Introduction to Oceanography

Chapter 2: Plate Tectonics – Overview

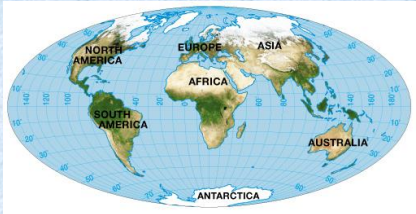
- Much evidence supports plate tectonics theory.
- The plate tectonics model describes features and processes on Earth.
- Plate tectonic science has applications to Earth Science studies.
- Configuration of land and oceans has changed in the past and will continue to change into the future.

Plate Tectonics

- Alfred Wegener first proposed in 1912
- Called it “Continental Drift”

Evidence for Continental Drift

- Wegener proposed **Pangaea** – one large continent existed 200 million years ago
- **Panthalassa** – one large ocean
- Included the **Tethys Sea**
- Noted puzzle-like fit of modern continents



(a) The positions of the continents today.

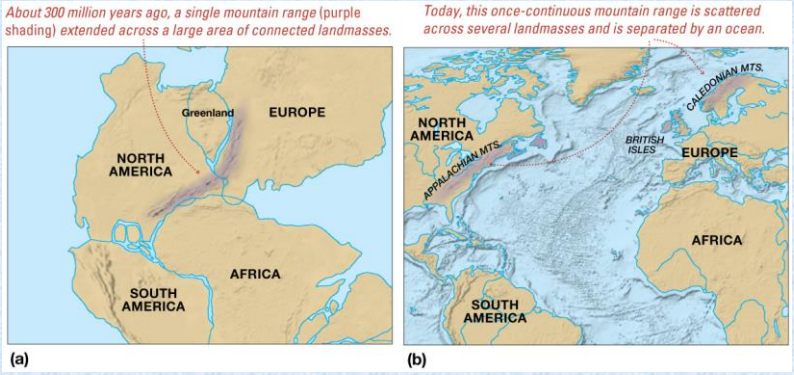
(b) The positions of the continents about 200 million years ago, showing the supercontinent of Pangaea and the single large ocean, Panthalassa.

Evidence for Continental Drift

- Puzzle-like fit corroborated in 1960s
- **Sir Edward Bullard** used computer models to fit continents.

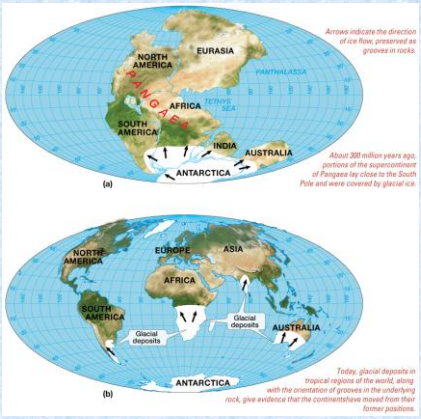
Evidence for Continental Drift

- Matching sequences of rocks and mountain chains
- Similar rock types, ages, and structures on different continents



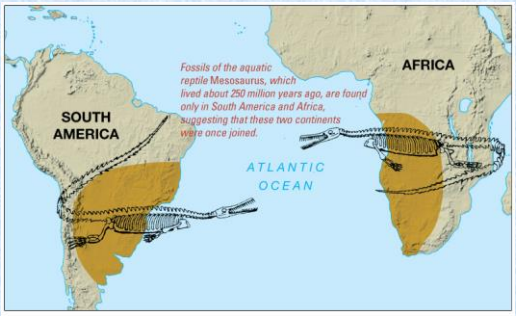
Evidence for Continental Drift

- Glacial ages and other climate evidence
- Evidence of glaciation in now tropical regions
- Direction of glacial flow and rock scouring
- Plant and animal fossils indicate different climate than today.



Evidence for Continental Drift

- Distribution of organisms
- Same fossils found on continents that today are widely separated
- Modern organisms with similar ancestries



Objections to Early Continental Drift Model

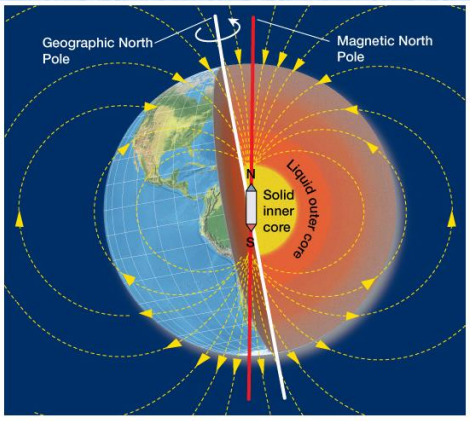
- 1915 – Wegener published *The Origins of Continents and Oceans*
  - Suggested continents plow through ocean basins
- Met with hostile criticism and open ridicule
- Tidal gravitational attractions too small to move continents
- Wegener's proposed mechanism defies laws of physics

