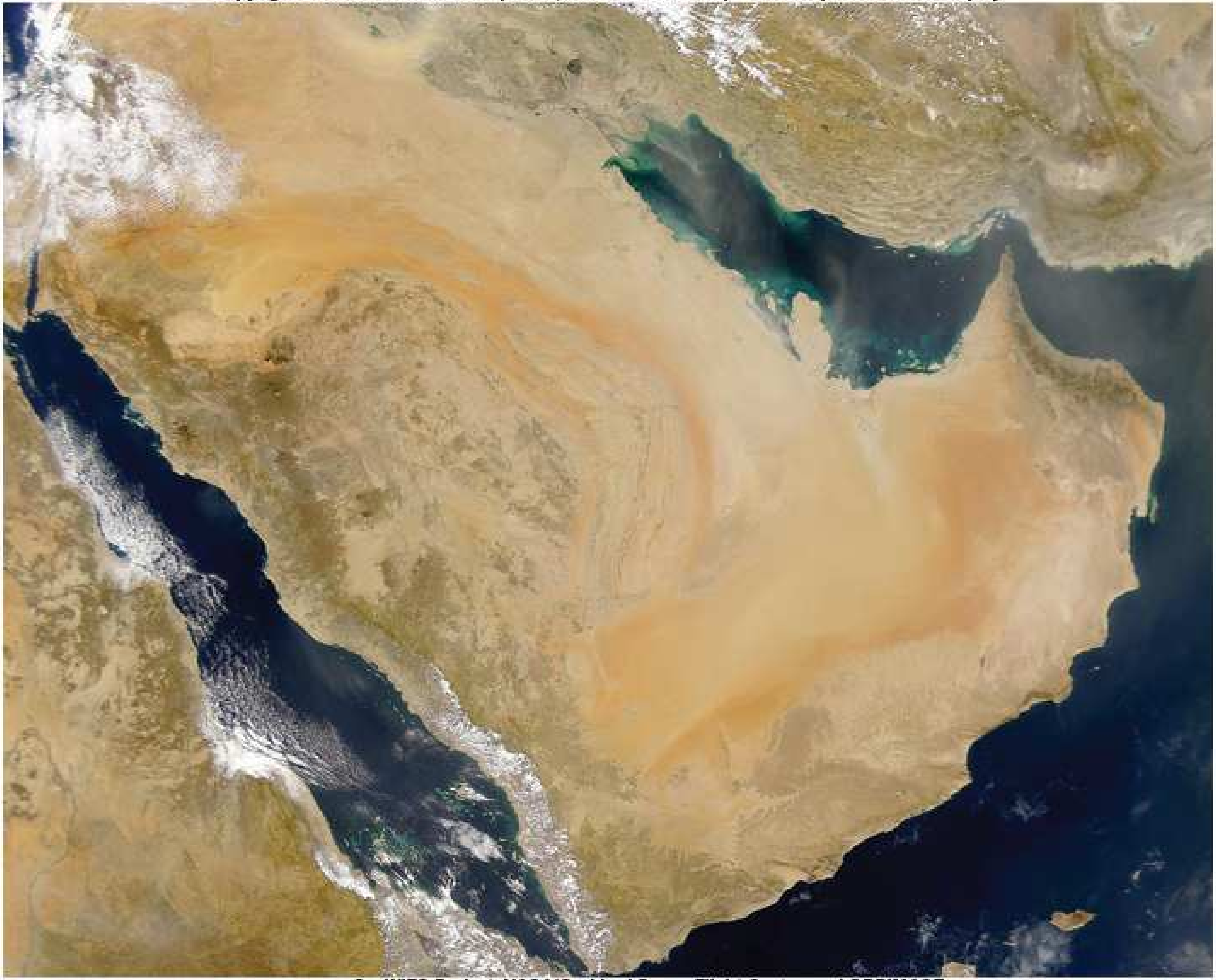
# Plate Tectonics

# Chapter 4



SeaWIFS Project, NASA/Goddard Space Flight Center, and ORBIMAGE

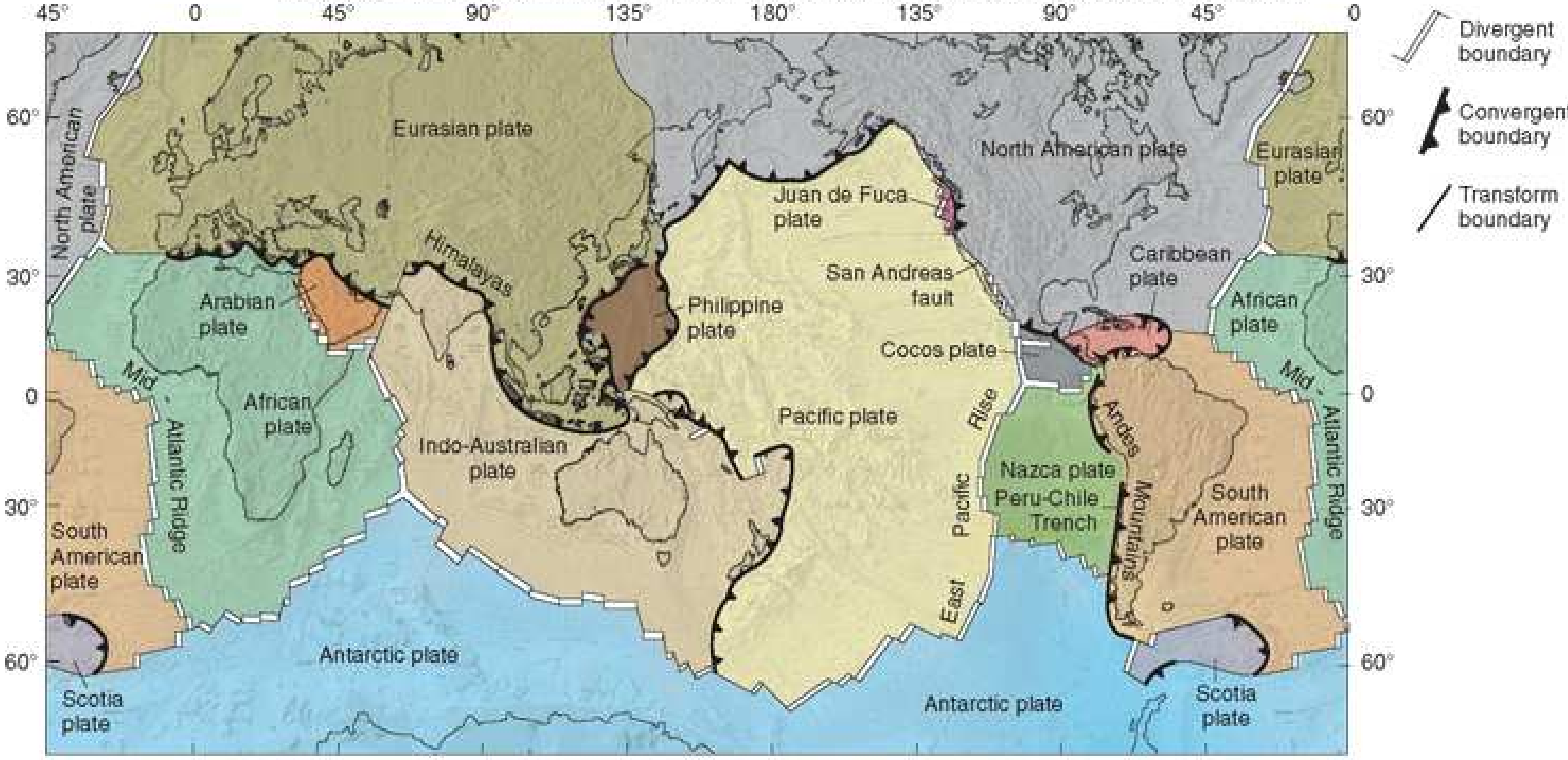
# Basic Definitions

- **Plate Tectonics** – the Earth's surface is divided into a few large, thick plates that move slowly and change in size over time

- Intense geologic activity is concentrated at *plate boundaries*, where plates move away, toward, or past each other

# Plate Tectonics






Modified from W. Hamilton, U.S. Geological Survey

# Plate Tectonics :

Combination of *continental drift* and *seafloor spreading* hypotheses in late 1960s

## –Continental Drift

**Continental Drift** – continents move freely over the surface of the Earth, changing their positions relative to one another

## –Seafloor Spreading

**Seafloor Spreading** – seafloor forms at the crest of mid-oceanic ridges, and moves horizontally away from the ridge, moving towards an oceanic trench

# Continental Drift

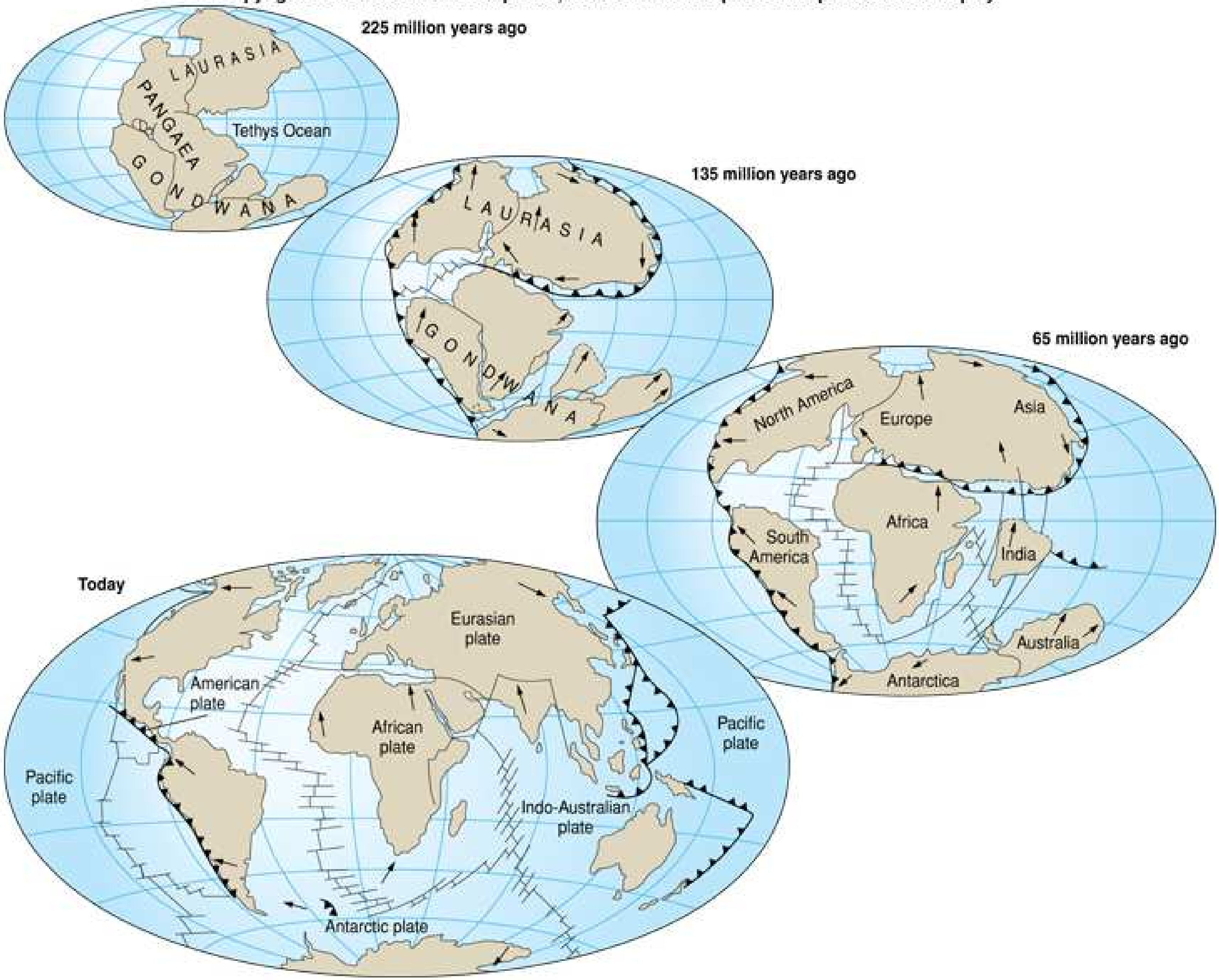
- Proposed by Alfred Wegener in 1912

- Supportive Evidence
  1. Rock evidence
  2. Glacial evidence
  3. Fossil evidence
  4. Jig-saw puzzle fit of continents shapes and geologic features

- Pangaea – Late Paleozoic (415 million yrs) to Mesozoic (65 million yrs)

# Early Case for Continental Drift

- Wegener reassembled continents into the supercontinent *Pangaea*
- Pangaea initially separated into *Laurasia* and *Gondwanaland*
  - *Laurasia* - northern supercontinent containing North America and Asia (excluding India)
  - *Gondwanaland* - southern supercontinent containing South America, Africa, India, Antarctica, and Australia


225 million years ago
LAURASIA
PANGAEA
Tethys Ocean
GONDWANA
135 million years ago
LAURASIA
GONDWANA
65 million years ago
North America
Europe
Asia
Africa
South America
India
Australia
Antarctica
Today
Eurasian plate
American plate
African plate
Pacific plate
Pacific plate
Indo-Australian plate
Antarctic plate

# Supportive Evidence

- The Rocks Match
- The Ice Matches
- The Fossils Match
- The Shapes Match
- The Positions Don't Match

# Rock Evidence

- *Coal beds* of North America and Europe: Fossils of same/similar plants - support reconstruction into Laurasia

- Broad belts of rocks in Africa and South America are the same type.

