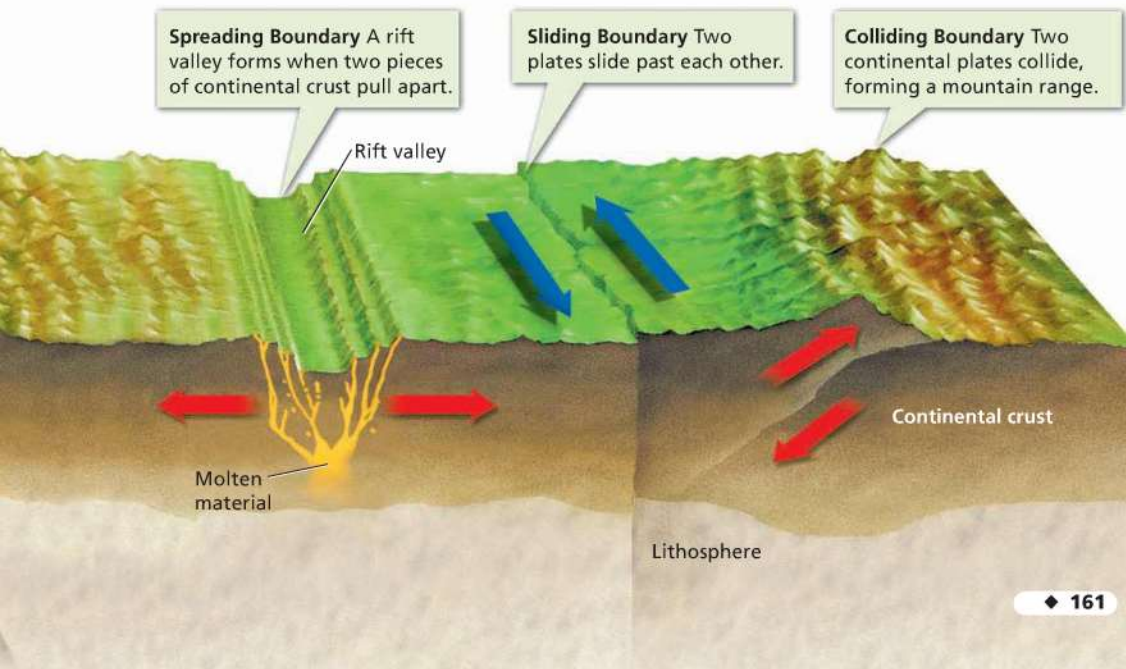
For example, a plate takes 2 million years to move 156 km. Calculate its rate of motion.

$$\frac{156 \text{ km}}{2,000,000 \text{ years}} = 7.8 \text{ cm per year}$$

Practice Problem The Pacific plate is sliding past the North American plate. It has taken 10 million years for the plate to move 600 km. What is the Pacific plate's rate of motion?



Reading Checkpoint What features form where two continental plates come together?





225 Million Years Ago

Plate Motions Over Time The movement of Earth's plates has greatly changed Earth's surface. Geologists have evidence that, before Pangaea existed, other supercontinents formed and split apart over billions of years. Pangaea itself formed when Earth's landmasses drifted together about 260 million years ago. Then, about 225 million years ago, Pangaea began to break apart. Figure 22 shows how major landmasses have moved since the breakup of Pangaea.



180–200 Million Years Ago

FIGURE 22
Continental Drift

Geologists have used computer modeling to trace the movements of the continents since the breakup of Pangaea. **Posing Questions** What questions would you need to answer in order to predict where the continents will be in 50 million years?



135 Million Years Ago



Earth Today

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Section 5 Assessment

S 6.1.c, E-LA: Reading 6.1.0

Vocabulary Skill Use Greek Word Origins This chapter is about the theory of plate tectonics. Use what you know about the Greek word origin of *tectonics* to explain the meaning of *plate tectonics*.

Reviewing Key Concepts

1. a. **Defining** What are plates?
 b. **Summarizing** What is the theory of plate tectonics?
 c. **Relating Cause and Effect** What do scientists think causes the movement of Earth's plates?
2. a. **Listing** What are the three types of plate boundaries?
 b. **Describing** Describe the type of movement that occurs at each type of plate boundary.
 c. **Predicting** What is likely to occur at a plate boundary where oceanic crust collides with continental crust?

