Al-Karkh University for Sciences
College of Remote Sensing and Geophysics
Geophysics Department

Lecture TWO

Plate Tectonics

What are Plate Tectonics?

It is a modern theory (found by Alfred Wegener in 1911) used to explain how Earth's physical features (geology and geography) have formed. This theory explains the formation, movement, and subduction of Earth's tectonic plates.

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. Imagine that you're Wegener's colleague. What sort of evidence would you look for to see if the continents had actually been joined and had moved apart?

Remember the Layers of the Earth in Lecture One

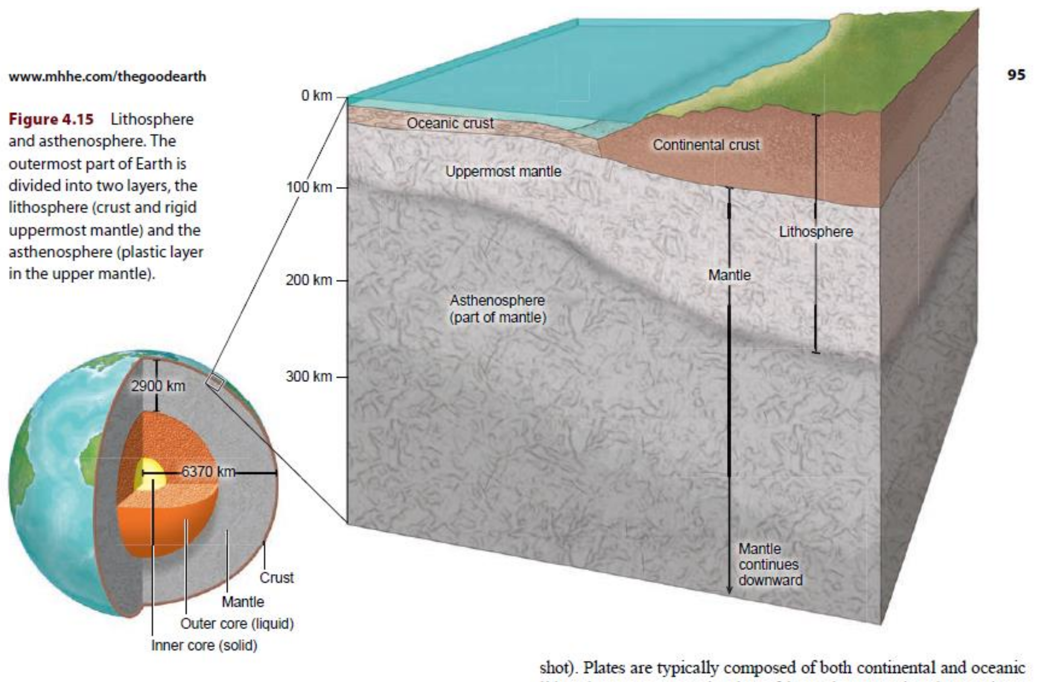


Figure 4.15 Lithosphere and asthenosphere. The outermost part of Earth is divided into two layers, the lithosphere (crust and rigid uppermost mantle) and the asthenosphere (plastic layer in the upper mantle).

Wegener’s Evidences

Here is the main evidence that Wegener and his supporters collected for the continental drift hypothesis:

