Plate Tectonics Essay, Research Paper

Plate Tectonics

Plate tectonics is the theory that the lithosphere (the outer part of solid Earth) is divided into a small number of plates that float on and travel independently over the Earth’s mantle. Much of the Earth’s seismic activity and volcanism, along with mountain-building processes, occurs at the boundaries of these plates.

The surface of the Earth is composed of about a dozen large plates and several small ones. Within each plate the rocks of the terrestrial crust move as a rigid body, with only minor flexuring and few manifestations of seismicity and volcanism. Narrow bands in which 80 percent of the world s earthquakes and volcanoes occur define the margins of the plates. There are three types of boundaries. The first of these is a very narrow band of shallow earthquakes caused by tensile stresses that follow exactly the crest of the 80,000-kilometre- (48,000-mile-) long, active mid-ocean ridges. The second boundary type occurs in areas where these ridges are offset. Earthquakes are much more violent along faults at such sites and result from the plates on either side of the faults grinding laterally past one another in opposite directions. Earthquakes forming the third boundary are distributed more diffusely but include all of the world’s deep earthquakes (i.e., those originating at depths greater than 145 km) and are associated with extremely narrow zones in which the ocean floor descends below its normal depth to as much as 10.5 km below sea level–the oceanic trenches. Across this margin, the maximum earthquake depths systematically increase along a dipping plane, with shallower earthquakes associated principally with the volcanic activity that borders each trench.

The ridge-crest earthquakes originate because of the tension created when the plates on either side move in opposite directions. This movement also releases the pressure on the underlying hot rocks, causing them to begin melting. The resulting magmas rise to form volcanoes (such as those in Iceland), which then solidify and later fracture as the tensional forces reassert themselves. Such new volcanic rocks thus become added to the edge of each plate, which grows at these “constructive” margins. The evidence for plate motion is not only the nature of the earthquakes but also the age of the volcanic oceanic rocks. Dating can be achieved by using both the fossil content of the sediments overlying the volcanic rocks and the time record represented by the anomalies in the magnetism of the rocks, which can be detected by ships sailing on the ocean surface. These show that the youngest volcanic rocks are at the crests of the mid-ocean ridges and the oldest are in the deepest areas, i.e., the oceanic trenches. Nowhere, however, are such rocks older than 190 million years, indicating that all older oceanic rocks must have been destroyed.

The trench margin is termed “destructive” because this is the region where the oceanic rocks are subducted (carried down) into the mantle along the dipping plane. Where subduction occurs along a continental edge, volcanism distorts the continental rocks, forming such mountain chains as the Andes. Elsewhere, volcanism creates island arcs, as in the southwestern Pacific. The composition of the volcanoes and their mineralization changes systematically with depth to the dipping plane, but their overall composition is that of continental crustal rocks. The destructive margins are thus regions where continental crustal rocks are created but oceanic rocks are recycled back to the mantle. The density of continental rocks is too low for them to be subducted, so if they are carried to a trench they will eventually collide, giving rise to mountain chains such as the Alps and Himalayas, which formed when Africa and India, respectively, collided with Europe and Asia.

Although the lateral extent of the plates is well defined, their thickness is less certain. At the crest of the oceanic ridge they are very thin, but heat-flow and seismic evidence suggest that their base increases rapidly with depth, reaching 48-57 km (30-36 miles) within about 9-19 km of the crest. By about 960 km distance from the crest the base has increased to 115 km. A plate may be subducted at any thickness but rarely exceeds 145 km. Each plate is composed of rigid mantle rocks with oceanic crustal rocks, but not necessarily those of the continental variety (e.g., the Pacific plate is devoid of continental rocks). The zone of rigid crustal and mantle rocks is termed the lithosphere to distinguish it from the deeper asthenosphere where mantle rocks are at a higher temperature and so deform plastically when subjected to tectonic stresses. The continental lithosphere is not consistently underlain by an asthenosphere. Moreover, the presence of volcanic rocks such as diamond-bearing kimberlites indicates that here the Earth’s lithosphere is at least 190 km thick, so that mantle flow, which causes plate motions, must occur at even greater depths.

The movements of the mantle result from the need to transfer to the Earth’s surface the heat generated within it by radioactive decay, and hence convective patterns vary with time. This is shown by changes in the location of past plate margins. The subduction that formed the Western Cordillera of North America largely ceased 10 million years ago, although some activity continues to produce volcanoes (e.g., the continuing eruptions of Mount Saint Helens in Washington) and earthquakes in Alaska.

Over time scales of hundreds of millions of years, changes in mantle convection initiated the formation of the Atlantic and Indian Oceans by splitting preexisting continents that were grouped as two major blocks, Laurasia and Gondwanaland, some 160 to 180 million years ago. Similarly, past continental collisions are recorded by largely eroded mountain chains, such as the Appalachian of eastern North America and the Caledonian-Hercynian Mountains of Europe and Africa, which were formed when these continents collided on successive occasions. The rate of mantle convection depends essentially on the square root of heat production within the mantle. This means that convection rates must have been at least twice as fast about 3 billion years ago, when the radiogenic heat being produced was about five times greater than today. The surface expressions of such motions, however, may have been different. There are no continental rocks more than 4 billion years old, possibly because the lithosphere was thin and was recycled without generating continental rocks. The nature of plate tectonic activity during most of the Earth’s history is still uncertain, and models of the way in which it would be reflected in the continental rocks are highly speculative.

