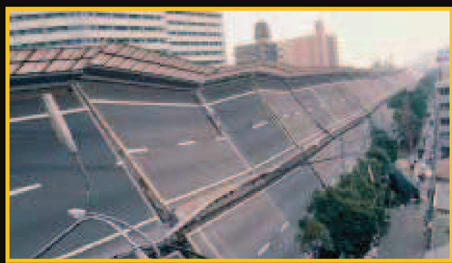
Unit 4 THE DYNAMIC EARTH

Unit 4 Outline

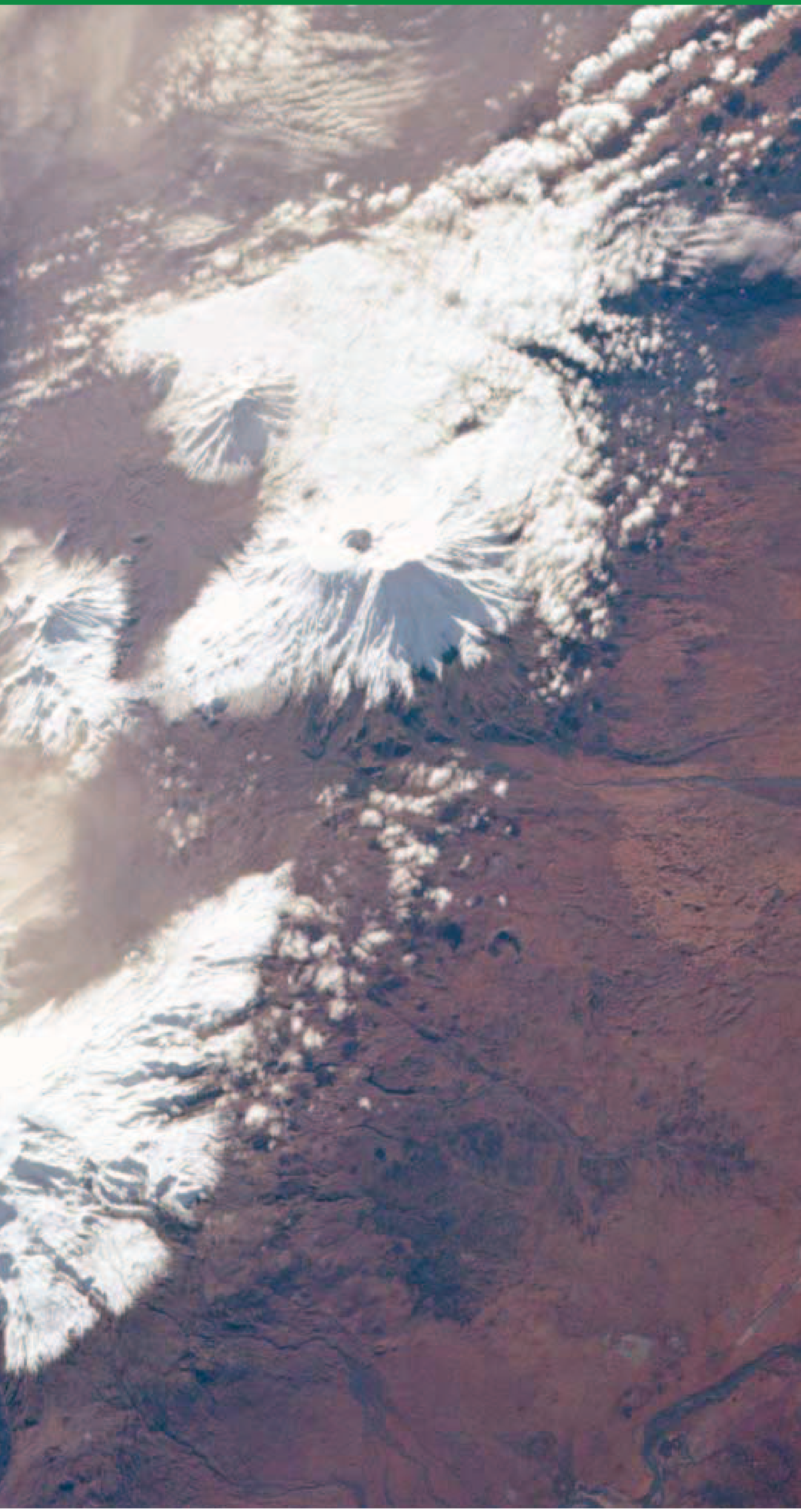
CHAPTER 10
Plate Tectonics

CHAPTER 11
Deformation of the Crust



CHAPTER 12
Earthquakes

CHAPTER 13
Volcanoes



▶ This photo was taken from the space shuttle *Endeavor* as Russia's Kliuchevskoi volcano erupted on September 30, 1994. The volcanic cloud reached 60,000 ft into the atmosphere, and wind carried the ash as far as 640 mi from the volcano.

Chapter 10

Plate Tectonics

Sections

1 Continental Drift

2 The Theory of Plate Tectonics

3 The Changing Continents

What You'll Learn

- How scientists developed the theory of plate tectonics
- Why tectonic plates move
- How Earth's geography has changed

Why It's Relevant

Understanding why and how tectonic plates move provides a basis for understanding other concepts of Earth science.

PRE-READING ACTIVITY

FOLDNOTES

Tri-Fold

Before you read this chapter, create the FoldNote entitled "TriFold" described in the Skills Handbook section of the Appendix. Write what you know about plate tectonics in the column labeled "Know." Then, write what you want to know in the column labeled "Want." As you read the chapter, write what you learn in the column labeled "Learn."

▸ The island of Iceland is being torn into two pieces as two tectonic plates pull apart. Iceland is one of only a few places on Earth where this process can be seen on land.

Section 1 Continental Drift

One of the most exciting recent theories in Earth science began with observations made more than 400 years ago. As early explorers sailed the oceans of the world, they brought back information about new continents and their coastlines. Mapmakers used the information to chart the new discoveries and to make the first reliable world maps.

As people studied the maps, they were impressed by the similarity of the continental shorelines on either side of the Atlantic Ocean. The continents looked as though they would fit together like parts of a giant jigsaw puzzle. The east coast of South America, for example, seemed to fit perfectly into the west coast of Africa, as shown in **Figure 1.**

OBJECTIVES

- **Summarize** Wegener's hypothesis of continental drift.
- **Describe** the process of sea-floor spreading.
- **Identify** how paleomagnetism provides support for the idea of sea-floor spreading.
- **Explain** how sea-floor spreading provides a mechanism for continental drift.

KEY TERMS

continental drift
mid-ocean ridge
sea-floor spreading
paleomagnetism

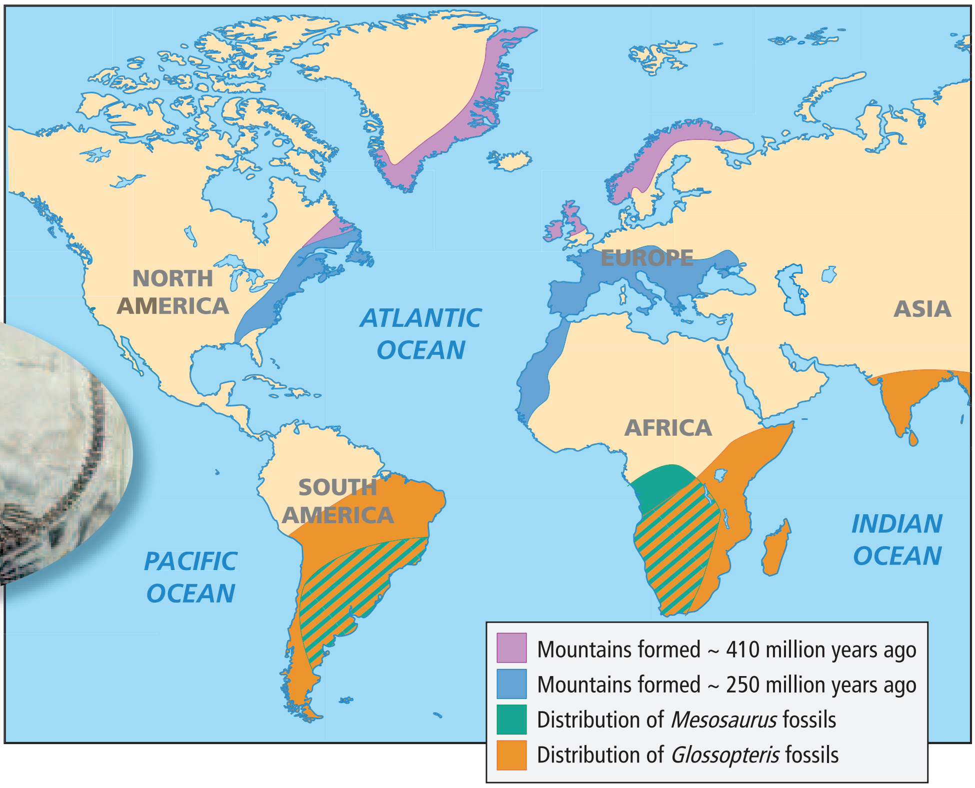
Wegener's Hypothesis

In 1912, a German scientist named Alfred Wegener (VAY guh nuhr) proposed a hypothesis that is now called **continental drift.** Wegener hypothesized that the continents once formed part of a single landmass called a *supercontinent*. According to Wegener, this supercontinent began breaking up into smaller continents about 250 million years ago (during the Mesozoic Era). Over millions of years, these continents drifted to their present locations. Wegener speculated that the crumpling of the crust in places may have produced mountain ranges such as the Andes on the western coast of South America.

continental drift the hypothesis that states that the continents once formed a single landmass, broke up, and drifted to their present locations

Figure 1 ▶ Early explorers noticed that the coastlines of Africa and South America could fit together like puzzle pieces. ***Can you identify any other continents that could fit together like puzzle pieces?***

Figure 2 ▶ Fossils of *Mesosaurus*, such as the one shown below, were found in both South America and western Africa. Mountain chains of similar ages also exist on different continents, as shown in the map at right.



Fossil Evidence

In addition to seeing the similarities in the coastlines of the continents, Wegener found other evidence to support his hypothesis. He reasoned that if the continents had once been joined, fossils of the same plants and animals should be found in areas that had once been connected. Wegener knew that identical fossils of *Mesosaurus,* a small, extinct land reptile, had been found in both South America and western Africa. *Mesosaurus,* a fossil of which is shown in **Figure 2,** lived 270 million years ago (during the Paleozoic Era). Wegener knew that it was unlikely that these reptiles had swum across the Atlantic Ocean. He also saw no evidence that land bridges had once connected the continents. So, he concluded that South America and Africa had been joined at one time in the past.

Evidence from Rock Formations

Geologic evidence also supported Wegener's hypothesis of continental drift. The ages and types of rocks in the coastal regions of widely separated areas, such as western Africa and eastern South America, matched closely. Mountain chains that ended at the coastline of one continent seemed to continue on other continents across the ocean, as shown in **Figure 2.** The Appalachian Mountains, for example, extend northward along the eastern coast of North America, and mountains of similar age and structure are found in Greenland, Scotland, and northern Europe. If the continents are assembled into a model supercontinent, the mountains of similar age fit together in continuous chains.

Climatic Evidence

Changes in climatic patterns also suggest that the continents have not always been located where they are now. Geologists discovered layers of debris from ancient glaciers in southern Africa and South America. Today, those areas have climates that are too warm for glaciers to form. Other fossil evidence—such as the plant fossil shown in **Figure 3**—indicated that tropical or subtropical swamps covered areas that now have much colder climates. Wegener suggested that if the continents were once joined and positioned differently, evidence of climatic differences would be easy to explain.

Missing Mechanisms

Despite the evidence that supports the hypothesis of continental drift, Wegener's ideas were strongly opposed. Other scientists of the time rejected the mechanism by which Wegener proposed that the continents moved. Wegener suggested that the continents plowed through the rock of the ocean floor. However, this idea was easily disproved by geologic evidence. Wegener spent the rest of his life searching for a mechanism that would gain scientific consensus. Unfortunately, Wegener died in 1930 before he identified a plausible explanation.

Reading Check **Why did many scientists reject Wegener's hypothesis of continental drift? (See the Appendix for answers to Reading Checks.)**

Figure 3 ▶ The climate of Antarctica was not always as harsh and cold as it is today. When the plant that became this fossil lived, the climate of Antarctica was warm and tropical.

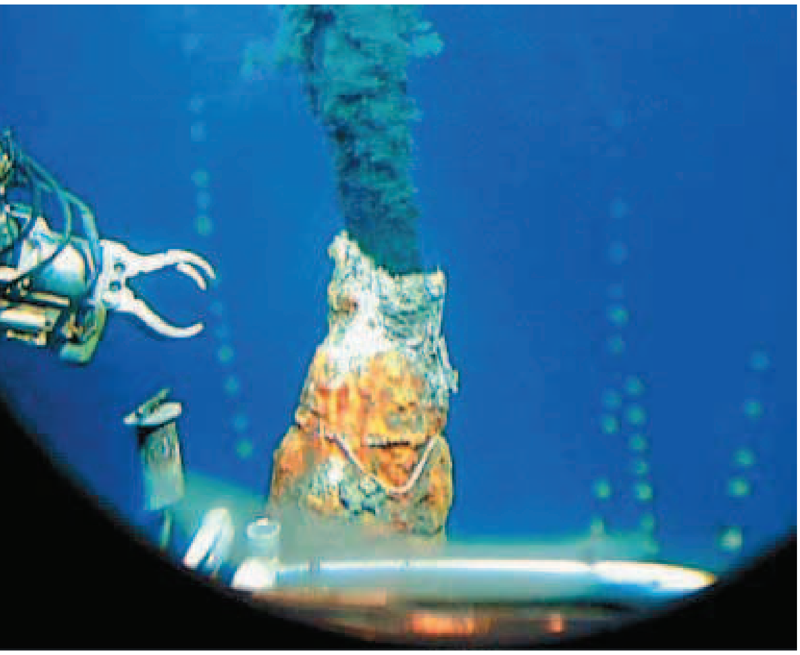


Figure 4 ▶ Black smokers are vents on the sea floor that form as hot, mineral-rich water rushes from the hot rock at mid-ocean ridges and mixes with the surrounding cold ocean water. This photo was taken from a submersible.

