Chapter 19, 20, 18 - Plate Tectonics

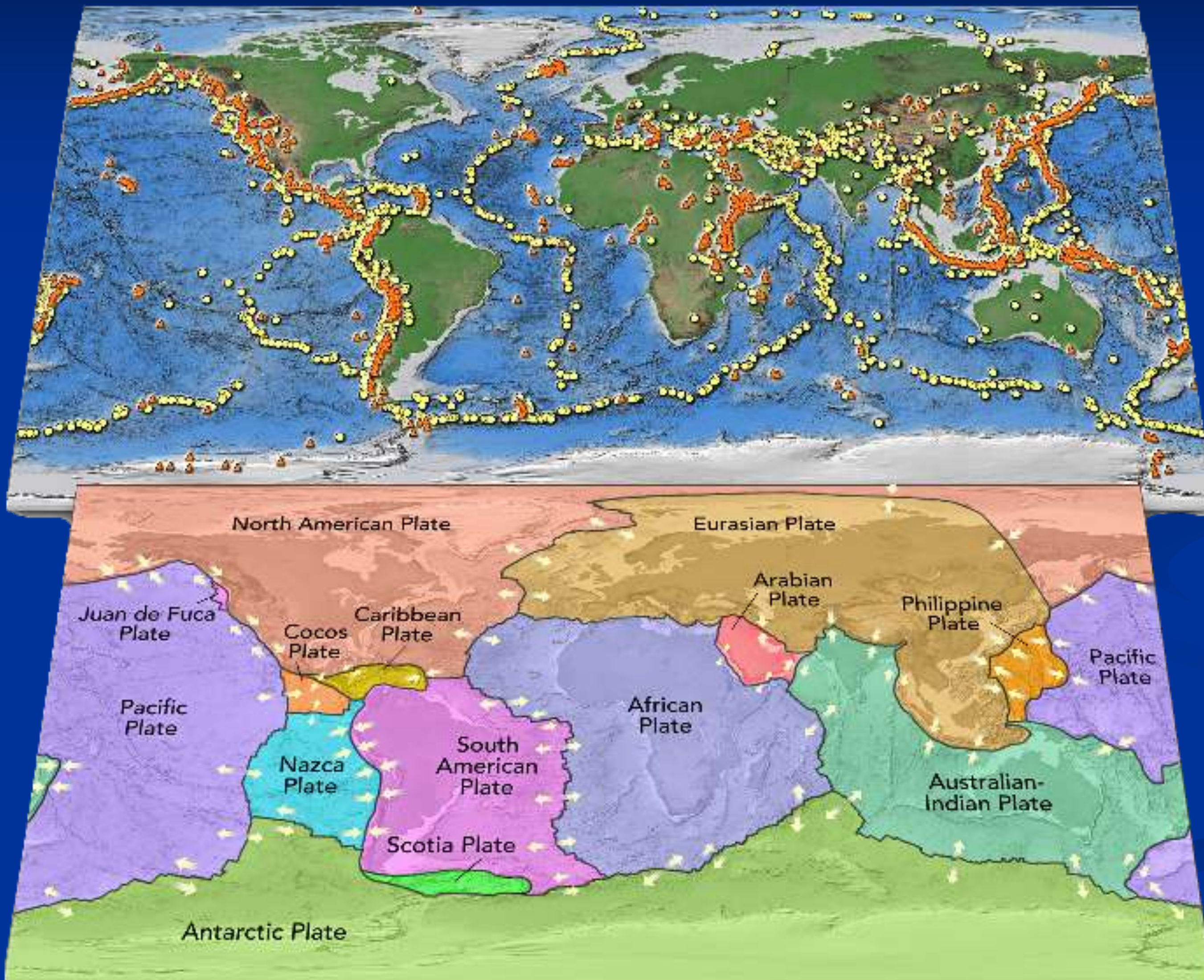
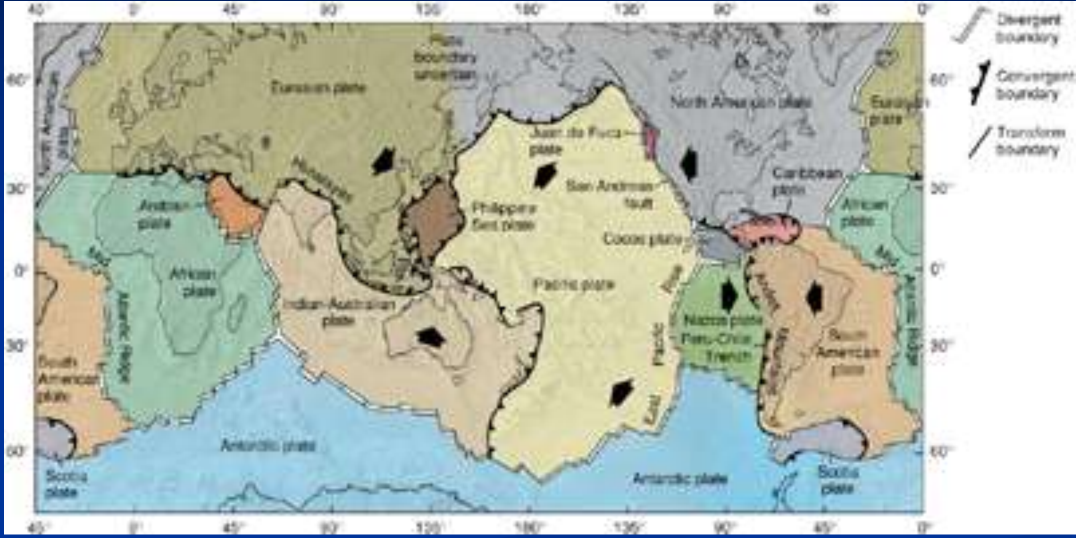


