9 Plate Tectonics

Big idea

Dynamic Earth

Q: How do moving plates affect Earth's surface?

VIRGINIA SCIENCE STANDARDS OF LEARNING

ES.1.a, ES.2.b, ES.2.c, ES.2.d, ES.7.b, ES.10.d.
See lessons for details.

The spectacular Great Rift Valley cuts through eastern Africa. It represents the surface of a divergent plate boundary, where one part of the African plate is tearing away from the other. In the distant future, the valley could be a sea.

INQUIRY

TRY IT!

HOW DO THE CONTINENTS FIT TOGETHER?

Procedure

1. Get a copy of a world map from your teacher. Cut out the continents along their coastlines. **CAUTION:** *Be careful when using scissors.*
2. Try to fit together the pieces into one large landmass. Look for a "best-fit" configuration.
3. Compare your large landmass with those of other students. Did anyone come up with a landmass that was very different from the others?

Think About It

1. **Observe** From your continental reconstruction, where did the continents fit together well? Where did problems occur?
2. **Form a Hypothesis** Use your observations to develop a hypothesis on how to get a better fit of the continents. How could the overlaps and large gaps be explained? (*Hint:* What if the outline of the coasts is not the same as the boundaries of the continents themselves?)

9.1 Continental Drift

ES.2 The student will demonstrate an understanding of the nature of science and scientific reasoning and logic. Key concepts include **b.** evidence is required to evaluate hypotheses and explanations.

Key Questions

What is the hypothesis of continental drift?

What evidence supported continental drift?

Why was Wegener's hypothesis rejected?

Vocabulary

- continental drift
- Pangaea

Reading Strategy

Summarize Copy the table. Fill it in as you read to summarize the evidence of continental drift.

Hypothesis	Evidence
Continental Drift	a. continental puzzle
	b. ___?___
	c. ___?___
	d. ___?___

MORE THAN 300 years ago, mapmakers produced world maps that accurately showed the shapes of the continents. Looking at these maps, people noticed that some continents fit together like pieces of a jigsaw puzzle. Few people thought much about this observation until the early twentieth century. Then, scientists began to look again at the fit of the continents and think about what it might mean.

The Continental Puzzle

A German scientist, Alfred Wegener, also noticed the similarity between the coastlines on opposite sides of the South Atlantic Ocean. As you can see in **Figure 1,** the shapes of South America and Africa are an approximate fit with each other. In 1915, Wegener proposed his radical hypothesis of **continental drift.** **According to Wegener's hypothesis of continental drift, the continents had once been joined to form a single supercontinent.** He called this supercontinent **Pangaea,** meaning "all land."

Wegener also hypothesized that about 200 million years ago Pangaea began breaking into smaller continents. The continents then drifted slowly to their present positions.

FIGURE 1 A Curious Fit
This map shows the best fit of South America and Africa at a depth of about 900 meters. Areas of overlap appear in brown.

Evidence for Continental Drift

Wegener presented a variety of evidence to support the hypothesis of continental drift. His evidence included similar fossils, types of rock, and traces of glaciation on widely separated landmasses.

Matching Fossils **Fossil evidence for continental drift includes several fossil organisms found on different landmasses.** Wegener reasoned that these organisms could not have crossed the vast oceans presently separating the continents. An example is *Mesosaurus,* a reptile whose fossil remains are limited to eastern South America and southern Africa, as shown in **Figure 2.** Scientists think that *Mesosaurus* lived in freshwater lakes and shallow bays. It could not have swum across a vast, salty ccean such as the Atlantic. Therefore, Wegener argued, South America and Africa must have been joined when *Mesosaurus* lived.

The distribution of other types of fossils also supported Wegener's hypothesis. For example, fossils of *Glossopteris,* a small plant, are found today in South America, southern Africa, India, Antarctica, and Australia. Yet the characteristics of *Glossopteris* seeds make it very unlikely that the seeds could have blown or floated long distances across the oceans. Fossils of the land reptile *Lystrosaurus* show a similar pattern of distribution across landmasses that are now far apart from each other.

In Wegener's time, the idea of land bridges was the accepted explanation for similar fossils being found on different landmasses. However, if land bridges did exist between South America and Africa, their remnants should still lie below sea level. But no signs of such land bridges have ever been found in the Atlantic Ocean.

Reading Checkpoint *How does the distribution of Mesosaurus fossils provide evidence for continental drift?*

INQUIRY APPLY IT!

Q: *If all the continents were once joined as Pangaea, what did the rest of Earth look like?*

A: When all the continents were together, there must also have been one huge ocean surrounding them. This ocean is called *Panthalassa* (*pan* = all, *thalassa* = sea). Today all that remains of Panthalassa is the Pacific Ocean, which has been decreasing in size since the breakup of Pangaea.

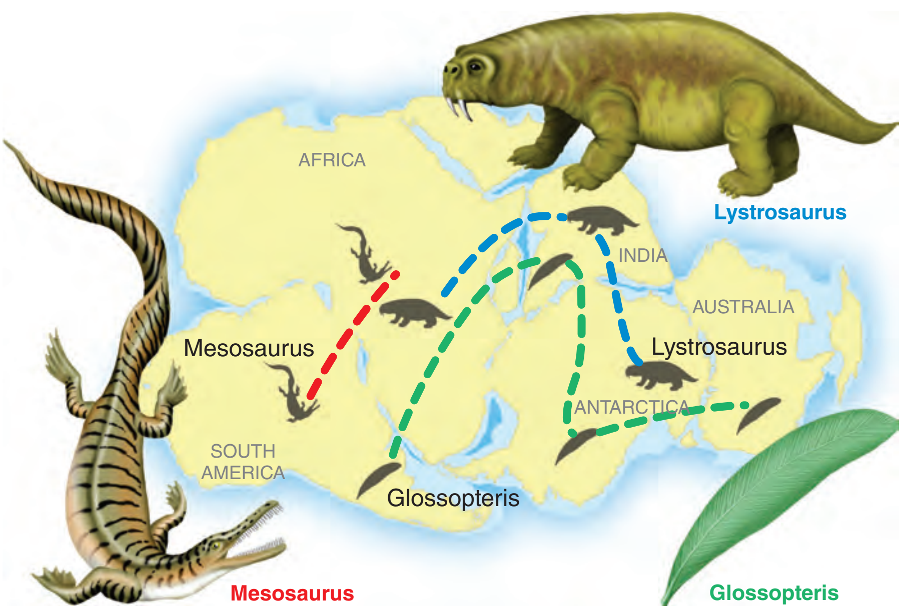


FIGURE 2 Fossil Evidence
Fossils of *Mesosaurus* have been found on both sides of the South Atlantic and nowhere else in the world. Fossil remains of this and other organisms on the continents of Africa and South America appear to link these landmasses at some time in Earth's history.

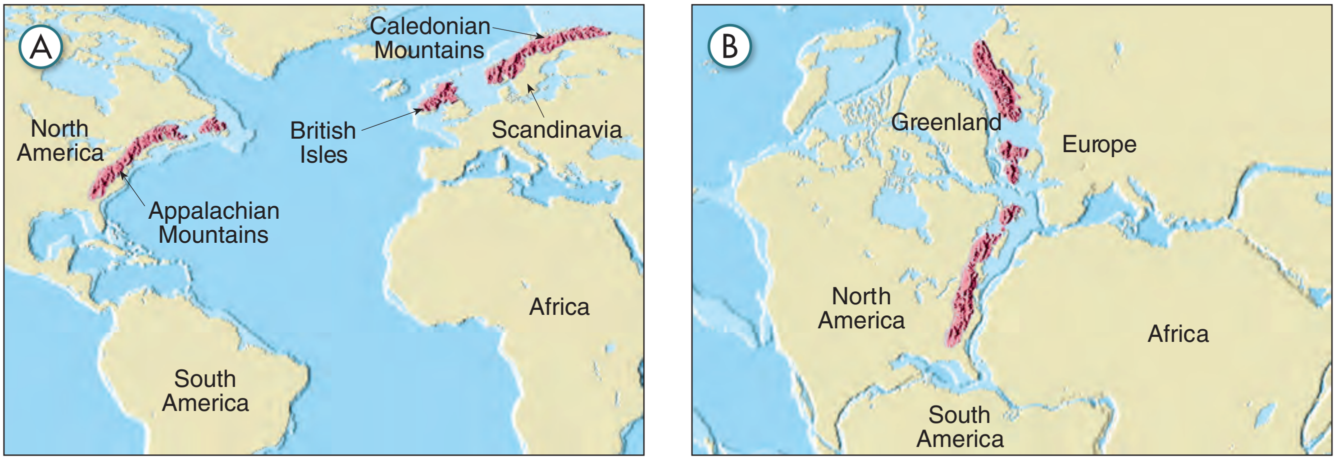


FIGURE 3 Matching Mountain Ranges
A The Appalachian Mountains run along the eastern side of North America and end off the coast of Newfoundland. Mountains that are similar in age and structure are found in the British Isles and Scandinavia.

B When these landmasses were united as Pangaea, these ancient mountain chains formed a nearly continuous belt.

Rock Types Anyone who has worked a jigsaw puzzle knows that the pieces must fit together to form a complete picture. The picture in the continental drift uzzle is one of matching rock types and mountain belts. If the continents were once part of Pangaea, the rocks found in a particular region on one continent should closely match in age and type those in adjacent positions on the adjoining continent.

Matching types of rock in several mountain belts that today are separated by oceans provide evidence for continental drift. For example, the Appalachian mountain belt in eastern North America ends off the coast of Newfoundland, as shown in **Figure 3A.** Mountains of the same age with similar rocks and structures are found in the British Isles and Scandinavia. When these landmasses are fitted together as in **Figure 3B,** the mountain chains form a nearly continuous belt.

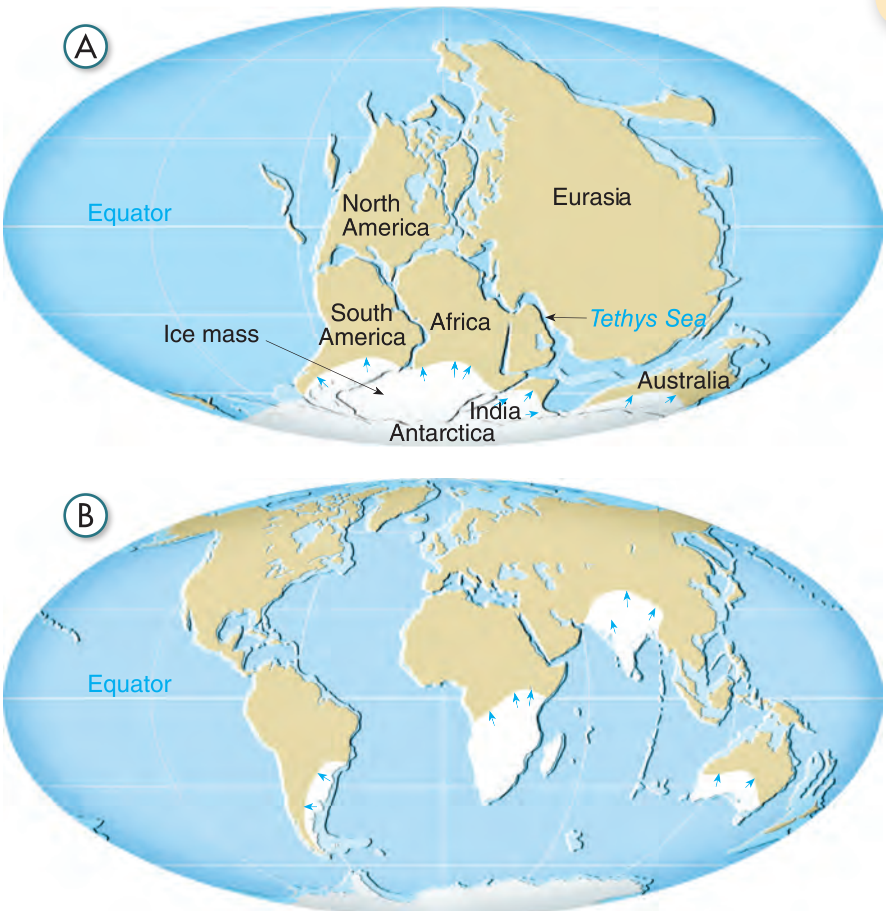
Ancient Climates Wegener found evidence for dramatic global climate changes that supported his hypothesis. **Wegener found glacial deposits showing that between 220 million and 300 million years ago, ice sheets covered large areas of the Southern Hemisphere. Deposits of glacial till occurred at latitudes that today have temperate or even tropical climates: southern Africa, South America, India, and Australia.** Below these beds of glacial debris lay scratched and grooved bedrock carved by the ice. In some locations, the scratches and grooves showed that the ice had moved from what is now the sea onto land. It is unusual for large continental glaciers to move from the sea onto land. It is also interesting that much of the land area that shows evidence of this glaciation now lies near the equator in a subtropical or tropical climate.

