## Chapter 10

## THEORY OF PLATE TECTONICS

### **Continental Drift Hypothesis**

Alfred Wegener (1880-1930) was a German scientist who specialized in meteorology and climatology. He had a knack for questioning accepted ideas, and this started in 1910 when he disagreed with isostasy (vertical land movement due to the weight being removed or added) as the explanation for the Bering Land Bridge. After literary reviews, he published a hypothesis stating the continents had moved in the past. While he did not have the precise mechanism worked out, he had an extensive list of evidence that backed up his hypothesis of **continental drift**.

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Video 1. The whole saga of supercontinents

<https://www.youtube.com/watch?v=KfYn9KVya-Q>

##### Early Evidence for Continental Drift

The first piece of evidence is that the shape of the coastlines of some continents fit together like pieces of a jigsaw puzzle. Since the first world map, people have noticed the similarities in the coastlines of South America and Africa, and the continents being ripped apart had even been mentioned as an explanation. Antonio Snider- Pellegrini even did preliminary work on continental separation and matching fossils in 1858.

What Wegener did differently than others was synthesized a significant amount of data in one place, as well as use the shape of

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the continental shelf, the actual edge of the continent, instead of the current coastline, which fit even better than previous efforts. Wegener also compiled and added to evidence of similar rocks, fossils, and glacial formations across the oceans.



Video 2. What did Pangea look like?

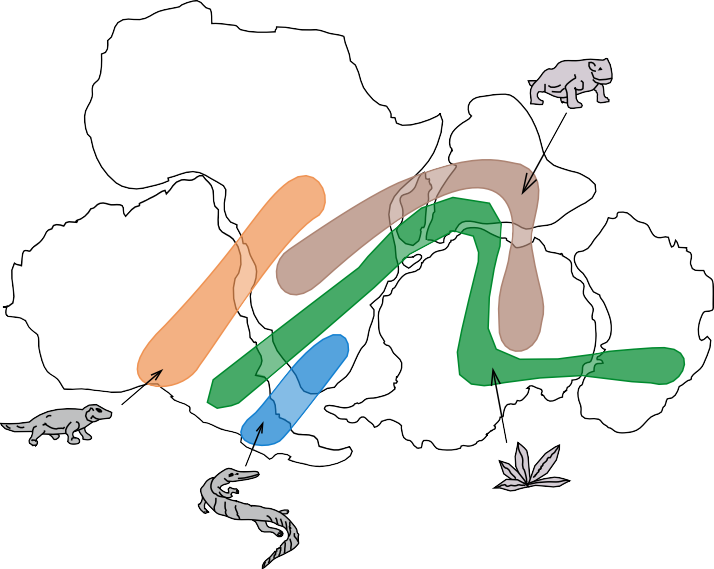
<https://www.youtube.com/watch?v=VKq0pr4rbRs>

##### Fossil Evidence

For example, the primitive aquatic reptile Mesosaurus was found on the separate coastlines of the continents of Africa and South America, and the reptile Lystrosaurus was found on Africa, India, and Antarctica. These were land-dwelling creatures that could not have swam across an entire ocean; thus, this was explained away by

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opponents of continental drift by land bridges. The land bridges had eroded, allowed animals and plants to move between the continents. However, some of the presumed land bridges would have had to have stretched across broad, deep oceans.



AFRICA

INDIA

Fossil evidence of the Triassic land reptile Lystrosaurus.

SOUTH AMERICA

AUSTRALIA

ANTARCTICA

Fossil remains of Cynognathus, a Triassic land reptile approximately

3m long.

Fossil remains of the freshwater reptile Mesosaurus.

Fossils of the fern Glossopteris, found in all of the southem continents, show that they were once joined.

Figure 10.1 “Snider-Pellegrini Wegener Fossil Map” is licensed under Public Domain.

##### Geologic Evidence

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. Wegener concluded that they formed a single mountain range that was separated as the continents drifted. (Dastrup, 2014)

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##### Climatic Evidence

Another significant piece of evidence was climate anomalies. Late Paleozoic glacial evidence was found in widespread, warm areas like southern Africa, India, Australia, and the Arabian subcontinent.

Wegener himself had found evidence of tropical plant fossils in areas north of the Arctic Circle. According to Wegener, the more straightforward explanation that fits all the climate, rock, and fossil observations, mainly as more data were collected, involved moving continents.

Grooves and rock deposits left by ancient glaciers are found today on different continents close to the equator. This would indicate that the glaciers either formed in the middle of the ocean 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 landmass close to the South Pole, and the continents later moved to their present positions.