Plate Tectonics

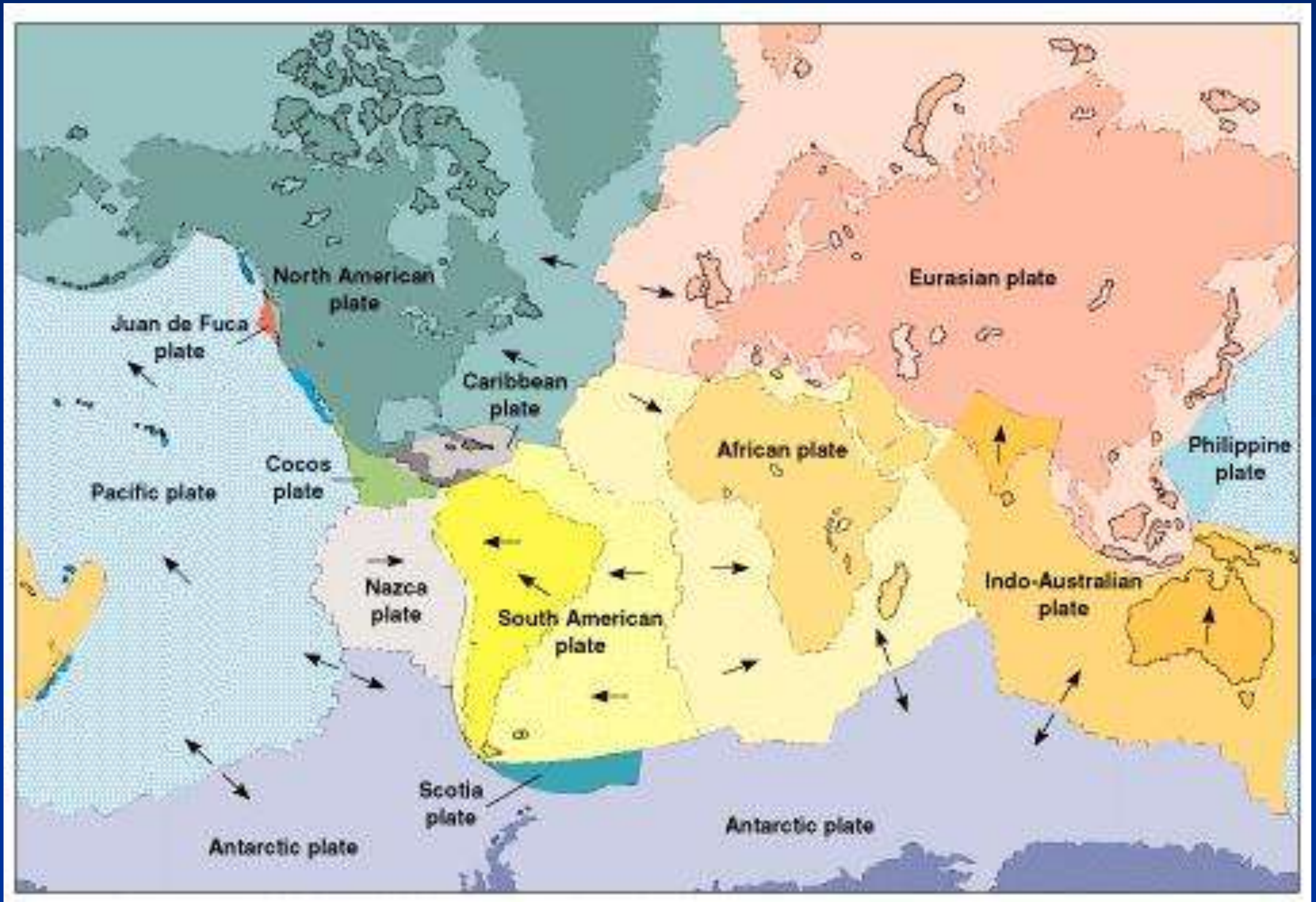
- Basic idea of ***plate tectonics*** theory is that Earth's surface is divided into a few large, thick plates that move slowly and change in size