Math Practice

3. **Calculating a Rate** There are two islands on opposite sides of a mid-ocean ridge in the Atlantic Ocean. During the last 8 million years, the distance between the islands has increased by 200 kilometers. Calculate the rate at which the two plates are moving apart.





Modeling Mantle Convection Currents

Materials



large bottle or container with tap water



small glass jar



red food coloring



aluminum foil or plastic wrap



rubber band



small pieces of paper or several paper hole punches



pencil



Problem How might convection in Earth's mantle affect tectonic plates?

Skills Focus making models, observing

Procedure

1. Fill the large jar about half full with cold tap water.
2. Partly fill the small jar with hot tap water and stir in 6 drops of food coloring. Carefully add enough hot water to fill the jar to the brim.
3. Cover the top of the jar with aluminum foil or plastic wrap and secure with a rubber band.
4. Carefully lower the jar into the bottle of tap water.
5. Place the pieces of paper on the surface of the water.
6. Without disturbing the water, use the tip of the pencil to make two small holes about 2–4 mm in diameter in the material covering the jar.
7. Predict what will happen to the colored water and to the pieces of paper floating on the surface.
8. Observe the contents of the jar, as well as the paper pieces on the surface of the water.

Analyze and Conclude

1. **Observing** Describe what happened to the colored water and to the pieces of paper after the holes were punched in the material covering the jar.
2. **Drawing Conclusions** How did your prediction compare with what actually happened to the colored water and pieces of paper?
3. **Inferring** What type of heat transfer took place in the bottle? Describe how the transfer occurred.
4. **Making Models** Which part of your model represents a tectonic plate? Which part represents Earth's mantle?
5. **Communicating** How well do you think this lab modeled the movement of Earth's plates? What similarities exist between this model and actual plate movement? What factors weren't you able to model in this lab?

Design an Experiment

Repeat this activity, but develop a plan to measure the temperature of the water inside the large jar. Is there a difference in temperature between the water's surface and the water near the top of the small jar? Do you observe any change in the convection currents as the water temperature changes? With your teacher's approval, carry out your plan.

 The **BIG Idea**

Earth's plates are large pieces of the lithosphere that move slowly, producing faults, mountain ranges, volcanoes, and deep-ocean trenches.

1 Earth's Interior

Key Concepts

 S 6.1.b

- Geologists have used two main types of evidence to learn about Earth's interior: direct evidence from rock samples and indirect evidence from seismic waves.
- The three main layers of Earth are the crust, the mantle, and the core. These layers vary greatly in size, composition, temperature, and pressure.
- The crust is a layer of solid rock that includes both dry land and the ocean floor.
- Earth's mantle is made up of rock that is very hot, but solid. Scientists divide the mantle into layers based on physical characteristics.
- The core is made mostly of the metals iron and nickel. It consists of two parts—a liquid outer core and a solid inner core.

Key Terms

- seismic waves
- pressure
- crust
- mantle
- lithosphere
- asthenosphere
- outer core
- inner core

2 Convection and the Mantle

Key Concepts

 S 6.4.c

- There are three types of heat transfer: radiation, conduction, and convection.
- Heating and cooling of the fluid, changes in the fluid's density, and the force of gravity combine to set convection currents in motion.
- Heat from the core and the mantle itself causes convection currents in the mantle.

Key Terms

- radiation
- conduction
- convection
- density
- convection current

3 Drifting Continents

Key Concepts

 S 6.1.a

- Wegener's hypothesis was that all the continents had once been joined together in a single landmass and have since drifted apart.

- Wegener gathered evidence from different scientific fields to support his ideas about continental drift. He studied land features, fossils, and evidence of climate change.
- Wegener could not provide a satisfactory explanation for the force that pushes or pulls the continents.

Key Terms

- continental drift
- Pangaea
- fossil

4 Sea-Floor Spreading

Key Concepts

 S 6.1.a

- In sea-floor spreading, the sea floor spreads apart along both sides of a mid-ocean ridge as new crust is added. As a result, the ocean floors move like conveyor belts, carrying the continents along with them.
- Several types of evidence supported the theory of sea-floor spreading: eruptions of molten material, magnetic stripes in the rock of the ocean floor, and the ages of the rocks.
- In a process taking tens of millions of years, part of the ocean floor sinks back into the mantle at deep-ocean trenches.

