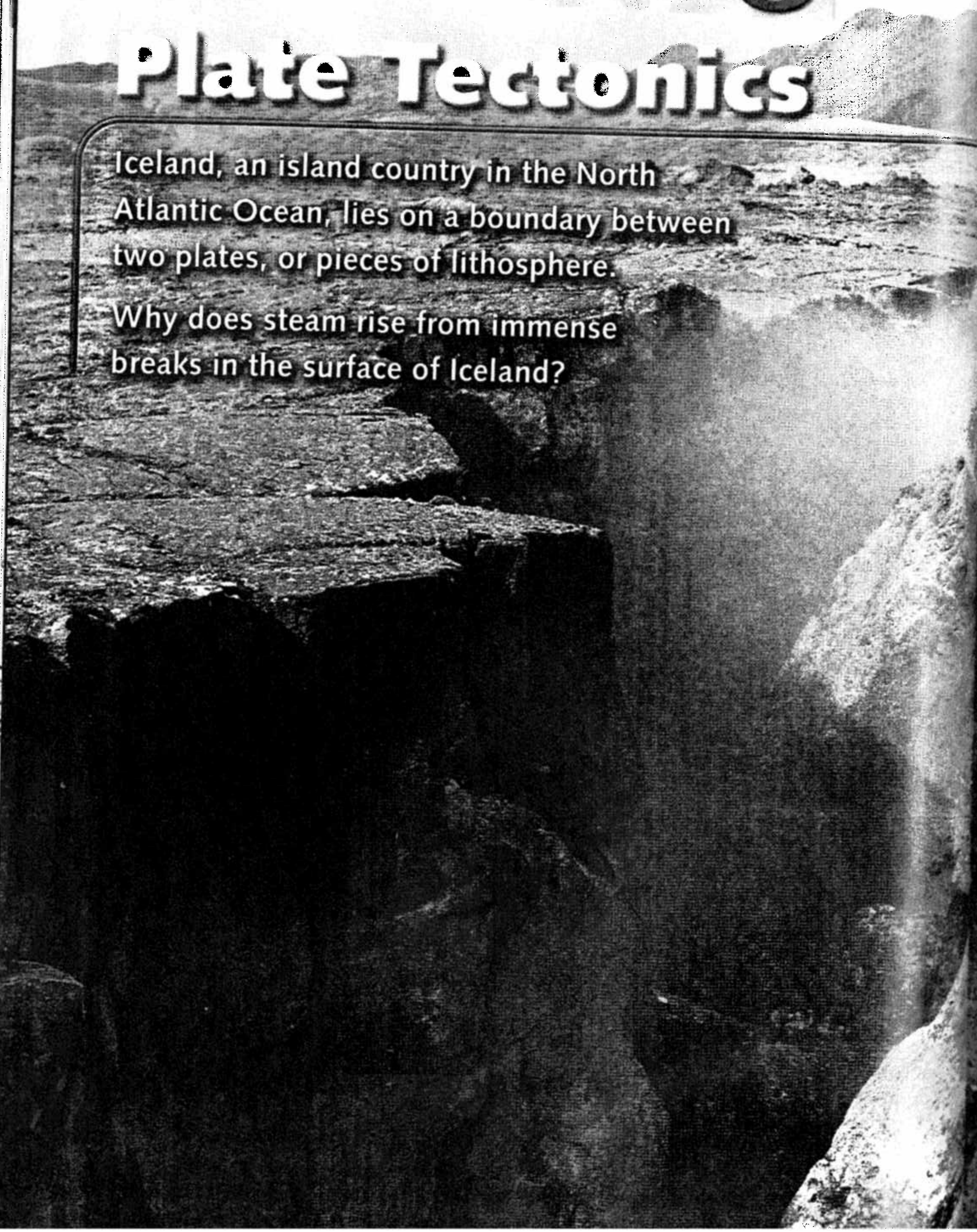
CHAPTER 8

Plate Tectonics

Iceland, an island country in the North Atlantic Ocean, lies on a boundary between two plates, or pieces of lithosphere.

Why does steam rise from immense breaks in the surface of Iceland?



CHAPTER 8

PREVIEW

▶ FOCUS QUESTIONS

In this chapter you will investigate plate tectonics and learn more about the key questions below.

Section 1 What evidence have scientists found to support the theory of plate tectonics?

Section 2 What are important features of different types of plate boundaries?

Section 3 What are some of the hypotheses scientists have about the causes of plate movements?

Section 4 How have plate movements caused changes in the positions and shapes of Earth's landmasses?

▶ REVIEW TOPICS

As you investigate plate tectonics, you will need to use information from earlier chapters.

- mantle **(p. 72)**
- asthenosphere **(p. 73)**
- magma **(p. 118)**
- lithosphere **(p. 73)**
- magnetic field **(p. 74)**

▶ READING STRATEGY

USE TEXT AIDS

Notice that, throughout the chapter, key terms appear in boldface type. The definition of each term is given where the term is boldfaced.

INTERNET RESOURCES
CLASSZONE.COM

At our Web site, you will find the following Internet support:

DATA CENTER

EARTH NEWS

VISUALIZATIONS

- Polarity at Mid-Ocean Ridges
- Processes at Plate Boundaries
- Convection in the Mantle
- Breakup of Pangaea
- Predicted Plate Movement
- Continental Growth

LOCAL RESOURCES

CAREERS

INVESTIGATIONS

- What Is the Earth's Crust Like?
- How Old Is the Atlantic Ocean?
- How Fast Do Plates Move?

8.1

KEY IDEA

The lithosphere is broken into rigid plates that move in relationship to one another on the asthenosphere.

KEY VOCABULARY

- plate tectonics
- continental drift
- mid-ocean ridge

What Is Plate Tectonics?

Earth's lithosphere is broken into plates that move on the asthenosphere. In some places, the plates are moving toward each other. In other places, they are moving apart, and in others, they are sliding past each other. **Plate tectonics** (tehk-TAHN-ihks) is a theory that describes the formation, movements, and interactions of these plates.

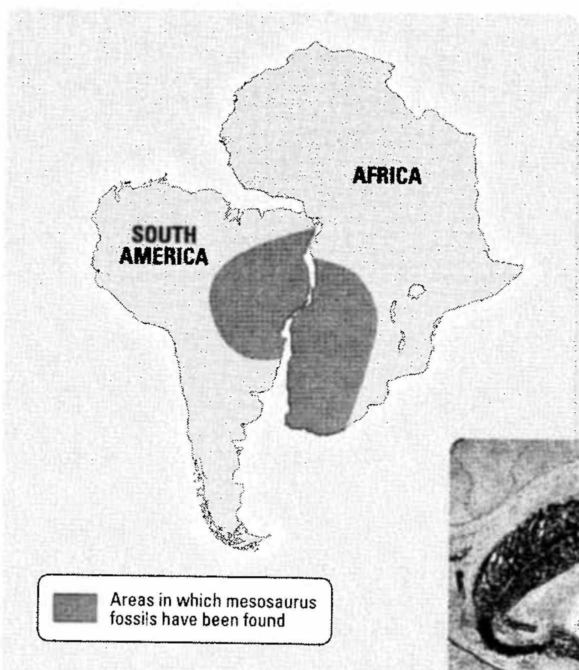
Early Ideas About Plate Movements

The idea that Earth's surface might be moving is not new. The theory of plate tectonics developed from early observations made about the shapes of the continents and from fossil and climate evidence.

In the early 1500s, explorers using maps noted the remarkable fit of the shape of the west coast of Africa and the shape of the east coast of South America. In 1596, a Dutch mapmaker suggested that the two continents may have been part of a larger continent that had broken apart.

In 1912, a German scientist named Alfred Wegener (VAY-guh-nuhr) proposed a hypothesis called **continental drift.** According to this hypothesis, the continents have moved, or drifted, from one location to another over time. Wegener used many observations to support his hypothesis. In addition to the similarities in the shapes of the continents, he noted that the fossil remains of *Mesosaurus,* a reptile that lived about 270 million years ago, are found only in parts of South America and Africa. This strange distribution is easily explained if the two continents were once joined, as suggested by the map below. Distinctive rock formations found on both continents would have matched up with each other if the continents had been joined in the past. Climate change evidence further supports the continental drift hypothesis.

MAP *Mesosaurus* fossils have been found in South America and Africa, lending support to the hypothesis that the continents were once joined together.



One of the strongest objections to Wegener's hypothesis was that it did not explain *how* the continents moved. Wegener suggested that the continents might float on deeper, more fluid layers, and that Earth's internal heat could provide the energy needed to move the continents through these layers. He had no evidence to support that explanation, however. Scientists continued to debate Wegener's ideas about continental drift for a number of years. During his lifetime, Wegener continued his efforts to defend the continental drift hypothesis, but he was not successful.

FOSSIL EVIDENCE This fossil *Mesosaurus* was found in Brazil. Similar fossils have been found in Africa.

The Theory of Plate Tectonics

In the 1950s and 1960s, discoveries about earthquakes, magnetism, and the age of rocks on the ocean floor added support to some, though not all, of Wegener's ideas. Evidence was strong that Earth's landmasses had moved over time; however, they did not move in the way Wegener had proposed. Instead, scientists proposed a new theory—the theory of plate tectonics.

According to the theory of plate tectonics, the continents are embedded in lithospheric plates. As these plates move, they carry the continents with them. The ocean basins are part of lithospheric plates as well.