1. Continental shelf fit: Continents appear to fit together in their edges.

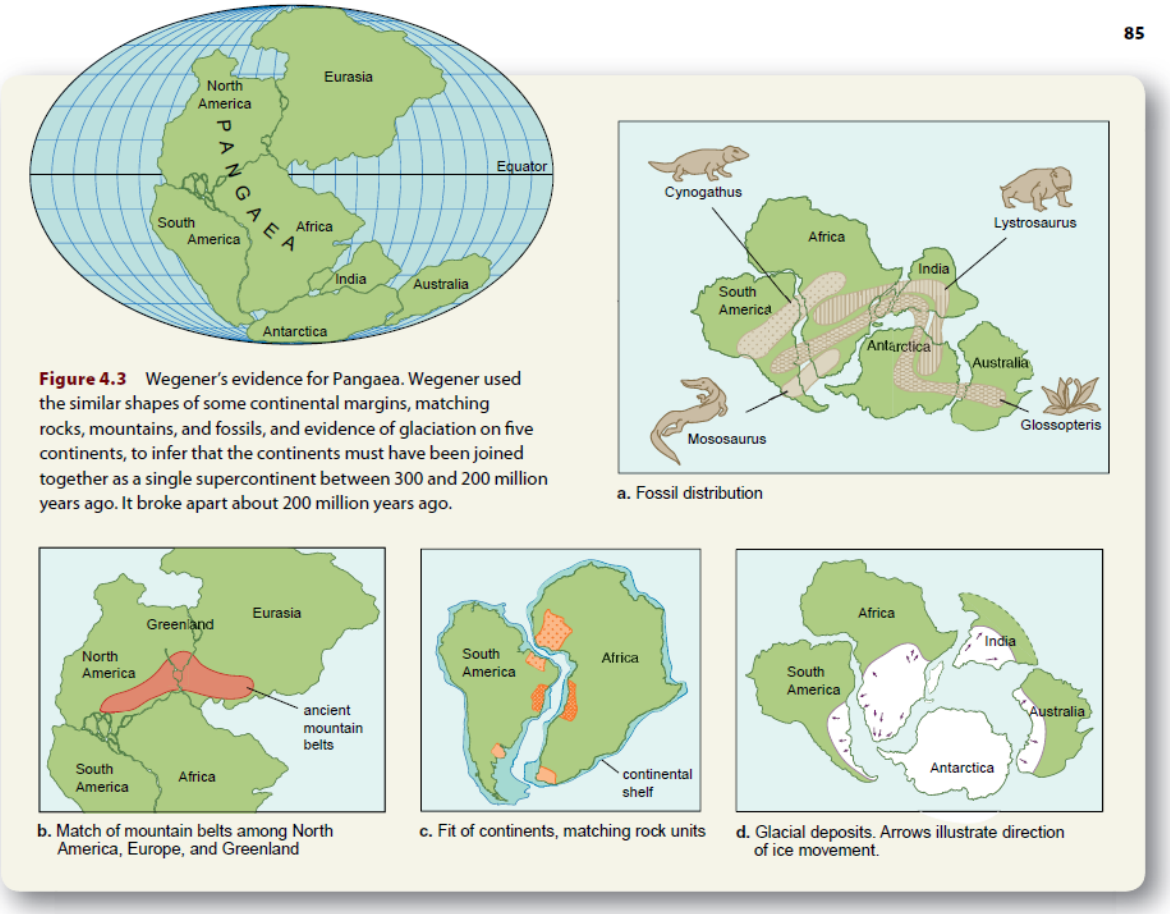
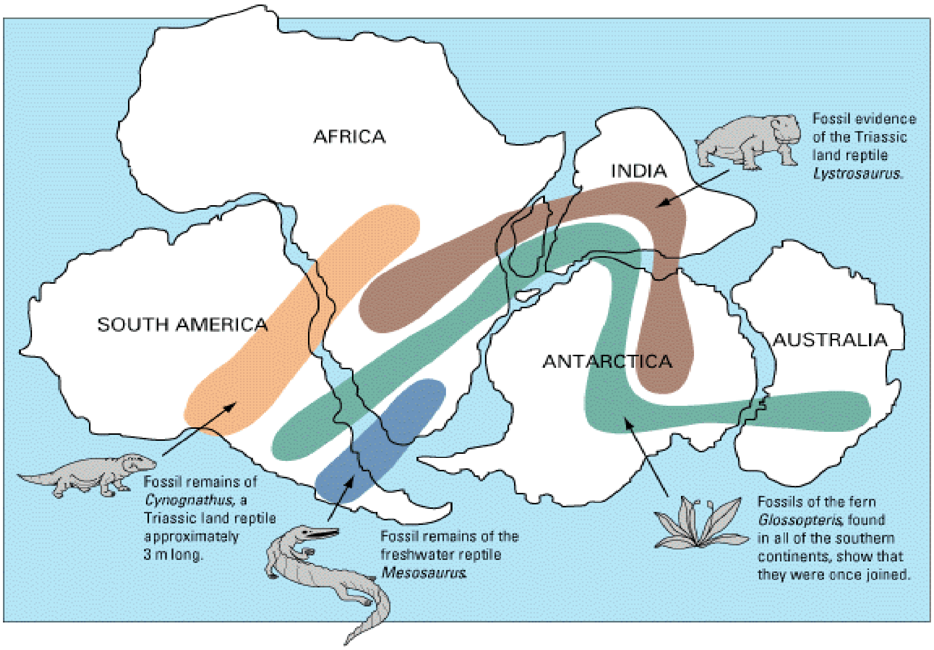


