Standard II: Inside Earth

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CHAPTER 1 Standard II: Inside Earth

CHAPTER OUTLINE

Standard 2: Students will understand Earth's internal structure and the dynamic nature of the tectonic plates that form its surface.

Objective 1: Evaluate the source of Earth's internal heat and the evidence of Earth's internal structure.

1. Identify that radioactive decay and heat of formation are the sources of Earth's internal heat.
2. Trace the lines of scientific evidence (e.g., seismic studies, composition of meteorites, and samples of the crust and mantle) that led to the inference that Earth's core, mantle, and crust are separated based on composition.
3. Trace the lines of scientific evidence that led to the inference that Earth's lithosphere, asthenosphere, mesosphere, outer core, and inner core are separated based on physical properties.
4. Model how convection currents help distribute heat within the mantle.

Objective 2: Describe the development of the current theory of plate tectonics and the evidence that supports this theory.

1. Explain Alfred Wegener's continental drift hypothesis, his evidence (e.g., fossil record, ancient climates, geometric fit of continents), and why it was not accepted in his time.
2. Cite examples of how the geologic record preserves evidence of past change.
3. Establish the importance of the discovery of mid-ocean ridges, oceanic trenches, and magnetic striping of the sea floor to the development of the modern theory of plate tectonics.
4. Explain how mantle plumes (hot spots) provide evidence for the rate and direction of tectonic plate motion.
5. Organize and evaluate the evidence for the current theory of plate tectonics: seafloor spreading, age of seafloor, distribution of earthquakes and volcanoes.

Objective 3: Demonstrate how the motion of tectonic plates affects Earth and living things.

1. Describe a lithospheric plate and identify the major plates of the Earth.
2. Describe how earthquakes and volcanoes transfer energy from Earth's interior to the surface (e.g., seismic waves transfer mechanical energy, flowing magma transfers heat and mechanical energy).
3. Model the factors that cause tectonic plates to move (e.g., gravity, density, convection).
4. Model tectonic plate movement and compare the results of plate movement along convergent, divergent, and transform boundaries (e.g., mountain building, volcanoes, earthquakes, mid-ocean ridges, oceanic trenches).
5. Design, build, and test a model that investigates local geologic processes (e.g., mudslides, earthquakes, flooding, erosion) and the possible effects on human- engineered structures (e.g., dams, homes, bridges, roads).

1.1 How does the internal structure of the Earth affect the temperature of the Earth?

Earth's Internal Heat

In the Nebular theory of the formation of our solar system there were many collisions that happened to create our present day planets. A lot of heat and energy was created in that process. Many small particles collided and stuck together so that energy was given to the newly formed Earth, raising the its temperature. At this period of the Earth's history it was so hot it was literally a big ball of molten rock.

As time progresses the Earth begins to cool and rocks on the surface harden. But scientists also use seismic waves to show evidence that the interior of the Earth is not as solid as the surface. Where is this heat coming from? Most of it is leftover heat from the formation of the Earth. Another source of Earth's interior heat comes from **radioactive decay** - An element breaks down into another element and energy is released from its nucleus as it breaks apart. That released energy is then absorbed by the surrounding rocks thus increasing their temperature.

Exploring Earth's Interior

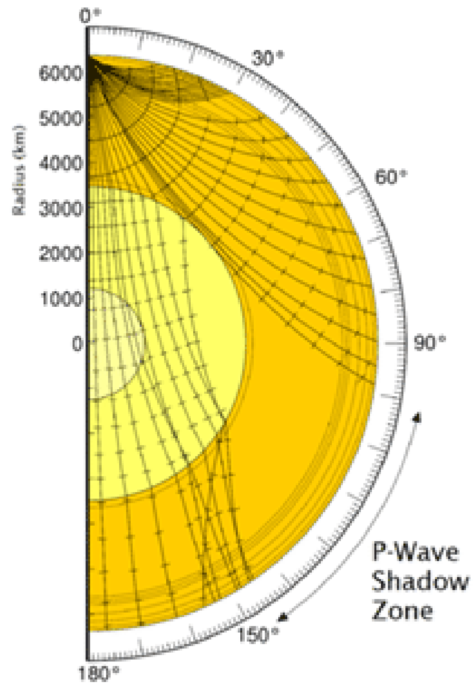
How do scientists know what is inside the Earth? We don't have direct evidence! Rocks yield some clues, but they only reveal information about the outer crust. In rare instances, a mineral, such as a diamond, comes to the surface from deeper down in the crust or the mantle. To learn about Earth's interior, scientists use energy to "see" the different layers of the Earth, just like doctors can use an MRI, CT scan, or x-ray to see inside our bodies.

Seismic Waves

One ingenious way scientists learn about Earth's interior is by looking at how energy travels from the point of an earthquake. These are seismic waves. Seismic waves travel outward in all directions from where the ground breaks at an earthquake. These waves are picked up by seismographs around the world. Two types of seismic waves are most useful for learning about Earth's interior.

- P-waves (primary waves) are fastest, traveling at about 6 to 7 kilometers (about 4 miles) per second, so they arrive first at the seismometer. P-waves move in a compression/expansion type motion, squeezing and unsqueezing earth materials as they travel. This produces a change in volume for the material. P-waves bend slightly when they travel from one layer into another. Seismic waves move faster through denser or more rigid material. As P-waves encounter the liquid outer core, which is less rigid than the mantle, they slow down. This makes the P-waves arrive later and further away than would be expected. The result is a P-wave shadow zone. No P-waves are picked up at seismographs 104° to 140° from the earthquakes focus.
- S-waves (secondary waves) are about half as fast as P-waves, traveling at about 3.5 km (2 miles) per second, and arrive second at seismographs. S-waves move in an up and down motion perpendicular to the direction of wave travel. This produces a change in shape for the earth materials they move through. Only solids resist a change in shape, so S-waves are only able to travel through solids. S-waves cannot travel through liquid. Some seismographs on Earth don't receive S-wave data leading scientists to infer that there is a liquid layer in the interior of the Earth not allowing S-waves to travel through.

By tracking seismic waves, scientists have learned what makes up the planet's interior (See the figure below).