The theory of plate tectonics is supported by a wealth of evidence and explains many important geological processes. The theory explains why earthquakes and volcanoes are likely to occur in particular locations and how new crust forms along the ocean floor.

INVESTIGATIONS
CLASSZONE.COM

What Is the Earth's Crust Like?
Examine the locations of volcanoes, earthquakes, and folded mountains to develop an understanding of Earth's lithosphere.
Keycode: ES0801

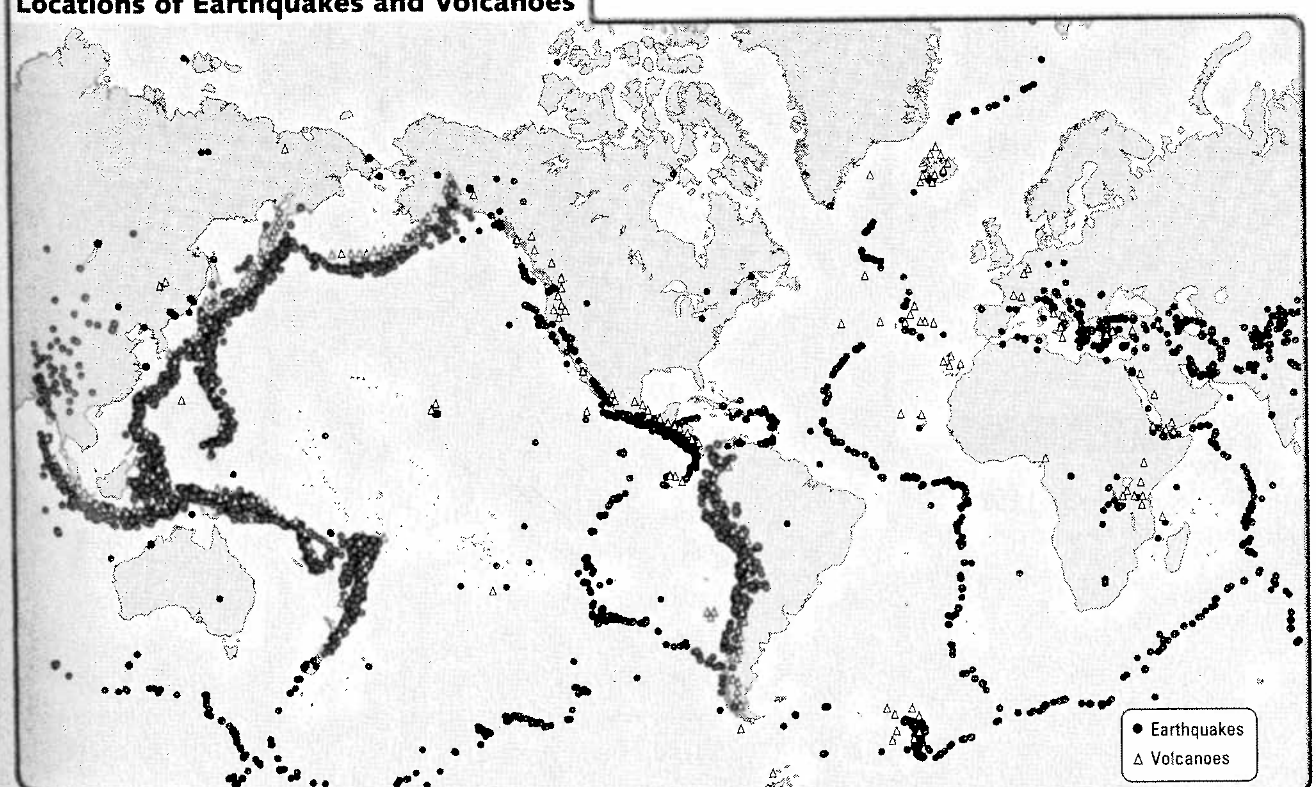
Locations of Earthquakes and Volcanoes

Data indicate that earthquakes and volcanic activity do not occur randomly throughout the world. Instead, they occur primarily in concentrated belts, as shown on the map below.

The theory of plate tectonics helps explain this pattern because the earthquake and volcano belts mark the locations of plate boundaries. These boundaries are places where two plates are pushing toward, pulling away, or sliding past each other. Strain builds up along plate boundaries, and when the strain becomes too great, fractures form and earthquakes occur. The boundaries are also areas of high heat flow, where molten rock moves upward to Earth's surface, causing volcanic activity.

MAP **The map shows earthquakes with magnitudes ranging from 5 to 9, from 1996 through 2000.**

Locations of Earthquakes and Volcanoes



INVESTIGATIONS
CLASSZONE.COM

How Old Is the Atlantic Ocean?
Explore a model showing the shape and age of the Atlantic seafloor. Determine how long ago Africa and South America separated.
Keycode: ES0802

Magnetism and the Age of the Ocean Floor

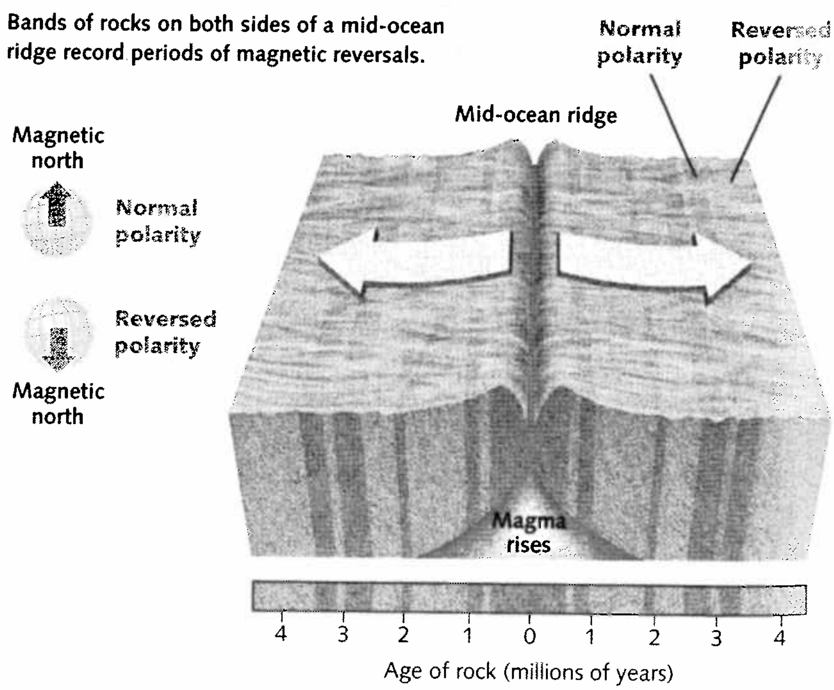
Important evidence that supports the theory of plate tectonics comes from studies of the magnetic properties and the ages of igneous rocks on the ocean floor. Plate tectonics explains patterns observed in data from these studies.

Some igneous rocks contain minerals that are magnetic. These minerals provide a record of the direction of Earth's magnetic field at the time when the molten matter that formed the rock cooled. One important discovery that geologists made when studying such igneous rocks was that some of the rocks recorded reversals in the direction of Earth's magnetic field. At certain times in the past, the present north magnetic pole became the south magnetic pole, and the present south magnetic pole became the north magnetic pole. A number of magnetic reversals have taken place at different times over a period of millions of years.

Geologists also studied the magnetic record of the rocks of the ocean floor, particularly the igneous rocks on the sides of mid-ocean ridges. A **mid-ocean ridge** is a long chain of volcanic mountains on the ocean floor with a deep central valley. It was discovered that the magnetic reversals are recorded in bands of rock on either side of a mid-ocean ridge. As shown in the diagram below, the pattern of the bands was mirrored on either side of the ridge, with the center of the ridge always showing the current orientation of the north and south poles.

Magnetism on the Ocean Floor

Bands of rocks on both sides of a mid-ocean ridge record periods of magnetic reversals.



VISUALIZATIONS
CLASSZONE.COM

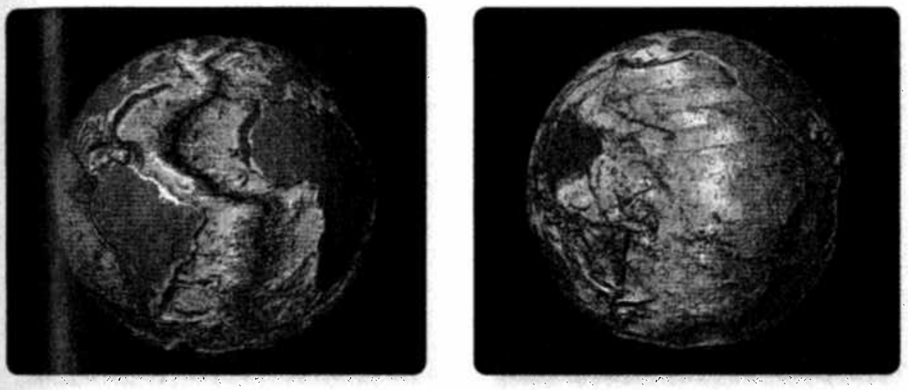
Observe how alternating magnetic polarity is recorded in rocks at mid-ocean ridges.
Keycode: ES0803

When geologists determined the ages of the rocks in the magnetic reversal bands on either side of mid-ocean ridges, they found that the rocks at the center of a mid-ocean ridge are the youngest. On either side, the rocks are older the farther they are from the ridge.

Based on studies of the ages and the magnetic properties of the rocks along the mid-ocean ridges, geologists have concluded that these ridges represent boundaries where lithospheric plates are moving apart.