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

Theory born in late 1960s by combining hypotheses ***of continental drift*** and ***seafloor spreading***

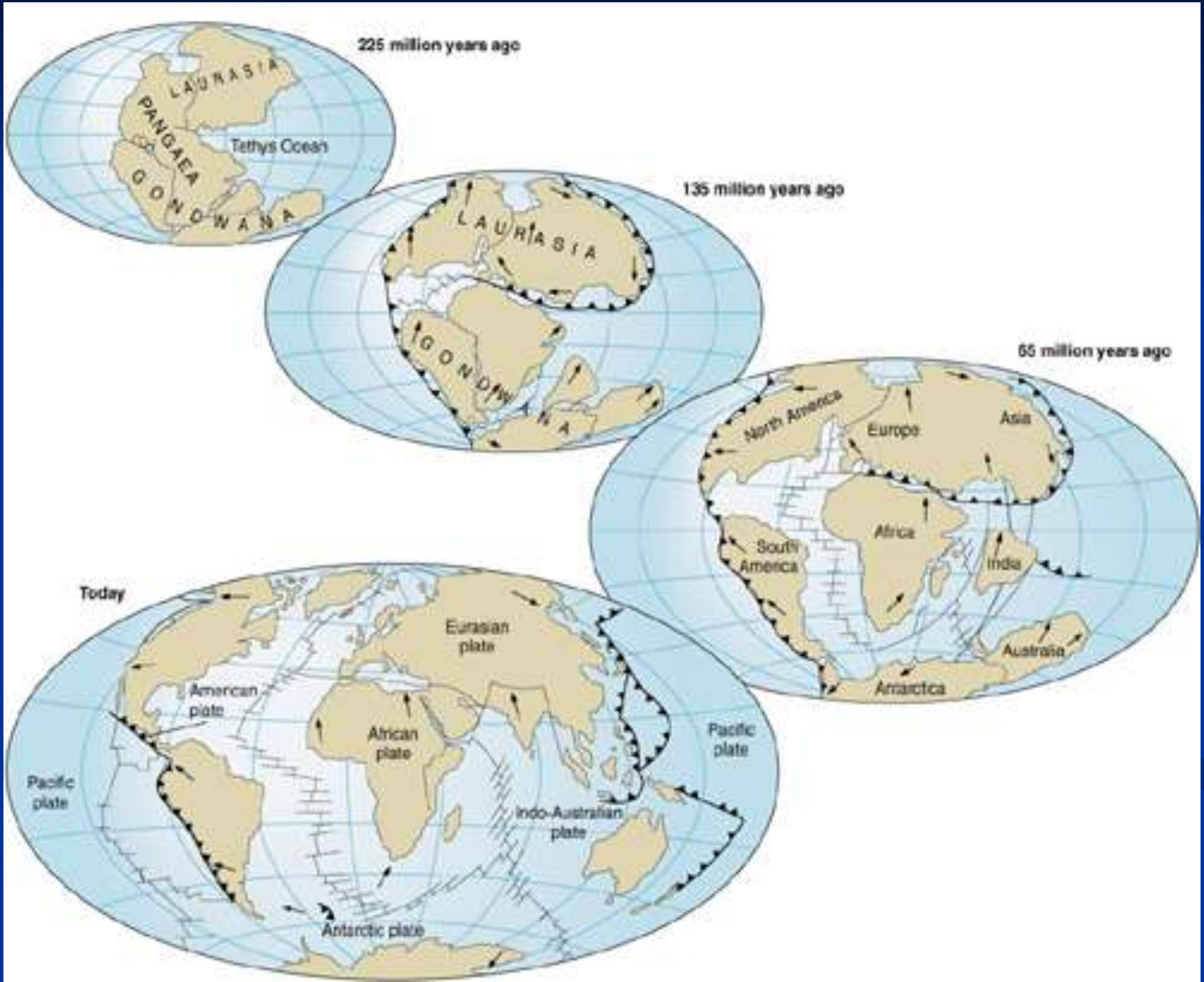
The lithosphere is divided into plates (about 7 large plates and 20 smaller ones).



