

Chapter 5

Plate Tectonics

5.1 Theory of Plate Tectonics

- The outer layer of the Earth, called the *lithosphere*, is broken into large rigid pieces known as tectonic plates. These plates move slowly over the softer, ductile *asthenosphere* beneath them.
- In geology, the development of plate tectonic theory marked a true scientific revolution.

5.2 Basic Principles of Plate Tectonics Theory

- The Earth's lithosphere is divided into plates that move relative to one another.
- The motion of one plate relative to its neighbor takes place by slip along plate boundaries.
- Continents are parts of some plates, so as the plates move, the continents are carried along with them.
- Because of plate tectonics, the Earth's surface is dynamic—the positions of continents and oceans change continuously over geologic time.

5.3 Lithosphere and Asthenosphere

5.3.1 Lithosphere

- Includes of the crust and the uppermost part of the upper mantle.
- Acts as a relatively rigid, hard layer. When subjected to stress, it does not flow but instead bends (elastic deformation) or breaks (faulting, fracturing).

5.3.2 Asthenosphere

- Made of upper mantle that is hotter and more ductile than the lithosphere.

- Can flow slowly when stressed, similar to convection in boiling water, but on geological timescales (million of years).

5.4 Lithosphere Plates

- The lithosphere is broken into ~ 20 discrete plates.

Major plates (12) : Cover large surface areas (e.g., Pacific, African plates).

Microplates : Smaller plates, often along plate boundaries or fragmented regions.

5.4.1 Plate Boundaries

- Defined as the contact zones where two plates meet.
- Many plate boundaries coincide with continental margins, the transition between continental crust and oceanic crust.

5.5 Location of Earthquakes and Plate Boundaries

- The distribution of earthquakes (red dots) is not random.
- Most earthquakes occur in narrow seismic belts, which trace the location of plate boundaries. The fracturing and sliding that take place along these boundaries as plates move generate the earthquakes.
- In contrast, plate interiors remain relatively earthquake-free because very little movement occurs within them.

5.6 Three Types of Plate Boundaries

- The three types of plate boundaries are distinguished by the nature of relative plate movement.

Divergent boundary two plates move away from each other.

Convergent boundary two plates move towards each other; downgoing plate sinks beneath the overriding plate.

Transform boundary two plates slide past each other on a vertical fault surface.

5.7 Divergent Boundaries and Seafloor Spreading

- Two oceanic plates move apart (diverge) by the process of seafloor spreading at mid-ocean ridges.
- As the plates move apart, new ocean floor forms along the divergent boundaries.

- Rising asthenosphere melts beneath the ridge axis.

5.8 Mid-Ocean Range

- All new seafloor forms at mid-ocean ridges, and as it moves away from the ridge axis, it becomes progressively older.
- The ridge itself sits much shallower than the surrounding abyssal plains.
- Along its length, the ridge is segmented and offset by transform-fault fracture zones.

5.8.1 Seafloor Age Map

- The youngest oceanic crust lies along ridge axis.
- The oldest oceanic crust is found farthest from the ridge axis, near subduction zones where the seafloor is eventually recycled back into the mantle.

5.9 Convergent Boundaries and Subduction

- At convergent boundaries, two plates move toward each other.
- When at least one of these plates is oceanic, it bends and sinks into the asthenosphere beneath the overriding plate. This process is called *subduction*.
- Because of this, convergent boundaries are also known as subduction zones.
- Subduction has important implications:
 - It consumes old oceanic lithosphere, recycling it back into the mantle.
 - For this reason, geologists often call convergent boundaries *consuming boundaries*.
 - At the surface, they appear as long, deep oceanic trenches.

5.10 Earthquakes at Subduction Zones

- As the downgoing plate descends, it grinds along the base of the overriding plate. This friction produces large earthquakes, which often occur relatively close to the Earth's surface near trenches.
- Earthquakes also occur within the downgoing plate itself as it bends and sinks into the mantle (~ 660 km). This distinct band of earthquakes marking this sinking slab is called a Wadati-Benioff zone.
- At depths greater than 660 km, plates continue sinking into the mantle. However, earthquakes stop occurring because the slab material adjusts to high pressures and temperatures in a more ductile manner rather than fracturing.

5.11 Transform Boundaries

- Researchers discovered that mid-ocean ridges are not continuous lines but are broken into short segments.
- These segments are offset at their ends.
- At each offset, a fracture zone develops. This fracture zone runs at a right angle to the ridge axis and connects one ridge segment to the next.
- At a transform boundary, one plate slides sideways relative to its neighbor along a vertical fault. The slip direction is horizontal.
- No new plate is created, and no old plate is consumed at a transform boundary.
- Fracture zone intersects the end of each ridge segment at a right angle and links it to the next ridge segment.
- Only the segment of the fracture zone between two ridge segments is active – earthquakes happen only along the active transform fault.

5.12 Special Locations

5.12.1 Triple Junctions

- A triple junction is a place where three plates intersect.

5.12.2 Hot Spot Volcanoes

- Hot spot volcanoes form where a stationary plume of hot mantle rises and melts through a moving tectonic plate, creating a chain of volcanoes
 - Active volcano represents the present-day location of the magma source.
 - The younger and active volcano moves off the hotspot and become inactive, and another, still younger one forms.
 - Associated chain of inactive volcanic islands is known as a hotspot track, and it provides clues to the direction and rate of plate movement.
- Big Island of Hawai'i lies over 4,000 km from the nearest ridge or trench (oceanic hot spot).
- Yellowstone National Park lies into the interior of the North American Plate (continental hot spot).

5.13 Formation of Plate Boundaries – Rifting

- Most new divergent boundaries form when a continent splits and separates into two continents.
- When continental lithosphere stretches and thins, faulting takes place, and volcanoes erupt. Eventually, the continent splits in two, and a new ocean basin forms.
- Continental rifting is the initial process and seafloor spreading is a later, more advanced stage of this process.
- Rift valley in Iceland
 - Stretches along the Mid-Atlantic Ridge, where the North American and Eurasian tectonic plates are pulling apart from each other.
 - The Thingvellir rift grows about one centimeter (0.4 in) each year.

5.14 Death of Plate Boundaries – Continental Collision

- A convergent boundary ends when buoyant lithosphere enters a subduction zone.
- Subduction continues until the oceanic plate is fully consumed, and then the two continents collide.
- During collision:
 - The oceanic plate detaches and sinks into the mantle.
 - Rocks in the collision zone are broken, bent, and compressed, forming large mountain ranges.
 - The Earth's surface rises, and the crust thickens significantly due to the stacking and deformation of rock layers.

5.15 Different Geological Settings

- Five geological settings related to volcanism
 - Island arc (oceanic-oceanic subduction)
 - Continental arc (oceanic-continental subduction)
 - Hot spot
 - Mid-ocean ridge
 - Rift

5.16 Velocity of Plate Motions

- The velocity of plate motion can be described in two ways:

Relative plate velocity describes motion of one plate relative to another.

Absolute plate velocity describes motion of one plate compared to a fixed reference plate.

- Estimating absolute plate velocity comes from the assumption that the location of a hot spot does not change much over time, in which case the hot-spot track on a plate provides a record of the plate's absolute velocity.
- Plate velocities can now be measured using global positioning system (GPS) satellites.
- GPS measurements in southern California show that the region west of the San Andreas fault system, a plate boundary, is moving northwest up to 6 cm/year. The length of an error represents the velocity.

5.17 Changing Face of Earth

- As a result of plate tectonics, the map of Earth's surface changes slowly and continuously.
- The assembly and the later breakup of Pangaea during the past 400 million years.