

The background of the page is a composite image. The top half shows a bright, cloudy sky. The bottom half shows a dark, rocky volcanic landscape with glowing red lava flows. Two fish are superimposed on the image: a yellow tang with a large white eye ring in the upper right, and a blue and yellow striped surgeonfish in the lower left.

# How Are Volcanoes & Fish Connected?

It's hard to know exactly what happened four and a half billion years ago, when Earth was very young. But it's likely that Earth was much more volcanically active than it is today. Along with lava and ash, volcanoes emit gases—including water vapor. Some scientists think that ancient volcanoes spewed tremendous amounts of water vapor into the early atmosphere. When the water vapor cooled, it would have condensed to form liquid water. Then the water would have fallen to the surface and collected in low areas, creating the oceans. Scientists hypothesize that roughly three and a half billion to four billion years ago, the first living things developed in the oceans. According to this hypothesis, these early life-forms gradually gave rise to more and more complex organisms—including the multitudes of fish that swim through the world's waters.



## unit projects

Visit [blue.msscience.com/unit\\_project](http://blue.msscience.com/unit_project) to find project ideas and resources.  
Projects include:

- **History** Create a time line of volcano trivia with facts such as location, greatest magnitude, most destructive, and first volcano recorded. Can volcanoes be predicted?
- **Careers** Study the specialized skills of various careers as you design and prepare a city for a natural disaster.
- **Model** Research, design, construct, test, evaluate, and present your home seismograph in a 5-minute infomercial.




*Volcanoes and the Ring of Fire* is an online study of plate tectonics. Design a chart of recent volcano activity, and use it to produce a map of the Ring of Fire with the names and ages of each volcano.



# Plate Tectonics

## chapter preview

### sections

- 1** Continental Drift
  - 2** Seafloor Spreading  
*Lab* Seafloor Spreading Rates
  - 3** Theory of Plate Tectonics  
*Lab* Predicting Tectonic Activity
-  **Virtual Lab** Where do most earthquake epicenters and volcanoes occur?

## Will this continent split?


Ol Doinyo Lengai is an active volcano in the East African Rift Valley, a place where Earth's crust is being pulled apart. If the pulling continues over millions of years, Africa will separate into two landmasses. In this chapter, you'll learn about rift valleys and other clues that the continents move over time.

**Science Journal** Pretend you're a journalist with an audience that assumes the continents have never moved. Write about the kinds of evidence you'll need to convince people otherwise.

# Start-Up Activities



## Reassemble an Image

Can you imagine a giant landmass that broke into many separate continents and Earth scientists working to reconstruct Earth's past? Do this lab to learn about clues that can be used to reassemble a supercontinent. 

1. Collect interesting photographs from an old magazine.
2. You and a partner each select one photo, but don't show them to each other. Then each of you cut your photos into pieces no smaller than about 5 cm or 6 cm.
3. Trade your cut-up photo for your partner's.
4. Observe the pieces, and reassemble the photograph your partner has cut up.
5. **Think Critically** Write a paragraph describing the characteristics of the cut-up photograph that helped you put the image back together. Think of other examples in which characteristics of objects are used to match them up with other objects.

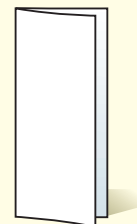


Preview this chapter's content and activities at [blue.msscience.com](http://blue.msscience.com)

## FOLDABLES™ Study Organizer

**Plate Tectonics** Make the following Foldable to help identify what you already know, what you want to know, and what you learned about plate tectonics.

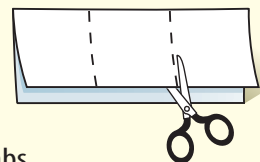
- STEP 1** **Fold** a vertical sheet of paper from side to side. Make the front edge about 1.25 cm shorter than the back edge.



- STEP 2** **Turn** lengthwise and fold into thirds.



- STEP 3** **Unfold and cut** only the layer along both folds to make three tabs.



- STEP 4** **Label** each tab.



**Identify Questions** Before you read the chapter, write what you already know about plate tectonics under the left tab of your Foldable, and write questions about what you'd like to know under the center tab. After you read the chapter, list what you learned under the right tab.



# Continental Drift

## as you read

### What You'll Learn

- **Describe** the hypothesis of continental drift.
- **Identify** evidence supporting continental drift.

### Why It's Important

The hypothesis of continental drift led to plate tectonics—a theory that explains many processes in Earth.



### Review Vocabulary

**continent:** one of the six or seven great divisions of land on the globe

### New Vocabulary

- continental drift
- Pangaea

## Evidence for Continental Drift

If you look at a map of Earth's surface, you can see that the edges of some continents look as though they could fit together like a puzzle. Other people also have noticed this fact. For example, Dutch mapmaker Abraham Ortelius noted the fit between the coastlines of South America and Africa more than 400 years ago.

**Pangaea** German meteorologist Alfred Wegener (VEG nur) thought that the fit of the continents wasn't just a coincidence. He suggested that all the continents were joined together at some time in the past. In a 1912 lecture, he proposed the hypothesis of continental drift. According to the hypothesis of **continental drift**, continents have moved slowly to their current locations. Wegener suggested that all continents once were connected as one large landmass, shown in **Figure 1**, that broke apart about 200 million years ago. He called this large landmass **Pangaea** (pan JEE uh), which means “all land.”



### Reading Check

*Who proposed continental drift?*

**Figure 1** This illustration represents how the continents once were joined to form Pangaea. This fitting together of continents according to shape is not the only evidence supporting the past existence of Pangaea.





**A Controversial Idea** Wegener's ideas about continental drift were controversial. It wasn't until long after Wegener's death in 1930 that his basic hypothesis was accepted. The evidence Wegener presented hadn't been enough to convince many people during his lifetime. He was unable to explain exactly how the continents drifted apart. He proposed that the continents plowed through the ocean floor, driven by the spin of Earth. Physicists and geologists of the time strongly disagreed with Wegener's explanation. They pointed out that continental drift would not be necessary to explain many of Wegener's observations. Other important observations that came later eventually supported Wegener's earlier evidence.

**Fossil Clues** Besides the puzzlelike fit of the continents, fossils provided support for continental drift. Fossils of the reptile *Mesosaurus* have been found in South America and Africa, as shown in **Figure 2**. This swimming reptile lived in freshwater and on land. How could fossils of *Mesosaurus* be found on land areas separated by a large ocean of salt water? It probably couldn't swim between the continents. Wegener hypothesized that this reptile lived on both continents when they were joined.



#### Reading Check

*How do Mesosaurus fossils support the past existence of Pangaea?*



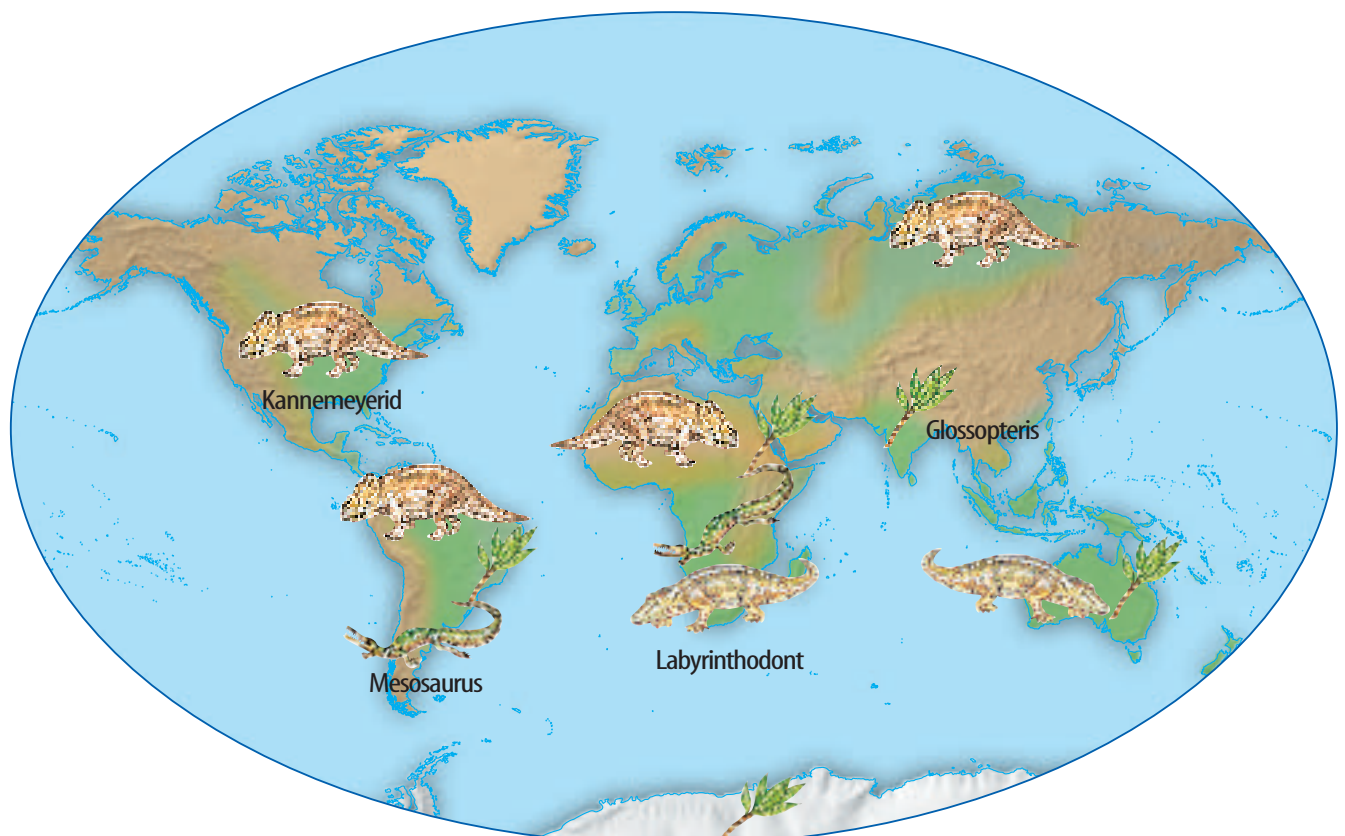
#### Topic: Continental Drift

Visit [blue.msscience.com](http://blue.msscience.com) for Web links to information about the continental drift hypothesis.

