Plate Tetonics Essay, Research Paper

Plate Tectonics

Plate tectonics are a relatively new theory that has revolutionized the way geologists think about the Earth. According to the theory, the surface of the Earth is broken into large plates. The size and position of these plates change over time. The edges of these plates, where they move against each other, are sites of intense geologic activity, such as earthquakes, volcanoes, and mountain building. Plate tectonics is a combination of two earlier ideas, continental drift and sea-floor spreading.

Continental drift is the movement of continents over the Earth’s surface and in their change in position relative to each other. Sea-floor spreading is the creation of new oceanic crust at mid-ocean ridges and movement of the crust away from the mid-ocean ridges.

The Earth is divided into three chemical layers: the core, the mantle and the crust. The core is composed of mostly iron and nickel and remains very hot, even after 4.5 billion years of cooling. The core is divided into two layers: a solid inner core and a liquid outer core. The middle layer of the Earth, the mantle, is made of minerals rich in the elements iron, magnesium, silicon, and oxygen. The crust is rich in the elements oxygen and silicon with lesser amounts of aluminum, iron, magnesium, calcium, potassium, and sodium. There are two types of crust. Basalt is the most common rock on Earth. Oceanic crust is made of relatively dense rock called basalt.

The outermost layers of the Earth can be divided by their physical properties into lithosphere and asthenosphere. It is made of lower density rocks, such as andesite and granite. The lithosphere is the rigid outermost layer made of crust and uppermost mantle. The lithosphere is the “plate” of the plate tectonic theory. The asthenosphere is part of the mantle that flows, a characteristic called plastic behavior. It might seem strange that a solid material can flow. The flow of the asthenosphere is part of mantle convection, which plays an important role in moving lithosphere plates.

Alfred Wegener, a German meteorologist, originally proposed continental drift in 1912. This geologist Wegener used the fit of the continents, the distribution of fossils, a similar sequence of rocks at numerous locations, ancient climates, and the apparent wandering of the Earth’s polar regions to support his idea. Wegener used his observations to hypothesize that all of the present-day continents were once part of a single super continent called Pangaea. Fossils of the same species were found on several different continents. Wegener proposed that the species dispersed when the continents were connected and later carried to their present positions as the continents drifted. For example, the specie Glossopteris, a fern, was found on the continents of South America, Africa, India, and Australia. The distribution of other species can also be accounted for by initially spreading across Pangaea, followed by the breakup of the super continent, and movement of the continents to their present positions.

Rock sequences in South America, Africa, India, Antarctica, and Australia show remarkable similarities. Wegener showed that the same three layers occur at each of these localities. The bottom (oldest) layer is called tillite and is thought to be a glacial deposit. The middle layer is composed of sandstone, shale, and coal beds. Glossopteris fossils are in the bottom and middle layers. The top (youngest) layer is lava flows. The same three layers are in the same order in areas just separated by great distances. Wegener proposed that the rock layers were made when all the continents were part of Pangaea. Thus, they formed in a smaller contiguous area that was later broken and drifted apart.

Glaciers covered all or part of each of these continents during the same time period in the geologic past. If the continents were in their present position, a major glaciation event that covered nearly all of the continents and extended north of the equator would be required. Geologists have found no evidence of glacial action in the northern hemisphere during this time period. In fact, during this time period, the climate in North America was warm. Wegener proposed that the continents were adjacent to each other during the glacial event. Therefore, glaciers spread over a much smaller area in the southern hemisphere and probably did not influence the climate of the northern hemisphere. Wegener used the distribution of specific rock types to determine the distribution of climate zones in the geologic past. For example, glacial till and striations, sand dunes, and coral reefs, indicate polar, desert, and tropical climates, respectively. Using the distribution of rock types, Wegener reconstructed the distribution of climates zones at specific times in the geologic past. He found that, unlike the present distribution, in which zones parallel the equator, the past zones occupied very different positions. This implies that the rotational pole was in very different locations relative to today. Wegener proposed an alternative interpretation. He believed that the climate zones remained stationary and the continents drifted to different locations. The drift of the continents caused the apparent movement of the climate zones. Wegener used the distribution of climate zones to determine the location of the poles at different times in the geologic past. He found that the rotational pole appears to gradually change location, arriving at its present position only in the very recent geologic past. The apparent movement in the pole position over time is called polar wandering. Wegener offered an alternative explanation. He suggested that the poles remained stationary and that the continents changed their positions relative to the poles.

