

From Continental Drift to Plate Tectonics

- Prior to the late 1960s, many geologists believed that the positions of the continents and ocean basins were fixed
- Continental drift, a hypothesis designed to explain continental movement, was first proposed in the twentieth century, but initially rejected by North American geologists

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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
 - This supercontinent was called **Pangaea** and began breaking apart about 200 million years ago

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Reconstructions of Pangaea

Modern reconstruction of Pangaea

Wegener's Pangaea, redrawn from his book published in 1912.

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Continental Drift: An Idea Before Its Time

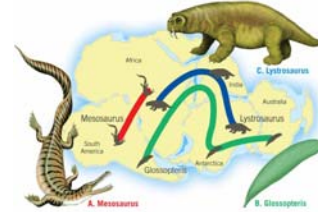
- Evidence used in support of continental drift hypothesis:
 - The Continental Jigsaw puzzle



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Continental Drift: An Idea Before Its Time

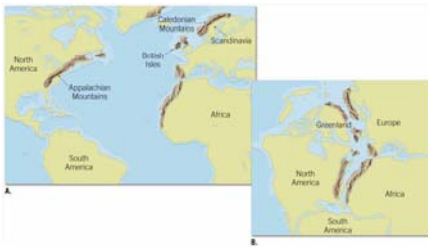
- Evidence used in support of continental drift hypothesis:
 - Fossil evidence—identical fossil organisms are found on continents now separated by vast oceans



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Continental Drift: An Idea Before Its Time

- Evidence used in support of continental drift hypothesis:
 - Rock types and geologic features



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Continental Drift: An Idea Before Its Time

- Evidence used in support of continental drift hypothesis:
 - Ancient climates



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The Great Debate

- Objections to the continental drift hypothesis:
 - Wegener incorrectly suggested that the gravitational forces of the Moon and Sun were capable of moving the continents
 - Wegener also incorrectly suggested that continents broke through the ocean crust
 - There was strong opposition to this hypothesis from all areas of the scientific community

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The Theory of Plate Tectonics

- Following World War II, oceanographers learned much about the seafloor
 - The oceanic ridge system winds through all of the major oceans
 - There is no oceanic crust older than 180 million years old
 - Sediment accumulation in the deep oceans was relatively minor
- These developments led to the theory of plate tectonics

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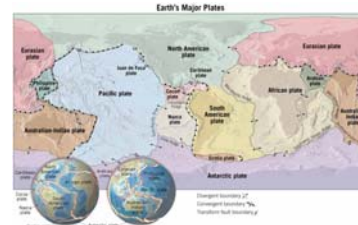
The Theory of Plate Tectonics

- 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

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The Theory of Plate Tectonics

- 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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The Theory of Plate Tectonics

- Plate Boundaries
 - Most interactions among individual plates occur along their 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 (also called a **transform fault**)

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Divergent Plate Boundaries

- New ocean floor is generated as two plates move apart
- Most divergent plate boundaries are located along the crests of oceanic ridges
- Oceanic ridges and seafloor spreading
 - Along well-developed divergent plate boundaries, the seafloor is elevated, forming oceanic ridges

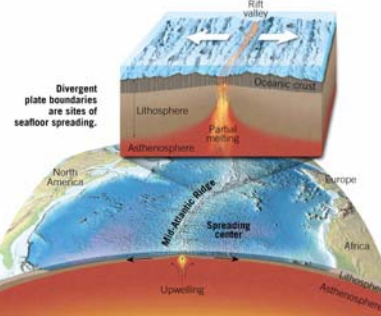
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Divergent Plate Boundaries

- 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 to create new ocean floor
- Spreading Rates
 - The average spreading rate is 5 cm/year
 - The Mid-Atlantic Ridge has a spreading rate of 2 cm/year
 - The East Pacific Rise has a spreading rate of 15 cm/year

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Divergent Plate Boundaries

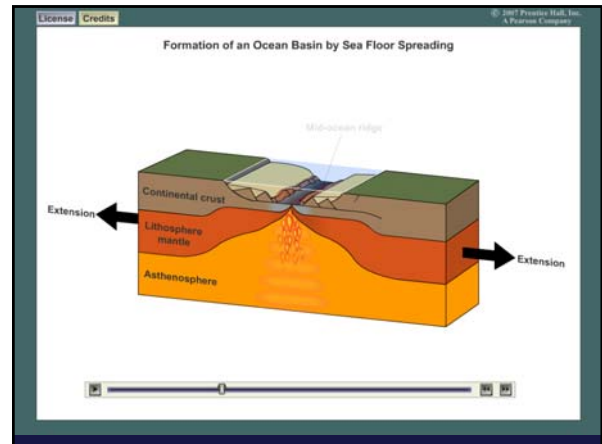


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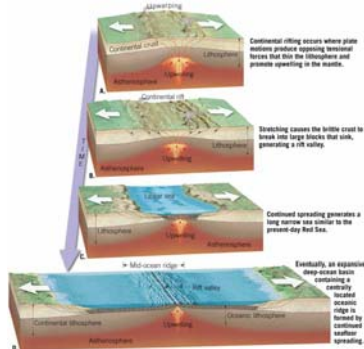
Divergent Plate Boundaries