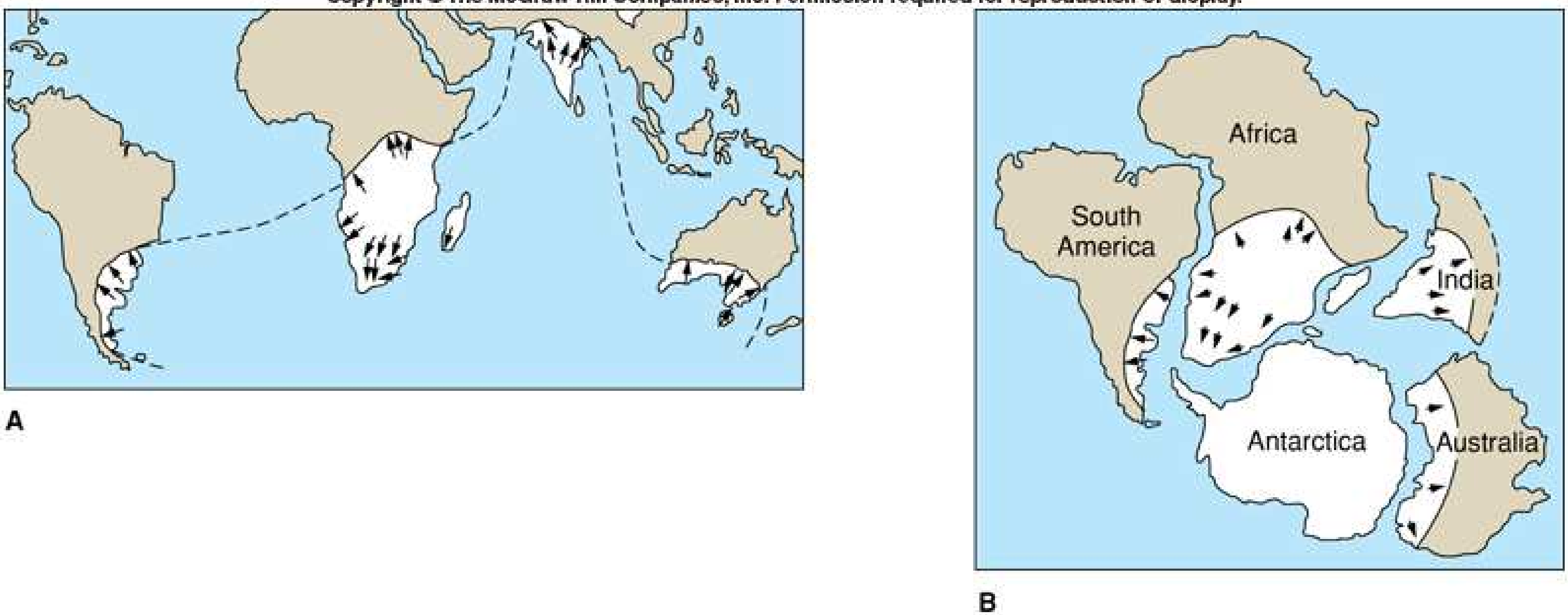
# Glacial (Ice) Evidence

- Late Paleozoic glaciation patterns on southern continents best explained by their reconstruction into Gondwanaland

- Glacial striations on rocks show that glaciers moved from Africa toward the Atlantic Ocean and from the Atlantic Ocean onto South America. Such glaciation is most likely if the Atlantic Ocean were missing and the continents joined.

# Similar glaciation patterns



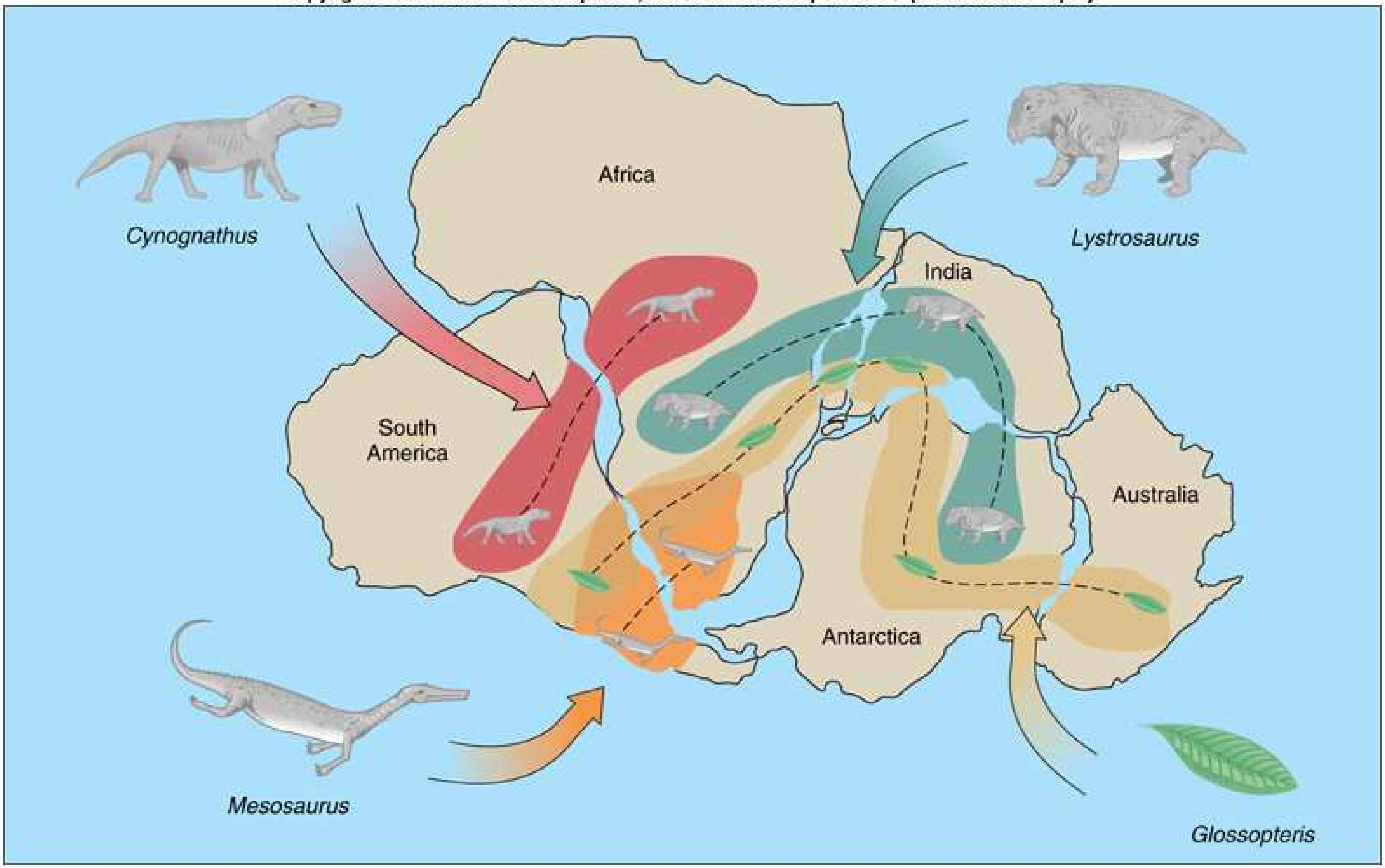


# Fossil Evidence

*Alfred Wegener* noted South America, Africa, India, Antarctica, and Australia have almost identical late Paleozoic rocks and *fossils*

- *Glossopteris* (plant), *Lystrosaurus* (animals) fossils found on all five continents
- *Mesosaurus* (reptile) fossils found in Brazil and South Africa only

He was intrigued by the occurrences of plant and animal fossils found on the matching coastlines of South America and Africa, which are now widely separated by the Atlantic Ocean. He reasoned that it was physically impossible for most of these organisms to have traveled or have been transported across the vast ocean.


Africa
Cynognathus
Lystrosaurus
India
South
America
Australia
Antarctica
Mesosaurus
Glossopteris

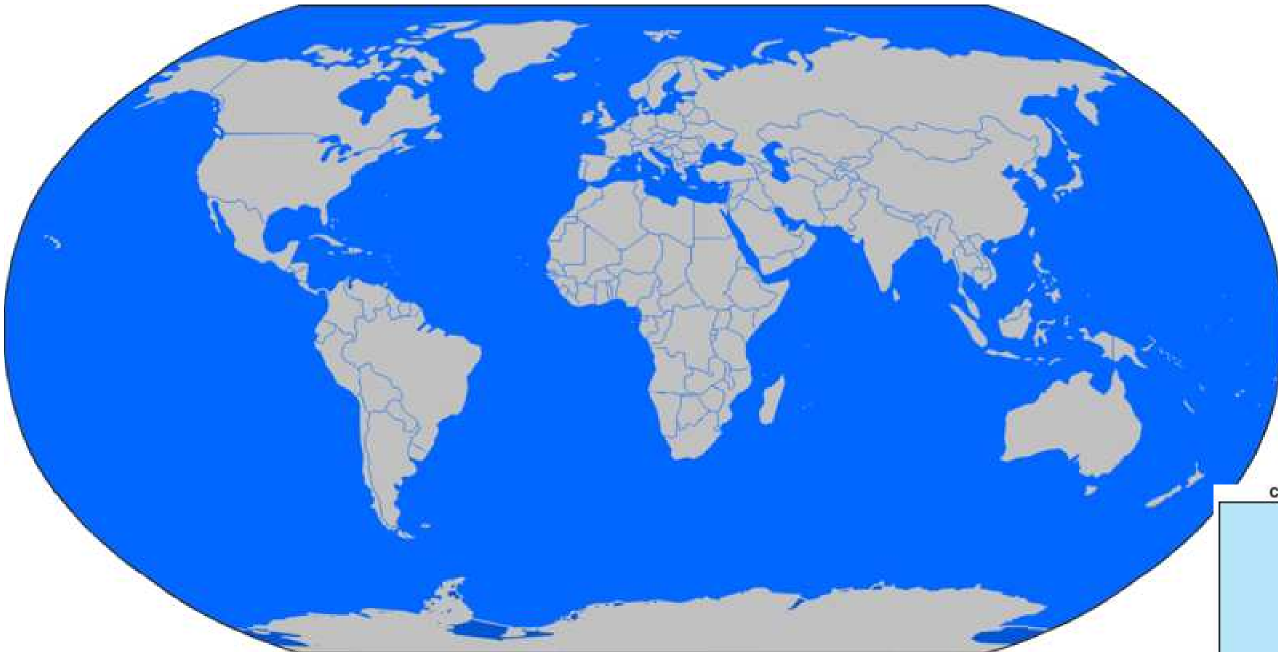
# Shape Evidence

The continents look as if they were pieces of a giant jigsaw puzzle that could fit together to make one giant super-continent.

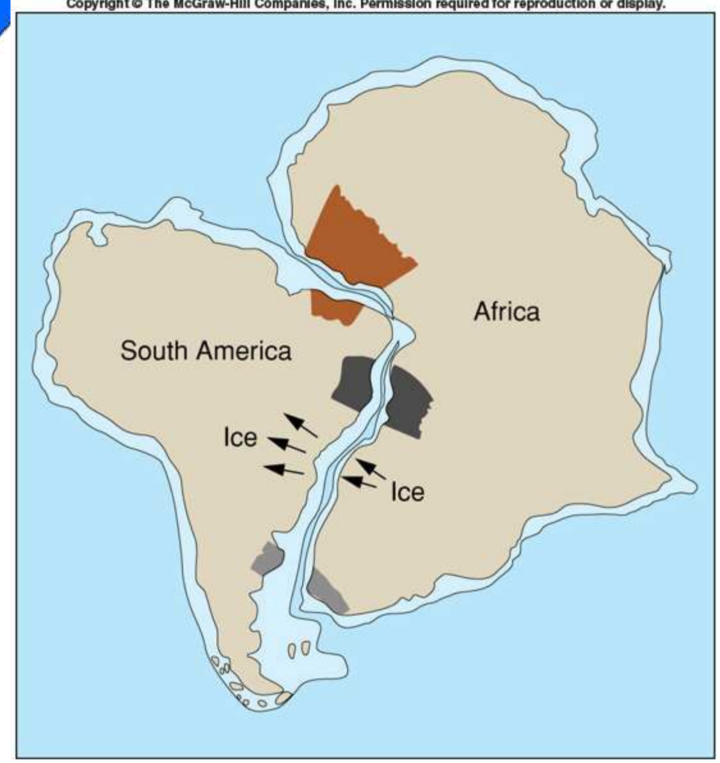
The bulge of Africa fits the shape of the coast of North America while Brazil fits along the coast of Africa beneath the bulge.