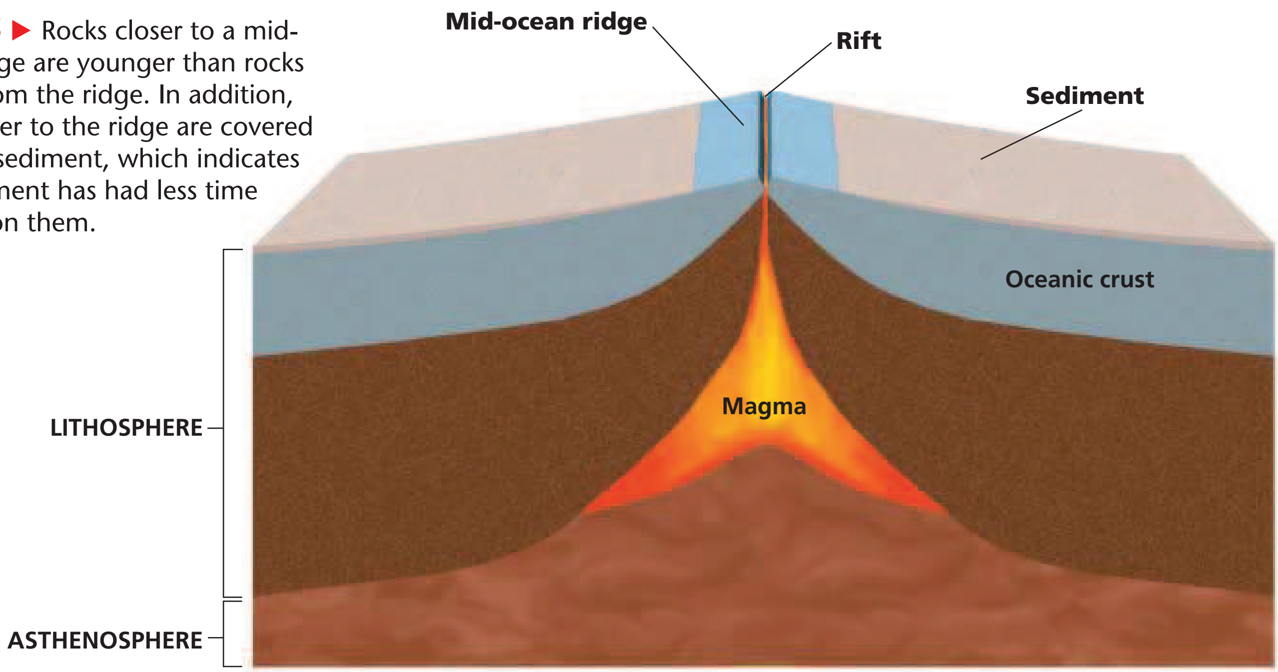
Mid-Ocean Ridges

The evidence that Wegener needed to support his hypothesis was discovered nearly two decades after his death. The evidence lay on the ocean floor. In 1947, a group of scientists set out to map the Mid-Atlantic Ridge. The Mid-Atlantic Ridge is part of a system of **mid-ocean ridges,** which are undersea mountain ranges through the center of which run steep, narrow valleys. A special feature of mid-ocean ridges is shown in **Figure 4.** While studying the Mid-Atlantic Ridge, scientists noticed two surprising trends. First, they noticed that the sediment that covers the sea floor is thinner closer to a ridge than it is farther from the ridge, as shown in **Figure 5.** This evidence suggests that sediment has been settling on the sea floor farther from the ridge for a longer time than it has been settling near the ridge. Scientists then examined the remains of tiny ocean organisms found in the sediment to date the sediment. The distribution of these organisms showed that the closer the sediment is to a ridge, the younger the sediment is. This evidence indicates that rocks closer to the ridge are younger than rocks farther from the ridge.

Second, scientists learned that the ocean floor is very young. While rocks on land are as old as 3.8 billion years, none of the oceanic rocks are more than 175 million years old. Radiometric dating also showed evidence that sea-floor rocks closer to a mid-ocean ridge are younger than sea-floor rocks farther from a ridge.

mid-ocean ridge a long, undersea mountain chain that has a steep, narrow valley at its center, that forms as magma rises from the asthenosphere, and that creates new oceanic lithosphere (sea floor) as tectonic plates move apart

Figure 5 ▶ Rocks closer to a mid-ocean ridge are younger than rocks farther from the ridge. In addition, rocks closer to the ridge are covered with less sediment, which indicates that sediment has had less time to settle on them.

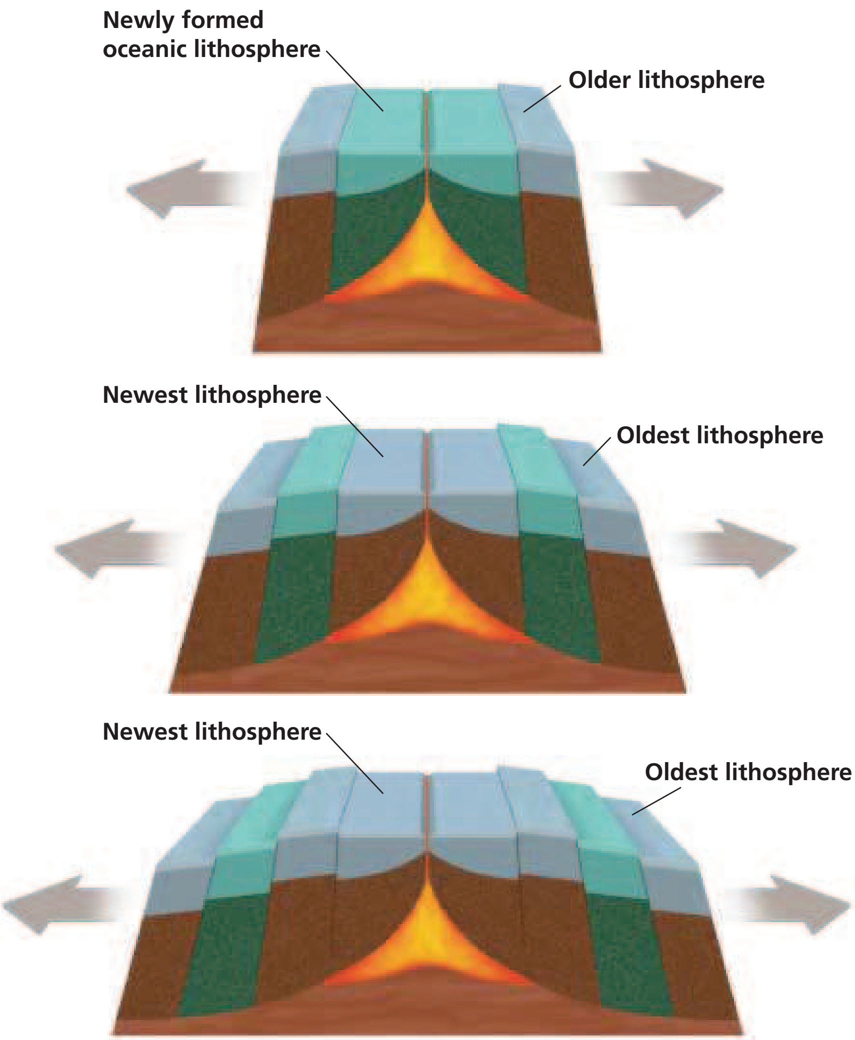


Sea-Floor Spreading

In the late 1950s, a geologist named Harry Hess suggested a new hypothesis. He proposed that the valley at the center of the ridge was a crack, or *rift,* in Earth's crust. At this rift, molten rock, or *magma*, from deep inside Earth rises to fill the crack. As the ocean floor moves away from the ridge, rising magma cools and solidifies to form new rock that replaces the ocean floor. This process is shown in **Figure 6.** Robert Dietz, another geologist, named this process by which new ocean lithosphere (sea floor) forms as magma rises to Earth's surface and solidifies at a mid-ocean ridge as **sea-floor spreading.** Hess suggested that if the ocean floor is moving, the continents might be moving, too. Hess thought that sea-floor spreading was the mechanism that Wegener had failed to find.

Still, Hess's ideas were only hypotheses. More evidence for sea-floor spreading would come years later, in the mid-1960s. This evidence would be discovered through **paleomagnetism,** the study of the magnetic properties of rocks.

Reading Check **How does new sea floor form? (See the Appendix for answers to Reading Checks.)**



sea-floor spreading the process by which new oceanic lithosphere (sea floor) forms as magma rises to Earth's surface and solidifies at a mid-ocean ridge

paleomagnetism the study of the alignment of magnetic minerals in rock, specifically as it relates to the reversal of Earth's magnetic poles; also the magnetic properties that rock acquires during formation

Graphic Organizer **Chain-of-Events Chart**

Create the Graphic Organizer entitled "Chain-of-Events Chart" described in the Skills Handbook section of the Appendix. Then, fill in the chart with details about each step of sea-floor spreading.

Figure 6 ▶ As the ocean floor spreads apart at a mid-ocean ridge, magma rises to fill the rift and then cools to form new rock. As this process is repeated over millions of years, new sea floor forms.

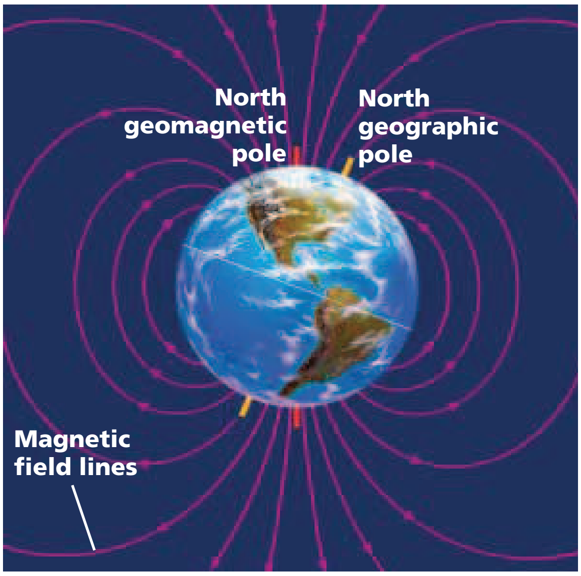


Figure 7 ▶ Earth acts as a giant magnet because of currents in Earth's core.

Paleomagnetism

If you have ever used a compass to determine direction, you know that Earth acts as a giant magnet. Earth has north and south geomagnetic poles, as shown in **Figure 7.** The compass needle aligns with the field of magnetic force that extends from one pole to the other.

As magma solidifies to form rock, iron-rich minerals in the magma align with Earth's magnetic field in the same way that a compass needle does. When the rock hardens, the magnetic orientation of the minerals becomes permanent. This residual magnetism of rock is called *paleomagnetism*.

Magnetic Reversals

Geologic evidence suggests that Earth's magnetic field has not always pointed north, as it does now. Scientists have discovered rocks whose magnetic orientations point opposite of Earth's current magnetic field. Scientists have dated rocks of different magnetic polarities. All rocks with magnetic fields that point north, or *normal polarity,* are classified in the same time periods. All rocks with magnetic fields that point south, or *reversed polarity,* also fell into specific time periods. When scientists placed these periods of normal and reverse polarity in chronological order, they discovered a pattern of alternating normal and reversed polarity in the rocks. Scientists used this pattern to create the *geomagnetic reversal time scale*.

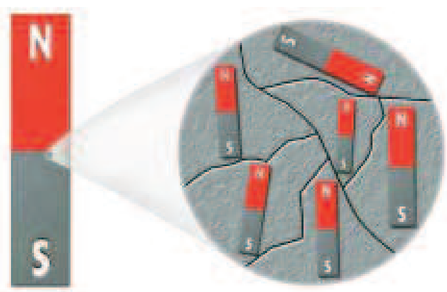
Connection to PHYSICS

What Makes Materials Magnetic?

Some materials are magnetic, while others are not. So, what makes a material magnetic? All matter is composed of atoms. In atoms, electrons are the negatively charged particles that move around the nucleus. The motion of electrons in an atom produces magnetic fields that can give the atom a north pole and a south pole.

In most materials, the magnetic fields of individual atoms are not aligned, so the materials are not magnetic. However, in some materials, such as the iron in some rocks, the atoms group together in tiny regions called *domains*. The atoms in a domain are arranged so that the north and south poles of the atoms are aligned to create a stronger magnetic field than that of a single atom. If most of the domains in an object are also aligned, their magnetic fields combine to make the whole object magnetic.

If the domains in an object are randomly arranged, the magnetic fields of individual domains cancel each other out and the object does not have magnetic properties.



If most of the domains in an object are aligned, the magnetic fields of individual domains combine to make the object magnetic.