The newer rocks along a mid-ocean ridge are formed by hot, molten rock rising between the spreading plates. As these new rocks form, the older rocks spread away from the ridge on either side.

In the computer-generated images below, colors indicate the ages of the rocks on the sides of mid-ocean ridges in the Atlantic and Pacific oceans. The red color represents the youngest rocks along a mid-ocean ridge. Moving away from the ridge on either side, the colors change gradually to indicate that the rocks of the ocean floor become increasingly older.



AGE OF THE OCEAN FLOOR The left-hand image shows the Mid-Atlantic Ridge, a mid-ocean ridge in the Atlantic Ocean. The right-hand image shows the East Pacific Rise, a mid-ocean ridge in the Pacific Ocean.

Measurements have shown that the flow of heat leaving the rocks along the mid-ocean ridges is unusually high. The amount of heat leaving the rocks decreases gradually farther away from the mid-ocean ridge. These observations support the conclusion that mid-ocean ridges are regions where new rock is being formed as Earth's plates move apart.

8.1 *Section Review*

1. What observations support the continental drift hypothesis?
2. How do observations of earthquake and volcanic activity support the theory of plate tectonics?
3. What evidence in support of plate tectonics is provided by studies of the ocean floor?
4. **CRITICAL THINKING** Identify the weaknesses in Wegener's continental drift hypothesis. Explain how the theory of plate tectonics differs from the continental drift hypothesis.
5. **PHYSICS** What would you expect to find if you measured the temperatures of rocks on the ocean floor at various distances from a mid-ocean ridge? Explain your thinking.

20-Minute

Mini LAB

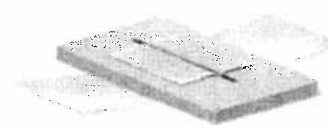
Ocean Floor Magnetism

Materials

- $8\frac{1}{2}$ in. by 11 in. sheet of paper
- scissors
- shoebox lid
- 2 different-colored markers

Procedure

1. Cut the paper in half lengthwise, making two long strips.
2. Cut a slit in the shoebox lid. Insert each strip of paper into the slit, leaving about 3 centimeters of each strip showing. Fold the strips back as shown below. Color the part of each strip that is showing.



3. Pull out each strip another 3 centimeters. Mark new stripes in a different color.
4. Repeat Step 3 three times.

Analysis

What landform does the slit represent? What do the stripes represent? How might you make this model more realistic?

8.2

KEY IDEA

Boundaries between plates are described generally as divergent, convergent, or transform, depending on how the plates move relative to each other.

KEY VOCABULARY

- divergent boundary
- rift valley
- rift
- convergent boundary
- subduction boundary
- deep-sea trench
- collision boundary
- transform boundary

Types of Plate Boundaries

Scientists classify boundaries between two plates according to plate movement. There are three main types of plate boundaries: divergent, convergent, and transform.

Divergent Boundaries

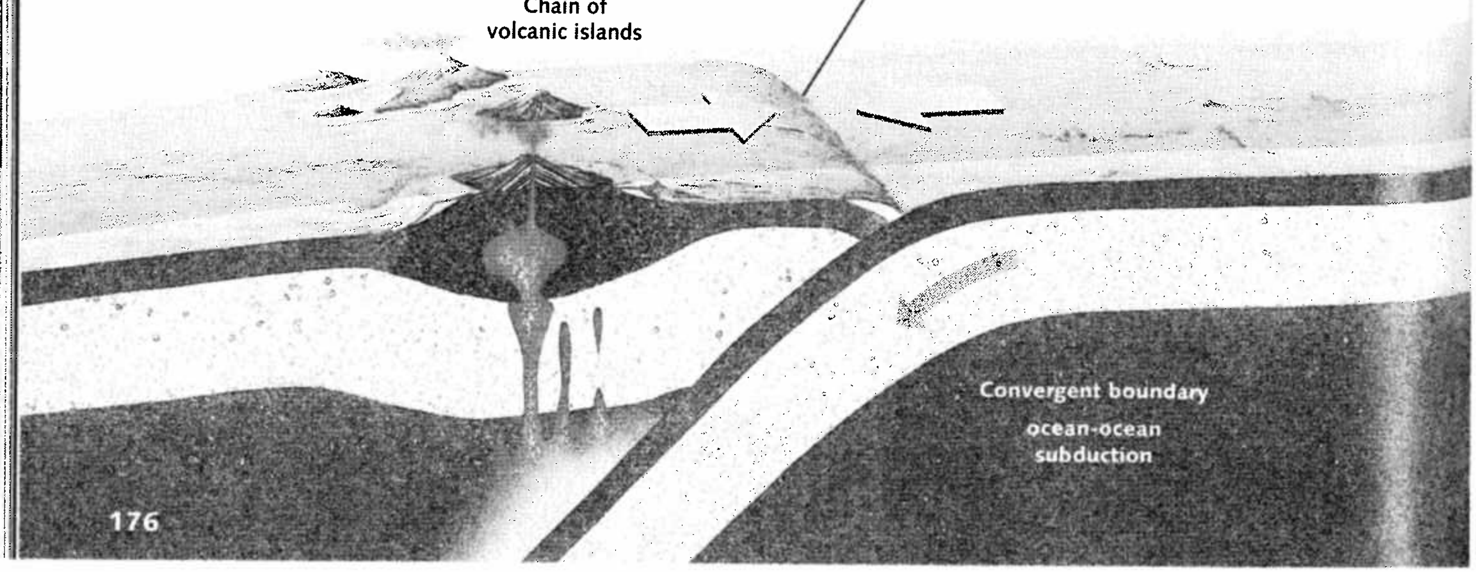
A **divergent boundary** is a boundary between two lithospheric plates that are moving apart. Divergent boundaries are sometimes called spreading centers. Most divergent boundaries lie along the ocean floor and have **rift valleys,** which are deep valleys at the center of a mid-ocean ridge. A rift valley runs along the entire length of the mid-ocean ridge.

The rift valley along a mid-ocean ridge forms the boundary between two diverging lithospheric plates. In a process sometimes called sea-floor spreading, molten rock forces its way upward through cracks, or **rifts,** along the valley. The molten rock cools, hardening into new oceanic crust. The older oceanic crust on either side of the valley moves away from the mid-ocean ridge.

A rift valley at a mid-ocean ridge is typically broken into segments that are offset from each other by breaks in the lithosphere called fracture zones. These fracture zones tend to lie perpendicular to the ridge. Movements along fracture zones have been found to be a source of the earthquakes that occur along mid-ocean ridges.

As shown on the plate boundary map on pages 712–713, two examples of mid-ocean ridges are the Mid-Atlantic Ridge and the East Pacific Rise. Along the rift valleys of these ridge systems, hot springs rise up from hydrothermal vents on the ocean floor. Scientists have found colonies of previously unknown organisms living around the hydrothermal vents.

SUBDUCTION BOUNDARY The Indonesian island of Krakatau has formed near the subduction boundary between two oceanic plates.



Convergent Boundaries

A **convergent boundary** is a boundary between two plates that are moving toward each other, or converging. Two broad classifications for convergent boundaries are subduction boundaries and collision boundaries.

Subduction Boundaries

When an oceanic plate plunges beneath another plate, the oceanic plate is said to be *subducting* (suhb-DUHK-tihng) beneath the overriding plate. The boundary between the plates is called a **subduction boundary.** One important feature of a subduction boundary is a long, deep trench called a **deep-sea trench** that forms along the boundary. Such trenches are the deepest parts of the ocean floor.

Subduction boundaries can occur at the convergence of two oceanic plates or at the convergence of an oceanic plate with a continental plate.

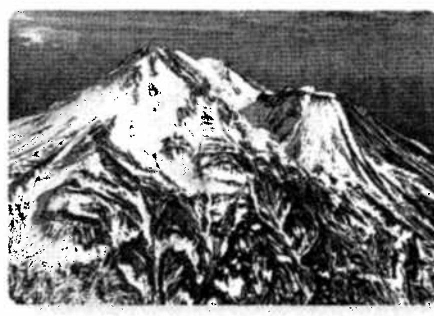
When two oceanic plates converge, the deep-sea trench that forms is accompanied by the formation of a chain of volcanic islands called a volcanic island arc on the overriding plate. For example, as the Pacific Plate subducts under the Philippine Plate, the Pacific Plate is pulled down to form the Mariana Trench. The leading edge of the overriding Philippine Plate is marked by a chain of volcanic islands, the Mariana Islands.

When an oceanic plate converges with a continental plate, the denser oceanic plate subducts beneath the less-dense continental plate. A deep-sea trench forms, as shown below. A mountain chain and volcanoes form inland on the overriding continental plate.