Evidence for Plate Tectonics

- Sea floor studies from World War II
  - Use of sonar
- New technology enabled study of Earth's **magnetic field**

Evidence for Plate Tectonics

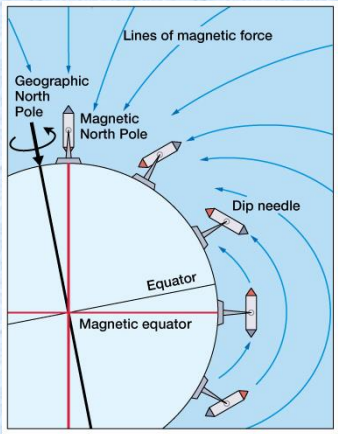
- Earth's magnetic field and **paleomagnetism**
- Earth has magnetic polarity
- North and South polarities
- Magnetic polarity recorded in igneous rocks
  - Magnetite in basalt



(a) Earth's magnetic field generates invisible lines of magnetic force similar to a large bar magnet. Note that the Geographic North Pole and the Magnetic North Pole are not in exactly the same location.

Evidence for Plate Tectonics

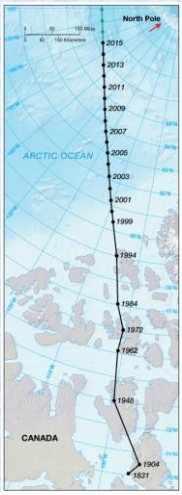
- **Paleomagnetism** – study of Earth's ancient magnetic field
  - Interprets where rocks first formed
- **Magnetic dip** – magnetite particles in sedimentary rocks or igneous rocks such as **basalt** align with Earth's magnetic field



(b) Earth's magnetic field causes a dip needle to align parallel to the lines of magnetic force and change orientation with increasing latitude. Consequently, an approximation of latitude can be determined based on the dip angle.

Earth's Magnetic Pole

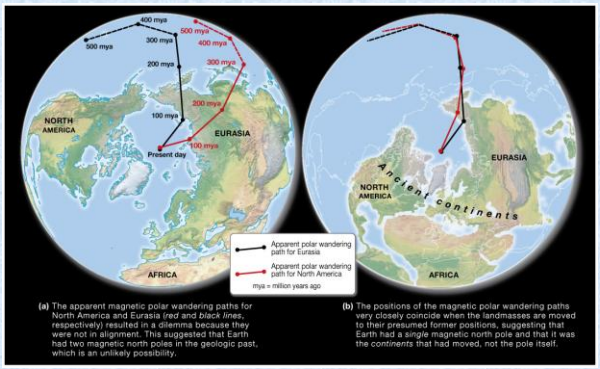
- **Magnetic polarity reversals**
  - Earth's magnetic poles switch
  - Average every 5000 years
  - Recorded in rocks



(c) Map showing the location of Earth's north magnetic pole since 1831 (black) and its projected location in the future (green).

Evidence for Plate Tectonics

- Apparent **polar wandering**
- Location of North Pole changed over time
- Magnetic dip data



(a) The apparent magnetic polar wandering paths for North America and Eurasia (*red* and *black lines*, respectively) resulted in a dilemma because they were not in alignment. This suggested that Earth had two magnetic north poles in the geologic past, which is an unlikely possibility.

(b) The positions of the magnetic polar wandering paths very closely coincide when the landmasses are moved to their presumed former positions, suggesting that Earth had a *single* magnetic north pole and that it was the *continents* that had moved, not the pole itself.

Paleomagnetism and the Ocean Floor

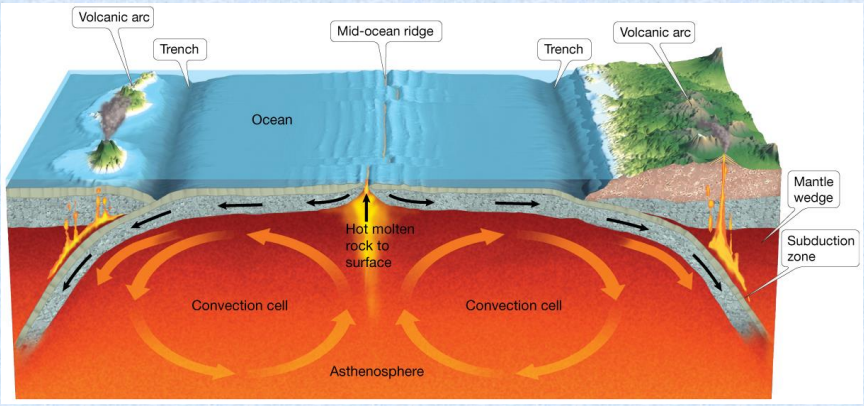
- 1955 – deep water rock mapping
- **Magnetic anomalies** – regular pattern of north-south magnetism "stripes"
- Stripes were symmetrical about long underwater mountain range