##### Proposed Mechanism for Continental Drift

Wegener’s work was considered a fringe theory for his entire life. One of the most significant flaws and easiest dismissals of Wegener’s hypothesis was a mechanism for the movement of the continents.

The continents did not appear to move, and extraordinary evidence would need to be provided to change the establishment’s minds, including a mechanism for movement. Other pro-continental drift followers had used expansion, contraction, or even the origin of the

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Moon as ideas to how the continents moved. Wegener used centrifugal forces and precession to explain the movement, but that was proven wrong. He had some speculation about **seafloor spreading**, with hints of convection within the earth, but these were unsubstantiated. As it turns out, convection within the mantle has been revealed as a significant force in driving plate movements, according to current knowledge.



Video 3. Continental drift 101

<https://www.youtube.com/watch?v=Wq9kLzm36h0>

### **Theory of Plate Tectonics**

Wegener died in 1930 on an expedition in Greenland. He was poorly respected in his lifetime, and his ideas of moving continents

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seemed destined to be lost to history as a fringe idea. However, starting in the 1950s, evidence started to trickle in that made continental drift more viable. By the 1960s, there was enough evidence supporting Wegener’s missing mechanism, seafloor spreading, allowing continental drift’s hypothesis to develop into the **Theory of Plate Tectonics**. Widespread acceptance among scientists has transformed Wegener’s hypothesis to a Theory. Today, GPS and earthquake data continue to back up the theory. Below are the pieces of evidence that allowed the transformation.

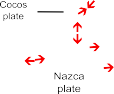
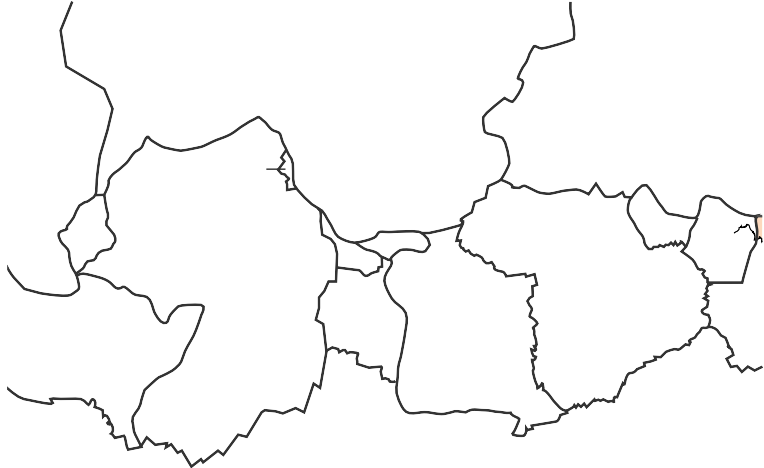
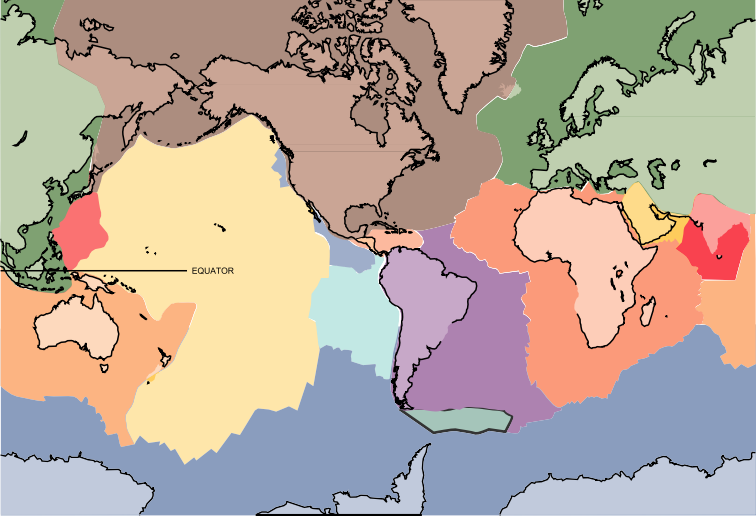


Figure 10.2 “Tectonic Plates” by the United States Geologic Survey (USGS) is licensed under Public Domain.