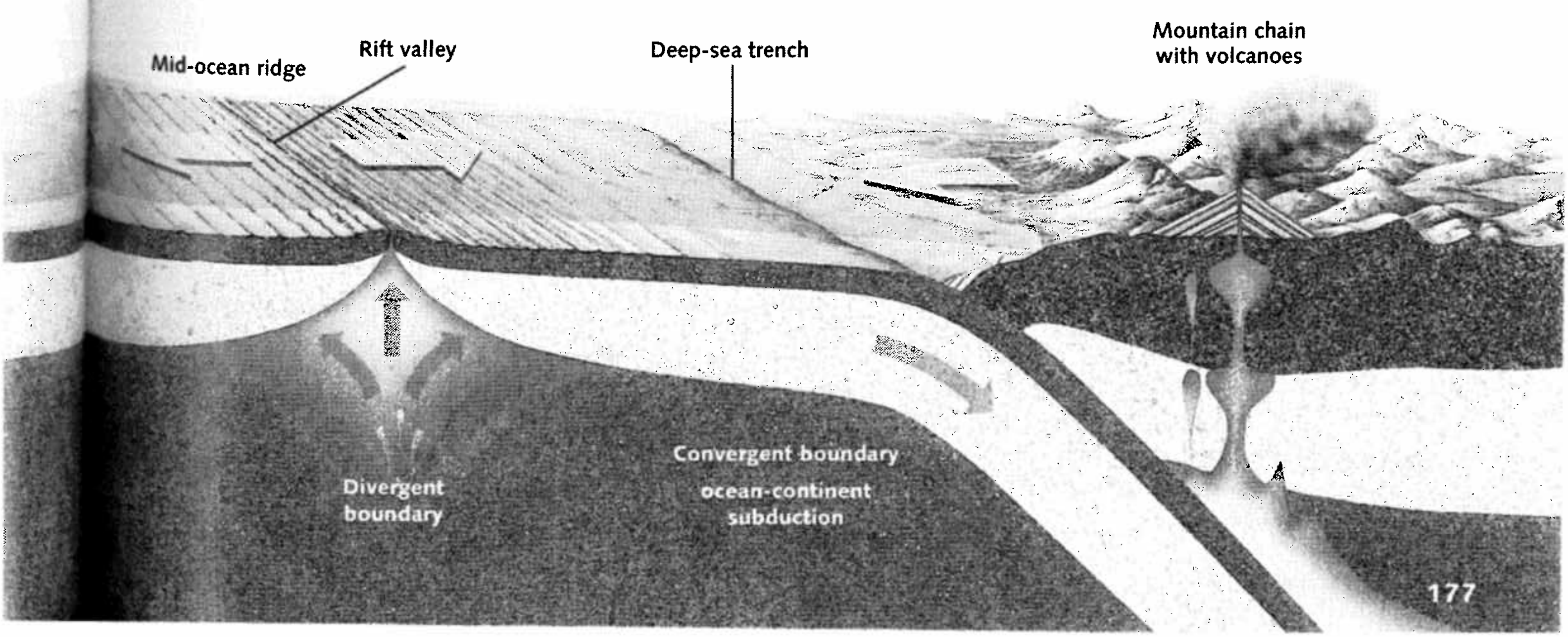
VOCABULARY STRATEGY

The prefix *sub-* in the words *subducting* and *subduction* means "below." *Subduction* comes from a Latin verb meaning "to draw away from below."

DIVERGENT BOUNDARY These hydrothermal vents are on the Mid-Atlantic Ridge.



SUBDUCTION BOUNDARY Mount Shasta is a volcano in California that has formed near a subduction boundary.



For example, off the west coast of South America, the Nazca Plate is subducting under the South American Plate. The Peru-Chile Trench has formed between the plates. The Andes Mountains and active volcanoes have formed along the western edge of the South American continent.

HIMALAYAS The world's tallest mountains, the Himalayas, have formed at a collision boundary.

Collision Boundaries

If two converging plates each carry continents, the two continents may become welded into a single, larger continent. The boundary that forms when two continents collide and are welded into a single, larger continent is called a **collision boundary.** The collision causes the crust at the boundary to be pushed upward into a mountain range.

The highest mountains in the world, the Himalayas, lie along a collision boundary where India is pushing northward into China at a rate of about 5 centimeters each year. The Indian subcontinent is now welded to the Eurasian continent. The Himalayas continue to grow even higher, and large numbers of earthquakes occur as the two plates push together. Mountain ranges have also formed at other collision boundaries in the past. The Ural Mountains in Russia formed about 250 million years ago when Europe collided with Siberia to form the Eurasian continent. The Appalachian Mountains formed by the same process during the collision of North America and northern Africa. At a much later time, the two continents moved apart, forming the Atlantic Ocean.

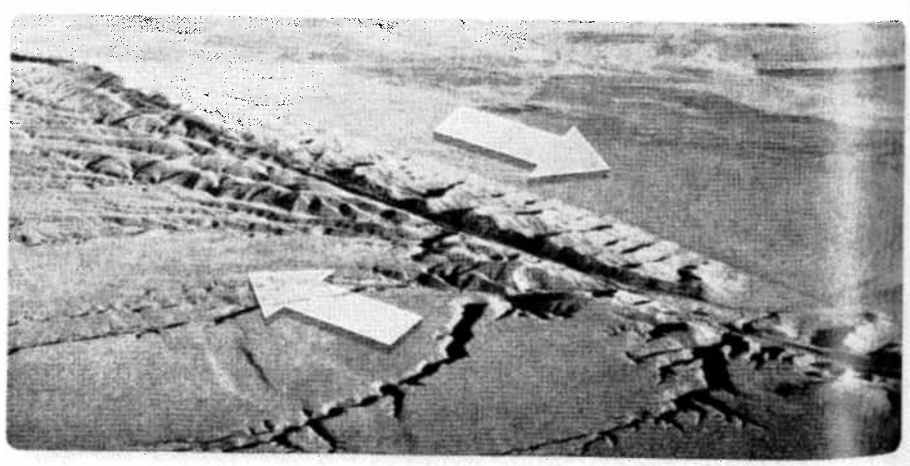
Transform Boundaries

A **transform boundary** is a boundary between two plates that are sliding past each other. The fracture zones that offset the segments of a mid-ocean ridge are transform boundaries. You will learn more about fracture zones in Chapter 23.

Another example of a transform boundary occurs in California, where the North American Plate and the Pacific Plate are sliding past each other along the San Andreas Fault. Southwestern California is part of the Pacific Plate, which is moving northwest. The rest of the United States is part of the North American Plate, which is moving southeast.

Movement along transform boundaries is not uniform. The rate of movement along the San Andreas Fault may be as high as 5 centimeters per year. However, some areas have not moved in over a century.

VISUALIZATIONS
CLASSZONE.COM
Observe animations of processes that occur along plate boundaries.
Keycode: ES0804



SAN ANDREAS FAULT This photograph shows a portion of the San Andreas Fault near Taft, California.

The chart below summarizes important information about each type of plate boundary.

SUMMARY Types of Plate Boundaries

Type of boundary	Process involved	Characteristic features	Current examples
Divergent	sea-floor spreading	• mid-ocean ridges • rift valleys • earthquake activity at fracture zones along mid-ocean ridges • volcanic activity	• Mid-Atlantic Ridge • East Pacific Rise
Convergent	ocean-ocean subduction	• deep-sea trenches • volcanic island arcs • earthquake activity	• islands of Indonesia • Mariana Islands
	ocean-continent subduction	• deep-sea trench bordering continent • volcanoes along coast of continent • earthquake activity	• western coast of South America
	continent-continent collision	• high continental mountain chains • earthquake activity	• Himalayas
Transform	plates sliding past each other	• earthquake activity	• San Andreas Fault • North Anatolian Fault (Turkey) • fracture zones along mid-ocean ridges

8.2 Section Review

1. Explain how new oceanic crust is formed at a divergent boundary.
2. Describe two different types of subduction boundaries. Use the plate boundary map on pages 712–713 to identify an example of each type.
3. Describe what happens at a collision boundary. Identify a collision boundary on the map on pages 712–713.
4. Describe the movement of plates at a transform boundary, and give some examples.
5. What types of plate boundaries are *not* shown in the diagram on pages 176–177?
6. **CRITICAL THINKING** Explain how the densities of oceanic crust and continental crust influence what happens when an oceanic plate converges with a continental plate.
7. **GEOGRAPHY** In 2001, a large earthquake related to the movements of two plates occurred about 20 kilometers northeast of Olympia, Washington. Use the map on pages 712–713 to identify the plates and the type of boundary they share.

8.3

KEY IDEA

Three hypotheses describe how mantle convection, ridge push, and slab pull may cause plate movements.

