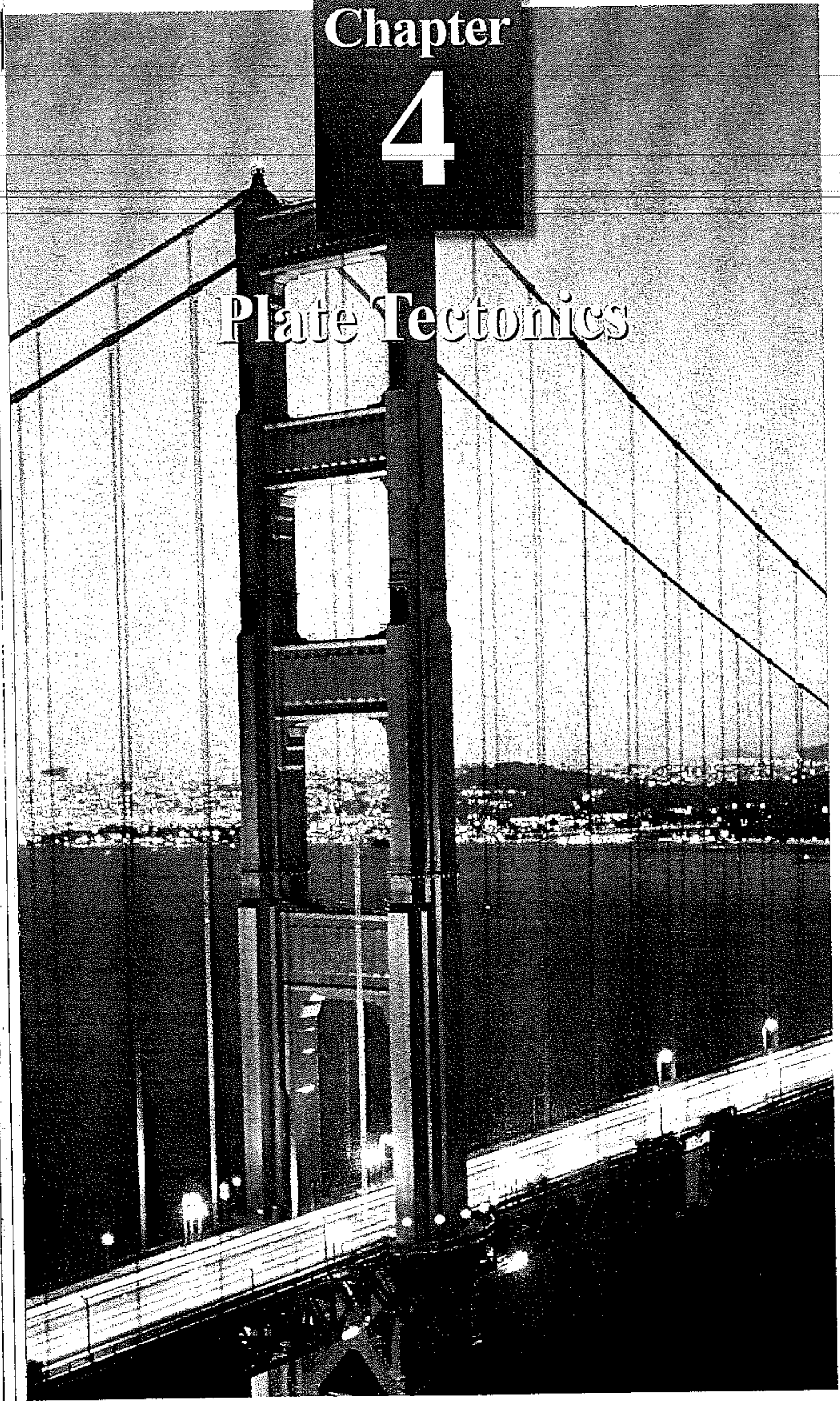
Chapter 4

Plate Tectonics



San Francisco is built on crust from the ancient ocean floor and possibly past continents.

The earth is in constant motion. The planet spins on its axis and orbits the sun. Earth scientists also believe that the surface of the earth itself is in motion, broken up into plates that drift slowly around the planet, a process called plate tectonics. Plate tectonics has shaped the San Francisco Bay area, which includes crust from the ocean floor as well as sediments possibly from past continents. In this chapter, you will learn how plate tectonics causes changes in the earth's crust.

Chapter Outline

4.1 Continental Drift

Section Objectives

- **Explain Wegener's hypothesis of continental drift.**
- **List evidence for Wegener's hypothesis of continental drift.**
- **Describe seafloor spreading.**

One of the most exciting recent theories in earth science began with observations made more than 400 years ago. As explorers such as Christopher Columbus and Ferdinand Magellan 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 seemed to fit perfectly into the west coast of Africa. Greenland seemed to fit between North America and northwestern Europe.

These observations soon led to questions. Were the continents once part of the same huge landmass? If so, what caused this landmass to break apart? What caused the continents to move to their present locations? These questions eventually led to the formulation of hypotheses.

In 1912, a German scientist, Alfred Wegener, proposed a hypothesis called **continental drift,** which stated that the continents had moved. Wegener hypothesized that the continents once formed part of a single landmass, which he named **Pangaea** (pan-JEE-uh), meaning "all lands." Surrounding Pangaea was a huge ocean, **Panthalassa,** meaning "all seas." According to Wegener, about 200 million years ago, Pangaea began breaking up into smaller continents, which drifted to their present locations. Wegener speculated that this motion may have crumpled the crust in places, producing mountain ranges such as the Andes on the western coast of South America.