- 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 within the region of the divergence
 - Examples include:
 - East African Rift

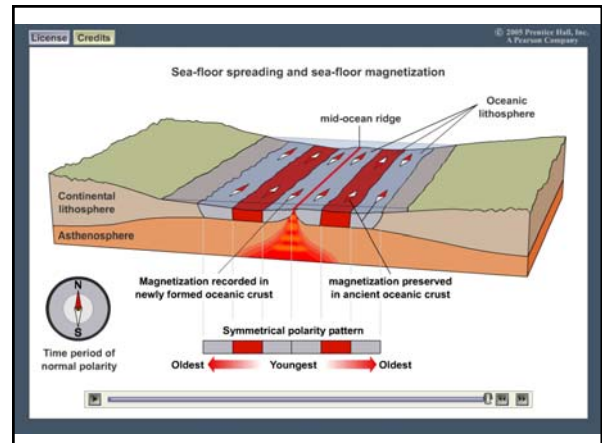
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Continental Rifting



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Convergent Plate Boundaries

- Two plates move toward each other at these destructive plate margins, where the older portions of oceanic plates are returned to the mantle
 - The leading edge of one plate is bent downward, as it slides beneath the other at **subduction zones**
 - **Deep-ocean trenches** are the surface manifestations produced at subduction zones
 - Examples include:
 - Peru-Chili Trench
 - Mariana Trench
 - Tonga Trench

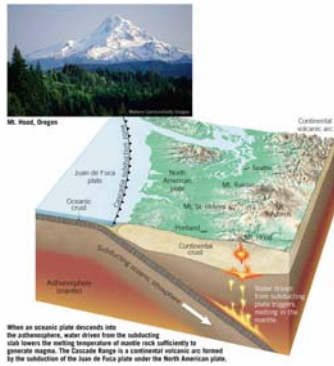
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Convergent Plate Boundaries

- Types of Convergent Boundaries:
 - Oceanic–continental convergence
 - The denser oceanic slab sinks beneath the continental block into the asthenosphere
 - At a depth of 100 kilometers, **partial melting** occurs when water from the subducting plate mixes with the hot rocks of the asthenosphere, generating magma
 - The resulting volcanic mountain chain is called a **continental volcanic arc**
 - » Examples include:
 - » The Andes
 - » The Cascade Range

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Oceanic–Continental Convergence



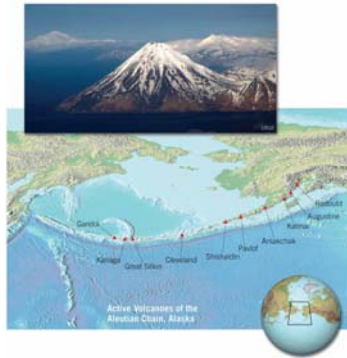
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Convergent Plate Boundaries

- Types of Convergent Boundaries:
 - 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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Oceanic–Oceanic Convergence



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Convergent Plate Boundaries

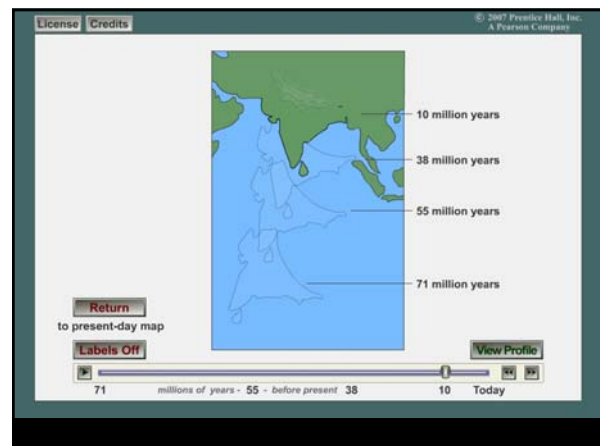
- Types of Convergent Boundaries:
 - Continental–continental convergence
 - Continued subduction can bring two continents together
 - Less dense, buoyant continental lithosphere does not subduct
 - The resulting collision produces mountains
 - » Examples include:
 - » The Himalayas
 - » The Alps
 - » The Appalachians

