Chapter 9 Plate Tectonics

Section 1 Continental Drift

Key Concepts
- What is the hypothesis of continental drift?
- What evidence supported continental drift?

Vocabulary
- continental drift
- Pangaea

An Idea Before Its Time

The idea that continents fit together like pieces of a jigsaw puzzle came about when better world maps became available. Figure 1 shows the two most obvious pieces of this jigsaw puzzle. However, little significance was given this idea until 1915, when Alfred Wegener, a German scientist, proposed his radical hypothesis of continental drift. Wegener’s continental drift hypothesis stated that 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. These continents then drifted to their present positions, as shown on page 250. Wegener and others collected much evidence to support these claims. Let’s examine their evidence.

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Figure 1 A Curious Fit This map shows the best fit of South America and Africa at a depth of about 900 meters. The areas where continents overlap appear in brown. Inferring Why are there areas of overlap?

Evidence: The Continental Puzzle

Wegener first thought that the continents might have been joined when he noticed the similarity between the coastlines on opposite sides of the South Atlantic Ocean. He used present-day shorelines to show how the continents fit together. However, his opponents correctly argued that erosion continually changes shorelines over time.

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.

Evidence: 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, an aquatic reptile whose fossil remains are limited to eastern South America and southern Africa, as shown in Figure 2. If Mesosaurus had been able to swim well enough to cross the vast South Atlantic

Ocean, its fossils should be more widely distributed. This is not the case. Therefore, Wegener argued, South America and Africa must have been joined somehow.

The idea of land bridges was once the most widely accepted explanation for similar fossils being found on different landmasses. Most scientists believed that during a recent glacial period, the lowering of sea level allowed animals to cross the narrow Bering Strait between Asia and North America. 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.

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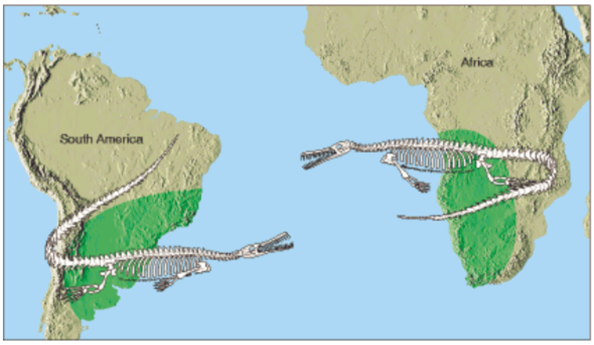

Figure 2 Location of Mesosaurus Fossils of Mesosaurus have been found on both sides of the South Atlantic and nowhere else in the world. Fossil remains of this and other organisms on the continents of Africa and South America appear to link these landmasses at some time in Earth’s history.

Evidence: Rock Types and Structures

Anyone who has worked a jigsaw puzzle knows that the pieces must fit together to form a clear picture. The clear picture in the continental drift puzzle is one of matching rock types and mountain belts. If the continents existed as 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.

Rock evidence for continental drift exists in the form of several mountain belts that end at one coastline, only to reappear on a landmass across the ocean. For example, the Appalachian mountain belt runs northeastward through the eastern United States, ending off the coast of Newfoundland, as shown in Figure 4A. Mountains of the same age with similar rocks and structures are found in the British Isles and Scandinavia. When these landmasses are fit together as in Figure 4B, the mountain chains form a nearly continuous belt.

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Figure 4 A The Appalachian Mountains run along the eastern side of North America and disappear 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 are united as Pangaea, these ancient mountain chains form a nearly continuous belt.

Evidence: Ancient Climates

Wegener was a meteorologist, so he was interested in obtaining data about ancient climates to support continental drift. And he did find evidence for dramatic global climate changes. Wegener found glacial deposits showing that between 220 million and 300 million years ago, ice sheets covered large areas of the Southern Hemisphere. Layers of glacial till were found in southern Africa and South America, as well as in 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 5.

Figure 5 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. Interpreting Diagrams Where were the continents located when the glaciers formed?

Rejecting a Hypothesis

Wegener's drift hypothesis faced a great deal of criticism from other scientists. One objection was that Wegener could not describe a mechanism that was capable of moving the continents across the globe. 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 of the size needed 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, no evidence existed 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 additional evidence of continents in motion.

Carr Clifton Photography

Figure 6 Mountain ranges are commonly formed at plate boundaries. This photograph shows part of the Canadian Rockies in Banff National Park, Alberta, Canada.

Q Some day will the continents come back together and form a single landmass?

A Yes, but not anytime soon. Based on current plate motions, it appears that the continents may meet up again in the Pacific Ocean—in about 300 million years.

A New Theory Emerges

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 1968, these findings led to a new theory, known as plate tectonics. This theory provides the framework for understanding most geologic processes, such as the formation of the mountains shown in Figure 6.

Section 2 Plate Tectonics

Key Concepts

- What is the theory of plate tectonics?
- What are lithospheric plates?
- What are the three types of plate boundaries?

Vocabulary

- plate tectonics
- plate
- divergent boundary
- convergent boundary
- transform fault boundary

Earth's Major Plates

According to the plate tectonics theory, the uppermost mantle, along with the overlying crust, behaves as a strong, rigid layer. This layer is known as the lithosphere. The outer shell lies over a weaker region in the mantle known as the asthenosphere. The lithosphere is divided into segments called plates, which move and continually change shape and size. Figure 8 on pages 256–257 shows the seven major plates. The largest is the Pacific plate, covering most of the Pacific Ocean. Notice that several of the large plates include an entire continent plus a large area of the seafloor. This is a major departure from Wegener's continental drift hypothesis, which proposed that the continents moved through the ocean floor, not with it. Note also that none of the plates is defined entirely by the margins of a continent.

