1 ***Plate Tectonics***

A Scientific Revolution Unfolds

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**

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

9 **Continental Drift: Supporting Evidence**

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

10 **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.
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- 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.

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- 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.

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

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- 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

15 **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

16 **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

17 **Divergent Plate Boundaries**

18 **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

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21 **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

22 **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

23 **Oceanic–Continental Convergence**

24 **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

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26 **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

27 **Continental–Continental Convergence**

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**

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34 ***Transform fault boundary***

35 **Transform Plate Boundaries**

36 **Transform Plate Boundaries**

37 **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

38 **Changing Plate Boundaries**

39 **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

40 **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

41 **Evidence from Ocean Drilling**

42 **JOIDES Resolution in San Diego**

43 **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

44 **Hot Spots and Hot Spot Tracks**

45 **Hot Spots and Hot Spot Tracks**

46 **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.

47 **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.

48 **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.

49 **Testing the Plate Tectonics Model**

50 **Ocean Floor as a Magnetic Recorder**

51 **Ocean Floor as a Magnetic Recorder**

52 **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
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53 **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
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54 **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.

55 **Forces Driving Plate Motions**

56 **Forces Driving Plate Motions**

57 **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

58 **Models of Plume-Mantle Convection**

59 **Age of ocean floor**

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