Continental Movement by Plate Tectonics

NGSS Performance Expectations:

MS-ESS1-4 Construct a scientific explanation based on evidence from rock strata for how the geologic time scale is used to organize Earth's 4.6-billion-year-old history.

MS-ESS2-3 Analyze and interpret data on the distribution of fossils and rocks, continental shapes, and seafloor structures to provide evidence of the past plate motions.

HS-ESS1-5 Evaluate evidence of the past and current movements of continental and oceanic crust and the theory of plate tectonics to explain the ages of crustal rocks.

HS-ESS2-3 Develop a model based on evidence of Earth's interior to describe the cycling of matter by thermal convection.

The content and activities in this topic will work towards building an understanding of how the surface of the earth has changed over time by the process of plate tectonics.

Earth's Tectonic Plates

Fig. 7.14. This map of the world shows the earth's major tectonic plates. Arrows indicate the direction of plate movement. This map only shows the 15 largest tectonic plates.
Image courtesy of United States Geological Survey (USGS)

The earth's crust is broken into separate pieces called **tectonic plates** (Fig. 7.14). Recall that the crust is the solid, rocky, outer shell of the planet. It is composed of two distinctly different types of material: the less-dense continental crust and the more-dense oceanic crust. Both types of crust rest atop solid, upper mantle material. The upper mantle, in turn, floats on a denser layer of lower mantle that is much like thick molten tar.

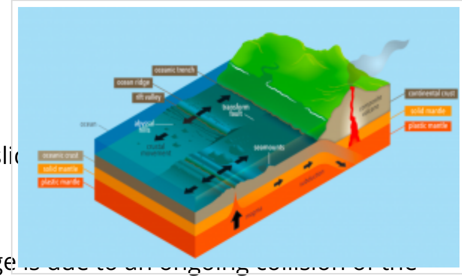
Each tectonic plate is free-floating and can move independently. Earthquakes and volcanoes are the direct result of the movement of tectonic plates at fault lines. The term **fault** is used to describe the boundary between tectonic plates. Most of the earthquakes and volcanoes around the Pacific ocean basin—a pattern known as the "ring of fire"—are due to the movement of tectonic plates in this region. Other observable results of short-term plate movement include the gradual widening of the Great Rift lakes in eastern Africa and the rising of the Himalayan Mountain range. The motion of plates can be described in four general patterns:

- **Collision**: when two continental plates are shoved together
- **Subduction**: when one plate plunges beneath another (Fig.

Fig 7.15. Diagram of the motion of plates
Image by Byron Inouye

7.15)

- **Spreading**: when two plates are pushed apart (Fig. 7.15)
- **Transform faulting**: when two plates sli



The rise of the Himalayan Mountain range is due to an ongoing collision of the Indian plate with the Eurasian plate. Earthquakes in California are due to transform fault motion.

Geologists have hypothesized that the movement of tectonic plates is related to convection currents in the earth's mantle. **Convection currents** describe the rising, spread, and sinking of gas, liquid, or molten material caused by the application of heat. An example of convection current is shown in Fig. 7.16. Inside a beaker, hot water rises at the point where heat is applied. The hot water moves to the surface, then spreads out and cools. Cooler water sinks to the bottom.

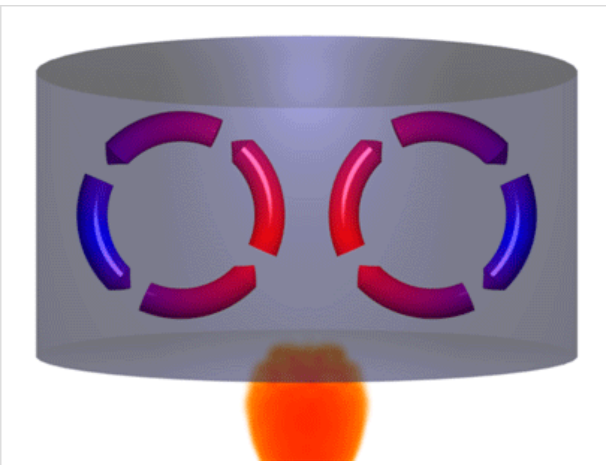


Fig. 7.16. In this diagram of convection currents in a beaker of liquid, the red arrows represent liquid that is heated by the flame and rises to the surface. At the surface, the liquid cools, and sinks back down (blue arrows).
Image courtesy of Oni Lukos, Wikimedia Commons

Earth's solid crust acts as a heat insulator for the hot interior of the planet. **Magma** is the molten rock below the crust, in the mantle. Tremendous heat and pressure within the earth cause the hot magma to flow in convection currents. These currents cause the movement of the tectonic plates that make up the earth's crust.

