Chapter 8

Plate Tectonics

In this chapter, you will learn about one of the most important discoveries of the 20th century—plate tectonics. You have already learned about Earth's surface and that it is covered with a lithosphere that is broken into pieces called "plates." Plate tectonics is the study of the movement of these plates. It is a relatively new field of study. Scientists have only arrived at our current understanding of plate tectonics over the past 40 years. This is a very short time in science years!

Key Questions

1. ***How is the surface of Earth like a giant jigsaw puzzle?***

2. ***Why are magnetic patterns important?***

3. ***How do rocks change?***

Photo courtesy U.S. Geological Survey

8.1 Alfred Wegener's Supercontinent

While looking at a map of the world, have you ever noticed that the continents look like pieces of a puzzle? If they are moved closer together across the Atlantic Ocean, they would fit neatly to form a giant landmass (Figure 8.1). In this section, you will learn about Alfred Wegener and his idea that a "supercontinent" once existed on Earth.

Movement of continents

Continental drift Alfred Wegener was a German climatologist and arctic explorer who suggested the concept of continental drift. **Continental drift** is the idea that the continents move around on Earth's surface.

Wegener's hypothesis In the early 1900s, Wegener hypothesized that the continents were once connected. Today, after a lot of scientific research and collected evidence, we know that Wegener was right.

Pangaea — a supercontinent In 1915, Wegener published his ideas in a book, *Origins of the Continents and Oceans*. Wegener thought that the continents we know today had once been part of an earlier *supercontinent*. He called this great landmass **Pangaea** (Greek for "all land"). According to continental drift, Pangaea broke apart and the pieces moved to their present places, becoming today's continents.

What is plate tectonics? In Chapter 1, you were introduced to plate tectonics, the study of lithospheric plates. You learned that the surface of Earth is broken into many pieces like a giant jigsaw puzzle. **Plate tectonics** describes how these pieces move on Earth's surface. By the time you finish this chapter, you will know more about this theory than any scientist knew only forty years ago. Wow! Additionally, you will learn that the development of this theory is an excellent example of how the scientific process works. Now, let's return to Wegener and his idea of continental drift.

Figure 8.1: *The continents on either side of the Atlantic Ocean fit together like puzzle pieces.*

VOCABULARY

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

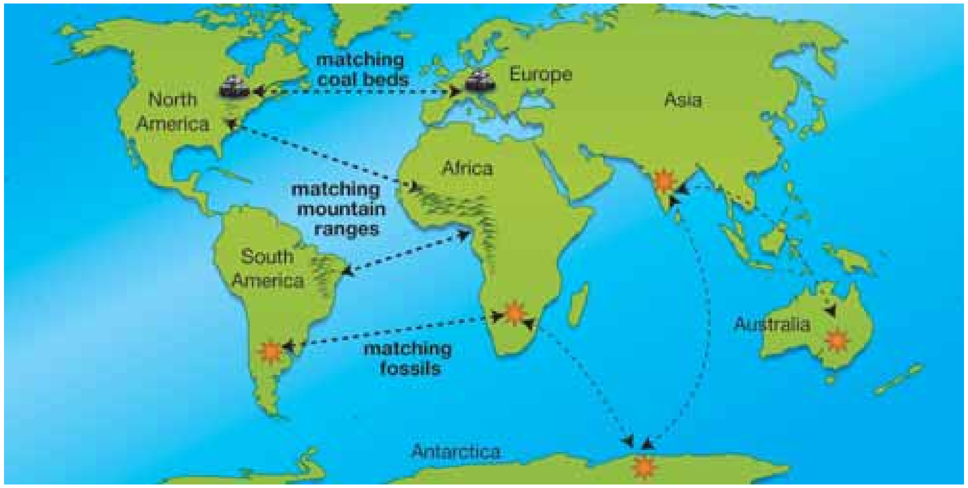
Pangaea - an ancient, huge landmass composed of earlier forms of today's continents; an ancient supercontinent.

plate tectonics - a theory explaining how the pieces of Earth's surface (the plates) move.

Evidence for continental drift

Matching coal beds, mountains, and fossils

Wegener was not the only scientist to suggest that continents moved. But his theory stood out because of the evidence that he gathered to support his idea of continental drift. Wegener's evidence is presented in the graphic below and listed at the right in the sidebar.



A good hypothesis

Wegener's belief that the continents had been connected in the past was a good idea. It was a *scientific hypothesis based on observations*.

Continental drift was rejected

Continental drift was a good hypothesis that was rejected by other scientists. A key part of Wegener's hypothesis was that some unknown force had caused the continents to slide over, or push through, the rocky bottoms of the oceans. Yet, neither he nor anyone else could identify the source of the force needed to move continents. Continental drift helped explain issues in geology—like why South America and Africa seem to fit together. However, continental drift could not be accepted by scientists because there was no evidence to explain how continents could move.

Wegener's evidence for continental drift

Coal beds stretch across the eastern United States and continue across southern Europe.

Matching plant fossils in South America, Africa, India, Australia, and Antarctica.

Matching reptile fossils have been found in South America and Africa.

Matching early mammal fossils found in South America, and Africa.

Fossils in South America and Africa are found in rocks of identical age and type.

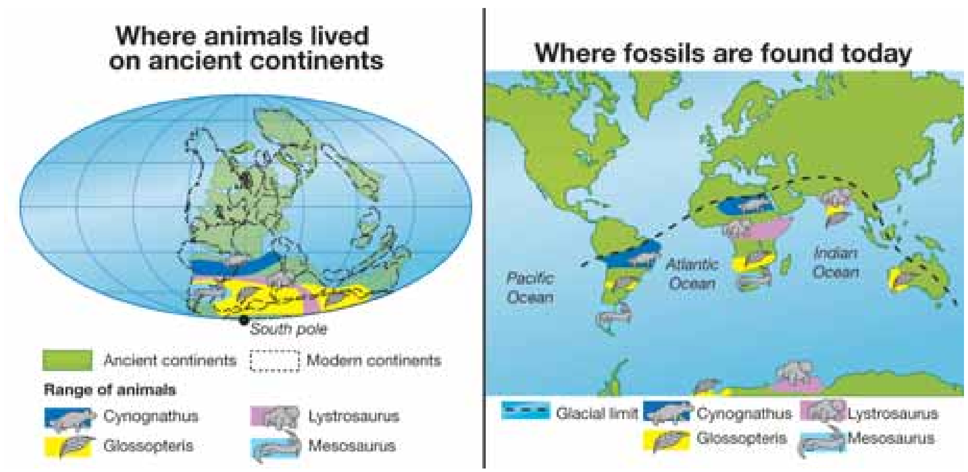
Matching mountain ranges in North America, Africa, and South America.

Evidence of glaciers is present in regions with warm, dry climates. This indicates that continents that are close to the equator today were once closer to the South Pole in the distant past.

Photograph courtesy of the Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany

8.1 Section Review

1. Who was Alfred Wegener?
2. Alfred Wegener thought that all continents were once connected. Explain one observation that led to this belief.
3. Why did scientists reject Wegener's idea of continental drift?
4. In this section, you read that the development of the theory of plate tectonics is a good example of the scientific process.
   a. How did Wegener follow the scientific process?
   b. When scientists rejected continental drift, were they using the scientific process? Why or why not?
5. Answer these challenge questions.
   a. Name the seven modern continents.
   b. Make a table that lists the modern continents and describes the animal fossils that are found on each, according to the graphic below (Figure 8.2).
   c. A long time ago, glaciers covered parts of some the continents. Why aren't glaciers on these continents today?