**Activity** Research and write a brief report about the initial reactions, from the public and scientific communities, toward Wegener's continental drift hypothesis.

**Figure 2** Fossil remains of plants and animals that lived in Pangaea have been found on more than one continent.

**Evaluate** *How do the locations of Glossopteris, Mesosaurus, Kannemeyrid, Labyrinthodont, and other fossils support Wegener's hypothesis of continental drift?*





**Figure 3** This fossil plant, *Glossopteris*, grew in a temperate climate.



## Mini LAB

### Interpreting Fossil Data

#### Procedure

1. Build a three-layer landmass using **clay** or **modeling dough**.
2. Mold the clay into mountain ranges.
3. Place similar “fossils” into the clay at various locations around the landmass.
4. Form five continents from the one landmass. Also, form two smaller landmasses out of different clay with different mountain ranges and fossils.
5. Place the five continents and two smaller landmasses around the room.
6. Have someone who did not make or place the landmasses make a model that shows how they once were positioned.
7. Return the clay to its container so it can be used again.

#### Analysis

What clues were useful in reconstructing the original landmass?



**A Widespread Plant** Another fossil that supports the hypothesis of continental drift is *Glossopteris* (glahs AHP tur us). **Figure 3** shows this fossil plant, which has been found in Africa, Australia, India, South America, and Antarctica. The presence of *Glossopteris* in so many areas also supported Wegener’s idea that all of these regions once were connected and had similar climates.

**Climate Clues** Wegener used continental drift to explain evidence of changing climates. For example, fossils of warm-weather plants were found on the island of Spitsbergen in the Arctic Ocean. To explain this, Wegener hypothesized that Spitsbergen drifted from tropical regions to the arctic. Wegener also used continental drift to explain evidence of glaciers found in temperate and tropical areas. Glacial deposits and rock surfaces scoured and polished by glaciers are found in South America, Africa, India, and Australia. This shows that parts of these continents were covered with glaciers in the past. How could you explain why glacial deposits are found in areas where no glaciers exist today? Wegener thought that these continents were connected and partly covered with ice near Earth’s south pole long ago.

**Rock Clues** If the continents were connected at one time, then rocks that make up the continents should be the same in locations where they were joined. Similar rock structures are found on different continents. Parts of the Appalachian Mountains of the eastern United States are similar to those found in Greenland and western Europe. If you were to study rocks from eastern South America and western Africa, you would find other rock structures that also are similar. Rock clues like these support the idea that the continents were connected in the past.



## How could continents drift?

Although Wegener provided evidence to support his hypothesis of continental drift, he couldn't explain how, when, or why these changes, shown in **Figure 4**, took place. The idea suggested that lower-density, continental material somehow had to plow through higher-density, ocean-floor material. The force behind this plowing was thought to be the spin of Earth on its axis—a notion that was quickly rejected by physicists. Because other scientists could not provide explanations either, Wegener's idea of continental drift was initially rejected. The idea was so radically different at that time that most people closed their minds to it.

Rock, fossil, and climate clues were the main types of evidence for continental drift. After Wegener's death, more clues were found, largely because of advances in technology, and new ideas that related to continental drift were developed. You'll learn about a new idea, seafloor spreading, in the next section.

**Figure 4** These computer models show the probable course the continents have taken. On the far left is their position 250 million years ago. In the middle is their position 135 million years ago. At right is their current position.

### section 1 review

#### Summary

##### Evidence for Continental Drift

- Alfred Wegener proposed in his hypothesis of continental drift that all continents were once connected as one large landmass called Pangaea.
- Evidence of continental drift came from fossils, signs of climate change, and rock structures from different continents.

##### How could continents drift?

- During his lifetime, Wegener was unable to explain how, when, or why the continents drifted.
- After his death, advances in technology permitted new ideas to be developed to help explain his hypothesis.

#### Self Check

1. **Explain** how Wegener used climate clues to support his hypothesis of continental drift.
2. **Describe** how rock clues were used to support the hypothesis of continental drift.
3. **Summarize** the ways that fossils helped support the hypothesis of continental drift.
4. **Think Critically** Why would you expect to see similar rocks and rock structures on two landmasses that were connected at one time.

#### Applying Skills

5. **Compare and contrast** the locations of fossils of the temperate plant *Glossopteris*, as shown in **Figure 2**, with the climate that exists at each location today.



# Seafloor Spreading

## as you read

### What You'll Learn

- **Explain** seafloor spreading.
- **Recognize** how age and magnetic clues support seafloor spreading.

### Why It's Important

Seafloor spreading helps explain how continents moved apart.



### Review Vocabulary

**seafloor:** portion of Earth's crust that lies beneath ocean waters

### New Vocabulary

- seafloor spreading

## Mapping the Ocean Floor

If you were to lower a rope from a boat until it reached the seafloor, you could record the depth of the ocean at that particular point. In how many different locations would you have to do this to create an accurate map of the seafloor? This is exactly how it was done until World War I, when the use of sound waves was introduced by German scientists to detect submarines. During the 1940s and 1950s, scientists began using sound waves on moving ships to map large areas of the ocean floor in detail. Sound waves echo off the ocean bottom—the longer the sound waves take to return to the ship, the deeper the water is.

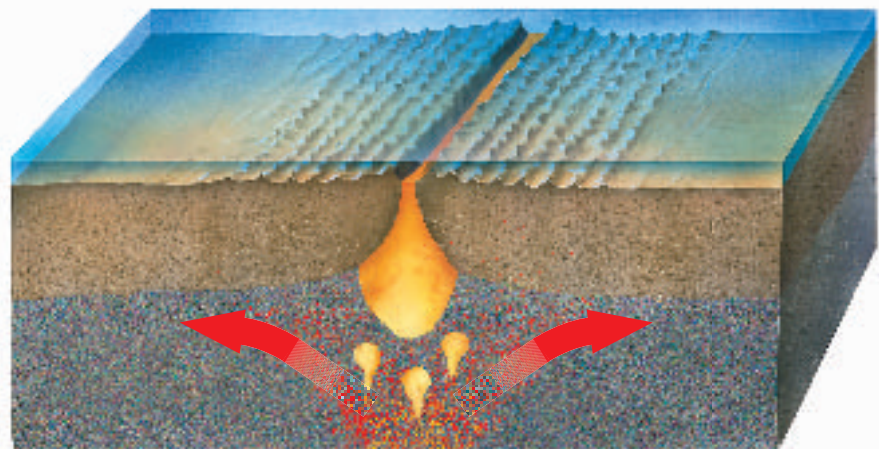
Using sound waves, researchers discovered an underwater system of ridges, or mountains, and valleys like those found on the continents. In some of these underwater ridges are rather long rift valleys where volcanic eruptions and earthquakes occur from time to time. Some of these volcanoes actually are visible above the ocean surface. In the Atlantic, the Pacific, and in other oceans around the world, a system of ridges, called the mid-ocean ridges, is present. These underwater mountain ranges, shown in **Figure 5**, stretch along the center of much of Earth's ocean floor. This discovery raised the curiosity of many scientists. What formed these mid-ocean ridges?



### Reading Check

*How were mid-ocean ridges discovered?*

**Figure 5** As the seafloor spreads apart at a mid-ocean ridge, new seafloor is created. The older seafloor moves away from the ridge in opposite directions.





**The Seafloor Moves** In the early 1960s, Princeton University scientist Harry Hess suggested an explanation. His now-famous theory is known as **seafloor spreading**. Hess proposed that hot, less dense material below Earth's crust rises toward the surface at the mid-ocean ridges. Then, it flows sideways, carrying the seafloor away from the ridge in both directions, as seen in **Figure 5**.

As the seafloor spreads apart, magma is forced upward and flows from the cracks. It becomes solid as it cools and forms new seafloor. As new seafloor moves away from the mid-ocean ridge, it cools, contracts, and becomes denser. This denser, colder seafloor sinks, helping to form the ridge. The theory of seafloor spreading was later supported by the following observations.



#### Reading Check

*How does new seafloor form at mid-ocean ridges?*

## Evidence for Spreading

In 1968, scientists aboard the research ship *Glomar Challenger* began gathering information about the rocks on the seafloor. *Glomar Challenger* was equipped with a drilling rig that allowed scientists to drill into the seafloor to obtain rock samples. Scientists found that the youngest rocks are located at the mid-ocean ridges. The ages of the rocks become increasingly older in samples obtained farther from the ridges, adding to the evidence for seafloor spreading.

Using submersibles along mid-ocean ridges, new seafloor features and life-forms also were discovered there, as shown in **Figure 6**. As molten material is forced upward along the ridges, it brings heat and chemicals that support exotic life-forms in deep, ocean water. Among these are giant clams, mussels, and tube worms.



#### Integrate Physics

**Magnetic Clues** Earth's magnetic field has a north and a south pole. Magnetic lines, or directions, of force leave Earth near the south pole and enter Earth near the north pole. During a magnetic reversal, the lines of magnetic force run the opposite way. Scientists have determined that Earth's magnetic field has reversed itself many times in the past. These reversals occur over intervals of thousands or even millions of years. The reversals are recorded in rocks forming along mid-ocean ridges.



**Figure 6** Many new discoveries have been made on the seafloor. These giant tube worms inhabit areas near hot water vents along mid-ocean ridges.