Could Earth have been cold enough to allow the formation of continental glaciers in what is now a tropical region? Wegener rejected this idea because, during this same time period, large tropical swamps existed in the Northern Hemisphere. The lush vegetation of these swamps eventually became the major coal fields of the eastern United States, Europe, and Siberia.

Wegener thought there was a better explanation for the ancient climate evidence he observed. Thinking of the landmasses as a supercontinent, with South Africa centered over the South Pole, would create the conditions necessary to form large areas of glacial ice over much of the Southern Hemisphere. The supercontinent idea would also place the northern landmasses nearer the tropics and account for their vast coal deposits, as shown in **Figure 4.**

Reading Checkpoint *Summarize the climate evidence for continental drift.*

FIGURE 4 Glacier Evidence
A The area of Pangaea covered by glacial ice 300 million years ago. **B** The continents as they are today. The white areas indicate where evidence of the old ice sheets exists.
Interpret Diagrams *Where were the continents located when the glaciers formed?*



INQUIRY QUICK LAB

CHARTING THE AGE OF THE ATLANTIC OCEAN

Procedure

1. The distance between two locations across the Atlantic Ocean, one in South America and one in Africa, is 4300 km.
2. Assume that these two locations were once joined as part of Pangaea.

Analyze and Conclude

1. **Calculate** If the landmasses moved apart at a rate of 3.3 cm per year, how long did it take to arrive at their current positions?

VISUAL SUMMARY

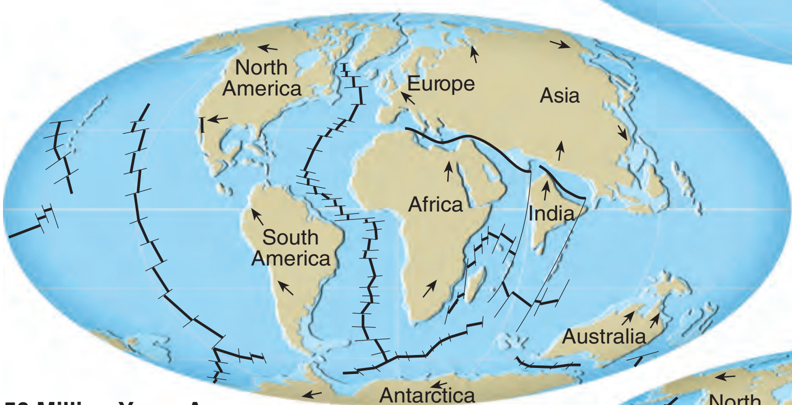
BREAKUP OF PANGAEA

FIGURE 5 Pangaea broke up gradually over a period of 200 million years.

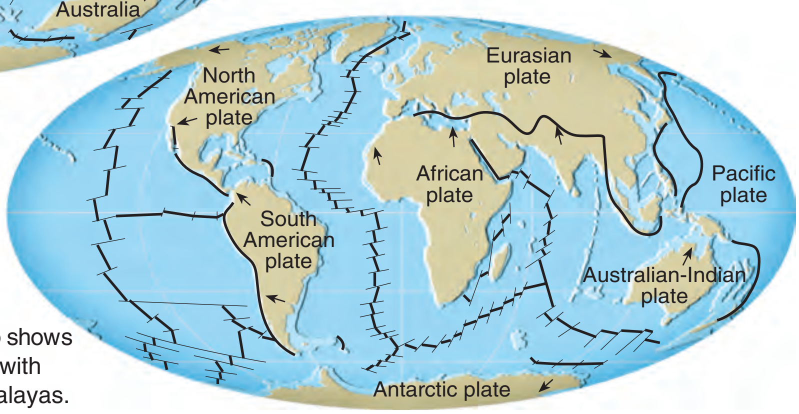
250 Million Years Ago Pangaea consisted of all the major continents.

200 Million Years Ago The rifting that eventually resulted in the Atlantic Ocean occurred over an extended period of time. The first rift developed between North America and Africa.

100 Million Years Ago Continued rifting of the souther n landmasses sent India on a northward journey.



50 Million Years Ago Australia began to separate from Antarctica.



Present A modern map shows that India has collided with Asia, creating the Himalayas.

ACTIVE ART

For: Continental Drift activity
Visit: PearsonSchool.com
Web Code: czp-3091

Rejection of Wegener's Hypothesis

Wegener's hypothesis faced a great deal of criticism from other scientists. **The m in objection to Wegener's hypothesis was that he could not describe a mechanism capable of moving the continents.** Wegener proposed that the tidal influence of the Moon was strong enough to give the continents a westward motion. However, physicists quickly responded that tidal friction great enough to move the continents would stop Earth's rotation.

Wegener also proposed that the larger and sturdier continents broke through the oceanic crust, much like ice-breakers cut through ice. However, there was no evidence to suggest that the ocean floor was weak enough to permit passage of the continents without the ocean floors being broken and deformed in the process.

Most scientists in Wegener's day rejected his hypothesis. However, a few geologists continued to search for evidence of continental drift.

During the years that followed Wegener's hypothesis, major strides in technology enabled scientists to map the ocean floor. Extensive data on earthquake activity and Earth's magnetic field also became available. By 1967, these fi dings led to a new theory, known as plate tectonics. The theory of plate tectonics proved that Wegener was correct—the continents move. The theory also provided the framework for understanding many other geologic processes, such as the formation of the mountains shown in **Figure 6.**

FIGURE 6 Mountain Origins Today, scientists know that plate movements pushed up mountain ranges such as the Canadian Rockies in Alberta, Canada.

9.1 Assessment

Review Key Concepts

1. What is the hypothesis of continental drift?
2. List the evidence that supported the hypothesis of continental drift.
3. Why did scientists reject Wegener's continental drift hypothesis?
4. What was Pangaea?

Think Critically

5. **Apply Concepts** How does the occurrence of the same plant fossils in South America and Africa support continental drift? Explain.
6. **Draw Conclusions** How did Wegener explain the existence of glaciers in the southern landmasses, and the lush tropical swamps in North America, Europe, and Siberia?
7. **Review** Write a paragraph describing Pangaea. Include the location and climate of Pangaea. Use the equator as your reference for position.

9.2 Sea-Floor Spreading

ES.2 The student will demonstrate an understanding of the nature of science and scientific reasoning and logic. Key concepts include **b.** evidence is required to evaluate hypotheses and explanations. **ES.10** The student will investigate and understand that oceans are complex, interactive physical, chemical, and biological systems and are subject to long- and short-term variations. Key concepts include **d.** features of the sea floor as reflections of tectonic processes.

Key Questions

What are mid-ocean ridges and deep-ocean trenches?

What occurs during sea-floor spreading?

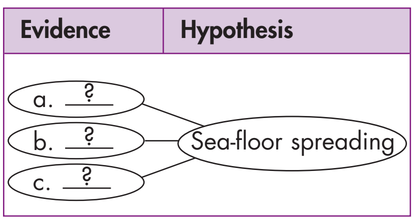
What is the evidence for sea-floor spreading?

Vocabulary

- sonar
- deep-ocean trench
- mid-ocean ridge
- rift valley
- sea-floor spreading
- subduction
- paleomagnetism

Reading Strategy

Identify Supporting Evidence Copy the graphic organizer. After you read, complete it to show the evidence that supported the hypothesis of sea-floor spreading.



WEGENER PUBLISHED his book *On the Origin of Continents and Oceans* in 1915. During the decades that followed, very few scientists studied continental drift. But discoveries in other branches of Earth science eventually led to new interest in Wegener's hypothesis. Surprisingly, important new data came from one of the least-known parts of Earth—the ocean floor.

Exploring the Ocean Floor

During the mid 1800s, several nations sent ships on scientific expeditions to gather data about the oceans. Scientists wanted to know more about the topography of the ocean floor. They measured ocean depths in many areas. Data from the middle of the Atlantic Ocean, where scientists expected the water to be very deep, revealed large undersea mountains. This discovery helped to fuel interest in mapping the ocean floor.

During the early 1900s, a new technology made it easier to map the ocean floor. **Sonar,** which stands for **so**und **na**vigation and **r**anging, is a system that uses sound waves to calculate the distance to an object. The sonar equipment on a ship sends out pulses of sound that bounce off he ocean floor. The equipment then measures how quickly the sound waves return to the ship. The deeper the water, the longer it takes the sound waves to return to the ship.

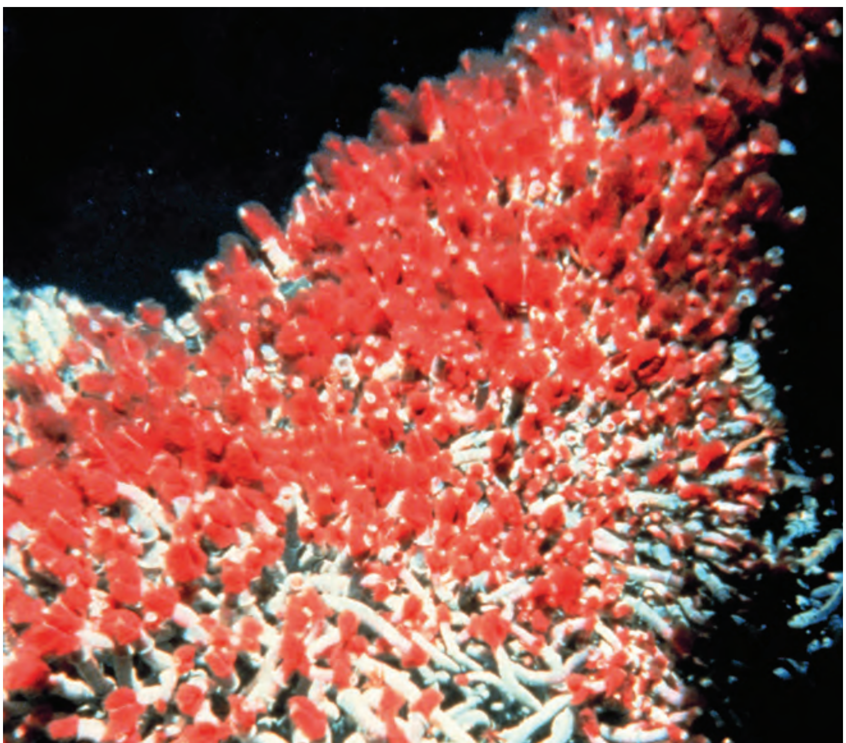


FIGURE 7 Sea-Floor Vents These worms live next to hydrothermal vents on the ocean floor. The vents are found around mid-ocean ridges and other areas where super-heated water, gases, and other materials emerge from below.

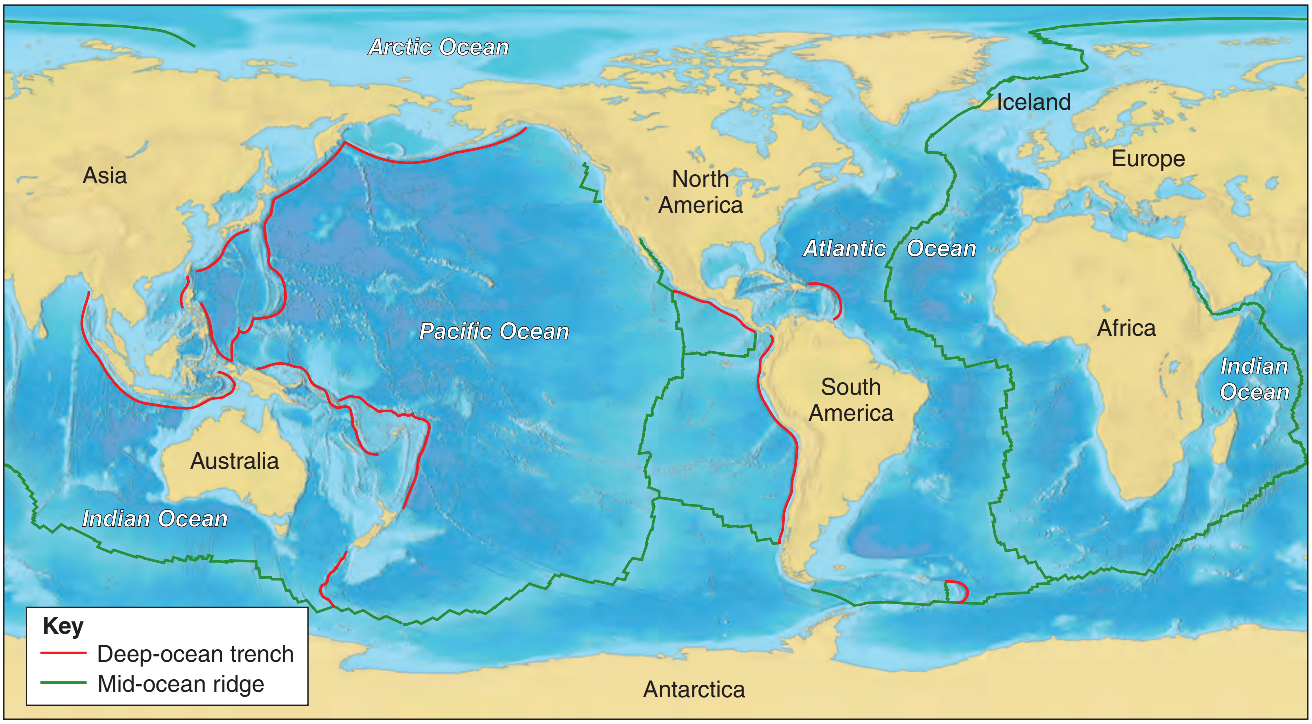


FIGURE 8 Ocean Basins Deep trenches and mountainous mid-ocean ridges are major features of Earth's ocean basins.
Observe *Which ocean has the most trenches?*

Deep-Ocean Trenches As scientists mapped the ocean floor, they found long, steep valleys called **deep-ocean trenches.** Trenches form the deepest parts of Earth's oceans. For example, the Mariana Trench in the Pacific Ocean is over 11 kilometers deep. Most trenches occur around the edges of the Pacific Ocean, although others occur in the Indian and Atlantic oceans.