This animation shows a seismic wave shadow zone:

- http://earthquake.usgs.gov/learn/animations/animation.php?flash_title=Shadow+Zone&flash_file=shadowzone&flash_width=220&flash_height=320

Other Clues about Earth's Interior

- Earth's overall density is higher than the density of crustal rocks, so the core must be made of something dense, like metal.
- Since Earth has a magnetic field, there must be metal within the planet. Iron and nickel are both magnetic.
- Meteorites are the remains of the material that formed the early Solar System and are thought to be similar to material in Earth's interior (Figure 1.1).

FIGURE 1.1
This meteorite contains silica minerals and iron-nickel. The material is like the boundary between Earth's core and mantle. The meteorite is 4.2 billion years old.

The Earth's Layers

The Earth's compositional and physical properties layers are pictured 1.2.

Core, mantle, and crust are divisions based on composition:

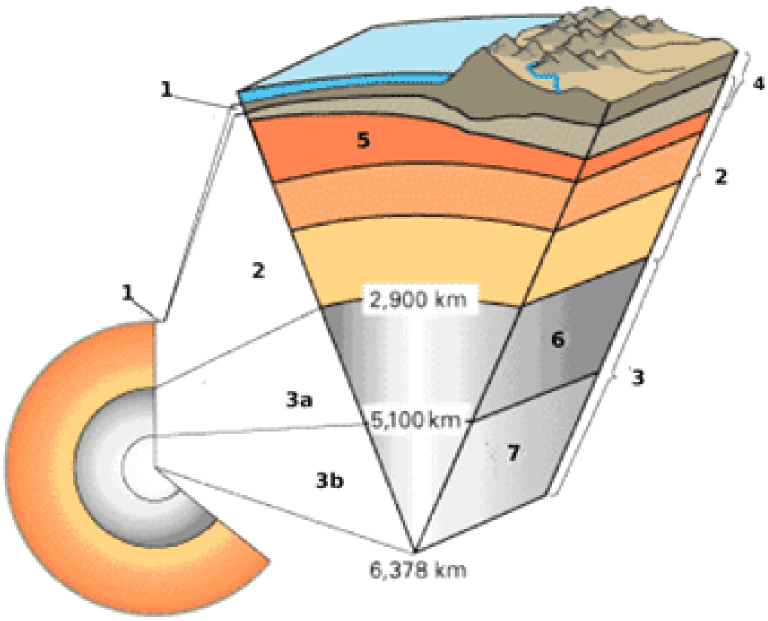


FIGURE 1.2
A cross section of Earth showing the following compositional layers: (1) crust (2) mantle (3a) outer core (3b) inner core and physical properties layers (4) lithosphere (5) asthenosphere (6) outer core (7) inner core.

- The crust is less than 1% of Earth by mass. The oceanic crust is mafic (minerals with high levels of ferromagnesian), while continental crust is often more felsic (minerals that are primarily made of feldspars and quartz) rock.
- The mantle is hot, ultramafic rock. It represents about 68% of Earth's mass.
- The core is mostly iron metal. The core makes up about 31% of the Earth.

Lithosphere and asthenosphere are divisions based on (physical) properties:

- The **lithosphere** is composed of both the crust and the portion of the upper mantle that behaves as a brittle, rigid solid.
- The **asthenosphere** is partially molten upper mantle material that behaves plastically and can flow.
- The **mesosphere** refers to the mantle in the region under the lithosphere, and the asthenosphere, but above the outer core. The difference between mesosphere and asthenosphere is likely due to density and rigidity differences, that is, physical factors, and not to any difference in chemical composition.

This animation shows the layers by composition and by mechanical (physical) properties:

- http://earthguide.ucsd.edu/eoc/teachers/t_tectonics/p_layers.html

Crust and Lithosphere

Earth's outer surface is its crust; a cold, thin, brittle outer shell made of rock. The crust is very thin, relative to the radius of the planet. There are two very different types of crust, each with its own distinctive physical and chemical properties, which are summarized in Table below.

[INSERT TABLE 3]

Oceanic crust is composed of mafic magma that erupts on the seafloor to create basalt lava flows or cools deeper down to create the intrusive igneous rock gabbro (Figure 1.3).

Continental crust is made up of many different types of igneous, metamorphic, and sedimentary rocks. The average composition is granite, which is much less dense than the mafic rocks of the oceanic crust (Figure 1.4). Because it is

FIGURE 1.3
Gabbro from ocean crust

thick and has relatively low density, continental crust rises higher on the mantle than oceanic crust, which sinks into the mantle to form basins. When filled with water, these basins form the planet's oceans.

FIGURE 1.4
This granite from Missouri is more than 1 billion years old.

The lithosphere is the outermost mechanical (physical) layer, which behaves as a brittle, rigid solid. The lithosphere is about 100 kilometers thick. The definition of the lithosphere is based on how earth materials behave, so it includes the crust and the uppermost mantle, which are both brittle. Since it is rigid and brittle, when stresses act on the lithosphere, it breaks. This is what we experience as an earthquake.

Mantle

The two most important things about the mantle are:

1. it is made of solid rock, and
2. it is hot.

Scientists know that the mantle is made of rock based on evidence from seismic waves, heat flow, and meteorites. The properties of the mantle are the same as those of the ultramafic rock peridotite, which is made of the iron- and magnesium-rich silicate minerals (Figure 1.5). Peridotite is rarely found at Earth's surface, leading to the conclusion that this type of rock is from the mantle.

At the planet's center lies a dense metallic core. Scientists infer that the core is metal because:

- The density of Earth's surface layers is much less than the overall density of the planet, as calculated from the planet's rotation. If the surface layers are less dense than average, then the interior must be denser than average. Calculations indicate that the core is about 85% iron metal with nickel metal making up much of the remaining 15%.
- Metallic meteorites are thought to be representative of the core. The 85% iron 15% nickel calculation above is also seen in metallic meteorites (See the Figure 1.6).

FIGURE 1.5
Peridotite is formed of crystals of olivine (green) and pyroxene (black).

If Earth's core were not metal, the planet would not have a magnetic field. Metals such as iron are magnetic, but rock, which makes up the mantle and crust, is not.

Scientists know that the outer core is liquid because:

1. S-waves stop at the inner core.
2. The strong magnetic field is caused by convection in the liquid outer core. Convection currents in the outer core are due to heat from the even hotter inner core.