Best fit: coastlines of Africa and South America

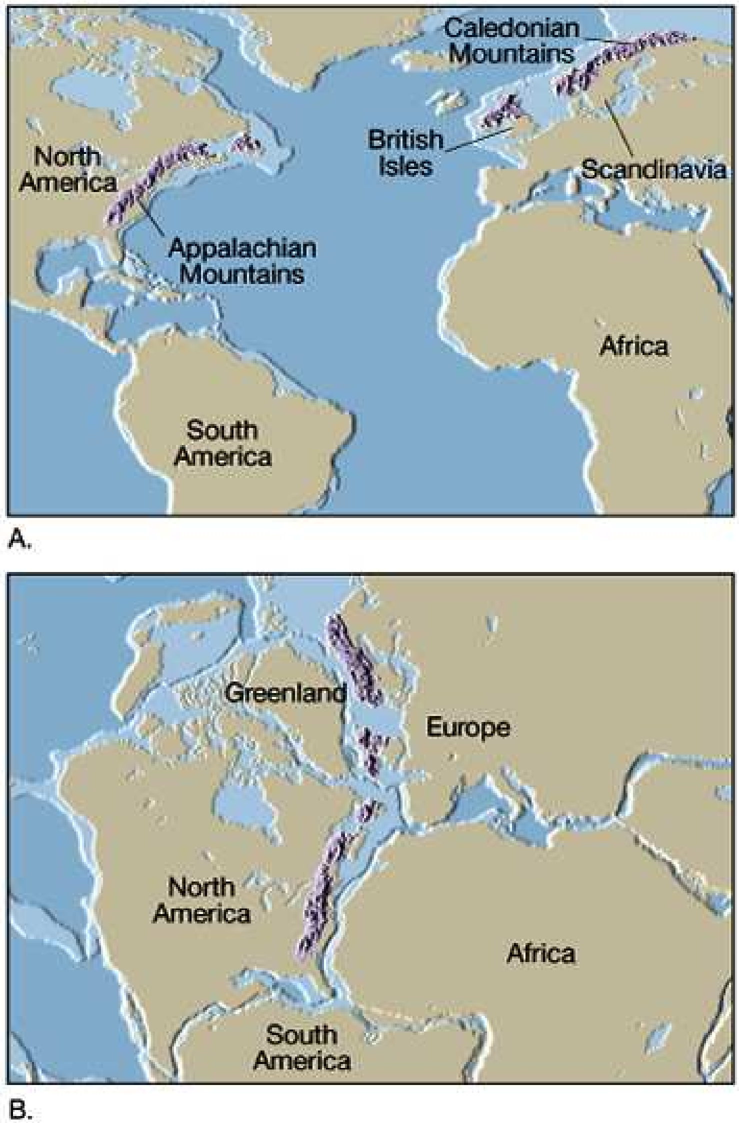
# Shape Evidence







# Shape Evidence



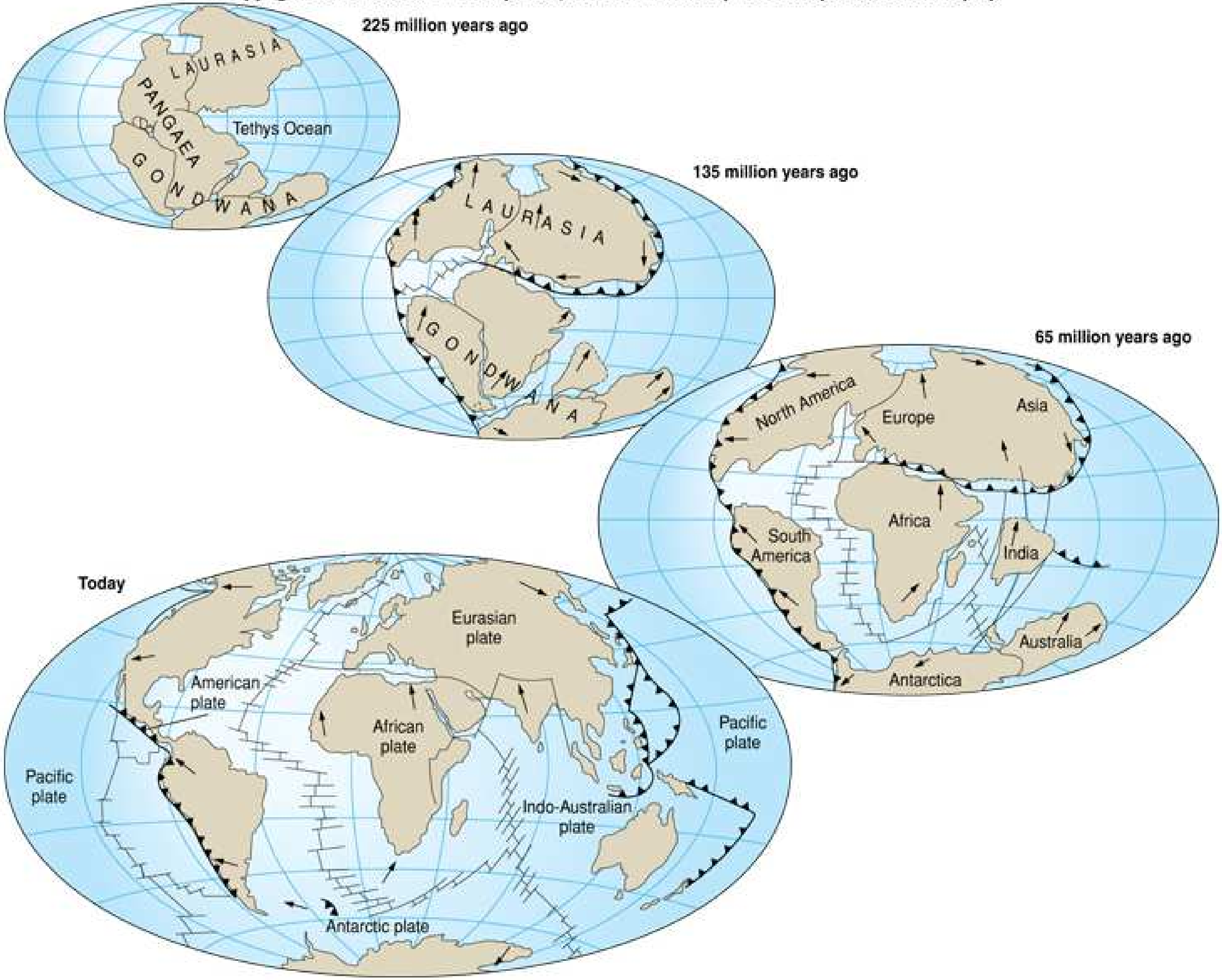

Matching mountain ranges on each side of the Atlantic Ocean.

The Appalachian Mountains off the coast of Newfoundland match mountains in the British Isles and Scandinavia which are comparable in age and structure.

# The Positions Don't Match

- The discovery of fossils of tropical plants (in *Coal beds*) in Antarctica led to the conclusion that this frozen land previously must have been situated closer to the equator, in a more temperate climate where lush, swampy vegetation could grow.

Impression fossil flowering plant leaves, Antarctica.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Eurasian plate
American plate
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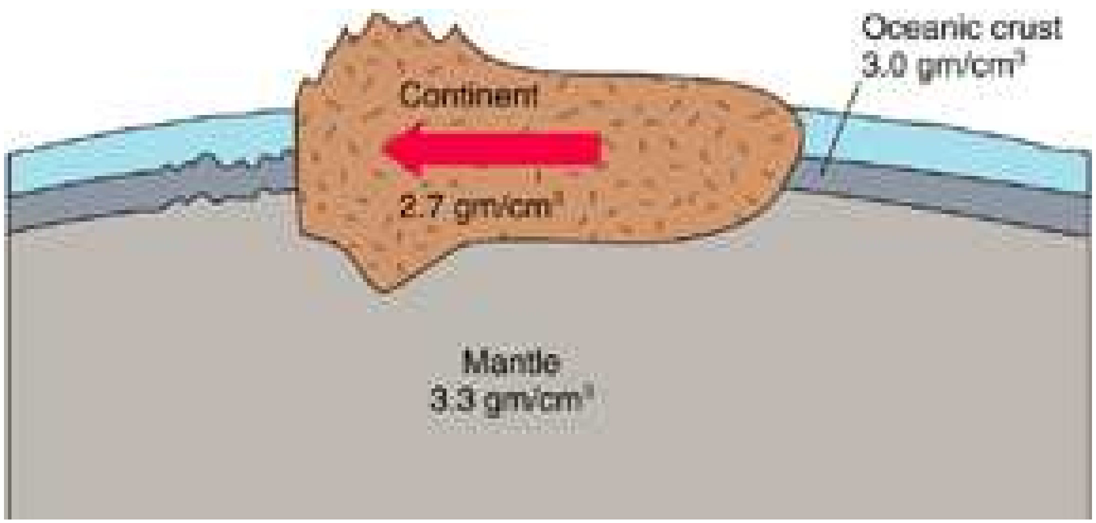
Pacific plate
Indo-Australian plate
Antarctic plate

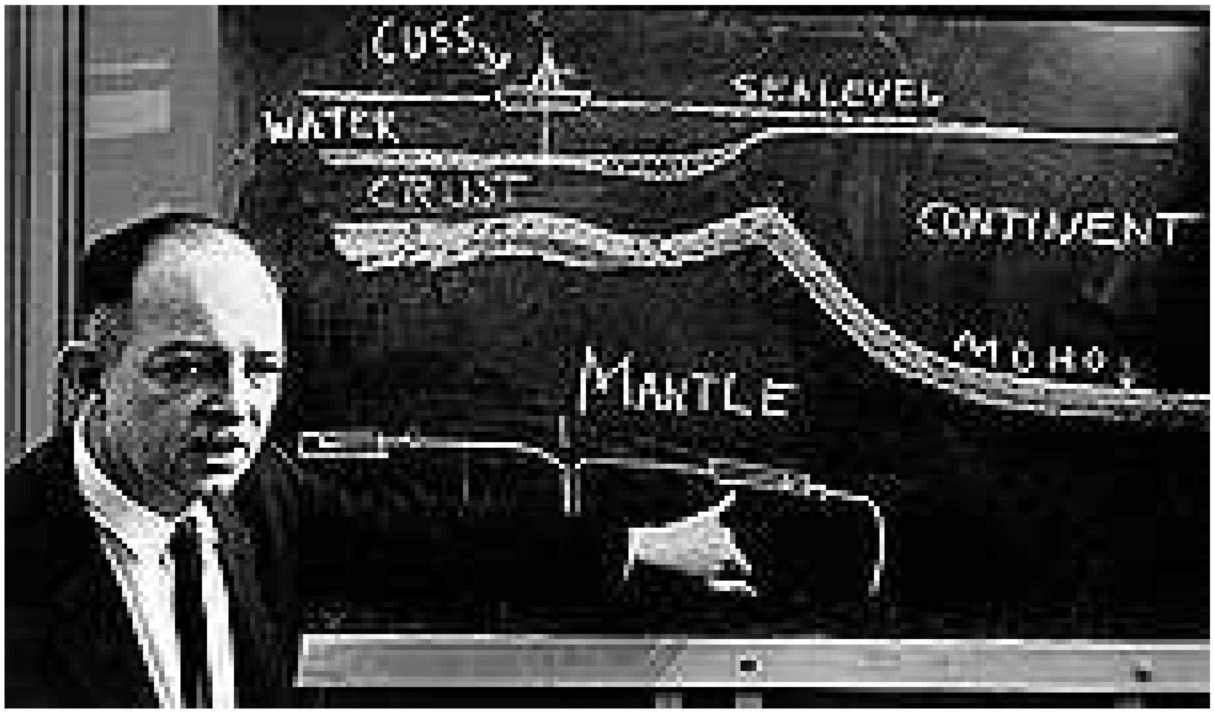
# Early Case for Continental Drift

Continental Drift hypothesis initially rejected

- Wegener could not come up with viable ***driving force***
- continents should not be able to "plow through" sea floor rocks while crumpling themselves but not the sea floor



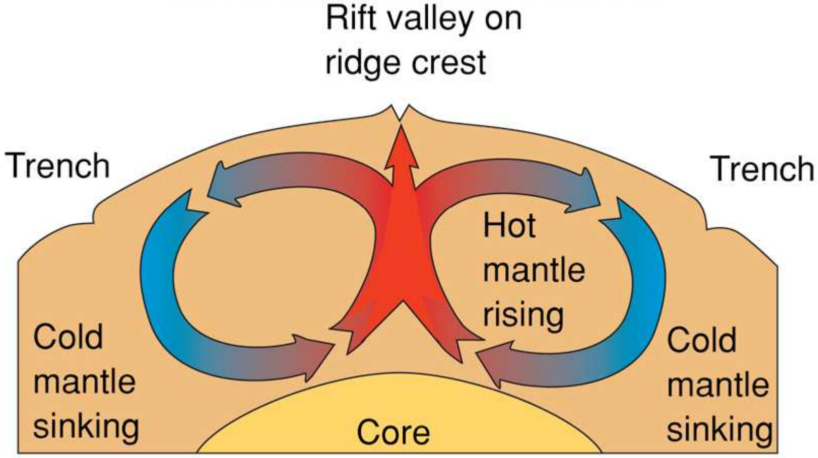
# Seafloor Spreading
## (Harry Hess)



# Seafloor Spreading

- In 1962, Harry Hess proposed *seafloor spreading*
  - Seafloor moves away from the mid-oceanic ridge due to mantle *convection*
  - *Convection* is circulation driven by rising hot material and/or sinking cooler material
- Hot mantle rock rises under mid-oceanic ridge
  - Ridge elevation, high heat flow, and abundant basaltic volcanism are evidence of this phenomenon