The lithospheric plates move relative to each other at a very slow but continuous rate that averages about 5 centimeters per year—about as fast as your fingernails grow. This movement is driven by the unequal distribution of heat within Earth. Hot material found deep in the mantle moves slowly upward as part of Earth's internal convection system. At the same time, cooler, denser slabs of oceanic lithosphere descend into the mantle, setting Earth's rigid outer shell into motion. The grinding movements of Earth's lithospheric plates generate earthquakes, create volcanoes, and deform large masses of rock into mountains.

Types of Plate Boundaries

All major interactions among individual plates occur along their boundaries. The three main types of boundaries are convergent, divergent, and transform fault boundaries.

Divergent boundaries

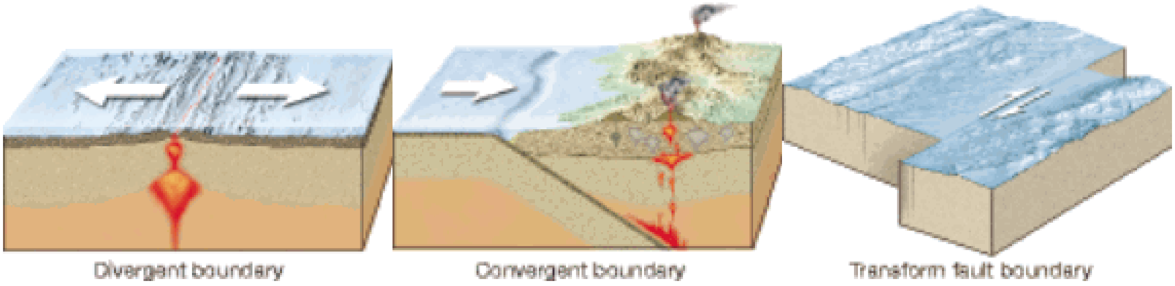
Divergent boundaries (also called spreading centers) occur when two plates move apart. This process results in upwelling of material from the mantle to create new seafloor, as shown in Figure 7A. A relatively new divergent boundary is located in Africa, in a region known as the East African Rift valley.

Convergent boundaries

Convergent boundaries form where two plates move together. This process results in oceanic lithosphere plunging beneath an overriding plate, and descending into the mantle, as shown in Figure 7B. At other locations, plates carrying continental crust are presently moving toward each other. Eventually, these continents may collide and merge. Thus, the boundary that once separated two plates disappears as the plates become one.

Transform fault boundaries

Transform fault boundaries are margins where two plates grind past each other without the production or destruction of lithosphere, as shown in Figure 7C. The San Andreas Fault zone in California is an example of a transform fault boundary.



- Figure 7 Three Types of Plate Boundaries

Each plate contains a combination of these three types of boundaries. Although the total surface area of Earth does not change, plates may shrink or grow in area. This shrinking or growing depends on the locations of convergent and divergent boundaries. The Antarctic plate is growing larger. The Philippine plate is descending into the mantle along its margins and is becoming smaller. New plate boundaries can be created because of changes in the forces acting on these rigid slabs.