Evidence of Continental Drift

In addition to the similarities in the coastlines of the continents, Wegener soon found other evidence to support his hypothesis. If the continents had once been joined, he reasoned, research should

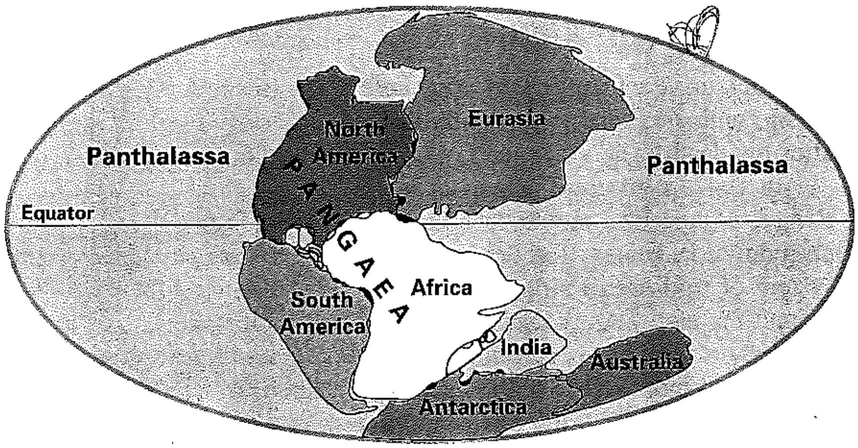


Figure 4–1. This map shows Pangaea as Alfred Wegener envisioned it.

uncover fossils of the same plants and animals in areas that had been adjoining parts of Pangaea. Wegener knew that identical fossil remains of *Mesosaurus*, a small, extinct land reptile that lived 270 million years ago, had already been found in both eastern South America and western Africa. Wegener knew that it was impossible for these reptiles to have swum across the Atlantic. And there was no evidence of any land bridges that might have connected the continents at some earlier time. Wegener thus concluded that South America and Africa must have been joined at one time.

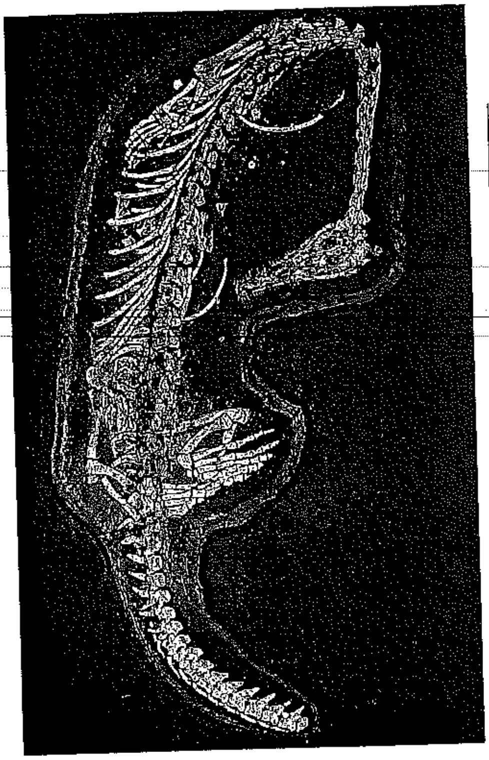


Figure 4–2. These *Mesosaurus* bones were discovered in Sao Paulo, Brazil. Identical fossil bones of *Mesosaurus* were found in western Africa, giving scientists strong evidence of continental drift.

Geologic evidence also supported Wegener's hypothesis of continental drift. The age and type of rocks in the coastal regions of widely separated areas, such as western Africa and eastern Brazil, matched closely. Mountain chains that ended at the coastline of one continent seemed to continue on landmasses across the ocean. The Appalachians, for example, extend northward along the eastern United States, while mountains of similar age and structure are found in Greenland and northern Europe. If these three landmasses are assembled in a model of Pangaea, the mountains fit together in one continuous chain.

Evidence of changes in climatic patterns added strength to Wegener's hypothesis. Geological research revealed layers of debris from glaciers in southern Africa and South America, areas that today have much warmer climates. Other fossil evidence—such as the coal deposits in the eastern United States, Europe, and Siberia—indicated that tropical or subtropical swamps covered much of the land area in the Northern Hemisphere. If the continents were once joined and positioned over the South Pole, Wegener suggested, these climatic differences would be easy to explain.

Despite the evidence supporting the hypothesis of continental drift, Wegener's ideas met with strong opposition. Many scientists rejected the hypothesis because it did not satisfactorily explain the force causing continental drift. In an effort to convince the scientific community that his hypothesis was valid, Wegener spent the rest of his life searching for evidence of that force. Unfortunately, Wegener died in 1930, while on an expedition to Greenland. He never found an explanation of what caused continents to move.

Seafloor Spreading

The conclusive evidence that Wegener sought to support his hypothesis of continental drift was finally 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,** an undersea mountain range with a steep, narrow valley running down its center. The Mid-Atlantic Ridge is one part of an entire system of **mid-ocean ridges** 65,000 km long that wind their way around the earth. As the scientists examined rock samples that they brought up from the ocean floor, they made a startling discovery. Contrary to most scientists' assumptions, the ocean floor was very young compared with the age of continental rocks. None of the oceanic rocks found were more than 150 million years old. The oldest continental rocks are about 4 billion years old. Why do you suppose scientists found this information surprising?

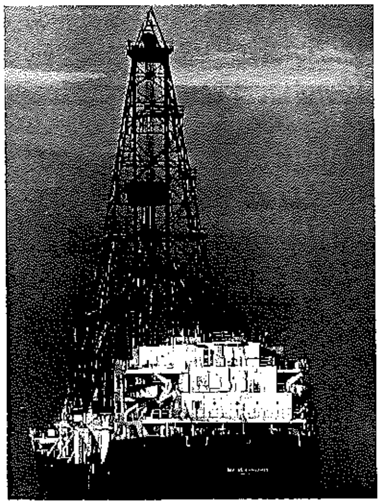
The Renewal of the Ocean Floor

After analyzing the data gathered from the Mid-Atlantic Ridge, Harry Hess, a geologist at Princeton University, suggested the following hypothesis. Suppose, he said, that the valley at the center of the ridge was actually a break, or rift, in the earth's crust and that molten rock, or magma, from deep inside the earth was welling up through the rift. This upwelling would be possible, Hess reasoned, if the ocean floor was moving away from both sides of the ridge. As the ocean floor moved away from the ridge, it was replaced by rising magma that cooled and solidified into new rock. Another

EARTHBEAT

Evidence of Seafloor Spreading

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



Explorations of the Mid-Atlantic Ridge have enabled scientists to obtain firsthand evidence of seafloor spreading. For 15 years, scientists aboard the *Glomar Challenger,* shown at left, traveled more than 575,000 km and collected nearly 100 km of core samples from 635 drill holes. Scientists examining the fossils embedded in the samples discovered that cores drilled closest to the ridge had the youngest fossils. The fossils proved to be progressively older as samples were taken farther from the ridge. This find supported the idea that new crust forms along the ridge as older crust moves aside.