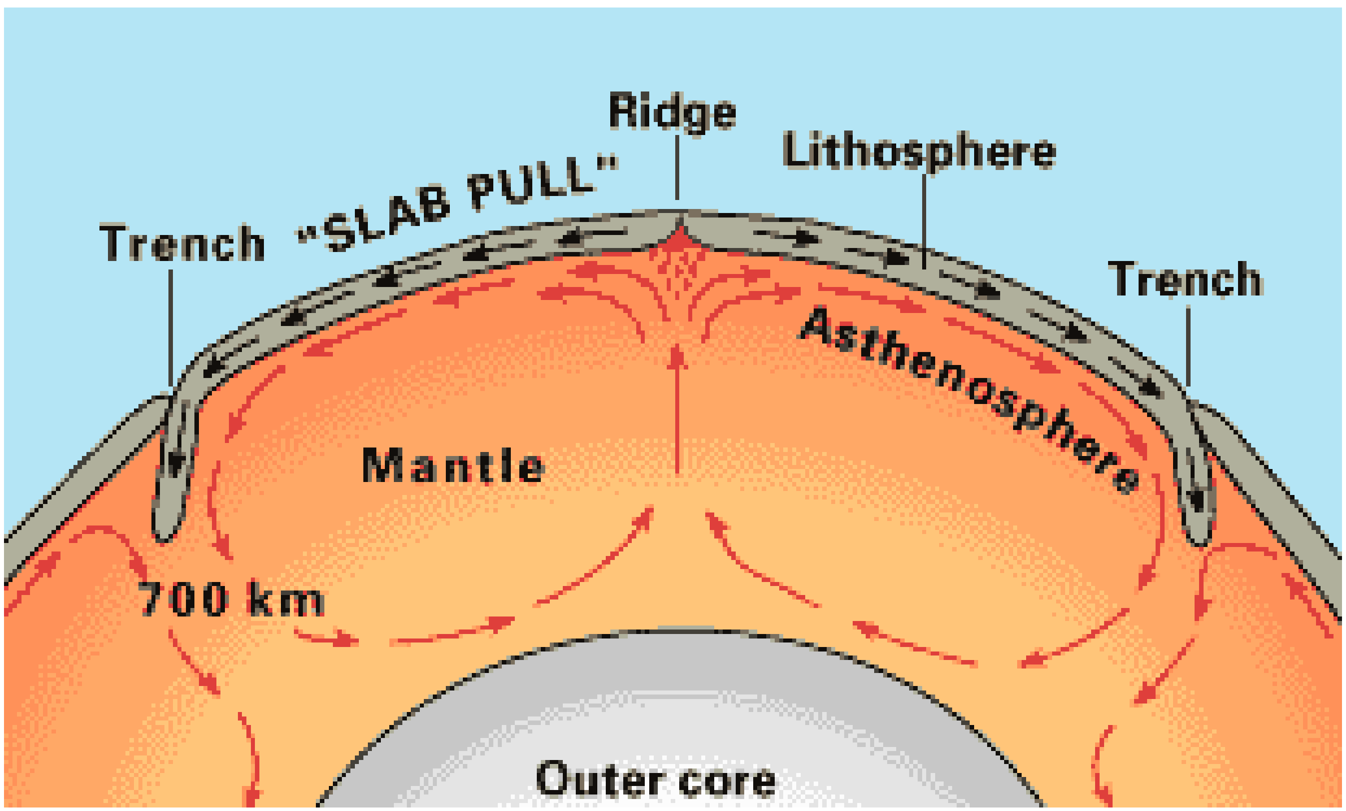





A

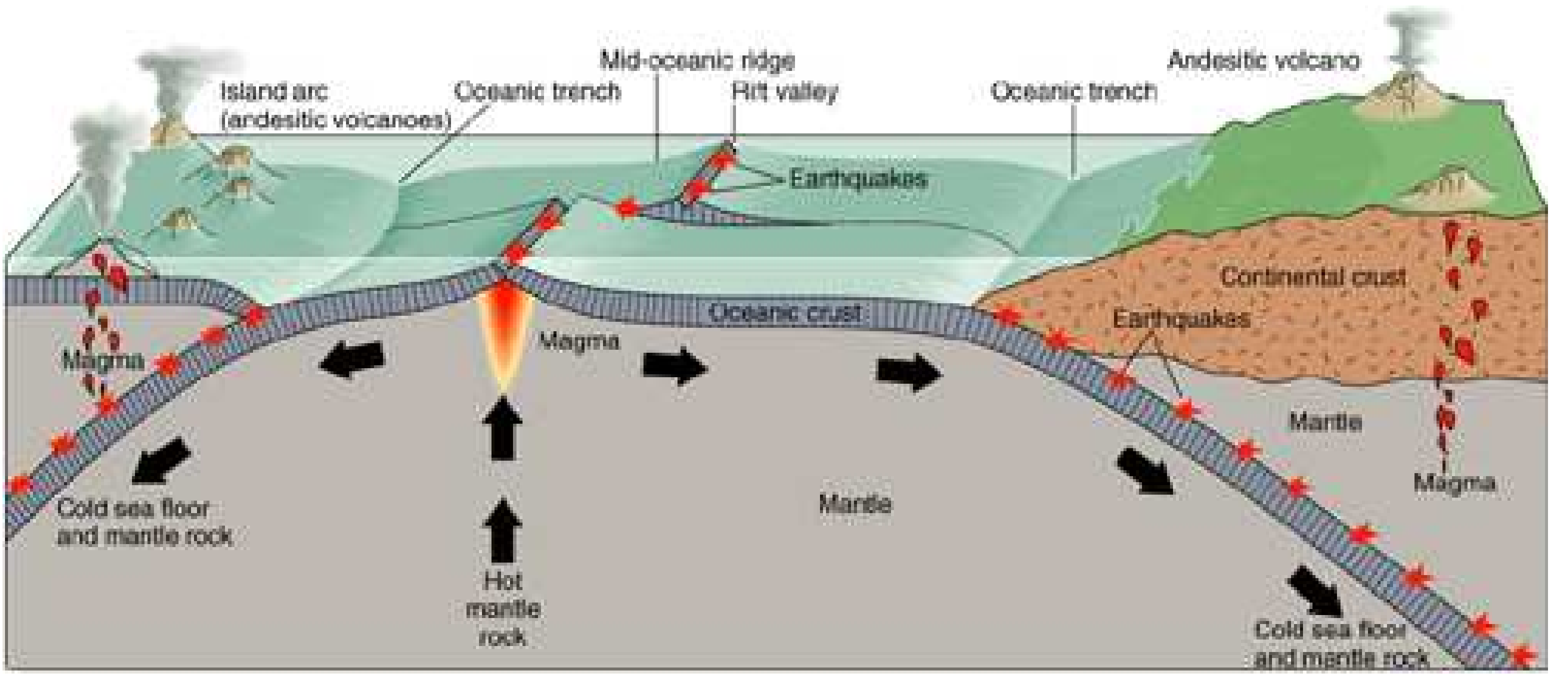
# Seafloor Spreading

- "Hypothesis that seafloor forms at the crest of mid-oceanic ridges, and moves horizontally away from the ridge, moving towards an oceanic trench, where it is destroyed"
- The youngest rocks are therefore found closest to the ridge where new crust is created from magma upwelling and the oldest rocks are found closest to trenches



# Seafloor Spreading

- Overall young age for sea floor rocks (everywhere <200 million years) is explained by this model



# 1960s

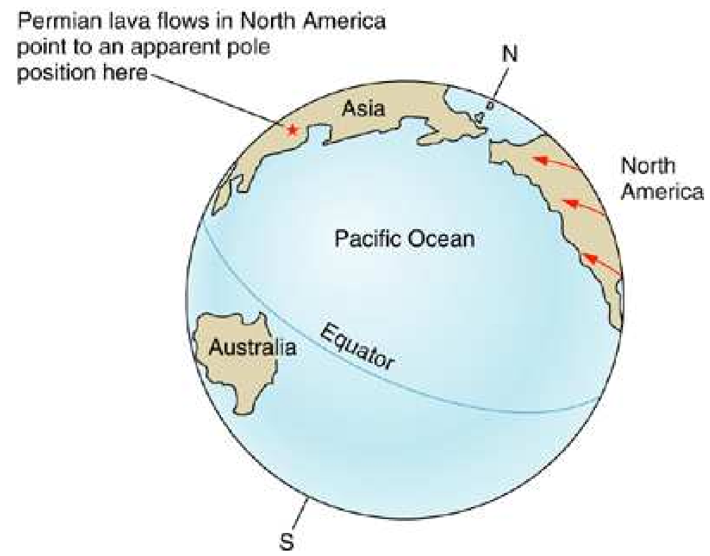
- New technology
- Earth’s magnetism study
- Geophysical (seismic) surveying techniques

# Paleomagnetism → Continental Drift

- Studies of *rock magnetism* allowed determination of magnetic pole locations (close to geographic poles) through time

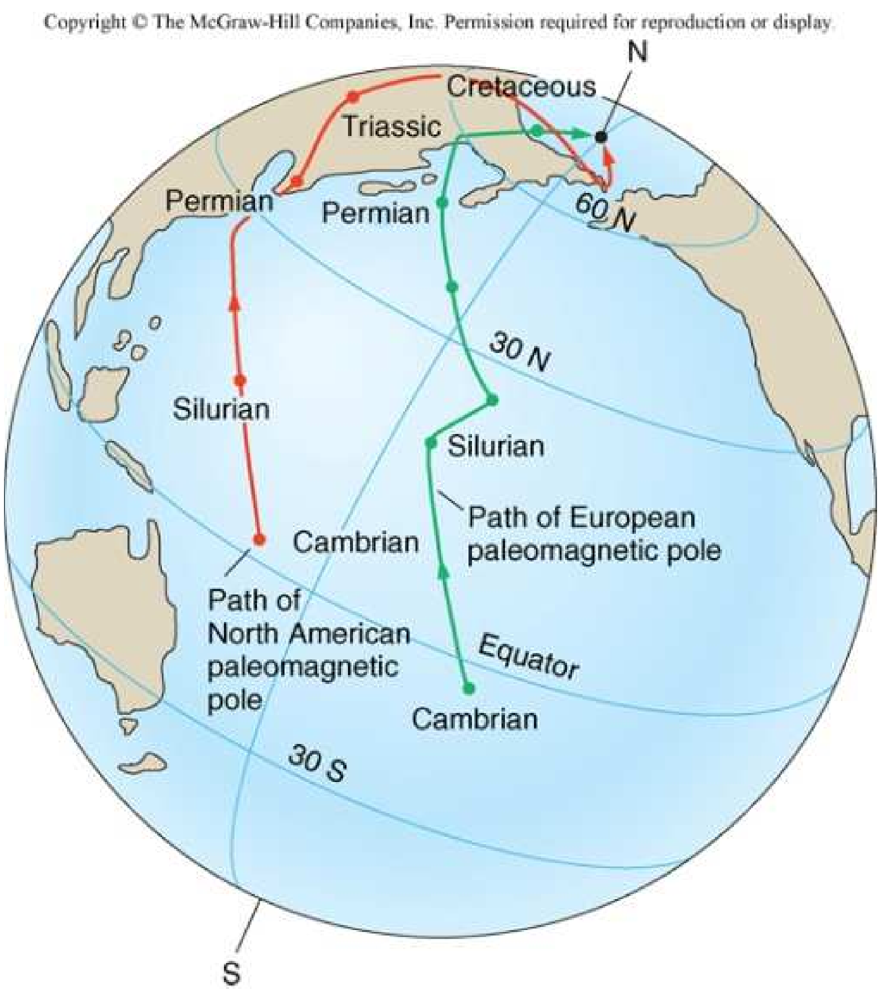
- *Paleomagnetism* uses mineral magnetic alignment direction and dip angle to determine the direction and distance to the magnetic pole when rocks formed
  - Steeper dip angles indicate rocks formed closer to the magnetic poles

- Rocks with increasing age point to pole locations increasingly far from present magnetic pole positions: Polar wandering



# Polar Wandering

- *Polar wandering* curves for different continents suggest real movement relative to one another



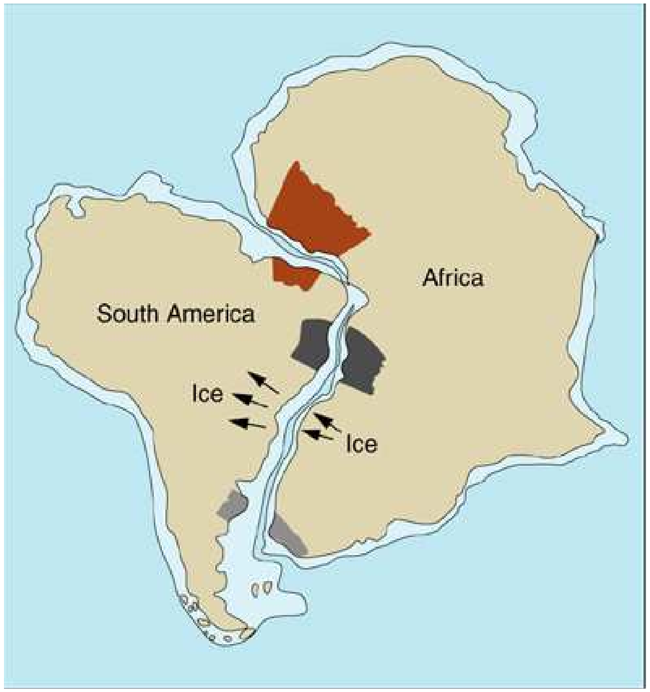

Rocks of the same age in Europe and North America suggested that the north pole was in two positions at the same time.

# Apparent Polar Wandering

- Reconstruction of supercontinents using paleomagnetic information fits the polar wandering curves, and Africa and South America like puzzle pieces
  - Improved fit results in rock units (and glacial ice flow directions) precisely matching up across continent margins


A.


B.



