


1 2  **Chapter 2 – Plate Tectonics**3  **From Continental Drift to Plate Tectonics**


- Prior to the late 1960s, most geologists believed that the positions of the continents and ocean basins were fixed.
- Continental drift, a hypothesis that challenged this belief, was first proposed in 1915.
- In the late 1960s, scientific developments led to the unfolding of the *theory of plate tectonics*.

4  **Continental Drift: An Idea Before Its Time**


- Alfred Wegener
 - First proposed continental drift hypothesis in 1915
 - Published *The Origin of Continents and Oceans*
- Continental drift hypothesis
 - A supercontinent, consisting of all of Earth's landmasses, once existed
 - During the Mesozoic, about 200 million years ago, this supercontinent began fragmenting
 - Wegener named the supercontinent Pangaea, meaning "all lands"

5  **Reconstructions of Pangaea**6  **Continental Drift: Supporting Evidence**


- The Continental Jigsaw puzzle

7  **Continental Drift: Supporting Evidence**

- Fossils Matching Across the Seas
 - Identical fossil organisms are found on continents now separated by vast oceans.

8  **Continental Drift: Supporting Evidence**

- Fossils Matching Across the Seas
 - Identical fossil organisms are found on continents now separated by vast oceans.

9  **Continental Drift: Supporting Evidence**

- Rock Types and Geologic Features
 - Matching mountain ranges across the Atlantic

10  **Continental Drift: Supporting Evidence**

- Ancient climates
 - Locations of ancient ice sheets and coal swamps

11  **The Great Debate**

- Objections to the continental drift hypothesis:
 - Wegener's inability to identify a credible mechanism for continental drift
 - Incorrectly proposed the gravitational forces of the Moon and Sun were capable of moving the continents.
 - Incorrectly suggested that continents broke through the ocean crust like icebreakers.
 - There was strong opposition to this hypothesis from all areas of the scientific community, and it was rejected.

12 

- Following World War II, oceanographers with new equipment explored the seafloor
 - Oceanic ridge system winds through all of the major oceans
 - No oceanic crust older than 180 million years old
 - Thin sediment accumulation in the deep oceans
- These developments and others led to the theory of plate tectonics.

13 

- Rigid Lithosphere Overlies Weak Asthenosphere
 - The lithosphere is Earth's strong, outer layer.

- The asthenosphere is a hotter, weaker region of the mantle under the lithosphere.
- Because of the differences in physical properties, the lithosphere is effectively detached from the asthenosphere, allowing layers to move separately.

14 

- Earth's Major Plates
 - The lithosphere is broken into approximately two dozen smaller sections called lithospheric plates.
 - These plates are in constant motion.

15 

- Plate Movement
 - Plates move as somewhat rigid units relative to each other.
 - Most interactions and deformations occur along plate boundaries.
 - Types of plate boundaries:
 - Divergent plate boundaries (constructive margins)
 - plates move apart
 - Convergent plate boundaries (destructive margins)
 - plates move together
 - Transform plate boundaries (conservative margins)
 - plates grind past each other without the production or destruction of lithosphere

16 

Divergent Plate Boundaries

- Also called spreading centers
- New ocean floor is generated as two plates move apart
- Most divergent plate boundaries are associated with oceanic ridges
- Oceanic ridge system is the longest topographic feature on Earth's surface
 - Exceeds 70,000 kilometers in length

17 

Divergent Plate Boundaries

- Oceanic Ridges and Seafloor Spreading
 - Along the crest of the ridge is a canyon-like feature called a rift valley
 - Seafloor spreading is the mechanism that operates along the ridge system to create new ocean floor.
- Spreading Rates
 - The average spreading rate is 5 cm/year
 - Mid-Atlantic Ridge has a spreading rate of 2 cm/year
 - East Pacific Rise has a spreading rate of 15 cm/year

18 

Divergent Plate Boundaries

19 

Divergent Plate Boundaries

- Continental Rifting
 - Occurs when a divergent plate boundary occurs within a continent
 - A landmass will split into two or more smaller segments
 - A continental rift, an elongated depression, will develop where continental crust sinks.
 - Eventually the depression lengthens and deepens, forming a narrow sea, and then a new ocean basin.
 - Example: East African Rift

20 21 22 

Convergent Plate Boundaries & Subduction

- Destructive margins
- Two plates move toward each other and leading edge of one slides beneath the other
 - Where lithosphere descends (subducts) into the mantle: subduction zones
 - Deep-ocean trenches are the surface manifestations produced at subduction zones
 - Examples include:

- Peru-Chili Trench
- Mariana Trench
- Tonga Trench

23 **Convergent Plate Boundaries & Subduction**

- Oceanic–continental convergence
 - The denser oceanic slab sinks into the mantle beneath the buoyant continental block
 - At a depth of ~100 kilometers, melting is triggered when water from the subducting plate mixes with the hot rocks of the asthenosphere.
 - This generates magma resulting volcanic mountain chain called a continental volcanic arc.
 - Examples include:
 - The Andes
 - The Cascade Range

24 **Oceanic–Continental Convergence**

25 **Convergent Plate Boundaries & Subduction**

- Oceanic–oceanic convergence
 - When two oceanic slabs converge, one descends beneath the other.
 - As with oceanic–continental convergence, partial melting initiates volcanic activity.
 - If the volcanoes emerge as islands, a volcanic island arc is formed.
 - Examples include:
 - The Aleutian Islands
 - The Mariana Islands