Figure 4.3 Wegener’s evidence for Pangaea. Wegener used the similar shapes of some continental margins, matching rocks, mountains, and fossils, and evidence of glaciation on five continents, to infer that the continents must have been joined together as a single supercontinent between 300 and 200 million years ago. It broke apart about 200 million years ago.

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 (See Figure below). 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 2.2a Image 3). Wegener concluded that they formed as a single mountain range that was separated as the continents drifted.
5. Paleoclimate: 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.
   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.

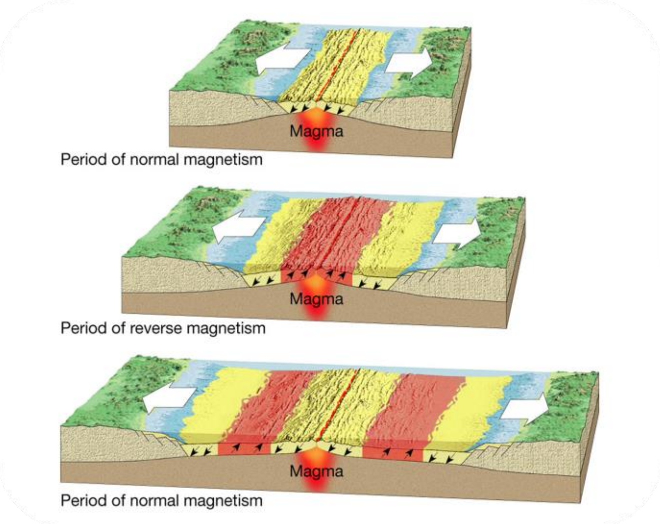
6. Seafloor Spreading Hypothesis

Because the observations just described contradicted predictions of the contracting Earth model, a new explanation for the origin of the ocean floor was needed. Scientists combined evidence of heat flow, volcanism, earthquakes, and changes in the topography and age of the seafloor (Figure 4.10a) to develop a new hypothesis. According to this new **seafloor spreading hypothesis, new oceanic floor is being *continuously* formed along the ridge system by magma rising from below, and as this occurs, the existing rocks move away from the ridge** (Figure 4.10b in Good Earth). The seafloor spreading hypothesis led scientists to conclude that the migration of hot magma from below the ridge heats the overlying seafloor, causing it to expand to produce the higher topography of the oceanic ridge. The ocean floor was interpreted to act as a conveyor belt, gradually moving away from the ridge and creating a gap that was continuously filled with new magma from below.

Because new material is constantly being generated at ridges, old material must be destroyed somewhere else, or Earth would expand. Since Earth is not expanding, there had to be places on Earth's surface where older ocean floor was destroyed. The fact that the deepest earthquakes and older ocean floor are adjacent to trenches led scientists to hypothesize that the **ocean floor is consumed as it *descends* into Earth's interior adjacent to ocean trenches.**

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

7. Paleomagnetism-Magnetic patterns in rocks indicate continental shift.



Magnetic patterns and Sea floor Spreading in the rock records.