With the help of deep-diving submarines, scientists were able to explore the rift valley that bisects the mid-ocean ridge. The crew on board the submarine *Archimede* were among the first to witness magma bubbling up from the mantle. A year later, cameras on board the *Alvin* photographed lava formations that had emerged from the mantle and hardened in the rift valley. One of these photographs is shown above. The lava formations provided further evidence of seafloor spreading.

If you had six core samples collected from the ridge outward, how many samples would you have to test to determine whether the samples on the right or the left were closer to the mid-ocean ridge? Why?

geologist, Robert Dietz, named this movement **seafloor spreading.** Hess suggested that if the ocean floor was moving, the continents might also be moving. Perhaps seafloor spreading was the force that Wegener had failed to find to support his hypothesis of continental drift.

Still, Hess's ideas were just hypotheses. The proof would come years later, in the mid-1960's, and would be discovered through paleomagnetism, the study of the past magnetic properties of rocks.

Paleomagnetism of the Ocean Floor

If you have ever used a compass to determine direction, you know that the earth acts as a giant magnet, with both a north and a south pole. The compass needle aligns with the field of magnetic force that extends from one pole to the other.

IMPACT ON SOCIETY

Living on the Mid-Atlantic Ridge

Although most of the earth's mid-ocean ridges lie completely underwater, part of the Mid-Atlantic Ridge rises above sea level just south of the Arctic Circle. This exposed section of the Mid-Atlantic Ridge forms the island country of Iceland. Since its founding by Vikings over 1,000 years ago, the inhabitants of Iceland have had to contend with the constant geological activity associated with seafloor spreading.

Separation of the earth's crust along the Mid-Atlantic Ridge affects Iceland's landscape in several ways. Tectonic motion, for example, 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 the earth in the last 500 years has occurred on Iceland.

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

If geologists want to locate the youngest rocks on Iceland, where should they look? Where should they look to find the oldest rocks? Why?

A similar phenomenon occurs when magma cools and solidifies. Certain iron-bearing minerals within the rock become magnetized. When the rock hardens, the magnetic orientation of the minerals becomes permanent and points to the north.

Scientists discovered, however, that this was not always the case. From the beginning of the nineteenth century, they had been finding rocks with magnetic orientations that pointed south. Some scientists concluded that the earth's magnetic field must have reversed itself at times during the earth's history. This conclusion was verified by dating rocks with different magnetic orientations. All the rocks with magnetic fields pointing north fell into the same time periods—periods of normal polarity. All the rocks with magnetic fields pointing south also fell into similar time periods—periods of reverse polarity. The scientists discovered that throughout the earth's history the magnetic field has reversed itself many times.

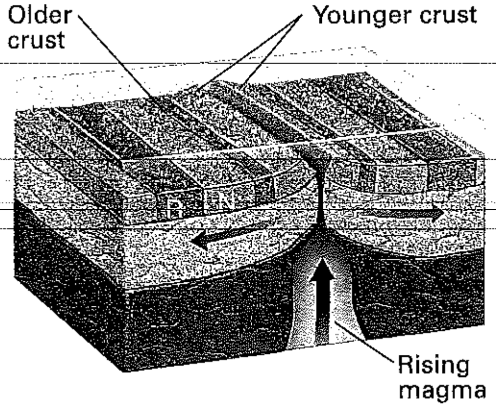


Figure 4–3. The stripes in the crust are shown here to illustrate the earth's alternating magnetic field. Dark stripes represent the ocean floor with reversed polarity (R), while the lighter stripes show normal polarity (N).

At the same time these discoveries about the earth's magnetic field were being made, scientists were also finding puzzling magnetic patterns on the ocean floor. These patterns, when drawn in on maps of the ocean floor, showed alternating bands of normal and reversed magnetism. As molten rock rises from the rift in a mid-ocean ridge, it quickly cools and hardens and its magnetic orientation becomes fixed. Its magnetic orientation will reflect the polarity of the earth's magnetic field at that time, either normal or reversed.

Scientists' confidence in the validity of this idea grew when they discovered that the striped patterns of magnetism on one side of a ridge are mirror images of the striped patterns on the other side of the ridge. This discovery supported Hess's idea that molten rock from a rift cools, hardens, and then moves away in opposite directions on both sides of the ridge. The ocean floor, it seemed, was indeed spreading.

Finally, in 1965, two groups of scientists working independently of each other discovered a previously unknown reversal in the earth's magnetic field. One group discovered the reversal in rocks on land, and the other group discovered the reversal in rocks on the ocean floor. The dates of both reversals were exactly the same. This was clear evidence that the earth's magnetic polarity does reverse itself and that the ocean floor does spread. Scientists reasoned that seafloor spreading provides a way for the continents to be moved over the surface of the earth. Here, at last, were the discoveries that Wegener had sought, the scientific evidence he needed to verify his hypothesis of continental drift.

Section 4.1 Review

1. What observation first led to Wegener's hypothesis of continental drift?
2. What types of evidence support Wegener's hypothesis?
3. Describe the process of seafloor spreading.
4. Explain how scientists know that the earth's magnetic poles have reversed themselves many times during earth's history.