Key Terms

- mid-ocean ridge
- sonar
- sea-floor spreading
- deep-ocean trench
- subduction

5 The Theory of Plate Tectonics

Key Concepts

 S 6.1.c

- The theory of plate tectonics explains the formation, movement, and subduction of Earth's plates.
- There are three kinds of plate boundaries: spreading boundaries, colliding boundaries, and sliding boundaries. A different type of plate movement occurs along each.

Key Terms

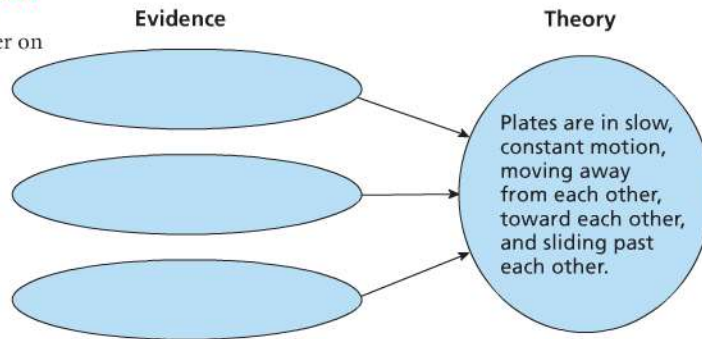
- plate
- plate tectonics
- fault
- spreading boundary
- rift valley
- colliding boundary
- sliding boundary



Target Reading Skill

Identify Supporting Evidence
Complete the graphic organizer on the theory of plate tectonics.

The Theory of Plate Tectonics



Reviewing Key Terms

Choose the letter of the best answer.

- HINT** The relatively soft layer of the upper mantle is the
 - asthenosphere.
 - lithosphere.
 - inner core.
 - continental crust.
- HINT** The transfer of heat by the direct contact of particles of matter is
 - pressure.
 - radiation.
 - conduction.
 - convection.
- HINT** Subduction of the ocean floor takes place at
 - the lower mantle.
 - mid-ocean ridges.
 - rift valleys.
 - trenches.
- HINT** The process that powers plate tectonics is
 - radiation.
 - convection.
 - conduction.
 - subduction.
- HINT** Two plates crash into each other at
 - a spreading boundary.
 - a colliding boundary.
 - the boundary between the mantle and the crust.
 - a sliding boundary.

Complete the following sentences so that your answers clearly explain the key terms.

- HINT** Granite is one of the main rocks that makes up **continental crust**, which is _____.
- HINT** Heat is transferred in the mantle by **convection currents**, which are _____.
- HINT** Continental drift formed the landmass called **Pangaea**, which was _____.
- HINT** Oceanic crust returns to the mantle at **deep-ocean trenches**, which are _____.
- HINT** A rift valley forms at a **spreading boundary**, which is _____.

Writing in Science

Prediction Now that you have learned about the theory of plate tectonics, write a paragraph predicting what the shape and positions of Earth's continents will be 50 million years in the future.



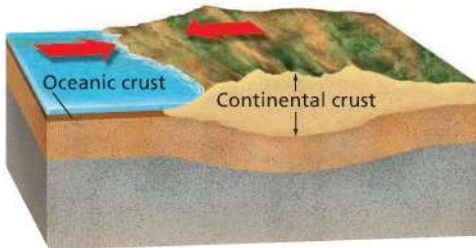
Review and Assessment

Checking Concepts

11. What kinds of indirect evidence do geologists use to study the structure of Earth?
12. How do temperature and pressure change as you go deeper into Earth?
13. What happens in Earth's interior to produce Earth's magnetic field? Describe the layer where the magnetic field is produced.
14. Why are there convection currents in the mantle?
15. How do magnetic stripes form on the ocean floor? Why are these stripes significant?
16. What type of geologic feature will form where two continental plates collide? Explain.

Thinking Critically

17. **Comparing and Contrasting** How are oceanic and continental crust alike? How do they differ?
18. **Sequencing** Place these terms in correct order so they begin at Earth's surface and move toward the center: inner core, asthenosphere, lower mantle, lithosphere, outer core.
19. **Predicting** In the diagram below, a plate of oceanic crust is colliding with a plate of continental crust. What will happen? Why?