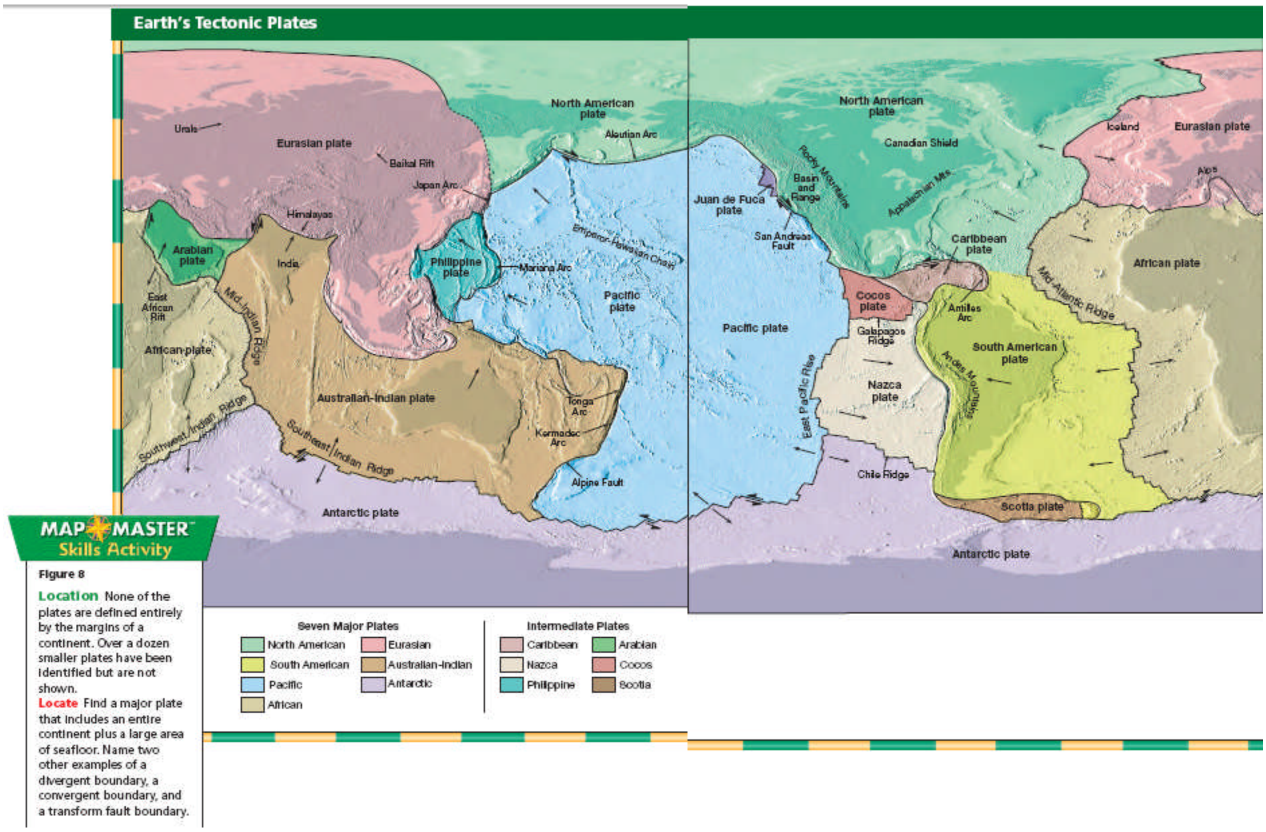


Figure 8

Location None of the plates are defined entirely by the margins of a continent. Over a dozen smaller plates have been identified but are not shown.

Locate Find a major plate that includes an entire continent plus a large area of seafloor. Name two other examples of a divergent boundary, a convergent boundary, and a transform fault boundary.

Section 3 Actions at Plate Boundaries

Key Concepts

- What is seafloor spreading?
- What is a subduction zone?

Vocabulary

- oceanic ridge
- rift valley
- seafloor spreading
- subduction zone
- trench
- continental volcanic arc
- volcanic island arc

Divergent Boundaries

Most divergent plate boundaries are located along the crests of oceanic ridges. These plate boundaries can be thought of as constructive plate margins because this is where new oceanic lithosphere is generated. Look again at the divergent boundary in Figure 7A on page 255. As the plates move away from the ridge axis, fractures are created. These fractures are filled with molten rock that wells up from the hot mantle below. Gradually, this magma cools to produce new slivers of seafloor. Spreading and upwelling of magma continuously adds oceanic lithosphere between the diverging plates.

Oceanic Ridges and Seafloor Spreading

Along well-developed divergent plate boundaries, the seafloor is elevated, forming the oceanic ridge. The system of ocean ridges is the longest physical feature on Earth’s surface, stretching more than 70,000 kilometers in length. This system winds through all major ocean basins like the seam on a baseball. The term ridge may be misleading. These features are not narrow like a typical ridge. They are 1000 to 4000 kilometers wide. Deep faulted structures called rift valleys are found along the axes of some segments. As you can see in Figure 9, rift valleys and spreading centers can develop on land, too.

Seafloor spreading is the process by which plate tectonics produces new oceanic lithosphere. Typical rates of spreading average around 5 centimeters per year. These rates are slow on a human time scale. However, they are rapid enough so that all of Earth’s ocean basins could have been generated within the last 200 million years. In fact, none of the ocean floor that has been dated is older than 180 million years.

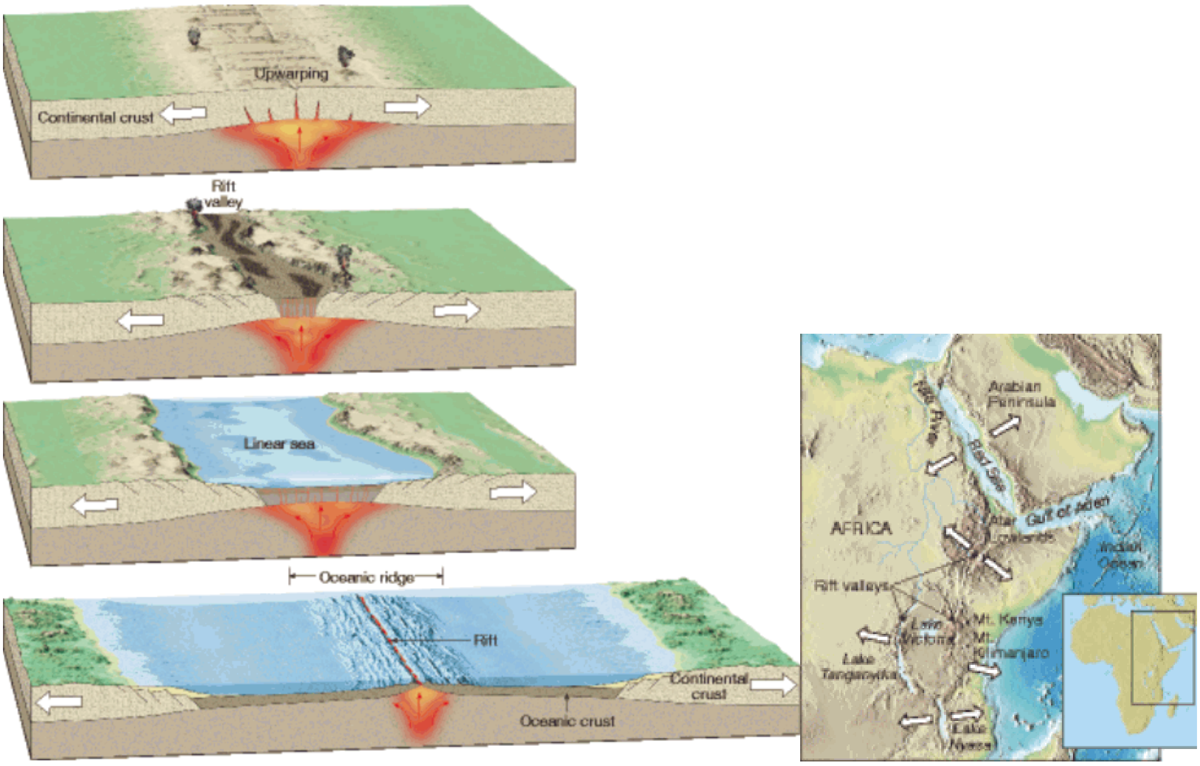
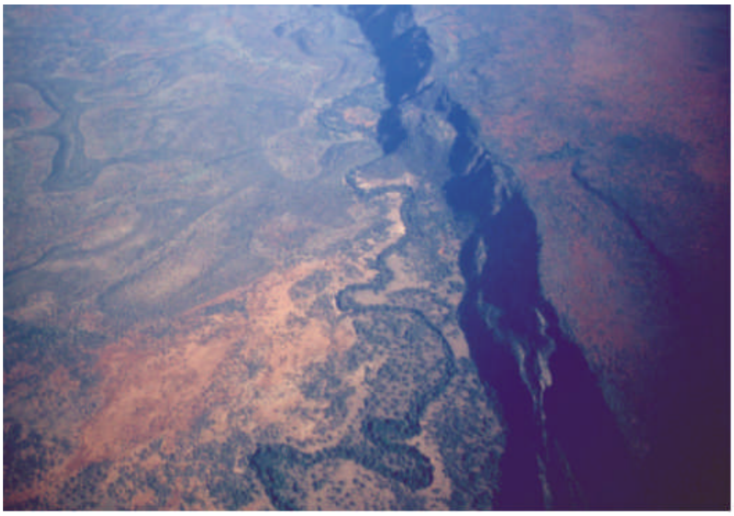