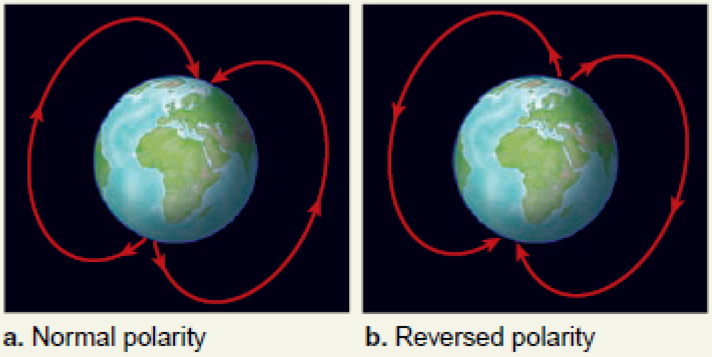


Figure 4.12 Polarity of Earth's magnetic field. (a) The inclination of the magnetic field varies with latitude. The field is horizontal at the magnetic equator, steeper at high latitudes, and vertical at the magnetic poles. The magnetic field is inclined downward in the Northern Hemisphere and upward (away from Earth's surface) in the Southern Hemisphere. (b) The magnetic field has reverse polarity, meaning that the positive and negative polarities have switched positions.

https://media.wr.usgs.gov/science/2004/jul04.mp4

https://www.nature.nps.gov/GEOLOGY/usgsnps/animate/A49.gif

8. 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. This is the type of wave demonstrated in the first two videos above.

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. This is the type of wave demonstrated in the third video above.

Surface Wave: Also known as a Love wave, the 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. Observe a QuickTime video of this type of wave. Notice the motion of the ball floating in the water. If you watch closely, you can see the circular motion. http://utahscience.oremjr.alpine.k12.ut.us/sciber08/8th/geology/html/wavenrgy.htm)

9. 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 maglavama 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.

(For more information and details see the references).

- ***How Paleomagnetism Supports the Seafloor Spreading Hypothesis?***

Plate Boundary Interactions

Plate Boundary: is a Border between two tectonic plates, which is usually an area of earthquake and volcano activity.

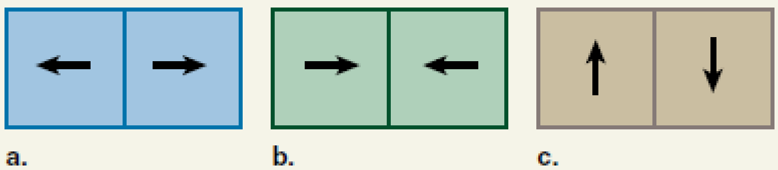


Figure 4.21 Three types of plate boundaries. (a) At a divergent boundary, plates move apart. (b) At a convergent boundary, plates move toward each other. (c) At a transform boundary, plates move parallel to one another in opposite directions.

Oceanic ridges and trenches, volcanoes, and earthquakes are just some of the phenomena present at the boundaries that separate the tectonic plates. The type and distribution of features are characteristic of the relative motions of the plates on either side of the boundary. We classify plate boundaries into three categories based on their relative plate motions:

• **<u>Divergent plate boundaries</u> occur where plate motions cause plates to move apart** (Figures 4.19, 4.21a). For example, South America and Africa are on either side of the Mid-Atlantic Ridge, a divergent plate boundary (see Chapter Snapshot).

The evolution of a divergent plate boundary has three recognizable stages that we can loosely characterize as birth, youth, and maturity. The birth of a divergent boundary occurs when an existing piece of continental lithosphere begins to break apart. Such a location is characterized by thinning of the lithosphere, often accompanied by volcanic activity (Figure 4.22). This process is happening today on the continent of Africa, in an area known as the East African Rift zone (Figure 4.23, Chapter Snapshot). As the continental lithosphere breaks apart, it **forms a wide, steep walled depression known as a rift valley (Figure 4.22a).** The underlying asthenosphere is close to the surface below the rift valley, and decompression melting generates magma that forms volcanoes. Eventually, the continental crust in the rift valley separates to form a gap where rising magma creates new oceanic floor. Inflow of seawater forms a narrow ocean (the youth stage), much like the Red Sea to the north of the East African Rift zone that separates the Arabian peninsula from Africa (Figures 4.23; 4.28). It takes millions of years for narrow oceans to expand to form a mature ocean like the present-day Atlantic or Pacifi c Ocean because the rates of plate motions are so slow (Figure 4.22c).