Section Objectives

- **Summarize the theory of plate tectonics.**
- **Compare the characteristic geologic activities that occur along the three types of plate boundaries.**
- **Explain the possible role of convection currents in plate movement.**
- **Summarize the theory of suspect terranes.**

4.2 The Theory of Plate Tectonics

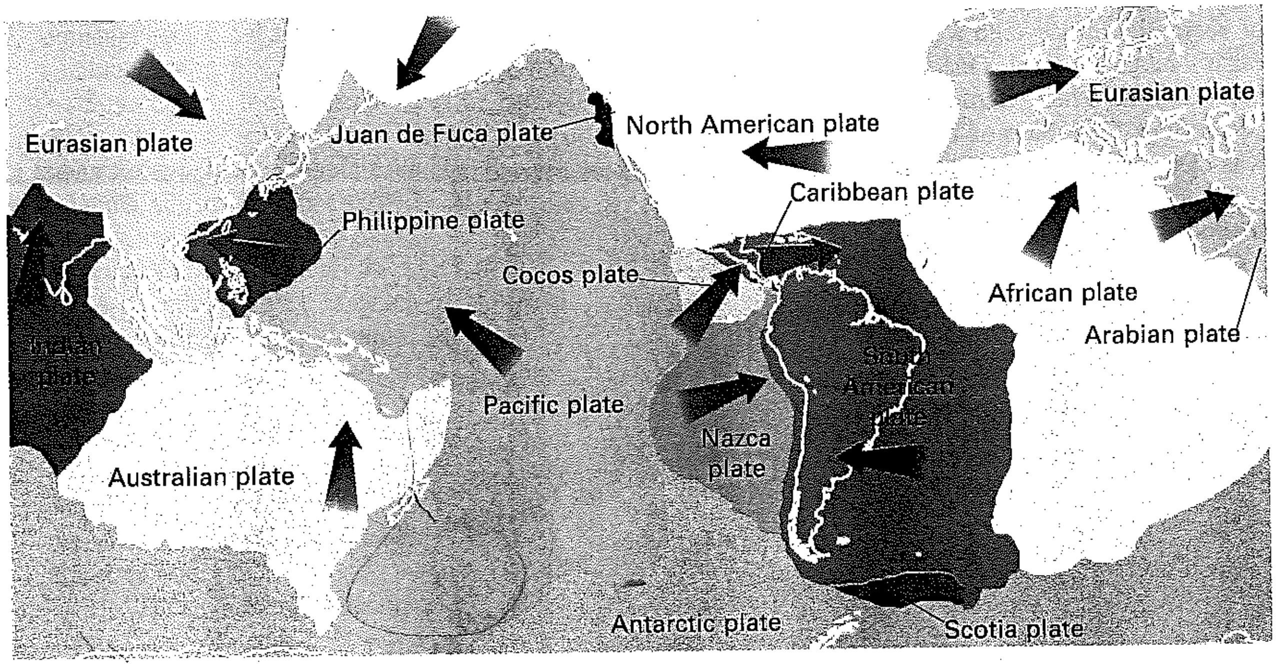
By the 1960's, accumulated evidence supporting the hypothesis of continental drift and seafloor spreading led to the formulation of a more far-reaching theory. This theory is called **plate tectonics.** The theory of plate tectonics not only describes continental movement but also proposes a possible explanation of why and how continents move. The term *tectonics* comes from the Greek word *tektonikos*, meaning ''construction.'' Tectonics is the study of the formation of features in the earth's crust.

The earth's crust consists of two types—**oceanic crust** and **continental crust.** Material on the ocean floor forms oceanic crust. Continental crust makes up the continental landmasses.

The oceanic and continental crust and the rigid upper mantle make up the **lithosphere.** It forms the thin outer shell of the earth. Beneath the lithosphere lies the **asthenosphere,** a layer of plastic rock, that is, solid rock that slowly flows (like putty) when under pressure. According to the theory of plate tectonics, the lithosphere is broken into separate plates that ride on the denser asthenosphere much like blocks of wood float on water. The continents and oceans are carried along as ''passengers'' on the moving lithospheric plates. Most lithospheric plates are composed of both continental and oceanic crust.

To date, about 30 lithospheric plates have been identified. Some plates are moving toward each other, some are moving apart, and some are sliding past each other. This constant movement has created the earth's major surface features, such as mountain ranges and deep-ocean trenches.

Figure 4-4. This map shows the location and movement of various lithospheric plates.



Lithospheric Plate Boundaries

Many changes in the earth's crust originate along lithospheric plate boundaries. The boundaries of the plates are not always easy to identify. As you can see in Figure 4–4, the familiar outlines of the continents and oceans depicted on maps do not always resemble the outlines made by the plate boundaries. Plate boundaries may be in the middle of the ocean floor, around the edges of continents, or within continents. There are three types of plate boundaries, each of which is associated with a characteristic type of geologic activity.

Divergent Boundaries

The geologic activity that occurs along plate boundaries differs according to the way plates move in relation to each other. For example, two plates moving away from each other form a **divergent** (die-VUR-junt) **boundary.** As the plates move apart, molten rock from the asthenosphere rises and fills the space between the plates. As the molten rock cools, it hardens onto the edges of the separating plates and creates new oceanic crust. Most divergent boundaries are found on the ocean floor. The locations of these spreading boundaries follow the mid-ocean ridges.

In the center of a mid-ocean ridge is a narrow valley formed as the plates separate. This formation is called a **rift valley.** Other rift valleys may 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.