20. **Relating Cause and Effect** What do many geologists think is the driving force of plate tectonics? Explain.
21. **Making Judgments** Scientists refer to plate tectonics as a *theory*. What is a theory? How is plate tectonics a theory? Why isn't continental drift considered a theory? (*Hint*: Refer to the Skills Handbook for more on theories.)

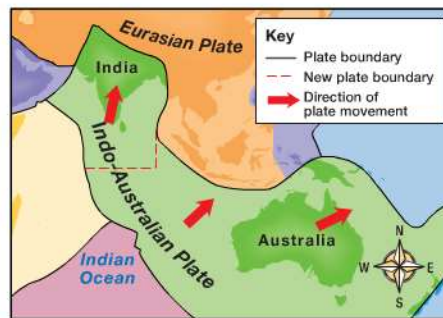
Math Practice

22. **Calculating a Rate** It takes 100,000 years for a plate to move about 14 kilometers. Calculate the rate of plate motion.

Applying Skills

Use the map to answer Questions 23–25.

Geologists think that a new plate boundary is forming in the Indian Ocean. The part of the plate carrying Australia is twisting away from the part of the plate carrying India.



23. **Interpreting Maps** In what direction is the part of the plate carrying Australia moving? In what direction is the part carrying India moving?
24. **Predicting** As India and Australia move in different directions, what type of plate boundary will form between them?
25. **Inferring** What features could occur where the northern part of the Indo-Australian plate is colliding with the Eurasian plate?

Lab zone

Standards Investigation

Performance Assessment Present your model to the class. Point out the types of plate boundaries on your model. Discuss the plate motions and landforms that result in these areas.

Choose the letter that best answers the question or completes the statement.

1. An island on the Pacific plate moves a distance of 550 cm in 50 years. What is the plate's rate of speed?
- A 44 cm per year
 - B 110 cm per year
 - C 2,750 cm per year
 - D 11 cm per year

S 6.1.c

2. The subduction of oceanic crust beneath continental crust occurs because
- A continental crust is denser than oceanic crust.
 - B oceanic crust is denser than continental crust.
 - C the heavy mountains on continental crust push the oceanic crust down.
 - D oceanic crust is warmer than continental crust.

S 6.1.c

3. Which statement best explains how convection currents can occur in Earth's mantle?
- A The mantle is made up of hot liquid.
 - B The mantle is made of hot but solid rock that can flow slowly.
 - C The density of rock increases as temperature increases in the mantle.
 - D Earth's rotation causes mantle convection.

S 6.1.b

4. Which of the following is evidence for sea-floor spreading?
- A matching patterns of magnetic stripes in the ocean floor
 - B volcanic eruptions along mid-ocean ridges
 - C older rock found farther from mid-ocean ridges
 - D all of the above

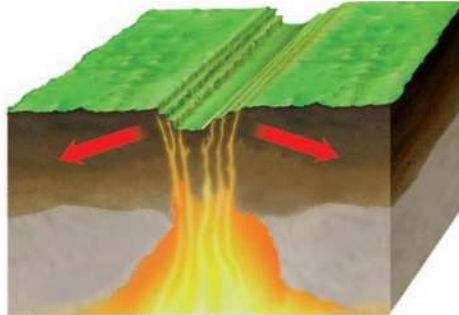
S 6.1.a

5. Wegener thought the continents moved because fossils of the same organisms are found on widely separated continents. Wegener's use of fossil evidence is an example of a(n)
- A prediction.
 - B observation.
 - C inference.
 - D controlled experiment.

S 6.1.a

6. In Earth's outer core heat is transferred mainly by
- A seismic waves.
 - B radiation.
 - C conduction.
 - D convection currents.

S 6.4.c



7. Which of the following best describes the process in the diagram below?
- A Colliding plates form a transform boundary.
 - B Colliding plates form volcanoes.
 - C Spreading plates form a mid-ocean ridge.
 - D Spreading plates form a rift valley.

S 6.1.e

Apply the BIG Idea

8. Today, the Mediterranean Sea lies between Europe and Africa. But the African plate is moving toward the Eurasian plate at a rate of a few centimeters per year. Predict how this area will change in 100 million years. In your answer, first explain how the Mediterranean Sea will change. Then explain what will happen on land.

S 6.1.e