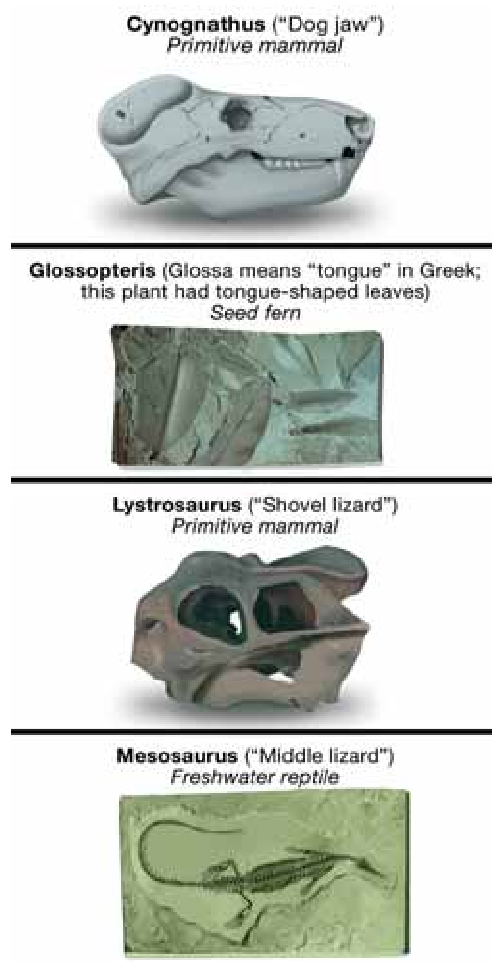


Figure 8.2: *Fossils that are found on modern continents. In the ancient past, the modern continents were connected as a supercontinent.*

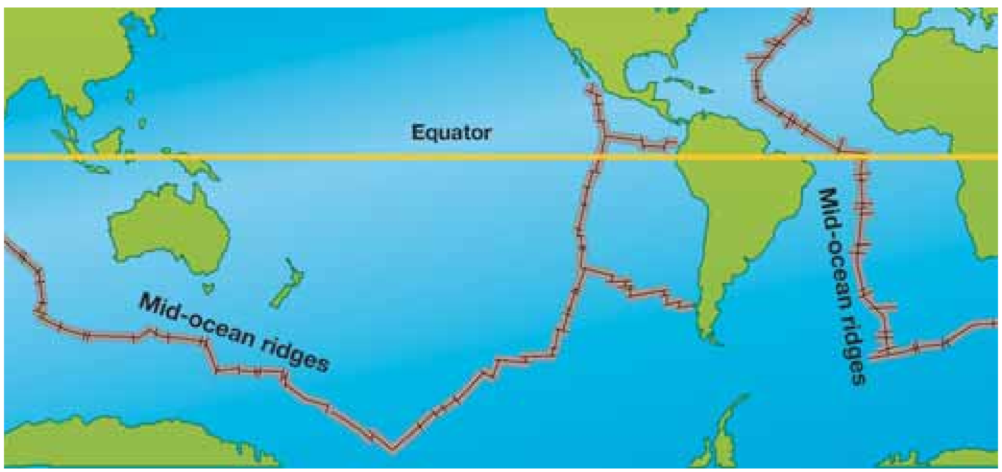
8.2 Sea-floor Spreading

In Wegener's time, the world's ocean floors were largely unexplored. Mapping the sea floor provided more important evidence for the theory of plate tectonics.

Undersea mountains discovered

A map of the ocean floor During World War II, the United States Navy needed to locate enemy submarines hiding on the bottom of shallow seas. Therefore, large areas of the ocean floor were mapped for the first time. American geophysicist and Naval officer Harry Hess did some of the mapping. His work helped develop the theory of plate tectonics.

Mid-ocean ridges The naval maps showed huge mountain ranges that formed a continuous chain down the centers of the ocean floors. These mountain ranges are called **mid-ocean ridges**. Hess was intrigued by their shape and location. He wondered if it was possible that new ocean floor was created at the mid-ocean ridges. If new ocean floor formed at the ridges, then continents on either side would get pushed apart during the process (Figure 8.3).



VOCABULARY

mid-ocean ridges - long chains of undersea mountains.

Figure 8.3: *Harry Hess wondered if it was possible that new ocean floor was created at the mid-ocean ridges.*

The sea-floor spreading hypothesis

A hypothesis is born Hess believed that Wegener was partly right. The continents *had* separated from a supercontinent, but not by plowing through the sea floor. Instead, continents moved along as a part of the growing sea floor! Hess called his hypothesis **sea-floor spreading**. Although his idea seemed to fit with existing observations, Hess realized that he didn't have enough supporting evidence for such a breathtaking idea. Because his theory was speculative, he called it "geo-poetry."

A good idea needs more evidence Sea-floor spreading was an attractive idea. But for many years scientists had viewed the continents as fixed in place. They felt that their shapes were due to causes that did not involve moving. Sea-floor spreading would need strong support before it would be more than geo-poetry.

Rapid scientific progress A time of tremendously rapid scientific progress followed Hess' sea-floor spreading hypothesis. Many scientists added to each other's work and found the strong evidence needed to explain sea-floor spreading.

Magnetic patterns and the age of rocks The key was the discovery that there are patterns (called "magnetic patterns") in the rocks on either side of the mid-ocean ridges (Figure 8.4). Scientists were able to read these patterns. They determined that on either side of a mid-ocean ridge, the oldest rocks were furthest from the ridge. They also found that the pattern on one side of a ridge matched the pattern on the other side. These patterns showed that Hess' geo-poetry was correct. New ocean floor is formed at mid-ocean ridges and the new floor moves away from the ridge as time passes.

VOCABULARY

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

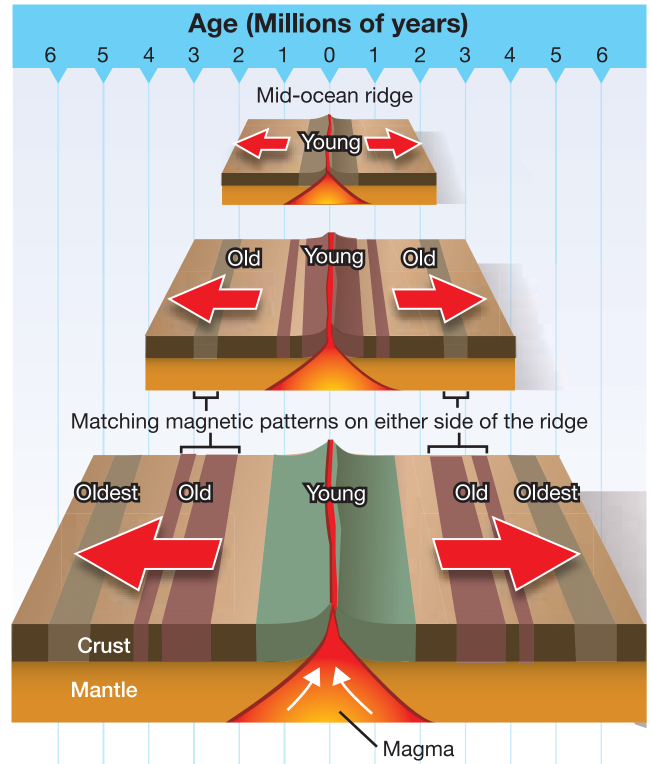


Figure 8.4: *Matching magnetic patterns and the age of rocks on either side of mid-ocean ridges provide strong evidence for sea-floor spreading.*

Moving pieces of the lithosphere

After a breakthrough

After the breakthrough discovery of magnetic patterns was understood, there was great scientific interest in the idea of sea-floor spreading. Scientists realized that large pieces of Earth's surface moved about like rafts on a river.

Today we know these "rafts" are pieces of lithosphere called **lithospheric plates** that move over the aesthenosphere (review the interior of Earth in Chapter 7). Plate tectonics is the study of these lithospheric plates.

There are two kinds of lithospheric plates: **oceanic plates** and **continental plates**. Oceanic plates form the floor of the ocean. They are thin and made of dense basalt. Continental plates are thick and made of less-dense granite. Often a lithospheric plate is a mix of both kinds of plates.

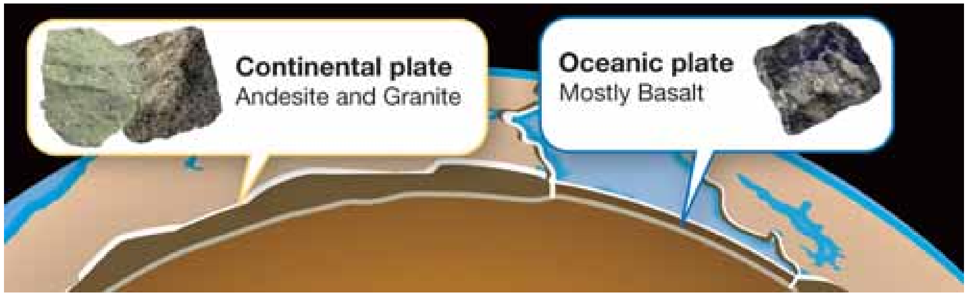


Plate tectonics answers other questions

Science is a process that builds on itself. Early discoveries provide a better understanding that leads to more discoveries. The evidence that Alfred Wegener collected to support an ancient supercontinent is valid today. And our understanding of plate tectonics has allowed us to answer other questions such as:

- Why are volcanoes and earthquakes located where they are?
- Where can we find oil, gas, gold, and other important resources?