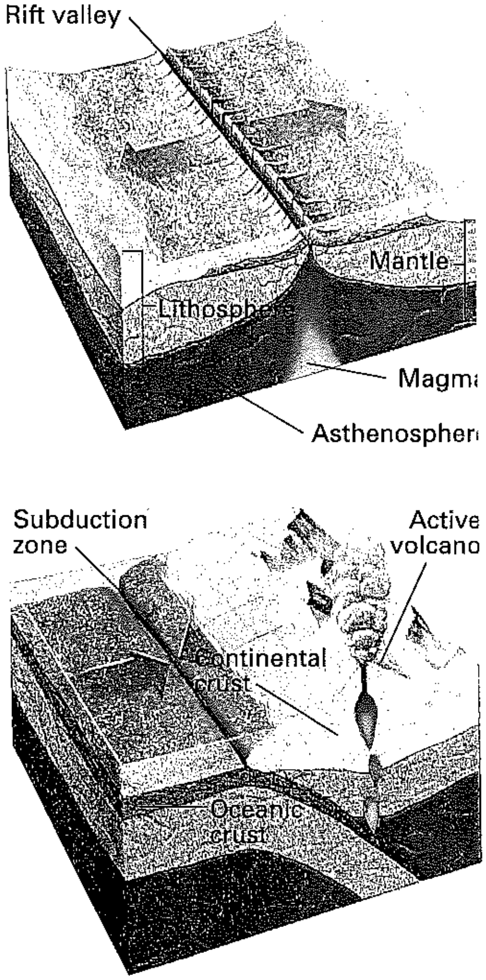


Figure 4–5. At divergent boundaries (top), plates separate. Plates collide at convergent boundaries (bottom).

Convergent Boundaries

As seafloor spreading pulls plates apart at one boundary, those plates push into neighboring plates at other boundaries. The direct collision of one plate with another makes another type of plate boundary—a **convergent** (kun-VUR-junt) **boundary.**

Three types of collisions can occur at convergent boundaries. One type occurs when a plate with oceanic crust at its leading edge collides with a plate with continental crust at its edge. Because oceanic crust is denser, it is *subducted,* or forced under the less dense continental crust, as shown in Figure 4–5. Scientists refer to the region along a plate boundary where one plate moves under another plate as a **subduction** (sub-DUK-shun) **zone.** A deep **ocean trench** generally forms along a subduction zone. As the oceanic plate moves down into a subduction zone, it melts and becomes part of the mantle material. Some of the magma formed rises to the surface through the continental crust and produces volcanic mountains.

A second type of collision occurs when two plates with continental crust at their leading edges come together. During this type of collision, neither plate is subducted because the two plates have the same density. Instead, the colliding edges are crumpled and uplifted, producing large mountain ranges. Scientists are convinced that the Himalayas were formed by this type of collision.

The third type of collision along convergent boundaries occurs between oceanic crust and oceanic crust. A deep ocean trench also

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forms when one of these plates is subducted. Part of the subducted plate melts, and the resulting molten rock rises to the surface along the trench to form a chain of volcanic islands, called an **island arc.**

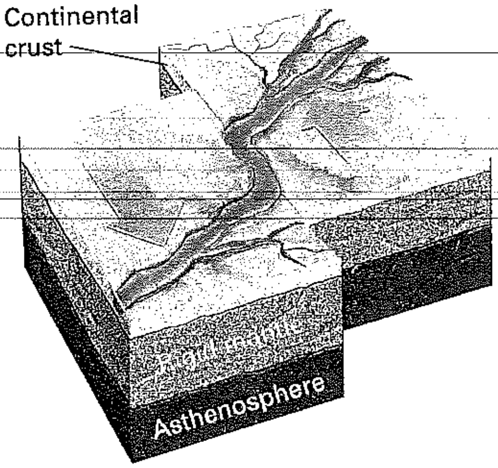


Figure 4–6. Plates scrape past each other at transform fault boundaries. Note the change in the course of the river as the plates move past each other.

Transform Fault Boundaries

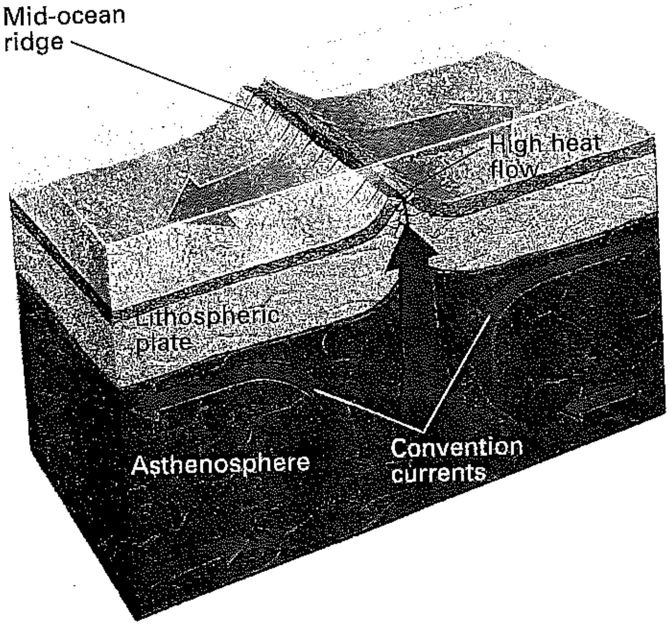
A plate boundary called a **transform fault boundary** forms where two plates are grinding past each other. The plate edges usually do not slide along smoothly. Instead, they scrape together and move in a series of sudden spurts of activity separated by periods of little or no motion. A major transform fault boundary is the San Andreas fault in California.

Causes of Plate Motion

Many earth scientists think that the movement of lithospheric plates is due to **convection,** the transfer of heat through the movement of heated fluid material. This same process occurs when you place a pot of water on the stove to boil. As the water at the bottom of the pot heats up, it expands and becomes less dense than the cool water above it. The cool water, which is now denser than the warm water, sinks and forces the warm water to the surface. This cycle of warm water rising and cool water sinking to replace it is called a **convection current.**

Scientists think a similar process results in convection currents within the asthenosphere. Heat from the earth's core and mantle causes some material in the lower asthenosphere to become hotter and therefore less dense than the material above it. The hot material rises. When this hot material reaches the base of the lithosphere, it cools. When the molten material cools, it becomes more dense and starts to sink. The cooling material is pushed to the side by new hot

Figure 4–7. Scientists think that convection currents are the mechanism that moves lithospheric plates



material that rises. As the process continues, the lithospheric plate is carried along with the moving material, as shown in Figure 4–7.