VOICE OF THE SEA

Voice of the Sea: Volcanoes

ACTIVITY

Activity: Modeling Plate Spreading

Simulate tectonic plate spreading by modeling convection currents that occur in the mantle.

ACTIVITY

Activity: Earth's Plates

Examine a map of the earth's tectonic plates. Based on evidence that has been found at plate boundaries, make some hypotheses about the movement of those plates.

COMPARE-CONTRAST-CONNECT

Compare-Contrast-Connect: Volcanoes

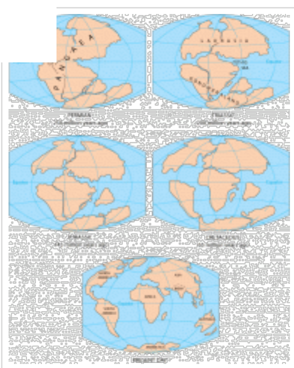


Fig. 7.18. Positions of the continental landmasses
Images courtesy of United States Geological Survey (USGS)

The earth has changed in many ways since it first formed 4.5 billion years ago. The locations of Earth's major landmasses today are very different from their locations in the past (Fig. 7.18). They have gradually moved over the course of hundreds of millions of years—alternately combining into supercontinents and pulling apart in a process known as **continental drift**. The supercontinent of Pangaea formed as the landmasses gradually combined roughly between 300 and 100 mya. The planet's landmasses eventually moved to their current positions and will continue to move into the future.

Plate tectonics is the scientific theory explaining the movement of the earth's crust. It is widely accepted by scientists today. Recall that both continental landmasses and the ocean floor are part of the earth's crust, and that the crust is broken into individual pieces called tectonic plates (Fig. 7.14). The movement of these tectonic plates is likely caused by convection currents in the molten rock in Earth's mantle below the crust. Earthquakes and volcanoes are the short-term results of this tectonic movement. The long-term result of plate tectonics is the movement of entire continents over millions of years (Fig. 7.18). The presence of the same type of fossils on continents that are now widely separated is evidence that continents have moved over geological history.

ACTIVITY

Activity: Continental Movement over Long Time Scales

Evaluate and interpret several lines of evidence for continental drift over geological time scales.

Evidence for the Movement of Continents

Fig 7.19. Some of the landmasses of the ancient supercontinent Gondwanaland show selected geological and fossil evidence.
Image by US Geological Survey and US Department of Interior modified by Byron Inuoye

The shapes of the continents provide clues about the past movement of the continents. The edges of the continents on the map seem to fit together like a jigsaw puzzle. For example, on the west coast of Africa, there is an indentation into which the bulge along the east coast of South America fits. The shapes of the continental shelves—the submerged landmass around continents—shows that the fit between continents is even more striking (Fig. 7.19).

Some fossils provide evidence that continents were once located nearer to one another than they are today. Fossils of a marine reptile called *Mesosaurus* (Fig. 7.20 A) and a land reptile called *Cynognathus* (Fig. 7.20 B) have been found in South America and South Africa. Another example is the fossil plant called Glossopteris, which is found in India, Australia, and Antarctica (Fig. 7.20 C). The presence of identical fossils in continents that are now widely separated is one of the main pieces of evidence that led to the initial idea that the continents had moved over geological history.

Fig. 7.20. (A) Fossil skeleton of *Mesosaurus* sp.
Image courtesy of Tommy, Flickr

Fig. 7.20. (B) Fossil skull of *Cynognathus* sp.
Image courtesy of Ghedoghedo, Wikimedia Commons

Fig. 7.20. (C) Fossil of *Glossopteris* sp. plant leaves
Image courtesy of Daderot, Wikimedia Commons

Fig. 7.20. (D) Fossil skeleton of *Lystrosaurus* sp.
Image courtesy of Ghedoghedo, Wikimedia Commons

Evidence for continental drift is also found in the types of rocks on continents. There are belts of rock in Africa and South America that match when the ends of the continents are joined. Mountains of comparable age and structure are found in the northeastern part of North America (Appalachian Mountains) and across the British Isles into Norway (Caledonian Mountains). These landmasses can be reassembled so that the mountains form a continuous chain.