Mid-Ocean Ridges By the late 1950s, scientists had constructed a more complete map of the ocean floor. The map showed that the mountain range in the middle of the Atlantic Ocean was not an isolated feature. Instead, it formed a **mid-ocean ridge,** a long chain of mountains extending throughout all the oceans. **Earth's mid-ocean ridge system forms the longest feature on Earth's surface.** The system winds more than 70,000 kilometers across the sea floors of every ocean basin, like the seam on a baseball. The term *ridge* may be misleading, because it is not narrow like the ridges that hikers fi d on mountains. It ranges from 1,000 to 4,000 kilometers wide. In a few places, such as Iceland, the mid-ocean ridge rises above the ocean surface.

Often, a deep, central valley runs down the center of a ridge. Called a **rift valley**, the central valley of a mid-ocean ridge resembles a long canyon. Some parts of the ridge system lack a rift v lley.

PLANET DIARY

For an activity on **Mid-Ocean Ridges**, visit PlanetDiary.com/HSES.

Reading Checkpoint *What are mid-ocean ridges?*

Composition of the Ocean Floor Earth's ocean floors are made of igneous rocks of basaltic composition. Recall that basalt forms when magma reaches the surface and hardens to form solid rock. Most of the ocean floor is covered with a thick layer of sediment. Scientists found that the sediment layer is progressively thinner to mid-ocean ridges, and that along the ridge there was no sediment.

FIGURE 9 Widening Sea
A spreading center in the Red Sea is slowly causing the sea to become wider.

The Process of Sea-Floor Spreading

The new map of the ocean floor aroused the curiosity of many scientists. One geologist, Harry Hess, thought that the mid-ocean ridges and deep-ocean trenches might help to explain how the ocean floor was formed. In 1963, Hess published his hypothesis of sea-floor spreading. **In the process of sea-floor spreading, ew ocean floor forms along Earth's mid-ocean ridges and slowly moves outward across ocean basins.** During sea-floor spreading, new oceanic lithosphere is formed, and the floor of a particular ocean basin can become wider. Today, the Atlantic Ocean is thousands of kilometers wide. Millions of years ago, the Atlantic would have been a narrow sea, like the Red Sea, shown in **Figure 9.**

Eruptions Along Mid-Ocean Ridges How did the mid-ocean ridges form? Scientists found evidence that the mid-ocean ridges formed as the result of volcanic activity. As shown in **Figure 10,** fractures along the central valley of a mid-ocean ridge fill with magma that wells up from the hot mantle below. (Recall that magma is molten rock that forms in the upper mantle and rises through the crust.) Spreading and upwelling of magma continuously adds new ocean floor.

The process can also begin on land when a rift v lley forms and splits a continental landmass. Over millions of years, the rift v lley widens to form a new ocean basin like the Red Sea, shown in Figure 9.

Movement of the Ocean Floor As new ocean floor is added along mid-ocean ridges, the older ocean floor moves outward and away from the ridge on both sides. Rates of sea-floor spreading average about 5 centimeters per year. These rates are slow on a human time scale. But they are fast enough that all of Earth's ocean basins could have been formed within the last 200 million years. This further supports the theory of plate tectonics.

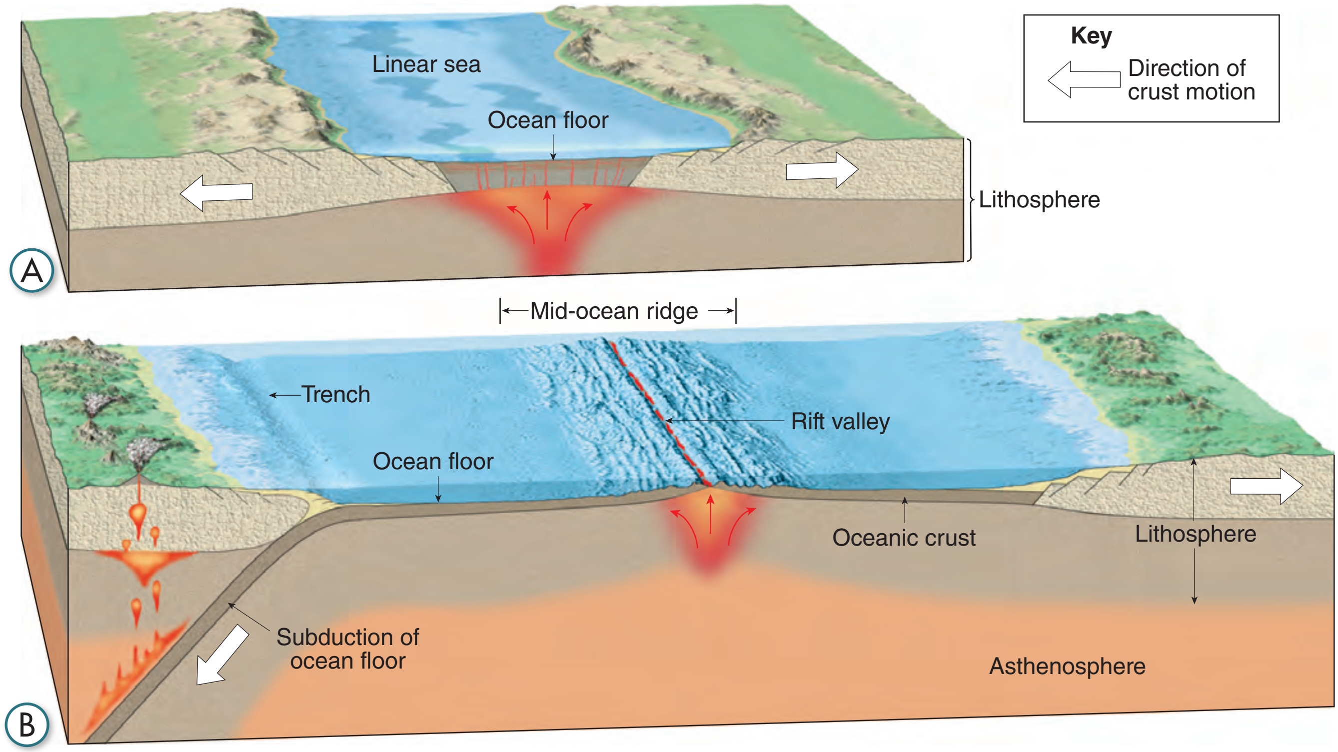


FIGURE 10 Sea-Floor Spreading and Subduction The process of sea-floor spreading produces the ocean floor. **A** A linear sea forms along a spreading center. **B** Over millions of years a mid-ocean ridge develops, and the ocean basin becomes wider. Overall, the addition of new crust at mid-ocean ridges is counteracted by subduction of old crust at deep-ocean trenches.
Relate Cause and Effect *What process adds new material to the ocean floor?*

Subduction at Deep-Ocean Trenches Although new ocean floor is constantly being added at the mid-ocean ridges, our planet is not growing larger. Earth's total surface area remains the same. How can that be? To accommodate newly created lithosphere, older portions of the ocean floor return to the mantle. In the process of **subduction,** ocean floor returns to the mantle as it sinks beneath a deep ocean trench. The areas where subduction occurs, shown in Figure 10, are called subduction zones.

☑ **Reading Checkpoint** *What happens during subduction?*

Evidence for Sea-Floor Spreading

Hess's hypothesis got the attention of geologists. Sea-floor spreading explained the formation and destruction of ocean floor and how ocean basins could grow wider or close up. But what evidence was there to support Hess's hypothesis? **Evidence for sea-floor spreading included magnetic strips in ocean-floor rock, earthquake patterns, and measurements of the ages of ocean floor rocks.**

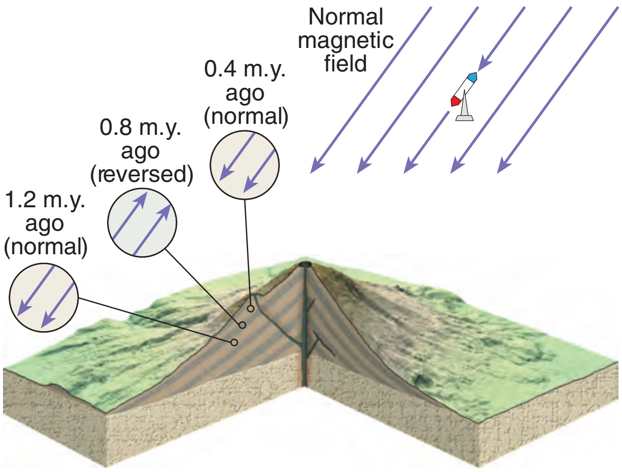


FIGURE 11 Paleomagnetism in Lava As lava cools, it becomes magnetized parallel to the magnetic field present at that time. When the polarity reverses, a record of the magnetism is preserved in the sequence of lava flows.

Magnetic Strips The magnetic properties of the rock that makes up the ocean floor provided evidence for sea-floor spreading. To understand this evidence, you need to understand how some rocks can become magnetized.

Recall that Earth's magnetic field is much like that of a bar magnet. Geophysicists learned that Earth's magnetic field occasionally reverses *polarity.* That is, the north magnetic pole becomes the south magnetic pole, and vice versa. Scientists graphed these reversals of polarity going back millions of years. When Earth's magnetic field lines up in the same direction as the present magnetic field, it is said to have *normal polarity.* When the magnetic field lines up in the opposite direction, it is said to have *reverse polarity.*

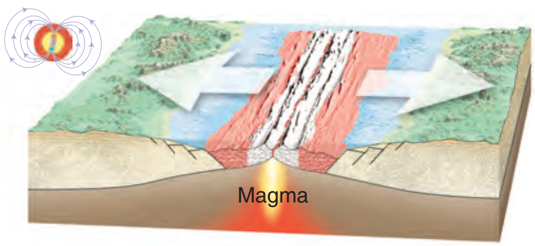
As certain rocks form, they acquire the polarity that Earth's magnetic field has at the time. These rocks possess **paleomagnetism.** How does a rock become magnetized? Many igneous rocks contain magnetite, an iron-rich mineral. As the rock cools and hardens, the iron-rich mineral grains become magnetized in the same direction as the existing magnetic field. You can see this process in **Figure 11.** Once the rock has formed, its polarity remains frozen unless the rock is reheated above a certain temperature. But what if the rock is moved or if the magnetic pole changes its position? The rock's paleomagnetism does not change.

Scientists collected data on the paleomagnetism of the rock that makes up the ocean floor. Ships towed instruments called magnetometers across the ocean floor. The data revealed a pattern of alternating strips of magnetized rock. Strips of rock with normal polarity alternated with strips of rock having reverse polarity. Scientists inferred that as new oceanic lithosphere forms along the mid-ocean ridges, it becomes magnetized according to the polarity of Earth's magnetic field at the time. The matching pattern of strips on both sides of a ridge, shown in **Figure 12,** is evidence that sea-floor spreading occurs.

☑ **Reading Checkpoint** *What is paleomagnetism?*

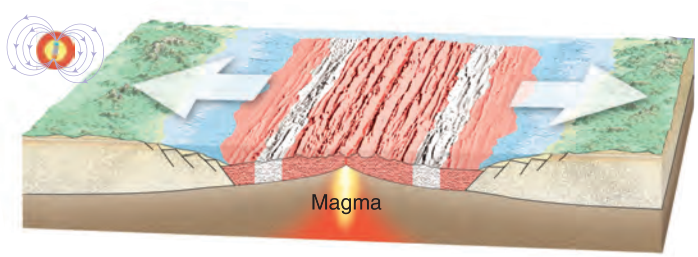
FIGURE 12 Polarity Reversals

1. Period of Normal Polarity



1 As new material is added to the ocean floor at the oceanic ridges, it is magnetized according to Earth's existing magnetic field.