Evidence for the existence of convection currents in the asthenosphere comes from recent studies of the ocean floor. Scientists have measured the amount of heat leaving rocks at various points in the lithosphere. They have found this heat flow to be higher along plate boundaries where two plates are moving apart than it is elsewhere on the ocean floor. If hot convection currents are rising along these plate boundaries as the theory suggests, these temperature differences can be explained.

Though convection currents can explain some aspects of plate movement, questions remain. Scientists asked whether convection currents alone are strong enough to move the plates at the rates suggested by geological evidence. If not, they speculated, another mechanism may be responsible.

INVESTIGATE!

To learn more about convection currents, try the In-Depth Investigation on pages 80–81.

SMALL-SCALE INVESTIGATION

Lithospheric Plate Boundaries

The movement of lithospheric plates has created many of the earth's topographical features. You can demonstrate the results of plate movement by using clay models of lithospheric plates.

Materials

ruler, paper, scissors, rolling pin or rod, modeling clay (2–3 lb.), plastic knife, lab apron

Procedure

1. Draw two 10 × 20 cm rectangles on your paper, and cut them out.
2. Use a rolling pin to flatten out two pieces of clay until they are about 1 cm thick. Cut each piece into a 10 × 20 cm rectangle. Place a paper rectangle on each piece of clay.
3. Place the two clay models side by side on a flat surface, paper side down. Place your hands directly on top of each piece, as shown, and slowly push the models together until the edges begin to buckle and rise off the surface of the table.
4. Turn the clay models around so that the unbuckled edges are touching. If these edges have been slightly deformed during Step 3, smooth them out before proceeding.

5. Place one hand on each clay model. Apply only slight pressure toward the seam. Slide one clay model forward and the other model backward about 7 cm.
6. Repeat Step 5 three more times, alternating the direction in which you push each model.

Analysis and Conclusions

1. What type of plate boundary are you demonstrating with the model in Step 3?
2. What type of plate boundary are you demonstrating in Steps 5 and 6?
3. How does the appearance of the facing edges of the models in the two processes compare? How do you think these processes might affect the appearance of the earth's surface?