VOCABULARY

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

oceanic plates - thin, dense lithospheric plates that are made of basalt and form the ocean floor.

continental plates - thick, less-dense lithospheric plates that are made of granite and form the continents.

MY JOURNAL

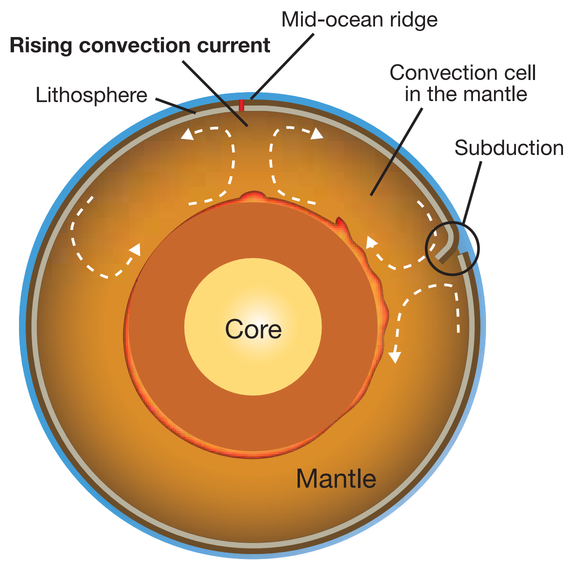
How is plate tectonics related to earthquakes and volcanoes?

Write an answer based on what you know. Then, check your answer by doing research to answer this question. Use research resources in your classroom and school library.

What drives lithospheric plates?

Convection cells

Convection cells in Earth's lower mantle drive the lithospheric plates on the surface. Here again we see the effect of heat on materials. The rocks of the lower mantle are not brittle like the rocks of the lithosphere. They are hot enough so that they flow very slowly. The core heats the rock material of the lower mantle. As it is heated, it expands and becomes less dense.



The lower mantle rock material rises toward Earth's surface and may divide the lithosphere above and form a mid-ocean ridge. The pieces of separated lithospheric plate will move away from each other on either side of the new mid-ocean ridge.

Subduction

The far edge of a lithospheric plate is much older than the edge close to the mid-ocean ridge that formed it. Over time, the far edge cools and becomes denser (Figure 8.5). Eventually, it may sink below another lithospheric plate and enter the lower mantle. This sinking process is called **subduction**. As the now-cool subducting plate enters the lower mantle, it cools the nearby lower mantle material in turn. Cooling makes the nearby material denser and it sinks deeper into the lower mantle. This sinking completes the lower mantle convection cell.

VOCABULARY

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

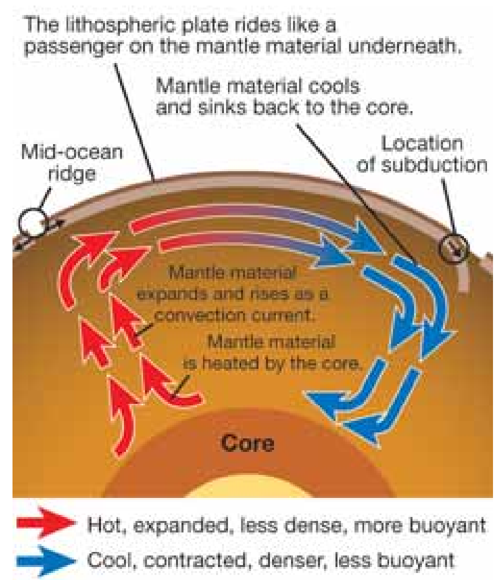
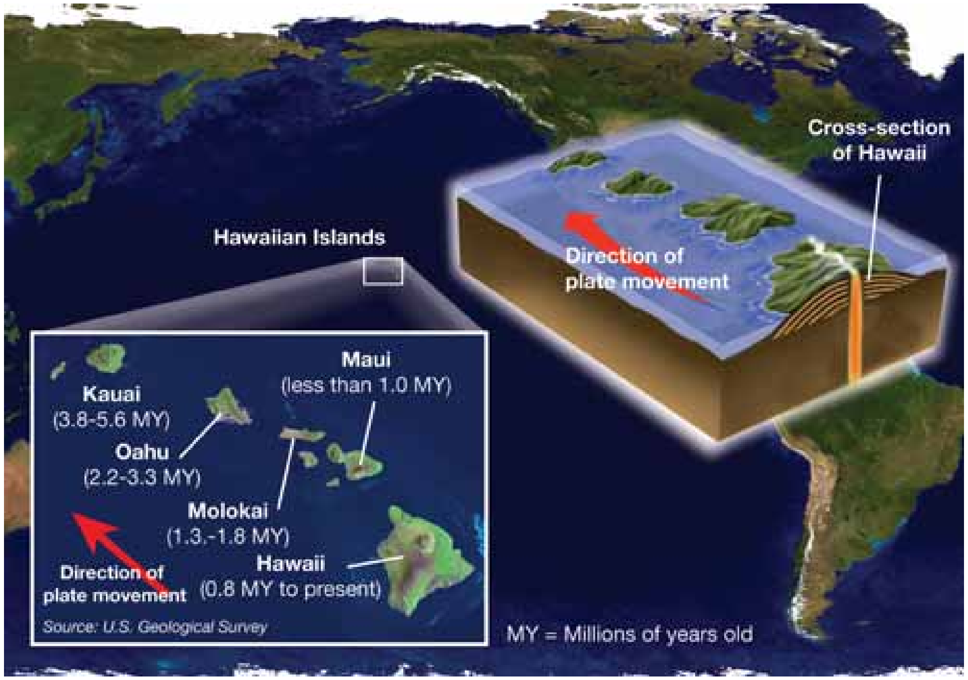


Figure 8.5: *A convection cell in the lower mantle.*

Hot spots and island chains

Mid-ocean ridges form when rising hot mantle rocks separate the plate above it. Sometimes a single hot rising plume, called a **mantle plume**, causes a volcanic eruption in the plate above it. If the eruption is strong and lasts long enough, the volcanic eruption may form an island on the plate. Plates move more quickly than the underlying mantle plumes. After the island forms, the movement of the plate carries it away from the mantle plume. Without the heat from the mantle plume underneath, the volcano that formed the island becomes dormant. In the meantime, a new volcano begins to form on the part of the plate that is now over the mantle plume.

This process repeats over and over and forms a string of islands. The first island formed in the string is made of old dormant volcanoes, while the most recent island in the string probably has active volcanoes. Scientists determine the direction and speed of plate movement by measuring these island chains. The Hawaiian Islands are a good example of an island chain formed by a mantle plume hot spot.



VOCABULARY

mantle plume - heated lower mantle rock that rises toward the lithosphere because it is less dense than surrounding mantle rock.

SOLVE IT!

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

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

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

8.2 Section Review

1. Explain why magnetic patterns are important evidence for plate tectonics?
2. How were mid-ocean ridges discovered?
3. What was Harry Hess' hypothesis regarding the ocean floor and how it was made?
4. What two discoveries supported Hess' hypothesis?
5. What is the study of lithospheric plates called?
6. Over what surface do lithospheric plates move?

   a. lower mantle   b. outer core
   c. inner core   d. aesthenosphere

7. Name the two types of lithospheric plates and describe them.
8. What are some questions that are answered by plate tectonics?
9. What is the source of energy that drives the movement of the lithospheric plates?
10. Do lithospheric plates move quickly or slowly? Explain your answer.
11. Describe the process of subduction in your own words. What causes subduction to happen?
12. Name an example of an island chain formed by a mantle plume hot spot. Describe/draw the process of how it forms.
13. Research question: The Mid-Atlantic Ridge (see page 16) goes through the country of Iceland. What effect is it having on this country?
14. Research question: It is thought that when Pangaea broke apart, it first split into two large landmasses, each of which were given names. What are the names? What do these names mean?

MY JOURNAL

Create a table to compare and contrast continental drift and plate tectonics. Include the answers to the following questions.

Which is a hypothesis and which is a theory?

What is the difference between these two ideas when explaining why Africa and South America seem to fit together like two puzzle pieces?