##### Mapping the Ocean Floors

Starting in 1947 and using an adaptation of sonar, researchers began to map a poorly understood topographic and thermal high in the mid-Atlantic. Bruce Heezen and Marie Tharp were the first to

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make a detailed map of the ocean floor, and this map revealed the

**mid-Atlantic Ridge**, a basaltic feature, unlike the continents. Initially, this was thought to be part of an expanding Earth or a mechanism for the ocean’s growth. Transform faults were also added to explain movements more completely. When it was later realized that earthquake epicenters were also found within this feature, the idea that this was part of the continental movement took hold.



Video 4. Marie Tharp’s maps

<https://www.youtube.com/watch?v=vE2FK0B7gPo>

Another way the seafloor was mapped was **magnetical**. Scientists had long known of strange magnetic anomalies (magnetic values that differ from expected values) associated with the ocean floor. This tool was adapted by geologists later for further study of the

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ocean depths, including strange alternating symmetrical stripes on both sides of a feature (which would be discovered later as the mid- ocean ridge) showing reversing magnetic pole directions. By 1963, these magnetic stripes would be explained in concordance with Hess’s spreading model and others.

**Seafloor sediment** was also an important feature that was measured in the oceans, both with dredging and with drilling. Sediment was believed to have been piling up on ocean floors for an exceptionally long time in a static model of accumulation. Initial studies showed less sediment than expected, and initial results were even used to argue against the continental movement. With more time, researchers discovered thinner sediment close to ridges, indicating a younger age.



Video 5. How Satellites Mapped The Whole Ocean Floor

<https://www.youtube.com/watch?v=HZVFsvjGx70&t=53s>

##### Wadati-Benioff Zones

Around the same time that mid-ocean ridges were being investigated, ocean trenches and island arcs were also being linked to seismic action, explaining the opposite sides of the plates. A zone of deep earthquakes that lay along a plane, trending from the surface near the trenches to inside the Earth beneath the continents and island arcs, were recognized independently by several scientists. Today called the **Wadati-Benioff zone**; it was an essential piece of the puzzle.

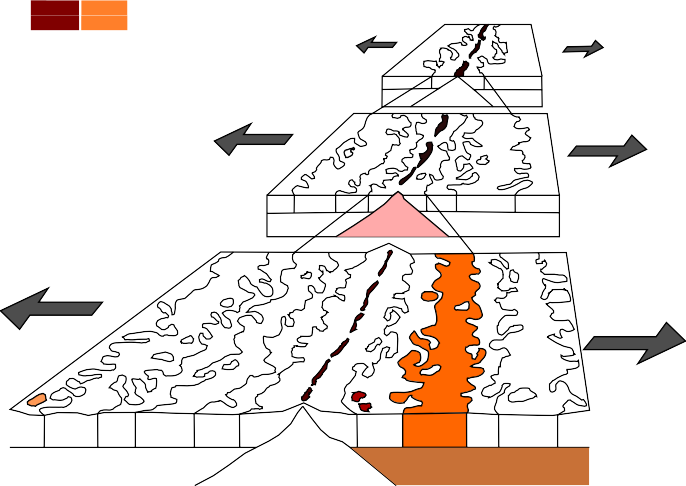
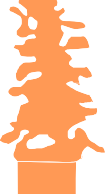
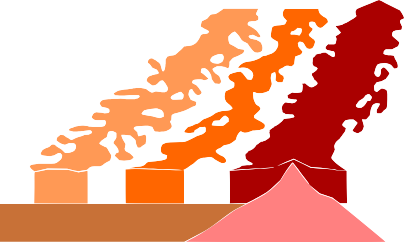
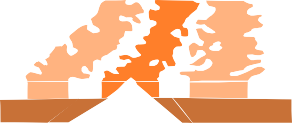
##### Paleomagnetism

Magnetic field mapping, as mentioned above, was not the only way magnetism was used in the development of plate tectonics. The first new hard evidence that supported plate motion came from paleomagnetism. **Paleomagnetism** is the study of magnetic fields frozen within rocks, basically a fossil compass. This is typically most useful with igneous rocks where magnetic minerals like magnetite crystallizing in the magma align with the Earth’s magnetic field and in the solid rock point to the paleo-magnetic north. The earth’s magnetic field creates flux lines surrounding the magnetic north and south poles (like a bar magnet), which are both close to the

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Earth’s rotational north and south poles. In igneous rocks, magnetic minerals align parallel with these flux lines. Thus, both magnetic inclination, related to latitude, and declination related to magnetic north are preserved in the rocks.

Scientists had noticed that, for some time, the magnetic north, to which many rocks pointed, was nowhere close to the current magnetic north. This was explained by implying the magnetic north pole moved over time. Eventually, scientists started to realize that moving continents explained the data better than moving the pole around alone.