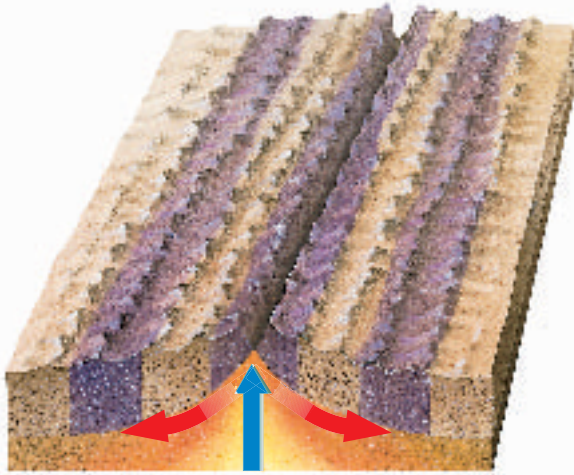


#### Integrate Chemistry

**Curie Point** Find out what the Curie point is and describe in your Science Journal what happens to iron-bearing minerals when they are heated to the Curie point. Explain how this is important to studies of seafloor spreading.



- Normal magnetic polarity
- Reverse magnetic polarity



**Figure 7** Changes in Earth's magnetic field are preserved in rock that forms on both sides of mid-ocean ridges.

**Explain** why this is considered to be evidence of seafloor spreading.

of this, normal polarities in rocks show up as large peaks. This discovery provided strong support that seafloor spreading was indeed occurring. The magnetic reversals showed that new rock was being formed at the mid-ocean ridges. This helped explain how the crust could move—something that the continental drift hypothesis could not do.

**Magnetic Time Scale** Iron-bearing minerals, such as magnetite, that are found in the rocks of the seafloor can record Earth's magnetic field direction when they form. Whenever Earth's magnetic field reverses, newly forming iron minerals will record the magnetic reversal.

Using a sensing device called a magnetometer (mag nuh TAH muh tur) to detect magnetic fields, scientists found that rocks on the ocean floor show many periods of magnetic reversal. The magnetic alignment in the rocks reverses back and forth over time in strips parallel to the mid-ocean ridges, as shown in **Figure 7**. A strong magnetic reading is recorded when the polarity of a rock is the same as the polarity of Earth's magnetic field today. Because

## section 2 review

### Summary

#### Mapping the Ocean Floor

- Mid-ocean ridges, along the center of the ocean floor, have been found by using sound waves, the same method once used to detect submarines during World War I.
- Harry Hess suggested, in his seafloor spreading hypothesis, that the seafloor moves.

#### Evidence for Spreading

- Scientists aboard *Glomar Challenger* provided evidence of spreading by discovering that the youngest rocks are located at ridges and become increasingly older farther from the ridges.
- Magnetic alignment of rocks, in alternating strips that run parallel to ridges, indicates reversals in Earth's magnetic field and provides further evidence of seafloor spreading.

### Self Check

1. **Summarize** What properties of iron-bearing minerals on the seafloor support the theory of seafloor spreading?
2. **Explain** how the ages of the rocks on the ocean floor support the theory of seafloor spreading.
3. **Summarize** How did Harry Hess's hypothesis explain seafloor movement?
4. **Explain** why some partly molten material rises toward Earth's surface.
5. **Think Critically** The ideas of Hess, Wegener, and others emphasize that Earth is a dynamic planet. How is seafloor spreading different from continental drift?

### Applying Math

6. **Solve One-Step Equations** North America is moving about 1.25 cm per year away from a ridge in the middle of the Atlantic Ocean. Using this rate, how much farther apart will North America and the ridge be in 200 million years?

## Seafloor Spreading Rates

How did scientists use their knowledge of seafloor spreading and magnetic field reversals to reconstruct Pangaea? Try this lab to see how you can determine where a continent may have been located in the past.

### Real-World Question

Can you use clues, such as magnetic field reversals on Earth, to help reconstruct Pangaea?

#### Goals

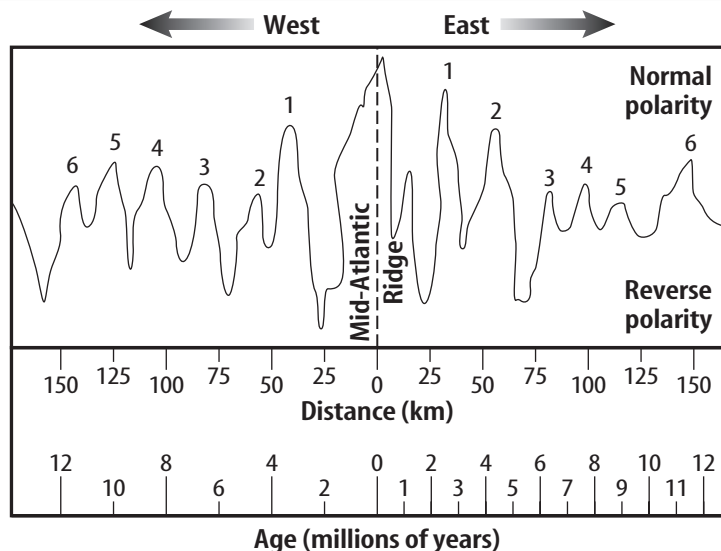
- **Interpret** data about magnetic field reversals. Use these magnetic clues to reconstruct Pangaea.

#### Materials

metric ruler  
pencil

### Procedure

1. Study the magnetic field graph above. You will be working only with normal polarity readings, which are the peaks above the baseline in the top half of the graph.
2. Place the long edge of a ruler vertically on the graph. Slide the ruler so that it lines up with the center of peak 1 west of the Mid-Atlantic Ridge.
3. **Determine** and record the distance and age that line up with the center of peak 1 west. Repeat this process for peak 1 east of the ridge.
4. **Calculate** the average distance and age for this pair of peaks.



5. Repeat steps 2 through 4 for the remaining pairs of normal-polarity peaks.
6. **Calculate** the rate of movement in cm per year for the six pairs of peaks. Use the formula  $\text{rate} = \frac{\text{distance}}{\text{time}}$ . Convert kilometers to centimeters. For example, to calculate a rate using normal-polarity peak 5, west of the ridge:

$$\begin{aligned} \text{rate} &= \frac{125 \text{ km}}{10 \text{ million years}} = \frac{12.5 \text{ km}}{\text{million years}} \\ &= \frac{1,250,000 \text{ cm}}{1,000,000 \text{ years}} = 1.25 \text{ cm/year} \end{aligned}$$

### Conclude and Apply

1. **Compare** the age of igneous rock found near the mid-ocean ridge with that of igneous rock found farther away from the ridge.
2. If the distance from a point on the coast of Africa to the Mid-Atlantic Ridge is approximately 2,400 km, calculate how long ago that point in Africa was at or near the Mid-Atlantic Ridge.
3. How could you use this method to reconstruct Pangaea?

# Theory of Plate Tectonics

## as you read

### What You'll Learn

- **Compare and contrast** different types of plate boundaries.
- **Explain** how heat inside Earth causes plate tectonics.
- **Recognize** features caused by plate tectonics.

### Why It's Important

Plate tectonics explains how many of Earth's features form.