CHALLENGE

Drummond Matthews and Fred Vine, British geologists from Cambridge University, England, are credited with recognizing the significance of magnetic patterns.

Research these magnetic patterns so that you understand what they are and how they are caused. Make a poster to display your findings.

Although the contributions of Matthews and Vine are considered huge among all earth scientists, they never received any special recognition for their work.

8.3 Plate Boundaries

In this section, you will learn how movement at the boundaries of lithospheric plates affects Earth's surface.

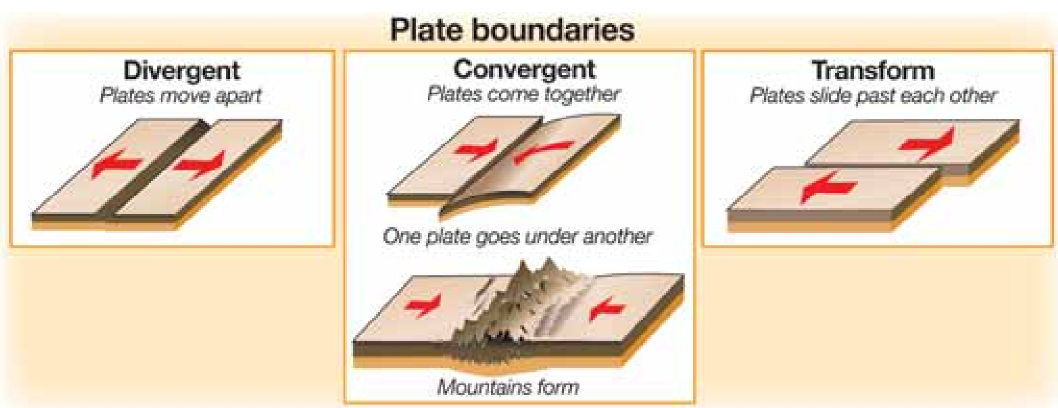
Moving plates

Three types of boundaries

Imagine a single plate, moving in one direction on Earth's surface (Figure 8.6). One edge of the plate—the trailing edge—moves away from things. This edge is called a **divergent boundary**. The opposite edge—called the leading edge— bumps into anything in the way. This edge is called a **convergent boundary**. The sides of our imaginary plate do not collide with or move away from another plate. These sides slide by other plates. An edge of a lithospheric plate that slides by another plate is called a **transform fault boundary**.

How plates move relative to each other

Earth's surface is covered with lithospheric plates. Unlike our single imaginary plate, the boundaries of real plates touch each other. Plates move apart at divergent boundaries, collide at convergent boundaries, and slide by each other at transform fault boundaries.



VOCABULARY

divergent boundary - a lithospheric plate boundary where two plates move apart.

convergent boundary - a lithospheric plate boundary where two plates come together.

transform fault boundary - a lithospheric plate boundary where two plates slide by each other.

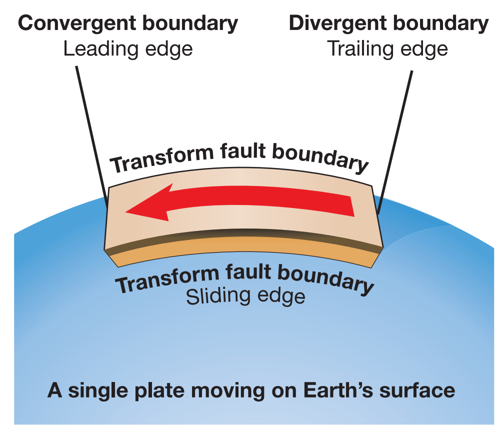


Figure 8.6: *Divergent, convergent, and transform fault boundaries.*

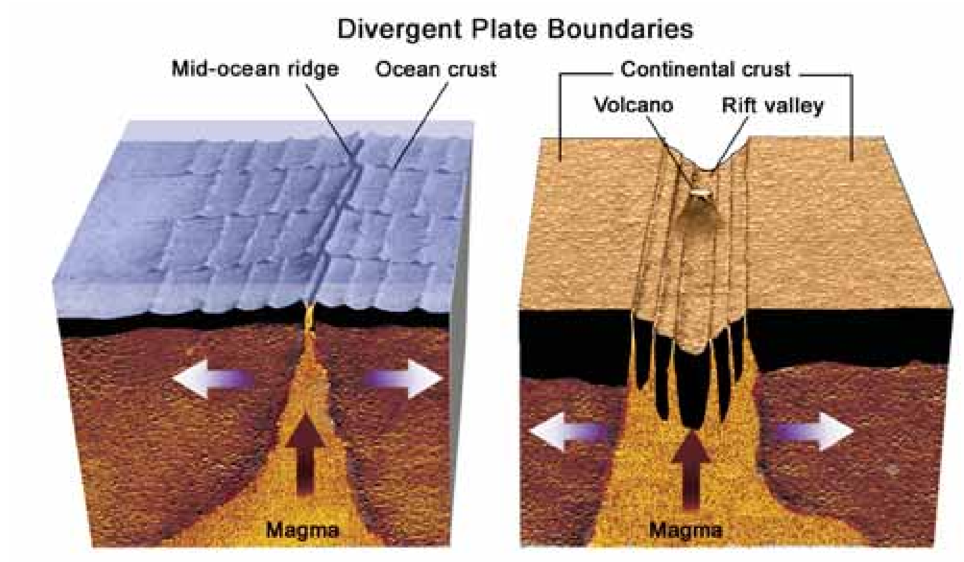
Divergent boundaries

New sea-floor at mid-ocean ridges

Divergent boundaries are found in the ocean as mid-ocean ridges. A divergent boundary is the line between two plates where they are moving apart. This type of boundary is found over the rising plume of a mantle convection cell. The convection cell causes the two plates to move away from each other. As they move, melted rock fills the space created by their motion. The melted rock hardens and becomes new ocean floor. This process is how new Earth surface is created!

Rift valleys

Divergent boundaries can also be found on continents as *rift valleys*. When a rift valley forms on land, it may eventually split the landmass wide enough so that the sea flows into the valley. When this happens, the rift valley becomes a mid-ocean ridge. The East African Rift Valley is an example of rifting in progress. This rift is marked by a series of long lakes that start near the southern end of the Red Sea and move southward toward Mozambique.



MY JOURNAL

Using clues to make discoveries

At the ocean floor, special lava formations called *pillow lava* are clues to the location of ancient mid-ocean ridges.

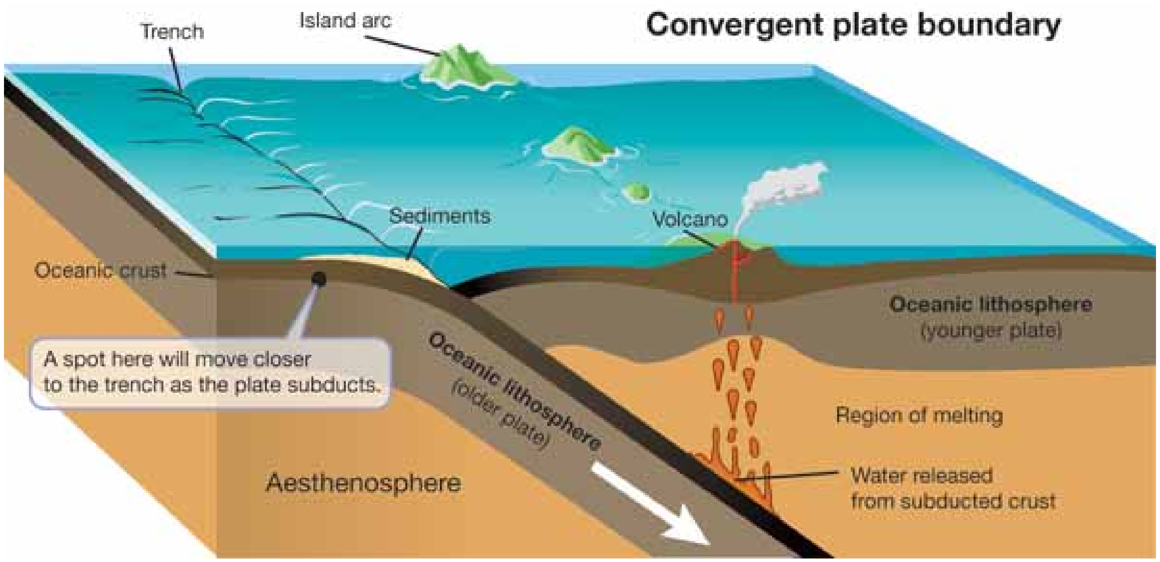
The pillow lava forms when basalt lava flows out under water. The water cools the surface of the lava, forming a crust. This crust stops the flow of lava for a moment. Then the crust cracks and a new jet of lava flows out. This process causes the lava to form what looks like a pile of pillows. Ancient mid-ocean ridges can be located near pillow lava formations.