KEY VOCABULARY

- mantle convection
- ridge push
- slab pull

VISUALIZATIONS
CLASSZONE.COM

Observe an animation of convection in the mantle.
Keycode: ES0805

Causes of Plate Movement

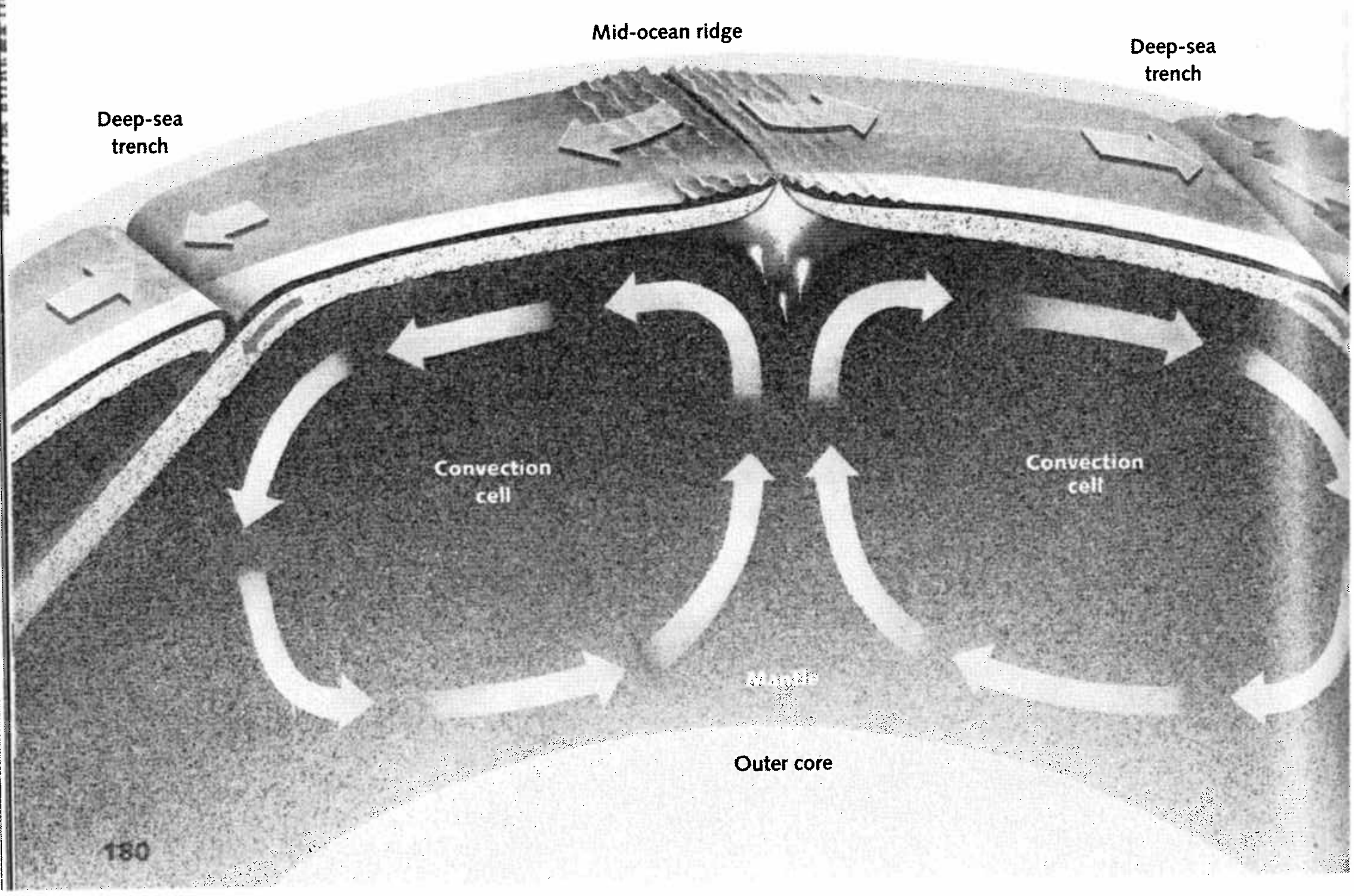
The fact that Earth's plates are moving is evident from the earthquakes and volcanic activity at plate boundaries. But what causes plate movements? Three major hypotheses describe how mantle convection, ridge push, and slab pull may each play a role in driving plate movements. All three hypotheses may be important in identifying the cause of plate movements.

To understand the hypotheses described below, it is important to remember that the asthenosphere—a layer in the upper mantle—provides the plates with a surface on which they can move. The asthenosphere has a composition similar to that of the lower lithosphere, but it has very different properties. Instead of being rigid, the asthenosphere is pliable because the rock materials there are hotter than those in the lithosphere.

Mantle Convection

Heat from Earth's inner and outer cores is transferred through the mantle by a process called **mantle convection.** According to the mantle convection hypothesis, the mantle may be moving the plates along with it as it convects.

The diagram below shows one model for how mantle convection may contribute to plate movement. In this model, magma that is hotter and less dense than its surroundings rises upward at a mid-ocean ridge. This upwelling occurs on one side of a convection cell. As the convection current moves away from the mid-ocean ridge, it drags the lithospheric plate with it. The cooler, denser rocks of the lithospheric plate sink down



at a subduction boundary, along a downwelling zone in the mantle that compensates for the upwelling on the other side of the convection cell.

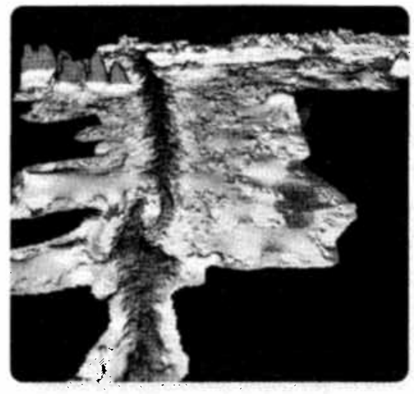
Many scientists think that mantle convection does not completely explain why plates move. In particular, the model does not account for the enormous force needed to move the lithospheric plates.

Ridge Push

The molten magma that rises at a mid-ocean ridge is very hot and heats the rocks around it. As the asthenosphere and lithosphere at the ridge are heated, they expand and become elevated above the surrounding sea floor. This elevation produces a slope down and away from the ridge.

Because the rock that forms from the magma is very hot at first, it is less dense and more buoyant than the rocks farther away from the mid-ocean ridge. However, as the newly formed rock ages and cools, it becomes more dense. Gravity then causes this older, denser lithosphere to slide away from the ridge, down the sloping asthenosphere. As the older, denser lithosphere slides away, new molten magma wells up at the mid-ocean ridge, eventually becoming new lithosphere.

Scientists have used computer models to show that the cooling, subsiding rock exerts a force on spreading lithospheric plates that could help drive their movements. This force is called **ridge push,** though the phrase "ridge push" is somewhat misleading. It might be more accurate to refer to ridge push as gravitational sliding.



MID-OCEAN RIDGE In this computer-generated topographic map of a section of the East Pacific Rise, the highest elevations are shown in red. The sea floor slopes down from the mid-ocean ridge to lower elevations, which are shown in blue.

Slab Pull

At a subduction boundary, one plate is denser and heavier than the other plate. The denser, heavier plate begins to subduct beneath the plate that is less dense. The edge of the subducting plate is much colder and heavier than the mantle, so it continues to sink, pulling the rest of the plate along with it. The force that the sinking edge of the plate exerts on the rest of the plate is called **slab pull.**

Slab pull can be compared to the following situation: Suppose your jacket is resting on a table. You drop a heavy set of keys into a pocket that is dangling over the edge. The weight of the keys pulls downward on the rest of the jacket, causing it to slide toward the edge of the table.

Currently, many scientists consider slab pull to be a much stronger factor than ridge push or mantle convection in driving plate movements.

8.3 Section Review

1. How does the mantle convection hypothesis explain plate movements at divergent boundaries and subduction boundaries?
2. **CRITICAL THINKING** Describe the differences between the ridge push hypothesis and the slab pull hypothesis.
3. **PHYSICS** Construct and label a model that shows the processes of ridge push and slab pull.

8.4

KEY IDEAS

Plate movements have caused Earth's continents to change their positions on the globe over time.

New material has been added to the continents as a result of plate tectonics.

KEY VOCABULARY

- Pangaea
- craton
- terrane

Plate Movements and Continental Growth

Understanding plate tectonics has enabled geologists to reconstruct what Earth's surface may have looked like millions of years ago.

Reconstructing the Past

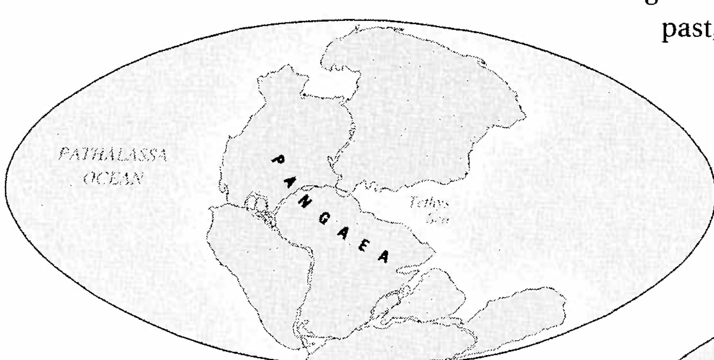
Geologists rely on many different kinds of evidence to reconstruct Earth's past. For example, consider the Ural Mountains in Russia and the Appalachian Mountains in the eastern United States. The rocks in these mountains show evidence of past subduction, suggesting that they formed at a convergent boundary. Yet neither of the mountain belts is located near a plate boundary today. Geologic evidence indicates that each range formed in the distant past at a plate boundary that no longer exists. The Appalachian Mountains formed when North America collided with Africa hundreds of millions of years ago. The Ural Mountains formed when separate lithospheric plates carrying Europe and Asia converged in a process similar to the one that is forming the Himalaya Mountains today.

Geologists can also use data about the ages of the rocks that form the ocean basins to reconstruct Earth's past. In addition, the magnetic record of igneous rocks on the continents can reveal the latitude at which an igneous rock formed, even if the rock has since moved from its original position on the globe.

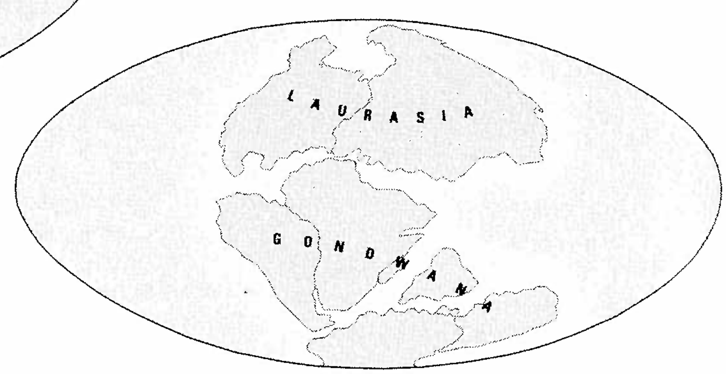
Fossils also provide clues about the past. Fossils of organisms that once lived in shallow seas have been found on high mountaintops.