Magnetic Symmetry

As scientists were learning about the age of the sea floor, they also were finding puzzling magnetic patterns on the ocean floor. The scientists used the geomagnetic reversal time scale to help them unravel the mystery of these magnetic patterns.

Scientists noticed that the striped magnetic pattern on one side of a mid-ocean ridge is a mirror image of the striped pattern on the other side of the ridge. These patterns are shown in **Figure 8.** When drawn on maps of the ocean floor, these patterns showed alternating bands of normal and reversed polarity that match the geomagnetic reversal time scale. Scientists suggested that as new sea floor forms at a mid-ocean ridge, the new sea floor records reversals in Earth's magnetic field.

By matching the magnetic patterns on each side of a mid-ocean ridge to the geomagnetic reversal time scale, scientists could assign ages to the sea-floor rocks. The scientists found that the ages of sea-floor rocks were also symmetrical. The youngest rocks were at the center, and older rocks were farther away on either side of the ridge. The only place on the sea floor that new rock forms is at the rift in a mid-ocean ridge. Thus, the patterns indicate that new rock forms at the center of a ridge and then moves away from the center in opposite directions. Thus, the symmetry of magnetic patterns—and the symmetry of ages of sea-floor rocks—supports Hess's idea of sea-floor spreading.

Reading Check **How are magnetic patterns in sea-floor rock evidence of sea-floor spreading? (See the Appendix for answers to Reading Checks.)**

Quick LAB — 10 min

Making Magnets

Procedure

1. Slide one end of a **bar magnet** down the side of a **5 inch iron nail** 10 times. Always slide the magnet in the same direction.
2. Hold the nail over a small pile of **steel paperclips.** Record what happens.
3. Slide the bar magnet back and forth 10 times down the side of the nail. Repeat step 2.

Analysis

1. What was the effect of sliding the magnet down the nail in one direction? in different directions?
2. How does this lab demonstrate the idea of domains?

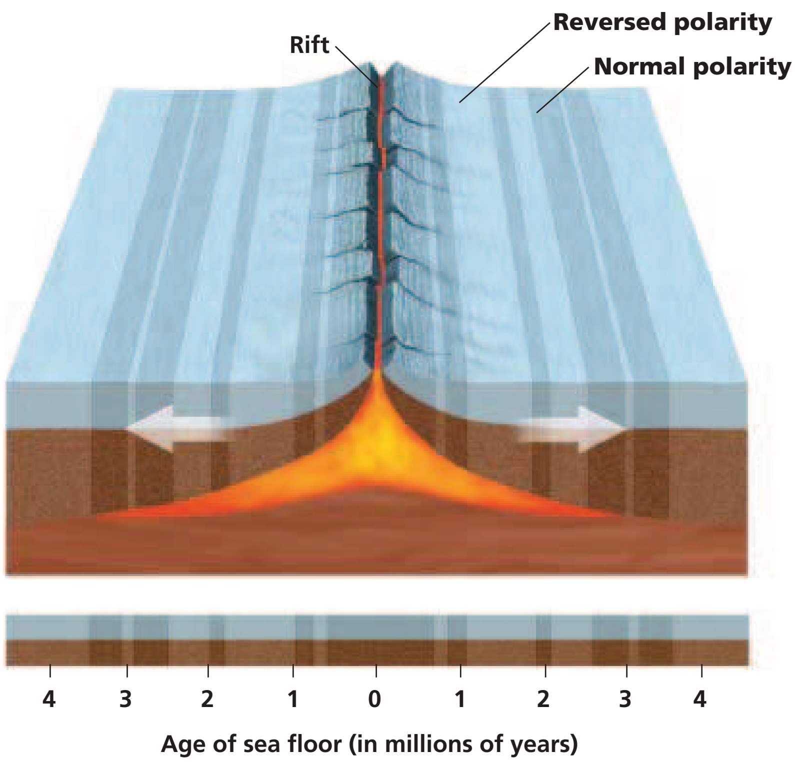


Figure 8 ▶ The stripes in the sea floor shown here illustrate Earth's alternating magnetic field. Dark stripes represent normal polarity, while the lighter stripes represent reversed polarity. ***What is the polarity of the rocks closest to the rift?***

Figure 9 ▶ Scientists collected samples of these sedimentary rocks in California and used the magnetic properties of the samples to date the rocks by using the geomagnetic reversal time scale.

Wegener Redeemed

Another group of scientists discovered that the reversal patterns seen in rocks on the sea floor also appeared in rocks on land, such as those shown in **Figure 9.** The reversals in the land rocks matched the geomagnetic reversal time scale. Because the same pattern occurs in rocks of the same ages on both land and the sea floor, scientists became confident that magnetic patterns show changes over time. Thus, the idea of sea-floor spreading gained further favor in the scientific community.

Scientists reasoned that sea-floor spreading provides a way for the continents to move over Earth's surface. Continents are carried by the widening sea floor in much the same way that objects are moved by a conveyer belt. The molten rock from a rift cools, hardens, and then moves away in the opposite direction on both sides of the ridge. Here, at last, was the mechanism that verified Wegener's hypothesis of continental drift.

Section 1 Review

1. **Describe** the observation that first led to Wegener's hypothesis of continental drift.
2. **Summarize** the evidence that supports Wegener's hypothesis.
3. **Compare** sea-floor spreading and the formation of mid-ocean ridges.
4. **Explain** how scientists know that Earth's magnetic poles have reversed many times during Earth's history.
5. **Identify** how magnetic symmetry can be used as evidence of sea-floor spreading.
6. **Explain** how scientists date sea-floor rocks.

CRITICAL THINKING

7. **Making Inferences** How does evidence that sea-floor rocks farther from a ridge are older than rocks closer to the ridge support the idea of sea-floor spreading?
8. **Analyzing Ideas** Explain how sea-floor spreading provides an explanation for how continents may move over Earth's surface.

CONCEPT MAPPING

9. Use the following terms to create a concept map: *continental drift, paleomagnetism, fossils, climate, sea-floor spreading, geologic evidence, supercontinent,* and *mid-ocean ridge.*

Section 2 The Theory of Plate Tectonics

By the 1960s, evidence supporting continental drift and sea-floor spreading led to the development of a theory called *plate tectonics*. **Plate tectonics** is the theory that explains why and how continents move and is the study of the formation of features in Earth's crust.

OBJECTIVES

- **Summarize** the theory of plate tectonics.
- **Identify** and describe the three types of plate boundaries.
- **List** and describe three causes of plate movement.

KEY TERMS

plate tectonics
lithosphere
asthenosphere
divergent boundary
convergent boundary
transform boundary

How Continents Move

Earth's crust and the rigid, upper part of the mantle form a layer of Earth called the **lithosphere.** The lithosphere forms the thin outer shell of Earth. It is broken into several blocks, called *tectonic plates,* that ride on a deformable layer of the mantle called the *asthenosphere* in much the same way that blocks of wood float on water. The **asthenosphere** (as THEN uh sfir) is a layer of "plastic" rock just below the lithosphere. Plastic rock is solid rock that is under great pressure and that flows very slowly, like putty does. **Figure 1** shows what tectonic plates may look like.

Earth's crust is classified into two types—*oceanic crust* and *continental crust.* Oceanic crust is dense and is made of rock that is rich in iron and magnesium. Continental crust has a low density and is made of rock that is rich in silica. Tectonic plates can include continental crust, oceanic crust, or both. The continents and oceans are carried along on the moving tectonic plates in the same way that passengers are carried by a bus.

plate tectonics the theory that explains how large pieces of the lithosphere, called *plates,* move and change shape

lithosphere the solid, outer layer of Earth that consists of the crust and the rigid upper part of the mantle

asthenosphere the solid, plastic layer of the mantle beneath the lithosphere; made of mantle rock that flows very slowly, which allows tectonic plates to move on top of it

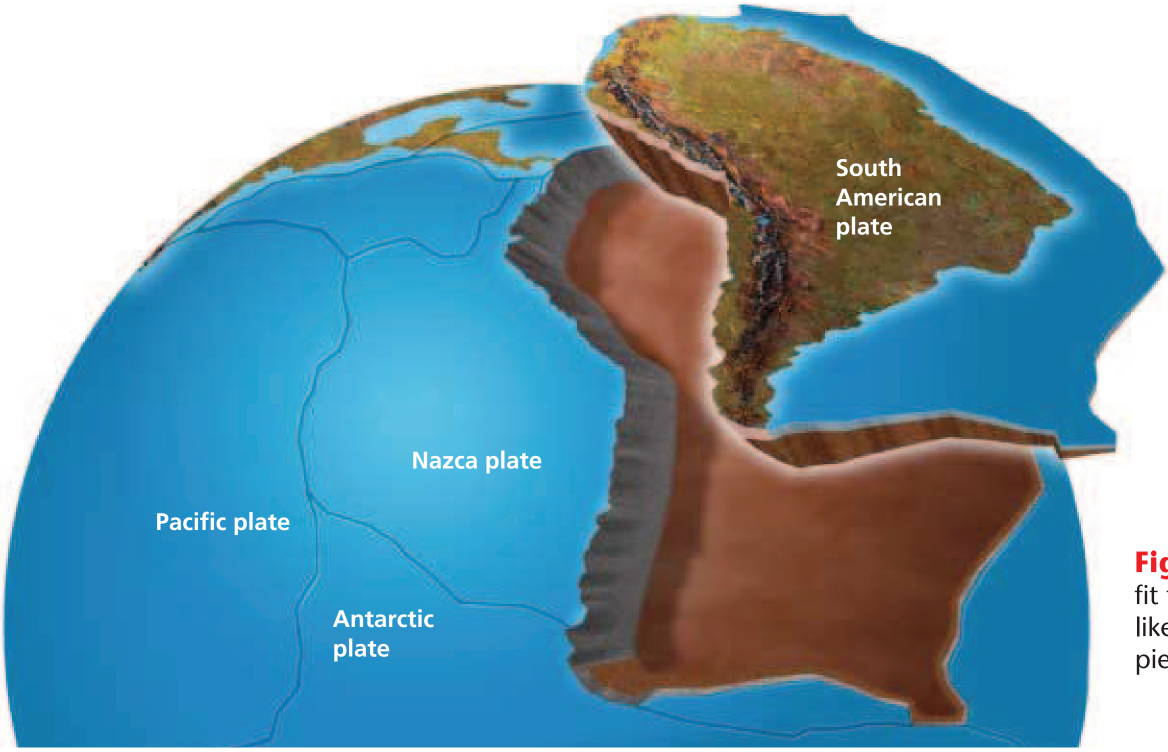


Figure 1 ▶ Tectonic plates fit together on Earth's surface like three-dimensional puzzle pieces.

Tectonic Plates

Scientists have identified about 15 major tectonic plates. While many plates are bordered by major surface features, such as mountain ranges or deep trenches in the oceans, the boundaries of the plates are not always easy to identify. As shown in **Figure 2**, the familiar outlines of the continents and oceans do not always match the outlines of plate boundaries. Some plate boundaries are located within continents far from mountain ranges.

Earthquakes

Scientists identify plate boundaries primarily by studying data from earthquakes. When tectonic plates move, sudden shifts can occur along their boundaries. These sudden movements are called *earthquakes*. Frequent earthquakes in a given zone are evidence that two or more plates may meet in that area.

Volcanoes

The locations of volcanoes can also help identify the locations of plate boundaries. Some volcanoes form when plate motions generate magma that erupts on Earth's surface. For example, the Pacific Ring of Fire is a zone of active volcanoes that encircles the Pacific Ocean. This zone is also one of Earth's major earthquake zones. The characteristics of this zone indicate that the Pacific Ocean is surrounded by plate boundaries.