• **<u>Convergent plate boundaries</u> occur where plate motions cause plates to collide with each other** (Figures 4.19, 4.21b). This most commonly occurs where plates move toward each other—for example, along the Peru- Chile trench where the Nazca plate meets the western edge of the South American plate (see Chapter Snapshot).

Oceanic lithosphere is consumed at subduction zones where it descends into the mantle beneath trenches. The less dense crust of the continental lithosphere does not descend into subduction zones but is piled up to form high mountain belts at convergent boundaries. Convergent boundaries come in three varieties, depending on the types of lithosphere involved in the collision (Figure 4.25).

* ***Oceanic Plate versus Oceanic Plate Convergence.***
* ***Oceanic Plate versus Continental Plate Convergence.***
* ***Continental Plate versus Continental Plate Convergence.***

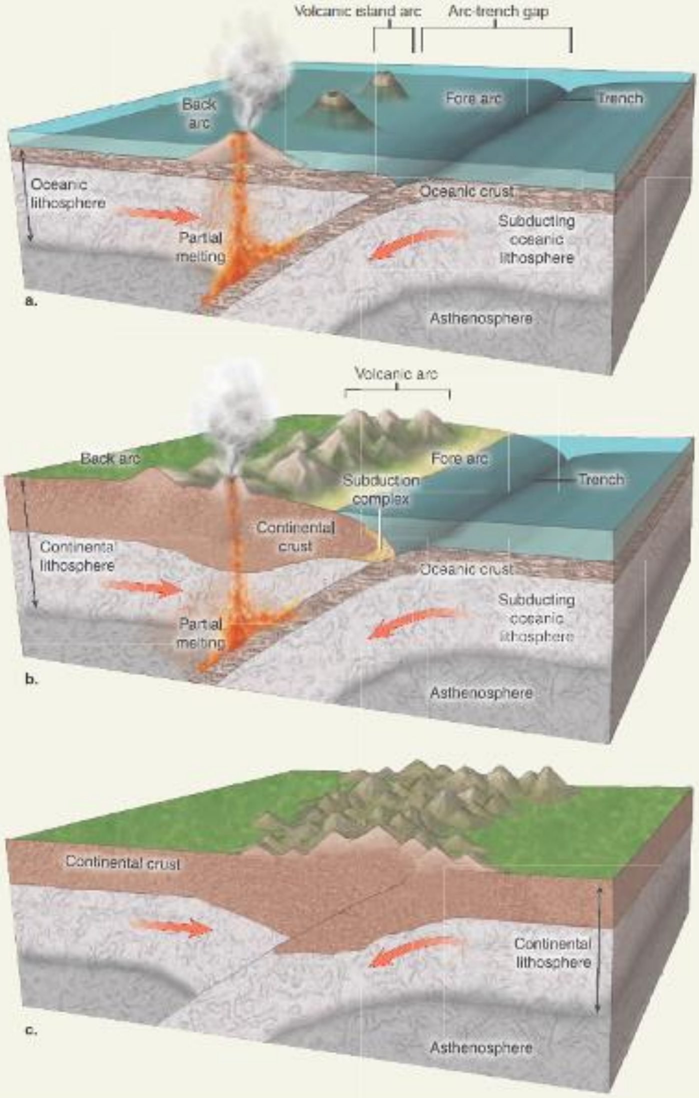


Figure 4.25 Cross sections of convergent plate boundaries. (a) When two oceanic plates collide, the plate with the older (cooler, denser) lithosphere descends into the subduction zone. A chain of volcanic islands (island arc) forms on the overriding plate. (b) In an oceanic-continental collision, the oceanic plate descends, and a chain of volcanoes forms on the continental plate. (c) A continental-continental collision is marked by a high mountain range but little volcanic activity. Crustal thickness is increased, but scientists still debate the fate of the mantle lithosphere in this type of collision.