Write a paragraph describing a recent experience where you used a clue to discover something about a place or an object.

Convergent boundaries

Trenches When oceanic plates collide, one subducts under the other. This forms a valley in the ocean floor called a **trench**.

Why does one plate subduct under another? A denser plate subducts under a less dense one. Older plates are cooler plates, and therefore denser than younger plates. So we can say that older plates tend to subduct under younger plates.



Oceanic and continental plate subduction What happens if an oceanic plate and a continental plate collide? Continental plates are largely made of andesite and granite. Andesite and granite are much less dense than the basalt of oceanic plates. Which plate would subduct? You're on the right track if you realized that the oceanic plate must subduct under the continental plate. A continental plate is simply too buoyant to subduct under an oceanic plate. A good example of this is the Nazca Plate off the coast of South America. The Nazca Plate is subducting under the South American Plate (Figure 8.7).

VOCABULARY

trench - a valley in the ocean created where one lithospheric plate subducts under another.

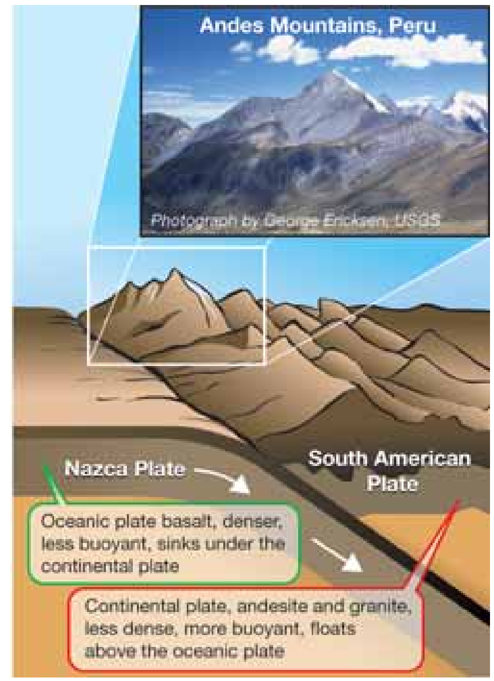


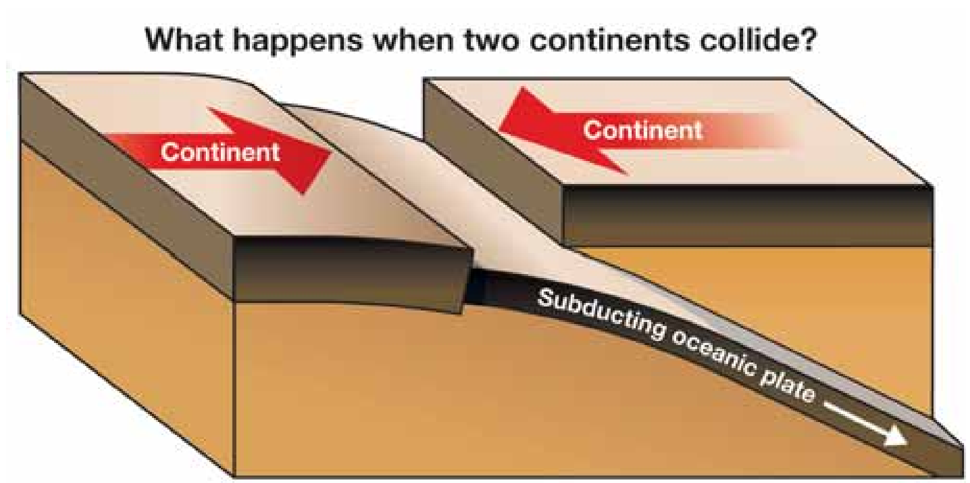
Figure 8.7: *The collision of the Nazca and South American Plates has deformed and pushed up the land to form the high peaks of the Andes Mountains. This photograph is of the Pachapaqui mining area in Peru.*

Mountains and convergent boundaries

What happens when two continents collide?

What happens if an oceanic plate with a continent on it subducts under a continental plate? Eventually the subducting plate brings its continent right up against the continental plate!

What happens then? The forces in the lower mantle that drive the movements of the lithospheric plates are too great to be changed by this collision. The continents cannot be sucked into the trench because their granite rocks are too buoyant to be subducted. Therefore, the two continents collide!



Colliding continents form mountains

Vast mountain ranges are formed when continents collide. Millions of years ago, India was a separate continent and not attached to South Asia. The Indo-Australian oceanic plate carried the landmass of India toward China as it subducted under the Eurasian continental plate. Today the Himalayan Mountains are the result of this collision (Figure 8.8). What's more, the impact of the collision continues today—it's a slow process and the Himalayan Mountains are still growing!

Figure 8.8: *The Himalayan Mountains are the result of the slow but powerful collision between India on the Indo-Australian Plate and the China on the Eurasian Plate.*

Transform fault boundaries

Finding boundaries Once scientists began to understand lithospheric plate boundaries, finding divergent and convergent boundaries was easy. Mid-ocean ridges and continental rift valleys are divergent boundaries. Trenches and mountain ranges mark convergent boundaries. Finding transform fault boundaries is more difficult. Transform faults leave few clues to indicate their presence.

Zones of activity One reason for the difficulty in locating transform faults is that they are not single straight lines of movement. Transform faults are usually branched and often change location with time. It's helpful to think of transform faults as a zone of motion rather than a line that separates two plates.

Zig-zags are clues Sometimes the action of a transform fault will form a small valley along the line of movement. Often there will be ponds along the line. A good clue for locating transform faults is *offsetting*. If a feature like a creek or a highway crosses a transform fault, the movement of the fault will break, or offset, the feature. When seen from above, the feature will appear to make a zig-zag (Figure 8.9).

Earthquakes are another clue The best way to detect transform faults is by the earthquakes they cause. Movement along a transform fault causes the vast majority of earthquakes. For example, the San Andreas Fault is a well-known fault that causes earthquakes in California (Figure 8.10). The San Andreas Fault is the boundary between two lithospheric plates—the Pacific Plate and the North American Plate.

Using plate tectonics to understand other events Before plate tectonics was understood, scientists knew where earthquakes commonly occurred, but they didn't know why. This is another example of how understanding plate tectonics leads to other new understandings. You will learn more about earthquakes and transform faults in the next chapter.

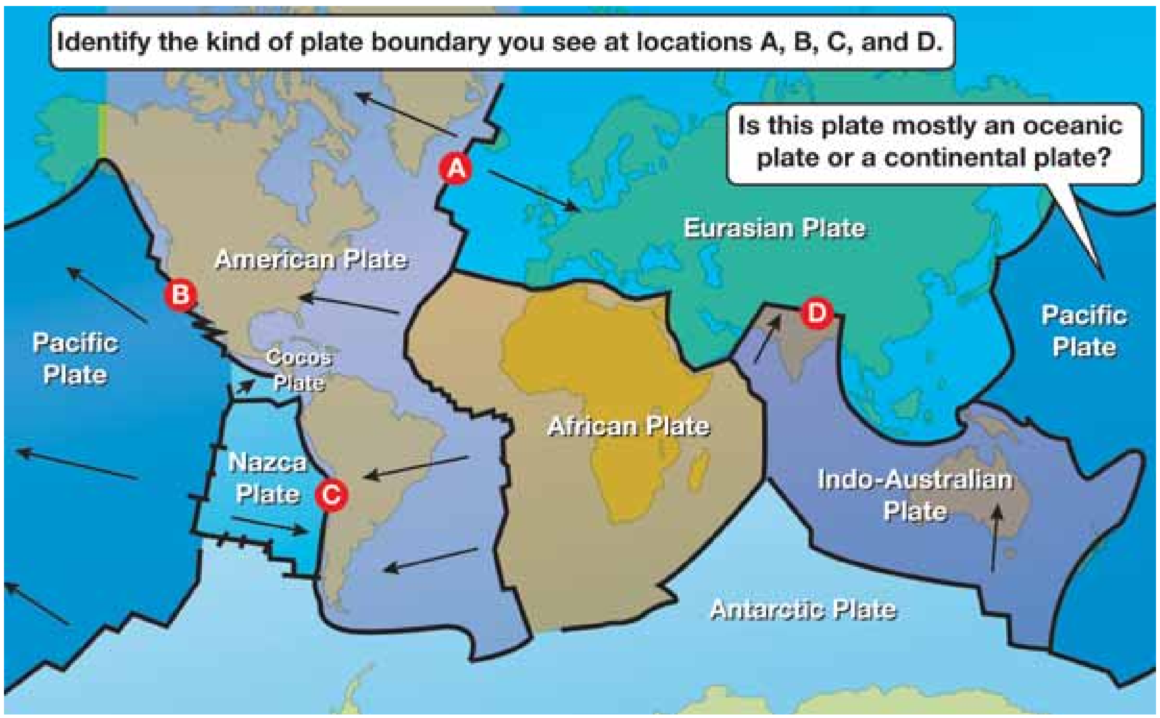
Figure 8.9: *The creek is offset to the right as viewed from bottom to top in the photo.*