### Review Vocabulary

**converge:** to come together

**diverge:** to move apart

**transform:** to convert or change

### New Vocabulary

- plate tectonics
- plate
- lithosphere
- asthenosphere
- convection current

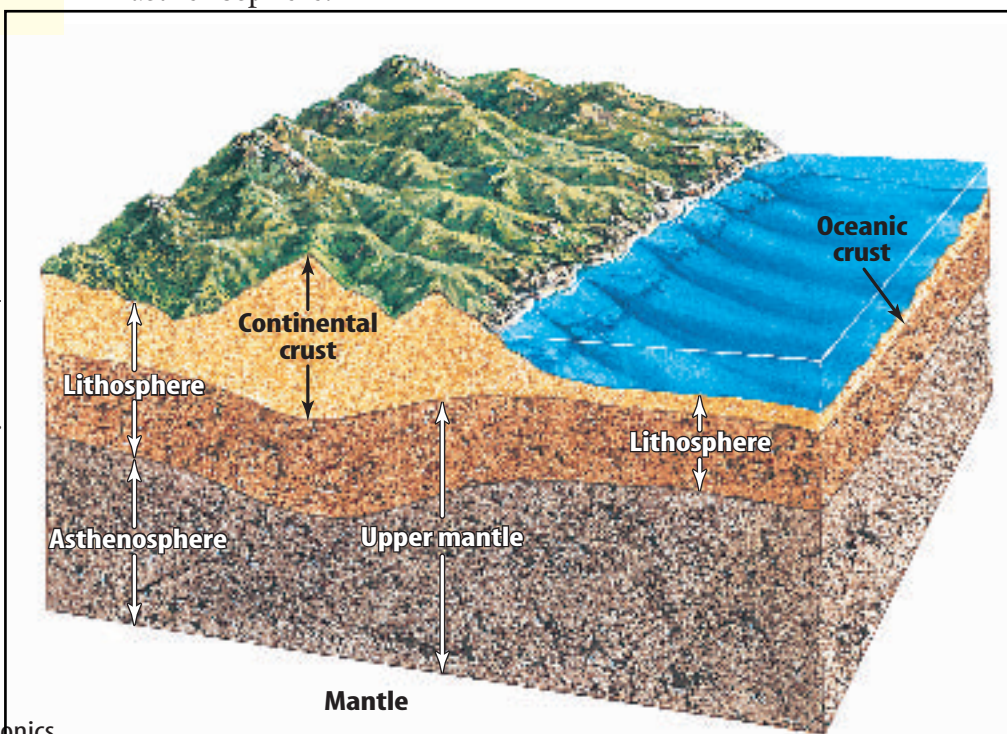
## Plate Tectonics

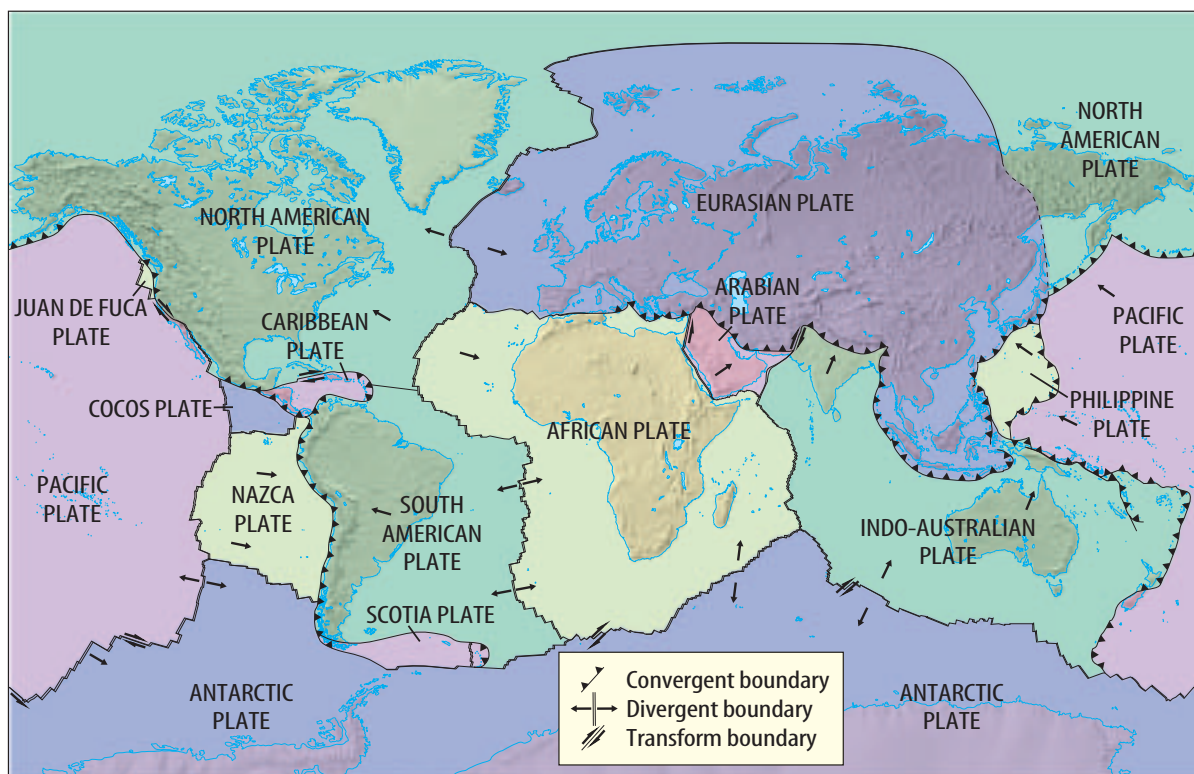
The idea of seafloor spreading showed that more than just continents were moving, as Wegener had thought. It was now clear to scientists that sections of the seafloor and continents move in relation to one another.

**Plate Movements** In the 1960s, scientists developed a new theory that combined continental drift and seafloor spreading. According to the theory of **plate tectonics**, Earth's crust and part of the upper mantle are broken into sections. These sections, called **plates**, move on a plasticlike layer of the mantle. The plates can be thought of as rafts that float and move on this layer.

**Composition of Earth's Plates** Plates are made of the crust and a part of the upper mantle, as shown in **Figure 8**. These two parts combined are the **lithosphere** (LIH tuh sfih). This rigid layer is about 100 km thick and generally is less dense than material underneath. The plasticlike layer below the lithosphere is called the **asthenosphere** (as THE nuh sfih). The rigid plates of the lithosphere float and move around on the asthenosphere.

**Figure 8** Plates of the lithosphere are composed of oceanic crust, continental crust, and rigid upper mantle.





## Plate Boundaries

When plates move, they can interact in several ways. They can move toward each other and converge, or collide. They also can pull apart or slide alongside one another. When the plates interact, the result of their movement is seen at the plate boundaries, as in **Figure 9**.



### Reading Check

*What are the general ways that plates interact?*

Movement along any plate boundary means that changes must happen at other boundaries. What is happening to the Atlantic Ocean floor between the North American and African Plates? Compare this with what is happening along the western margin of South America.

**Plates Moving Apart** The boundary between two plates that are moving apart is called a divergent boundary. You learned about divergent boundaries when you read about seafloor spreading. In the Atlantic Ocean, the North American Plate is moving away from the Eurasian and the African Plates, as shown in **Figure 9**. That divergent boundary is called the Mid-Atlantic Ridge. The Great Rift Valley in eastern Africa might become a divergent plate boundary. There, a valley has formed where a continental plate is being pulled apart. **Figure 10** shows a side view of what a rift valley might look like and illustrates how the hot material rises up where plates separate.

**Figure 9** This diagram shows the major plates of the lithosphere, their direction of movement, and the type of boundary between them.

**Analyze and Conclude** Based on what is shown in this figure, what is happening where the Nazca Plate meets the Pacific Plate?



### Topic: Earthquakes and Volcanoes

Visit [blue.msscience.com](http://blue.msscience.com) for Web links to recent news or magazine articles about earthquakes and volcanic activity related to plate tectonics.

**Activity** Prepare a group demonstration about recent volcanic and earthquake events. Divide tasks among group members. Find and copy maps, diagrams, photographs, and charts to highlight your presentation. Emphasize the locations of events and the relationship to plate tectonics.

**Plates Moving Together** If new crust is being added at one location, why doesn't Earth's surface keep expanding? As new crust is added in one place, it disappears below the surface at another. The disappearance of crust can occur when seafloor cools, becomes denser, and sinks. This occurs where two plates move together at a convergent boundary.

When an oceanic plate converges with a less dense continental plate, the denser oceanic plate sinks under the continental plate. The area where an oceanic plate subducts, or goes down, into the mantle is called a subduction zone. Some volcanoes form above subduction zones. **Figure 10** shows how this type of convergent boundary creates a deep-sea trench where one plate bends and sinks beneath the other. High temperatures cause rock to melt around the subducting slab as it goes under the other plate. The newly formed magma is forced upward along these plate boundaries, forming volcanoes. The Andes mountain range of South America contains many volcanoes. They were formed at the convergent boundary of the Nazca and the South American Plates.

## Applying Science

### How well do the continents fit together?

**R**ecall the Launch Lab you performed at the beginning of this chapter. While you were trying to fit pieces of a cut-up photograph together, what clues did you use?

#### Identifying the Problem

Take a copy of a map of the world and cut out each continent. Lay them on a tabletop and try to fit them together, using techniques you used in the Launch Lab. You will find that the pieces of your Earth puzzle—the continents—do not fit together well. Yet, several of the areas on some continents fit together extremely well.



Take out another world map—one that shows the continental shelves as well as the continents. Copy it and cut out the continents, this time including the continental shelves.

#### Solving the Problem

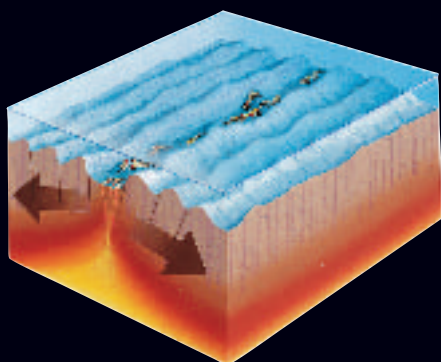
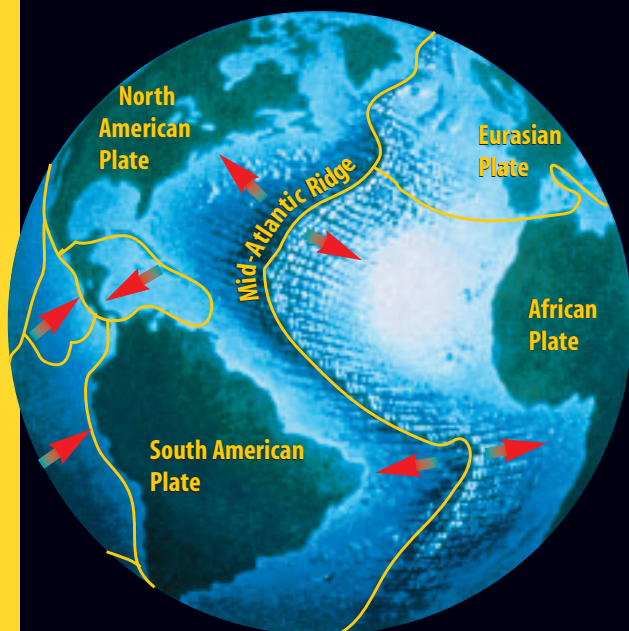
1. Does including the continental shelves solve the problem of fitting the continents together?
2. Why should continental shelves be included with maps of the continents?



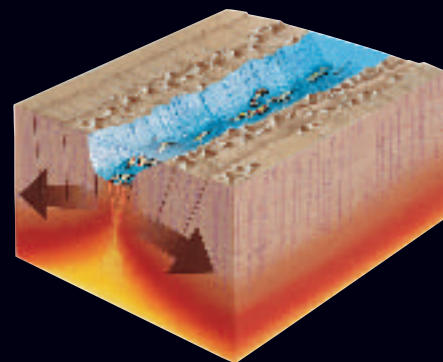


**Figure 10**

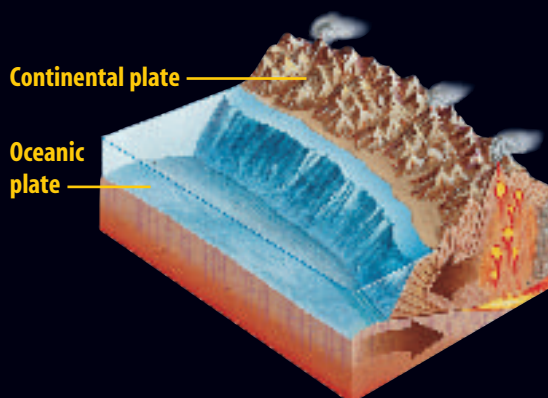
**B**y diverging at some boundaries and converging at others, Earth's plates are continually—but gradually—reshaping the landscape around you. The Mid-Atlantic Ridge, for example, was formed when the North and South American Plates pulled apart from the Eurasian and African Plates (see globe). Some features that occur along plate boundaries—rift valleys, volcanoes, and mountain ranges—are shown on the right and below.