• **<u>Transform plate boundaries</u> occur where plates slide past each other** (Figures 4.19, 4.21c) without opening a gap or undergoing a direct collision, like two cars driving in opposite directions on different sides of the same street. For example, a thin strip of southwest California is separated from the rest of North America by a transform boundary along the San Andreas Fault system (see Chapter Snapshot).

<u>The Mechanism for Continental Drift</u>

Seafloor spreading is the mechanism for Wegener's drifting continents. Convection currents within the mantle take the continents on a conveyor-belt ride of oceanic crust that, over millions of years, takes them around the planet's surface. The spreading plate takes along any continent that rides on it. Seafloor spreading is the topic of this Discovery Education video:

- http://video.yahoo.com/watch/1595570/5390151.

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 (8:05).

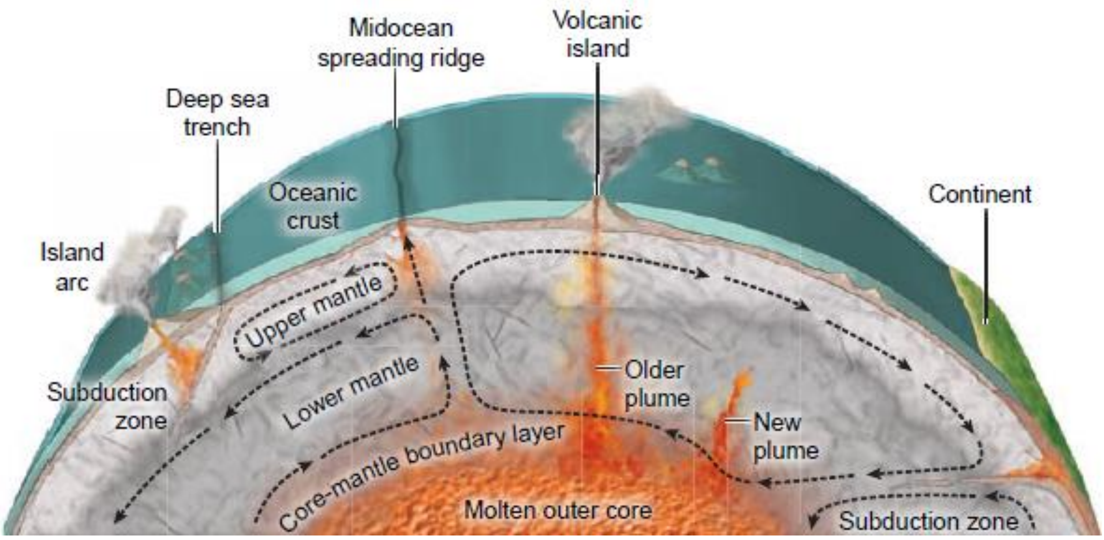
The Theory of Plate Tectonics—what is a Plate?

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 earthquake epicenters outline the plates. This is because earthquakes occur everywhere plates come into contact with each other. In addition to this, a vast number of volcanoes from around the world are also located where plates meet. 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. The Plate Tectonics theory provides the answers to the two questions that Alfred Wegener could not explain. 1) What causes plates to move, and 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, each topped by its own kind of crust. 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, subduction 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. Tectonic plates are able to move because the Earth's lithosphere has a higher strength and lower density than the underlying asthenosphere. Plate movement is thought to be driven by a combination of the motion of the seafloor away from the mid-ocean ridges (due to variations in topography and density of the crust, which result in differences in gravitational forces) and drag, downward suction, at the subduction zones.

[Synopsis: Hot magma in the earth moves toward the surface, cools, and then sinks again and creates convection currents beneath the plates that cause the plates to move] as shown in video below.

https://www.youtube.com/watch?v=ryrXAGY1dmE



The concept of the convection currents and its implication in plate movement.