Normal magnetic polarity

a

Reversed magnetic polarity

b

c

Lithosphere Magma

Figure 10.3 “Oceanic Stripe Magnetic Anomalies Scheme” by the United States Geologic Survey (USGS) is licensed under Public Domain.

##### Seafloor Spreading

World War II gave scientists the tools to find the mechanism for

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continental drift that had eluded Wegener. Maps and other data gathered during the war allowed scientists to develop the **seafloor spreading hypothesis**. This hypothesis traces oceanic crust from its origin at a mid-ocean ridge to its destruction at a deep-sea trench and is the mechanism for continental drift. (Seafloor Spreading | Earth Science, n.d.)

During World War II, battleships and submarines carried echo sounders to locate enemy submarines. 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 sound speed 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. This animation shows how sound waves are used to create pictures of the seafloor and ocean crust.

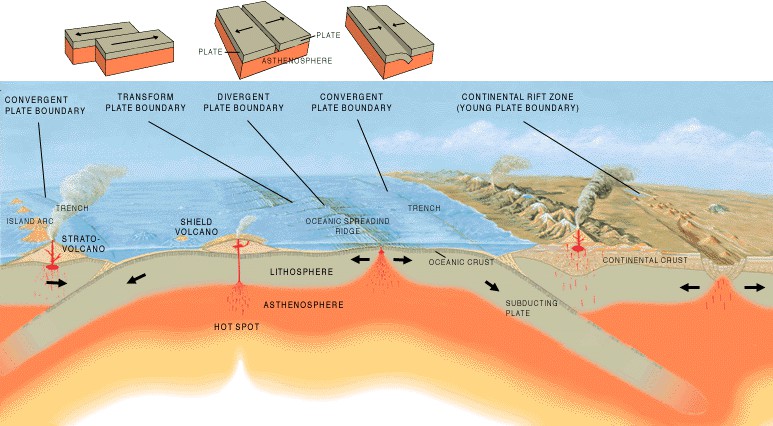


Figure 10.4 “Tectonic Plate Boundaries” by the United States Geologic Survey (USGS) is licensed under Public Domain.

After the war, scientists pieced together the ocean depths to

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produce bathymetric maps, which revealed the ocean floor features as if the water were taken away. Even scientists were amazed that the seafloor was not completely flat. What was discovered was a large chain of mountains along the deep seafloor, called mid-ocean ridges. Scientists also discovered deep-sea trenches along the edges of continents or in the sea near active volcanic chains. Finally, large, flat areas called abyssal plains we found. When they first observed these bathymetric maps, scientists wondered what had formed these features.

Scientists brought these observations together in the early 1960s to create the **seafloor spreading hypothesis**. In this hypothesis, a hot, buoyant mantle creates a mid-ocean ridge, causing the ridge to rise upward. The hot magma at the ridge erupts as lava that forms new seafloor. When the lava cools, the magnetite crystals take on the current magnetic polarity, and as more lava erupts, it pushes the seafloor horizontally away from the ridge axis. (Seafloor Spreading | Earth Science, n.d.)

The magnetic stripes continue across the seafloor. As oceanic crust forms and spreads, moving away from the ridge crest, it pushes the continent away from the ridge axis. If the oceanic crust reaches a deep-sea trench, it sinks into the trench and is lost into the mantle. Scientists now know that the oldest crust is coldest and lies deepest in the ocean because it is less buoyant than the hot new crust.