Paleoclimatologists (*paleo* = ancient; *climate* = long term temperature and weather patterns) study evidence of prehistoric climates. Evidence from glacial striations in rocks, the deep grooves in the land left by the movement of glaciers, shows that 300 mya there were large sheets of ice covering parts of South America, Africa, India, and Australia. These striations indicate that the direction of glacial movement in Africa was toward the Atlantic ocean basin and in South America was from the Atlantic ocean basin. This evidence suggests that South America and Africa were once connected, and that glaciers moved across Africa and South America. There is no glacial evidence for continental movement in North America, because there was no ice covering the continent 300 million years ago. North America may have been nearer the equator where warm temperatures prevented ice sheet formation.

PRACTICES OF SCIENCE

▶ Practices of Science: Opinion, Hypothesis & Theory

Seafloor Spreading at Mid-Ocean Ridges

Convection currents drive the movement of Earth's rigid tectonic plates in the planet's fluid molten mantle. In places where convection currents rise up towards the crust's surface, tectonic plates move away from each other in a process known as **seafloor spreading** (Fig. 7.21). Hot magma rises to the crust's surface, cracks develop in the ocean floor, and the magma pushes up and out to form mid-ocean ridges. **Mid-ocean ridges** or spreading centers are fault lines where two tectonic plates are moving away from each other.

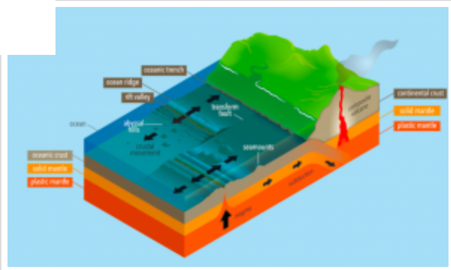


Fig. 7.21. Seafloor spreading and the formation of transform faults.
Image by Byron Inouye

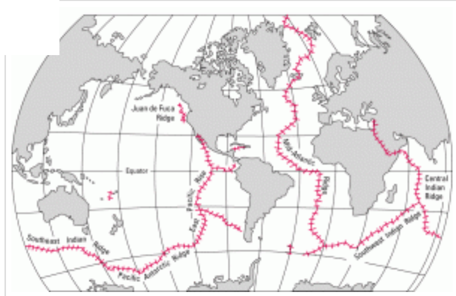


Fig. 7.22. World map of mid-ocean ridges
Image courtesy of United States Geological Survey (USGS)

Mid-ocean ridges are the largest continuous geological features on Earth. They are tens of thousands of kilometers long, running through and connecting most of the ocean basins. Oceanographic data reveal that seafloor spreading is slowly widening the Atlantic ocean basin, the Red Sea, and the Gulf of California (Fig. 7.22).

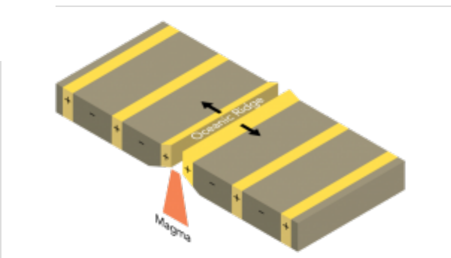


Fig. 7.22.1. The positive and negative magnetic polarity bands in this diagram of rocks near mid-ocean ridges indicate reversals of earth's magnetic field.
Image by Bryon Inouye

The gradual process of seafloor spreading slowly pushes tectonic plates apart while generating new rock from cooled magma. Ocean floor rocks close to a mid-ocean ridge are not only younger than distant rocks, they also display consistent bands of magnetism based on their age (Fig. 7.22.1). Every few hundred thousand years the earth's magnetic field reverses, in a process known as geomagnetic reversal. Some bands of rock were produced during a time when the polarity of the earth's magnetic field was the reverse of its current polarity. Geomagnetic reversal allows scientists to study the movement of ocean floors over time.