Reading Check **How do scientists identify locations of plate boundaries? (See the Appendix for answers to Reading Checks.)**

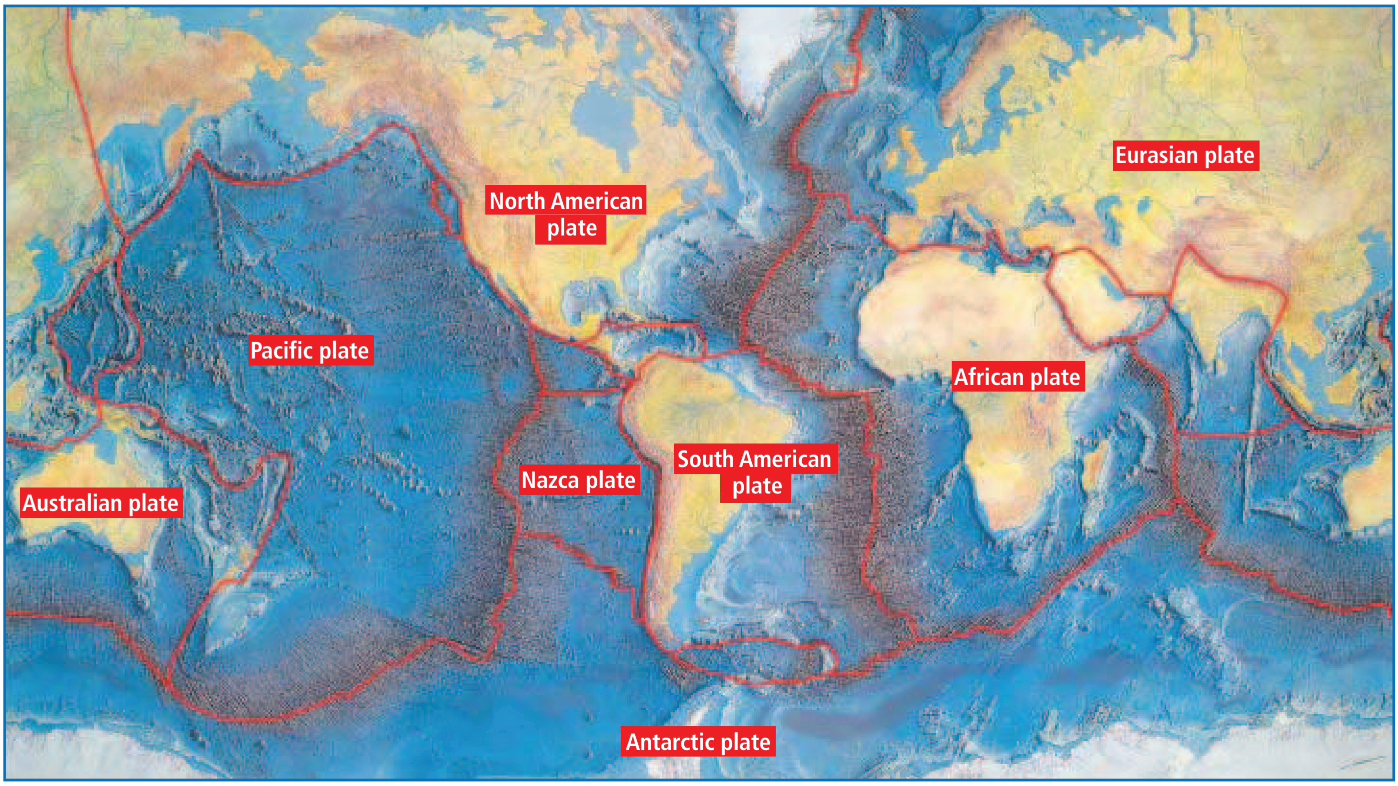
MATHPRACTICE

The Rate of Plate Movement Tectonic plates move slowly on Earth's surface. The rate of plate movement can be calculated by using the following equation:

$$rate = \frac{distance}{time}$$

In kilometers, how far would a plate that moves 4 cm per year move in 2 million years?

Figure 2 ▶ Tectonic plates may contain both oceanic and continental crust. Notice that the boundaries of plates do not always match the outlines of continents.



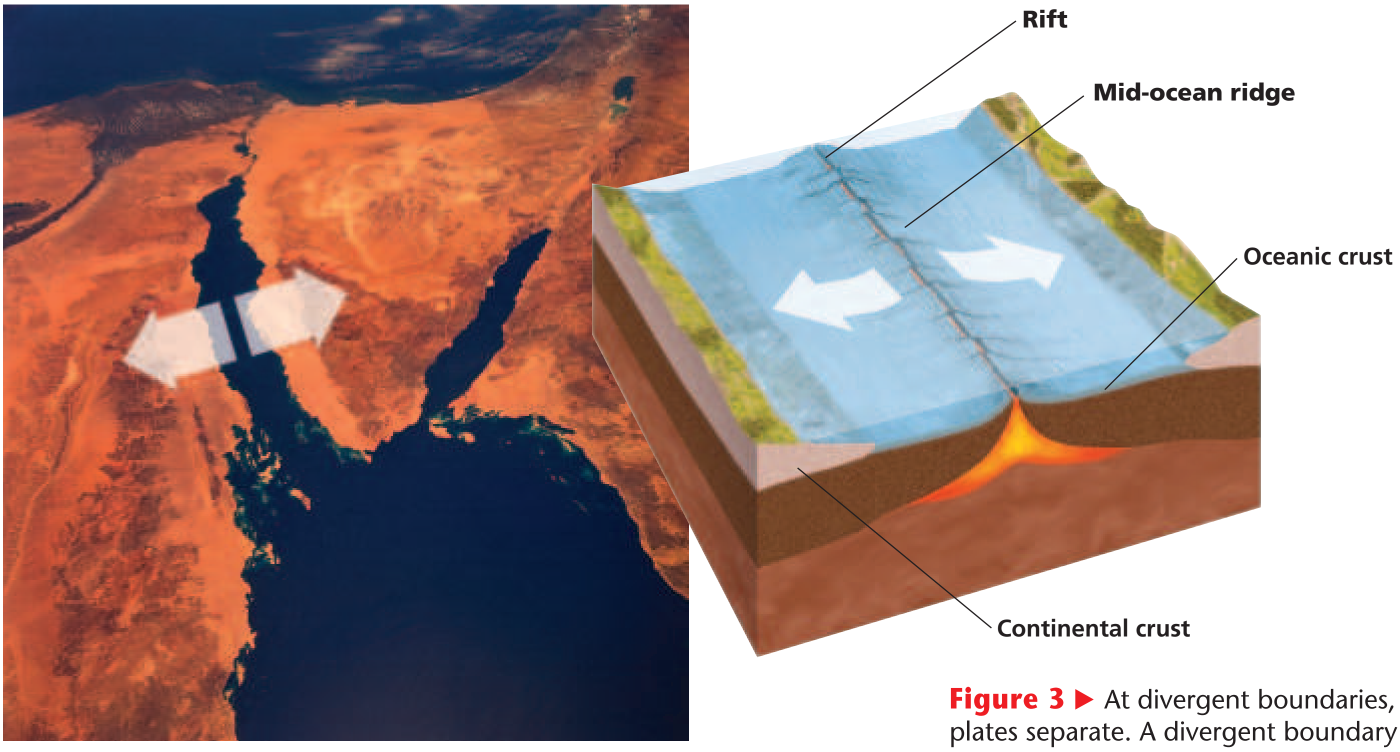


Figure 3 ▶ At divergent boundaries, plates separate. A divergent boundary exists in the Red Sea between the Arabian Peninsula and Africa.

Types of Plate Boundaries

Some of the most dramatic changes in Earth's crust, such as earthquakes and volcanic eruptions, happen along plate boundaries. Plate boundaries may be in the middle of the ocean floor, around the edges of continents, or even within continents. There are three types of plate boundaries. These plate boundaries are divergent boundaries, convergent boundaries, and transform boundaries. Each plate boundary is associated with a characteristic type of geologic activity.

Divergent Boundaries

The way that plates move relative to each other determines how the plate boundary affects Earth's surface. At a **divergent boundary,** two plates move away from each other. A divergent boundary is illustrated in **Figure 3.**

At divergent boundaries, magma from the asthenosphere rises to the surface as the plates move apart. The magma then cools to form new oceanic lithosphere. The newly formed rock at the ridge is warm and light. This warm, light rock sits higher than the surrounding sea floor because it's less dense. This rock forms undersea mountain ranges known as *mid-ocean ridges.* Along the center of a mid-ocean ridge is a *rift valley,* a narrow valley that forms where the plates separate.

Most divergent boundaries are located on the ocean floor. However, rift valleys may also form where continents are separated by plate movement. For example, the Red Sea occupies a huge rift valley formed by the separation of the African plate and the Arabian plate, as shown in **Figure 3.**

divergent boundary the boundary between tectonic plates that are moving away from each other

Convergent Boundaries

convergent boundary the boundary between tectonic plates that are colliding

As plates pull apart at one boundary, they push into neighboring plates at other boundaries. **Convergent boundaries** are boundaries that form where two plates collide.

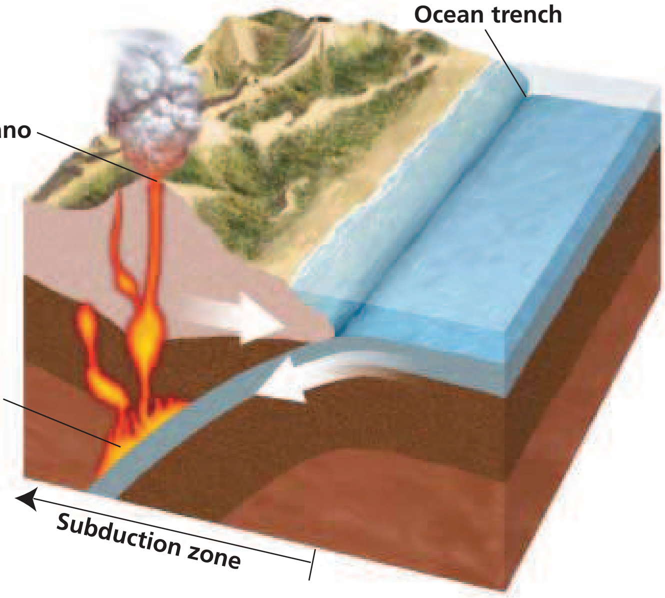
Three types of collisions can happen at convergent boundaries. One type happens when oceanic lithosphere collides with continental lithosphere, as shown in **Figure 4.** Because oceanic lithosphere is denser, it *subducts,* or sinks, under the less dense continental lithosphere. The region along a plate boundary where one plate moves under another plate is called a *subduction zone.* Deep-ocean trenches form at subduction zones. As the oceanic plate subducts, it heats up and releases fluids into the mantle above it. The addition of these fluids causes material in the overlying mantle to melt to form magma. The magma rises to the surface and forms volcanic mountains.

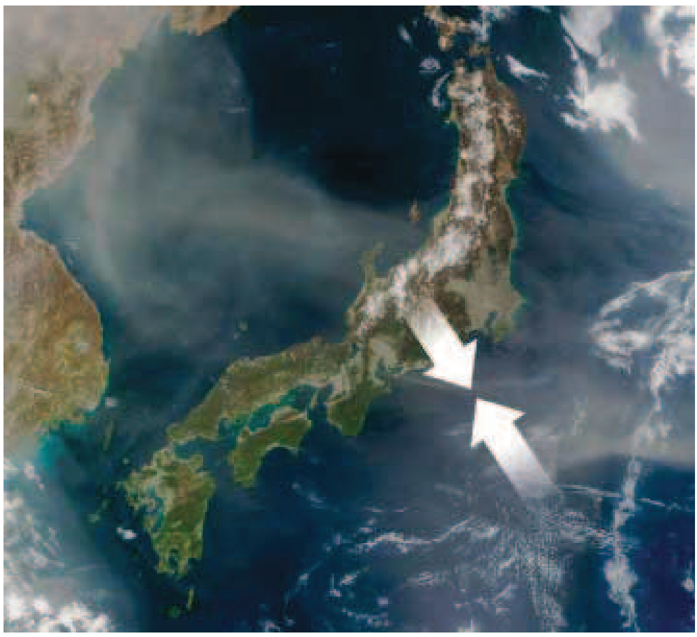
A second type of collision happens when two plates made of continental lithosphere collide. In this type of collision, neither plate subducts because neither plate is dense enough to subduct under the other plate. Instead, the colliding edges crumple and thicken, which causes uplift that forms large mountain ranges. The Himalaya Mountains formed in this type of collision.

The third type of collision happens between two plates that are made of oceanic lithosphere. One plate subducts under the other plate, and a deep-ocean trench forms. Fluids released from the subducted plate cause mantle rock to melt and form magma. The magma rises to the surface to form an *island arc,* which is a chain of volcanic islands. Japan is an example of an island arc.

Reading Check **Describe the three types of collisions that happen at convergent boundaries. (See the Appendix for answers to Reading Checks.)**

Figure 4 ▶ Plates collide at convergent boundaries. The islands of Japan are formed by the subduction of the Pacific plate and the Philippine plate under the Eurasian plate.





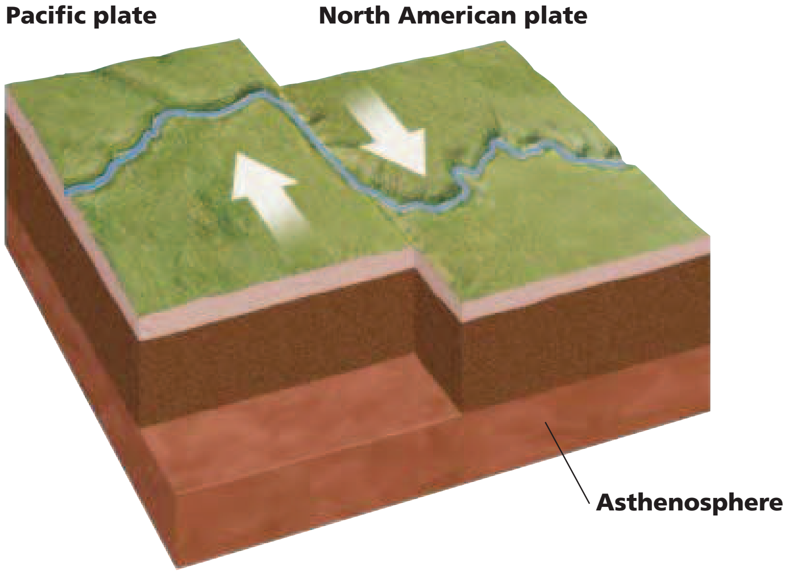


Figure 5 ▶ Plates slide past each other at transform boundaries. The course of the stream in the photo changed because the plates moved past each other at the San Andreas Fault in California.

Transform Boundaries

The boundary at which two plates slide past each other horizontally, as shown in **Figure 5,** is called a **transform boundary.** However, the plate edges usually do not slide along smoothly. Instead, they scrape against each other in a series of sudden spurts of motion that are felt as earthquakes. Unlike other types of boundaries, transform boundaries do not produce magma. The San Andreas Fault in California is a major transform boundary between the North American plate and the Pacific plate.

Transform motion also occurs along mid-ocean ridges. Short segments of a mid-ocean ridge are connected by transform boundaries called *fracture zones*.