2. Period of Reverse Polarity



2 A period of reverse polarity is recorded in the same way.

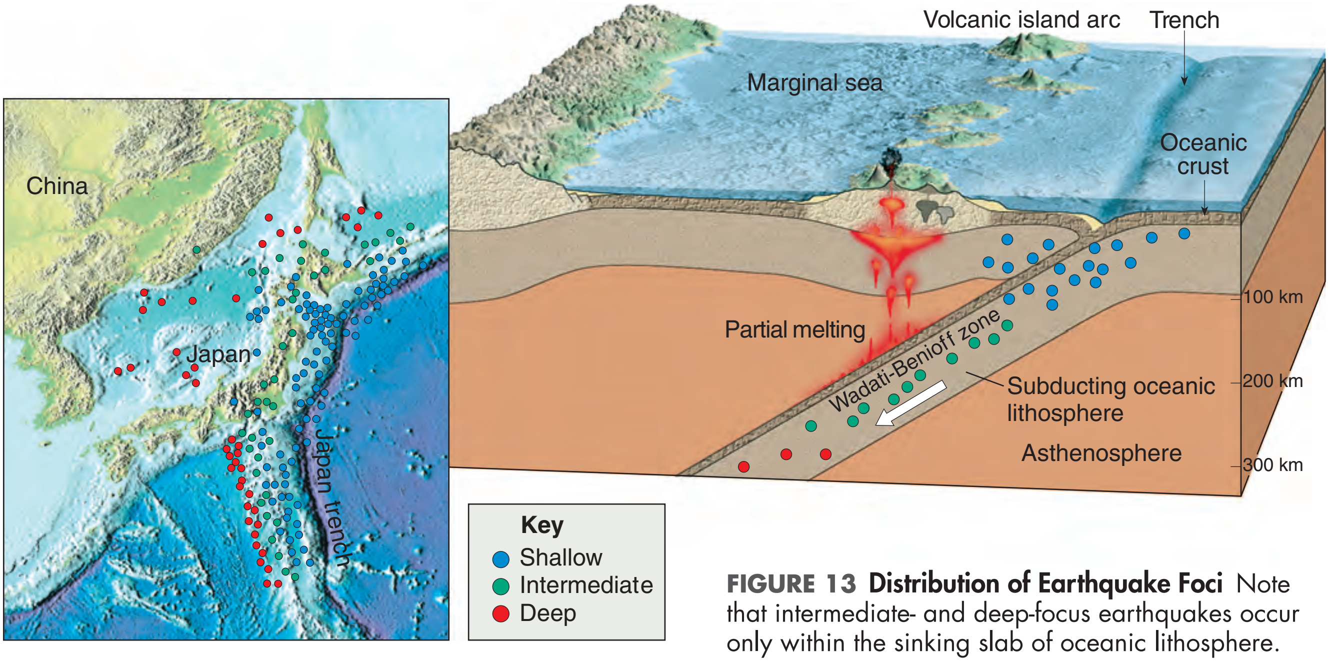


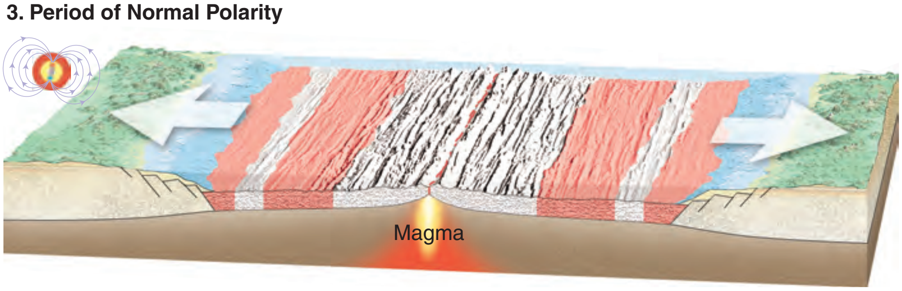
FIGURE 13 Distribution of Earthquake Foci Note that intermediate- and deep-focus earthquakes occur only within the sinking slab of oceanic lithosphere.

Earthquake Patterns More evidence for sea-floor spreading came from studies of the depth at which certain earthquakes occur. Scientists knew that there were many earthquakes in subduction zones. Two scientists, Kiyoo Wadati and Hugo Benioff, found a pattern when they plotted the depth of earthquakes in relation to their distance from deep-ocean trenches.

Shallow-focus earthquakes occur in and around a trench. Wadati and Benioff bserved that intermediate-focus and deep-focus earthquakes occur in a belt about 50 kilometers thick. This belt extends through the lithosphere and deep into the asthenosphere. As you can see in **Figure 13,** the deeper the earthquake, the farther away its focus is from the deep-ocean trench. No earthquakes have been recorded below about 700 kilometers. At this depth the subducting slab of ocean floor has been heated enough to soften.

Scientists considered the pattern of earthquakes in Wadati-Benioff ones in relation to sea-floor spreading. The pattern was what scientists expected would result from subduction of the ocean floor. These data convinced scientists that slabs of ocean floor return to the mantle in subduction zones.

3. Period of Normal Polarity



3 Note that the pattern of magnetism is captured on both sides of the ridge.
Apply Concepts *Why are the magnetized strips about equal width on either side of the ridge?*

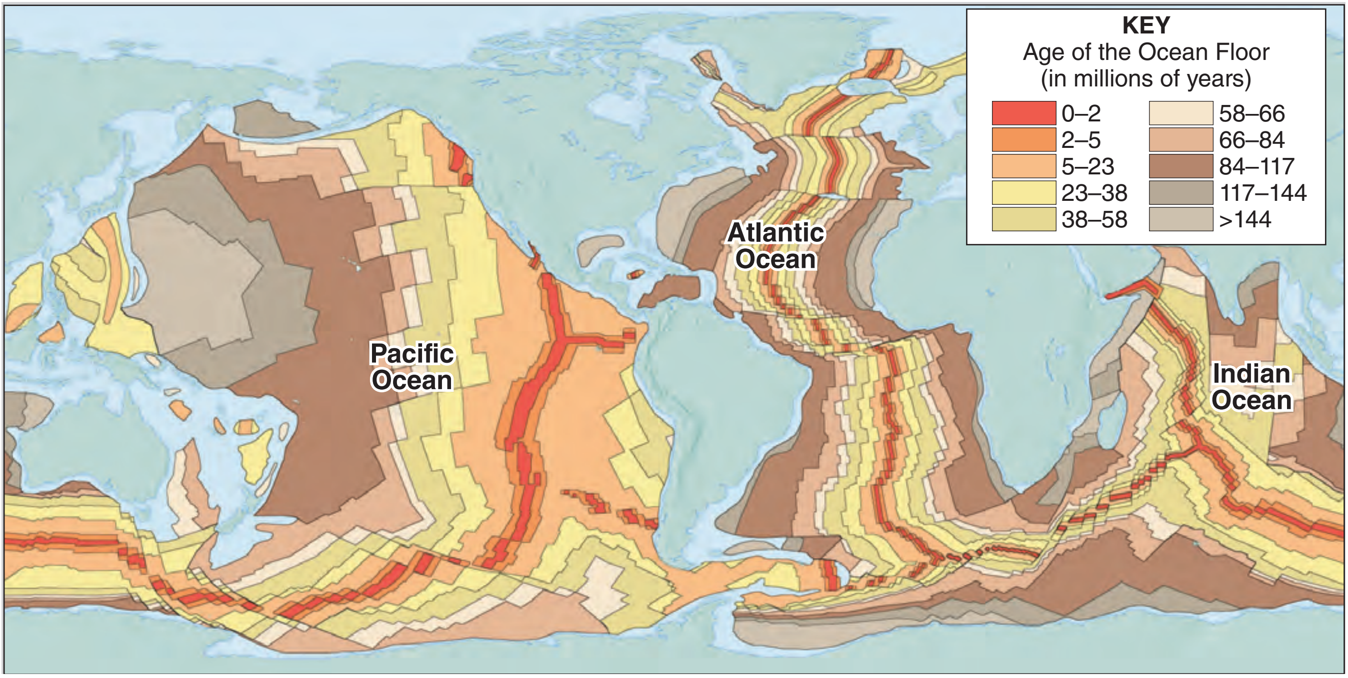


FIGURE 14 Sea-Floor Ages
As the map shows, the youngest parts of the ocean floor lie along the mid-ocean ridges. The oldest parts of the ocean floor are found along the outer edges of ocean basins.

The Age of the Ocean Floor Drilling into sediment on the ocean floor and the crust beneath it provided some of the best evidence for sea-floor spreading. Beginning in 1968, the drilling ship *Glomar Challenger* collected data on both sides of mid-ocean ridges.

The data confi med what the sea-floor spreading hypothesis predicted. The ocean floor is youngest along the central valley of the mid-ocean ridge, as shown in **Figure 14.** The ocean floor is oldest in subduction zones or near the edges of continents far from the ridge. The data also confi med that none of the ocean floor is more than about 180 million years old. Older oceanic rock would have returned to the mantle through subduction.

9.2 Assessment

Review Key Concepts

1. Describe mid-ocean ridges and deep-ocean trenches.

2. Explain what occurs during sea-floor spreading.

3. List the evidence for sea-floor spreading.

4. What is a Wadati-Benioff zone?

Think Critically

5. Infer Why are the oldest parts of the ocean floor less than 200 million years old?

6. Apply Concepts How do strips of magnetized rock on the ocean floor provide evidence of sea-floor spreading?

7. Relate Cause and Effect Do earthquakes occur at a depth of more than 700 kilometers? Explain your answer.

WRITING IN SCIENCE

8. Explain Write a paragraph explaining how scientists learned the age of the ocean floor and how these data supported sea-floor spreading.

9.3 Theory of Plate Tectonics

ES.2 The student will demonstrate an understanding of the nature of science and scientific reasoning and logic. Key concepts include **d.** evidence is evaluated for scientific theories. **ES.7** The student will investigate and understand geologic processes including plate tectonics. Key concepts include **b.** tectonic processes.

Key Questions

What is the theory of plate tectonics?

What are the three types of plate boundaries?

Vocabulary

- plate
- plate tectonics
- divergent boundary
- convergent boundary
- transform fault boundary
- continental volcanic arc
- volcanic island arc

Reading Strategy

Compare and Contrast
Copy the table. After you read, compare the three types of plate boundaries by completing the table.

Boundary Type	Relative Plate Motion
convergent	a. ___?___
divergent	b. ___?___
transform fault	c. ___?___

DURING the 1960s, scientists realized that sea-floor spreading explained part of Alfred Wegener's idea of continental drift. Namely, it explained how ocean basins could open and close. Canadian geologist J. Tuzo Wilson combined the evidence for sea-floor spreading with other observations. Wilson and other scientists soon developed a new theory that led to a revolution in geology.

Earth's Moving Plates

Wilson suggested that the lithosphere is broken into several huge pieces, called **plates.** Deep faults, like cracks in the shell of a hard-boiled egg, separate the different plates. **In the theory of plate tectonics, Earth's lithospheric plates move slowly relative to each other, driven by convection currents in the mantle.** The plates, shown in **Figure 15** on the following pages, generally are made up of both oceanic lithosphere and continental lithosphere. Some plates may contain no continents and just a small number of landmasses.

Causes of Plate Motion

Recall that Wegener had failed to explain how the lithosphere could move. The theory of plate tectonics identified a force that could set Earth's outer shell in motion. According to J. Tuzo Wilson, convection currents within Earth drive plate motion. Hot material deep in the mantle moves upward by convection. At the same time, cooler, denser slabs of oceanic lithosphere sink into the mantle.

Effects of Plate Motion

Lithospheric plate motion averages about 5 centimeters per year. That's about as fast as your fi gernails grow. The results of plate motion include earthquakes, volcanoes, and mountain building, which are some of the most powerful and violent forces on Earth.