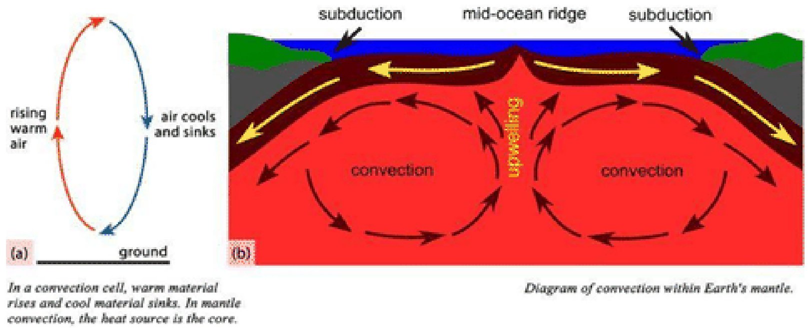
Even though the inner core is very hot it is solid because of the intense pressure keeping the atoms as moving freely as they would in a liquid.

The heat that keeps the outer core from solidifying is produced by the breakdown of radioactive elements in the inner core.

FIGURE 1.6
An iron meteorite is the closest thing to the Earth's core that we can hold in our hands.

Heat flows in two different ways within the Earth:

1. **Conduction:** When one material is touching another or within a single material energy is transferred heat flows from warmer to cooler places until all are the same temperature. The mantle is hot mostly because of heat conducted from the core.
2. **Convection:** If a material is able to move, even if it moves very slowly, convection currents can form. Convection in the mantle is the same as convection in a pot of water on a stove. Convection currents within Earth's mantle form as material near the core heats up. As the core heats the bottom layer of mantle material, particles move more rapidly, decreasing its density and causing it to rise. The rising material begins the convection current. When the warm material reaches the surface, it spreads horizontally. The material cools because it is no longer near the core. It eventually becomes cool and dense enough to sink back down into the mantle. At the bottom of the mantle, the material travels horizontally and is heated by the core. It reaches the location where warm mantle material rises, and the mantle convection cell is complete (Figure below).



Summary

- Heat of formation and radioactive decay are the sources of Earth's internal heat.
- Earth is divided into layers based on compositional and physical properties.
- The hot core warms the base of the mantle, which causes mantle convection.

Think like a Geologist

1. How do scientists learn about Earth's interior composition?
2. What is the difference between crust and lithosphere? Include in your answer both where they are located and what their properties are.
3. How do the differences between oceanic and continental crust lead to the presence of ocean basins and continents?
4. How do scientists know that the outer core is liquid?
5. Why is the outer core liquid and the inner core solid?
6. Describe the properties of each of these parts of the Earth's interior: lithosphere, asthenosphere, and mesosphere. What are they made of? How hot are they? What are their physical properties?
7. When you put your hand above a pan filled with boiling water, does your hand warm up because of convection or conduction? If you touch the pan, does your hand warm up because of convection or conduction? Based on your answers, which type of heat transfer moves heat more easily and efficiently?

1.2 What causes earthquakes and volcanoes?

"Doesn't the east coast of South America fit exactly against the west coast of Africa, as if they had once been joined? This is an idea I'll have to pursue." - Alfred Wegener said to his future wife, in December, 1910. We can't really get into Alfred Wegener's head, but we can imagine that he started his investigations by trying to answer this question: Why do the continents of Africa and South America appear to fit together so well? Is it a geometric coincidence that they do, or is there some geological reason?

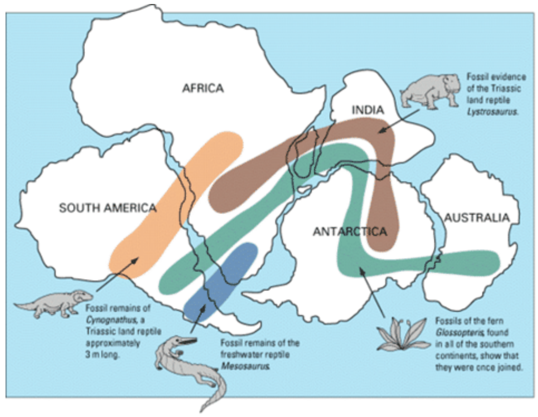
Wegener's Idea

Alfred Wegener, born in 1880, was a meteorologist and explorer. In 1911, Wegener found a scientific paper that listed identical plant and animal fossils on opposite sides of the Atlantic Ocean. Intrigued, he then searched for and found other cases of identical fossils on opposite sides of oceans. The explanation put out by the scientists of the day was that land bridges had once stretched between these continents. Instead, Wegener pondered the way Africa and South America appeared to fit together like puzzle pieces. Other scientists had suggested that Africa and South America had once been joined, but Wegener was the idea's greatest supporter. Wegener obtained a tremendous amount of evidence to support his hypothesis that the continents had once been joined.

Wegener's Evidence

The main evidences that Wegener and his supporters collected for the continental drift hypothesis:

1. The continents appear to fit together.
2. Ancient fossils of the same species of extinct plants and animals are found in rocks of the same age but are on continents that are now widely separated. Wegener proposed that the organisms had lived side by side, but that the lands had moved apart after they were dead and fossilized. His critics suggested that the organisms moved over long-gone land bridges, but Wegener thought that the organisms could not have been able to travel across the oceans.



- Fossils of the seed fern Glossopteris were too heavy to be carried so far by wind.
- Mesosaurus was a swimming reptile, but could only swim in fresh water.
- Cynognathus and Lystrosaurus were land reptiles and were unable to swim.

3. Identical rocks, of the same type and age, are found on both sides of the Atlantic Ocean. Wegener said the rocks had formed side by side and that the land had since moved apart.
4. Mountain ranges with the same rock types, structures, and ages are now on opposite sides of the Atlantic Ocean. The Appalachians of the eastern United States and Canada, for example, are just like mountain ranges in eastern Greenland, Ireland, Great Britain, and Norway (See Figure below). Wegener concluded that they formed as a single mountain range that was separated as the continents drifted.

5. Grooves and rock deposits left by ancient glaciers are found today on different continents very close to the equator. This would indicate that the glaciers either formed in the middle of the ocean and/or covered most of the Earth. Today, glaciers only form on land and nearer the poles. Wegener thought that the glaciers were centered over the southern land mass close to the South Pole and the continents moved to their present positions later on.
6. Coral reefs and coal-forming swamps are found in tropical and subtropical environments, but ancient coal seams and coral reefs are found in locations where it is much too cold today. Wegener suggested that these creatures were alive in warm climate zones and that the fossils and coal later drifted to new locations on the continents. An animation showing that Earth's climate belts remain in roughly the same position while the continents move is seen here: http://www.scotese.com/paleocli.htm .
7. Wegener thought that mountains formed as continents ran into each other. This got around the problem of the leading hypothesis of the day, which was that Earth had been a molten ball that bulked up in spots as it cooled (the problem with this idea was that the mountains should all be the same age and they were known not to be).