Table 1 summarizes the three types of plate boundaries. The table also describes how each type of plate boundary changes Earth's surface and includes examples of each type of plate boundary.

transform boundary the boundary between tectonic plates that are sliding past each other horizontally

Table 1 ▼

Plate Boundary Summary

Type of boundary	Description	Example
Divergent	plates moving away from each other to form rifts and mid-ocean ridges	North American and Eurasian plates at the Mid-Atlantic Ridge
Convergent	plates moving toward each other and colliding to form ocean trenches, mountain ranges, volcanoes, and island arcs	South American and Nazca plates at the Chilean trench along the west coast of South America
Transform	plates sliding past each other while moving in opposite directions	North American and Pacific plates at the San Andreas Fault in California

Causes of Plate Motion

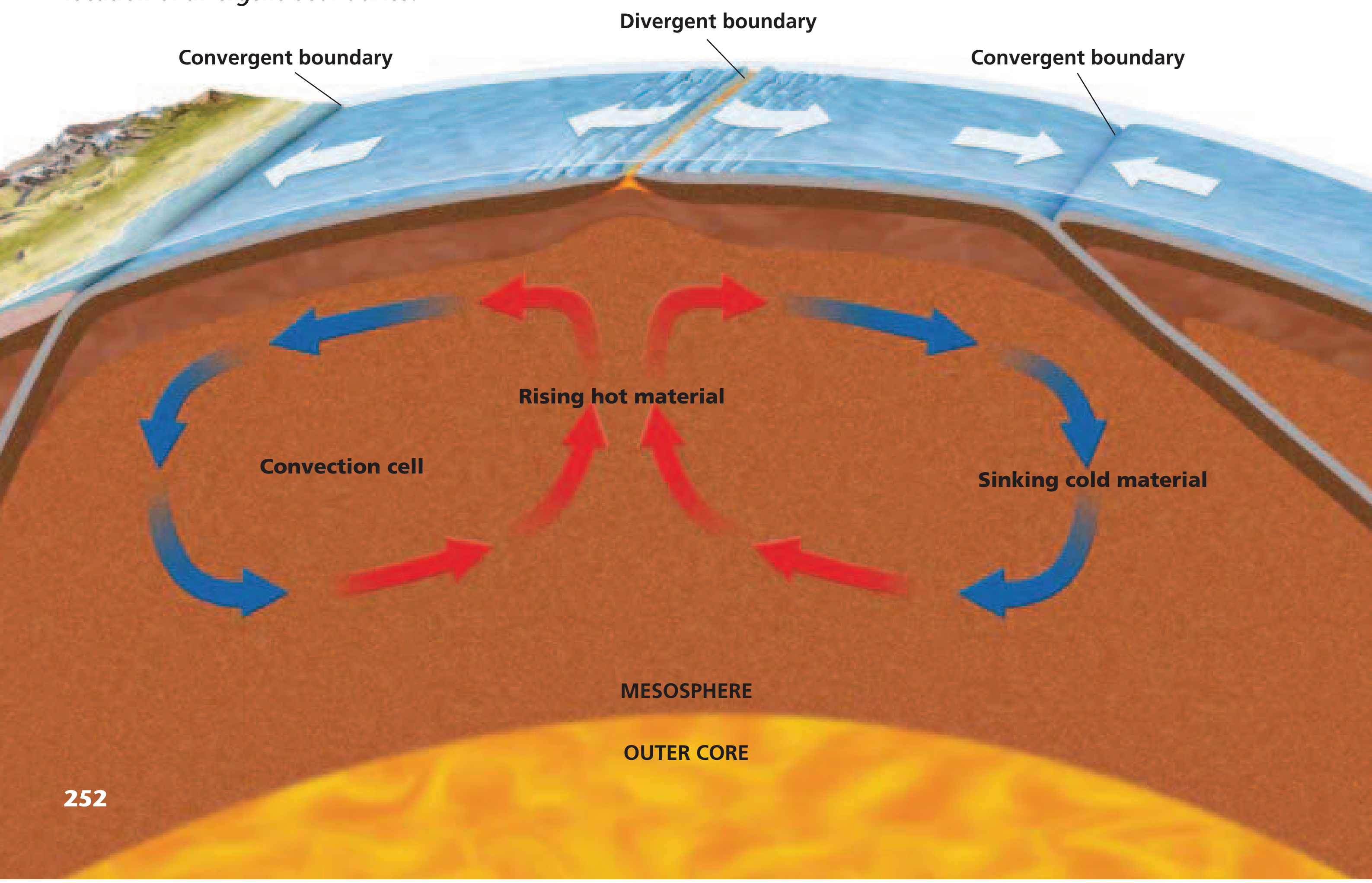
Scientists don't fully understand what force drives plate tectonics. Many scientists think that the movement of tectonic plates is partly due to convection. *Convection* is the movement of heated material due to differences in density that are caused by differences in temperatures. This process can be modeled by boiling water in a pot on the stove. As the water at the bottom of the pot is heated, the water at the bottom expands and becomes less dense than the cooler water above it. The cooler, denser water sinks, and the warmer water rises to the surface to create a cycle called a *convection cell*.

Mantle Convection

Scientists think that Earth is also a convecting system. Energy generated by Earth's core and radioactivity within the mantle heat mantle material. This heated material rises through the cooler, denser material around it. As the hot material rises, the cooler, denser material flows away from the hot material and sinks into the mantle to replace the rising material. As the mantle material moves, it drags the overlying tectonic plates along with it, as shown in **Figure 6.**

Convection currents and the resulting drag on the bottoms of tectonic plates can explain many aspects of plate movement. But scientists have identified two specific mechanisms of convection that help drive the process of plate movement.

Figure 6 ▶ Scientists think that tectonic plates are part of a convection system. ***How is the rising of hot material related to the location of divergent boundaries?***



Ridge Push

Newly formed rock at a mid-ocean ridge is warm and less dense than older rock nearby. The warm, less dense rock is elevated above nearby rock, and older, denser rock slopes downward away from the ridge. As the newer, warmer rock cools and becomes denser, it begins to sink into the mantle and pull away from the ridge.

As the cooling rock sinks, the asthenosphere below it exerts force on the rest of the plate. This force is called *ridge push*. This force pushes the rest of the plate away from the mid-ocean ridge. Ridge push is illustrated in **Figure 7.**

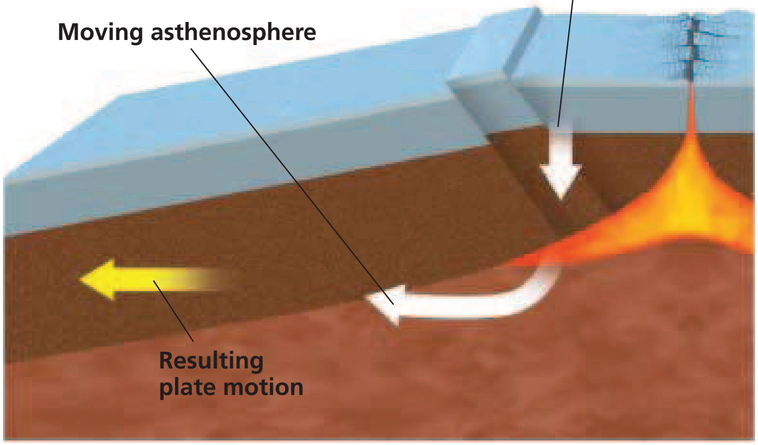


Figure 7 ▶ As the cooling lithosphere sinks, the asthenosphere moves away from the sinking lithosphere and pushes on the bottom of the plate. The plate moves in the direction that it is pushed by the asthenosphere.

Scientists think that ridge push may help drive plate motions. However, most scientists agree that ridge push is not the main driving force of plate motion. So, scientists looked to convergent boundaries for other clues to the forces that drive plate motion.

Reading Check **How may density differences in the rock at a mid-ocean ridge help drive plate motion? (See the Appendix for answers to Reading Checks.)**

QuickLAB 30 min

Tectonic Plate Boundaries

Procedure

1. Using a **ruler,** draw two 7 cm × 12 cm rectangles on a **piece of paper.** Cut them out with **scissors.**
2. Use a rolling pin to flatten **two different colored pieces of clay** to about 1/2 cm thick.
3. Use a **plastic knife** to cut each piece of clay into a 7 cm × 12 cm rectangle. Place a paper rectangle on each piece of clay.
4. Place the two clay models side by side on a flat surface and paper side down.
5. Place one hand on each piece of clay, and slowly push the blocks together until the edges begin to buckle and rise off the surface of the table.
6. Turn the clay models around so that the unbuckled edges are touching each other.
7. Place one hand on each clay model. Apply slight pressure toward the plane where the two blocks meet. Slide one clay model forward 7 cm and the other model backward about 7 cm.

Analysis

1. What type of plate boundary are you modeling in step 5?
2. What type of plate boundary are you modeling in step 7?
3. How do you think the processes modeled in this activity might affect the appearance of Earth's surface?

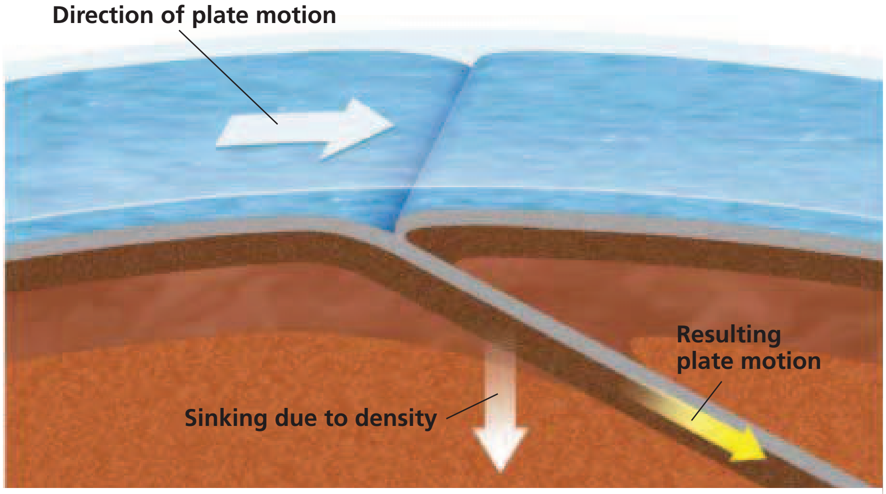


Figure 8 ▶ The leading edge of the subducting plate pulls the rest of the subducting plate into the asthenosphere in a process called *slab pull*.

Slab Pull

Where plates pull away from each other at mid-ocean ridges, magma from the asthenosphere rises to the surface. The magma then cools to form new lithosphere. As the lithosphere moves away from the mid-ocean ridge, the lithosphere cools and becomes denser. Where the lithosphere is dense enough, it begins to subduct into the asthenosphere. As the leading edge of the plate sinks, it pulls the rest of the plate along behind it. The force exerted by the sinking plate is called *slab pull*. This process is shown in **Figure 8.** In general, plates that are subducting move faster than plates that are not subducting. This evidence indicates that the downward pull of the subducting lithosphere is a strong driving force for tectonic plate motion.

All three mechanisms of Earth's convecting system—drag on the bottoms of tectonic plates, ridge push, and slab pull—work together to drive plate motions. These mechanisms form a system that makes Earth's tectonic plates move constantly.

Section 2 Review

1. **Summarize** the theory of plate tectonics.
2. **Explain** why most earthquakes and volcanoes happen along plate boundaries.
3. **Identify and describe** the three major types of plate boundaries.
4. **Compare** the changes in Earth's surface that happen at a convergent boundary with those that happen at a divergent boundary.
5. **Describe** the role of convection currents in plate movement.
6. **Describe** how ridge push and slab pull contribute to the movement of tectonic plates.

CRITICAL THINKING

7. **Making Inferences** How do convergent boundaries add material to Earth's surface?
8. **Determining Cause and Effect** Explain how the outward transfer of heat energy from inside Earth drives the movement of tectonic plates.

CONCEPT MAPPING

9. Use the following terms to create a concept map: *tectonic plate, divergent, convergent, convection, transform, ridge push, slab pull, subduction zone,* and *mid-ocean ridge.*

Section 3 The Changing Continents

The continents did not always have the same shapes that they do today. And geologic evidence indicates that they will not stay the same shape forever. In fact, the continents are always changing. Slow movements of tectonic plates change the size and shape of the continents over millions of years.

OBJECTIVES

- **Identify** how movements of tectonic plates change Earth's surface.
- **Summarize** how movements of tectonic plates have influenced climates and life on Earth.
- **Describe** the supercontinent cycle.

KEY TERMS

rifting
terrane
supercontinent cycle
Pangaea
Panthalassa

Reshaping Earth's Crust

All of the continents that exist today contain large areas of stable rock, called *cratons,* that are older than 540 million years. Rocks within the cratons that have been exposed at Earth's surface are called *shields*. Cratons represent ancient cores around which the modern continents formed.

Rifting and Continental Reduction

One way that continents change shape is by breaking apart. **Rifting** is the process by which a continent breaks apart. New, smaller continents may form as a result of this process. The reason that continents rift is not entirely known. Because continental crust is thick and has a high silica content, continental crust acts as an insulator. This insulating property prevents heat in Earth's interior from escaping. Scientists think that as heat from the mantle builds up beneath the continent, continental lithosphere becomes thinner and begins to weaken. Eventually, a rift forms in this zone of weakness, and the continent begins to break apart, as shown in **Figure 1.**

rifting the process by which Earth's crust breaks apart; can occur within continental crust or oceanic crust

Figure 1 ▶ The East African Rift Valley formed as Africa began rifting about 30 million years ago.