Figure 8.10: *This line of students stretches across part of the San Andreas Fault in California.*

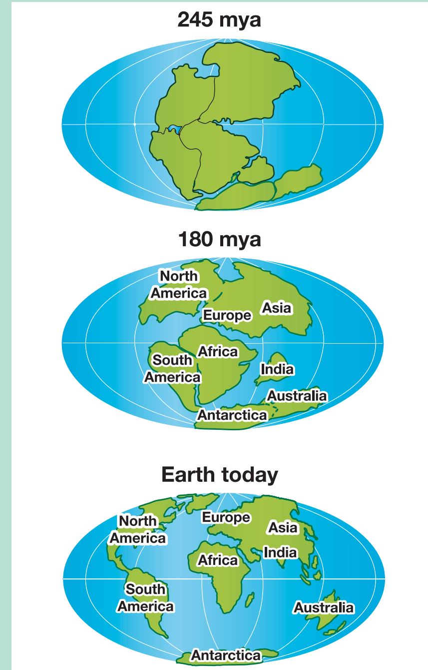
Earth's lithospheric plates

This map shows the largest lithospheric plates that cover Earth. There are many small plates, but some of these have been combined with the larger ones to simplify the map.

Study the map. Can you identify the labeled plate boundaries? Use the arrows on the map to help you. Remember that the three types of plate boundaries are divergent, convergent, and transform. Then, see if you can answer the question.



From Pangaea to Today



About 245 million years ago (mya), all land on Earth was part of the supercontinent called Pangaea. About 180 mya, this huge landmass began to split apart into many sections. Seven of the largest sections form our continents. It is important to note that Pangaea was not the original landmass formation. Before Pangaea, there were other earlier formations of the oceans and continents and over a very long period of time, forces brought them together to form Pangaea.

8.3 Section Review

1. What are the three types of plate boundaries and what does each do in relation to other plate boundaries?
2. What kind of boundary is a mid-ocean ridge?
3. What is pillow lava and where is it found?
4. What is a place (on land) where divergent boundaries can be found? Give an example of a divergent boundary on land.
5. What happens when ocean plates come together? What landform does this event create?
6. What features of a plate determine whether a plate will subduct under another plate? Pick the two correct features:

a. How much ocean water is on top of the plate	b. The age of the plate
c. Whether the plate is made of basalt or granite	d. How fast the plate is traveling
e. Whether the plate is in the northern or southern hemisphere	f. Whether the plate is traveling east or west

7. Which is more buoyant—a continental plate or oceanic plate? Which would subduct if the two were to collide with each other?
8. What happens when two continental plates collide? Give an example of continents colliding today.
9. Why are transform faults harder to find than divergent and convergent boundaries?
10. What are three clues to finding transform faults?

CHALLENGE

1. The oldest parts of Earth are found on the continents and not in the oceans. Why do you think this is?

2. Earth is 4.6 billion years old but the oldest sea floor is only 200 million years old. Why do you think this is?

3. Where might you find the oldest rocks on Earth?

4. How likely are we to find any rocks that are as old as Earth itself?

MY JOURNAL

Careers in Earth Science

Have you ever thought about being an earth scientist?

Find out what kinds of careers are available to people who study earth science and geology.

For example, a *geodynamacist* studies how lithospheric plates move and change shape.

Write a description of one earth science career that interests you.

8.4 Metamorphic Rocks

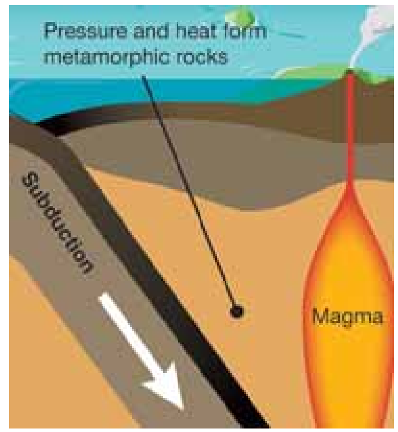
Metamorphism means to change the form of something. A **metamorphic rock** is a rock formed from another kind of rock due to heat and pressure. A metamorphic rock might have originally been a rock made from sediments that formed at the bottom of a lake—a *sedimentary rock*. Or it might have been a rock formed from material that flowed from a volcano—an *igneous rock*.

VOCABULARY

metamorphic rock - a rock formed from another kind of rock due to heat and pressure.

Heat and pressure at subduction zones

Many metamorphic rocks are formed at convergent boundaries where there is pressure and heat. A subduction zone is a place where metamorphic rocks are formed. Also, metamorphic rocks can be formed by heat alone. For example, when magma comes in contact with another type of rock, the high heat may form metamorphic rock near the point of contact. This is called *contact metamorphism*.



Heat and pressure when continents collide

Heat and pressure result when colliding continents form mountains at a convergent boundary. Therefore, mountains are locations where you can find metamorphic rocks. In Chapter 7 you learned that continents are thicker than ocean floor, and that continents can push down into the warm lower mantle. Therefore the mantle provides heat for metamorphic rock formation.

Metamorphism example

Limestone is a sedimentary rock that forms on the ocean bottom from the shells of tiny one-celled animals and other material. When this ocean bottom is squeezed at a subduction zone, the limestone is metamorphosed into marble (Figure 8.11). Italy lies near a convergent boundary. Italy is also the source of some of the world's finest marble.

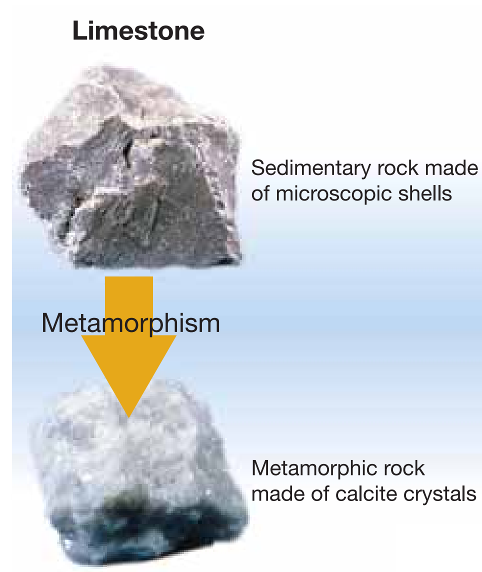


Figure 8.11: *Limestone is a sedimentary rock made of shells. At subduction zones, it is metamorphosed into marble.*

8.4 Section Review

1. What does the term *metamorphism* mean?
2. What two things can cause metamorphic rock formation?
3. What is contact metamorphism?
4. Look at the rock images in Figure 8.12. Which image is most likely to be a metamorphic rock? Explain your answer.
5. Metamorphic rocks are commonly formed at what kind of plate boundary?
6. In which location would you be most likely to find a metamorphic rock?
    a. The beach
    b. A forest
    c. On a mountain
    d. At the bottom of a stream
    e. Near a volcano
7. At what type of plate boundary can limestone be metamorphosed into marble?
8. Challenge question: The introduction of this section discusses three types of rocks. For the following questions, state whether the description describes a metamorphic, sedimentary, or igneous rock. You will learn more about these rocks in later chapters.
    a. A rock formed from particles of sand and soil.
    b. A rock formed after a volcano erupts.
    c. This kind of rock is likely to be formed at a subduction zone.