Problems with his Theory

Even with many forms of evidence that the continents had once fit together and had since moved apart into their present locations, the scientific community at the time could not fully accept his theory. The biggest reason for the rejection of his evidence was that Wegener could not provide an explanation for how something as large as continents could move or by which force they could collide into one another. Wegener incorrectly proposed that the continents were plowing through the ocean floor, but there was no obvious mechanism for how this could be accomplished. Because of this lack of an explanation, Alfred Wegener's hypothesis of continental drift was not widely accepted in his day. However, modern discoveries in plate tectonic theory have greatly led to a further understanding and wider acceptance of his theory.

Seafloor Spreading

Seafloor Bathymetry

During World War II, battleships and submarines carried echo sounders to locate enemy submarines (Figure 1.7). Echo sounders produce sound waves that travel outward in all directions, bounce off the nearest object, and then return to the ship. By knowing the speed of sound in seawater, scientists calculate the distance to the object based on the time it takes for the wave to make a round-trip. During the war, most of the sound waves ricocheted off the ocean bottom.

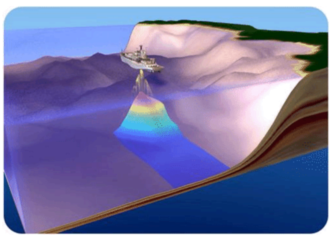


FIGURE 1.7
This echo sounder has many beams and creates a three dimensional map of the seafloor. Early echo sounders had a single beam and created a line of depth measurements.

This animation shows how sound waves are used to create pictures of the sea floor and ocean crust:

- http://earthguide.ucsd.edu/eoc/teachers/t_tectonics/p_sonar.html

After the war, scientists pieced together the ocean depths to produce bathymetric maps, which reveal the features of the ocean floor as if the water were taken away. Even scientist were amazed that the seafloor was not completely flat (Figure 1.8).

The major features of the ocean basins and their colors on the map in Figure 1.8 include:

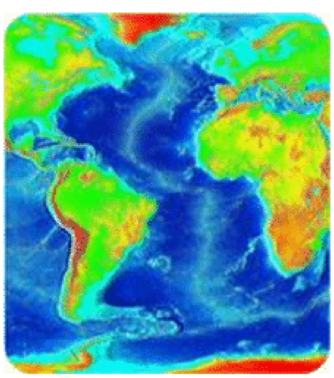


FIGURE 1.8
A modern map of the southeastern Pacific and Atlantic Oceans.

- **Mid-ocean Ridges:** rise up high above the deep seafloor as a long chain of mountains; e.g. the light blue gash in middle of Atlantic Ocean.

- **Deep Sea Trenches:** found at the edges of continents or in the sea near chains of active volcanoes; e.g. the very deepest blue, off of western South America.
- **Abyssal Plains:** flat areas, although many are dotted with volcanic mountains; e.g. consistent blue off of southeastern South America.

When they first observed these bathymetric maps, scientists wondered what had formed these features.

Magnetic Polarity Evidence

The next breakthrough in the development of the theory of plate tectonics came two decades after Wegener's death. Magnetite crystals are shaped like a tiny bar magnet. As basalt lava cools, the magnetite crystals line up in the Earth's magnetic field like tiny magnets. When the lava is completely cooled, the crystals point in the direction of magnetic north pole at the time they form. How do you expect this would help scientists see whether continents had moved or not?

You have just learned of a new tool that may help you. A magnetometer is a device capable of measuring the magnetic field intensity. This allows scientists to look at the magnetic properties of rocks in many locations, including basalt along the ocean floor.

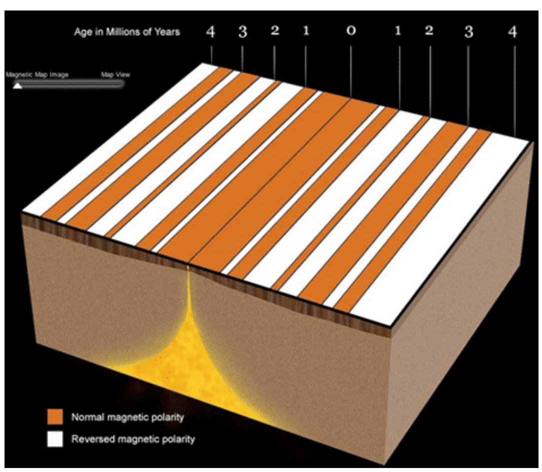
What causes the Magnetic Stripes on the seafloor?

This pattern of magnetic stripes could represent what scientists see on the seafloor. Note that the stripes are symmetrical about the central dusky purple stripe. In the oceans, magnetic stripes are symmetrical about a mid-ocean ridge axis. What could cause this? What could it possibly mean?

Seafloor Magnetism

During World War II, ships towed magnetometers in the ocean in order to find enemy submarines. They observed that the magnetic field strength changed from normal to reversed polarity as they sailed across the ocean. When scientists plotted the points of normal and reversed polarity on a seafloor map they made an astonishing discovery: the normal and reversed magnetic polarity of seafloor basalts creates a pattern:

- Stripes of normal polarity and reversed polarity alternate across the ocean bottom.
- Stripes form mirror images on either side of the mid-ocean ridges.
- Stripes end abruptly at the edges of continents, sometimes at a deep sea trench.



Seafloor Age

By combining magnetic polarity data from rocks on land and on the seafloor with radiometric age dating and fossil ages, scientists came up with a time scale for the magnetic reversals. The scientists noticed that the rocks got older with distance from the mid-ocean ridges. The youngest rocks were located at the ridge crest and the oldest rocks were located the farthest away, next to continents. Scientists also noticed that the characteristics of the rocks and sediments changed with distance from the ridge axis as seen in the Table below.

This animation illustrates how magnetic stripes form as the seafloor spreads.

- http://earthguide.ucsd.edu/eoc/teachers/t_tectonics/p_paleomag.html

Data From the sea Floor

[INSERT TABLE 4]

Away from the ridge crest, sediment becomes older and thicker, and the seafloor becomes thicker. Heat flow, which indicates that ocean crust is highest at the mid-ocean ridge.