Plate tectonics has revolutionized virtually every discipline of the Earth sciences since the late 1960s and early 1970s. It has served as a unifying model or paradigm for explaining geologic phenomena that were formerly considered in unrelated fashion. Plate tectonics describes seismic activity, volcanism, mountain building, and various other Earth processes in terms of the structure and mechanical behaviour of a small number of enormous rigid plates thought to constitute the outer part of the planet (i.e., the lithosphere). This all-encompassing theory grew out of observations and ideas about continental drift and seafloor spreading.

In 1912 the German meteorologist Alfred Wegener proposed that throughout most geologic time there was only one continental mass, which he named Pangaea. At some time during the Mesozoic Era, Pangaea fragmented and the parts began to drift apart. Westward drift of the Americas opened the Atlantic Ocean, and the Indian block drifted across the Equator to join with Asia. In 1937 the South African Alexander Du Toit modified Wegener’s hypothesis by suggesting the existence of two primordial continents: Laurasia in the north and Gondwanaland in the south. Aside from the congruency of continental shelf margins across the Atlantic, proponents of continental drift have amassed impressive geologic evidence to support their views. Similarities in fossil terrestrial organisms in pre-Cretaceous (older than 140,000,000 years) strata of Africa and South America and in pre-Jurassic rocks (older than 200,000,000 years) of Australia, India, Madagascar, and Africa are explained if these continents were formerly connected but difficult to account for otherwise. Fitting the Americas with the continents across the Atlantic brings together similar kinds of rocks and structures. Evidence of widespread glaciations during the Upper Paleozoic is found in Antarctica, southern South America, southern Africa, India, and Australia. If these continents were formerly united around the South Polar Region, this glaciation becomes explicable as a unified sequence of events in time and space.

Interest in continental drift heightened during the 1950s as knowledge of the Earth’s magnetic field during the geologic past developed from the studies of Stanley K. Runcorn Patrick M.S.Blackett, and others. Ferromagnetic minerals such as magnetite acquire a permanent magnetization when they crystallize as components of igneous rock. The direction of their magnetization is the same as the direction of the Earth’s magnetic field at the place and time of crystallization. Particles of magnetized minerals released from their parent igneous rocks by weathering may later realign themselves with the existing magnetic field at the time these particles are incorporated into sedimentary deposits. Studies of the in suitable rocks of different ages from over the world indicate that the magnetic poles were in different places at different times. The polar wandering curves are different for the several continents, but in important instances these differences are reconciled on the assumption that continents now separated were formerly joined. The curves for Europe and North America, for example, are reconciled by the assumption that America has drifted about 30| westward relative to Europe since the Triassic Period (195,000,000 to 230,000,000 years ago).

In the early 1960s a major breakthrough in understanding the way the modern Earth works came from two studies of the ocean floor. First, the American geophysicists Harry H. and Robert S. Dietz suggested that new ocean crust was formed along mid-oceanic ridges between separating continents; and second, Drummond H. Matthews and Frederick J. Vine of Britain proposed that the new oceanic crust acted like a magnetic tape recorder insofar as magnetic anomaly strips parallel to the ridge had been magnetized alternately in normal and reversed order, reflecting the changes in polarity of the Earth’s magnetic field. This theory of seafloor spreading then needed testing, and the opportunity arose from major advances in deep-water drilling technology. The Joint Oceanographic Institutions Deep Earth Sampling (JOIDES) project began in 1969, continued with the Deep Sea Drilling Project (DSDP), and, since 1976, with the International Phase of Ocean Drilling (IPOD) project. These projects have produced more than 500 boreholes in the floor of the world’s oceans, and the results have been as outstanding as the plate-tectonic theory itself. They confirm that the oceanic crust is everywhere younger than about 200,000,000 years and that the stratigraphic age determined by micropaleontology of the overlying oceanic sediments is close to the age of the oceanic crust calculated from the magnetic anomalies.

The plate-tectonic theory, which embraces both continental drift and seafloor spreading, was formulated in the mid-1960s by the Canadian geologist J. Tuzo Wilson, who described the network of mid-oceanic ridges, transform faults, and subduction zones as boundaries separating an evolving mosaic of enormous plates, and who proposed the idea of the opening and closing of oceans and eventual production of an orogenic belt by the collision of two continents.

Up to this point, no one had considered in any detail the implications of the plate-tectonic theory for the evolution of continental orogenic belts; most thought had been devoted to the oceans. In 1969 John Dewey of the University of Cambridge outlined an analysis of the Caledonian-Appalachian orogenic belts in terms of a complete plate-tectonic cycle of events, and this provided a model for the interpretation of other pre-Mesozoic (Paleozoic and Precambrian) belts. For a detailed discussion of plate-tectonic theory and its far-reaching effects,