Other information about Earth's past comes from rocks that show evidence of having been covered by glaciers in the past. Land areas that now lie in tropical regions of the Southern Hemisphere show evidence of having been covered by moving ice sheets at some time in the past, suggesting that the land areas were once located in a colder part of the globe.

BREAKUP OF PANGAEA The maps below illustrate the movements of Earth's landmasses over the last 200 million years.



200 MILLION YEARS AGO Earth's landmasses were welded together. An area of water that geologists call the Tethys Sea would eventually become the Mediterranean Sea.



180 MILLION YEARS AGO Pangaea broke apart into two separate landmasses called Laurasia and Gondwana.

Plate Tectonics and Pangaea

Evidence indicates that around 250 million years ago, all the continents were welded together into one landmass. Geologists use the name **Pangaea** (pan-JEE-uh) to refer to this giant landmass.

VOCABULARY STRATEGY

The word *Pangaea* comes from the Greek words *pan* and *gaia*. *Pan* means "all," and *gaia* means "Earth."

Formation of Pangaea

How did Pangaea form? Geologists must study data from the continents to make models of what Earth may have looked like before the formation of Pangaea. They cannot use data from the ocean floor, because the oldest oceanic crust is less than 200 million years old. Subduction has destroyed older oceanic crust.

One proposal is that, before the formation of Pangaea, a large continental mass stretched between the south pole and the equator. Geologists use the name Gondwana (gahnd-WAH-nuh) for this landmass. Gondwana was made up of smaller landmasses that would eventually become South America, southern Europe, Africa, the Near East, India, Australia, New Zealand, and Antarctica. Other, smaller landmasses ranged over the rest of the globe. Eventually Gondwana moved northward and converged with other landmasses to form Pangaea, as shown in the map at the far left on page 182.

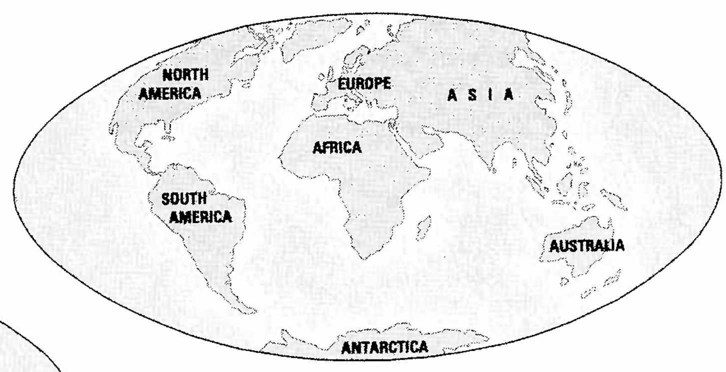
Breakup of Pangaea

Over time, the landmasses that had formed Pangaea began to break apart. As shown in the diagrams on page 182 and below, they broke into two separate landmasses, Gondwana and Laurasia (law-RAY-zhuh). Over time, Gondwana and Laurasia broke into smaller landmasses whose shapes began to resemble the shapes of the continents today.

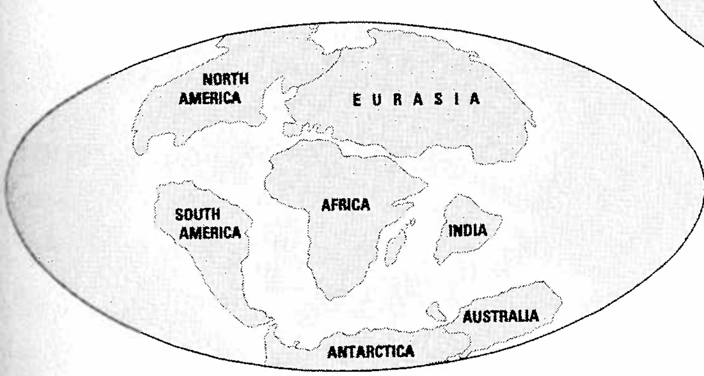
Pangaea is still breaking up, and the process by which landmasses have broken apart and converged may have happened many times before the formation of Pangaea.

VISUALIZATIONS
CLASSZONE.COM

Observe an animation of the breakup of Pangaea.
Keycode: ES0806



MODERN DAY The breakup of Pangaea continues today.



65 MILLION YEARS AGO The positions of the continents were beginning to resemble their modern-day positions.

SCIENCE & Technology

Shifting Ground: Tracking Plate Movements

Don't panic, but the ground beneath your feet is moving!

Except during earthquakes, the movement of Earth's lithospheric plates is too slight for you to detect. Nevertheless, as a result of these plate movements, Earth's continents are slowly moving across the face of the globe.

How do scientists measure plate movement? How can they use technology to predict the positions of Earth's landmasses in the distant future?

SATELLITE LASER RANGING
A satellite covered with reflectors is used to measure plate movement.

Since Pangaea broke apart about 180 million years ago, North America and Europe have been moving apart at a rate of about 2.5 centimeters per year. Now the two continents are nearly 5000 kilometers apart.

Scientists can track this slow movement of lithospheric plates very precisely using a technique called satellite laser ranging (SLR). A laser pulse from an Earth-based station is directed toward a satellite covered with reflectors. These reflectors bounce the light directly back to the ground station. By timing how long it takes the light to travel to and from the satellite and multiplying half this time by the speed of light, scientists can calculate the distance to the satellite. A comparison of measurements taken over several years shows how the location of the ground station has changed, as well as the rate of movement for the plate on which the station is located.

For example, SLR measurements show that the Hawaiian island of Maui, which is part of the Pacific Plate, is moving northwest toward Japan at a rate of about 7 centimeters per year. Even such gradual movement of the Pacific Plate will cause substantial change over time.

Patterns of plate movement can be used to make predictions about how Earth's landmasses may shift in the future. One prediction forecasts that in 100 million to 150 million years, Australia and Antarctica will have become one landmass. Africa may have collided with Europe, forming a new mountain range where the Mediterranean Sea is today. ■

Extension

GEOGRAPHY Based on the map below, predict the positions of Earth's landmasses 75 million years from now and 100 million years from now. Sketch maps showing your predictions.

VISUALIZATIONS
CLASSZONE.COM

Examine an animation of plate movement predicted for the future.

Keycode: ES0807

PREDICTING This map shows one prediction of what Earth might look like in 150 million years.

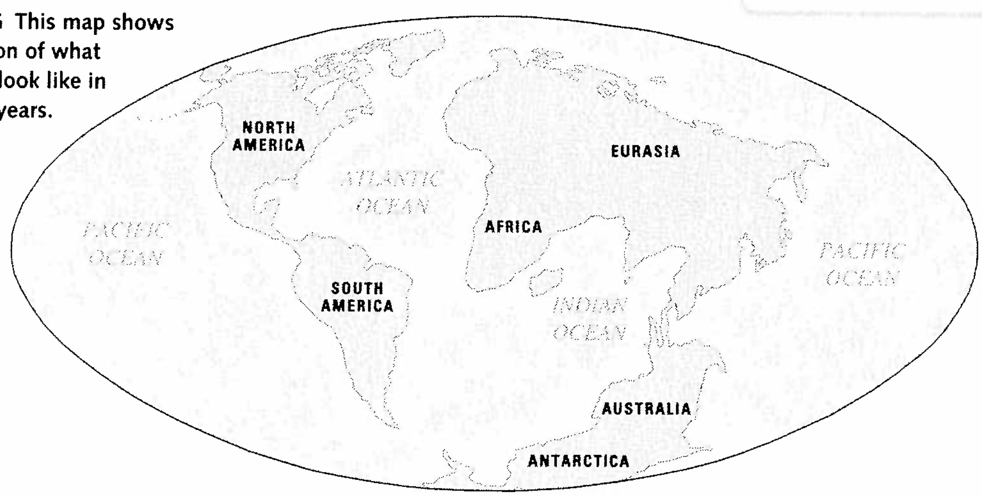


Plate Tectonics and Continental Growth

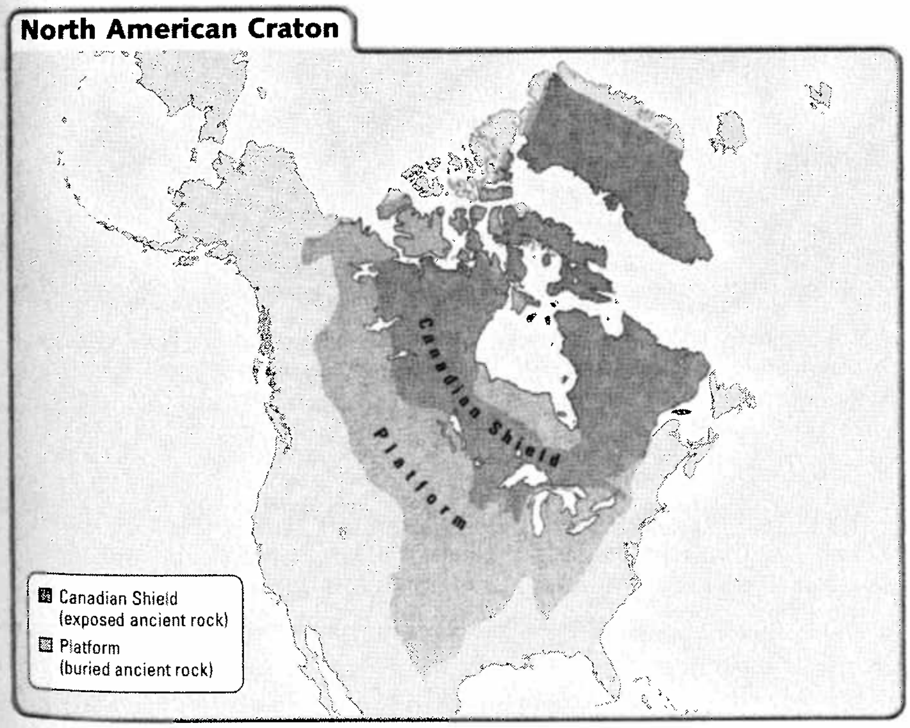
Plate tectonics has affected the shapes of the continents as well as their positions. The ancestors of most modern continents were smaller. Processes associated with plate movements have added rock materials to the margins of the ancient continent cores. The shapes that are familiar today have formed gradually.