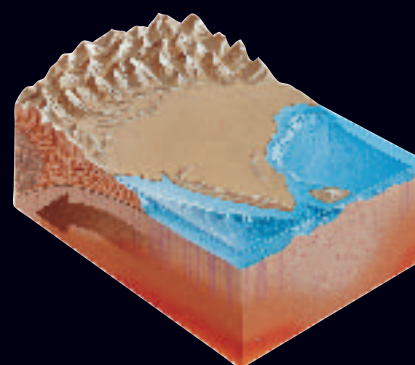
**SEAFLOOR SPREADING** A mid-ocean ridge, like the Mid-Atlantic Ridge, forms where oceanic plates continue to separate. As rising magma (yellow) cools, it forms new oceanic crust.



**A RIFT VALLEY** When continental plates pull apart, they can form rift valleys. The African continent is separating now along the East African Rift Valley.



**SUBDUCTION** Where oceanic and continental plates collide, the oceanic plate plunges beneath the less dense continental plate. As the plate descends, molten rock (yellow) forms and rises toward the surface, creating volcanoes.



**CONTINENTAL COLLISION** Where two continental plates collide, they push up the crust to form mountain ranges such as the Himalaya.



**Figure 11** The San Andreas Fault in California occurs along the transform plate boundary where the Pacific Plate is sliding past the North American Plate.

Overall, the two plates are moving in roughly the same direction.

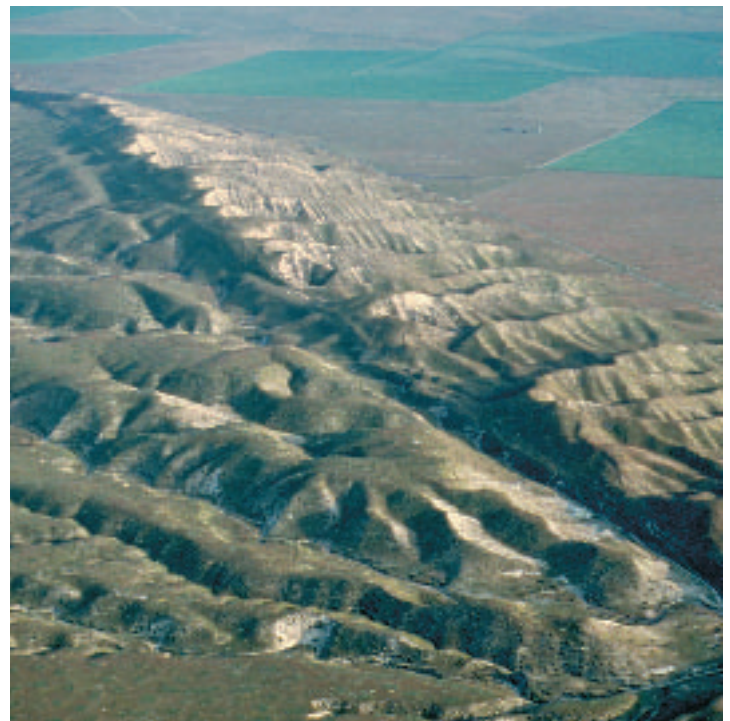
**Explain** Why, then, do the red arrows show movement in opposite directions?



**Where Plates Collide** A subduction zone also can form where two oceanic plates converge. In this case, the colder, older, denser oceanic plate bends and sinks down into the mantle. The Mariana Islands in the western Pacific are a chain of volcanic islands formed where two oceanic plates collide.

Usually, no subduction occurs when two continental plates collide, as shown in **Figure 10**. Because both of these plates are less dense than the material in the asthenosphere, the two plates collide and crumple up, forming mountain ranges. Earthquakes are common at these convergent boundaries. However, volcanoes do not form because there is no, or little, subduction. The Himalaya in Asia are forming where the Indo-Australian Plate collides with the Eurasian Plate.

**Where Plates Slide Past Each Other** The third type of plate boundary is called a transform boundary. Transform boundaries occur where two plates slide past one another. They move in opposite directions or in the same direction at different rates. When one plate slips past another suddenly, earthquakes occur. The Pacific Plate is sliding past the North American Plate, forming the famous San Andreas Fault in California, as seen in **Figure 11**. The San Andreas Fault is part of a transform plate boundary. It has been the site of many earthquakes.



This photograph shows an aerial view of the San Andreas Fault.



## Causes of Plate Tectonics

Many new discoveries have been made about Earth's crust since Wegener's day, but one question still remains. What causes the plates to move? Scientists now think they have a good idea. They think that plates move by the same basic process that occurs when you heat soup.

**Convection Inside Earth** Soup that is cooking in a pan on the stove contains currents caused by an unequal distribution of heat in the pan. Hot, less dense soup is forced upward by the surrounding, cooler, denser soup. As the hot soup reaches the surface, it cools and sinks back down into the pan. This entire cycle of heating, rising, cooling, and sinking is called a **convection current**. A version of this same process, occurring in the mantle, is thought to be the force behind plate tectonics. Scientists suggest that differences in density cause hot, plasticlike rock to be forced upward toward the surface.

**Moving Mantle Material** Wegener wasn't able to come up with an explanation for why plates move. Today, researchers who study the movement of heat in Earth's interior have proposed several possible explanations. All of the hypotheses use convection in one way or another. It is, therefore, the transfer of heat inside Earth that provides the energy to move plates and causes many of Earth's surface features. One hypothesis is shown in **Figure 12**. It relates plate motion directly to the movement of convection currents. According to this hypothesis, convection currents cause the movements of plates.



### Modeling Convection Currents

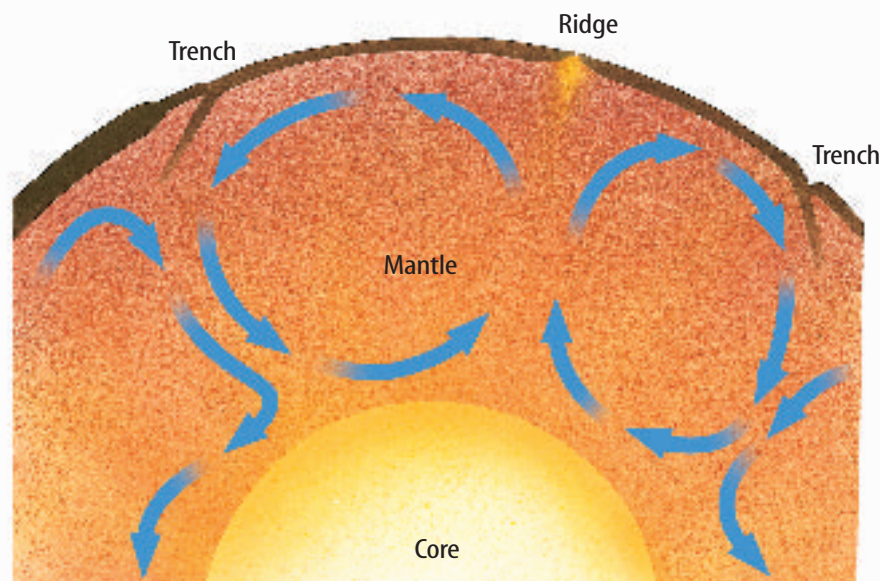
#### Procedure



1. Pour water into a clear, colorless casserole dish until it is 5 cm from the top.
2. Center the dish on a **hot plate** and heat it. **WARNING:** Wear **thermal mitts** to protect your hands.
3. Add a few drops of **food coloring** to the water above the center of the hot plate.
4. Looking from the side of the dish, observe what happens in the water.
5. Illustrate your observations in your **Science Journal**.

#### Analysis

1. Determine whether any currents form in the water.
2. Infer what causes the currents to form.



**Figure 12** In one hypothesis, convection currents occur throughout the mantle. Such convection currents (see arrows) are the driving force of plate tectonics.



## Features Caused by Plate Tectonics

Earth is a dynamic planet with a hot interior. This heat leads to convection, which powers the movement of plates. As the plates move, they interact. The interaction of plates produces forces that build mountains, create ocean basins, and cause volcanoes. When rocks in Earth's crust break and move, energy is released in the form of seismic waves. Humans feel this release as earthquakes. You can see some of the effects of plate tectonics in mountainous regions, where volcanoes erupt, or where landscapes have changed from past earthquake or volcanic activity.

**Figure 13** Fault-block mountains can form when Earth's crust is stretched by tectonic forces. The arrows indicate the directions of moving blocks.

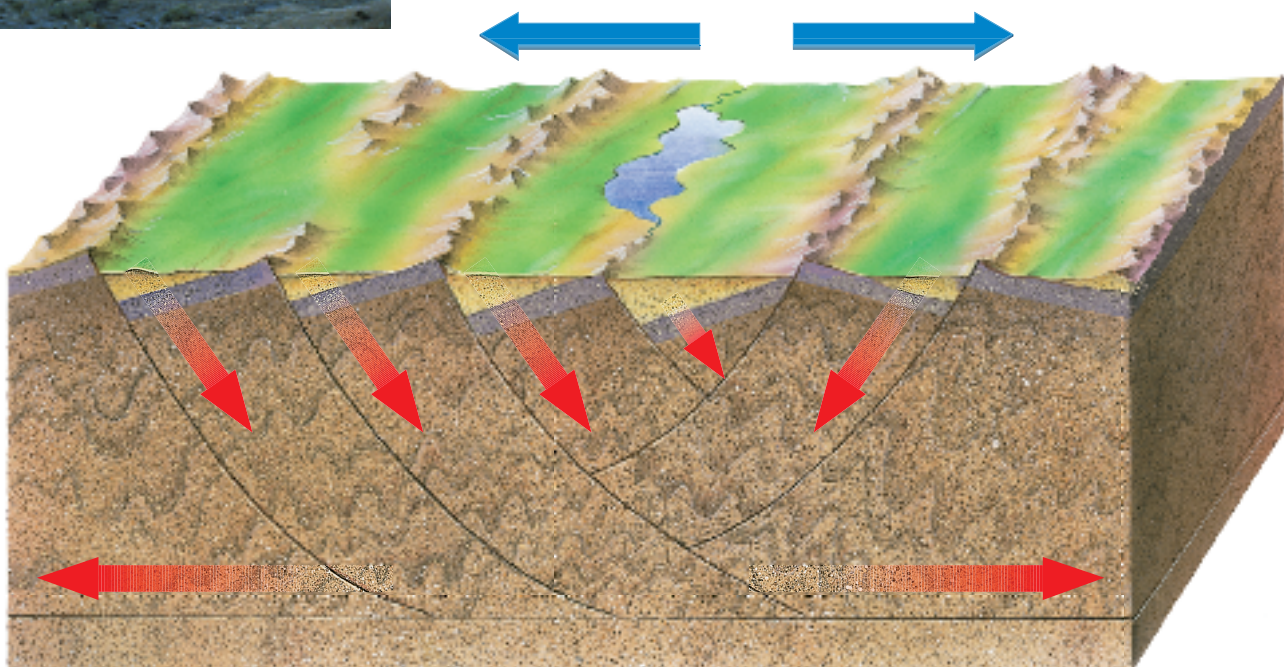
**Name** the type of force that occurs when Earth's crust is pulled in opposite directions.