Figure 9 The East African rift valleys may represent the initial stages of the breakup of a continent along a spreading center. A Rising magma forces the crust upward, causing numerous cracks in the rigid lithosphere. B As the crust is pulled apart, large slabs of rock sink, causing a rift zone. C Further spreading causes a narrow sea. D Eventually, an ocean basin and ridge system is created. Relating Cause And Effect What causes the continental crust to stretch and break?

Continental Rifts

When spreading centers develop within a continent, the landmass may split into two or more smaller segments. Examples of active continental rifts include the East African rift valley and the Rhine Valley in Northwest Europe.



"M. Timothy O'Keefe/Bruce Coleman, Inc."

Figure 10 East African Rift Valley This valley may be where the African continent is splitting apart. Interpreting Diagrams What stage in the drawings on page 259 does this photograph show?

The most widely accepted model for continental breakup suggests that forces that are stretching the lithosphere must be acting on the plate. These stretching forces by themselves are not large enough to actually tear the lithosphere apart. Rather, the rupture of the lithosphere is thought to begin in those areas where plumes of hot rock rise from the mantle. This hot-spot activity weakens the lithosphere and creates domes in the crust directly above the hot rising plume. Uplifting stretches the crust and makes it thinner, as shown in Figure 9A. Along with the stretching, faulting and volcanism form a rift valley, as in Figure 9B.

The East African rift valley, shown in Figure 10, may represent the beginning stage in the breakup of a continent. Large mountains, such as Kilimanjaro and Mount Kenya, show the kind of volcanic activity that accompanies continental rifting. If the stretching forces continue, the rift valley will lengthen and deepen, until the continent splits in two. At this point, the rift becomes a narrow sea with an outlet to the ocean, similar to the Red Sea. The Red Sea formed when the Arabian Peninsula rifted from Africa about 20 million years ago. In this way, the Red Sea provides scientists with a view of how the Atlantic Ocean may have looked in its infancy.

Convergent Boundaries

Although new lithosphere is constantly being added at the oceanic ridges, our planet is not growing larger. Earth’s total surface area remains the same. How can that be? To accommodate the newly created lithosphere, older portions of oceanic plates return to the mantle along convergent plate boundaries. Because lithosphere is “destroyed” at convergent boundaries, they are also called destructive plate margins. As two plates slowly converge, the leading edge of one is bent downward, allowing it to slide beneath the other. Destructive plate margins where oceanic crust is being pushed down into the mantle are called subduction zones. The surface feature produced by the descending plate is an ocean trench, as shown in Figure 11. A subduction zone occurs when one oceanic plate is forced down into the mantle beneath a second plate.

Convergent boundaries are controlled by the type of crust involved and the forces acting on the plate. Convergent boundaries can form between two oceanic plates, between one oceanic plate and one continental plate, or between two continental plates.

Oceanic-Continental

When the leading edge of a continental plate converges with an oceanic plate, the less dense continental plate remains floating. The denser oceanic slab sinks into the asthenosphere. When a descending plate reaches a depth of about 100 to 150 kilometers, some of the asthenosphere above the descending plate melts. The newly formed magma, being less dense than the rocks of the mantle, rises. Eventually, some of this magma may reach the surface and cause volcanic eruptions.

The volcanoes of the Andes, located along western South America, are the product of magma generated as the Nazca plate descends beneath the continent. Figure 11 shows this process. The Andes are an example of a continental volcanic arc. Such mountains are produced in part by the volcanic activity that is caused by the subduction of oceanic lithosphere.