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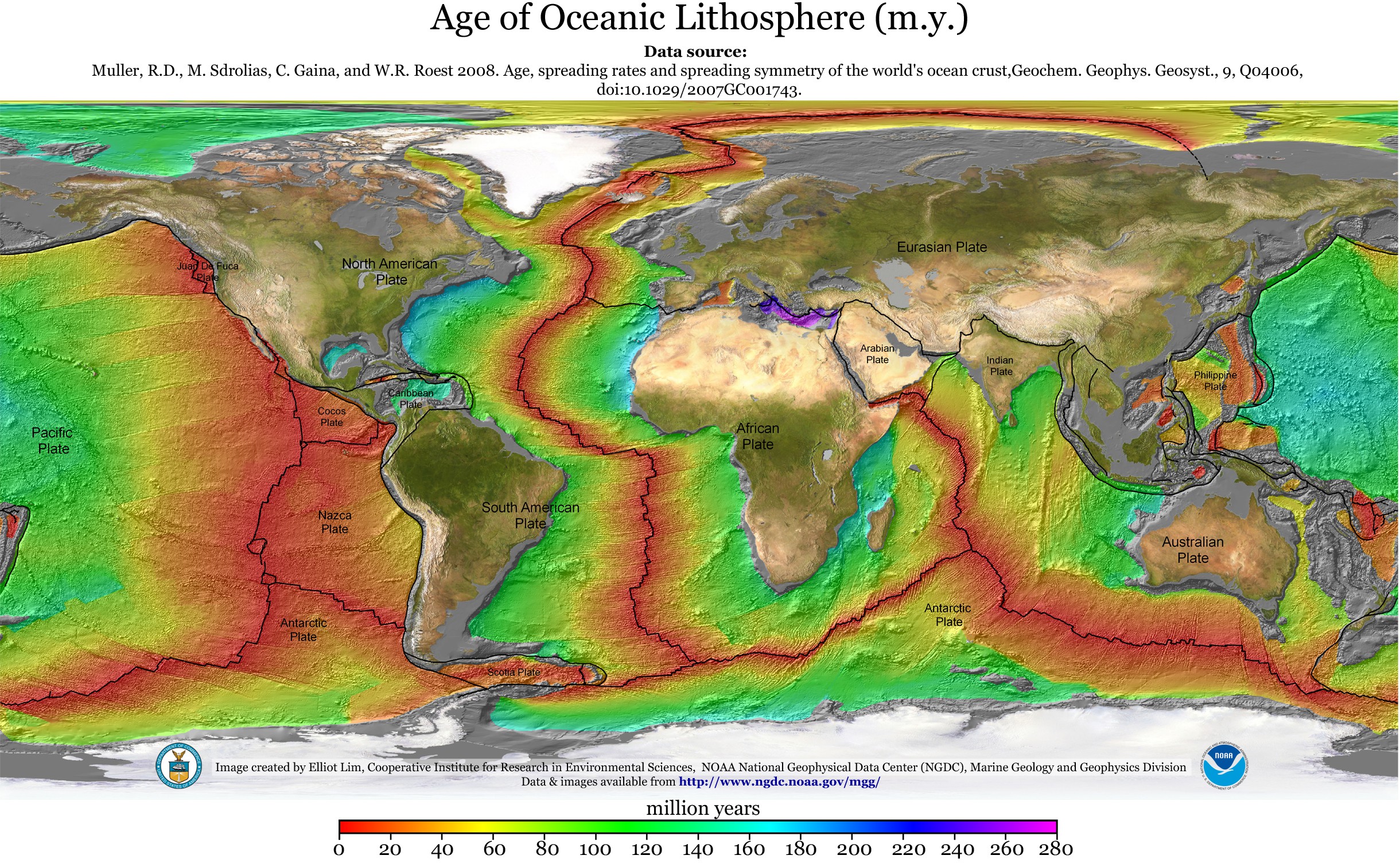


Figure 10.5 “Age of Oceanic Lithosphere” by the National Oceanic and Atmospheric Administration (NOAA) is licensed under Public Domain.

##### Unifying Theory of Plate Tectonics

Using all the evidence mentioned, the theory of plate tectonics took shape. In 1966, J. Tuzo Wilson was the first scientist to put the entire picture together of an opening and closing ocean. Before long, models were proposed showing the plates moving concerning each other with clear boundaries between them, and scientists had also started to piece together complicated tectonic histories. The plate tectonic revolution had taken hold.

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Video 6. Why it took scientists so long to accept this very obvious idea

<https://www.youtube.com/watch?v=KB7HzF2O3Kg&t=58s>

Seafloor and continents move around on Earth’s surface, but what is moving? What part of the Earth makes up the “plates” in plate tectonics? This question was also answered because of technology developed during the Cold War. The **tectonic plates** are made up of the lithosphere. 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 the earthquakes around the planet. The seismic records could be used to locate an earthquake’s epicenter, the point on Earth’s surface directly above the earthquake’s place. Earthquake epicenters outline these tectonic plates. Mid-ocean ridges, trenches, and significant faults mark the edges of these plates along with where earthquakes

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occur. (Reading: Theory of Plate Tectonics | Geology (Modification for Lehman College, CUNY), n.d.)

The lithosphere is divided into a dozen major and several minor tectonic plates. The plates’ edges can be drawn by connecting the dots that mark earthquakes’ epicenters. A single tectonic plate can be made of all oceanic lithosphere or all continental lithosphere, but nearly all plates are made of a combination of both. 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. (Theory of Plate Tectonics | Earth Science, n.d.)

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