Paleomagnetism is the study of magnetism in ancient rocks. As molten rock cools and solidifies, particles within the rocks align themselves with the earth's magnetic field. In other words, the particles will point in the direction of the magnetic field present as the rock was cooling. If the plate containing the rock drifts or rotates, then the particles in the rock will no longer be aligned with the earth's magnetic field. Scientists can compare the directional magnetism of rock particles to the direction of the magnetic field in the rock's current location and estimate where the plate was when the rock formed (Fig. 7.22.1).

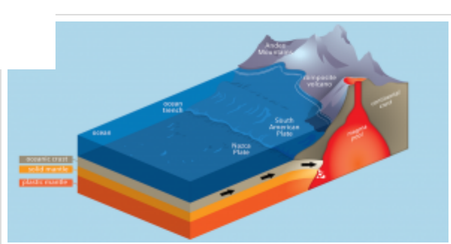


Fig. 7.23. Subduction of the Nazca Plate below

Seafloor spreading gradually pushes tectonic plates apart at mid-ocean ridges. When this happens, the opposite edge of these plates push against other tectonic plates. **Subduction** occurs when two tectonic plates meet and one moves underneath the other (Fig. 7.23). Oceanic crust is primarily composed of basalt,

the South American Plate, forming the composite volcanoes that make up the Andes Mountains.
Image by Byron Inouye

which makes it slightly denser than continental crust, which is composed primarily of granite. Because it is denser, when oceanic crust and continental crust meet, the oceanic crust slides below the continental crust. This collision of oceanic crust on one plate with the continental crust of a second plate can result in the formation of volcanoes (Fig. 7.23). As the oceanic crust enters the mantle, pressure breaks the crustal rock, heat from friction melts it, and a pool of magma develops. This thick magma, called andesite lava, consists of a mixture of basalt from the oceanic crust and granite from the continental crust. Forced by tremendous pressure, it eventually flows along weaker crustal channels toward the surface. The magma periodically breaks through the crust to form great, violently explosive **composite volcanoes**—steep-sided, cone-shaped mountains like those in the Andes at the margin of the South American Plate (Fig. 7.23).

Continental collision occurs when two plates carrying continents collide. Because continental crusts are composed of the same low-density material, one does not sink under the other. During collision, the crust moves upward, and the crustal material folds, buckles, and breaks (Fig. 7.24 A). Many of the world's largest mountain ranges, like the Rocky Mountains and the Himalayan Mountains, were formed by the collision of continents resulting in the upward movement of the earth's crust (Fig. 7.24 B). The Himalayan Mountains were formed by the collision between Indian and Eurasian tectonic plates.

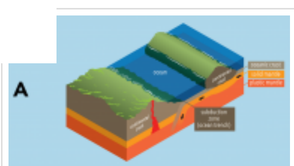


Fig. 7.24. (A) A subduction zone forms when oceanic crust slides under continental crust.
Image by Byron Inouye

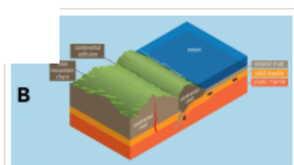


Fig. 7.24. (B) The collision of two continental crusts interrupts the subduction process and forms a new mountain chain.
Image by Byron Inouye

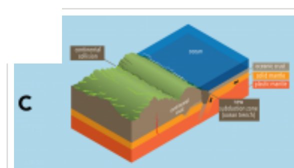


Fig. 7.24. (C) Oceanic crust continues sliding under the continental crust forming a new subduction zone and a new submarine trench. The two continental crusts begin to fuse.
Image by Byron Inouye

Ocean trenches are steep depressions in the seafloor formed at subduction zones where one plate moves downward beneath another (Fig. 7.24 C). These trenches are deep (up to 10.8 km), narrow (about 100 km), and long (from 800 to 5,900 km), with very steep sides. The deepest ocean trench is the Mariana Trench just east of Guam. It is located at the subduction zone where the Pacific plate plunges underneath the edge of the Filipino plate. Subduction zones are also sites of deepwater earthquakes.