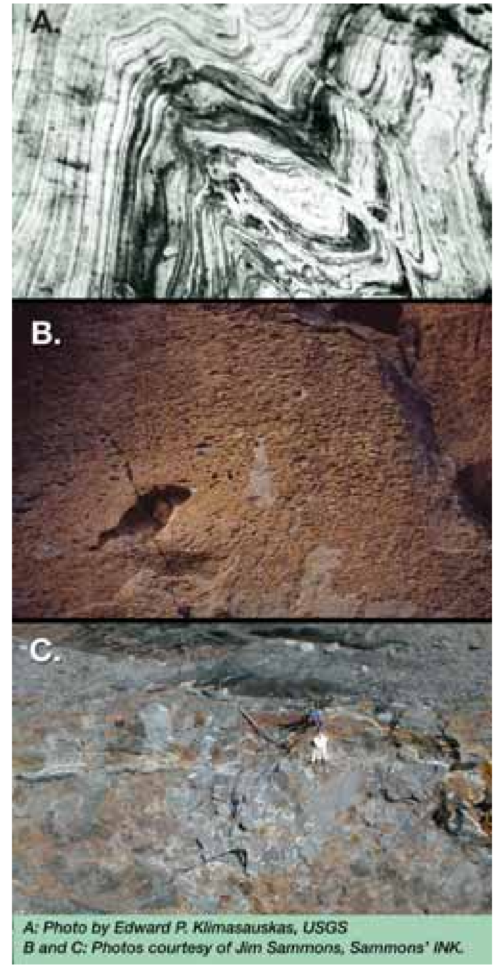


Figure 8.12: *Which one of these images is of a metamorphic rock?*

ARCHAEOLOGY CONNECTION

Fossils of the Ice Age

Sticky. Tacky. Gooey. What do you think of when you hear those words? Bubble gum? Marshmallow? Glue? Tar? Could any of those materials have preserved fossils for thousands of years? Indeed, sticky tar formed from seeping crude oil in what is now California helped to preserve one of the world's richest fossil sites.

Fossils are the preserved remains of animals or plants. Some fossils can include animal tracks and prints. Natural remains are usually recycled back into the earth. The creation of a fossil is a special and rare event because those remains must be buried and preserved quickly.

Imagine finding fossils from an ice age. There have been several long ice ages on Earth. The most recent lasted from 1.6 million years ago to 10,000 years ago. Over an ice age Earth is cooler and covered by huge sheets of ice. During the last ice age, glaciers covered large sections of North America and Europe. You might have fossils right in your backyard.

La Brea tar pits

The La Brea tar pits are located in Los Angeles, California. For thousands of years, Native Americans used the tar, or more accurately, asphalt, as glue and waterproof caulking. Colonists used it for roofing. In the early 1900s, researchers from the University of California at Berkeley identified ice age fossils at the site.

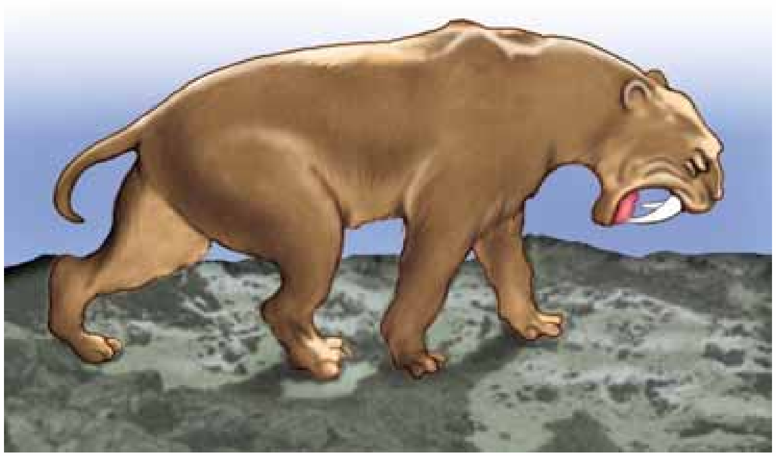
During the ice age, rainwater covered the tar pits. Animals and plants became trapped in the tar and died. The La Brea tar pits contain a large number of mammal remains including saber-toothed cats, mammoths, dire wolves, and short-faced bears. Scientists believe large animals or prey became trapped in the tar. Meat-eating predators then followed the prey into the tar also becoming trapped. Predators hunting prey explains the large number of remains found; La Brea has over 3 million fossils and the oldest are nearly 38,000 years old. This site has provided fossils of over 500 mammal, bird, insect, and plant species.

Smilodon californicus

Do you know your state flower? Your state bird? How about your state fossil! Not every state has one, but in Alaska and Nebraska, for instance, the state fossil is the woolly mammoth. Montana and New Jersey share the duck-billed dinosaur. California adopted the saber-toothed cat, *Smilodon californicus*, in January 1974.

The word Smilodon means "knife tooth." The Smilodon had 7-inch-long saber-like canine teeth. It was about 4 or 5 feet long, about 3 feet tall, and weighed over 400 pounds. It was not as large as today's lion, but weighed more. It did not run fast, but could pounce upon its prey. Smilodon is the second most common mammal found at La Brea.

Smilodon californicus



Chapter 8 Connection

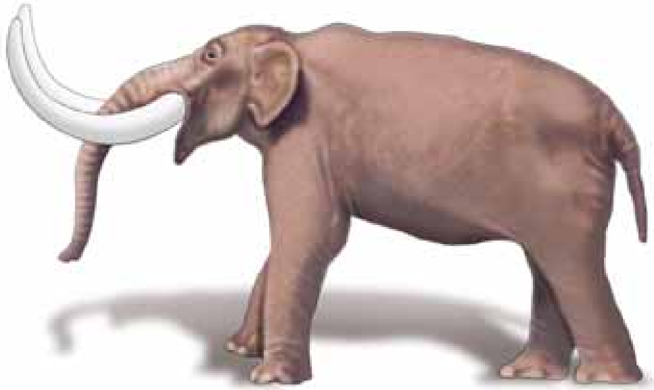
Other ice age fossils

In Australia, scientists discovered remains of the largest marsupial that ever lived. A marsupial is a mammal that carries its young in a pouch. *Diprotodon optatum* weighed over 6,000 pounds, humongous compared with today's largest marsupial, the red kangaroo, at about 187 pounds.

Diprotodon opatum
The largest marsupial that ever lived

In South Dakota, the world's largest collection of Columbian mammoths is housed at Mammoth Site in Hot Springs. Fossils were found by chance in 1974 during excavations for a housing development. More than 26,000 years ago, these animals walked into a pond and were trapped. Over 50 woolly and Columbian mammoths have been found here. The Columbian mammoth weighed 16,000-20,000 pounds and ate about 700 pounds of vegetation daily.

In Los Angeles, subway construction unearthed over 2,000 fossils. The Metropolitan Transportation Authority digs with caution and works closely with the Natural History Museum of Los Angeles County to protect fossils. Fossils include ground sloths, mammoths, horses, camels, and mastodons. Fossils of the mormon tea plant have helped scientists understand the climate of Los Angeles in the ice age. The plant grows now in the Mojave Desert, so scientists believe ice age Los Angeles had hotter summers and cooler winters similar to the modern-day desert.



So you want to study fossils?

Paleontology could be your life's calling. It is the study of life using fossils from past geological times. Paleontologists study extinct animals and plants in order to understand ancient life and explain how life has changed. Preparing for a career in paleontology includes studying biology, geology, and computers. A keen eye and the desire to find hidden treasures are also helpful.

Questions:

1. What is an ice age and when did the most recent ice age occur?
2. What is a fossil and why are fossils relatively rare?
3. Why are the tar pits of Rancho La Brea so rich with fossils?
4. Name several ice age fossils and where they have been found.

Chapter 8 Connection

CHAPTER ACTIVITY Make a Plate Tectonics Book

In this chapter, you learned about plate tectonics—about how Earth has large blocks of lithospheric plates moving about, interacting with one another. You learned that some blocks move toward each other and make mountains and others get subducted below a less dense lithospheric plate. In the oceans, plates are moving apart from each other, creating new floor. In places like the Pacific Rim, there are many earthquakes which means transform fault boundaries are there. Earth is an amazing place!