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Continental–Continental Convergence



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Transform Plate Boundaries

- Plates slide past one another and no lithosphere is created or destroyed
- Most join two segments of an oceanic ridge system along breaks in the oceanic crust known as **fracture zones**
- Transform faults can also move ridge crests toward subduction zones
- A few transform faults cut through continental crust
 - Examples include:
 - The San Andreas Fault
 - The Alpine Fault of New Zealand

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Transform Fault Boundaries

Fracture zones are long, narrow scar-like features in the seafloor that are roughly perpendicular to the offset ridge segments. They include both the active transform fault and its "fossilized" trace.

Most transform faults offset segments of a spreading center, producing a step-like plate margin.

A. The Mid-Atlantic Ridge, with its zigzag pattern, roughly reflects the shape of the ridge zone which resulted in the break-up of Pangaea.

KEY
 Spreading centers
 Fracture zones
 Transform faults

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Labels Off
Reset

Active transform fault, plates moving in opposite direction

Inactive fracture zone, plates moving in same direction

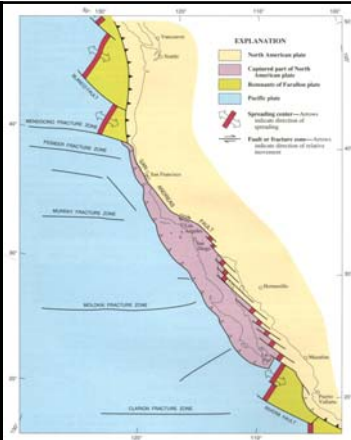
Inactive fracture zone, plates moving in same direction

Transform fault = strike-slip motion

Example



Transform fault boundary

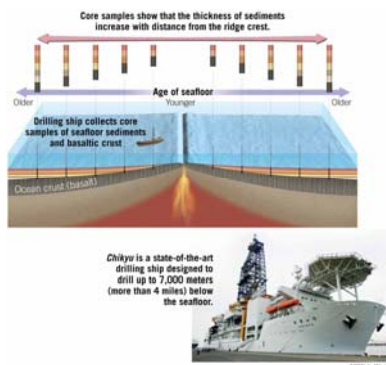


Testing the Plate Tectonics Model

- Evidence from Ocean Drilling
 - Some of the most convincing evidence has come from drilling directly into ocean-floor sediment
 - Age of the deepest sediments: The oldest sediments are furthest from the spreading center
 - The thickness of ocean-floor sediments verifies seafloor spreading: Sediments are almost absent on the ridge crest and thickest furthest from the spreading center

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Evidence from Ocean Drilling



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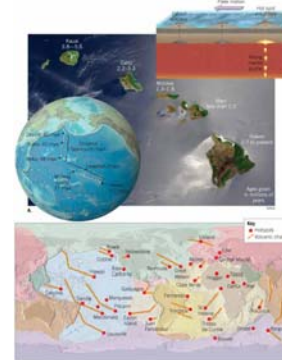


Testing the Plate Tectonics Model

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

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Hot Spots and Hot Spot Tracks



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Testing the Plate Tectonics Model

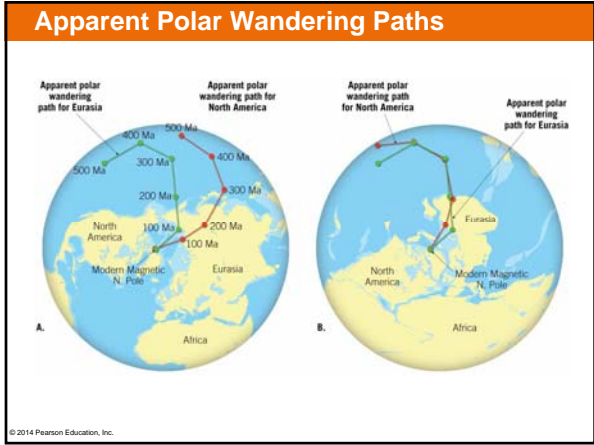
- Paleomagnetism
 - Basaltic rocks contain magnetite, an iron-rich mineral affected by Earth's magnetic field
 - When the basalt cools below the **Curie point**, the magnetite aligns toward the position of the north pole
 - The magnetite is then "frozen" in position and indicates the position of the north pole at the time of rock solidification. This is referred to as **paleomagnetism**