Terranes and Continental Growth

terrane a piece of lithosphere that has a unique geologic history and that may be part of a larger piece of lithosphere, such as a continent

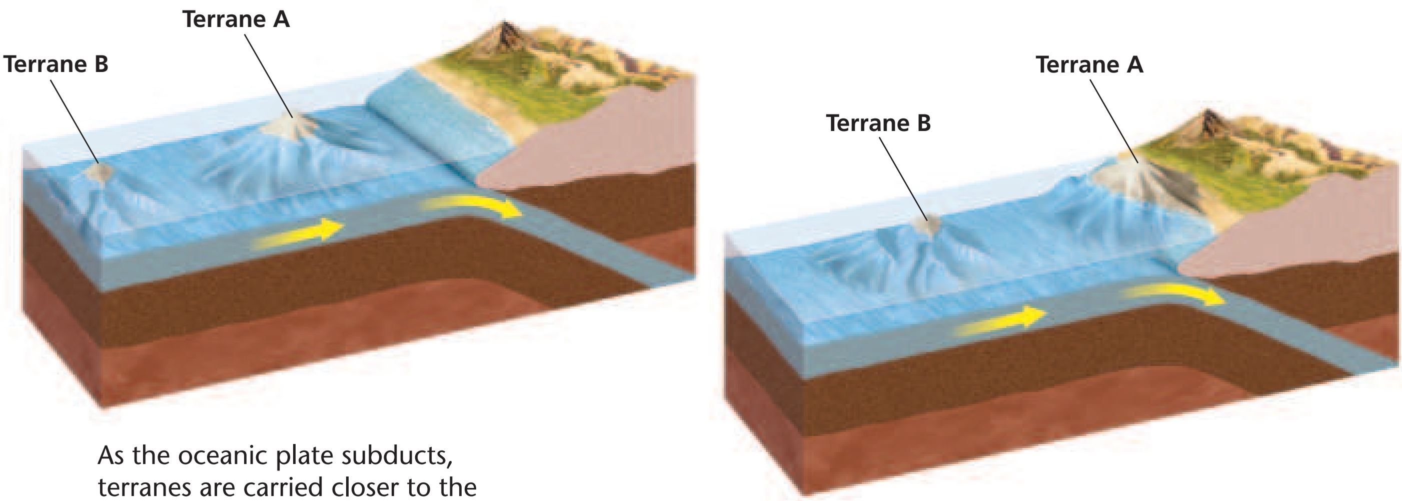
Continents change not only by breaking apart but also by gaining material. Most continents consist of cratons surrounded by a patchwork of terranes. A **terrane** is a piece of lithosphere that has a unique geologic history that differs from the histories of surrounding lithosphere. A terrane can be identified by three characteristics. First, a terrane contains rock and fossils that differ from the rock and fossils of neighboring terranes. Second, there are major faults at the boundaries of a terrane. Third, the magnetic properties of a terrane generally do not match those of neighboring terranes.

Terranes become part of a continent at convergent boundaries. When a tectonic plate carrying a terrane subducts under a plate made of continental crust, the terrane is scraped off the subducting plate, as shown in **Figure 2.** The terrane then becomes part of the continent. Some terranes may form mountains, while other terranes simply add to the surface area of a continent. The process in which a terrane becomes part of a continent is called *accretion* (uh KREE shuhn).

A variety of materials can form terranes. Terranes may be small volcanic islands or underwater mountains called *seamounts*. Small coral islands, or *atolls,* can also form terranes. And large chunks of continental crust can be terranes. When large terranes and continents collide, major mountain chains often form. For example, the Himalaya Mountains formed when India began colliding with Asia about 50 million years ago (during the Cenozoic Era).

Reading Check **Describe the process of accretion. (See the Appendix for answers to Reading Checks.)**

Figure 2 ▶ As oceanic crust subducts, a terrane is scraped off the ocean floor and becomes part of the continental crust. ***What would you expect to happen to sediments on the sea floor when the plate they are on subducts?***



As the oceanic plate subducts, terranes are carried closer to the continent.

When the terrane reaches the subduction zone, the terrane is scraped off the subducting plate and is added to the continent's edge.

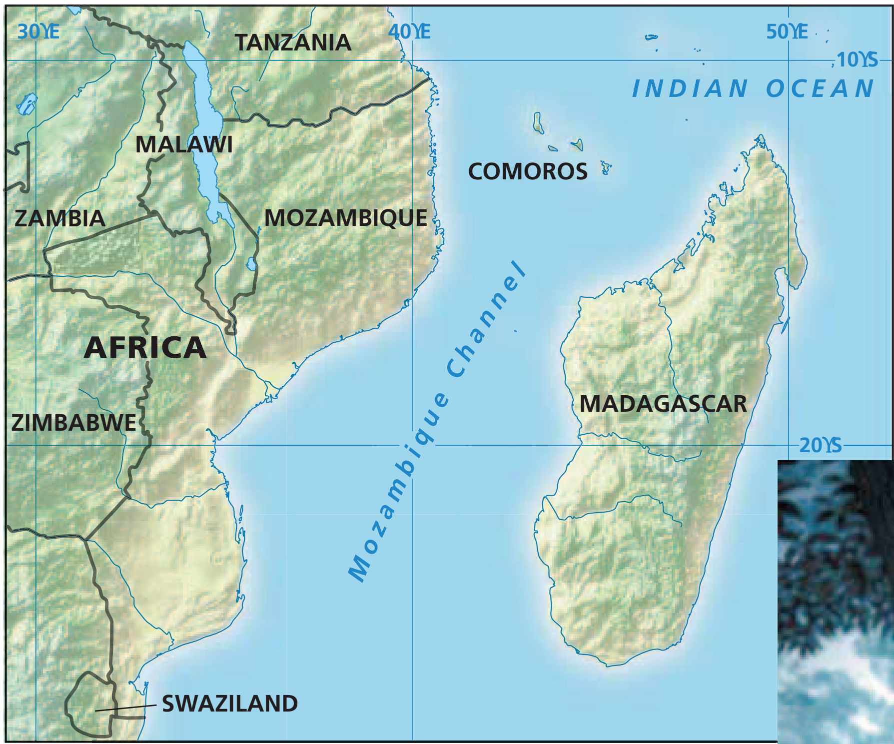


Figure 3 ▶ Madagascar separated from Africa about 165 million years ago and separated from India about 88 million years ago. This separation isolated the plants and animals on the island of Madagascar. As a result, unique species of plants and animals evolved on Madagascar. These species, such as the fossa (below), are found nowhere else on Earth.

Effects of Continental Change

Modern climates are a result of past movements of tectonic plates. A continent's location in relation to the equator and the poles affects the continent's overall climate. A continent's climate is also affected by the continent's location in relation to oceans and other continents. Mountain ranges affect air flow and wind patterns around the globe. Mountains also affect the amount of moisture that reaches certain parts of a continent. When continents move, the flow of air and moisture around the globe changes and causes climates to change.

Changes in Climate

Geologic evidence shows that ice once covered most of Earth's continental surfaces. Even the Sahara in Africa, one of the hottest places on Earth today, was once covered by a thick ice sheet. This ice sheet formed when all of the continents were close together and were located near the South Pole. As continents began to drift around the globe, however, global temperatures changed and much of the ice sheet melted.

Changes in Life

As continents rift or as mountains form, populations of organisms are separated. When populations are separated, new species may evolve from existing species. Sometimes, isolation protects organisms from competitors and predators and may allow the organismsm to evolve into unique organisms, as shown in **Figure 3.**

The Supercontinent Cycle

Using evidence from many scientific fields, scientists can construct a general picture of continental change throughout time. They think that at several times in the past, the continents were arranged into large landmasses called *supercontinents*. These supercontinents broke apart to form smaller continents that moved around the globe. Eventually, the smaller continents joined again to form another supercontinent. When the last supercontinent broke apart, the modern continents formed. A new supercontinent is likely to form in the future. The process by which supercontinents form and break apart over time is called the **supercontinent cycle** and is shown in **Figure 4.**

supercontinent cycle the process by which supercontinents form and break apart over millions of years

Pangaea the supercontinent that formed 300 million years ago and that began to break up beginning 250 million years ago

Panthalassa the single, large ocean that covered Earth's surface during the time the supercontinent Pangaea existed

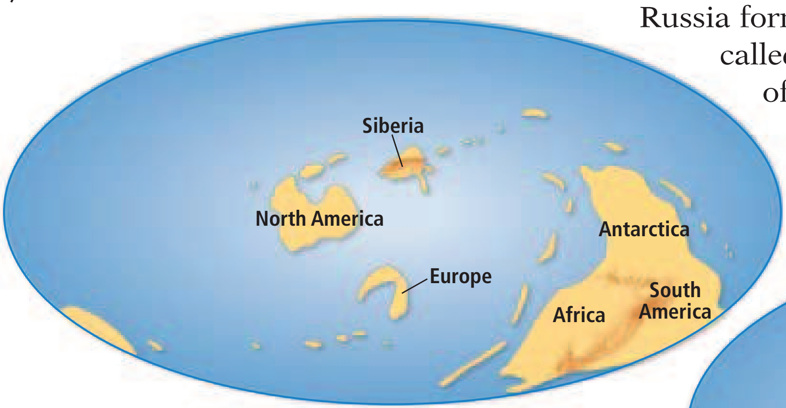
Why Supercontinents Form

The movement of plates toward convergent boundaries eventually causes continents to collide. Because continental lithosphere does not subduct, the convergent boundary between two continents becomes inactive, and a new convergent boundary forms. Over time, all of the continents collide to form a supercontinent. Then, heat from Earth's interior builds up under the supercontinent, and rifts form in the supercontinent. The supercontinent breaks apart, and plates carrying separate continents move around the globe.

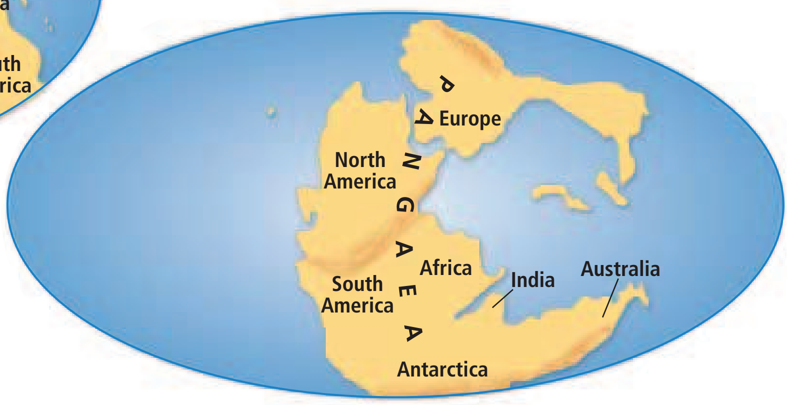
Formation of Pangaea

The supercontinent **Pangaea** (pan JEE uh) formed about 300 million years ago (during the Paleozoic Era). As the continents collided to form Pangaea, mountains formed. The Appalachian Mountains of eastern North America and the Ural Mountains of Russia formed during these collisions. A body of water called the Tethys Sea cut into the eastern edge of Pangaea. The single, large ocean that surrounded Pangaea was called **Panthalassa.**

Figure 4 ▶ Over millions of years, supercontinents form and break apart in a cycle known as the *supercontinent cycle*.



About 450 million years ago Earth's continents were separated, as they are today.



260 million to 240 million years ago Pangaea had formed and was beginning to break apart.

Breakup of Pangaea

About 250 million years ago (during the Paleozoic Era), Pangaea began to break into two continents—*Laurasia* and *Gondwanaland*. A large rift split the supercontinent from east to west. Then, Laurasia began to drift northward and rotate slowly, and a new rift formed. This rift separated Laurasia into the continents of North America and Eurasia. The rift eventually formed the North Atlantic Ocean. The rotation of Laurasia also caused the Tethys Sea to close. The Tethys Sea eventually became the Mediterranean Sea.

As Laurasia began to break apart, Gondwanaland also broke into two continents. One continent broke apart to become the continents of South America and Africa. About 150 million years ago (during the Mesozoic Era), a rift between Africa and South America opened to form the South Atlantic Ocean. The other continent separated to form India, Australia, and Antarctica. As India broke away from Australia and Antarctica, it started moving northward, toward Eurasia. About 50 million years ago (during the Cenozoic Era), India collided with Eurasia, and the Himalaya Mountains began to form.

SCILINKS® Developed and maintained by the National Science Teachers Association

For a variety of links related to this subject, go to www.scilinks.org

Topic: Pangaea

SciLinks code: HQ61105

The Modern Continents

Slowly, the continents moved into their present positions. As the continents drifted, they collided with terranes and other continents. These collisions welded new crust onto the continents and uplifted the land. Mountain ranges, such as the Rocky Mountains, the Andes, and the Alps, formed. Tectonic plate motion also caused new oceans to open up and caused others to close.

Reading Check **What modern continents formed from Gondwanaland? (See the Appendix for answers to Reading Checks.)**

70 million to 50 million years ago
The continents were moving toward their current positions. The current positions of the continents are shown here in red.

160 million to 140 million years ago
Pangaea split into two continents—Laurasia to the north and Gondwanaland to the south.