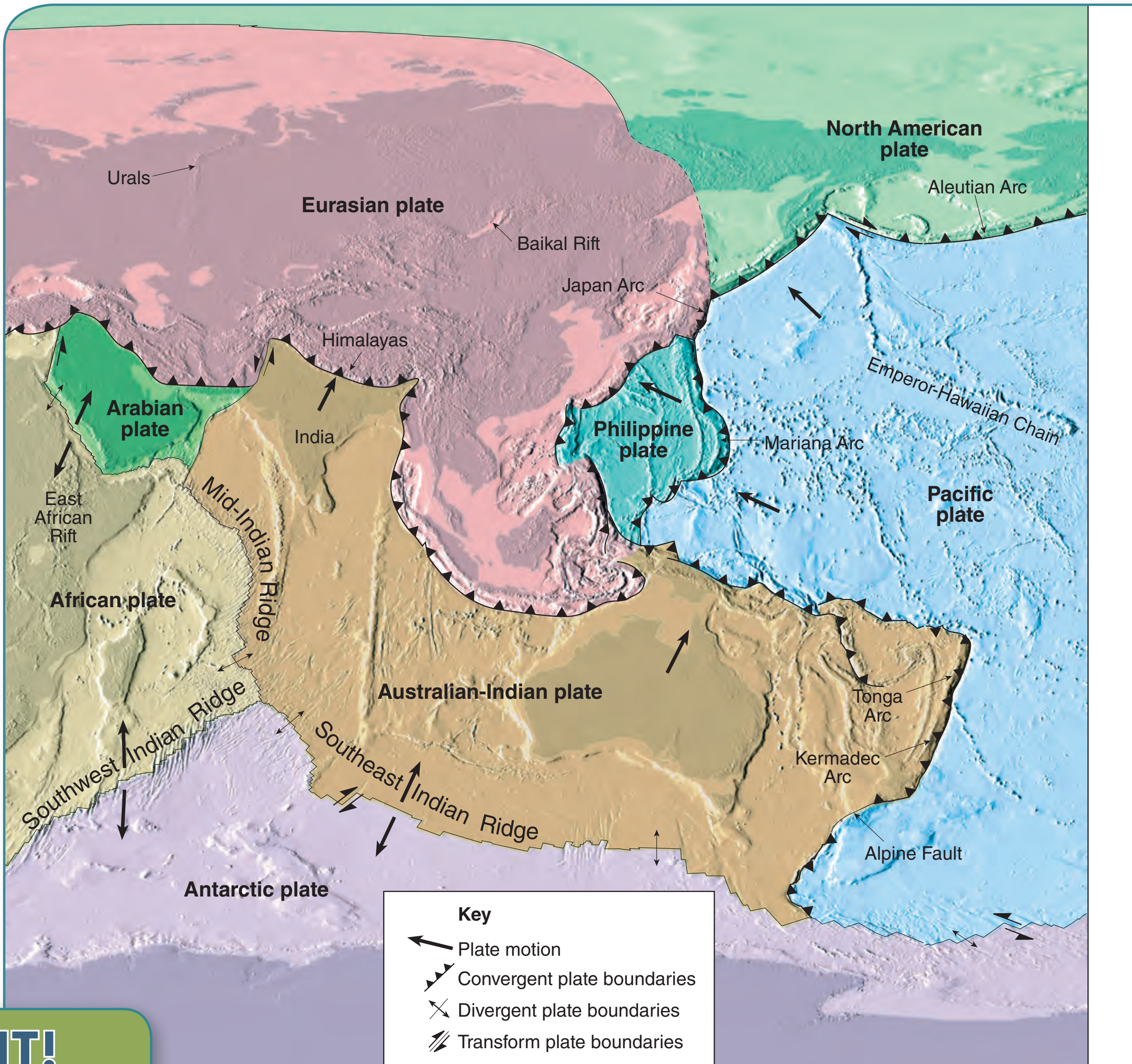


FIGURE 15 **Earth's Tectonic Plates**

MAP IT! ACTIVITY

As shown in **Figure 15,** most of the Earth's plates are made up of both oceanic and continental lithosphere. **Identify** Find a major plate that includes an entire continent plus a large area of ocean floor. Then locate two examples of a divergent boundary, a convergent boundary, and a transform fault boundary.

Types of Plate Boundaries Interactions among individual plates occur along plate boundaries. The three types of plate boundaries are convergent, divergent, and transform fault boundaries. Most plates feature a combination of each of the three types.

Divergent boundaries are found where two of Earth's plates move apart. Oceanic lithosphere is created at divergent boundaries—think of how sea-floor spreading adds rock to the ocean floor.

Convergent boundaries form where two plates move together. Lithosphere can be destroyed at convergent boundaries—think about how oceanic lithosphere sinks into the mantle during subduction.

Transform fault boundaries occur where two plates grind past each other. Along transform boundaries, lithosphere is neither created nor destroyed.

Plates may shrink or grow in area, depending on the locations of convergent and divergent boundaries. For example, you can see in Figure 15 that the Philippine plate is subducting beneath Asia, but has no ridges as boundaries to create new lithosphere. As a result, the plate is getting smaller because of subduction.

Reading Checkpoint *What is a transform fault boundary?*

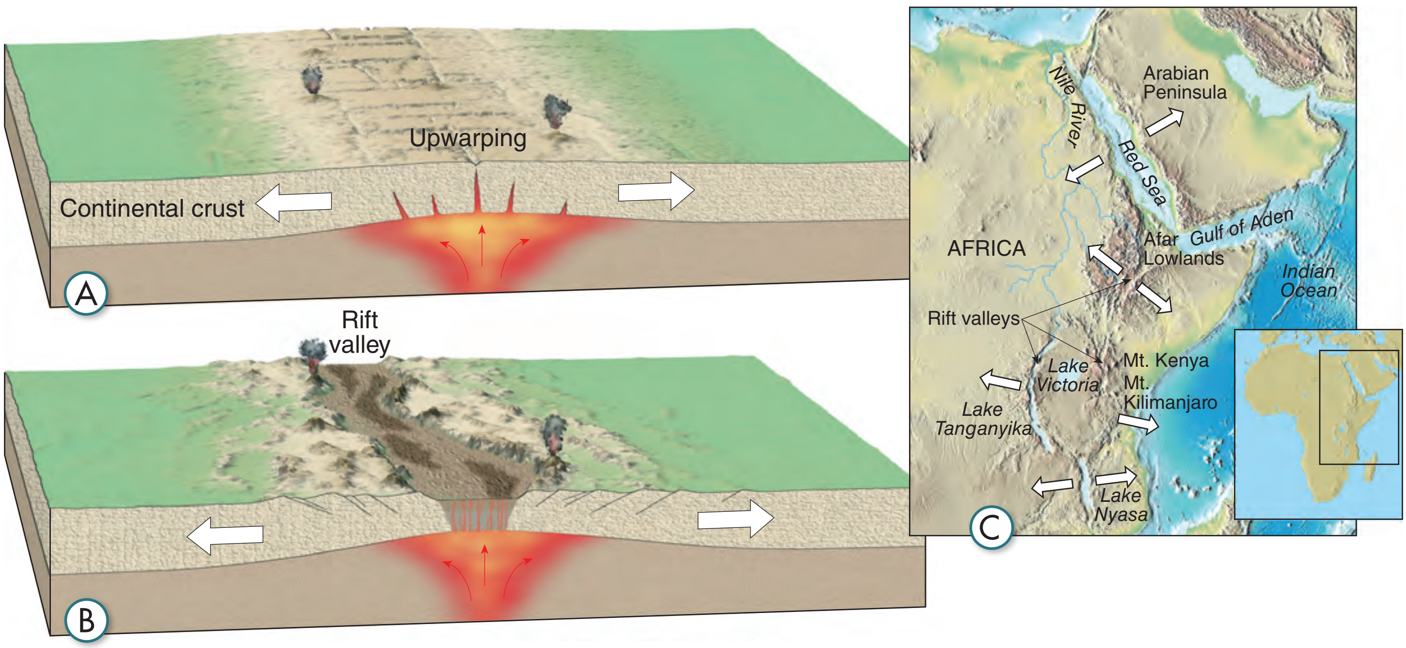


FIGURE 16 Formation of a Rift Valley The East African rift valleys may represent the initial stages of the breakup of a continent along a spreading center. **A** Rising hot rock forces the crust upward, causing numerous cracks in the rigid lithosphere. **B** As the crust is pulled apart, large slabs of rock sink, causing a rift zone. **C** Further spreading produces a narrow sea like the Red Sea.

Relate Cause and Effect ***What causes the continental crust to stretch and break?***

Divergent Boundaries

Along divergent boundaries, plates move apart. Because they are the areas where sea-floor spreading begins, divergent boundaries are also called spreading centers. **Most divergent boundaries are spreading centers located along the crests of mid-ocean ridges. Some spreading centers, however, occur on the continents.** You can think of these plate boundaries as *constructive* plate margins because this is where new lithosphere is produced.

When a spreading center forms on land, the process can literally split a continent apart. As shown in **Figure 16A,** the process begins when the forces of plate motion begin to stretch an area of the lithosphere. Plumes of hot rock rise from the mantle. In a process called upwarping, the rising plumes bend the crust upward, fracturing it. The fractures allow magma to reach the surface. The result is the floor of a new rift v lley, as shown in **Figure 16B.**

Examples of active rift v lleys include the Rhine Valley in northwestern Europe and the Great Rift alley, a series of connected rifts in eastern Africa, as shown in **Figure 16C.** The Great Rift Valley, which is also seen at the opening of this chapter, may represent the fi st stage in the breakup of the African continent. If the sides of the rift v lley continue to move apart, the rift ould eventually become a narrow sea similar to the Red Sea.

Reading Checkpoint *How do rift valleys begin to form?*

Convergent Boundaries

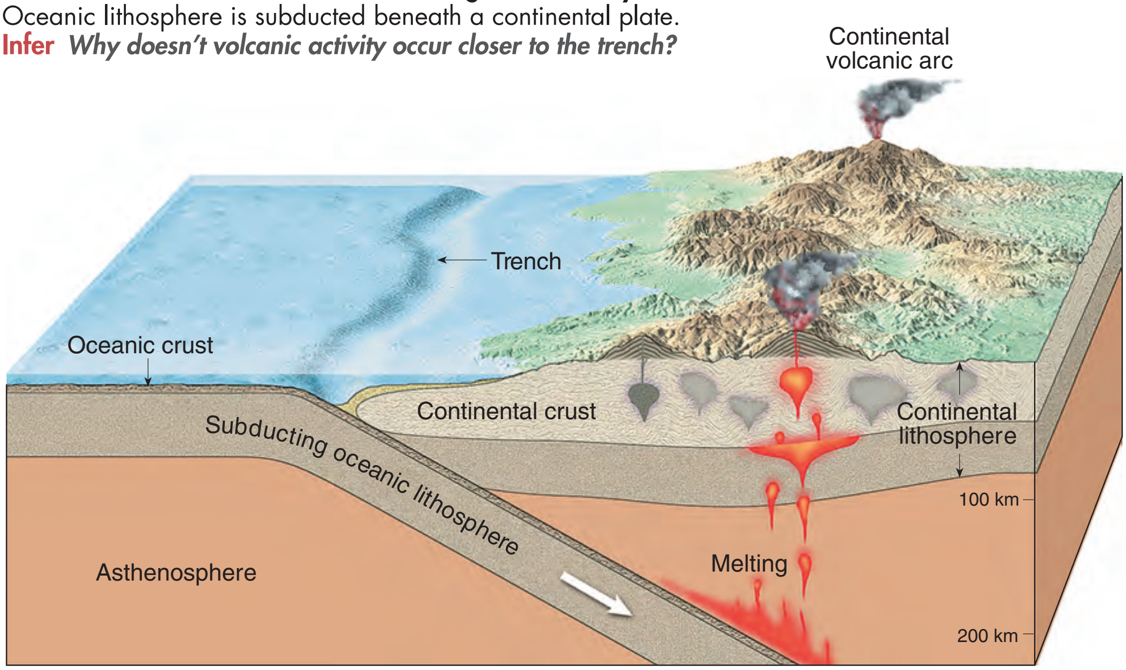
At convergent boundaries, plates collide and interact, producing features including trenches, volcanoes, and mountain ranges. Along convergent boundaries, old portions of oceanic lithosphere return to the mantle. As a result, Earth's total surface area can remain the same, even though new lithosphere is constantly being added at mid-ocean ridges. Because lithosphere is "destroyed" at convergent boundaries, they are sometimes called *destructive* plate margins.

The type of lithosphere involved and the forces acting upon it determine what happens at convergent boundaries. Convergent boundaries can form between plate edges made of oceanic lithosphere, between oceanic lithosphere and continental lithosphere, or between plate edges made of continental lithosphere.

Oceanic-Continental When continental lithosphere converges with oceanic lithosphere, the less dense continental lithosphere continues to float. The denser oceanic lithosphere sinks into the asthenosphere. When a descending, or subducting, plate reaches a depth of about 100 to 150 kilometers, some of the asthenosphere above the subducting plate melts. The newly formed magma, being less dense than the rock of the mantle, rises. Eventually, some of this magma may reach the surface and cause volcanic eruptions.

A **continental volcanic arc** is a range of volcanic mountains within a continent produced in part by the subduction of oceanic lithosphere, as shown in **Figure 17.** The volcanoes of the Andes in South America are the product of magma formed during subduction of the Nazca plate.