Materials

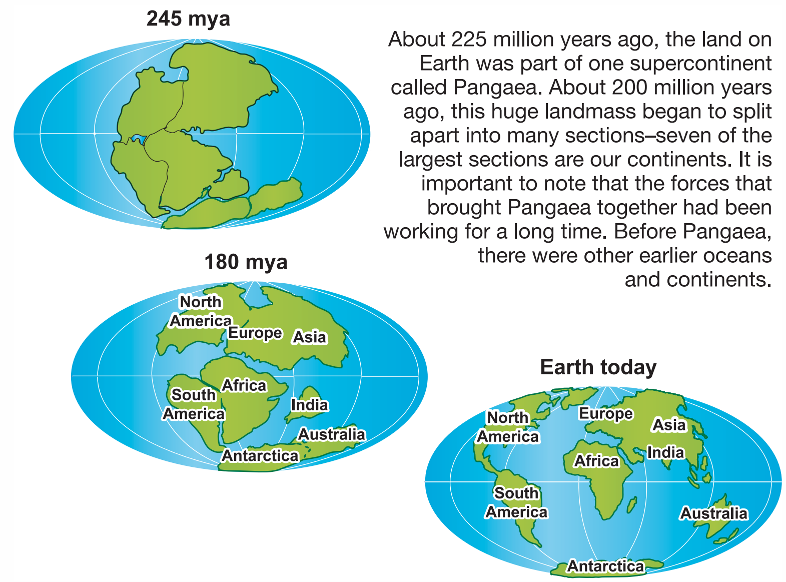
Pieces of paper (copy paper, construction paper, or newsprint), staples and a stapler, glue, colored pencils and markers, pens, scissors, old magazines, and any other material you need to make your book

What you will do

1. Get into a group of three or four people to make the book.
2. With your group, decide on a title for your book. Here are a couple of ideas: *Plate Tectonics* or *How South America and Africa Moved Apart*.
3. Your book will recount part of the plate tectonics story. Use the graphic on this page and others in Chapter 8 to help you outline your story.

If you would like, you can come up with mythical creatures that lived on the ancient continents before they reached their current positions—just as long as you explain in some way how the continents got to where they are today. Use lots of pictures. Maybe someone in your group is an artist.

Your book will need a cover and back, a title, and a list of the authors. You may want to give credit to the artist or maybe there were a few artists in the group. The book size is optional. An oversized book can be very attractive to younger children. Use whatever resources you can find, but ask your teacher to check your information for accuracy. Maybe the book will be in the form of a poem or a pop-up book. There are many creative ways to tell a story—have fun!



About 225 million years ago, the land on Earth was part of one supercontinent called Pangaea. About 200 million years ago, this huge landmass began to split apart into many sections–seven of the largest sections are our continents. It is important to note that the forces that brought Pangaea together had been working for a long time. Before Pangaea, there were other earlier oceans and continents.

Applying your knowledge

a. What was the title of your group's book?
b. Imagine your book will be in a library or sold in a book store. Write a short summary of the book so that a reader will know what it is about.
c. What did you like most about making the book with your group?
d. Share your plate tectonics story in class or read it to a group of younger students. Describe your experience at sharing your book with others.

Chapter 8 Assessment

Vocabulary

Select the correct term to complete the sentences.

Pangaea	oceanic plates	mid-ocean ridges
mantle plume	trench	lithospheric plates
subduction	plate tectonics	sea-floor spreading
continental plates	continental drift	transform fault boundary
metamorphic rock	divergent boundary	convergent boundary

Section 8.1

1. _____, meaning "all land," is the name for the great landmass that existed millions of years ago.
2. The idea that the continents move around on Earth's surface is called _____.
3. The study of Earth's lithospheric plates is called _____.

Section 8.2

4. The _____ are thick and made of granite.
5. The sinking process that completes the lower mantle convection cell is _____.
6. _____ move over the aesthenosphere.
7. New ocean floor is created at the locations of these undersea features called _____.
8. Hess proposed the idea of _____.
9. _____ are thin and made of basalt.
10. A _____ rises to the surface and may create a volcanic center.

Section 8.3 and Section 8.4

11. Mountains form along a _____.
12. Mid-ocean ridges indicate the presence of this type of boundary: _____.
13. The occurrence of earthquakes and offsetting are clues that a location is near a _____.
14. A _____, or valley in the ocean floor, is created when one lithospheric plate subducts under another.
15. A sedimentary rock that experiences intense heat and pressure will become a _____.

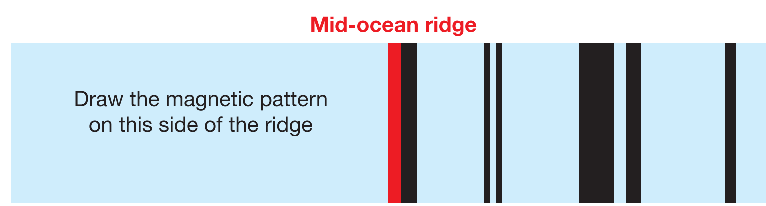
Concepts

Section 8.1

1. According to the hypothesis of continental drift, how would a world map have changed over the last 250 million years?
2. How do fossils support the idea of continental drift?
3. Earth's surface is often described as a giant jigsaw puzzle. What are the pieces of the puzzle?
4. Wegener collected a lot of evidence to support his idea of continental drift. Was his evidence enough to prove continental drift was correct? Why or why not?

Section 8.2

5. Describe how Harry Hess thought the continents moved apart. What did Hess call his set of ideas?
6. The Mid-Atlantic Ridge is a mid-ocean ridge in the Atlantic Ocean. Is the Atlantic ocean getting larger or smaller?
7. The graphic below shows the magnetic pattern on one side of a mid-ocean ridge. Make a sketch of the magnetic pattern that would appear on the other side of the ridge.



8. Where would you find the oldest rocks on the sea floor? Where would you find the youngest rocks?
9. In your own words, describe how an island chain forms.

Section 8.3 and Section 8.4

10. List the three types of plate boundaries. What famous feature in California represents one of these boundaries?
11. What kinds of geologic features form when two continental plates come together?
12. Under what conditions are metamorphic rocks formed?

Math and Writing Skills

Section 8.1

1. How can evidence of a glacier be in a place that has a warm, dry climate?

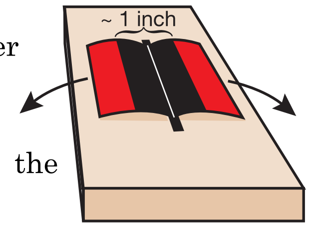
Section 8.2

2. To calculate the speed of plate motion, divide the distance the plate moves by the time it takes to move that distance (speed = distance ÷ time). Give your answer in kilometers per one million years (km/one million years). (Usually these values are stated in centimeters/year or millimeters/ year.)
   a. It takes 10 million years for the Pacific Plate to slide 600 kilometers past the North American Plate. How fast is the Pacific Plate moving?
   b. There are two islands on opposite sides of a mid-ocean ridge. During the last 8 million years, the distance between the islands has increased by 200 kilometers. What is the rate at which the two plates are diverging?

Section 8.3 and Section 8.4

3. Draw diagrams of the three types of plate boundaries.
4. Give an example of a metamorphic rock that changes from sedimentary to metamorphic. How does this rock form?

Chapter Project—Sea-Floor Spreading Model



Keep creating stripes until you're almost finished with the paper.

Materials: Shoe box lid, piece of copy paper cut lengthwise (in half), red and black markers, scissors.

1. Cut a slit in the shoe box so that the paper can fit in widthwise.
2. Put the pieces of paper in the slit from the underside of the shoebox lid. Allow about 2 cm of paper to show through the slit.
3. One piece of paper will be folded back to the left of the slit and one will be folded to the right of the slit.
4. Use your red marker to color the paper that is showing (on both sides of the slit). Optional: Write the year you were born on this stripe.
5. Now pull another inch or so of paper through the slit. The amount pulled through doesn't matter as much as the fact that both sides need to pull through the same amount.
6. Now color this new strip of white paper in black marker. Optional: Write the year after you were born on this stripe.
7. Continue to pull the paper through the slit and coloring the strips (in alternate colors), until you almost run out of paper. You have now created a model for sea-floor spreading. Optional: Keep writing the year on each stripe. This shows that the older stripes end up further away from the ridge and the youngest are closest to the ridge.
8. Questions: (a) Where can you find the landform represented by the box top and paper? and (b) How do these magnetic patterns on the sea-floor support plate tectonics.