 **Reading Check** What happens when seismic energy is released as rocks in Earth's crust break and move?

**Normal Faults and Rift Valleys** Tension forces, which are forces that pull apart, can stretch Earth's crust. This causes large blocks of crust to break and tilt or slide down the broken surfaces of crust. When rocks break and move along surfaces, a fault forms. Faults interrupt rock layers by moving them out of place. Entire mountain ranges can form in the process, called fault-block mountains, as shown in **Figure 13**. Generally, the faults that form from pull-apart forces are normal faults—faults in which the rock layers above the fault move down when compared with rock layers below the fault.

Rift valleys and mid-ocean ridges can form where Earth's crust separates. Examples of rift valleys are the Great Rift Valley in Africa, and the valleys that occur in the middle of mid-ocean ridges. Examples of mid-ocean ridges include the Mid-Atlantic Ridge and the East Pacific Rise.





**Mountains and Volcanoes** Compression forces squeeze objects together. Where plates come together, compression forces produce several effects. As continental plates collide, the forces that are generated cause massive folding and faulting of rock layers into mountain ranges such as the Himalaya, shown in **Figure 14**, or the Appalachian Mountains. The type of faulting produced is generally reverse faulting. Along a reverse fault, the rock layers above the fault surface move up relative to the rock layers below the fault.



### Reading Check

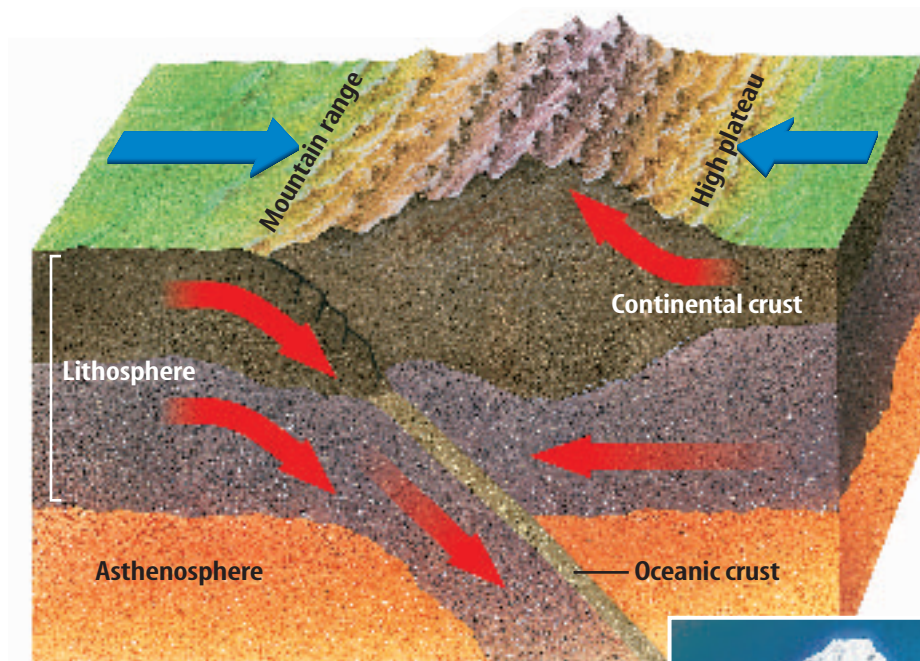
*What features occur where plates converge?*

As you learned earlier, when two oceanic plates converge, the denser plate is forced beneath the other plate. Curved chains of volcanic islands called island arcs form above the sinking plate. If an oceanic plate converges with a continental plate, the denser oceanic plate slides under the continental plate. Folding and faulting at the continental plate margin can thicken the continental crust to produce mountain ranges. Volcanoes also typically are formed at this type of convergent boundary.



### INTEGRATE Career

**Volcanologist** This person's job is to study volcanoes in order to predict eruptions. Early warning of volcanic eruptions gives nearby residents time to evacuate. Volcanologists also educate the public about the hazards of volcanic eruptions and tell people who live near volcanoes what they can do to be safe in the event of an eruption. Volcanologists travel all over the world to study new volcanic sites.



**Figure 14** The Himalaya still are forming today as the Indo-Australian Plate collides with the Eurasian Plate.





**Figure 15** Most of the movement along a strike-slip fault is parallel to Earth's surface. When movement occurs, human-built structures along a strike-slip fault are offset, as shown here in this road.



**Strike-Slip Faults** At transform boundaries, two plates slide past one another without converging or diverging. The plates stick and then slide, mostly in a horizontal direction, along large strike-slip faults. In a strike-slip fault, rocks on opposite sides of the fault move in opposite directions, or in the same direction at different rates. This type of fault movement is shown in **Figure 15**. One such example is the San Andreas Fault. When plates move suddenly, vibrations are generated inside Earth that are felt as an earthquake.

Earthquakes, volcanoes, and mountain ranges are evidence of plate motion. Plate tectonics explains how activity inside Earth can affect Earth's crust differently in different locations. You've seen how plates have moved since Pangaea separated. Is it possible to measure how far plates move each year?

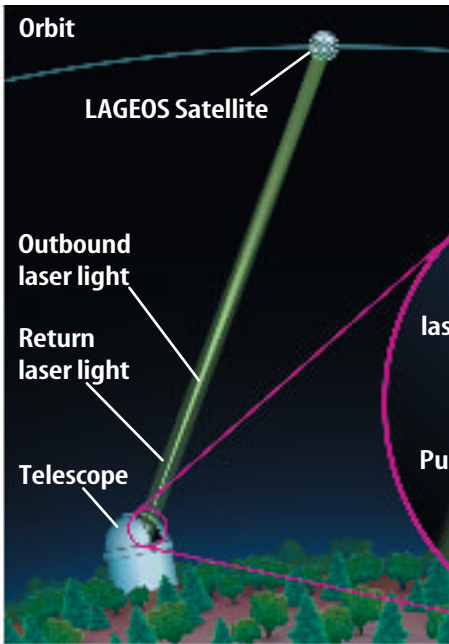
## Testing for Plate Tectonics

Until recently, the only tests scientists could use to check for plate movement were indirect. They could study the magnetic characteristics of rocks on the seafloor. They could study volcanoes and earthquakes. These methods supported the theory that the plates have moved and still are moving. However, they did not provide proof—only support—of the idea.

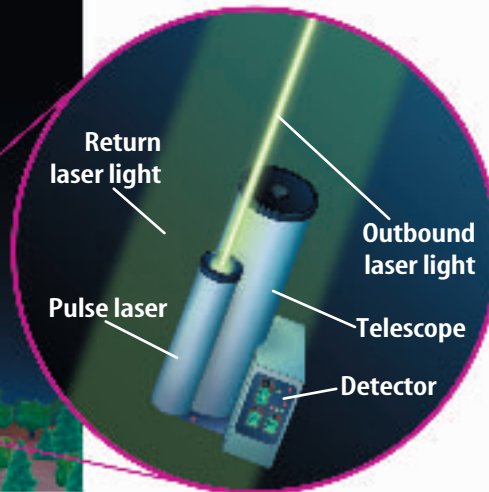
New methods had to be discovered to be able to measure the small amounts of movement of Earth's plates. One method, shown in **Figure 16**, uses lasers and a satellite. Now, scientists can measure exact movements of Earth's plates of as little as 1 cm per year.



**Direction of Forces** In which directions do forces act at convergent, divergent, and transform boundaries? Demonstrate these forces using wooden blocks or your hands.



**Figure 16** When using the Satellite Laser Ranging System, scientists on the ground aim laser pulses at a satellite. The pulses reflect off the satellite and are used to determine a precise location on the ground.



**Current Data** Satellite Laser Ranging System data show that Hawaii is moving toward Japan at a rate of about 8.3 cm per year. Maryland is moving away from England at a rate of 1.7 cm per year. Using such methods, scientists have observed that the plates move at rates ranging from about 1 cm to 12 cm per year.

## section 3 review

### Summary

#### Plate Tectonics

- The theory of plate tectonics states that sections of the seafloor and continents move as plates on a plasticlike layer of the mantle.

#### Plate Boundaries

- The boundary between two plates moving apart is called a divergent boundary.
- Plates move together at a convergent boundary.
- Transform boundaries occur where two plates slide past one another.

#### Causes of Plate Tectonics

- Convection currents are thought to cause the movement of Earth's plates.

#### Features Caused by Plate Tectonics

- Tension forces cause normal faults, rift valleys, and mid-ocean ridges at divergent boundaries.
- At convergent boundaries, compression forces cause folding, reverse faults, and mountains.
- At transform boundaries, two plates slide past one another along strike-slip faults.