At the core of each continent is an expanse of ancient rock called the **craton** (KRAY-TAHN). Around 2.5 billion years ago, this core continental material stabilized. Before then, Earth's surface was probably too hot and unstable for continents to form. One example of a craton is the North American craton, which is exposed at the surface in most of eastern Canada. Geologists call this part of the craton the Canadian Shield. Some of the rock materials found there are among the oldest ever dated and are estimated to have formed about 3.96 billion years ago. The remainder of the North American craton lies buried under a platform of sediments.

The North American craton shows the approximate shape of the continent one billion years ago. The remainder of North America has been added to the craton as the continent developed into its present dimensions.

VOCABULARY STRATEGY

The word *craton* comes from a Greek word meaning "power."



NORTH AMERICAN CRATON The Canadian Shield and the platform make up the North American craton. Newer materials, shown in green, have been added to the continent over time.

Sources of Growth Material

Material that is added to continents can come from a number of sources, including deep-sea sediments, igneous rock, river sediments, and terranes.

Deep-Sea Sediments

Deep-sea sediments can be added to the edges of a continent when an oceanic plate plunges under a continental plate at a subduction boundary. Some of the sediments from the ocean floor may be scraped off and left behind as growth material on the edge of the continent.

VISUALIZATIONS
CLASSZONE.COM

Observe an animation showing growth of a continent.
Keycode: ES0808

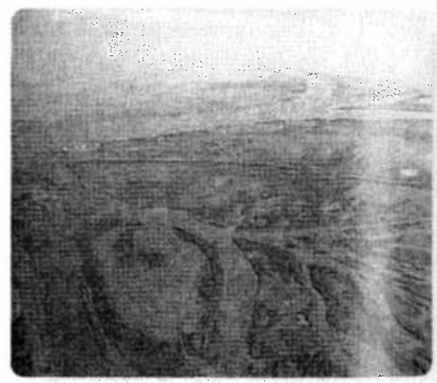
Igneous Rock

A second source of growth material is igneous rock. Plutons formed from magma that rises beneath the surface and cools are one example. In addition, volcanoes at subduction boundaries eject lava, ash, and rock materials. These materials are added to the edges of continents. Chains of volcanic islands are also characteristic of many subduction zones. The volcanic rock that builds up on such islands may be added eventually to a continent by plate movements. Geologists have even found that volcanic rock from mid-ocean ridges has been added to land areas.

River Sediments

Another source of growth material are the sediments deposited by rivers that flow across continents. These sediments, which consist of weathered and eroded rock materials and soils, build up at the edges of continents. The Mississippi River delta is a region where sediments are building up at the edge of the North American continent.

VOLCANIC ROCK Rock materials ejected by Mount Katmai, a volcano in Alaska, have been deposited in this valley.



RIVER SEDIMENTS The Mississippi River deposits sediments at its mouth.

Terranes

A **terrane** (tuh-RAYN) is a large block of lithospheric plate that has been moved, often over a distance of thousands of kilometers, and attached to the edge of a continent. Terranes are found on all continents and range greatly in age. The attachment of terranes may have been the primary process contributing to continental growth in western North America.

Geologists use three characteristics to identify a terrane. First, each terrane block is bounded on all sides by major faults. Second, the rocks and fossils found in the terrane do not match those of neighboring terranes. And third, the magnetic record found in the terrane does not match that of neighboring terranes. All of these characteristics are strong evidence that a terrane formed in another place and was transported to its present location.

One example of a terrane is the Cache Creek terrane of British Columbia in Canada. The rocks of this terrane include shallow-water limestones deposited on oceanic crust. The limestones contain fossil shells of tiny ocean animals called fusulinids (FYOO-zuh-LY-nihdz). These shells are totally unlike fusulinid fossils found in rocks of the same age in other

VOCABULARY STRATEGY

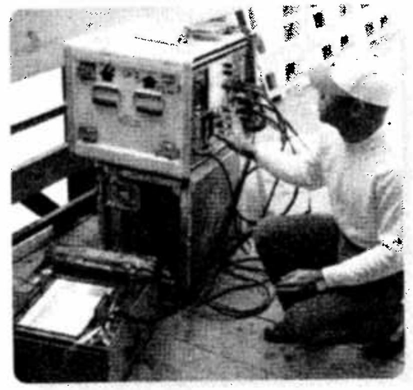
Do not confuse the geologic term *terrane* with the common word *terrain*. Both words come from the Latin word terra, meaning "earth" or "land."

CAREER

Electromagnetic Geophysicist

Electromagnetic (EM) geophysicists travel to all corners of the globe. Using an assortment of sophisticated instruments, they measure electric and magnetic fields and gather data for a variety of purposes: mapping tectonic-plate boundaries, locating natural resources (especially oil and gas), and conducting environmental analyses. EM geophysicists' assignments range from locating plate boundaries in the Himalayas to finding diamond deposits in Canada's Northwest Territories.

Like all geophysicists, EM specialists are well-grounded in the principles of plate tectonics and related Earth processes. EM specialists usually have a bachelor's degree in geophysics and an advanced degree. Students take math, physics, electronics, chemistry, and computer-science classes. They often gain hands-on experience of EM methods by working on special projects. EM specialists must enjoy gathering, interpreting, and synthesizing data and be able to communicate their findings clearly and accurately. Because EM specialists often work in far-flung places—sometimes commuting to work via helicopter or camel—a sense of adventure and willingness to "rough it" also come in handy. ■



THIS ELECTROMAGNETIC GEOPHYSICIST uses ground-penetrating radar to analyze the earth's composition and stability underneath a bridge.

CAREERS
CLASSZONE.COM

Find out more about a career in geophysics.
Keycode: ES0809

parts of North America. Instead, the Cache Creek fusulinids resemble shells found in Japan and large parts of Asia. From this evidence, scientists have hypothesized that plate movements carried the Cache Creek terrane thousands of kilometers across the Pacific Ocean before subduction processes welded it to the North American continent.

8.4 *Section Review*

1. **Describe what scientists hypothesize Earth's surface looked like 200 million years ago and 180 million years ago.**
2. **What is a craton?**
3. **Describe at least two processes that contribute to the growth of continents over time.**
4. **CRITICAL THINKING Some regions in South America show evidence of having been covered by moving ice sheets. How might plate movements have made it possible for ice to form on land that now lies in tropical regions of the world?**
5. **MATH Due to plate movements, the Hawaiian island of Maui is moving toward Japan at a rate of about 7 centimeters per year. At this rate, about how long would it take Maui to move 7 meters? 7 kilometers?**

CHAPTER 8

MAP Activity

Nuclear Facilities and Plate Boundaries

Skills and Objectives

- ***Compare*** locations of earthquakes and volcanoes with plate boundaries.
- ***Assess*** the value of GIS technology in decision-making.
- ***Determine*** categories of information pertinent to nuclear decision-makers.

Materials

- **Appendix B** *Earth's Tectonic Plates Map,* pages 712–713

Nuclear energy is an important source of electrical power in the United States. The radioactive elements contained inside a nuclear reactor are very dangerous, and special precautions must be taken in order to prevent these elements from leaking into the biosphere. Most nuclear sites in the United States are situated near the population and industrial centers of the eastern half of the United States or along the west coast.

The map on the following page was produced by combining three map layers derived from Geographic Information Systems (GIS) software. GIS "smart maps" display many varieties of data. They can be customized for use by scientists, regulators, and others to combine data for answering any number of questions. These maps help people to visualize how environments, places, and people interact. In this case, the map shows locations of significant earthquakes, volcanoes, and nuclear facilities in the contiguous United States.