- **Magnetometer** – instrument towed behind ocean vessel
  - Measures Earth's magnetic field and how it was affected by sea floor rocks

Sea Floor Spreading

- **Harry Hess**
  - World War II submarine captain and geologist
- Depth recordings show sea floor features
- History of Ocean Basins
  - **Seafloor spreading**
  - **Mantle convection cells** as driving mechanism

Plate Tectonic Processes



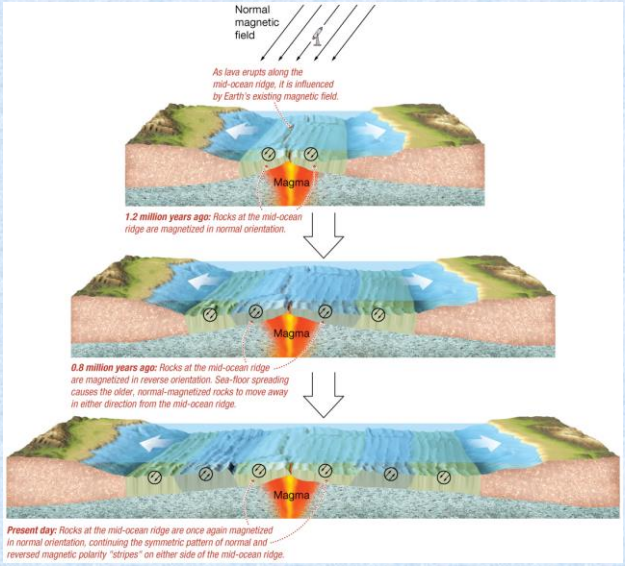
Sea Floor Spreading

- **Mid-ocean ridge** – spreading center
- **Subduction zones** – oceanic trench site of crust destruction
- Subduction can generate **deep ocean trenches.**

Sea Floor Spreading Evidence

- **Frederick Vine** and **Drummond Matthews** (1963)
- Analysis of igneous rock stripes around mid-ocean ridge
- Sea floor stripes record Earth's magnetic polarity

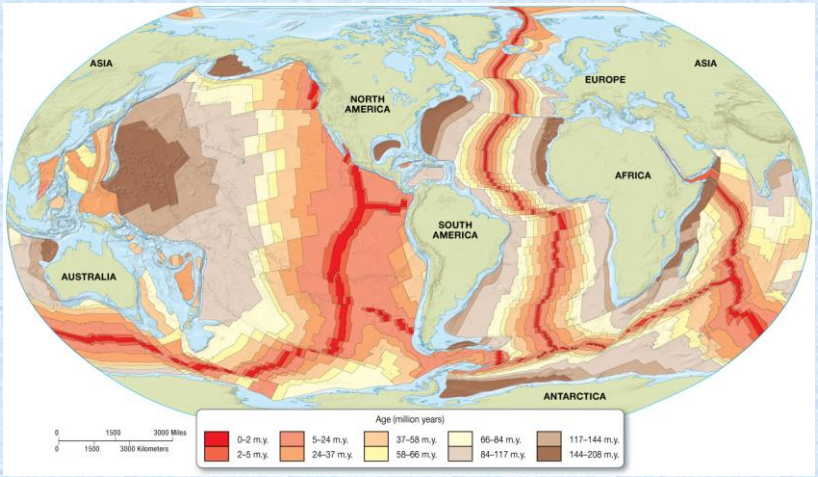
Sea Floor Spreading Evidence



Age of Ocean Floor

- Late 1960s deep-sea drilling
- Radiometric dating of ocean rocks
- Symmetric pattern of age distribution about mid-ocean ridges
- Oldest ocean floor only 180 million years old

Age of Ocean Floor

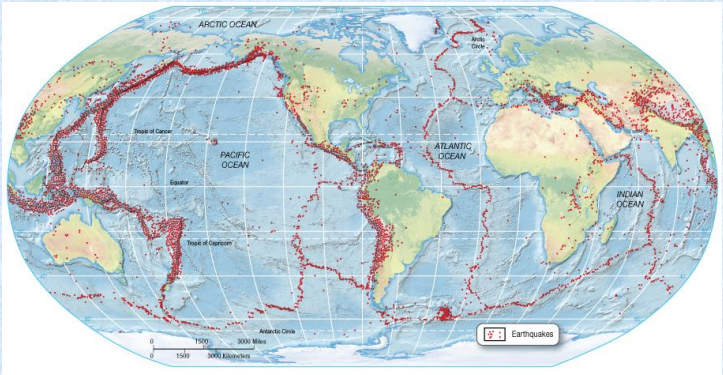


Heat Flow

- **Heat flow** – heat from Earth's interior released to surface
- Very high at mid-ocean ridges
- Low at subduction zones