### Self Check

1. **Describe** what occurs at plate boundaries that are associated with seafloor spreading.
2. **Describe** three types of plate boundaries where volcanic eruptions can occur.
3. **Explain** how convection currents are related to plate tectonics.
4. **Think Critically** Using **Figure 9** and a world map, determine what natural disasters might occur in Iceland. Also determine what disasters might occur in Tibet. Explain why some Icelandic disasters are not expected to occur in Tibet.

### Applying Skills

5. **Predict** Plate tectonic activity causes many events that can be dangerous to humans. One of these events is a seismic sea wave, or tsunami. Learn how scientists predict the arrival time of a tsunami in a coastal area.
6. **Use a Word Processor** Write three separate descriptions of the three basic types of plate boundaries—divergent boundaries, convergent boundaries, and transform boundaries. Then draw a sketch of an example of each boundary next to your description.

## Predicting Tectonic Activity

### Goals

- **Research** the locations of earthquakes and volcanic eruptions around the world.
- **Plot** earthquake epicenters and the locations of volcanic eruptions.
- **Predict** locations that are tectonically active based on a plot of the locations of earthquake epicenters and active volcanoes.

### Data Source



Visit [blue.msscience.com/internet\\_lab](http://blue.msscience.com/internet_lab) for more information about earthquake and volcano sites, and data from other students.

### Real-World Question

The movement of plates on Earth causes forces that build up energy in rocks. The release of this energy can produce vibrations in Earth that you know as earthquakes. Earthquakes occur every day. Many of them are too small to be felt by humans, but each event tells scientists something more about the planet. Active volcanoes can do the same and often form at plate boundaries.

Can you predict tectonically active areas by plotting locations of earthquake epicenters and volcanic eruptions?

Think about where earthquakes and volcanoes have occurred in the past. Make a hypothesis about whether the locations of earthquake epicenters and active volcanoes can be used to predict tectonically active areas.



# Using Scientific Methods

## Make a Plan

1. Make a data table in your Science Journal like the one shown.
2. Collect data for earthquake epicenters and volcanic eruptions for at least the past two weeks. Your data should include the longitude and latitude for each location. For help, refer to the data sources given on the opposite page.

### Locations of Epicenters and Eruptions

Earthquake Epicenter/ Volcanic Eruption	Longitude	Latitude

Do not write in this book.

## Follow Your Plan

1. Make sure your teacher approves your plan before you start.
2. **Plot** the locations of earthquake epicenters and volcanic eruptions on a map of the world. Use an overlay of tissue paper or plastic.
3. After you have collected the necessary data, predict where the tectonically active areas on Earth are.
4. **Compare and contrast** the areas that you predicted to be tectonically active with the plate boundary map shown in **Figure 9**.

## Analyze Your Data

1. What areas on Earth do you predict to be the locations of tectonic activity?
2. How close did your prediction come to the actual location of tectonically active areas?

## Conclude and Apply

1. How could you make your predictions closer to the locations of actual tectonic activity?
2. Would data from a longer period of time help? Explain.
3. What types of plate boundaries were close to your locations of earthquake epicenters? Volcanic eruptions?
4. **Explain** which types of plate boundaries produce volcanic eruptions. Be specific.

### Communicating Your Data

Find this lab using the link below. Post your data in the table provided. **Compare** your data to those of other students. Combine your data with those of other students and **plot** these combined data on a map to recognize the relationship between plate boundaries, volcanic eruptions, and earthquake epicenters.

Scienceonline

[blue.msscience.com/internet\\_lab](http://blue.msscience.com/internet_lab)

## Listening In

by Gordon Judge

I'm just a bit of seafloor on this mighty solid sphere.  
With no mind to be broadened, I'm quite content  
down here.  
The mantle churns below me, and the sea's in turmoil, too;  
But nothing much disturbs me, I'm rock solid through  
and through.  
I do pick up occasional low-frequency vibrations –  
(I think, although I can't be sure, they're sperm whales'  
conversations).  
I know I shouldn't listen in, but what else can I do?  
It seems they are all studying for degrees from the OU.  
They've mentioned me in passing, as their minds begin  
improving:



I think I've heard them say  
"The theory says the sea-  
floor's moving...".  
They call it "Plate Tectonics", this  
new theory in their noddle.  
If they would only ask me, I  
could tell them it's all  
twaddle....

But, how can I be moving, when I know full well myself  
That I'm quite firmly anchored to a continental shelf?  
"Well, the continent is moving, too; you're *pushing* it,  
you see,"  
I hear those OU whales intone, hydro-acoustically....  
Well, thank you very much, OU. You've upset my  
composure.  
Next time you send your student whales to look at  
my exposure  
I'll tell them it's a load of tosh: it's *they* who move,  
not me,  
Those arty-smarty blobs of blubber, clogging up the sea!

## Understanding Literature

**Point of View** Point of view refers to the perspective from which an author writes. This poem begins, "I'm just a bit of seafloor. . . ." Right away, you know that the poem, or story, is being told from the point of view of the speaker, or the "first person." What effect does the first-person narration have on the story?

## Respond to the Reading

1. Who is narrating the poem?
2. Why might the narrator think he or she hasn't moved?
3. **Linking Science and Writing**  
Using the first-person point of view, write an account from the point of view of a living or nonliving thing.



INTEGRATE  
Earth Science

Volcanoes can occur where two plates move toward each other. When an oceanic plate and a continental plate collide, a volcano will form. Subduction zones occur when one plate sinks under another plate. Rocks melt in the zones where these plates converge, causing magma to move upward and form volcanic mountains.

### Reviewing Main Ideas

#### Section 1 Continental Drift

1. Alfred Wegener suggested that the continents were joined together at some point in the past in a large landmass he called Pangaea. Wegener proposed that continents have moved slowly, over millions of years, to their current locations.
2. The puzzlelike fit of the continents, fossils, climatic evidence, and similar rock structures support Wegener's idea of continental drift. However, Wegener could not explain what process could cause the movement of the landmasses.

#### Section 2 Seafloor Spreading

1. Detailed mapping of the ocean floor in the 1950s showed underwater mountains and rift valleys.

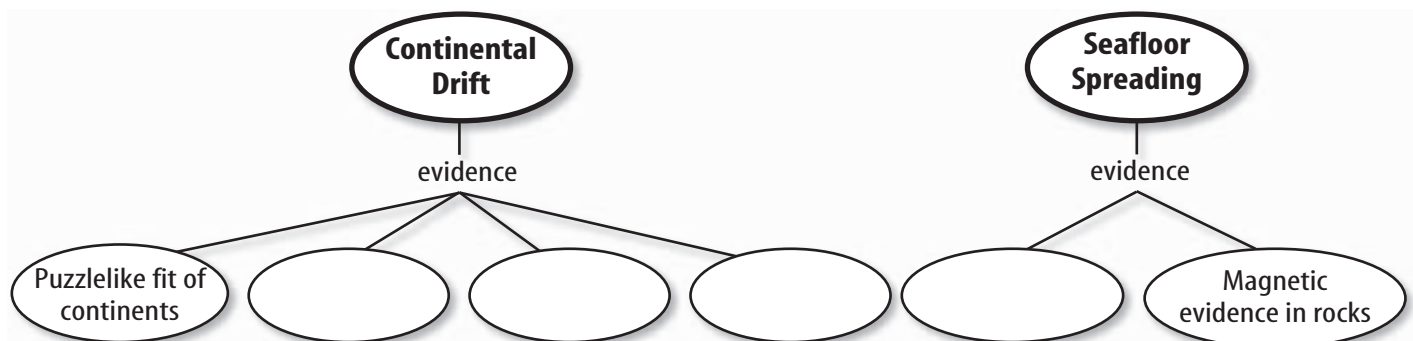
2. In the 1960s, Harry Hess suggested seafloor spreading as an explanation for the formation of mid-ocean ridges.
3. The theory of seafloor spreading is supported by magnetic evidence in rocks and by the ages of rocks on the ocean floor.

#### Section 3 Theory of Plate Tectonics

1. In the 1960s, scientists combined the ideas of continental drift and seafloor spreading to develop the theory of plate tectonics. The theory states that the surface of Earth is broken into sections called plates that move around on the asthenosphere.
2. Currents in Earth's mantle called convection currents transfer heat in Earth's interior. It is thought that this transfer of heat energy moves plates.
3. Earth is a dynamic planet. As the plates move, they interact, resulting in many of the features of Earth's surface.

### Visualizing Main Ideas

Copy and complete the concept map below about continental drift, seafloor spreading, and plate tectonics.



## Using Vocabulary

asthenosphere p. 190	Pangaea p. 182
continental drift p. 182	plate p. 190
convection current p. 195	plate tectonics p. 190
lithosphere p. 190	seafloor spreading p. 187

Each phrase below describes a vocabulary term from the list. Write the term that matches the phrase describing it.

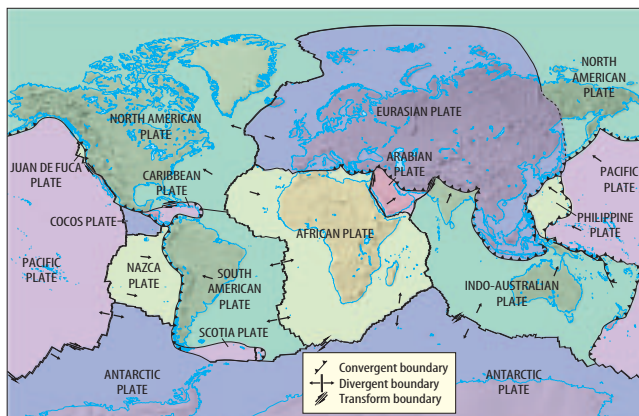
1. plasticlike layer below the lithosphere
2. idea that continents move slowly across Earth's surface
3. large, ancient landmass that consisted of all the continents on Earth
4. composed of oceanic or continental crust and upper mantle
5. explains locations of mountains, trenches, and volcanoes
6. theory proposed by Harry Hess that includes processes along mid-ocean ridges

## Checking Concepts

Choose the word or phrase that best answers the question.