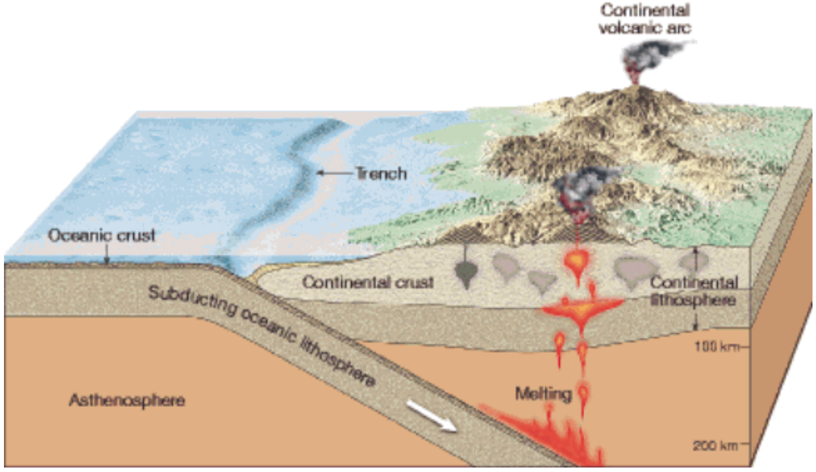


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Figure 11 Oceanic-Continental Convergent Boundary Oceanic lithosphere is subducted beneath a continental plate. Inferring Why doesn’t volcanic activity occur closer to the trench?

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 12. 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 Aleutian Islands off the shore of Alaska are an example of a volcanic island arc. Next to the Aleutians is the Aleutian trench.

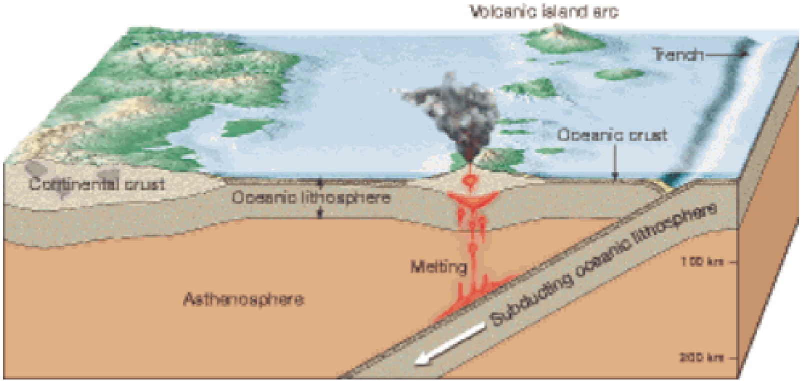


Figure 12 Oceanic-Oceanic Convergent Boundary One oceanic plate is subducted beneath another oceanic plate, forming a volcanic island arc. Predicting What would happen to the volcanic activity if the subduction stopped?

Continental-Continental

When an oceanic plate 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 13. Continental lithosphere is buoyant, which prevents it from being subducted to any great depth. The result is a collision between the two continents, which causes the formation of complex mountains such as the Himalayas in South Asia.

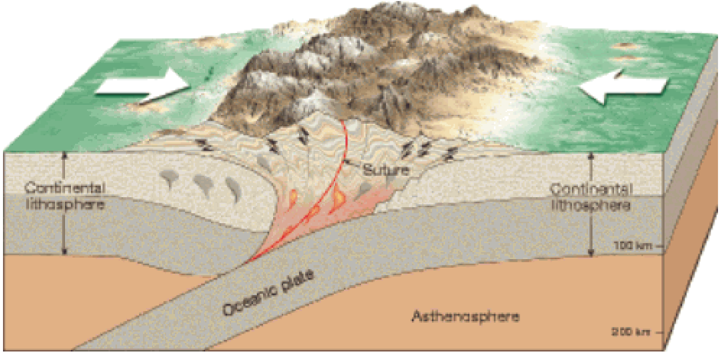


Figure 13 Continental-Continental Convergent Boundary Continental lithosphere cannot be subducted because it floats. The collision of two continental plates forms mountain ranges.

Transform Fault Boundaries

The third type of plate boundary is the transform fault boundary. At a transform fault boundary, plates grind past each other without destroying the lithosphere. Most transform faults join two segments of a mid-ocean ridge, as shown in Figure 15. These faults are present about every 100 kilometers along the ridge axis. Active transform faults lie between the two offset ridge segments. The seafloor produced at one ridge axis moves in the opposite direction as seafloor is produced at an opposing ridge segment. So between the ridge segments these slabs of oceanic crust are grinding past each other along a transform fault.

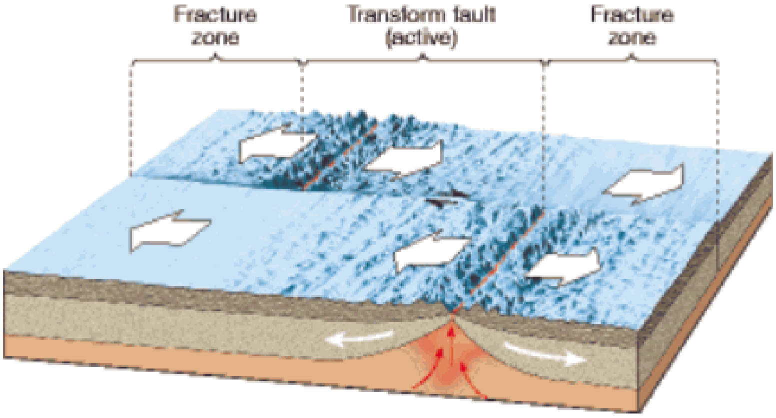


Figure 15 A transform fault boundary offsets segments of a divergent boundary at an oceanic ridge.

Although most transform faults are located within the ocean basins, a few cut through the continental crust. One example is the San Andreas Fault of California. Along the San Andreas, the Pacific plate is moving toward the northwest, past the North American plate. If this movement continues, that part of California west of the fault zone will become an island off the west coast of the United States and Canada. It could eventually reach Alaska. However, a more immediate concern is the earthquake activity triggered by movements along this fault system.

Section 4 Testing Plate Tectonics

Key Concepts

- What evidence supports the theory of plate tectonics?
- How does paleomagnetism support the theory of plate tectonics?