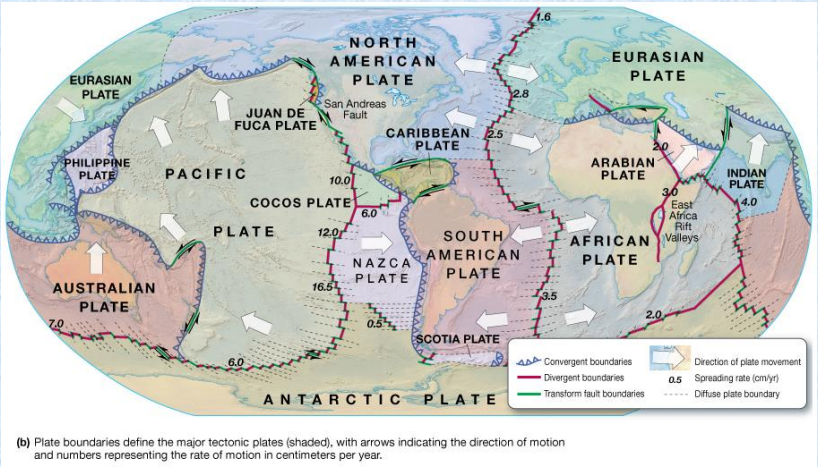
Earthquakes as Evidence

- Most large earthquakes occur at subduction zones.
- Earthquake activity mirrors tectonic plate boundaries.



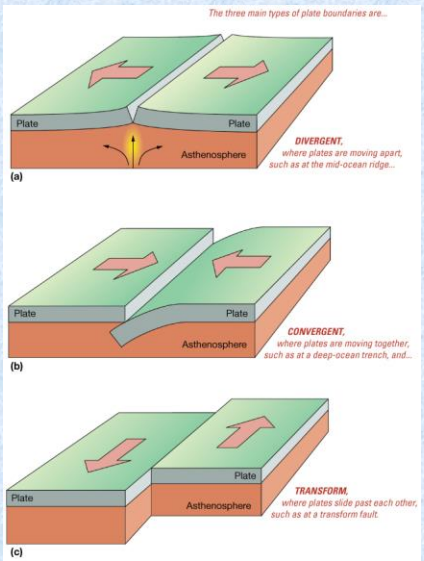
(a) Distribution of earthquakes with magnitude equal to or greater than $M_W = 5.0$ for the period 1980–1990.

Global Plate Boundaries



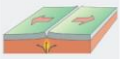
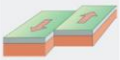
(b) Plate boundaries define the major tectonic plates (shaded), with arrows indicating the direction of motion and numbers representing the rate of motion in centimeters per year.

Types of Plate Boundaries



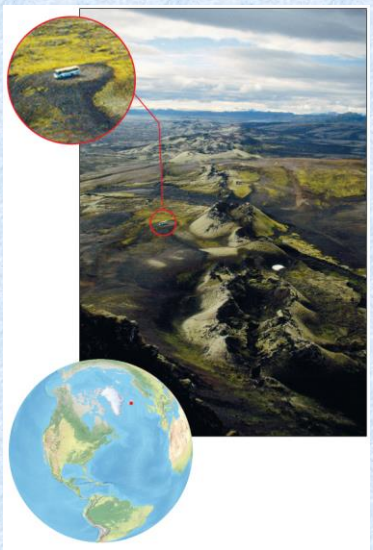
Examples of Plate Boundaries

SmartTable 2.1 Characteristics, Tectonic Processes, Features, and Examples of Plate Boundaries