The oldest seafloor is near the edges of continents or deep sea trenches and is less than 180 million years old. Since the oldest ocean crust is so much younger than the oldest continental crust, scientists realized that something was happening to the older seafloor.

How can you explain the observations that scientists have made in the oceans? Why is rock younger at the ridge and oldest at the farthest points from the ridge? The scientists suggested that seafloor was being created at the ridge. Since the planet is not getting larger, they suggested that it is destroyed in a relatively short amount of geologic time.

This 65 minute video explains "The Role of Paleomagnetism in the Evolution of Plate Tectonic Theory":

- http://online.wr.usgs.gov/calendar/2004/jul04.html

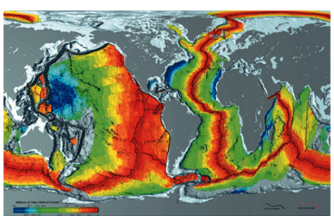


FIGURE 1.9
Seafloor is youngest at the mid-ocean ridges and becomes progressively older with distance from the ridge.

The Mechanism for Continental Drift

Seafloor spreading is the mechanism for Wegener's drifting continents. When new oceanic crust is brought to the surface of the ocean floor at mid-oceanic ridges it pushes old crust outward. The continents weren't moving through the ocean floor but more ocean floor was being formed in between them.

The history of the seafloor spreading hypothesis and the evidence that was collected to develop it are the subject of this video:

- http://www.youtube.com/watch?v=6CsTTmvX6mc&feature=rec-LGOUT-exp_fresh+div-1r-2

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/178207

The Theory of Plate Tectonics—What is a Plate?

During the 1950s and early 1960s, scientists set up seismograph networks to see if enemy nations were testing atomic bombs. These seismographs also recorded all of the earthquakes around the planet. The seismic records were used to locate an earthquake's epicenter, the point on Earth's surface directly above the place where the earthquake occurs.

Why is this relevant? It turns out that the locations of earthquake epicenters are concentrated along areas which outline specific land chunks or "plates" on the Earth. In addition to this, a vast number of volcanoes from around the world are also located in along these plate boundary areas. With this evidence and the combined evidences about Sea Floor Spreading, magnetic striping of the ocean floor, and more, the answer to what could cause the Continents to Drift apart became real.

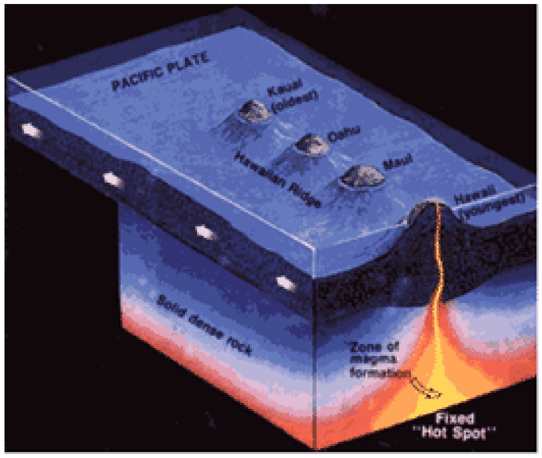
With the addition of this new information, Wegener's theory of Continental Drift has been modified and is now known as the Plate Tectonics theory. This theory provides the answers to the two questions that Alfred Wegener could not explain.

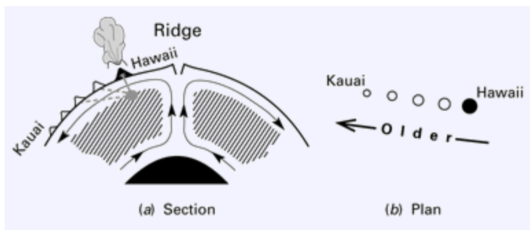
1. What causes plates to move, and
2. What force could cause this to happen?

Today, our general understanding about the Plate Tectonic Theory is that the Earth is divided into several crustal plates composed of oceanic lithosphere and thicker continental lithosphere, Tectonic plates are able to move because the Earth's lithosphere has a higher strength and lower density than the underlying asthenosphere. Along convergent boundaries, (where two plates are moving toward one another) subduction (the more dense oceanic plate moves under the less dense continental plate) carries plates into the mantle; the material lost is roughly balanced by the formation of new (oceanic) crust along mid-ocean ridges by seafloor spreading. In this way, the total surface of the globe remains the same. Plate movement is thought to be driven by a combination of the motion of the seafloor moving away from the mid-ocean ridges and a drag, downward of plates at the subduction zones.

Mantle Plumes and Hotspots

The portion of the mantle below specific parts of the lithosphere is hotter than normal. This is known as a mantle plume or hotspot. These hot spots can be used to determine the direction and rate at which tectonic plates are moving. One example of this is the Hawaiian islands. As the hot spot melts the plate above it, it melts the crust and causes new magma to rise and volcanoes to form- as it cools it turns to rock. Over time, these rocks build until they are above the surface of the ocean and an island is formed. As the plate moves the island is carried away from the hotspot, magma no longer rises and the volcano stops erupting. Magma begins to rise and form a new island under the hot spot. Over even longer periods of time, the islands move in the direction the plates are moving over the hot spot thus creating the chain of islands we see in present day Hawaii.



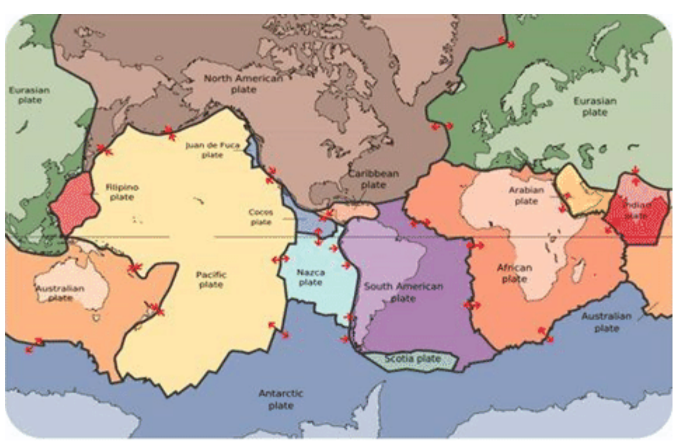


Check out this video for more information on hot spots:

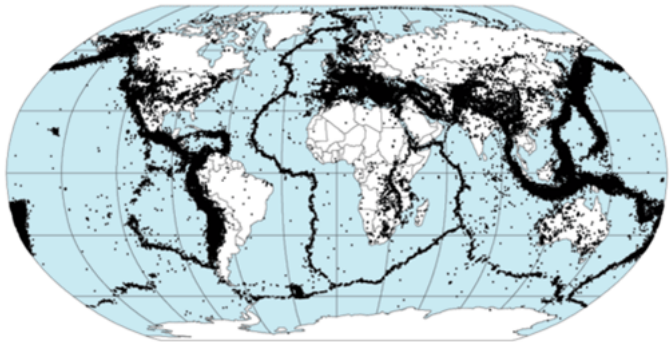
- http://www.ck12.org/earth-science/Volcanoes-at-Hotspots/enrichment/Hawaiian-Hot-Spots%3A-Undersea-Volcanic-Studies/

Earth's Tectonic Plates

The lithosphere is divided into a dozen major and several minor plates (Figure below). The plates' edges can be drawn by connecting the dots that mark earthquakes' epicenters. A single plate can be made of all oceanic lithosphere or all continental lithosphere, but nearly all plates are made of a combination of both.



The lithospheric plates and their names are shown in the figure above. The arrows show whether the plates are moving apart, moving together, or sliding past each other.



Movement of the plates over Earth's surface is termed plate tectonics. Plates move at a rate of a few centimeters a year, about the same rate fingernails grow.

Volcanoes

During a volcano, the heat energy is transferred through lava to the Earth's surface. The magma may come up to the surface as lava bringing heat energy with it. The volcanoes which erupt on the island of Hawaii are an example of this transfer of heat energy. Notice, the lava is very hot as it comes up to the surface. The lava immediately begins to cool. As the heat escapes, the lava hardens to dark black rock.

Magma which becomes trapped below the surface can build up pressure that must be released as mechanical energy. An example of this release of mechanical energy was the eruption of Mt. Saint Helens in Washington State. As the heat energy in the magma built up below the surface of the mountain, the pressure increased. This pressure was released in a gigantic explosion which blew off the top of the mountain.

Earthquakes

The transfer of earthquake energy happens in the form of waves. These waves can happen in a couple of different ways.

The energy from an earthquake arrives in three distinct waves. The fastest and therefore the first to arrive was named the Primary wave or p-wave. The second to arrive was named the secondary wave or s-wave. The slowest and last to arrive was named the surface wave.

P-wave: P-waves are a form of longitudinal waves. These waves vibrate in a direction parallel to the direction in which the energy is transferred. For example, in an east moving p-wave objects vibrate in an east-west direction.

S-wave: S-waves are a form of transverse waves. These waves vibrate in a direction perpendicular to the direction in which the energy is transferred. For example, in an east moving s-wave, objects vibrate in a north-south direction. This is more destructive than the vibrations in a p-wave.

Surface Wave: A surface wave is much slower than the p-wave or s-wave. A surface wave is a combination of a transverse and a longitudinal wave in which the particles vibrate both perpendicularly and parallel to the direction of energy transfer. An object struck by a surface wave would vibrate both north-south and east-west. The result is that the objects move in a circle. This is the most destructive of the three types of wave. A surface wave is similar to the ripples you see when an object is dropped into a body of water.

Summary

- Alfred Wegener did some background reading and made an observation. Wegener then asked an important question and set about to answer it. He collected a great deal of evidence to support his idea. Wegener's evidence included the fit of the continents, the distribution of ancient fossils, the placement of similar rocks and structures on the opposite sides of oceans, and indicators of ancient climate found in locations where those climates do not exist today.
- Data from magnetometers dragged behind ships looking for enemy submarines in WWII discovered magnetic patterns on the seafloor.
- Rocks of normal and reversed polarity are found in stripes symmetrically about the mid-ocean ridge axis.
- The age of seafloor rocks increases from the ridge crest to rocks the farthest from the ridges. Still, the rocks of the ocean basins are much younger than most of the rocks of the continents.
- Seafloor spreading brought together the mantle convection idea of Holmes, the continental drift idea of Wegener, based on new bathymetric and magnetic data from the seafloor, improved Wegener's theory of Continental Drift and led to the formation of the theory of Plate Tectonics, made a coherent single idea.
- Large chunks of lithosphere are called tectonic plates. These plates are separated by boundaries that can be marked by earthquake epicenters and volcanoes.

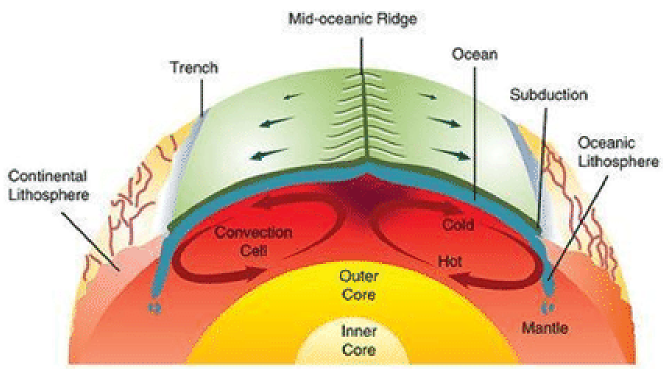
Think like a Geologist

1. How did Wegener use fossil evidence to support his Continental Drift theory?
2. How did Wegener use climate evidence from rocks to support his Continental Drift theory?
3. How does the pattern of magnetic stripes give evidence for seafloor spreading?
4. How does the topography of the sea floor give evidence for seafloor spreading?
5. How does sea-floor spreading fit into the Theory of Plate Tectonics?

1.3 Does the movement of Earth's plates affect all living things?

How Plates Move

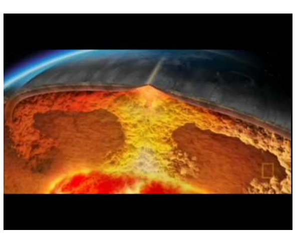
- If seafloor spreading drives the plates, what drives seafloor spreading? Picture two convection cells side-by-side in the mantle, similar to the illustration in Figure below.
- Hot mantle from the two adjacent cells rises at the ridge axis, creating new ocean crust.
- The top limb of the convection cell moves horizontally away from the ridge crest, as does the new seafloor.
- The outer limbs of the convection cells plunge down into the deeper mantle, dragging oceanic crust as well. This takes place at the deep sea trenches.
- The material sinks to the core and moves horizontally.
- The material heats up and reaches the zone where it rises again.