Geography of the Future

As tectonic plates continue to move, Earth's geography will change dramatically. If plate movements continue at current rates, in about 150 million years, Africa will collide with Eurasia, and the Mediterranean Sea will close. A new ocean will form as east Africa separates from the rest of Africa and moves eastward. New subduction zones will form off the east coast of North and South America. North and South America will then move east across the Atlantic Ocean. The Atlantic Ocean will close as North and South America collide with Africa.

In North America, Mexico's Baja Peninsula and the part of California that is west of the San Andreas Fault will move to where Alaska is today. If this plate movement occurs as predicted, Los Angeles will be located north of San Francisco's current location. Scientists predict that in 250 million years, the continents will come together again to form a new supercontinent, as shown in **Figure 5.**

Figure 5 ▶ Scientists predict that movements of tectonic plates will cause a supercontinent to form in the future.

Section 3 Review

1. **Identify** how rifting and accretion change the shapes of continents.
2. **Describe** why a terrane has a different geologic history from that of the surrounding area.
3. **Summarize** how continental rifting may lead to changes in plants and animals.
4. **Describe** the supercontinent cycle.
5. **Explain** how the theory of plate tectonics relates to the formation and breakup of Pangaea.
6. **Compare** Pangaea and Gondwanaland.
7. **List** three changes in geography that are likely to happen in the future.

CRITICAL THINKING

8. **Identifying Relationships** The interior parts of continents generally have drier climates than coastal areas do. How does this fact explain the evidence that the climate on Pangaea was drier than many modern climates?
9. **Determining Cause and Effect** Explain how mountains on land can be composed of rocks that contain fossils of marine animals.

CONCEPT MAPPING

10. Use the following terms to create a concept map: *supercontinent, rifting, atoll, continent, terrane, seamount, accretion,* and *Pangaea.*

Chapter 10 Highlights

Sections

1 Continental Drift

Key Terms

- **continental drift,** 239
- **mid-ocean ridge,** 242
- **seafloor spreading,** 243
- **paleomagnetism,** 243

Key Concepts

- Fossil, rock, and climatic evidence supports Wegener's hypothesis of continental drift. However, Wegener could not explain the mechanism by which the continents move.
- New ocean floor is constantly being produced through sea-floor spreading, which creates mid-ocean ridges and changes the topography of the sea floor.
- Sea-floor spreading provides a mechanism for continental drift.

2 The Theory of Plate Tectonics

Key Terms

- **plate tectonics,** 247
- **lithosphere,** 247
- **asthenosphere,** 247
- **divergent boundary,** 249
- **convergent boundary,** 250
- **transform boundary,** 251

Key Concepts

- The theory of plate tectonics proposes that changes in Earth's crust are caused by the very slow movement of large tectonic plates.
- Earthquakes, volcanoes, and young mountain ranges tend to be located in belts along the boundaries between tectonic plates.
- Tectonic plates meet at three types of boundaries—divergent, convergent, and transform. The geologic activity that occurs along the three types of plate boundaries differs according to the way plates move relative to each other.
- Tectonic plates may be part of a convecting system that is driven by differences in density and heat.

3 The Changing Continents

Key Terms

- **rifting,** 255
- **terrane,** 256
- **supercontinent cycle,** 258
- **Pangaea,** 258
- **Panthalassa,** 258

Key Concepts

- Continents grow through the accretion of terranes. Continents break apart through rifting.
- Movements of tectonic plates have altered climates on continents and have created conditions that lead to changes in plants and animals.
- Continents collide to form supercontinents and then break apart in a cycle called the *supercontinent cycle*.
- Earth's tectonic plates continue to move, and in the future, the continents will likely be in a different configuration.

Chapter 10 Review

Using Key Terms

Use each of the following terms in a separate sentence.

1. *sea-floor spreading*
2. *convection*
3. *divergent boundary*
4. *terrane*

For each pair of terms, explain how the meanings of the terms differ.

5. *convergent boundary* and *subduction zone*
6. *continental drift* and *plate tectonics*
7. *ridge push* and *slab pull*
8. *Pangaea* and *Panthalasa*

Understanding Key Concepts

9. Support for Wegener's hypothesis of continental drift includes evidence of changes in
   a. climatic patterns. **c.** terranes.
   b. Panthalassa. **d.** subduction.

10. New ocean floor is constantly being produced through the process known as
    a. subduction.
    b. continental drift.
    c. sea-floor spreading.
    d. terranes.

11. An underwater mountain chain that formed by sea-floor spreading is called a
    a. divergent boundary.
    b. subduction zone.
    c. mid-ocean ridge.
    d. convergent boundary.

12. Scientists think that the upwelling of mantle material at mid-ocean ridges is caused by the motion of tectonic plates and comes from
    a. the lithosphere. **c.** the asthenosphere.
    b. terranes. **d.** rift valleys.

13. The layer of plastic rock that underlies the tectonic plates is the
    a. lithosphere. **c.** oceanic crust.
    b. asthenosphere. **d.** terrane.

14. The region along tectonic plate boundaries where one plate moves beneath another is called a
    a. rift valley.
    b. transform boundary.
    c. subduction zone.
    d. convergent boundary.

15. Two plates grind past each other at a
    a. transform boundary.
    b. convergent boundary.
    c. subduction zone.
    d. divergent boundary.

16. Convection occurs because heated material becomes
    a. less dense and rises.
    b. denser and rises.
    c. denser and sinks.
    d. less dense and sinks.

Short Answer

17. Explain the role of technology in the progression from the hypothesis of continental drift to the theory of plate tectonics.
18. Summarize how the continents moved from being part of Pangaea to their current locations.
19. Why do most earthquakes and volcanoes happen at or near plate boundaries?
20. Explain the following statement: "Because of sea-floor spreading, the ocean floor is constantly renewing itself."
21. Describe how rocks that form at a mid-ocean ridge become magnetized.
22. How may continental rifting influence the evolution of plants and animals?

Critical Thinking

23. Making Comparisons How are tectonic plates like the pieces of a jigsaw puzzle?

24. Making Inferences If Alfred Wegener had found identical fossil remains of plants and animals that had lived no more than 10 million years ago in both eastern Brazil and western Africa, what might he have concluded about the breakup of Pangaea?

25. Identifying Relationships Assume that the total surface area of Earth is not changing. If new material is being added to Earth's crust at one boundary, what would you expect to be happening at another boundary?

26. Making Predictions One hundred fifty million years from now, the continents will have drifted to new locations. How might these changes affect life on Earth?

Concept Mapping

27. Use the following terms to create a concept map: *asthenosphere, lithosphere, divergent boundary, convergent boundary, transform boundary, subduction zone, mid-ocean ridge, plates, convection, continental drift, theory of plate tectonics,* and *sea-floor spreading*.

Math Skills

28. Making Calculations The coasts of Africa and South America began rifting about 150 million years ago. Today, the coast of South America is about 6,660 km from the coast of Africa. Using the equation *velocity* = *distance* ÷ *time*, determine how fast the continents moved apart in millimeters per year.

29. Using Equations Assume that scientists know the rate at which the North American and Eurasian plates are moving away from each other. If t = time, d = distance, and v = velocity, what equation can they use to determine when North America separated from Eurasia during the breakup of Pangaea?

Writing Skills

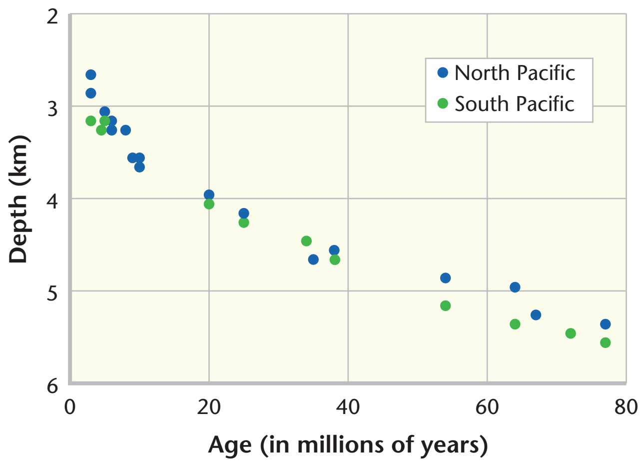
30. Writing Persuasively Imagine that you are Alfred Wegener. Write a persuasive essay to explain your idea of continental drift. Use only evidence originally used by Wegener to support his hypothesis.

31. Communicating Main Ideas Explain how the research of Wegener, Hess, and others led to the theory of plate tectonics.

Interpreting Graphics

The graph below shows the relationship between the age of sea floor rocks and the depth of the sea floor beneath the ocean surface. Use the graph to answer the questions that follow.

Ocean Depth Vs. Sea-floor Age



32. How old is the sea floor at a depth of 4 km?

33. Approximately how deep is the sea floor when it is 55 million years old?

34. What can you infer about the age of very deep sea floor from the data in the graph?

35. The ridge in the South Pacific Ocean is spreading faster than the ridge in the North Pacific Ocean. If this graph showed the depth of the sea floor in relation to the distance from the ridge, how would the graphs of the North Pacific and South Pacific ridges differ?

Chapter 10

FCAT Prep

For questions 1–5, write your answers on a separate sheet of paper.

1 By what process does new oceanic lithosphere form as magma rises to Earth's surface and solidifies at a mid-ocean ridge?

A. plate tectonics
B. paleomagnetism
C. mantle convection
D. sea-floor spreading

2 Which of the following is a weakness of Wegener's proposal of continental drift that caused the scientific community to raise doubts about the proposal when he first proposed the hypothesis?

F. an absence of fossil evidence
G. unsupported climatic evidence
H. unrelated continent features
I. a lack of proven mechanisms

3 What is the name for the layer of plastic rock directly below the lithosphere?

A. asthenosphere
B. continental crust
C. magma
D. oceanic crust

4 READ INQUIRE EXPLAIN One way that a transform boundary differs from convergent and divergent boundaries is that it does not produce magma. Transform boundaries can change the course of rivers and disrupt the continuity of human-made structures, such as roads.

Describe how the movement of plates at a transform boundary can lead to the effects on rivers and roads as described above.

5 READ INQUIRE EXPLAIN The Himalaya Mountains are a range of mountains that is 2,400 km long and that arcs across Pakistan, India, Tibet, Nepal, Sikkim, and Bhutan. The Himalaya Mountains are the highest mountains on Earth. Nine mountains, including Mount Everest, the highest mountain on Earth, rise to heights of more than 8,000 m. Mount Everest stands 8,850 m tall.

The formation of the Himalaya Mountains began around 80 million years ago. A tectonic plate carrying the Indian subcontinent collided with the Eurasian plate. In the process, the Indian plate was driven beneath the Eurasian plate. This collision caused the uplift of the Eurasian plate and the subsequent formation of the Himalaya Mountains. This process is ongoing today as the Indian plate continues to push under the Eurasian plate. New measurements show that Mount Everest is moving northeast by as much as 10 cm per year.

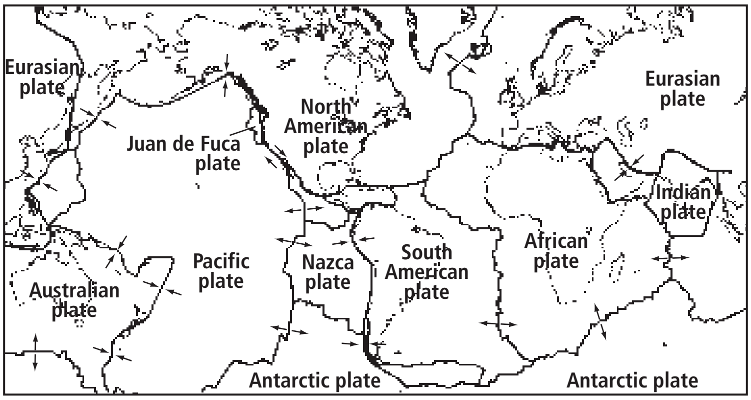
Part A What type of boundary is being described in the passage, and what two plates are involved?

Part B Describe the geologic process that led to the formation of the Himalaya Mountains.

For questions 6–9 write your answers on a separate sheet of paper.

The map below shows the locations of Earth's major tectonic plate boundaries. Use this map to answer questions 6 and 7.

EARTH'S TECTONIC PLATES



6 What type of boundary is found between the Australian plate and the Pacific plate?

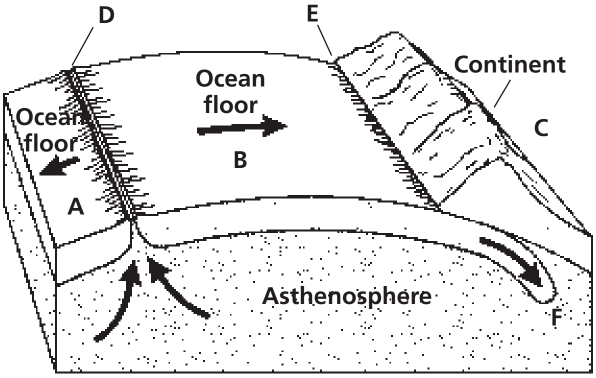
F. convergent
G. divergent
H. transform
I. rift valley

7 According to the map, where are most divergent boundaries located?

A. on the floor of the oceans
B. along surface mountain ranges
C. along continental divides
D. on the edges of continents

Base your answer to question 8 on the diagram of plate boundaries below.

PLATE BOUNDARIES



8 What type of crustal interaction is occurring in the area indicated by the letter E?

F. continental rifting
G. sea-floor spreading
H. divergence
I. subduction

9 A computer simulation of sea-floor spreading predicts that 2.35 cm of new material is added to the width of an island each year. How many years will it take for the island to increase in width by 2.35 km?