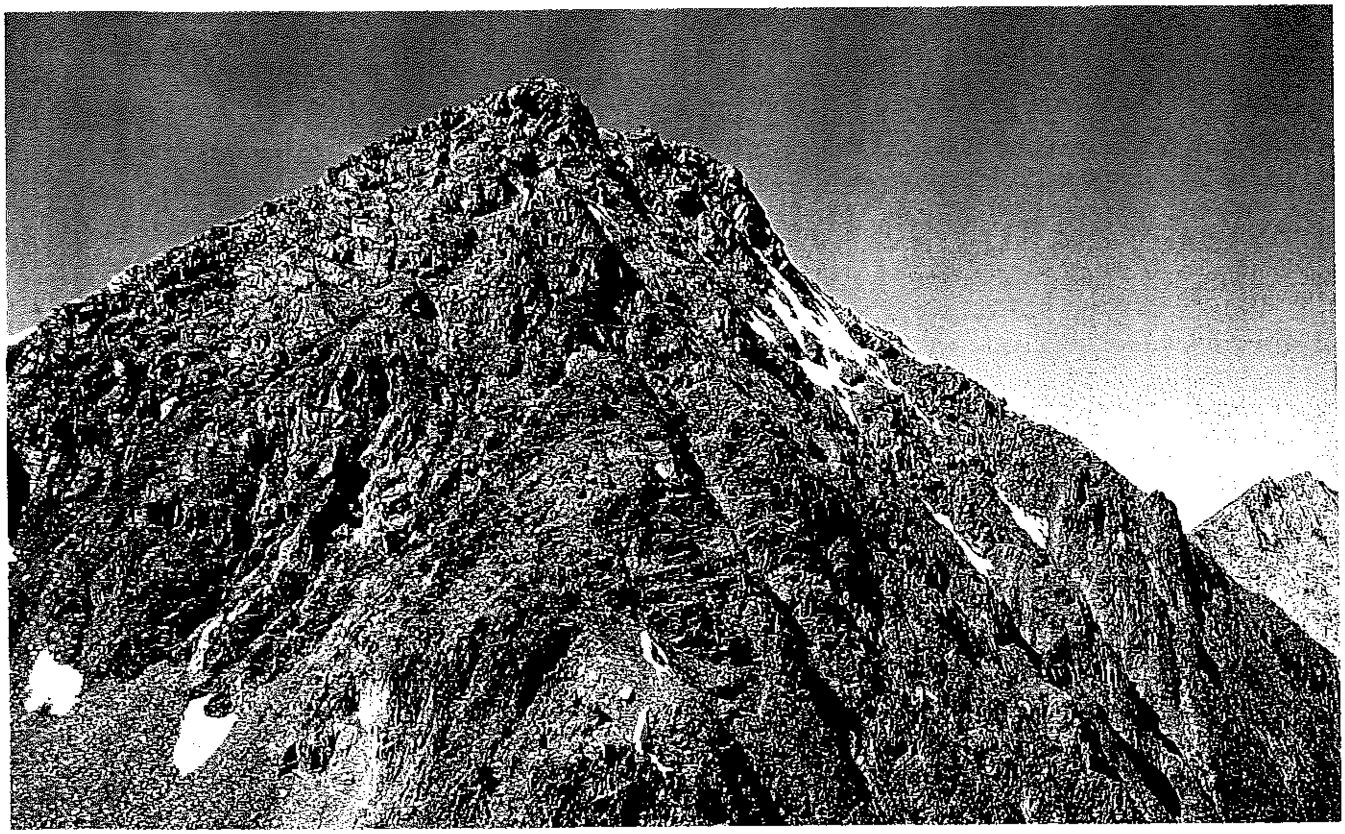
Suspect Terranes

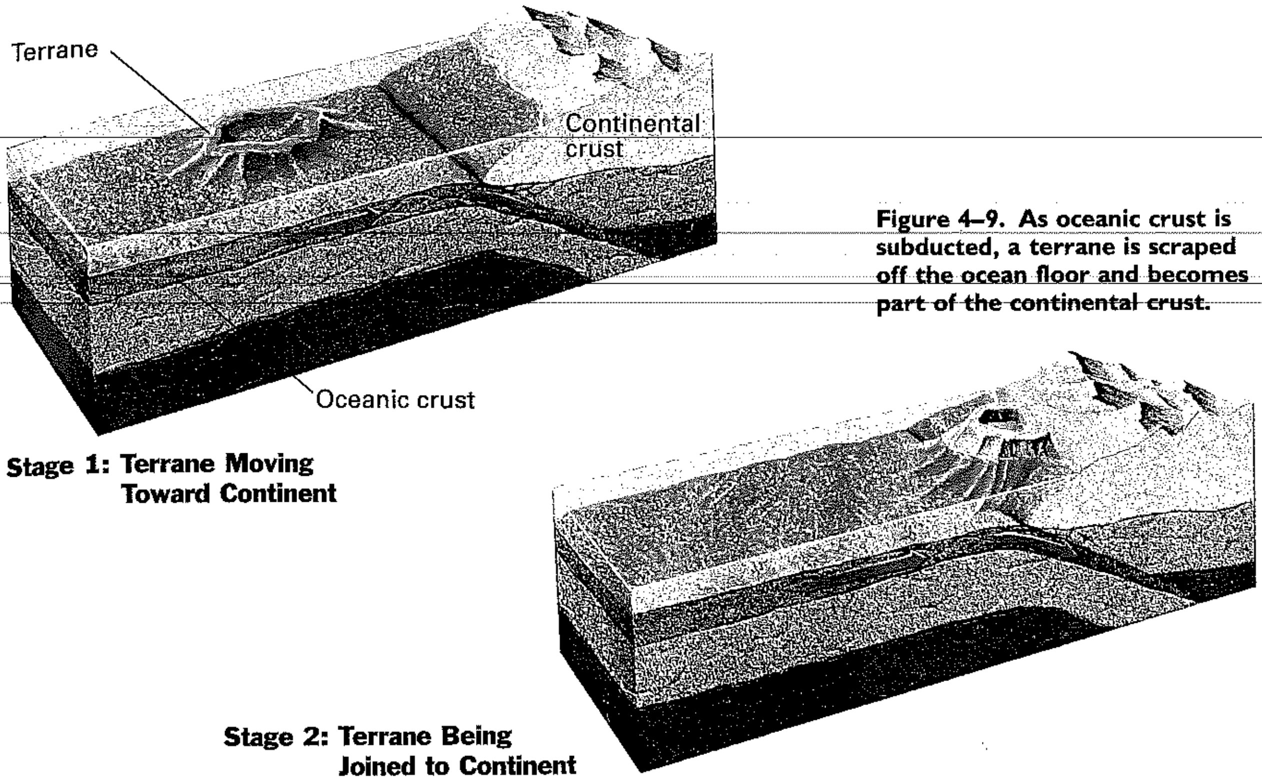
Alfred Wegener's hypothesis of continental drift was an attempt to explain how the continents arrived at their present locations. The theory of plate tectonics refined Wegener's hypothesis, suggesting the actual mechanisms by which the continents might move. Neither continental drift nor plate tectonics, however, can explain how the continents were formed.

New discoveries are providing some possible explanations of how continents formed. These new discoveries provide the basis for the **theory of suspect terranes.** Simply put, this theory suggests that the continents are actually a patchwork of **terranes**—pieces of lithosphere, each with its own distinct geologic history. Each terrane has three identifying 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. Finally, the magnetic properties of a terrane do not match those of neighboring terranes.

Geologists have found evidence to support the suspect terrane theory. Northern California is a good place to observe this evidence. Geologists have found 10 different terranes in the San Francisco Bay area alone. For example, in the hills of Palo Alto, there is fossil evidence of coral atolls—tropical ocean islands made up of coral, the skeletons of sea organisms. Farther south lies a terrane called Permanette. The limestone of Permanette contains fossils that prob-

Figure 4–8. The rocks of the Slide Mountain terrane are fragments of the ancient ocean floor that are now part of North America.





Stage 1: Terrane Moving Toward Continent

Stage 2: Terrane Being Joined to Continent

Figure 4–9. As oceanic crust is subducted, a terrane is scraped off the ocean floor and becomes part of the continental crust.

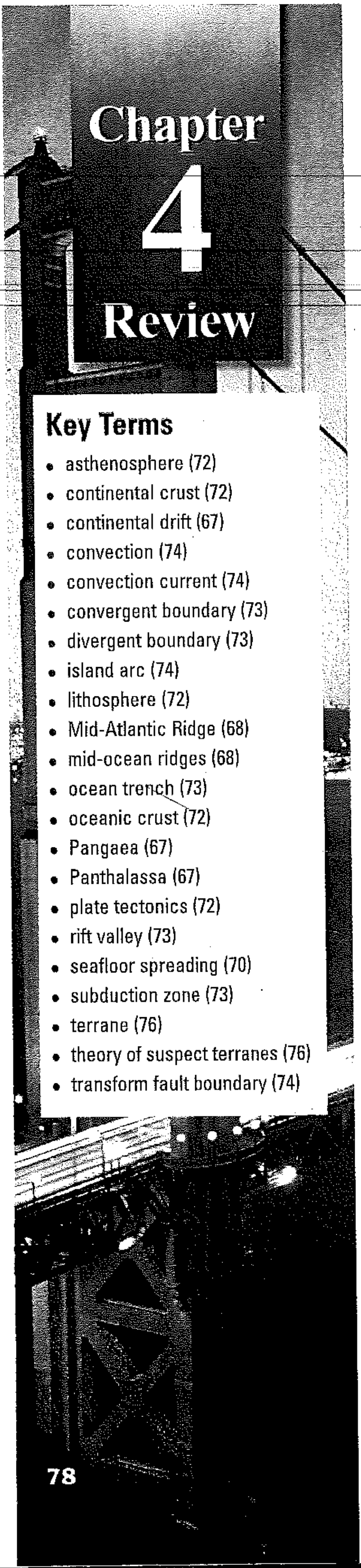
ably originated from the ocean depths near the equator. The theory of suspect terranes explains how tropical coral atolls and equatorial ocean fossils became part of the geology of northern California.