FIGURE 17 Oceanic-Continental Convergent Boundary
Oceanic lithosphere is subducted beneath a continental plate.
Infer *Why doesn't volcanic activity occur closer to the trench?*



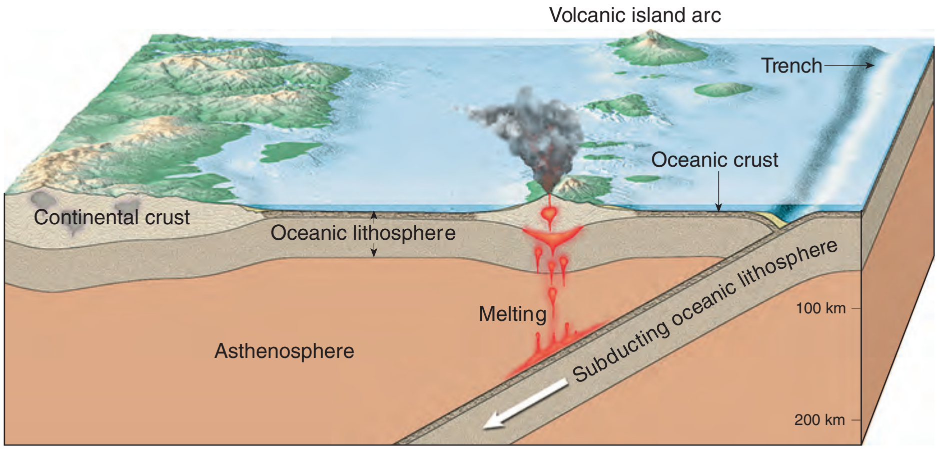
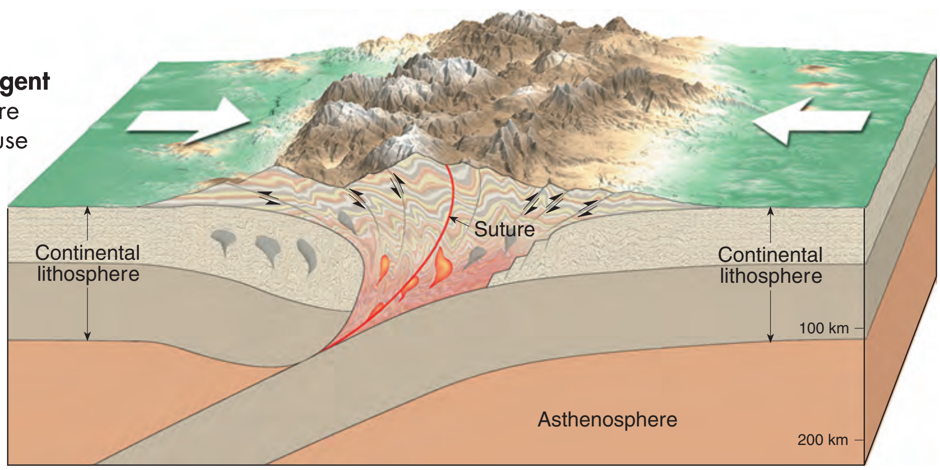


FIGURE 18 Oceanic-Oceanic Convergent Boundary One oceanic plate is subducted beneath another oceanic plate, forming a volcanic island arc.
Predict ***What would happen to the volcanic activity if the subduction stopped?***

Oceanic-Oceanic When two oceanic slabs converge, one descends beneath the other. This causes volcanic activity similar to what occurs at an oceanic-continental boundary. However, the volcanoes form on the ocean floor instead of on a continent, as shown in **Figure 18.** If this activity continues, it will eventually build a chain of volcanic structures that become islands. This newly formed land consisting of an arc-shaped chain of small volcanic islands is called a **volcanic island arc.** The islands of Java and Sumatra in the Indian Ocean are an example of a volcanic island arc. Next to these islands is the Java trench, where one of the most powerful earthquakes ever recorded occurred in 2004.

Continental-Continental When oceanic lithosphere is subducted beneath continental lithosphere, a continental volcanic arc develops along the margin of the continent. However, if the subducting plate also contains continental lithosphere, the subduction eventually brings the two continents together, as shown in **Figure 19.** Because continental lithosphere is less dense than oceanic lithosphere, it is not subducted. Instead, the result is a collision between the two continents and the formation of complex mountains.

FIGURE 19 Continental-Continental Convergent Boundary Continental lithosphere cannot be fully subducted, because it isn't very dense. The collision of two continents forms mountain ranges. The suture (red line) represents the zone where the two plates meet.



Before continents collide, they are separated by an ocean basin. As the continents move toward each other, the ocean floor between them is subducted beneath one of the plates. When the continents collide, the collision folds and deforms the sediments along the margin as if they were placed in a giant vise. A new mountain range forms that is composed of deformed and metamorphosed sedimentary rocks, fragments of the volcanic arc, and possibly slivers of oceanic crust.

This kind of collision occurred when the subcontinent of India rammed into Asia and produced the Himalayas, as shown in **Figure 20.** During this collision, the continental crust buckled and fractured. Several other major mountain systems, including the Alps, Appalachians, and Urals, were also formed by this process.

☑ **Reading Checkpoint** *What caused the Himalayas to form?*

FIGURE 20 Collision of India and Asia A The leading edge of the plate carrying India is subducted beneath the Eurasian plate. **B** The landmasses collide and push up the crust. **C** India's collision with Asia continues today.

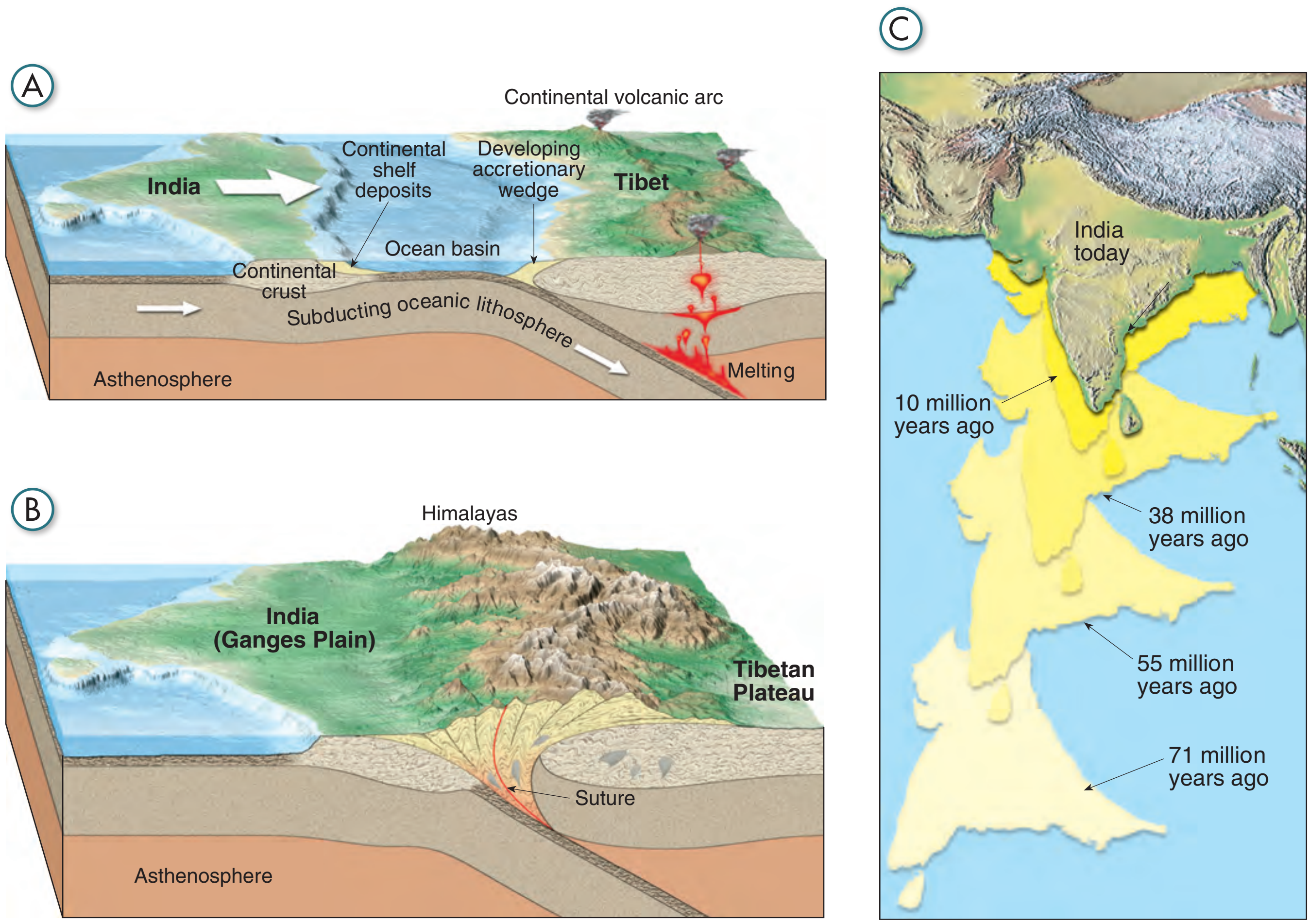
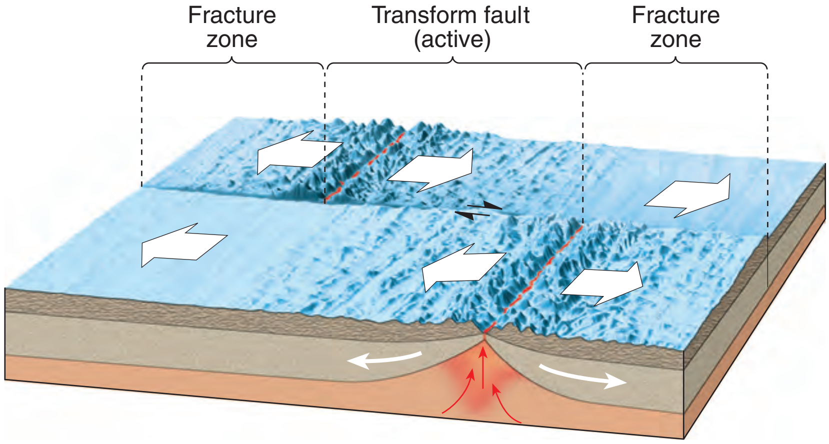


FIGURE 21 **Transform Faults**
A transform fault boundary offsets segments of a divergent boundary at an oceanic ridge.



Transform Fault Boundaries

The third type of plate boundary is the transform fault boundary, where pieces of lithosphere move past each other. **At a transform fault boundary, plates grind past each other without destroying the lithosphere.** Most transform faults join two parallel segments of a mid-ocean ridge, as shown in **Figure 21.** These faults occur about every 100 kilometers along the ridge axis. Active transform faults lie between the two offset ridge segments. These are considered active because the parallel segments of young ocean floor are moving in opposite directions and grinding past each other.

Although most transform faults are located within the ocean basins, a few cut through continental lithosphere. One example is the San Andreas fault in California, where the Pacific plate is moving past the North American plate. If this movement continues, that part of California west of the fault will become an island off he West Coast. However, a more immediate concern is the earthquake activity triggered by movements along this fault system.

9.3 Assessment

Review Key Concepts

1. In your own words, briefly explain the theory of plate tectonics.
2. List the three types of plate boundaries.
3. Why is a divergent boundary considered a constructive plate margin?

Think Critically

4. **Calculate** If a plate moves at a rate of 10 cm per year, how far will the plate move in 20,000,000 years? Give your answer in kilometers.
5. **Predict** Suppose you could view the Great Rift Valley in Africa millions of years from now. How might the region have changed?
6. **Relate Cause and Effect** What forms when oceanic lithosphere collides with continental lithosphere at a convergent boundary? Explain.

WRITING IN SCIENCE

7. **Predict** A series of deep-ocean trenches rings the Pacific Ocean. Write a paragraph that describes how the Pacific Ocean might change over millions of years, based on the theory of plate tectonics.

EARTH & ITS SYSTEMS

Plate Tectonics into the Future

Two geologists, Robert Dietz and John Holden, used present-day plate movements to predict the locations of landmasses in the future. The map below shows where they predict Earth's landmasses will be 50 million years from now if plate movements continue at their present rates.