Vocabulary

- paleomagnetism
- normal polarity
- reverse polarity
- hot spot

Evidence for Plate Tectonics

With the birth of the plate tectonics model, researchers from all of the Earth sciences began testing it. You have already seen some of the evidence supporting continental drift and seafloor spreading. Additional evidence for plate tectonics came as new technologies developed.

Paleomagnetism

If you have ever used a compass to find direction, you know that the magnetic field has a north pole and a south pole. These magnetic poles align closely, but not exactly, with the geographic poles.

In many ways, Earth's magnetic field is much like that produced by a simple bar magnet. Invisible lines of force pass through Earth and extend from one pole to the other. A compass needle is a small magnet that is free to move about. The needle aligns with these invisible lines of force and points toward the magnetic poles.

Certain rocks contain iron-rich minerals, such as magnetite. When heated above a certain temperature, these magnetic minerals lose their magnetism. However, when these iron-rich mineral grains cool down, they become magnetized in the direction parallel to the existing magnetic field. Once the minerals solidify, the magnetism they possess stays frozen in this position. So magnetized rocks behave much like a compass needle because they point toward the existing magnetic poles. If the rock is moved or if the magnetic pole changes position, the rock's magnetism retains its original alignment. Rocks formed millions of years ago thus show the location of the magnetic poles at the time of their formation, as shown in Figure 16. These rocks possess paleomagnetism.

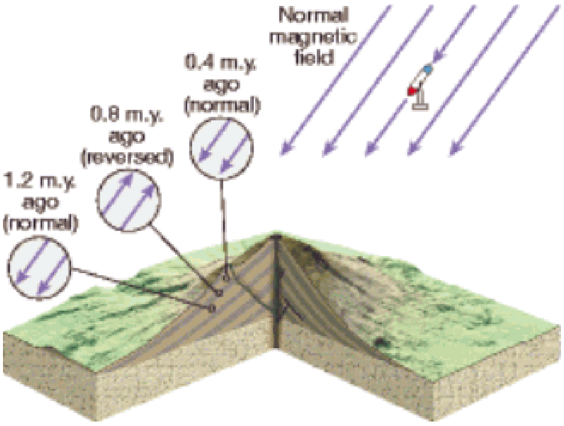
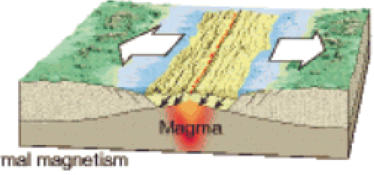


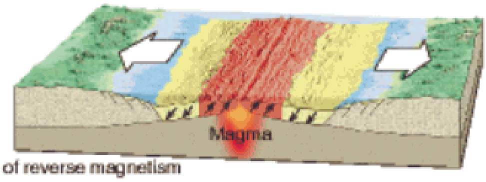
Figure 16 Paleomagnetism Preserved in Lava Flows As the lava cools, it becomes magnetized parallel to the magnetic field present at that time. When the polarity randomly reverses, a record of the paleomagnetism is preserved in the sequence of lava flows.

Geophysicists learned that Earth's magnetic field periodically reverses polarity. The north magnetic pole becomes the south magnetic pole, and vice versa. A rock solidifying during one of the periods of reverse polarity will be magnetized with the polarity opposite that of rocks being formed today.

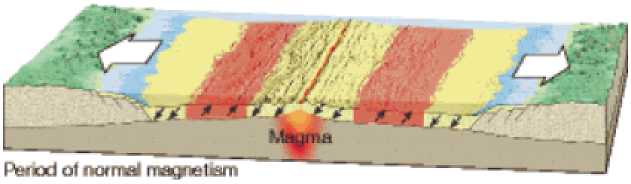
When rocks show the same magnetism as the present magnetic field, they are described as having normal polarity. Rocks that show the opposite magnetism are said to have reverse polarity. A relationship was discovered between the magnetic reversals and the seafloor-spreading hypothesis. Ships towed instruments called magnetometers across segments of the ocean floor. This research revealed alternating strips of high- and low-intensity magnetism that ran parallel to the ridges. The strips of high-intensity magnetism are regions where the paleomagnetism of the ocean crust is of the normal type. These positively magnetized rocks enhance the existing magnetic field. The low-intensity strips represent regions where the ocean crust is polarized in the reverse direction and, therefore, weaken the existing magnetic field. As new basalt is added to the ocean floor at the oceanic ridges, it becomes magnetized according to the existing magnetic field, as shown in Figure 17. The discovery of strips of alternating polarity, which lie as mirror images across the ocean ridges, is among the strongest evidence of seafloor spreading.



Period of normal magnetism



Period of reverse magnetism



Period of normal magnetism

Figure 17 A As new material is added to the ocean floor at the oceanic ridges, it is magnetized according to Earth's existing magnetic field. B This process records each reversal of Earth's magnetic field. C Because new rock is added in approximately equal amounts to the trailing edges of both plates, strips of equal size and polarity parallel both sides of the ocean ridges. Applying Concepts Why are the magnetized strips about equal width on either side of the ridge?

Earthquake Patterns

Scientists found a close link between deep-focus earthquakes and ocean trenches. Also, the absence of deep-focus earthquakes along the oceanic ridge system was shown to be consistent with the new theory.

Compare the distribution of earthquakes shown in Chapter 8 on page 226 with the map of plate boundaries on pages 256–257. The close link between plate boundaries and earthquakes is obvious. When the depths of earthquake foci and their locations within the trench systems are plotted, a pattern emerges.

Look at Figure 18. It shows the distribution of earthquakes near the Japan trench. Here, most shallow-focus earthquakes occur within or adjacent to the trench. Intermediate- and deep-focus earthquakes occur toward the mainland.