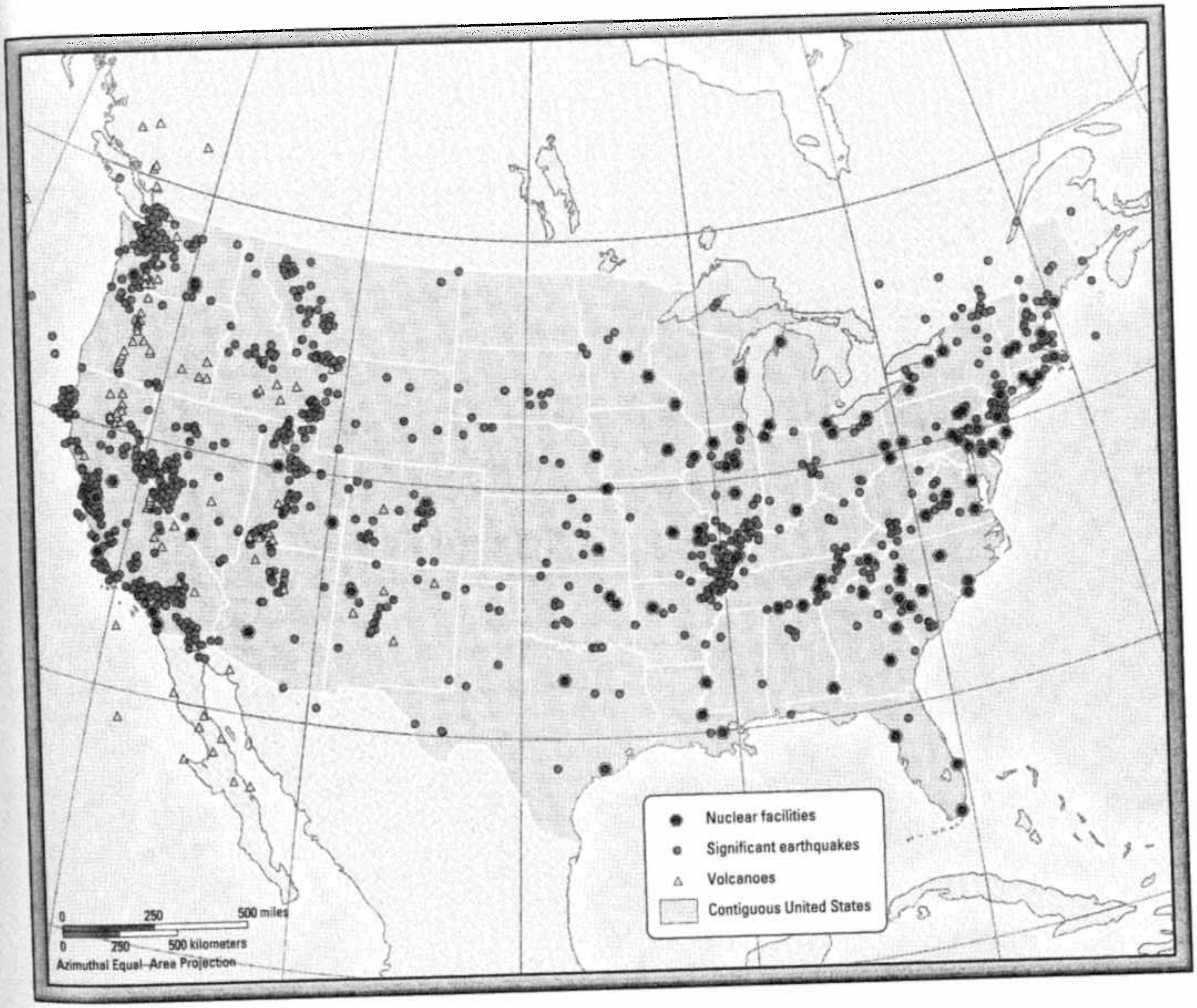
Places where there are multiple blue marks on the map indicate that several earthquakes have occurred in approximately the same location. Some nuclear sites, such as ones in California and New Hampshire, are obscured on the map because of a large amount of earthquake activity in the area. To whom would a map like this be of interest? Explain.

Procedure

1. Refer to the map comparing nuclear sites with the locations of known volcanoes and earthquake activity. Which of these three types of data is most numerous? Explain.
2. Compare the locations of volcanic and earthquake activity with the Earth's Tectonic Plates Map on pages 712 and 713. Write a sentence summarizing the pattern you observe between earthquake/volcanic activity and plate boundaries.
3. Suppose you are a regulator with the Nuclear Regulatory Commission, assigned to reviewing past decisions made on siting nuclear facilities. Use the map to help decide which facilities you would immediately call into question. Describe your reasoning.
4. Which facilities seem to be best sited? Explain.

Analysis and Conclusions

1. Does this map help predict future events that might occur in the United States? Explain.



2. What additional data would you seek to help explain any earthquake or volcanic activity not located on plate boundaries? How might a GIS-derived map help you determine what factors contribute to earthquake or volcanic activity?

3. Certainly safety is a prime consideration when siting a nuclear facility, but what other factors must play into the decision-making process? List categories of data you would request in your role as a regulator reviewing past siting decisions.

4. Assess the value of this map for your review of nuclear siting decisions.

DATA CENTER
CLASSZONE.COM
Learn more about GIS mapping.
Keycode: ES0811

CHAPTER 8 REVIEW

Summary of Key Ideas

8.1 According to the theory of plate tectonics, the lithosphere is broken into plates that move on the asthenosphere. The theory of plate tectonics explains why volcanoes and earthquakes tend to occur in concentrated belts and why the ages of rocks on the ocean floor show a distinctive pattern.

8.2 Plates move apart at divergent boundaries, toward each other at convergent boundaries, and past each other at transform boundaries. Convergent boundaries can be classified as subduction boundaries or collision boundaries.

8.3 Mantle convection, ridge push, and slab pull are hypothetical models for the causes of plate movements.

8.4 Plate movements have caused the positions of Earth's landmasses to shift over time. The shapes of the landmasses have also changed. The North American craton contains the oldest rocks of the continent. Other materials have been added to the continent over time.

KEY VOCABULARY

collision boundary (p. 178)
continental drift (p. 172)
convergent boundary (p. 177)
craton (p. 185)
deep-sea trench (p. 177)
divergent boundary (p. 176)
mantle convection (p. 180)
mid-ocean ridge (p. 174)
Pangaea (p. 183)
plate tectonics (p. 172)
ridge push (p. 181)
rift (p. 176)
rift valley (p. 176)
slab pull (p. 181)
subduction boundary (p. 177)
terrane (p. 186)
transform boundary (p. 178)

Vocabulary Review

Write the term from the key vocabulary list that best completes the sentence.

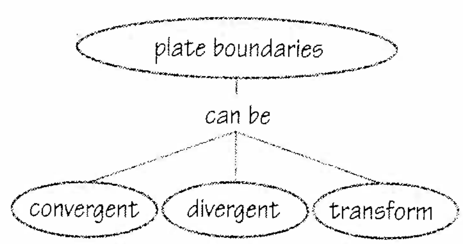
1. Wegener relied on fossil evidence, climate evidence, and continent shapes to support his hypothesis of ___?___ .
2. A large block of lithosphere that has been moved and attached to a continent is called a ___?___ .
3. The exposed part of the North American ___?___ is called the Canadian Shield.

Write the term from the key vocabulary list that best completes the analogy.

4. Ridge push : divergent boundary as slab pull : ___?___ .
5. Collision boundary : Himalayas as ___?___ : Mariana Islands

Concept Review

6. Describe some different types of data that support the theory of plate tectonics.
7. Describe what happens at a transform boundary.
8. Compare and contrast an oceanic-oceanic subduction boundary with an oceanic-continental subduction boundary.
9. Describe three hypotheses about the causes of plate motion.
10. What is Pangaea?
11. Describe several ways that new rock materials can be added to a continent.
12. Describe how geologists can identify a terrane.
13. **Graphic Organizer** Copy the concept map below. Then add to the concept map to include additional information about different types of convergent boundaries.



Critical Thinking

14. **Infer** How might coal deposits found in Antarctica provide evidence for plate tectonics?
15. **Analyze** The Great Pyramid of Giza in Egypt was built more than 4000 years ago. The structure faces slightly east of true north. Assuming they wanted the structure to face true north, did the Egyptian surveyors make a mistake in laying the pyramid's foundation or could there be some other explanation for the pyramid's position?
16. **Communicate** Draw a diagram to explain how the age and the elevation of the sea floor are related to distance from the rift valley along a mid-ocean ridge.
17. **Draw Conclusions** The oldest rocks of the continents are almost 4 billion years old, while the oldest rocks of the ocean basin are not even 200 million years old. Explain why this difference in age occurs and how it supports the theory of plate tectonics.

Internet Extension

INVESTIGATIONS CLASSZONE.COM

How Fast Do Plates Move? Examine maps of Hawaii and the Pacific seafloor. Use the age of volcanic rocks to calculate the rate of plate motion.

Keycode: ES0810

Writing About the Earth System

SCIENCE NOTEBOOK It may seem that plate movements affect only the geosphere, by creating mountains, causing earthquakes, and forming volcanoes. Do research on how the movement of Earth's plates affects the other spheres of Earth, and write about what you discover in your Science Notebook.

Interpreting Graphs

The graph shows a computer model of a slab of a lithospheric plate subducting into the asthenosphere. The subducting plate is shown in red, and the overriding plate is shown in blue. The dots represent earthquakes. The vertical axis of the graph shows the depth inside Earth. The horizontal axis of the graph shows the distance from the point where the plate starts to subduct. The graph also shows temperatures inside Earth.

18. Determine the temperature of the asthenosphere at a distance of 600 kilometers and a depth of 100 kilometers.
19. What is the approximate depth of earthquakes that occur at a distance of 200 kilometers from the point where the plate starts to subduct?
20. Describe the relationship between the distance from the point at which the plate begins to subduct and the depth of an earthquake.
21. How does the subducting plate appear to affect temperatures in the asthenosphere?
22. What is the approximate depth at which earthquake activity in the subducting plate stops?

Subduction and Temperature