# Plate Tectonics

- By the mid-1960s, the twin ideas of moving continents and a moving sea floor were causing great excitement among geologists

- By the late 1960s, these ideas had been combined into a single theory "Theory of Plate Tectonics" that revolutionized geology

# Plates

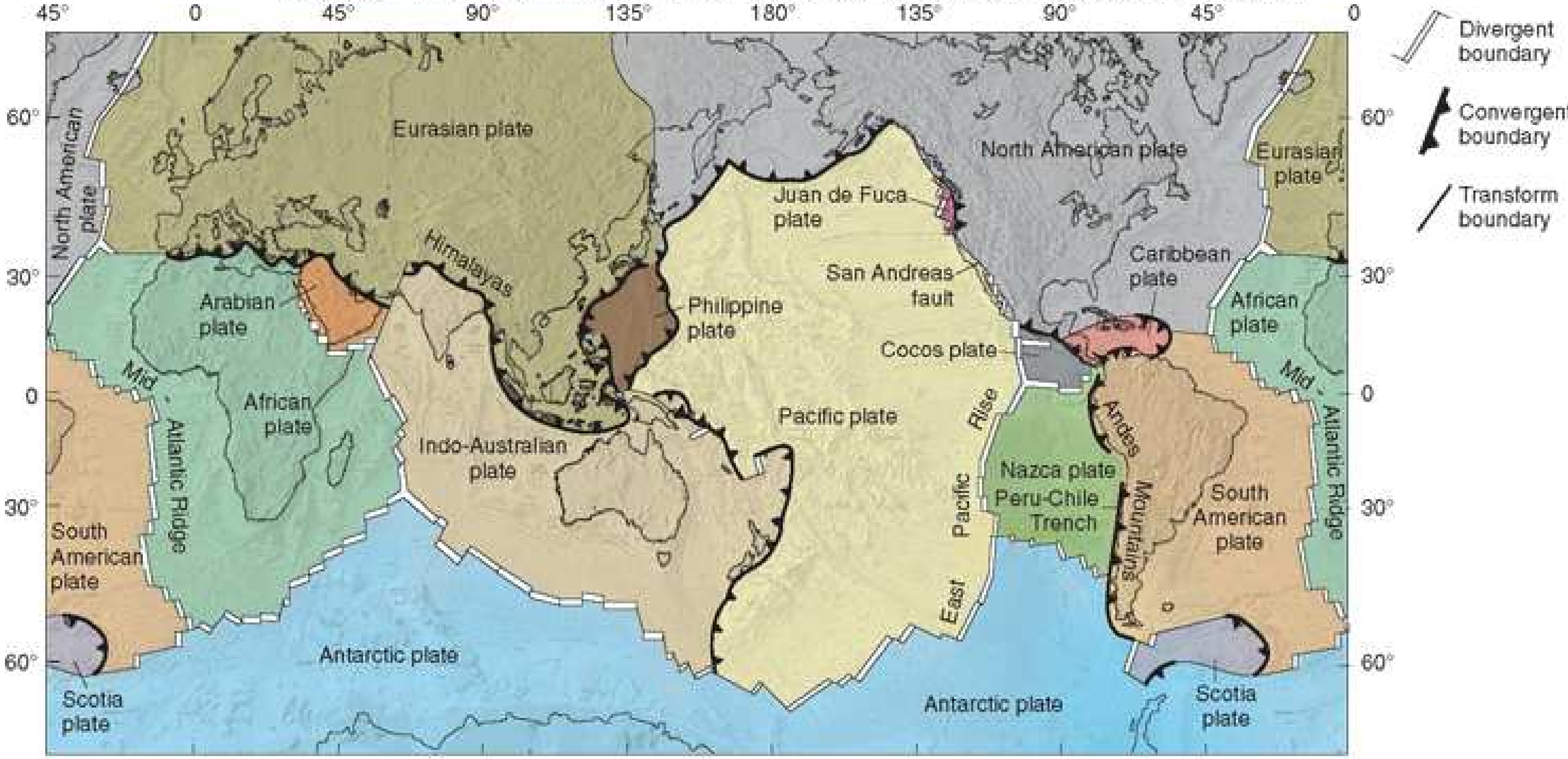
- Plate is a large mobile slab of rock that is part of the Earth's surface.

- The surface of a plate may be made up entirely of sea floor (Nazca Plate), or it may be made up of both continental and oceanic plate (North American Plate).

- Some of the small plates are entirely continental, but all the large plates contain some sea floor.

# Plate Tectonics



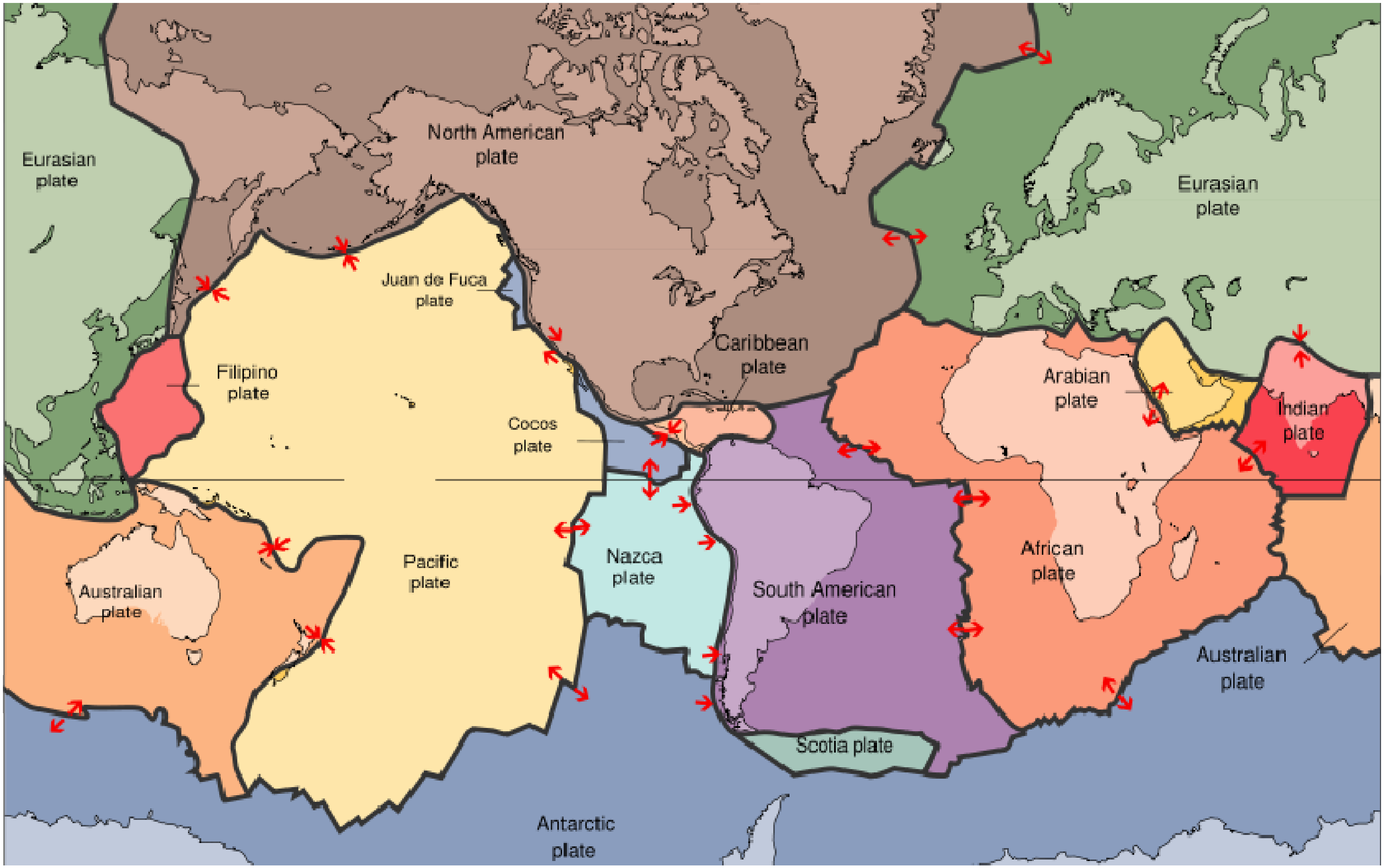



Modified from W. Hamilton, U.S. Geological Survey

# Plates and Plate Motion

- Tectonic plates are composed of the relatively rigid *lithosphere*
- Plates "float" upon ductile *asthenosphere*
- Plates interact at their boundaries, which are classified by relative plate motion
  - Plates move apart at *divergent* boundaries, together at *convergent* boundaries, and slide past one another at *transform* boundaries

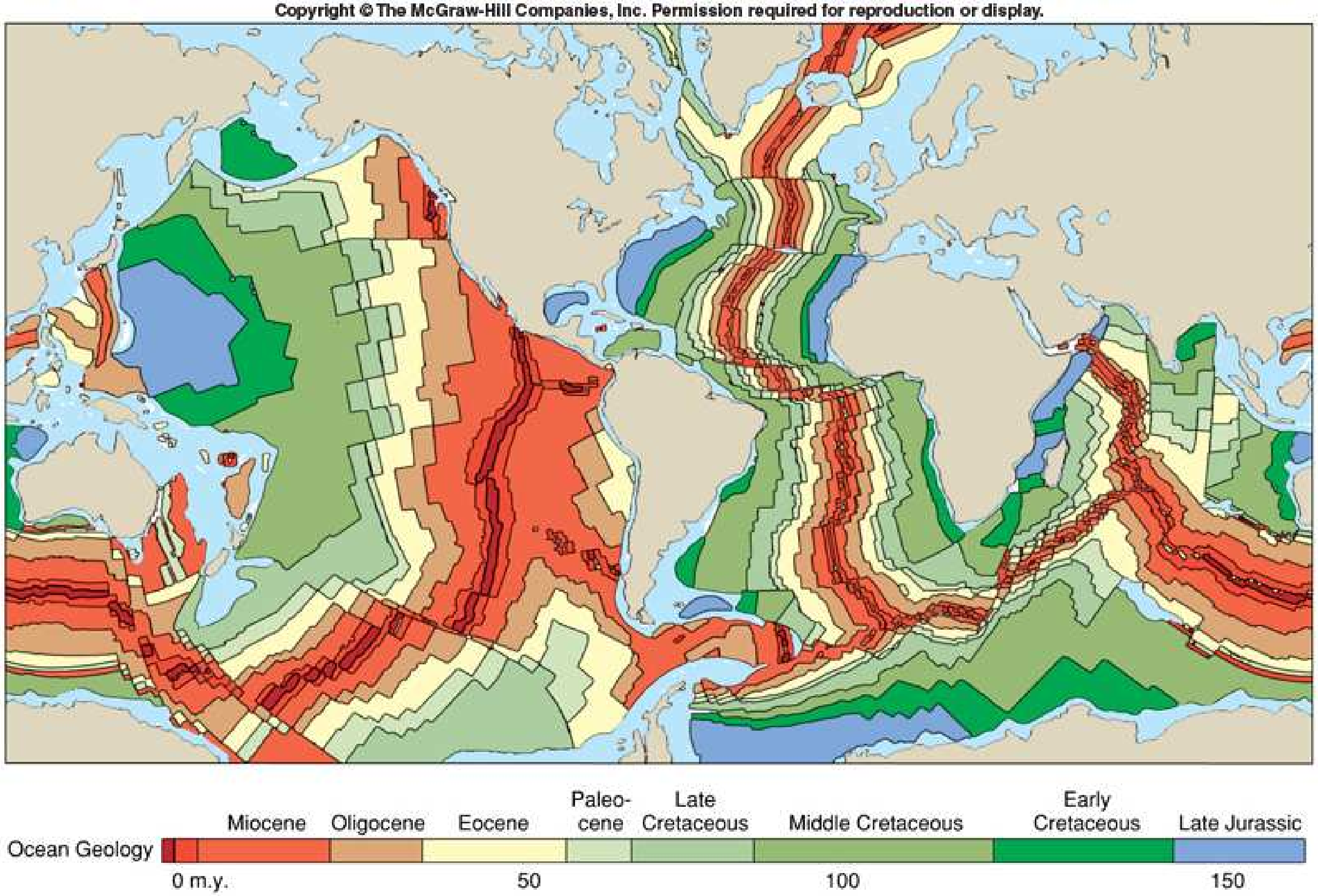
# Plate Motion and Direction



# Indirect Evidence of Plate Motion

- Seafloor age *increases with distance* from mid-oceanic ridge
  - *Rate of plate motion* equals distance from the ridge divided by age of rocks
  - Symmetric age pattern reflects plate motion away from ridge





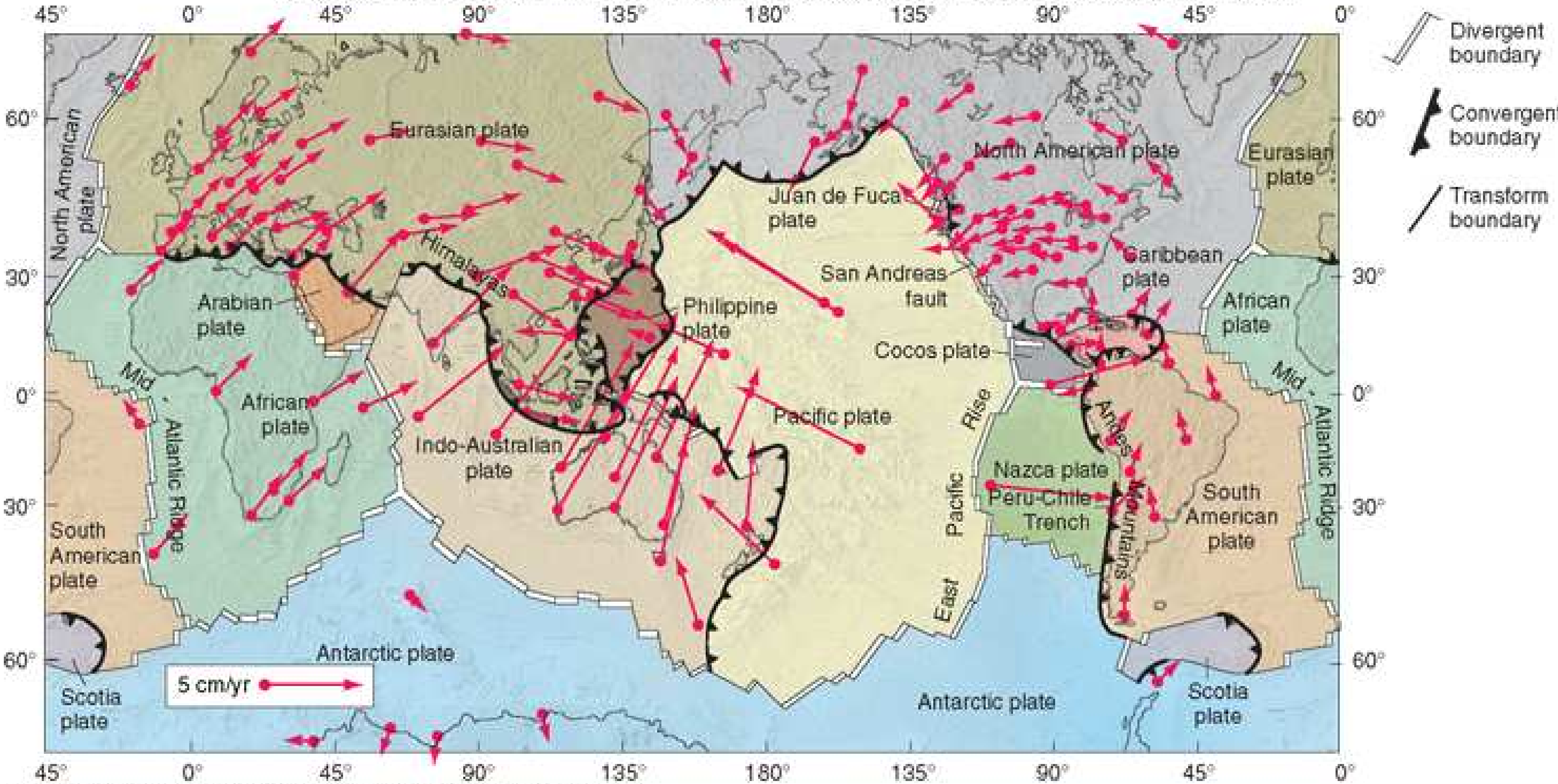
# Direct Evidence of Plate Motion

- Plate motion can be measured using satellites, and **global positioning systems**
  - Measurements accurate to within 1 cm