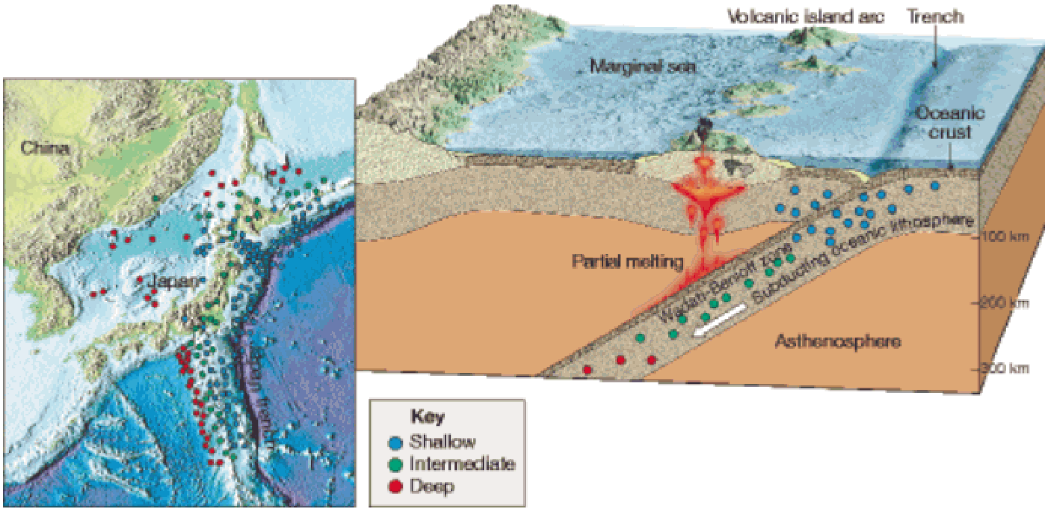


Figure 18 Distribution of Earthquake Foci Note that intermediate- and deep-focus earthquakes occur only within the sinking slab of oceanic lithosphere.

In the plate tectonics model, deep-ocean trenches are produced where cool, dense slabs of oceanic lithosphere plunge into the mantle. Shallow-focus earthquakes are produced as the descending plate interacts with the lithosphere above it. As the slab descends farther into the mantle, deeper-focus earthquakes are produced. No earthquakes have been recorded below 700 kilometers. At this depth, the slab has been heated enough to soften.

Ocean Drilling

Some of the most convincing evidence confirming the plate tectonics theory has come from drilling directly into ocean-floor sediment. The Deep Sea Drilling Project from 1968 to 1983 used the drilling ship Glomar Challenger to drill hundreds of meters into the sediments and underlying crust.

When the oldest sediment from each drill site was plotted against its distance from the ridge crest, it was revealed that the age of the sediment increased with increasing distance from the ridge. The data on the ages of seafloor sediment confirmed what the seafloor-spreading hypothesis predicted. The youngest oceanic crust is at the ridge crest and the oldest oceanic crust is at the continental margins.

The data also reinforced the idea that the ocean basins are geologically young. No sediment older than 180 million years was found. By comparison, some continental crust has been dated at 4.0 billion years.

Hot Spots

Mapping of seafloor volcanoes in the Pacific revealed a chain of volcanic structures extending from the Hawaiian Islands to Midway Island and then north to the Aleutian trench, as shown in Figure 19. Dates of volcanoes in this chain showed that the volcanoes increase in age with increasing distance from Hawaii. Suiko Seamount is 65 million years old. Midway Island is 27 million years old. The island of Hawaii formed less than a million years ago and still forming today.

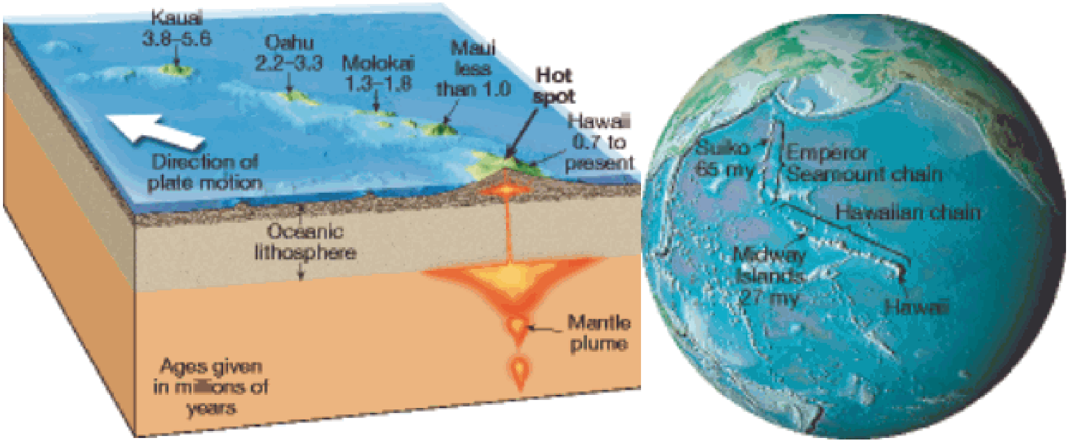


Figure 19 Hot Spot The chain of islands and seamounts that extends from Hawaii to the Aleutian trench results from the movement of the Pacific plate over a stationary hot spot. Predicting Where will a new Hawaiian island be located?

A rising plume of mantle material is located below the island of Hawaii. Melting of this hot rock as it nears the surface creates a volcanic area, or hot spot. As the Pacific plate moves over the hot spot, successive volcanic mountains have been created. The age of each volcano indicates the time when it was situated over the hot spot. Kauai is the oldest of the large islands in the Hawaiian chain. Its volcanoes are extinct. The youthful island of Hawaii has two active volcanoes—Mauna Loa and Kilauea. Hot spot evidence supports the idea that the plates move over Earth's surface.