All geologists did not accept Wegener s model. Some thought that dispersion by winds or ocean currents could explain the distribution of fossil species. Other geologists thought the poles might wander and continents remain stationary. Many geologists thought Wegener’s evidence was insufficient.

The greatest shortcoming, at least in the eyes of American geologists, was the lack of an adequate mechanism for moving the continents. Wegener proposed that the Earth’s spin caused the continents to move, plowing through the oceanic plate and producing mountains on their leading edges. Geologists at that time understood enough about the strength of rocks to know that this was highly unlikely. Wegener’s work was largely unaccepted in the northern hemisphere. In the southern hemisphere, where geologists were familiar with the rocks that Wegener used to support his hypothesis, continental drift was generally accepted. A mechanism to move continents was proposed by Arthur Holmes, Scottish geologist in 1928. He believed heat trapped in the Earth caused convection currents, areas where fluids beneath the Earth’s crust rise, flow laterally, and then fall. The currents would rise beneath continents, spread laterally, and then plunge beneath the oceans. Unfortunately, Wegener died in 1930 while exploring the Greenland ice cap. He never had the opportunity to adapt Holmes’ ideas to his views of continental drift.

During the 1940s and 1950s, great advances were made in our knowledge of the sea floor and in the magnetic properties of rocks. Both of these fields of study provided new evidence to support continental drift.

Geologists have known for over a century that a ridge exists in the middle of the Atlantic Ocean. The Mid-Atlantic Ridge is 6,500 feet above the adjacent sea floor, which is at a depth of about 20,000 feet below sea level. In the 1950s, a seismologist, a scientist who specializes in the study of earthquakes, showed that the global system of mid-ocean ridges was also an active seismic belt, or zone of earthquakes. An international group of geologists proposed that the seismic belt corresponded to a trough, or rift, system similar to the trough known at the crest of the Mid-Atlantic Ridge. The rifts are about 20 miles wide and 6,500 feet deep. In all, the oceanic ridges and their rifts extend for more than 37,500 miles in all the world’s oceans.

In 1962, a geologist presented an explanation for the global rift system. Harry Hess proposed that new ocean floor is formed at the rift of mid-ocean ridges or sea floor spreading. The ocean floor, and the rock beneath it are produced by magma that rises from deeper levels. Hess suggested that the ocean floor moved laterally away from the ridge and plunged into an oceanic trench along the continental margin.

A trench is a steep-walled valley on the sea floor adjacent to a continental margin. For example, ocean crust formed at the East Pacific Rise, an oceanic ridge in the east Pacific, plunges into the trench adjacent to the Andes Mountains on the west side of the South American continent. In Hess’ model, convection currents push the ocean floor from the mid-ocean ridge to the trench. The convection currents might also help move the continents, much like a conveyor belt. As Hess formulated his hypothesis, Robert Dietz independently proposed a similar model and called it sea floor spreading. Dietz’s model had a significant addition. It assumed the sliding surface was at the base of the lithosphere, not at the base of the crust. Hess and Dietz succeeded where Wegener had failed. Continents are no longer thought to plow through oceanic crust but are considered to be part of plates that move on the soft, plastic asthenosphere. A driving force, convection currents, moved the plates. Technological advances and detailed studies of the ocean floor, both unavailable during Wegener’s time, allowed Hess and Dietz to generate the new hypotheses.

One test for the sea-floor-spreading hypothesis involved magnetic patterns on the sea floor. In the late 1950’s, scientists mapped the present-day magnetic field generated by rocks on the floor of the Pacific Ocean. The volcanic rocks, which make up the sea floor have magnetization because, as they cool, magnetic minerals within the rock align to the Earth’s magnetic field. The intensity of the magnetic field they measured was very different from the intensity they had calculated. Thus, the scientists detected magnetic anomalies, or differences in the magnetic field from place to place. They found positive and negative magnetic anomalies. Positive magnetic anomalies are places where the magnetic field is stronger than expected. Positive magnetic anomalies are induced when the rock cools and solidifies with the Earth’s north magnetic pole in the northern geographic hemisphere. The Earth’s magnetic field is enhanced by the magnetic field of the rock. Negative magnetic anomalies are magnetic anomalies that are weaker than expected. Negative magnetic anomalies are induced when the rock cools and solidifies with the Earth’s north magnetic pole in the southern geographic hemisphere. The resultant magnetic field is less than expected because the Earth’s magnetic field is reduced by the magnetic field of the rock. When mapped, the anomalies produce a zebra-striped pattern of parallel positive and negative bands. The pattern was centered along, and symmetrical to, the mid-ocean ridge.