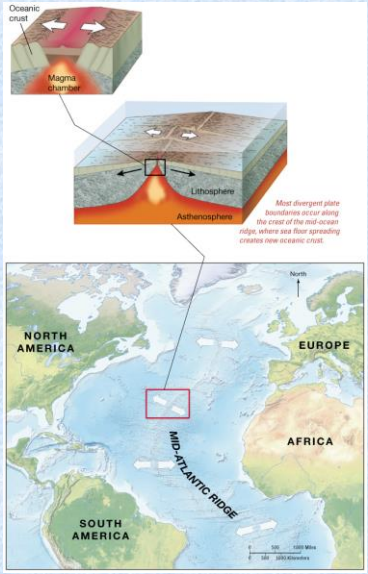
Plate boundary	Plate movement	Crust types	Sea floor created or destroyed?	Tectonic process	Sea floor feature(s)	Geographic examples
Divergent plate boundaries	Apart 	Oceanic–oceanic	New sea floor is created	Sea floor spreading	Mid-ocean ridge; volcanoes; young lava flows	Mid-Atlantic Ridge, East Pacific Rise
		Continental–continental	As a continent splits apart, new sea floor is created	Continental rifting	Rift valley; volcanoes; young lava flows	East Africa Rift Valleys, Red Sea, Gulf of California
Convergent plate boundaries	Together 	Oceanic–continental	Old sea floor is destroyed	Subduction	Trench; volcanic arc on land	Peru–Chile Trench, Andes Mountains
		Oceanic–oceanic	Old sea floor is destroyed	Subduction	Trench; volcanic arc as islands	Mariana Trench, Aleutian Islands
		Continental–continental	N/A	Collision	Tall mountains	Himalaya Mountains, Alps
Transform plate boundaries	Past each other 	Oceanic	N/A	Transform faulting	Fault	Mendocino Fault, Eltanin Fault (between mid-ocean ridges)
		Continental	N/A	Transform faulting	Fault	San Andreas Fault, Alpine Fault (New Zealand)

Divergent Boundary Features

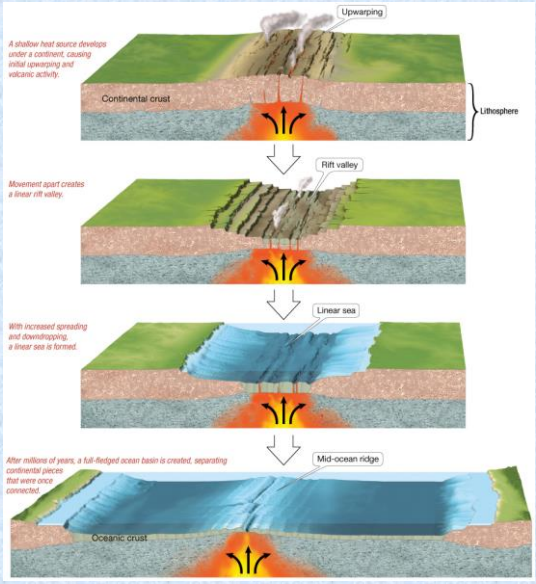
- Plates move apart
- Mid-ocean ridge
  - **Rift valley**
- New ocean floor created
  - **Rifting**
- Shallow focus earthquakes
  - Intensity measured with **seismic moment magnitude**



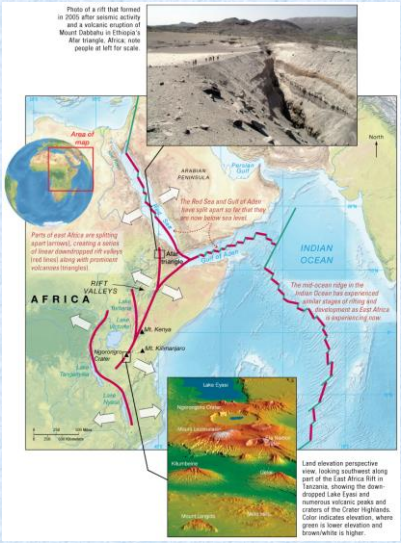
Divergent Plate Boundary



Generation of a Divergent Boundary



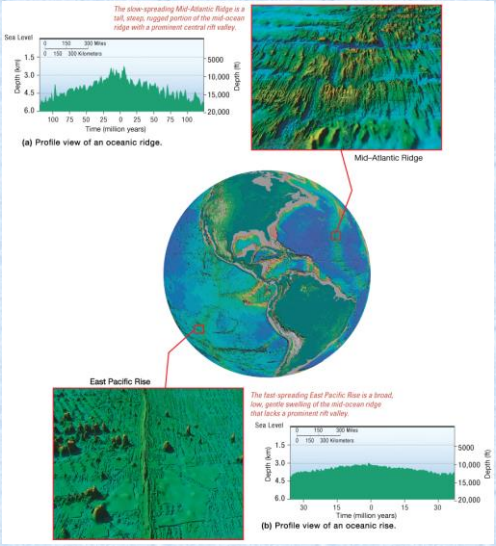
Formation of a Rift Valley



Types of Spreading Centers

- **Oceanic rise**
  - Fast-spreading
  - Gentle slopes
  - East Pacific
- **Oceanic ridge**
  - Slow-spreading
  - Steep slopes
  - Mid-Atlantic
- **Ultra-slow**
  - Deep rift valley
  - Widely scattered volcanoes
  - Arctic and southwest India