Transform faults are found where two tectonic plates move past each other. As the plates slide past one another, there is friction, and great tension can build up before slippage occurs, eventually causing shallow earthquakes. People living near the San Andreas Fault, a transfom fault in California, regularly experience such quakes.

Hot Spots

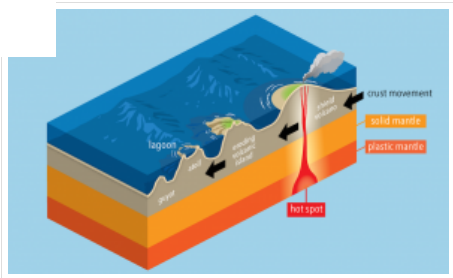


Fig. 7.25. Formation of volcanic islands
Image by Byron Inouye

Recall that some volcanoes form near plate boundaries, particularly near subduction zones where oceanic crust moves underneath continental crust (Fig. 7.24). However, some volcanoes form over hot spots in the middle of tectonic plates far away from subduction zones (Fig. 7.25). A **hot spot** is a place where magma rises up from the earth's mantle toward the surface crust. When magma erupts and flows at the surface, it is called **lava**. The basalt lava commonly found at hot spots flows like hot, thick syrup and gradually forms shield volcanoes. A **shield volcano** is shaped like a dome with gently sloping sides. These volcanoes are much less explosive than the composite volcanoes formed at subduction zones.

Fig. 7.26. An example of a fringing reef off the Nā pali coastline on Kaua'i, Hawai'i
Image courtesy of Dsamuelis, Wikimedia Commons

Some shield volcanoes, such as the islands in the Hawaiian archipelago, began forming on the ocean floor over a hot spot. Each shield volcano grows slowly with repeated eruptions until it reaches the surface of the water to form an island (Fig. 7.25). The highest peak on the island of Hawai'i reaches 4.2 km above sea level. However, the base of this volcanic island lies almost 7 km below the water surface, making Hawai'i's peaks some of the tallest mountains on Earth—much higher than Mount Everest. Almost all of the mid-Pacific and mid-Atlantic ocean basin islands formed in a similar fashion over volcanic hot spots. Over millions of years as the tectonic plate moves, a volcano that was over the hot spot moves away, ceases to erupt, and becomes extinct (Fig. 7.25). Erosion and subsidence (sinking of the earth's crust) eventually causes older islands to sink below sea level. Islands can erode through natural processes such as wind and water flow. Reefs continue to grow around the eroded land mass and form fringing reefs, as seen on Kaua'i in the main Hawaiian Islands (Fig. 7.26).

Eventually all that remains of the island is a ring of coral reef. An **atoll** is a ring-shaped coral reef or group of coral islets that has grown around the rim of an extinct submerged volcano forming a central lagoon (Fig. 7.27). Atoll formation is dependent on erosion of land and growth of coral reefs around the island. Coral reef atolls can only occur in tropical regions that are optimal for coral growth. The main Hawaiian Islands will all likely become coral atolls millions of years into the future. The older Northwestern Hawaiian Islands, many of which are now atolls, were formed by the same volcanic hot spot as the younger main Hawaiian Islands.

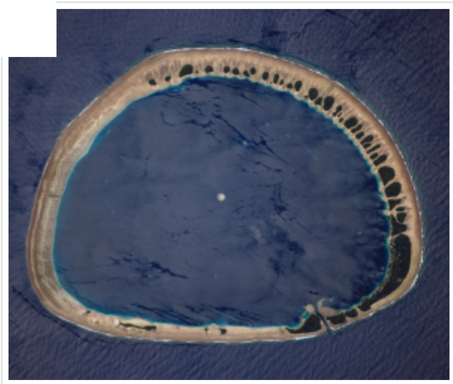


Fig. 7.27. (A) Nukuoro Atoll, Federated States of Micronesia
Image courtesy of National Aeronautics and Space Administration (NASA)

Fig. 7.27. (B) Midway Atoll, Northwestern Hawaiian Islands, Hawai'i
Image courtesy of United States Fish and Wildlife Service (USFWS), Wikimedia Commons

QUESTION SET

Question Set: Ocean Floor and Volcanoes

FURTHER INVESTIGATIONS

Further Investigations: Continental Movement by Plate Tectonics