GPS system being installed in Iceland

# Direct Evidence of Plate Motion






From NASA (http://slideshow.jpl.nasa.gov/mbh/series.html)

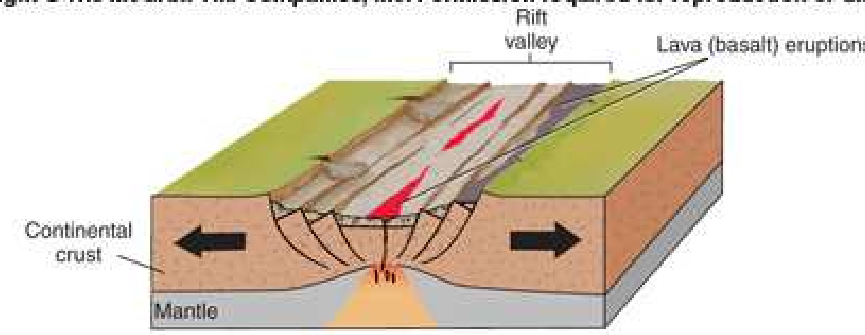
Yearly Plate Motion From Stations around the World

# Divergent Plate Boundaries

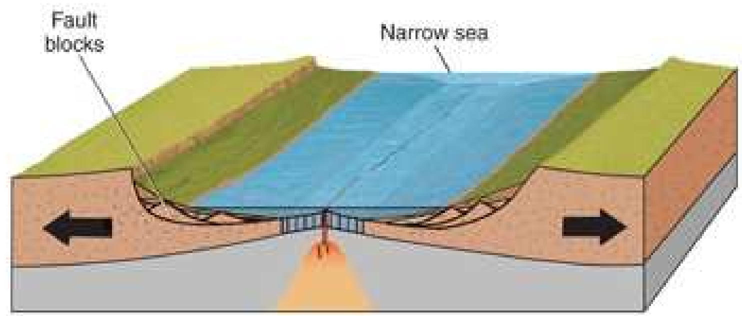
- At *divergent plate boundaries*, plates move away from each other
  - Can occur in the middle of the ocean or within a continent
  - Divergent motion eventually creates a new ocean basin
- Marked by rifting, basaltic volcanism
  - During rifting, crust is stretched and thinned
  - Volcanism common as magma rises through thinner crust

# Divergent Plate Boundaries

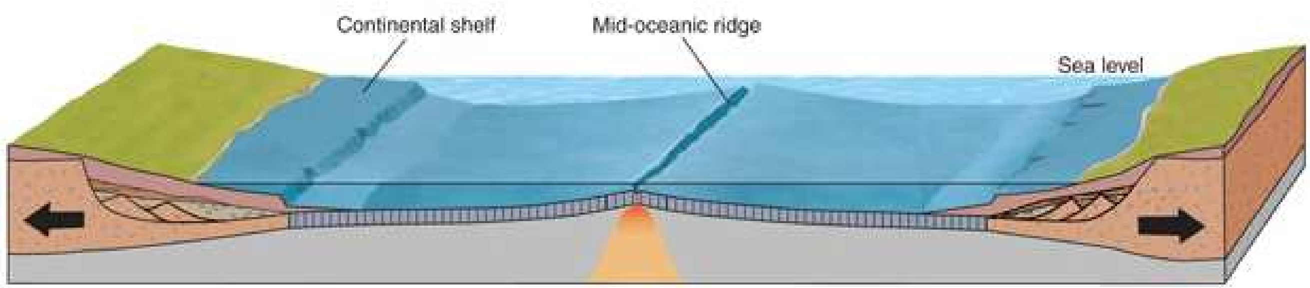





**A** Continent undergoes extension. The crust is thinned and a rift valley forms.




**B** Continent tears in two. Continent edges are faulted and uplifted. Basalt eruptions form oceanic crust.




**C** Continental sediments blanket the subsiding margins to form continental shelves. The ocean widens and a mid-oceanic ridge develops, as in the Atlantic Ocean.

# Divergent Plate Boundaries



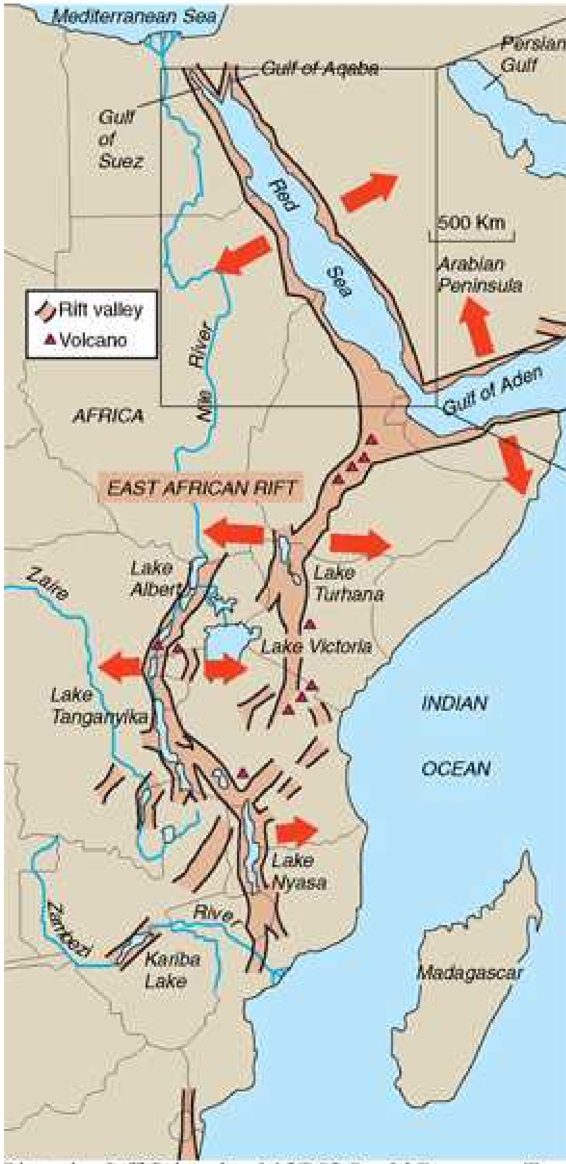



Photo by Jeff Schmaltz, MODIS Rapid Response Team, NASA/GSFC (http://visibleearth.nasa.gov/)

# Convergent Plate Boundaries

- At *convergent plate boundaries*, plates move toward one another
- Nature of boundary depends on plates involved (oceanic vs. continental)
  - *Ocean-ocean plate convergence*

    Marked by *ocean trench, Benioff zone earthquake,* and *volcanic island arc*

  - *Ocean-continent plate convergence*

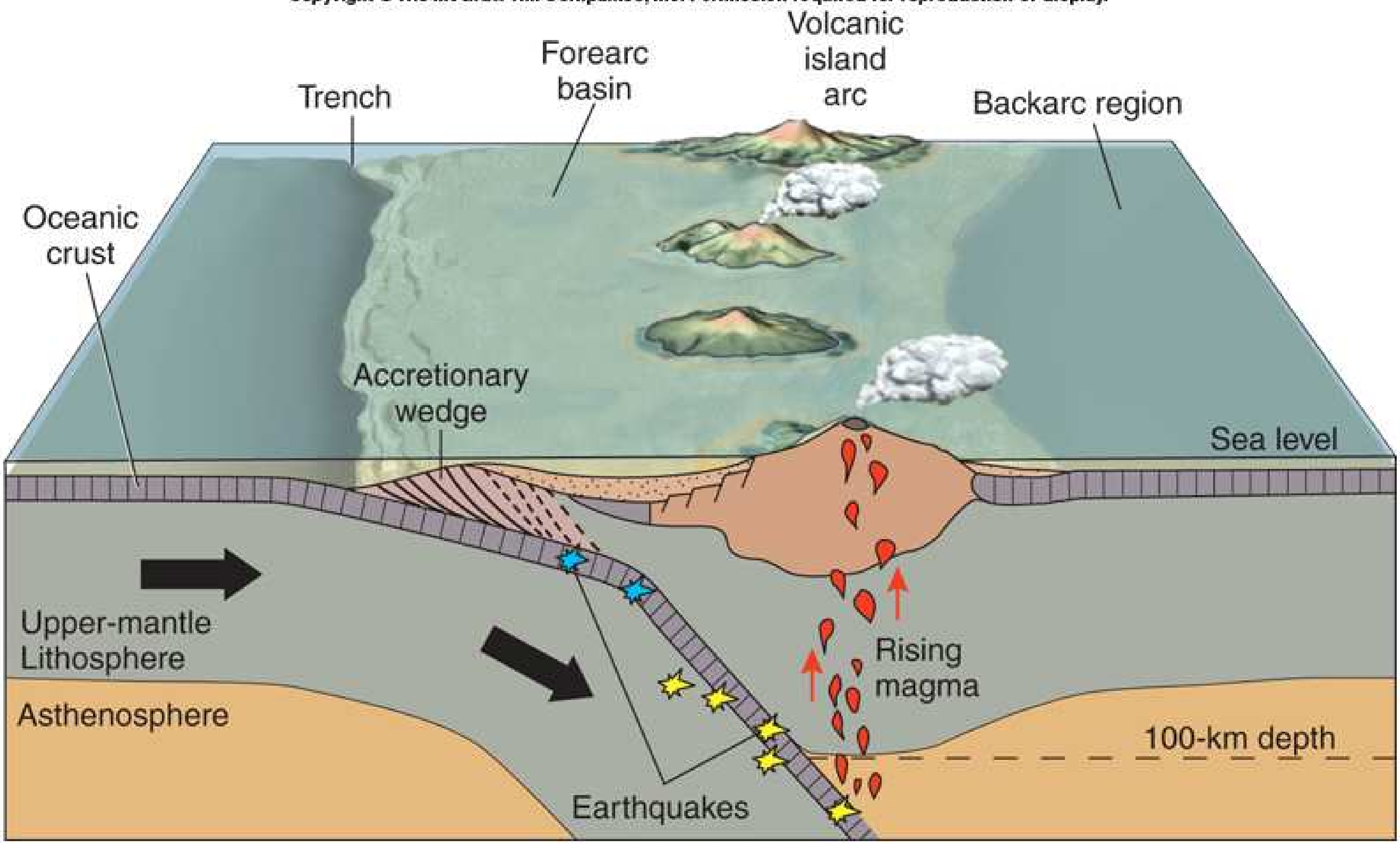
    Marked by ocean trench, Benioff zone earthquake, and *volcanic chain*