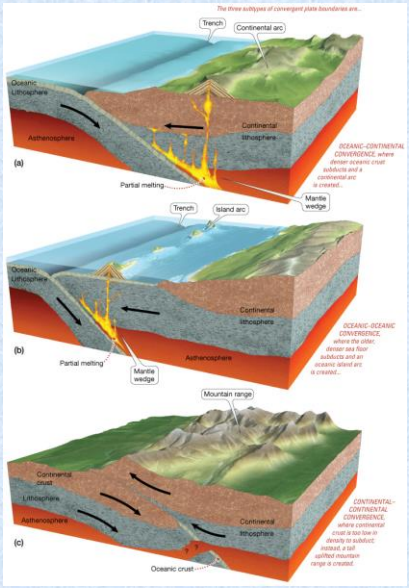
Types of Spreading Centers



Convergent Boundary Features

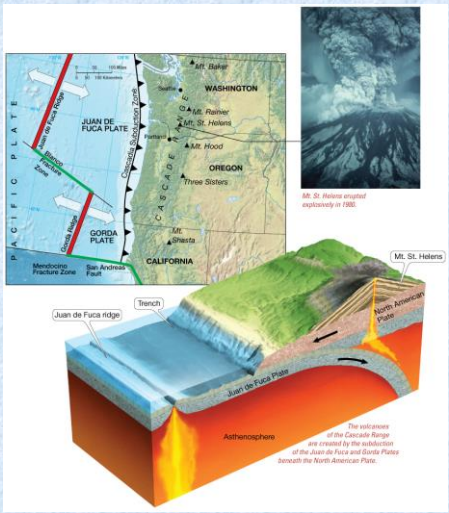
- Plates move toward each other
- Oceanic crust destroyed
  - **Ocean trench**
  - **Volcanic arc**
- Deep focus earthquakes
- Great forces involved
- Mineral structure changes associated

Three Types of Convergent Boundaries



Types of Convergent Boundaries

- **Oceanic-Continental Convergence**
  - Ocean plate is subducted
  - Continental arcs generated
  - Explosive andesitic volcanic eruptions

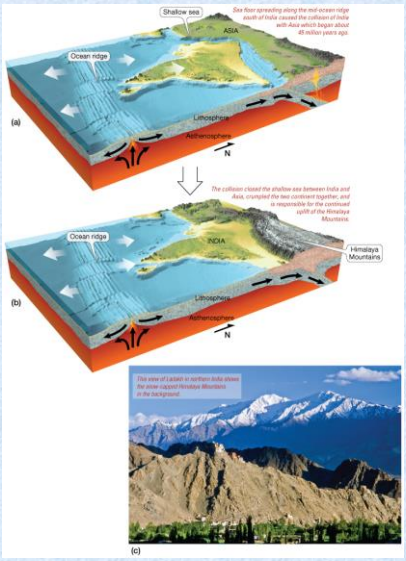


Types of Convergent Boundaries

- **Oceanic-Oceanic Convergence**
- Denser plate is subducted
- Deep trenches generated
- Volcanic **island arcs** generated

Types of Convergent Boundaries

- **Continental-Continental Convergence**
  - No subduction
  - Tall mountains uplifted
- Himalayas from India-Asia collision