Test TIP

If you become short on time, quickly scan the unanswered questions to see which questions are easiest to answer.

Chapter 10

Making Models Lab

Objectives

- **Model** the formation of sea floor.
- **Identify** how magnetic patterns are caused by sea-floor spreading.

Materials

- marker
- paper, unlined
- ruler, metric
- scissors or utility knife
- shoebox

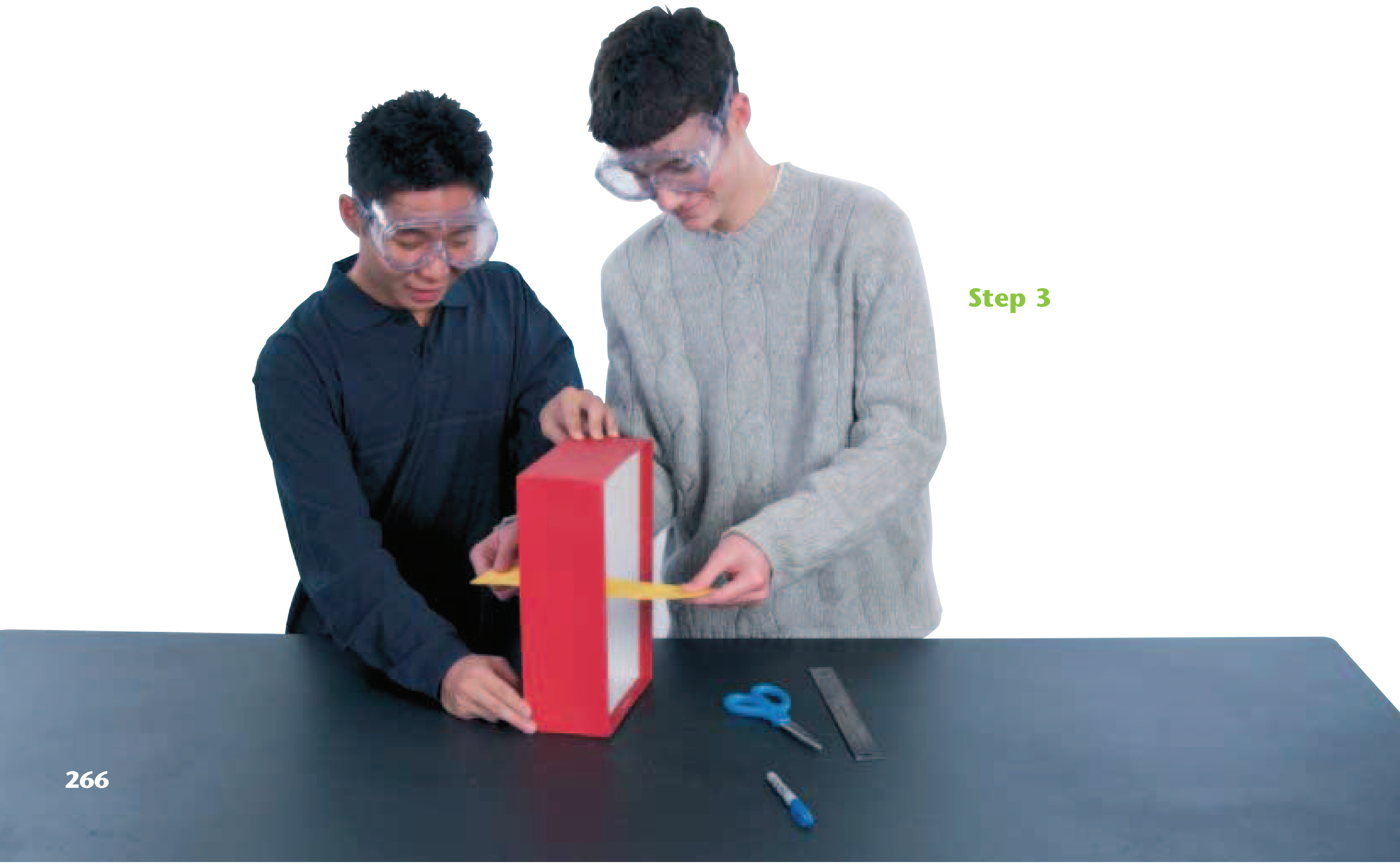
Safety

Sea-Floor Spreading

The places on Earth's surface where plates pull apart have many names. They are called divergent boundaries, mid-ocean ridges, and spreading centers. The term *spreading center* refers to the fact that sea-floor spreading happens at these locations. In this lab, you will model the formation of new sea floor at a divergent boundary. You will also model the formation of magnetic patterns on the sea floor.

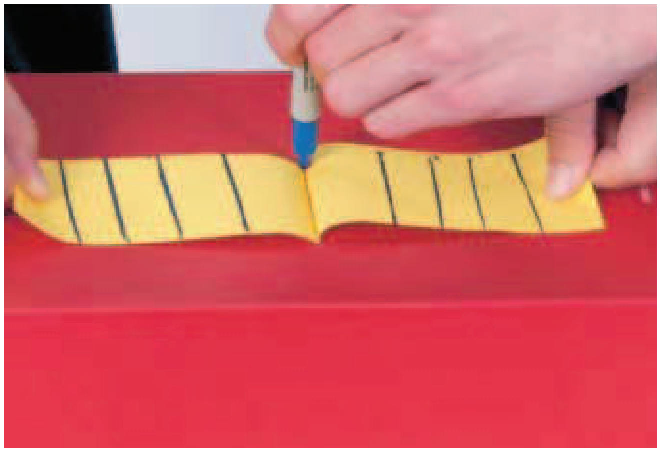
PROCEDURE

1. Cut two identical strips of unlined paper, each 7 cm wide and 30 cm long.
2. Cut a slit 8 cm long in the center of the bottom of a shoebox.
3. Lay the strips of paper together on top of each other end to end so that the ends line up. Push one end of the strips through the slit in the shoe box, so that a few centimeters of both strips stick out of the slit.



Step 3

4. Place the shoe box flat on a table open side down, and make sure the ends of the paper strips are sticking up.
5. Separate the strips, and hold one strip in each hand. Pull the strips apart. Then, push the strips down against the shoe box.
6. Use a marker to mark across the paper strips where they exit the box. One swipe with the marker should mark both strips.
7. Pull the strips evenly until about 2 cm have been pulled through the slit.
8. Mark the strips with the marker again.
9. Repeat steps 7 and 8, but vary the length of paper that you pull from the slit. Continue this process until both strips are pulled out of the box.



Step 6

ANALYSIS AND CONCLUSION

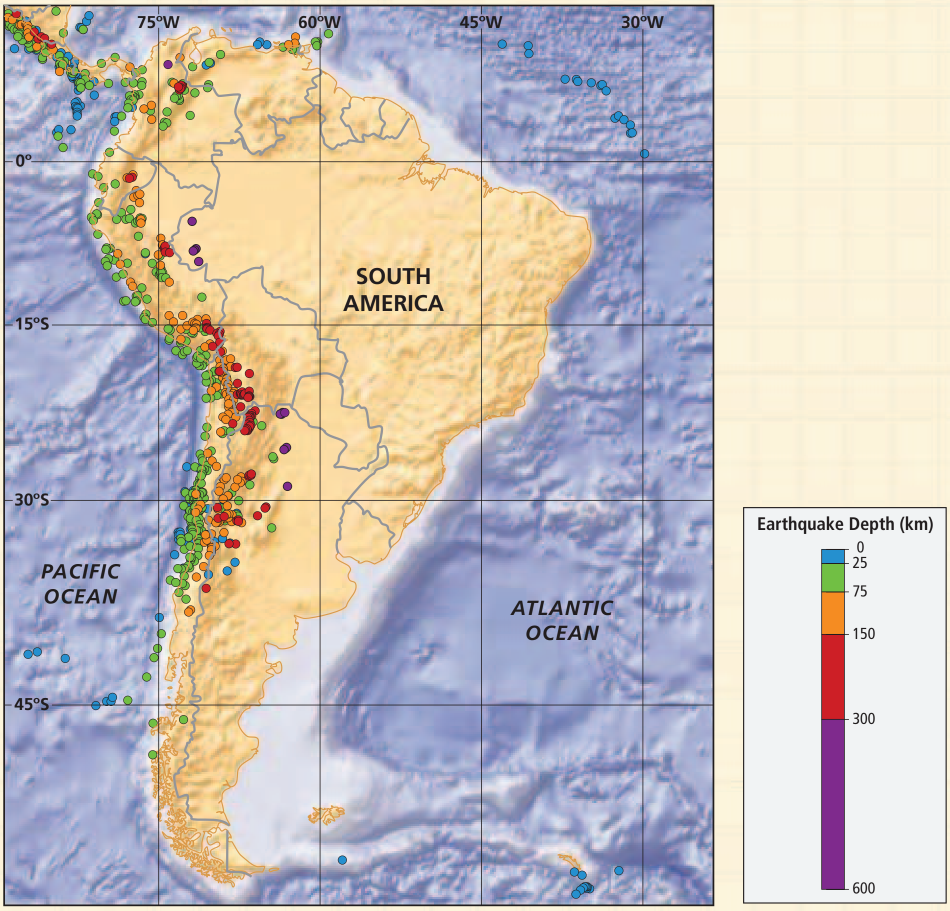
1. **Evaluating Models** How does this activity model sea-floor spreading?
2. **Analyzing Models** What do the marker stripes in this model represent?
3. **Analyzing Methods** If each 2 cm marked on the paper is equal to 3 million years, how could you use your model to determine the age of certain points on the sea floor?
4. **Applying Conclusions** You are given only the paper strips with marks already drawn on them. How would you use the paper strips to reconstruct the way in which the sea-floor was formed?

Extension

1. **Making Models** Design a model that shows what happens at a convergent boundary and what happens at a transform boundary. Present these models to the class.

MAPS in Action

Locations of Earthquakes in South America, 2002–2003



Map Skills Activity

This map shows the locations and depths of earthquakes that registered magnitudes greater than 5 and that happened in South America in 2002 and 2003. Use the map to answer the questions below.

1. **Using the Key** How many earthquakes happened at a depth greater than 300 km?

2. **Analyzing Data** Deep earthquakes are earthquakes that happen at a depth greater than 300 km. Which earthquakes happen more frequently: deep earthquakes or shallow earthquakes?

3. **Making Comparisons** How does the earthquake activity on the eastern edge of South America differ from the earthquake activity on the western edge?

4. **Inferring Relationships** The locations of earthquakes and plate boundaries are related. Where would you expect to find a major plate boundary?

5. **Identifying Trends** In what part of South America do most deep earthquakes happen? What relationships do you see between the locations of shallow and deep earthquakes in South America?

6. **Analyzing Relationships** Most deep earthquakes happen where subducting plates move deep into the mantle. What type of plate boundary is indicated by the earthquake activity in South America? Explain your answer.

The Mid-Atlantic Ridge

Deep in the Atlantic Ocean lies a mountain range so vast that it dwarfs the Himalaya Mountains. This mountain range, called the *Mid-Atlantic Ridge,* is the mid-ocean ridge at the diverging boundary between the North American and Eurasian plates and also between the South American and African plates.

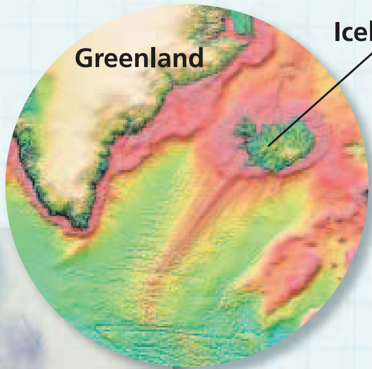
Sea-Floor Spreading on Land

Most of Earth's mid-ocean ridges are underwater, but part of the Mid-Atlantic Ridge rises above sea level just south of the Arctic Circle. The exposed section of the Mid-Atlantic Ridge forms the country of Iceland. Since Iceland was founded by Vikings more than 1,000 years ago, its inhabitants have contended with constant geologic activity associated with sea-floor spreading.

Lots and Lots of Lava

Separation of Earth's crust along the Mid-Atlantic Ridge affects Iceland's landscape in several ways. The movement of magma causes frequent earthquakes. Iceland is also one of the most volcanically active areas in the world. It contains about 200 volcanoes and averages one eruption every five years. Magma flowing up from the mantle creates numerous hot springs, geysers, and sulfurous gas vents. Scientists estimate that one-third of the total lava flow from Earth in the last 500 years has occurred on Iceland.

Despite Iceland's numerous volcanoes, much of its lava comes not from isolated eruptions but from cracks, or *fissures,* in the crust. In a recent rifting episode that lasted nearly 10 years, a series of fissures spit out enough molten basalt to cover 35 km^2 of land and individual fissures grew as much as 8 m in width. At present, sea-floor spreading adds an average of 2.5 cm of new material to Iceland each year. At this rate, Iceland will grow 25 km in width during the next million years.



◀ The Helgafjell volcano erupted in a curtain of fire that rained black ash on the town of Reykjavik Iceland, in 1973.

Extension

1. **Making Inferences** If geologists want to locate the youngest rocks on Iceland, where should they look? Where should they look to find the oldest rocks? Explain your answers.

SCILINKS
NSTA
Developed and maintained by the National Science Teachers Association

For a variety of links related to this chapter, go to www.scilinks.org

Topic: Mid-Atlantic Ridge
SciLinks code: HQ60960