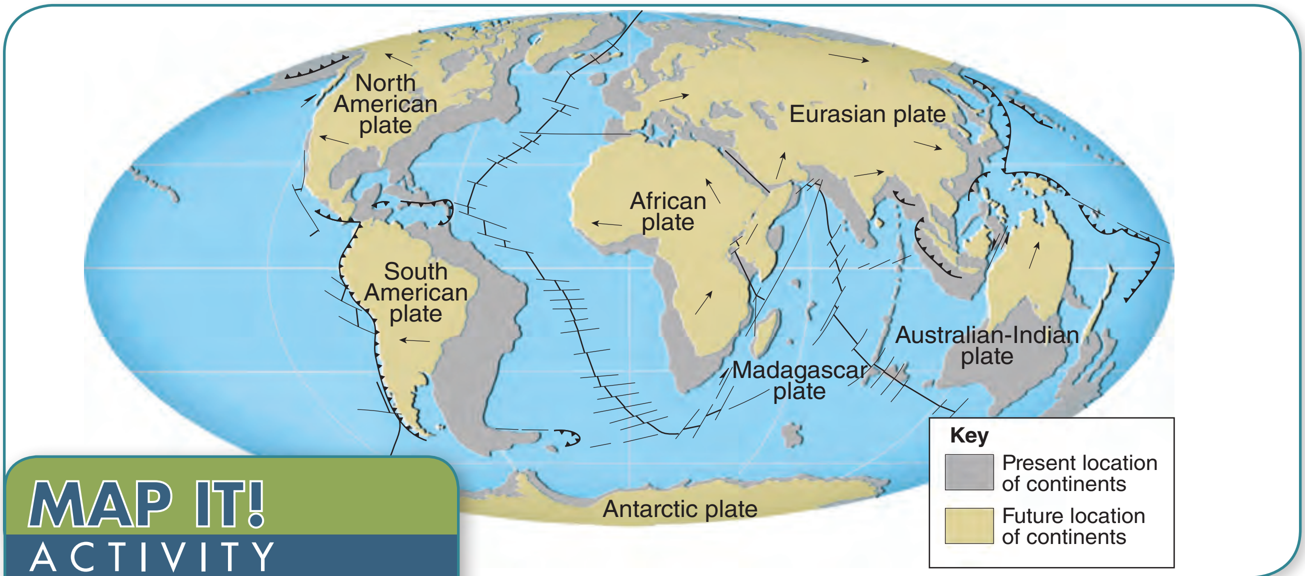


FIGURE 22 **Future Continent Positions**

MAP IT! ACTIVITY

As shown in **Figure 22,** the world may look quite different 50 million years from now.

Interpret Maps What effect will the movement of the North American and South American plates have on the Atlantic Ocean?

L.A. on the Move

In North America, the Baja Peninsula and the portion of southern California that lies west of the San Andreas fault will have slid past the North American plate. If this northward motion takes place, Los Angeles and San Francisco will pass each other in about 12 million years.

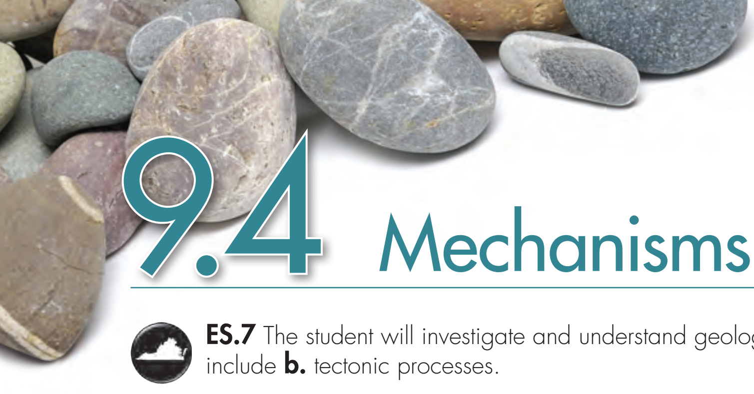
New Sea in Africa

Major changes are seen in Africa, where a new sea will emerge as eastern Africa is ripped away from the mainland. In addition, the African plate will collide with the Eurasian plate, perhaps triggering the next major mountain-building phase. Meanwhile, the Arabian Peninsula will move away from Africa, causing the Red Sea to widen.

Atlantic Ocean Grows

In other parts of the world, Australia will straddle the equator and, along with New Guinea, will be on a collision course with Asia. Meanwhile, North and South America will begin to separate, while the Atlantic and Indian oceans will continue to grow as the Pacific Ocean shrinks.

These projections, although interesting, must be viewed critically. Many assumptions must be correct for these events to occur. We can be sure that large changes in the shapes and positions of continents will occur for millions of years to come, but directions and rates of plate movement could change.



9.4 Mechanisms of Plate Motion

ES.7 The student will investigate and understand geologic processes including plate tectonics. Key concepts include **b.** tectonic processes.

Key Questions

What causes plate motions?

What are the mechanisms of plate motions?

Vocabulary

- convection current
- slab-pull
- ridge-push
- mantle plume

Reading Strategy

Review Copy the table. As you read, write the main ideas for each topic.

Topic	Main Idea
Mantle convection	a. ___?___
Slab pull	b. ___?___
Ridge push	c. ___?___

YOU MAY have watched bits of vegetables rising and sinking in a pot of soup on the stove. This rising and sinking is an example of a convection current. A **convection current** is the continuous, circular flow that occurs in a fluid because of differences in density. Warm material is less dense, so it rises. Cool material is denser, so it sinks. Some convection currents, such as the hypothetical pot of soup on a stove, are driven by heat.

What Causes Plate Motions?

The convection currents in a pot of soup can serve as a model for the causes of plate motion. **Convection currents in the mantle provide the basic driving forces for plate motions.** The hot, but solid, rock of the mantle behaves in a plastic way over geologic time—that is, it can flow slowly. The main heat source for mantle convection is energy released by radioactive isotopes in the mantle, such as uranium, thorium, and potassium. Another source is heat from the core. Since most of the heat comes from within the mantle, a bowl of soup in a microwave oven may be a better analogy for this process than a pot on a stove.

But how does mantle convection produce plate motions? The plates are simply the top part of mantle convection currents. The weakness of the asthenosphere allows the stiff l thosphere above to slide across it. The relatively new oceanic lithosphere at the top of the convection current cools and becomes denser than the mantle rock beneath it. As a result, a plate edge of oceanic lithosphere will eventually subduct beneath another plate. The density of the oceanic lithosphere causes it to sink down toward the base of the mantle. Meanwhile, material from the lower mantle rises up to the upper mantle. It reaches the surface at mid-ocean ridges. Where it emerges, new lithosphere is formed. This cyclic flow of material from the mantle to the surface and back again, which may take a half-billion years, is called whole-mantle convection, shown in **Figure 23.**

Plate Motion Mechanisms

Density plays a major role in sending lithosphere back into the mantle. **The sinking of dense oceanic lithosphere directly drives the motions of mantle convection through slab-pull and ridge-push.** In **slab-pull,** gravity pulls dense oceanic lithosphere down into the deep mantle. In **ridge-push,** the oceanic lithosphere slides down the asthenosphere that is elevated near mid-ocean ridges. Acting together, ridge-push and slab-pull take oceanic lithosphere from mid-ocean ridges toward subduction zones and back to the mantle.

Because Earth is not growing or shrinking in size, the downward flow of subducted oceanic lithosphere must equal the upward flow of rock back toward the surface. Scientists are debating how this happens. Some scientists think that most upwelling of mantle rock occurs in the form of hot-spot **mantle plumes,** which are rising columns of hot mantle rock. Other scientists disagree. They think that rock replaces sinking oceanic lithosphere through a slow, broad rise of rock throughout the mantle. Most scientists think both processes are involved.

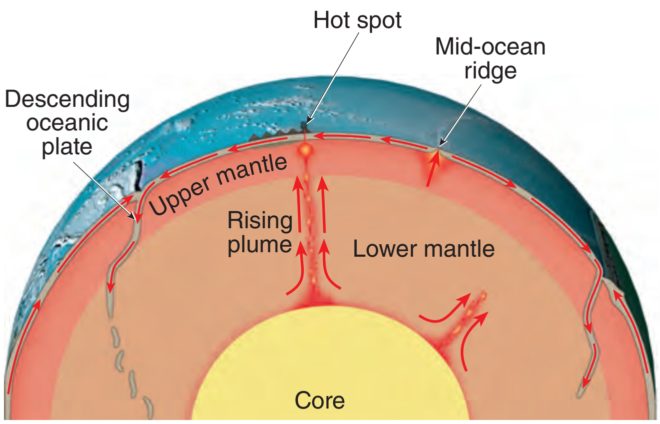


FIGURE 23 Whole-Mantle Convection In the whole-mantle convection model, cold oceanic lithosphere descends into the mantle. Hot mantle plumes transfer heat toward the surface.

9.4 Assessment

Review Key Concepts

1. How are plate motions connected with motions within the rest of Earth's mantle?

2. How are the forces of slab-pull and ridge-push related to plate motions?

3. What is the ultimate source of heat that moves the plates?

Think Critically

4. **Predict** If Earth did not form with very much uranium, thorium, or potassium, how might it have been different than it is today?

5. **Infer** What characteristic of old, oceanic lithosphere in a subduction zone contributes to slab-pull? Explain.

BIGIDEA DYNAMIC EARTH

6. **Explain** Review Lesson 9.2. Use what you learned about sea-floor spreading and about the role of convection currents in plate tectonics to write the "life story" of a plate made of oceanic lithosphere.

INQUIRY

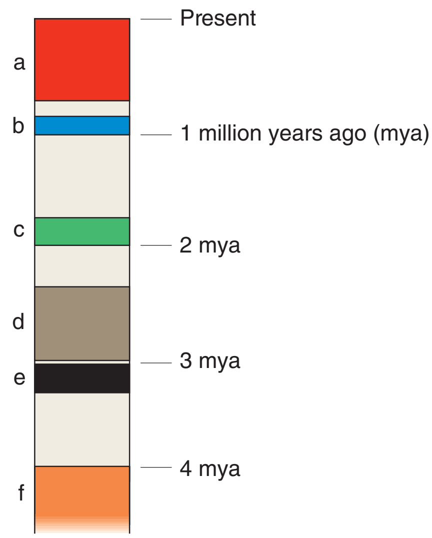
EXPLORATION LAB

Paleomagnetism and the Ocean Floor

Problem How are the paleomagnetic patterns on the ocean floor used to determine the rate of sea-floor spreading?

Materials pencil, metric ruler, calculator, photocopy of diagrams on next page

Skills Measure, Interpret Diagrams, Calculate



Connect to the Big idea When Wegener proposed his hypothesis of continental drift, little was known about the ocean floor. He thought that the continents plowed through the ocean floor like icebreaking ships plowing through ice. Later studies of the oceans provided one of the keys to the plate tectonic hypothesis. In this lab, you will observe how the magnetic rocks on the ocean floor can be used to understand plate tectonics.

Procedure

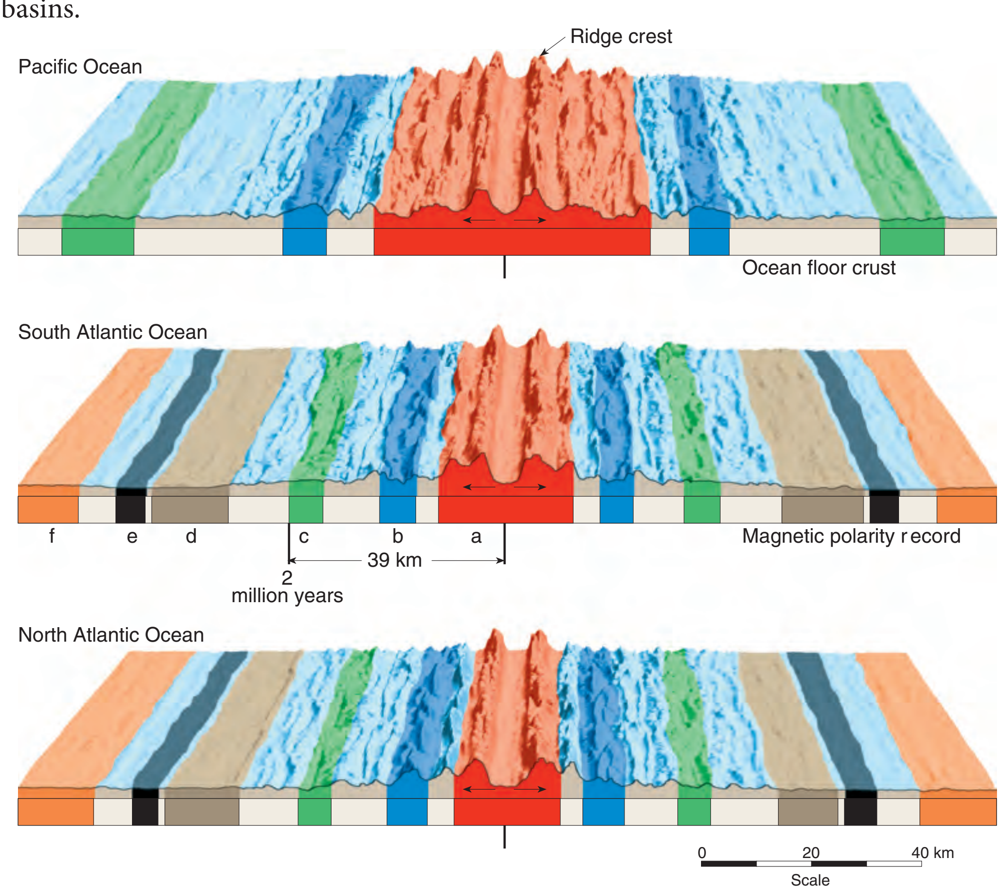
1. Scientists have reconstructed Earth's magnetic polarity reversals over the past several million years. A record of these reversals is shown above. Periods of normal polarity, when a compass would have pointed north as it does today, are shown in color. Periods of reverse polarity are shown in white. Record the number of times Earth's magnetic field has had reversed polarity in the last 4 million years.
2. The three diagrams on the next page illustrate the magnetic polarity reversals across sections of the mid-ocean ridges in the Pacific, South Atlantic, and North Atlantic oceans. Periods of normal polarity are shown in color and match the colors in the illustration above. Observe that the patterns of polarity in the rock match on either side of the ridge for each ocean basin.
3. On the photocopy of the three ocean-floor diagrams, identify and mark the periods of normal polarity with the letters *a–f.* Begin at the rift v lley and label along both sides of each ridge. (*Hint:* The left ide of the South Atlantic has already been done and can act as a guide.)
4. Using the South Atlantic as an example, label the beginning of the normal polarity period c, "2 million years ago," on the left ides of the Pacific and North Atlantic diagrams.
5. Using the distance scale shown with the ocean floor diagrams, determine which ocean basin has spread the greatest distance during the last 2 million years. (Measure from the center of the rift v lley.)
6. Refer to the distance scale. Notice that the left side of the South Atlantic basin has moved approximately 39 kilometers from the center of the rift v lley in 2 million years.