26 

27 **Convergent Plate Boundaries**

- Continental–continental convergence
 - Continued subduction can bring two continents together.
 - Less dense, buoyant continental lithosphere does not subduct.
 - This results in continental collision and produces mountain belts of deformed rocks.
 - Examples include:
 - The Himalayas
 - The Alps
 - The Appalachians

28 **Continental–Continental Convergence**

29 **Transform Plate Boundaries**

- Also called a transform fault
- Plates slide horizontally past one another, without production or destruction of lithosphere.
- Most occur on the seafloor joining two spreading center
 - Known as fracture zones
- Can move oceanic ridges toward subduction zones
- A few transform faults cut through continental crust
 - Examples include:
 - The San Andreas Fault
 - The Alpine Fault of New Zealand

30 **Transform Plate Boundaries**

31 **Transform Plate Boundaries**

32 **Transform Plate Boundaries**

33 **Changing Plate Boundaries**

- Although Earth's total surface area does not change, the size and shape of individual plates are constantly changing.
 - Plate boundaries migrate
 - Plate boundaries are created and destroyed
- Breakup of Pangaea
 - Formation of the Atlantic Ocean basin

- India collided with Asia to form the Himalayas

34  **Changing Plate Boundaries**

35  **Changing Plate Boundaries**

- Plate Tectonics in the Future
 - Geologists use present plate motions to extrapolate plate movements into the future.
 - Baja and southern California will eventually slide past the North American Plate
 - Africa will continue to collide with Eurasia

36  **Testing the Plate Tectonics Model**

- Evidence from Ocean Drilling
 - Some of the most convincing evidence has come from drilling directly into the ocean floor.
 - Hundreds of holes were drilled through layers of sediments that blanket the ocean floor and the basaltic crust
 - Sediments increase in age with distance from the ridge crest
 - Sediments are almost absent on the ridge crest and thickest furthest from the spreading center
 - Pattern of distribution is expected with seafloor spreading hypothesis being correct

37  **Evidence from Ocean Drilling**

38  **Testing the Plate Tectonics Model**

- Evidence from Hot Spots and Mantle Plumes
 - A mantle plume is a cylindrically shaped upwelling of hot rock.
 - The surface expression of a mantle plume is an area of volcanism called a hot spot.
 - As a plate moves over a hot spot, a chain of volcanoes, known as a hot-spot track, forms.
 - The age of each volcano indicates how much time has elapsed since it was over the mantle plume.
 - Examples include:
 - Hawaiian Island chain
 - Yellowstone

39  **Hot Spots and Hot Spot Tracks**

40  **Hot Spots and Hot Spot Tracks**

41  **Testing the Plate Tectonics Model**

- Evidence from Paleomagnetism
 - Basaltic rocks contain magnetite, an iron-rich mineral influenced by Earth's magnetic field.
 - When the basalt cools below the Curie point, the iron-rich minerals become magnetized and align with the existing magnetic field.
 - The magnetite is then "frozen" in position and, like a compass needle, indicates the position of the north pole at the time of rock solidification.
 - This is referred to as paleomagnetism.


42  **Testing the Plate Tectonics Model**


- Apparent Polar Wandering
 - The apparent movement of the magnetic poles indicates that the continents have moved.
 - It also indicates North America and Europe were joined in the Mesozoic.

43  **Testing the Plate Tectonics Model**

- Magnetic Reversals and Seafloor Spreading
 - Over periods of hundreds of thousands of years, Earth's magnetic field reverses polarity.
 - During a magnetic reversal, the north pole becomes the south pole, and vice versa.
 - Rocks that exhibit the same magnetism as the present magnetic field exhibit normal polarity.
 - Rocks that exhibit the opposite magnetism exhibit reverse polarity.
 - Once this concept was confirmed, researchers established a timescale for these occurrences, called the magnetic time scale.

44  **Testing the Plate Tectonics Model**

45  **Ocean Floor as a Magnetic Recorder**

46  **Ocean Floor as a Magnetic Recorder**47  **How Is Plate Motion Measured?**

- Geologic Measurement of Plate Motion
 - Dates of ocean floor from hundreds of locations gathered by ocean-drilling ships
 - Combined with paleomagnetism data to make maps of the age of the ocean floor

48  **How Is Plate Motion Measured?**

- Measuring Plate Motion from Space
 - Global Positioning System (GPS) data are collected at numerous sites over years
 - Measure plate motions to the millimeter

49  **What Drives Plate Motions?**

- Researchers agree that convection in the mantle is the ultimate driver of plate tectonics
- Forces That Drive Plate Motion:
 - The subduction of cold, dense oceanic lithosphere is a slab-pull force.
 - Elevated lithosphere at oceanic ridges will slide down due to gravity, causing the ridge-push force.

50  **Forces Driving Plate Motions**51  **Forces Driving Plate Motions**52  **What Drives Plate Motions?**

- Models of Plate–Mantle Convection
 - The slab-pull and ridge-push forces of plate tectonics are part of the same system as mantle convection.
 - What is not known is the exact structure of this convective flow.
 - Whole-Mantle Convection
 - Also called the plume model
 - Cold lithosphere sinks to the core-mantle boundary and stirs the entire mantle
 - Layer Cake Model
 - Mantle is divided somewhere between 660 kilometers and 1000 kilometers
 - Two zones of convection: a thin, dynamic upper layer and a larger, deeper, sluggish one

53  **Models of Plume-Mantle Convection**54 

End of Chapter 2