If new oceanic lithosphere is created at mid-ocean ridges, subduction takes place. Geologists had the answer to this question before Vine and Matthews presented their hypothesis. In 1935, K. Wadati, a Japanese seismologist, showed that earthquakes occurred at greater depths towards the interior of the Asian continent. Earthquakes beneath the Pacific Ocean occurred at shallow depths. Earthquakes beneath Siberia and China occurred at greater depths. After World War II, H. Benioff observed the same distribution of earthquakes but could not offer a reasonable explanation.

The movement of oceanic lithosphere away from mid-ocean ridges provides an explanation. Convection cells in the mantle help carry the lithosphere away from the ridge. The lithosphere arrives at the edge of a continent, where it is subducted or sinks into the asthenosphere. Thus, oceanic lithosphere is created at mid-ocean ridges and consumed at subduction zones, areas where the lithosphere sinks into the asthenosphere. Earthquakes are generated in the rigid plate as it is subducted into the mantle. The dip of the plate under the continent accounts for the distribution of the earthquakes. Magma generated along the top of the sinking slab rises to the surface to form stratovolcanoes.

The new hypotheses of the early 1960s explained several puzzling sets of observations. All that remained was a synthesis of these hypotheses. The synthesis began in 1965 when Tuzo Wilson introduced the term plate for the broken pieces of the Earth’s lithosphere. In 1967, Jason Morgan proposed that the Earth’s surface consists of 12 rigid plates that move relative to each other. Two months later, Xavier Le Pichon published a synthesis showing the location and type of plate boundaries and their direction of movement. Since the mid-1960s, the plate tectonic model has been rigorously tested. Because the model has been successfully tested by numerous methods, it is now called the plate tectonic theory and is accepted by almost all geologists.

Earthquakes and volcanoes, evidence of unrest in the Earth, help locate the edges of plates. Earthquakes are distributed in narrow, linear belts that circle the Earth. Some of these belts have only shallow (0-20 miles) earthquakes, like the mid-Atlantic and east Pacific ridges. In contrast, earthquakes in other belts, like western South America and south-central Asia, are at shallow, intermediate (20-45 miles), and deep (45-450 miles) levels.

Volcanoes are also distributed in long belts that circle the Earth. A dramatic example is the line of volcanoes that circles most of the Pacific Ocean. This belt is known as the “Ring of Fire” because it is the site of frequent volcanic eruptions.

The distribution of earthquakes and volcanoes coincides at most locations. The Ring of Fire is an excellent example. Geologists believe that areas of intense geologic activity, indicated by earthquakes, volcanoes, and/or mountain building, mark the boundaries between lithosphere plates. The distribution of earthquakes, volcanoes, and mountain ranges define 7 large plates and 20 smaller plates. The Nazca and Juan de Fuca Plates consist of only oceanic lithosphere. The Pacific Plate is mostly oceanic lithosphere only a small slice of continental lithosphere in southern California and Baja Mexico. Most of the other plates consist of both oceanic and continental lithosphere. The ways that plates interact depend on their relative motion and whether oceanic or continental crust is at the edge of the lithosphere plate. Plates move away from, toward, or slide past each other. Geologists call these divergent, convergent, and transform plate boundaries. At a divergent plate boundary lithospheric plates move away from each other. The mid-Atlantic Ridge, a topographically high area near the middle of the Atlantic Ocean, is an example of a divergent plate boundary. At a convergent plate boundary, lithospheric plates move toward each other. The west margin of the South American continent, where the oceanic Nazca Plate is pushed toward and beneath the continental portion of the South American Plate, is an example of a convergent plate boundary. At a transform plate boundary, plates slide past each other. The San Andreas Fault in California is an example of a transform plate boundary, where the Pacific Plate slides past the North American Plate.