  - *Continent-Continent plate convergence*

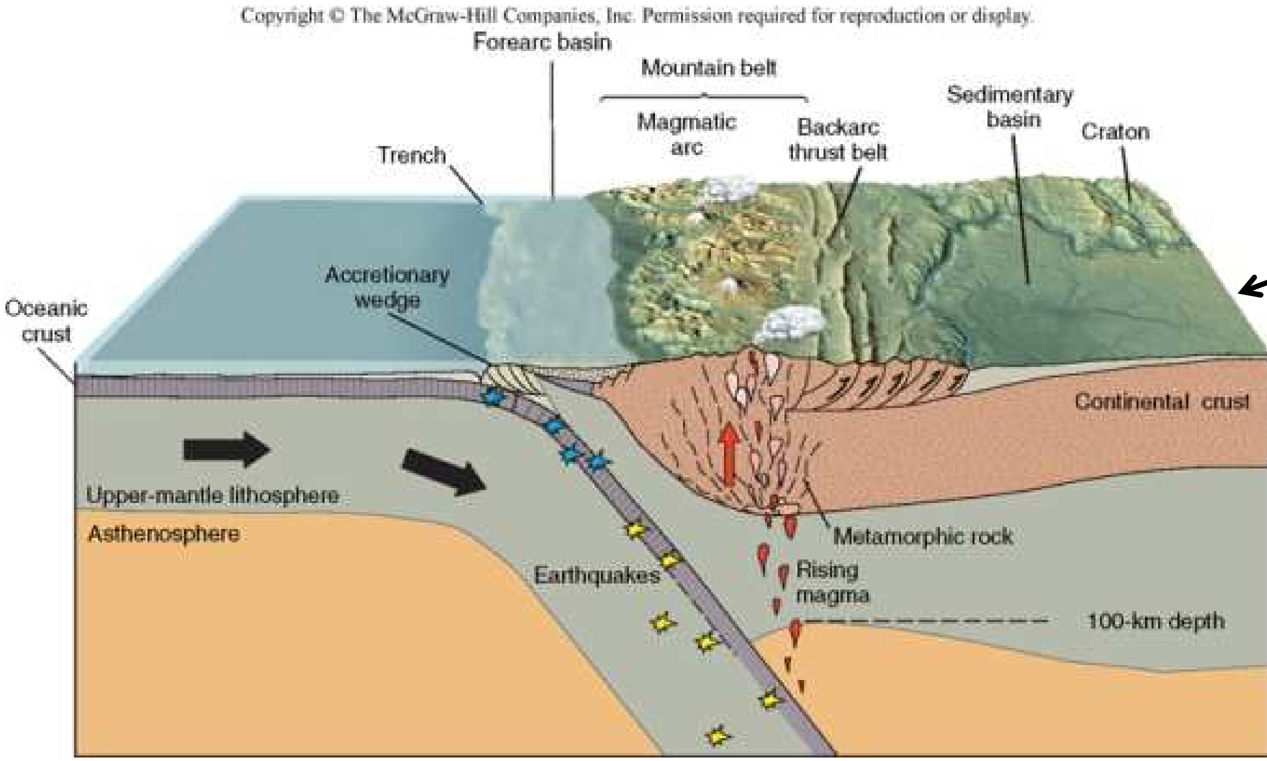
    Marked by mountain belts

# Oceanic – Oceanic Convergence

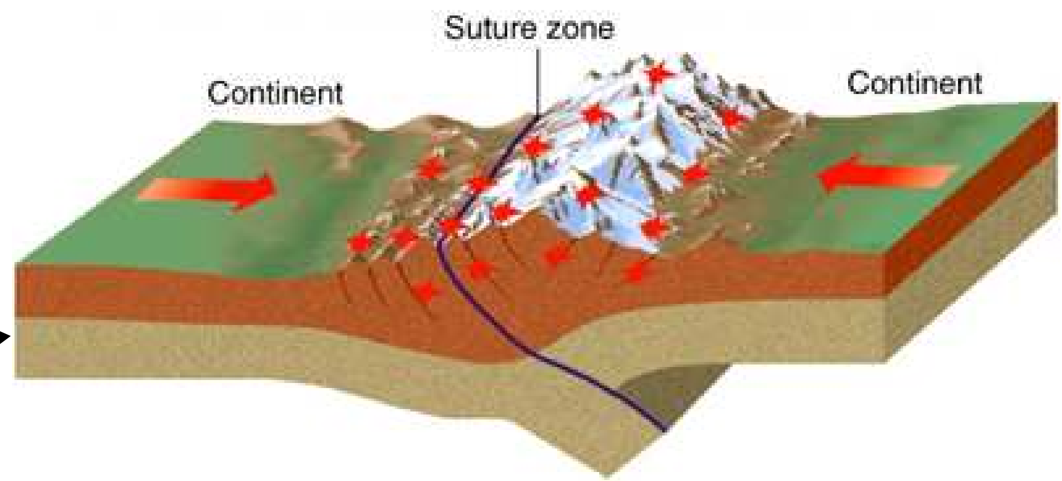




# Convergent Plate Boundaries



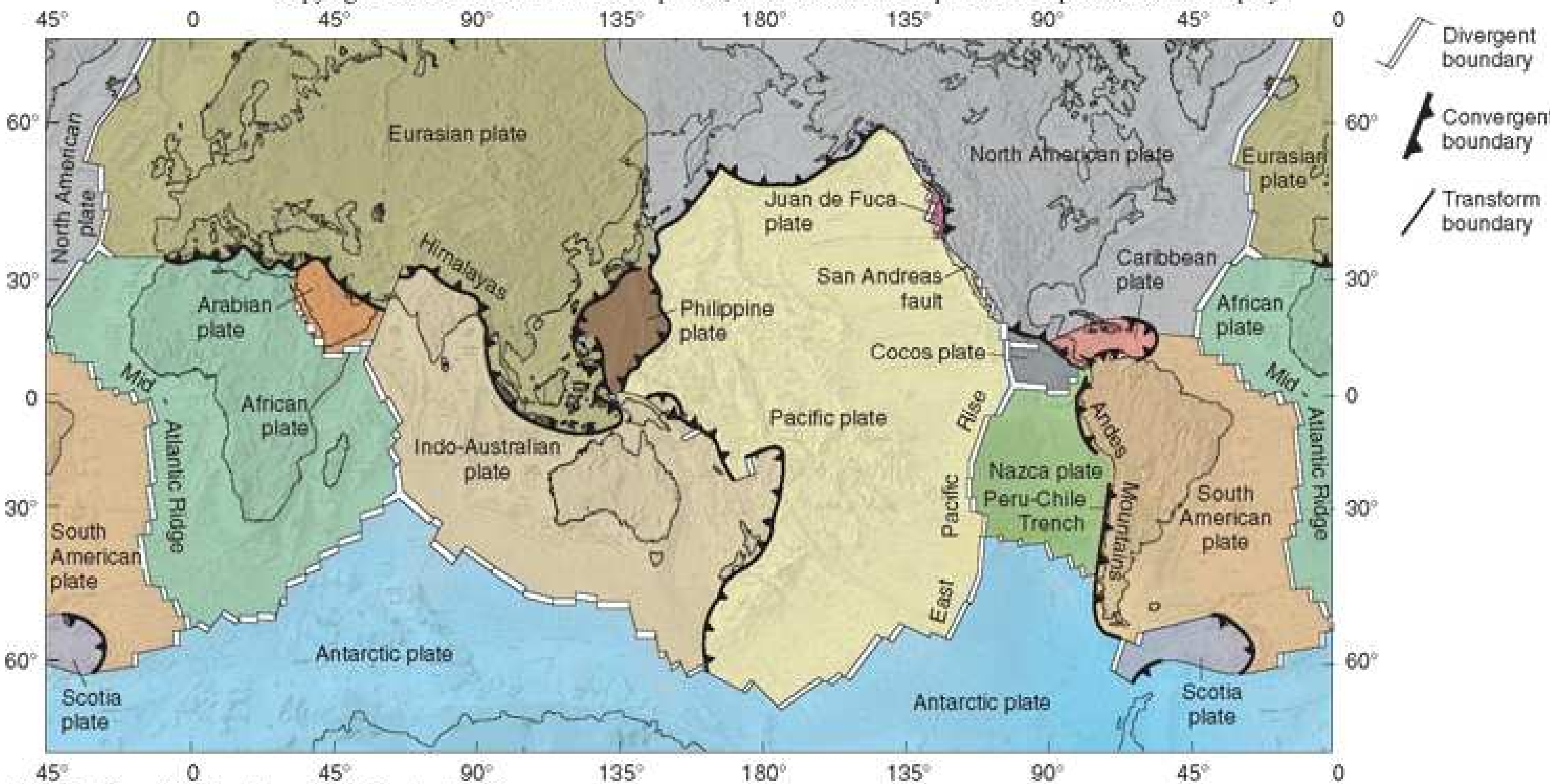

Oceanic - Continental




Continental - Continental

# Convergent Plate Boundaries



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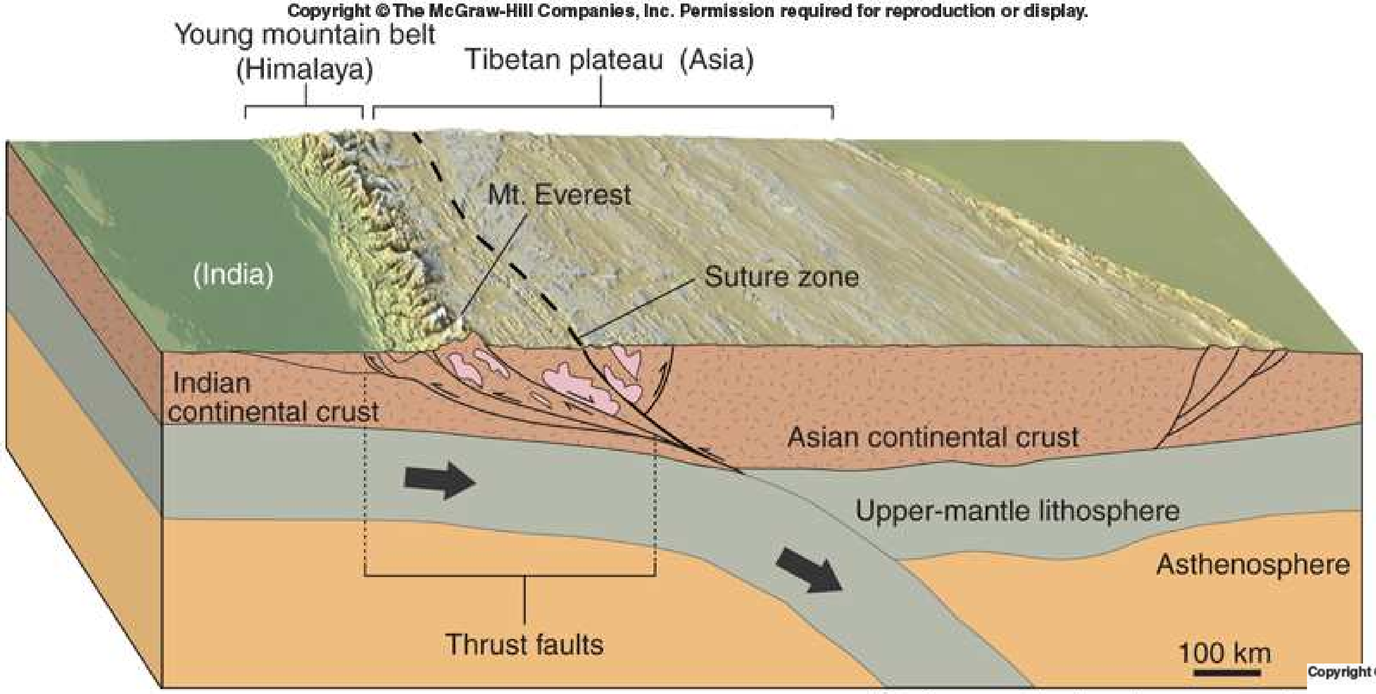
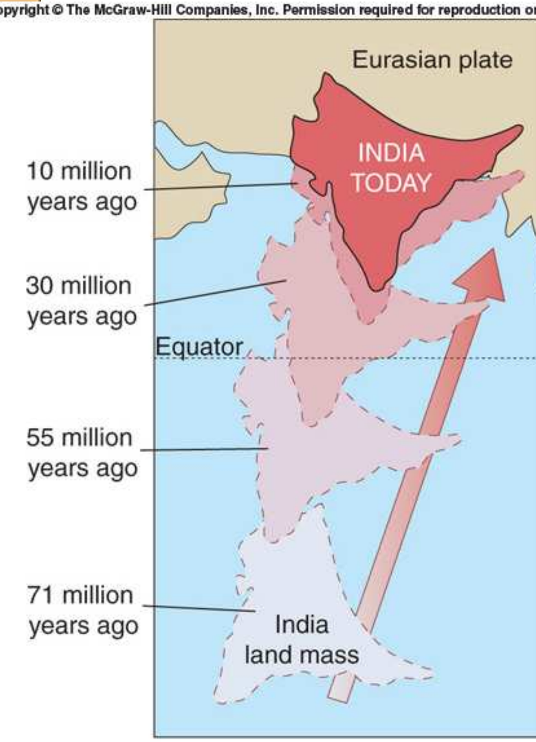



**B** Continent-continent collision

(Surface vertical scale exaggerate






**C**

# Transform Plate Boundaries

- At *transform plate boundaries*, plates slide horizontally past one another
  - Marked by *transform faults*