Analyze and Conclude

1. **Analyze Data** How many kilometers has the left side of the Pacific basin moved in 2 million years?
2. **Analyze Data** How many kilometers has the left ide of the North Atlantic basin moved in 2 million years?
3. **Infer** By how many kilometers has each ocean basin spread in the past 2 million years?

4. **Calculate** If both the distance that each ocean basin has spread and the time it took to do so are known, the rate of sea-floor spreading can be calculated. Determine the rate of sea-floor spreading for the South Atlantic Ocean basin in centimeters per year. (*Hint:* To determine the rate of spreading in centimeters per year for each ocean basin, fi st convert the distance from kilometers to centimeters and then divide this distance by the time, 2 million years.)
5. **Calculate** Determine the rate of sea-floor spreading for the North Atlantic and Pacific Ocean basins.
6. **Draw Conclusions** Which ocean basin is spreading the fastest? The slowest?
7. **Infer** Do ocean basins spread uniformly over the entire basin? Explain.

GO FURTHER Use the library or the Internet to research the spreading rates for other divergent plate boundaries on Earth. Where is the fastest spreading rate? The slowest spreading rate?



ES.1 The student will plan and conduct investigations in which **a.** volume, area, mass, elapsed time, direction, temperature, pressure, distance, density, and changes in elevation/depth are calculated utilizing the most appropriate tools. **ES.2** The student will demonstrate an understanding of the nature of science and scientific reasoning and logic. Key concepts include **c.** observation and logic are essential for reaching a conclusion. **ES.10** The student will investigate and understand that oceans are complex, interactive physical, chemical, and biological systems and are subject to long- and short-term variations. Key concepts include **d.** features of the sea floor as reflections of tectonic processes.

9 Study Guide

Big idea Dynamic Earth

9.1 Continental Drift

According to Wegener's hypothesis of continental drift, the continents were once joined to form a single supercontinent.

Fossil evidence for continental drift includes several fossil organisms found on different landmasses.

Matching types of rock in several mountain belts that today are separated by oceans provide evidence for continental drift.

Wegener found glacial deposits showing that between 220 million and 300 million years ago, ice sheets covered large areas of the Southern Hemisphere. Deposits of glacial till occurred at latitudes that today have temperate or even tropical climates: southern Africa, South America, India, and Australia.

The main objection to Wegener's hypothesis was that he could not describe a mechanism capable of moving the continents.

continental drift (248)
Pangaea (248)

9.2 Sea-Floor Spreading

Earth's mid-ocean ridge system forms the longest feature on Earth's surface.

In the process of sea-floor spreading, new ocean floor forms along Earth's mid-ocean ridges and slowly moves outward across ocean basins.

Evidence for sea-floor spreading included magnetic strips in ocean-floor rock, earthquake patterns, and measurements of the age of the ocean floor.

sonar (254)
deep-ocean trench (255)
mid-ocean ridge (255)
rift valley (255)
sea-floor spreading (256)
subduction (257)
paleomagnetism (258)

9.3 Theory of Plate Tectonics

In the theory of plate tectonics, Earth's lithospheric plates move slowly relative to each other, driven by convection currents in the mantle.

Most divergent boundaries are spreading centers located along the crests of mid-ocean ridges. Some spreading centers, however, occur on the continents.

At convergent boundaries, plates collide and interact, producing features including trenches, volcanoes, and mountain ranges.

At a transform fault boundary, plates grind past each other without destroying the lithosphere.

plate (261)
plate tectonics (261)
divergent boundary (262)
convergent boundary (262)
transform fault boundary (263)
continental volcanic arc (265)
volcanic island arc (266)

9.4 Mechanisms of Plate Motion

Convection currents in the mantle provide the basic driving forces for plate motions.

The sinking of dense oceanic lithosphere directly drives the motions of mantle convection through slab-pull and ridge-push.

convection current (270)
slab-pull (271)
ridge-push (271)
mantle plume (271)

9 Assessment

Review Content

Choose the letter that best answers the question or completes the statement.

1. What is the weaker, hotter zone beneath the lithosphere that allows for motion of Earth's rigid outer shell?
a. crust **c.** outer core
b. asthenosphere **d.** inner core

2. Alfred Wegener is best known for what hypothesis?
a. plate tectonics
b. sea-floor spreading
c. continental drift
d. subduction

3. What is the name given by Wegener to the supercontinent he proposed existed before the current continents?
a. Euroamerica **c.** Pangaea
b. Atlantis **d.** Panamerica

4. Support for Harry Hess's hypothesis of sea-floor spreading did NOT include
a. magnetic stripes in ocean floor rock.
b. granitic rock in the ocean floor.
c. earthquake patterns in subduction zones.
d. the age of the ocean floor rock.

5. Most of Earth's earthquakes, volcanoes, and mountain building occur
a. in the center of continents.
b. in the Himalayas.
c. at plate boundaries.
d. at volcanic island arcs.

6. Complex mountain systems such as the Himalayas are the result of
a. oceanic-oceanic convergence.
b. oceanic-continental convergence.
c. continental volcanic arcs.
d. continental-continental convergence.

7. Which of the following mountain ranges was NOT the result of continental-continental convergence?
a. Himalayas **c.** Appalachians
b. Alps **d.** Andes

8. What is the type of plate boundary where two plates move together, causing one of the slabs of lithosphere to descend into the mantle beneath an overriding plate?
a. oceanic-continental convergent
b. divergent
c. transform fault
d. continental-continental convergent

9. Most deep-focus earthquakes occur near
a. rift v lleys.
b. trenches.
c. mid-ocean ridges.
d. transform fault boundaries.

10. One of the main objections to Wegener's hypothesis of continental drift w s that he was unable to provide an acceptable
a. rate of continental drift.
b. date of continental drift.
c. mechanism for continental drift.
d. direction of continental drift.

Understand Concepts

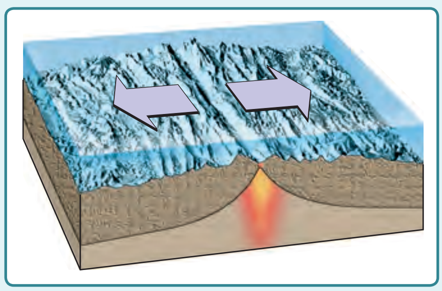
11. Describe the process of sea-floor spreading.

12. What are the three types of convergent plate boundaries?

13. How were earthquake patterns used to provide evidence of sea-floor spreading?

14. Briefly explain the theory of plate tectonics.

15. What type of plate boundary is shown? What types of lithosphere are involved?



16. At what location is most lithosphere created? At what location is most lithosphere destroyed?

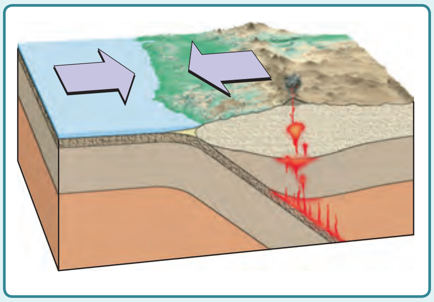
17. At what types of plate boundaries do subduction zones form?

Think Critically

18. **Draw Conclusions** In the Atlantic Ocean basin, where is the oldest oceanic lithosphere found?
19. **Review** Describe the evidence that supported the hypothesis of continental drift.
20. **Relate Cause and Effect** Explain how changes in the polarity of Earth's magnetic field provided one type of evidence for the hypothesis of sea-floor spreading.
21. **Infer** Why did the discovery of *Mesosaurus,* in both South America and Africa but nowhere else, support the hypothesis of continental drift
22. **Compare and Contrast** What is the difference between the collision of oceanic lithosphere with continental lithosphere and the collision of two plates of continental lithosphere?

Analyze Data

Use the diagram below to answer Questions 23–25.



23. **Interpret Diagrams** What type of boundary is shown? What types of lithosphere are involved?
24. **Infer** What process occurs as the slab of oceanic lithosphere descends beneath the other plate?
25. **Apply Concepts** What pattern would the foci of earthquakes form if they were plotted in the diagram?

Concepts in Action

26. **Predict** How would the age of a rock sample obtained by drilling in the ocean floor near a mid-ocean ridge compare with the age of a rock sample from the ocean floor near a trench? Explain.
27. **Classify** What type of plate boundary is formed when two plates grind past each other? Give an example of this type of boundary.
28. **Form a Hypothesis** Form a hypothesis to explain what you think would happen if the direction of motion between India and Asia changed and India began to move in a southward direction.
29. **Calculate** How much wider would the Atlantic Ocean become in 10 million years if the spreading rate at the Mid-Atlantic Ridge were 2.5 cm/yr? Give your answer in kilometers.
30. **Explain** Write a paragraph explaining why earthquakes are less likely in the middle of the North American plate than they are along the edges of the plate.

Performance-Based Assessment

Classify Use a world map to choose ten different locations around the world. Then use Figure 15 on pages 262–263 to find the plate boundary nearest each location. Classify each boundary.

Virginia SOL Test Prep

Tips for Success

Eliminating Unreasonable Answers When you answer a multiple-choice question, you can often eliminate at least one answer choice because it is clearly incorrect. If you eliminate one or more choices, you increase your odds of choosing the correct answer.

In the question below, you can immediately eliminate choice B because the outer core is located deep in Earth's interior. The mantle, answer choice A, is another layer that is found in Earth's interior. So you can eliminate A. You have narrowed your choices down to either C, the lithosphere, or D, the asthenosphere. The asthenosphere is not rigid. It is a weak layer over which the plates move. The remaining choice, C, must be the correct answer.

What is Earth's strong, rigid outer layer called?

A the mantle
B the outer core
C the lithosphere
D the asthenosphere

(Answer: C)

Choose the letter that best answers the question.

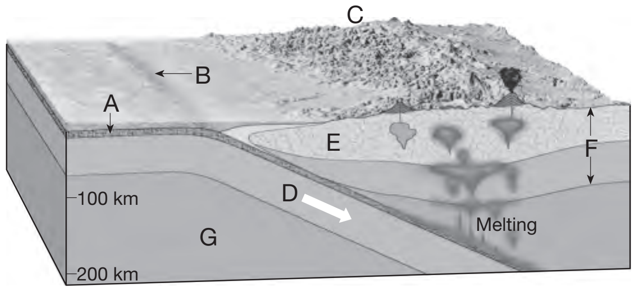
1 **Which one of the following was *not* used as support of Wegener's continental drift hypothesis?**
A fossil evidence
B paleomagnetism
C the fit of South America and Africa
D ancient climates ES.2.b

2 **At what type of plate boundary do plates move apart, resulting in the upwelling of material from the mantle to create new seafloor?**
F divergent
G convergent
H transform fault
J subduction ES.10.d

If You Have Trouble With . . .

Question	1	2	3	4	5
See Lesson	9.1	9.2	9.3	9.3	9.4

Use the diagram below to answer Questions 3–5.



3 **What feature is labeled F?**
A a continental volcanic arc
B a subduction zone
C continental lithosphere
D an ocean ridge ES.10.d

4 **The process occurring at the location labeled D is—**
F the creation of oceanic lithosphere
G the creation of continental lithosphere
H a continental-continental collision
J the subduction of oceanic lithosphere ES.10.d

5 **What characteristic of the lithosphere contributes to the process occurring at the location labeled D?**
A The oceanic lithosphere is denser than the continental lithosphere.
B The continental lithosphere is denser than the oceanic lithosphere.
C The older continental lithosphere is denser than the newly formed continental lithosphere.
D The newly formed continental lithosphere is denser than the older continental lithosphere. ES.7.b