Section 5 Mechanisms of Plate Motion

Key Concepts
- What are the mechanisms of plate motion?
- What causes plate motion?

Vocabulary
- convective flow
- slab-pull
- ridge-push
- mantle plume

Causes of Plate Motion

Scientists generally agree that convection occurring in the mantle is the basic driving force for plate movement. During convection, warm, less dense material rises and cooler, denser material sinks. The motion of matter resulting from convection is called convective flow. The slow movements of the plates and mantle are driven by the unequal distribution of Earth's heat. The heat is generated by the radioactive decay of elements, such as uranium, found within Earth's mantle and crust.

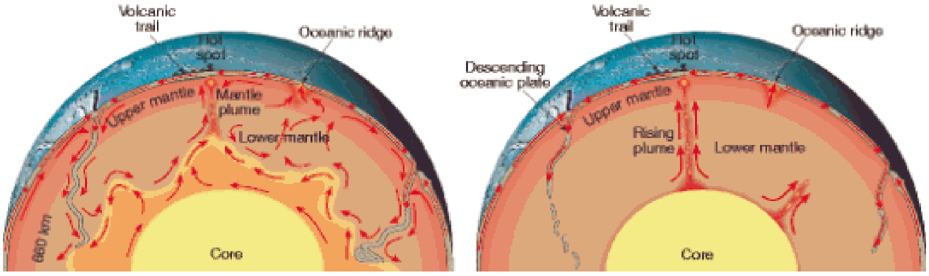
Slab-Pull and Ridge-Push

Several mechanisms produce forces that cause plate motion. One mechanism, called slab-pull, occurs because old oceanic crust, which is relatively cool and dense, sinks into the asthenosphere and "pulls" the trailing lithosphere along. Slab-pull is thought to be the primary downward arm of convective flow in the mantle. By contrast, ridge-push results from the elevated position of the oceanic ridge system. Ridge-push causes oceanic lithosphere to slide down the sides of the oceanic ridge. The downward slide is the result of gravity acting on the oceanic lithosphere. Ridge-push, although active in some spreading centers, is probably less important than slab-pull.

Mantle Convection

Most models suggest that hot plumes of rock are the upward flowing arms in mantle convection. These rising mantle plumes sometimes show themselves on Earth’s surface as hot spots and volcanoes.

One recent model is called whole-mantle convection. In this model, slabs of cold oceanic lithosphere descend into the lower mantle. This process provides the downward arm of convective flow, as shown in Figure 20A. At the same time, hot mantle plumes originating near the mantle-core boundary move heat toward the surface. Another model is the deep-layer model. You might compare this model to a lava lamp on a low setting. As shown in Figure 20B, the lower mantle is like the colored fluid in the bottom layer of a lava lamp. Like a lava lamp, heat from Earth’s interior causes the two layers to slowly swell and shrink in complex patterns without much mixing. A small amount of material from the lower layer flows upward as mantle plumes, creating hot-spot volcanism at the surface.



- Figure 20 Mantle Convection Models A In the whole-mantle convection model, cold oceanic lithosphere descends into the mantle. Hot mantle plumes transport heat toward the surface. B The deep-layer model suggests that Earth’s heat causes these layers of convection to slowly swell and shrink in complex patterns. Some material from the lower layer flows upward as mantle plumes.

There is still much to be learned about the mechanisms that cause plates to move. But one thing is clear. The unequal distribution of heat within Earth causes the thermal convection in the mantle that ultimately drives plate motion. Exactly how this convection operates is still being debated.

understanding **EARTH**

Plate Tectonics into the Future

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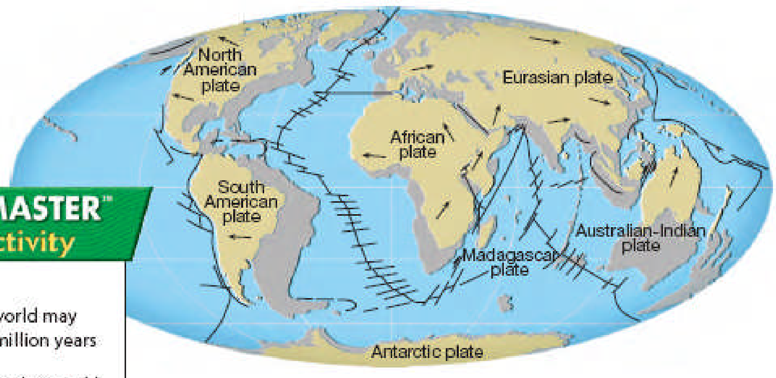
Two geologists, Robert Dietz and John Holden, used present-day plate movements to predict the locations of landmasses in the future. The map below shows where they predict Earth's landmasses will be 50 million years from now if plate movements remain at their present rates.

Future Continent Positions



MAP MASTER™ Skills Activity

Figure 21

Location The world may look like this 50 million years from now.

Identify Effects What could happen to Los Angeles and San Francisco if this proposed movement occurs?

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 10 million years. In about 60 million years Los Angeles will begin to descend into the Aleutian trench.

New Sea in Africa

Major changes are seen in Africa, where a new sea emerges as East Africa is ripped away from the mainland. In addition, Africa will have moved slowly into Europe, perhaps creating the next major mountain-building stage on Earth. Meanwhile, the Arabian Peninsula continues to move away from Africa, allowing the Red Sea to widen and close the Persian Gulf.

Atlantic Ocean Grows

In other parts of the world, Australia will be located across 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 into the future, although interesting, must be viewed with caution because 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.