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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

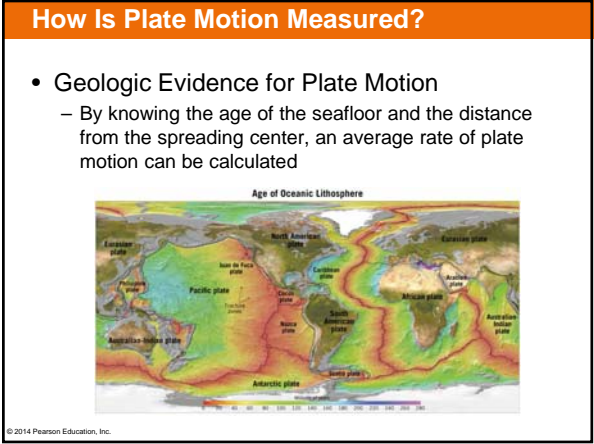
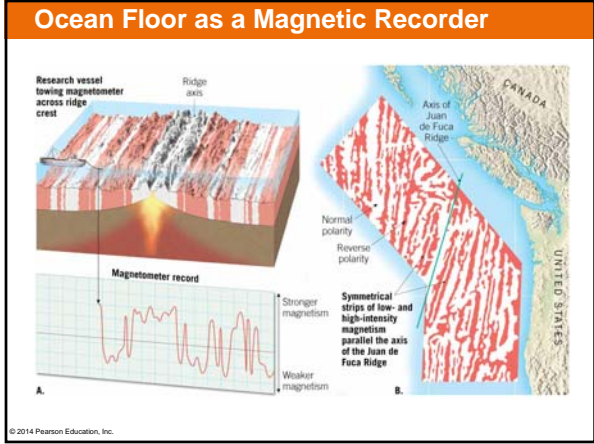
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Testing the Plate Tectonics Model

- Magnetic Reversals and Seafloor Spreading
 - During a **magnetic reversal**, Earth's magnetic field periodically reverses polarity—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**
 - The **magnetic time scale** shows the sequence of shifts in the polarity of Earth's magnetic field, determined from lava flows

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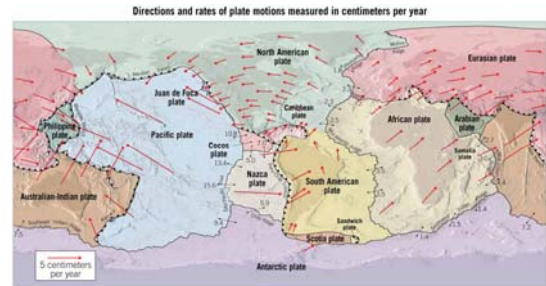


How Is Plate Motion Measured?

- Measuring Plate Motion from Space
 - Accomplished by using the Global Positioning System to measure various points on Earth's surface
 - GPS data are collected over various points repeatedly for many years to establish plate motion

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Plate Motions



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How Does Plate Motion Affect Plate Boundaries?

- The total surface of Earth does not change, despite movement along plate boundaries
- Plates can grow or shrink depending on the plate boundaries surrounding each plate
 - Examples include:
 - The African plate is bounded by divergent boundaries and is growing
 - The Pacific plate is bounded by convergent boundaries and is shrinking

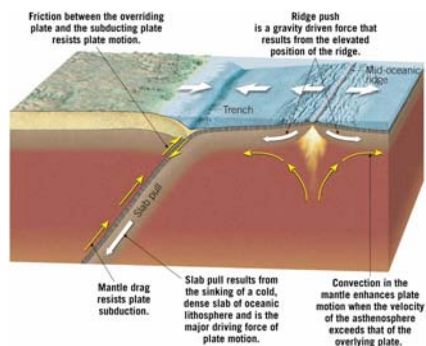
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What Drives Plate Motions?

- Researchers agree that convective flow in the mantle is the basic driving force of plate tectonics
- Forces That Drive Plate Motion:
 - The subduction of cold oceanic lithosphere is a **slab-pull** force
 - Elevated lithosphere on an oceanic ridge will slide down due to gravity, called the **ridge-force**

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Forces Driving Plate Motions



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What Drives Plate Motions?

- Models of Plate–Mantle Convection
 - **Convection** in the mantle, where warm, buoyant rocks rise and cool, dense rocks sink, is the underlying driving force of plate tectonics
 - The slab-pull and ridge-push forces of plate tectonics are part of the same system as mantle convection
 - Convective flow in the mantle is a major force for transporting heat away from the interior of Earth

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