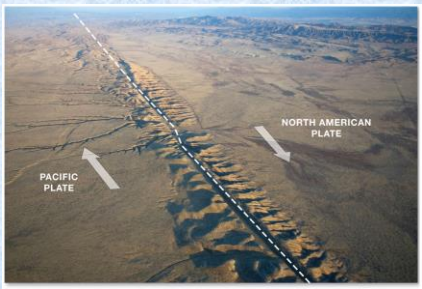


Transform Boundary Features

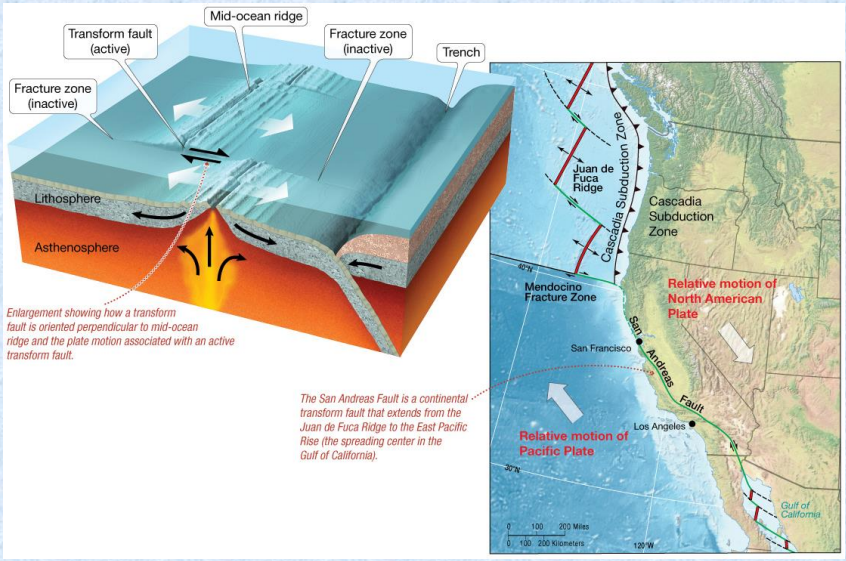
- Offsets oriented perpendicular to mid-ocean ridge
  - Segments of plates slide past each other
- Offsets permit mid-ocean ridge to move apart at different rates
- Shallow but strong earthquakes

Transform Boundary Features

- **Oceanic Transform Fault** – ocean floor only
- **Continental Transform Fault** – cuts across continent
  - San Andreas Fault
- Transform faults occur between mid-ocean ridge segments.

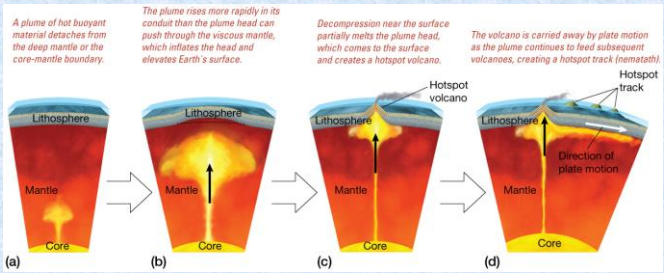


Transform Boundary Features

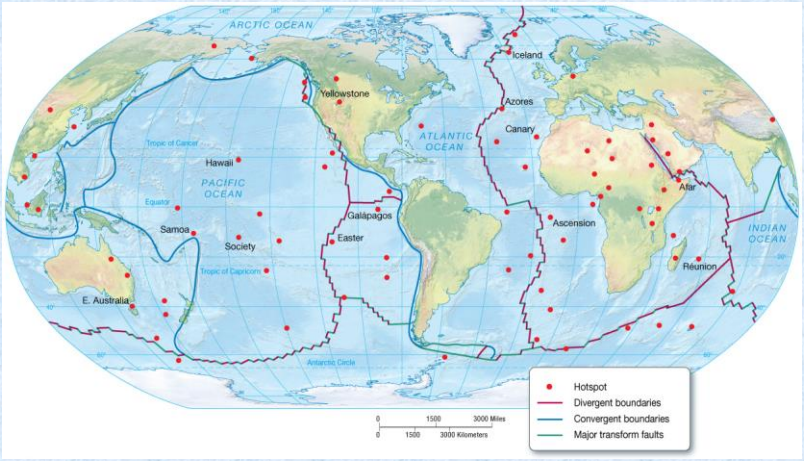


Applications of Plate Tectonics

- **Mantle Plumes** and **Hotspots**
  - Intraplate features
    - Volcanic islands within a plate
    - Island chains
- Record ancient plate motions
  - **Nematath** – hotspot track



Global Hotspot Locations



Hawaiian Island – Emperor Seamount Nematath

- More than 100 intraplate volcanoes
- Stretches over 5800 km (3000 mi)
- Age relationships of volcanoes suggest northwest migration of Pacific Plate

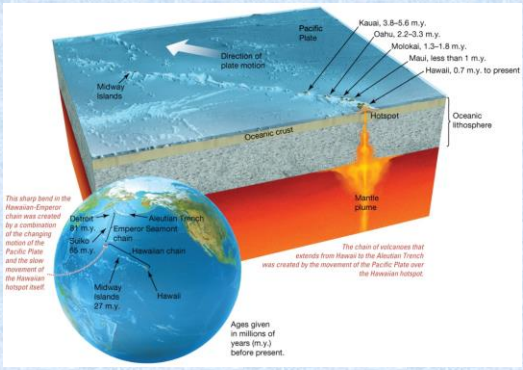
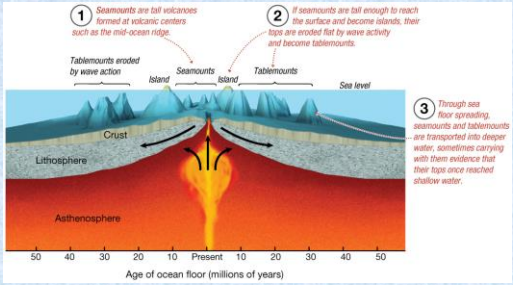