According to the suspect terrane theory, blocks of terranes are carried along on the ocean floor by the action of seafloor spreading to a lithospheric plate boundary where subduction is occurring. As the plate with oceanic crust moves under the plate with continental crust, the terranes are scraped off the descending ocean floor, as shown in Figure 4–9. Some terranes may form mountains, while others simply add to the surface area of a continent.

When Alfred Wegener first proposed his hypothesis of continental drift, he could not have imagined the explosion of scientific inquiry it would inspire. Like many hypotheses, continental drift raised more questions than it answered. The theories of plate tectonics and suspect terranes are attempts to answer some of those questions.

Section 4.2 Review

1. Summarize the theory of plate tectonics.
2. Name and describe the three types of plate boundaries.
3. Describe the three types of plate collisions that occur along convergent boundaries.
4. How might convection currents cause plate movement?
5. Explain how mountains on land can be composed of rocks that contain fossils of animals that lived in the ocean.



Chapter 4 Review

Key Terms

- asthenosphere (72)
- continental crust (72)
- continental drift (67)
- convection (74)
- convection current (74)
- convergent boundary (73)
- divergent boundary (73)
- island arc (74)
- lithosphere (72)
- Mid-Atlantic Ridge (68)
- mid-ocean ridges (68)
- ocean trench (73)
- oceanic crust (72)
- Pangaea (67)
- Panthalassa (67)
- plate tectonics (72)
- rift valley (73)
- seafloor spreading (70)
- subduction zone (73)
- terrane (76)
- theory of suspect terranes (76)
- transform fault boundary (74)

Key Concepts

Wegener's hypothesis of continental drift states that the continents were once a single landmass. **See page 67.**

Scientists have found fossil, geological, paleomagnetic, and climatic evidence to support the hypothesis of continental drift. **See page 67.**

New ocean floor is constantly being produced through seafloor spreading. **See page 68.**

The theory of plate tectonics proposes that changes in the earth's crust are caused by the very slow movement of large lithospheric plates. **See page 72.**

The geological activity that occurs along the three types of plate boundaries differs according to the way plates move in relation to each other. **See page 73.**

Convection currents may be responsible for plate movements. **See page 74.**

The theory of suspect terranes proposes that portions of the continents are a patchwork of terranes scraped off subducting lithospheric plates. **See page 76.**

Review

On your own paper, write the letter of the term that best completes each of the following statements.

1. The German scientist Alfred Wegener proposed the existence of a huge landmass called
a. Panthalassa. b. rift valley.
c. Mesosaurus. d. Pangaea.

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

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

4. An underwater mountain chain formed with molten rock from seafloor spreading is called a
a. divergent boundary. b. subduction zone.
c. mid-ocean ridge. d. convergent boundary.

5. The term *tectonics* comes from a Greek word meaning
a. "movement." b. "plate."
c. "continent." d. "construction."

6. The layer of mantle with plastic rock that underlies and moves the plates is called the
a. lithosphere. b. asthenosphere.
c. oceanic crust. d. terrane.

7. To date, scientists have identified approximately
a. 5 plates. b. 30 plates.
c. 15 plates. d. 50 plates.

8. Two plates moving away from each other form a
a. transform fault boundary. b. convergent boundary.
c. fracture. d. divergent boundary.

9. The collision of one lithospheric plate with another forms a
a. convergent boundary. b. transform fault boundary.
c. rift valley. d. divergent boundary.

10. The region along lithospheric plate boundaries where one plate is moved beneath another is called a
a. rift valley. b. transform fault boundary.
c. subduction zone. d. convergent boundary.

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

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

13. Scientists think that the convection currents that are responsible for the movement of lithospheric plates are found in the
a. lithosphere. b. asthenosphere.
c. terranes. d. rift valleys.

14. Geologists think that portions of the continents are made up of formerly separate pieces of lithosphere called
a. terranes. b. plates.
c. continental crust. d. oceanic crust.

Critical Thinking

On your own paper, write answers to the following questions.

1. In what ways might the concept of continental drift be compared to a jigsaw puzzle?
2. 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?
3. Assume that the total surface area of the earth is not changing. If new material is being added to the earth's crust at one boundary, what would you expect to find happening at another boundary?
4. Explain the following statement: Due to the action of convection currents, the ocean floor is constantly renewing itself.

Application

1. Explain the role of technology in the progression from the hypothesis of continental drift to the theory of plate tectonics.
2. If you wanted to prove that a suspect terrane had been scraped onto the North American plate, what kind of evidence would you search for?
3. Construct a **concept map** using 10 of the new terms listed on the previous page by making connections that illustrate the relationship among the terms.

Extension

1. Copy a world map showing the outlines of the continents. Cut out the continents and assemble a model of Pangaea. Compare your model to Wegener's model of Pangaea that is shown on page 67.
2. In the late 1800's, Eduard Suess, an Austrian scientist, developed the concept of a supercontinent called Gondwanaland. Look up information about Suess's ideas and compare them with the hypothesis of continental drift proposed by Wegener.
3. Plate tectonics is a relatively new theory. Conduct library research to find out how early scientists accounted for changes in the continents long before the theory of plate tectonics. Report your findings to the class.