Mantle convection helps drive plate tectonics. Hot material rises at mid-ocean ridges and sinks at deep sea trenches, which keeps the plates moving along the Earth's surface.

Mantle convection is shown in these animations:

- http://www.youtube.com/watch?v=p0dWF_3PYh4



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URL: http://www.ck12.org/flx/render/embeddedobject/176318

- http://earthguide.ucsd.edu/eoc/teachers/t_tectonics/p_convection2.html

Plate Boundaries

Plate boundaries are the edges where two plates meet. Most geologic activities, including volcanoes, earthquakes, and mountain building, take place at plate boundaries. How can two plates move relative to each other?

- **Divergent Plate Boundaries:** the two plates move away from each other.
- **Convergent Plate Boundaries:** the two plates move towards each other.
- **Transform Plate Boundaries:** the two plates slip past each other.

The type of plate boundary and the type of crust found on each side of the boundary determines what sort of geologic activity will be found there.

Divergent Plate Boundaries

Plates move apart at mid-ocean ridges where new seafloor forms. Between the two plates is a rift valley. Lava flows at the surface cool rapidly to become basalt (a type of rock), but deeper in the crust, magma cools more slowly to form gabbro (another type of rock).

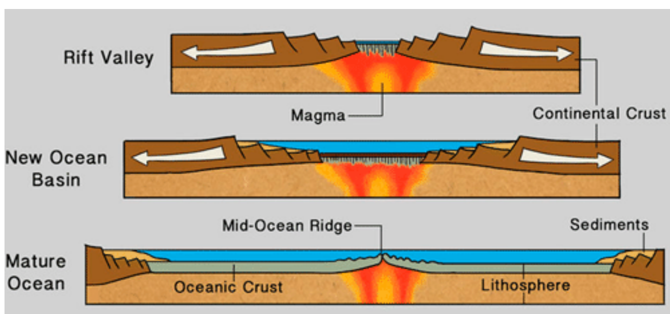
USGS animation of divergent plate boundary at mid-ocean ridge:

- http://earthquake.usgs.gov/learn/animations/animation.php?flash_title=Divergent+Boundary&flash_file=divergent&flash_width=500&flash_height=200

Divergent plate boundary animation:

- http://www.iris.edu/hq/files/programs/education_and_outreach/aotm/11/AOTM_09_01_Divergent_480.mov

See the images below for examples of divergent plate boundaries:



Can divergent plate boundaries occur within a continent? What is the result? In continental rifting, magma rises beneath the continent, causing it to become thinner, break, and ultimately split apart. New ocean crust erupts in the void, creating an ocean between continents.

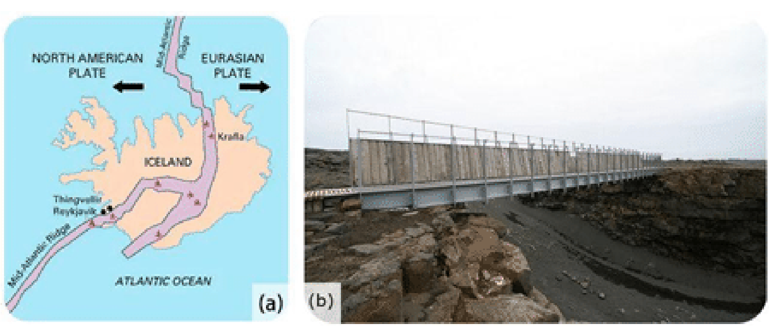


FIGURE 1.10
(a) Iceland is the one location where the ridge is located on land: the Mid-Atlantic Ridge separates the North American and Eurasian plates; (b) The rift valley in the Mid-Atlantic Ridge on Iceland.

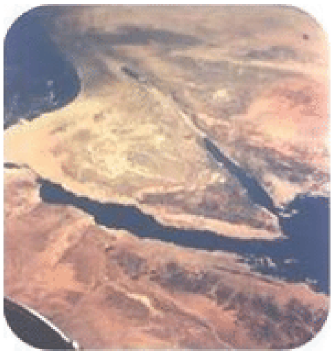


FIGURE 1.11

The Arabian, Indian, and African plates are rifting apart, forming the Great Rift Valley in Africa. The Dead Sea fills the rift with seawater.

Convergent Plate Boundaries

When two plates converge, the result depends on the type of lithosphere the plates are made of. No matter what, smashing two enormous slabs of lithosphere together results in magma generation and earthquakes.

Ocean-continent: When oceanic crust converges with continental crust, the denser oceanic plate plunges beneath the continental plate. This process, called subduction, occurs at the oceanic trenches (Figure 1.12). The entire region is known as a subduction zone. Subduction zones have a lot of intense earthquakes and volcanic eruptions. The subducting plate causes melting in the mantle. The magma rises and erupts, creating volcanoes. These coastal volcanic mountains are found in a line above the subducting plate (Figure 1.12). The volcanoes are known as a continental arc.

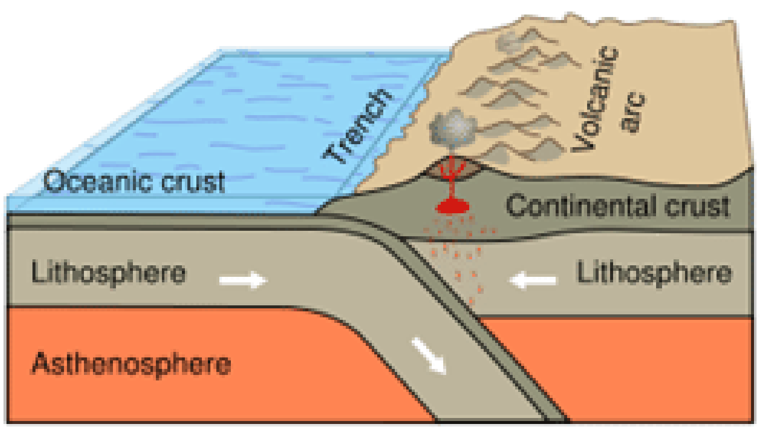


FIGURE 1.12

Subduction of an oceanic plate beneath a continental plate causes earthquakes and forms a line of volcanoes known as a continental arc.