Plate Tectonics and Intraplate Features

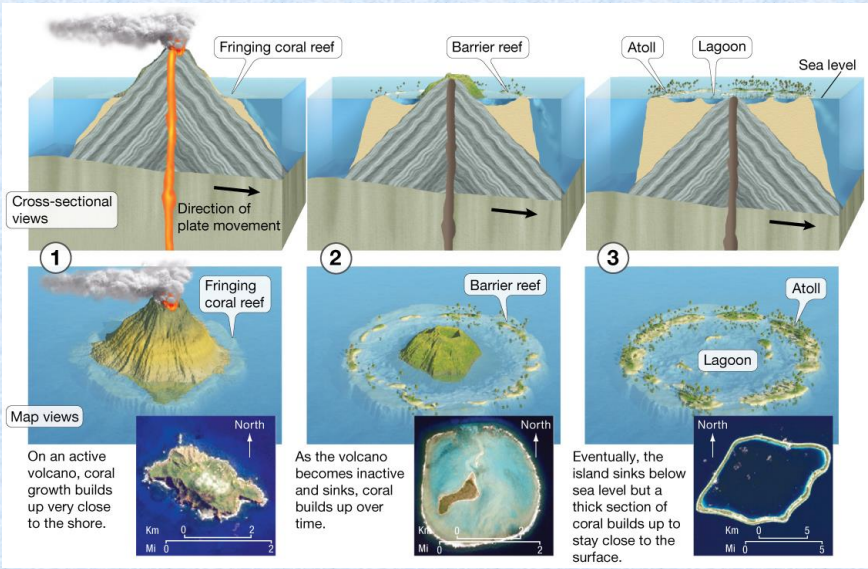
- **Seamounts**
  - Rounded tops
- **Tablemounts** or **guyots**
  - Flattened tops
- Subsidence of flanks of mid-ocean ridge
- Wave erosion may flatten seamount.



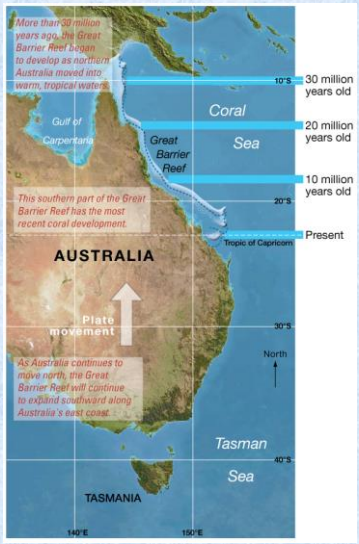
Coral Reef Development

- **Fringing reefs** – develop along margin of landmass
- **Barrier reefs** – separated from landmass by lagoon
- **Atolls** – reefs continue to grow after volcanoes are submerged

Coral Reef Development Stages



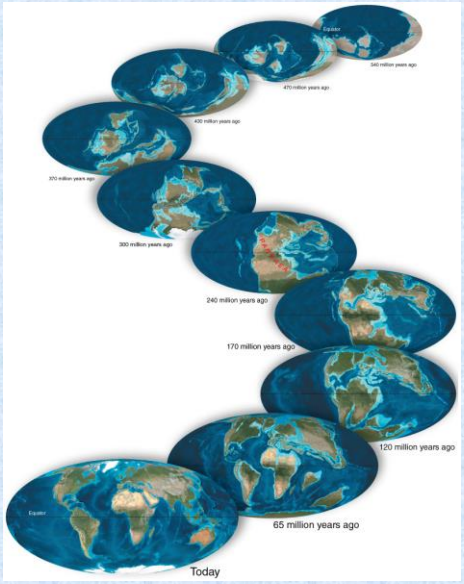
Great Barrier Reef Records Plate Movement



Paleogeography

- **Paleogeography** – study of ancient continents
- **Continental accretion**
  - Continental material added to edges of continents through plate motion
- **Pangaea** – 540 million to 300 million years ago

Paleogeographic Reconstructions



Breakup of Pangaea

- 180 million years ago – Pangaea separated
  - N. and S. America rifted from Europe and Africa
  - Atlantic Ocean forms
- 120 million years ago – S. America and Africa clearly separated
- 45 million years ago – India starts Asia collision
  - Australia moving north from Antarctica

Future Predictions

- Assume same direction and rate of plate motions as now
  - Atlantic will enlarge, Pacific will shrink
  - New sea from East Africa rift valleys
  - Further Himalaya uplift
  - Separation of North and South America
  - Part of California in Alaska

World Map 50 Million Years in Future