7. Which layer of Earth contains the asthenosphere?
  - A) crust
  - B) mantle
  - C) outer core
  - D) inner core
8. What type of plate boundary is the San Andreas Fault part of?
  - A) divergent
  - B) subduction
  - C) convergent
  - D) transform
9. What hypothesis states that continents slowly moved to their present positions on Earth?
  - A) subduction
  - B) erosion
  - C) continental drift
  - D) seafloor spreading

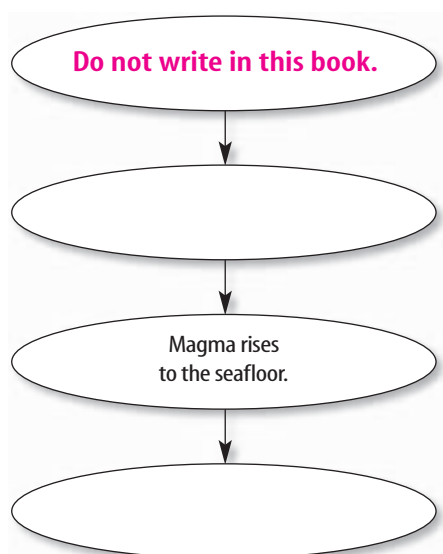
Use the illustration below to answer question 10.



10. Which plate is subducting beneath the South American Plate?
  - A) Nazca
  - B) African
  - C) North American
  - D) Indo-Australian
11. Which of the following features are evidence that many continents were at one time near Earth's south pole?
  - A) glacial deposits
  - B) earthquakes
  - C) volcanoes
  - D) mid-ocean ridges
12. What evidence in rocks supports the theory of seafloor spreading?
  - A) plate movement
  - B) magnetic reversals
  - C) subduction
  - D) convergence
13. Which type of plate boundary is the Mid-Atlantic Ridge a part of?
  - A) convergent
  - B) divergent
  - C) transform
  - D) subduction
14. What theory states that plates move around on the asthenosphere?
  - A) continental drift
  - B) seafloor spreading
  - C) subduction
  - D) plate tectonics

### Thinking Critically

15. **Infer** Why do many earthquakes but few volcanic eruptions occur in the Himalaya?
16. **Explain** Glacial deposits often form at high latitudes near the poles. Explain why glacial deposits have been found in Africa.
17. **Describe** how magnetism is used to support the theory of seafloor spreading.
18. **Explain** why volcanoes do not form along the San Andreas Fault.
19. **Explain** why the fossil of an ocean fish found on two different continents would not be good evidence of continental drift.
20. **Form Hypotheses** Mount St. Helens in the Cascade Range is a volcano. Use **Figure 9** and a U.S. map to hypothesize how it might have formed.
21. **Concept Map** Make an events-chain concept map that describes seafloor spreading along a divergent plate boundary. Choose from the following phrases: *magma cools to form new seafloor, convection currents circulate hot material along divergent boundary, and older seafloor is forced apart.*



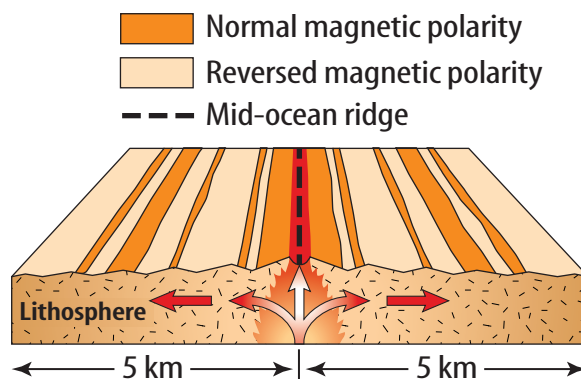
### Performance Activities

22. **Observe and Infer** In the MiniLab called “Modeling Convection Currents,” you observed convection currents produced in water as it was heated. Repeat the experiment, placing sequins, pieces of wood, or pieces of rubber bands into the water. How do their movements support your observations and inferences from the MiniLab?

### Applying Math

23. **A Growing Rift** Movement along the African Rift Valley is about 2.1 cm per year. If plates continue to move apart at this rate, how much larger will the rift be (in meters) in 1,000 years? In 15,500 years?

Use the illustration below to answer questions 24 and 25.



24. **New Seafloor** 10 km of new seafloor has been created in 50,000 years, with 5 km on each side of a mid-ocean ridge. What is the rate of movement, in km per year, of each plate? In cm per year?
25. **Use a Ratio** If 10 km of seafloor were created in 50,000 years, how many kilometers of seafloor were created in 10,000 years? How many years will it take to create a total of 30 km of seafloor?

**Part 1 Multiple Choice**

Record your answers on the answer sheet provided by your teacher or on a sheet of paper.

Use the illustration below to answer question 1.



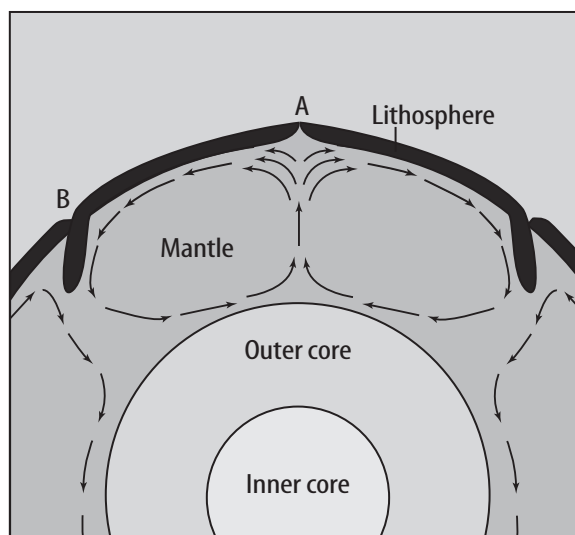
- What is the name of the ancient supercontinent shown above?
  - Pangaea
  - Gondwanaland
  - Laurasia
  - North America
- Who developed the continental drift hypothesis?
  - Harry Hess
  - J. Tuzo Wilson
  - Alfred Wegener
  - W. Jason Morgan
- Which term refers to sections of Earth's crust and part of the upper mantle?
  - asthenosphere
  - plate
  - lithosphere
  - core
- About how fast do plates move?
  - a few millimeters each year
  - a few centimeters each year
  - a few meters each year
  - a few kilometers each year

**Test-Taking Tip**

**Marking Answers** Be sure to ask if it is okay to mark in the test booklet when taking the test, but make sure you mark all answers on your answer sheet.

- Where do Earth's plates slide past each other?
  - convergent boundaries
  - divergent boundaries
  - transform boundaries
  - subduction zones

Study the diagram below before answering questions 6 and 7.



- Suppose that the arrows in the diagram represent patterns of convection in Earth's mantle. Which type of plate boundary is most likely to occur along the region labeled "A"?
  - transform
  - reverse
  - convergent
  - divergent
- Which statement is true of the region marked "B" on the diagram?
  - Plates move past each other sideways.
  - Plates move apart and volcanoes form.
  - Plates move toward each other and volcanoes form.
  - Plates are not moving.

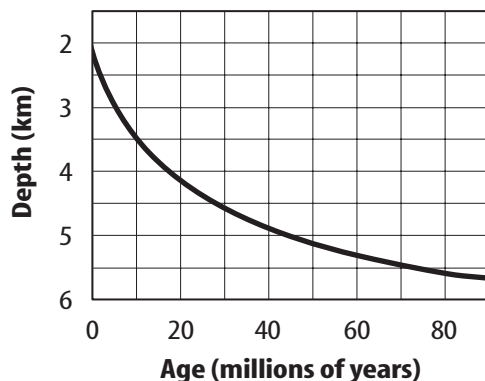
## Part 2 Short Response/Grid In

Record your answers on the answer sheet provided by your teacher or on a sheet of paper.

8. What is an ocean trench? Where do they occur?
9. How do island arcs form?
10. Why do earthquakes occur along the San Andreas Fault?
11. Describe a mid-ocean ridge.
12. Why do plates sometimes sink into the mantle?

Use the graph below to answer questions 13–15.

**Relationship Between Depth and Age of Seafloor**

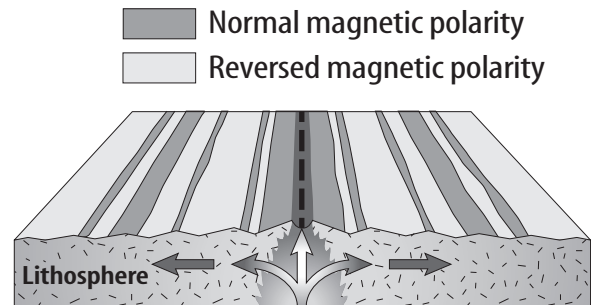


13. Use the graph to estimate the average depth below the ocean of ocean crust that has just formed.
14. Estimate the average depth of ocean crust that is 60 million years old.
15. Describe how the depth of ocean crust is related to the age of ocean crust.
16. On average, about how fast do plates move?
17. What layer in Earth's mantle do plates slide over?
18. Describe how scientists make maps of the ocean floor.

## Part 3 Open Ended

Record your answers on a sheet of paper.

Use the illustration below to answer question 19.



19. Examine the diagram above. Explain how the magnetic stripes form in rock that makes up the ocean crust.
20. What causes convection in Earth's mantle?
21. Explain the theory of plate tectonics.
22. What happened to the continents that made up Pangaea after it started to break up?
23. How does Earth's lithosphere differ from Earth's asthenosphere?
24. What types of life have been discovered near mid-ocean ridges?
25. What are the three types of motion that occur at plate boundaries? Describe each motion.
26. What forms when continents collide? Describe the process.
27. What occurs at the center of a mid-ocean ridge? What might you find there?
28. What evidence do we have that supports the hypothesis of continental drift?
29. Who proposed the first theories about plate tectonics? Explain why other scientists questioned these theories.