This animation shows the relationship between subduction of the lithosphere and creation of a volcanic arc:

- http://earthguide.ucsd.edu/eoc/teachers/t_tectonics/p_subduction.html

Ocean-ocean: When two oceanic plates converge, the older, denser plate will subduct into the mantle. An ocean trench marks the location where the plate is pushed down into the mantle. The line of volcanoes that grows on the upper oceanic plate is an island arc. Earthquakes are common in these regions.

Continent-continent: Continental plates are less dense than oceanic plates and do not easily undergo subduction. The rock builds up on top of the plates as they collide. This results in the creation of some of the world's largest mountains ranges. (Figure 1.15). Magma cannot penetrate this thick crust so there are no volcanoes, although

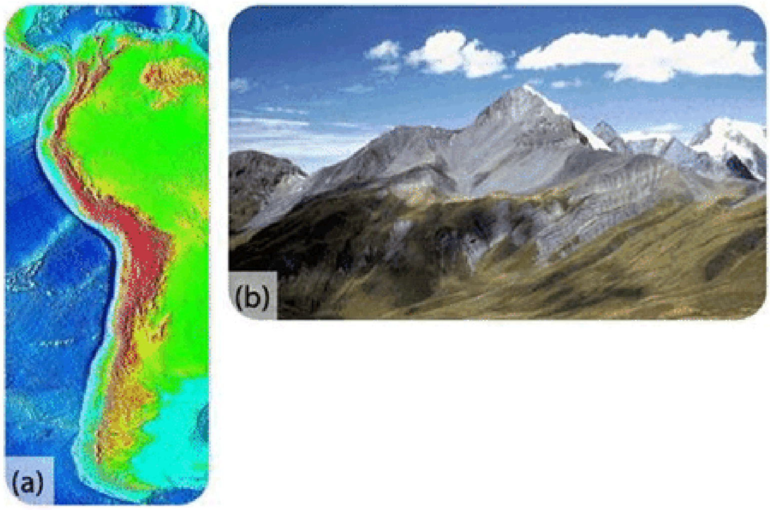


FIGURE 1.13
(a) At the trench lining the western margin of South America, the Nazca plate is subducting beneath the South American plate, resulting in the Andes Mountains (brown and red uplands); (b) Convergence has pushed up limestone in the Andes Mountains where volcanoes are common.

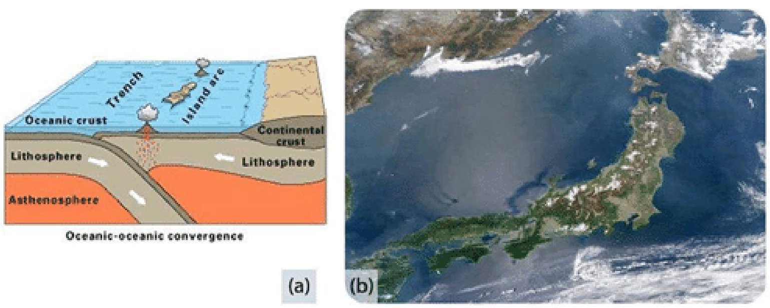


FIGURE 1.14
(a) Subduction of an ocean plate beneath an ocean plate results in a volcanic island arc, an ocean trench and many earthquakes. (b) Japan is an arc-shaped island arc composed of volcanoes off the Asian mainland, as seen in this satellite image.

the magma stays in the crust. Metamorphic rocks are common because of the stress the continental crust experiences. With enormous slabs of crust smashing together, continent-continent collisions bring on numerous and large earthquakes.

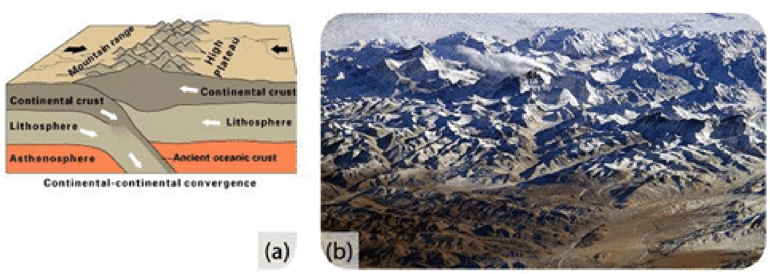
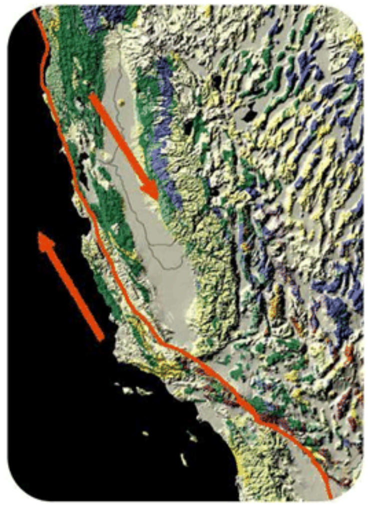


FIGURE 1.15
(a) In continent-continent convergence, the plates push upward to create a high mountain range. (b) The world's highest mountains, the Himalayas, are the result of the collision of the Indian Plate with the Eurasian Plate, seen in this photo from the International Space Station.

Transform Plate Boundaries

Transform plate boundaries are seen as transform faults, where two plates move past each other in opposite directions. Transform faults on continents bring massive earthquakes (Figure below).



At the San Andreas Fault in California, the Pacific Plate is sliding northeast relative to the North American plate, which is moving southwest.

A brief review of the three types of plate boundaries and the structures that are found there is the subject of this video:

- https://www.youtube.com/watch?v=_hKosm0h3kI

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Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/178284

Use this simulator to improve your understanding of how plate boundaries affect Earth's Geography:

- http://sepuplhs.org/middle/iaes/students/simulations/sepup_plate_motion.html

Think like a Geologist

1. Describe a lithospheric plate.
2. Draw and identify the major tectonic plates of Earth.
3. How does a volcano transfer energy from Earth's interior to the surface?
4. What is a convergent boundary and what are the results of its movement?
5. What is a divergent boundary and what are the results of its movement?
6. What is a transform boundary and what are the results of its movement?
7. Explain how gravity, density and convection cause tectonic plates to move.

1.4 References

1. http://oceanexplorer.noaa.gov/edu/learning/2_midocean_ridges/activities/seafloor_spreading.html#none. .