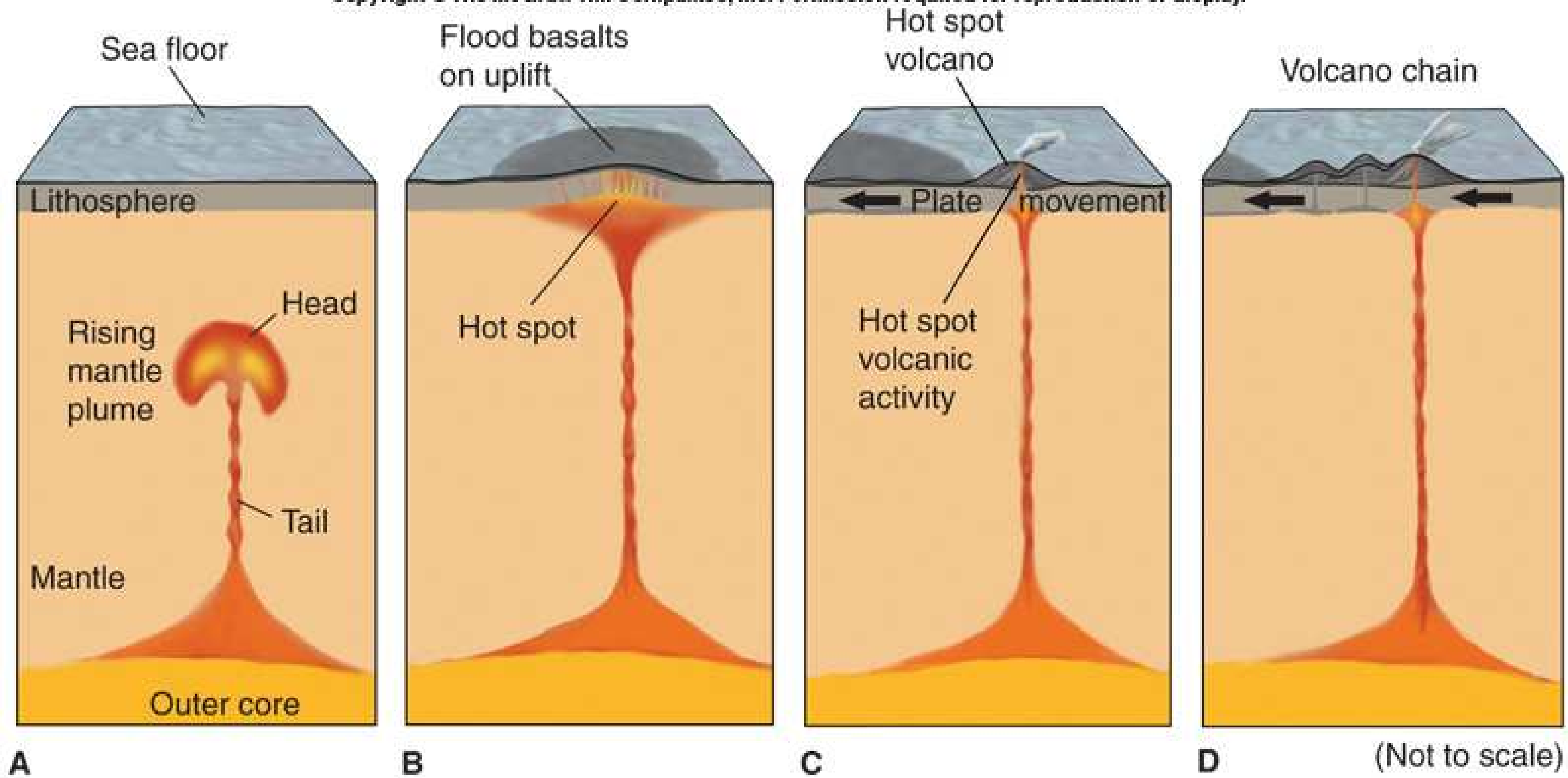

D

# Mantle Plumes and Hot Spots

- Mantle plumes - narrow columns of hot mantle rock rise through the mantle
  - Stationary with respect to moving plates
  - Large mantle plumes may spread out and tear apart the overlying plate
    - Basalt eruptions
    - Rifting apart of continental land masses
  - New divergent boundaries may form

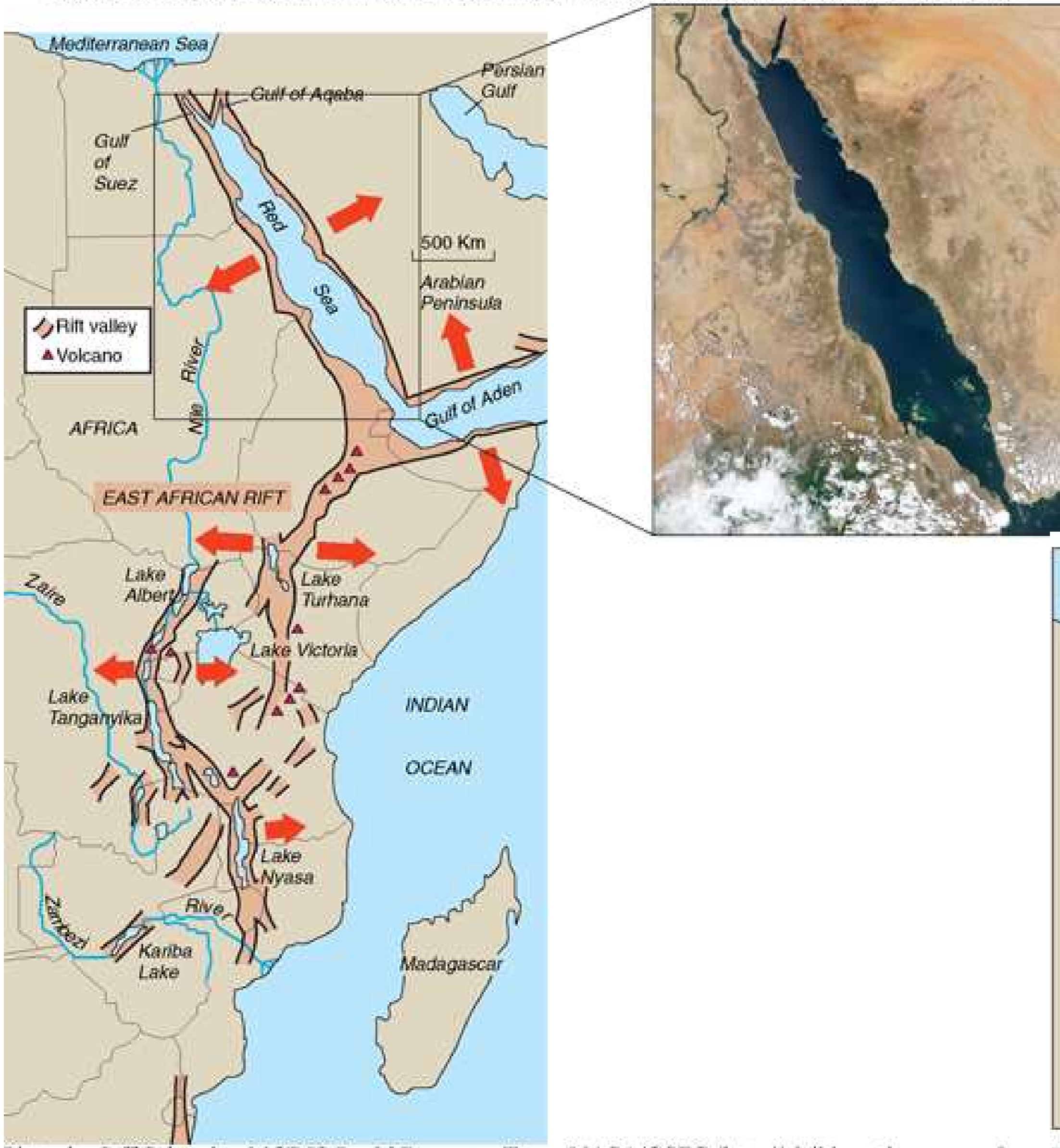
# Mantle Plumes and Hot Spots





# Mantle Plume and Divergent Plate Boundaries



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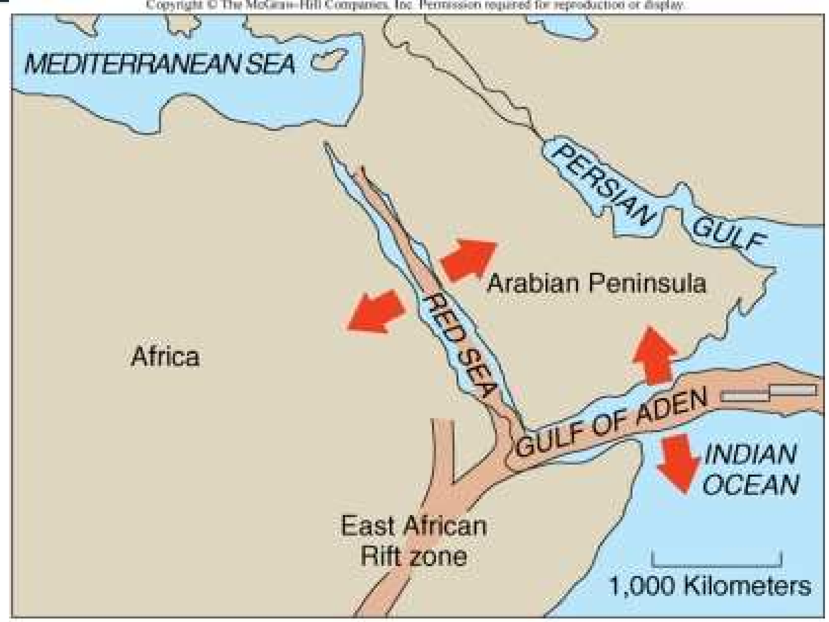
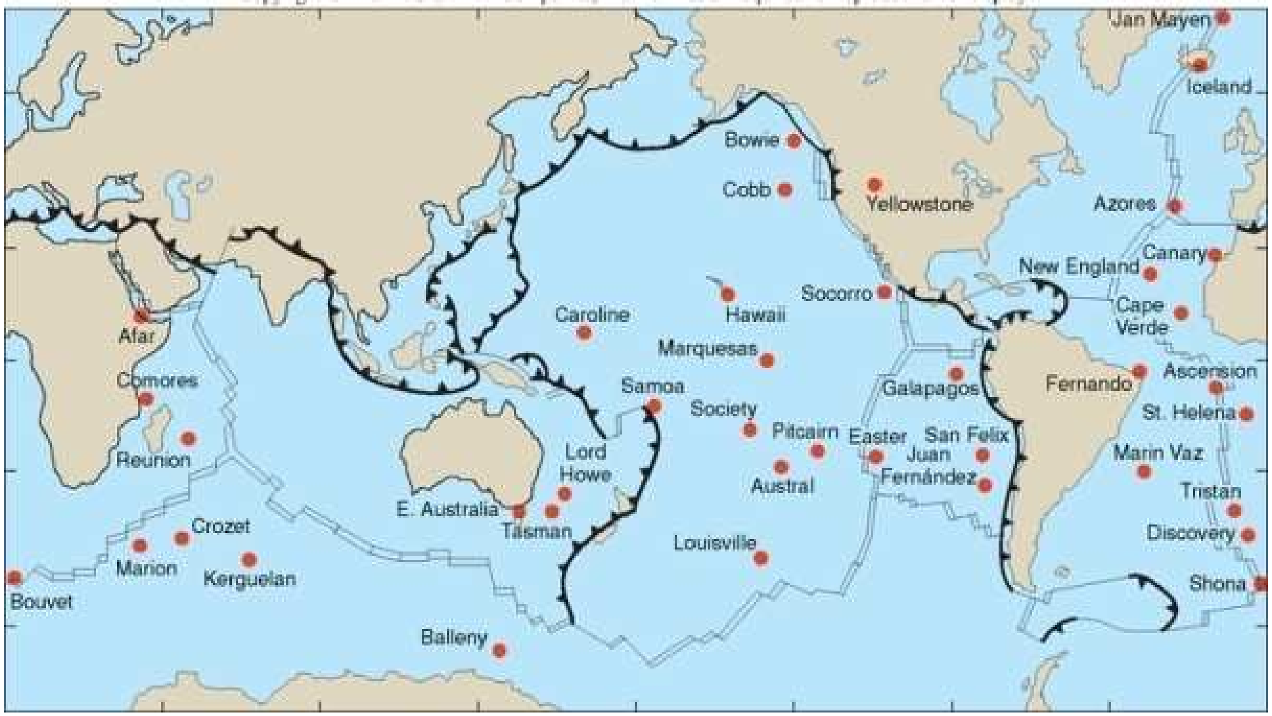



D

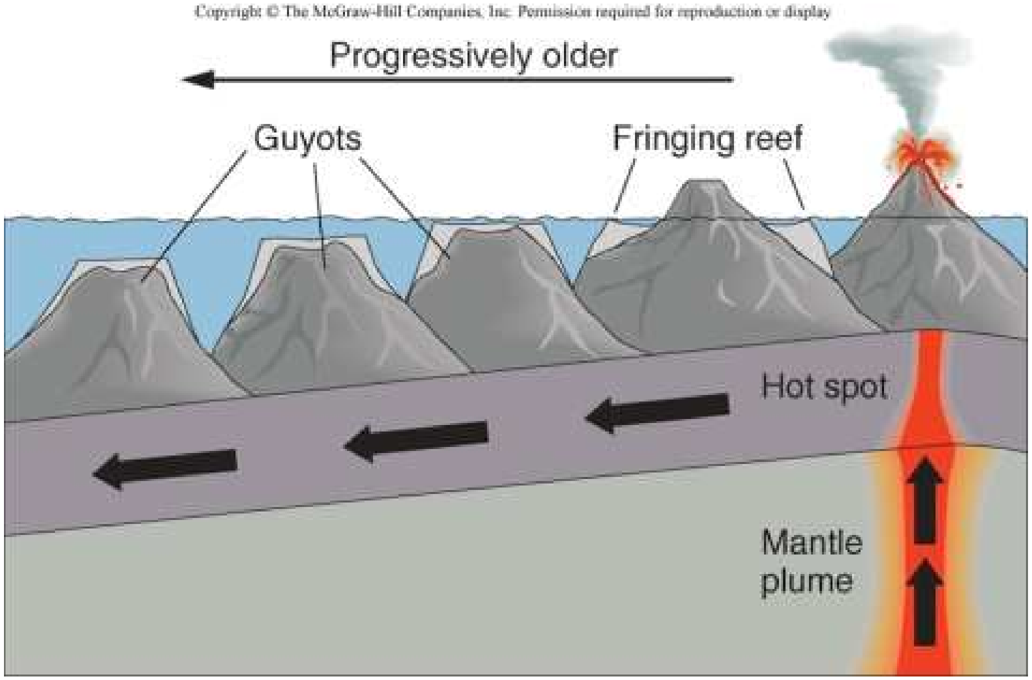
# Mantle Plumes and Hot Spots

- Mantle plumes may form *"hot spots"* of active volcanism at Earth's surface
  - Approximately 45 known hotspots
- Hot spots in the interior of a plate produce *volcanic chains*
  - Hawaiian islands are a good example





# Mantle Plume - Hawaii




- *Orientation* of the volcanic chain shows *direction* of plate motion over time
- *Age* of volcanic rocks can be used to determine *rate* of plate movement