Outline

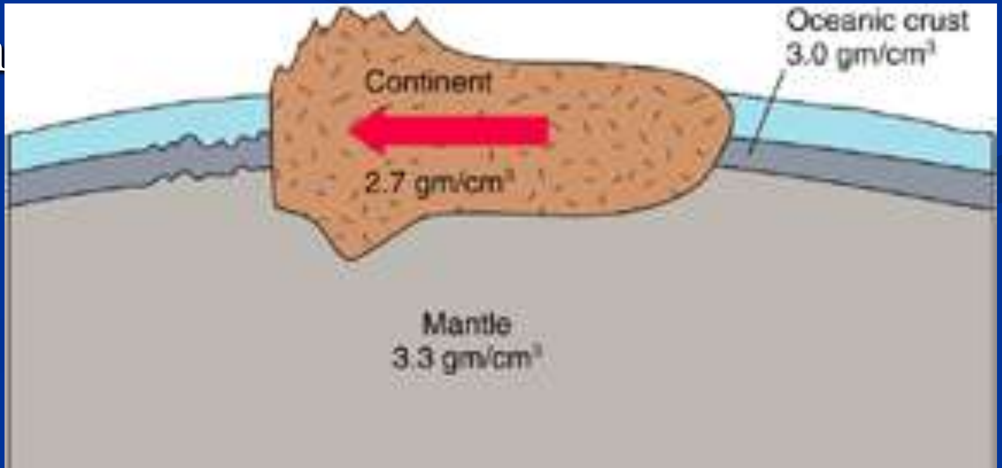
- Continental drift
- Paleomagnetism
- Types of boundaries
  - Divergent
  - Convergent
  - Transform
- Hot spots – Mantle plumes
- Driving force?
- Ore Deposits
- Exotic terranes

Continental Drift 225 My to now



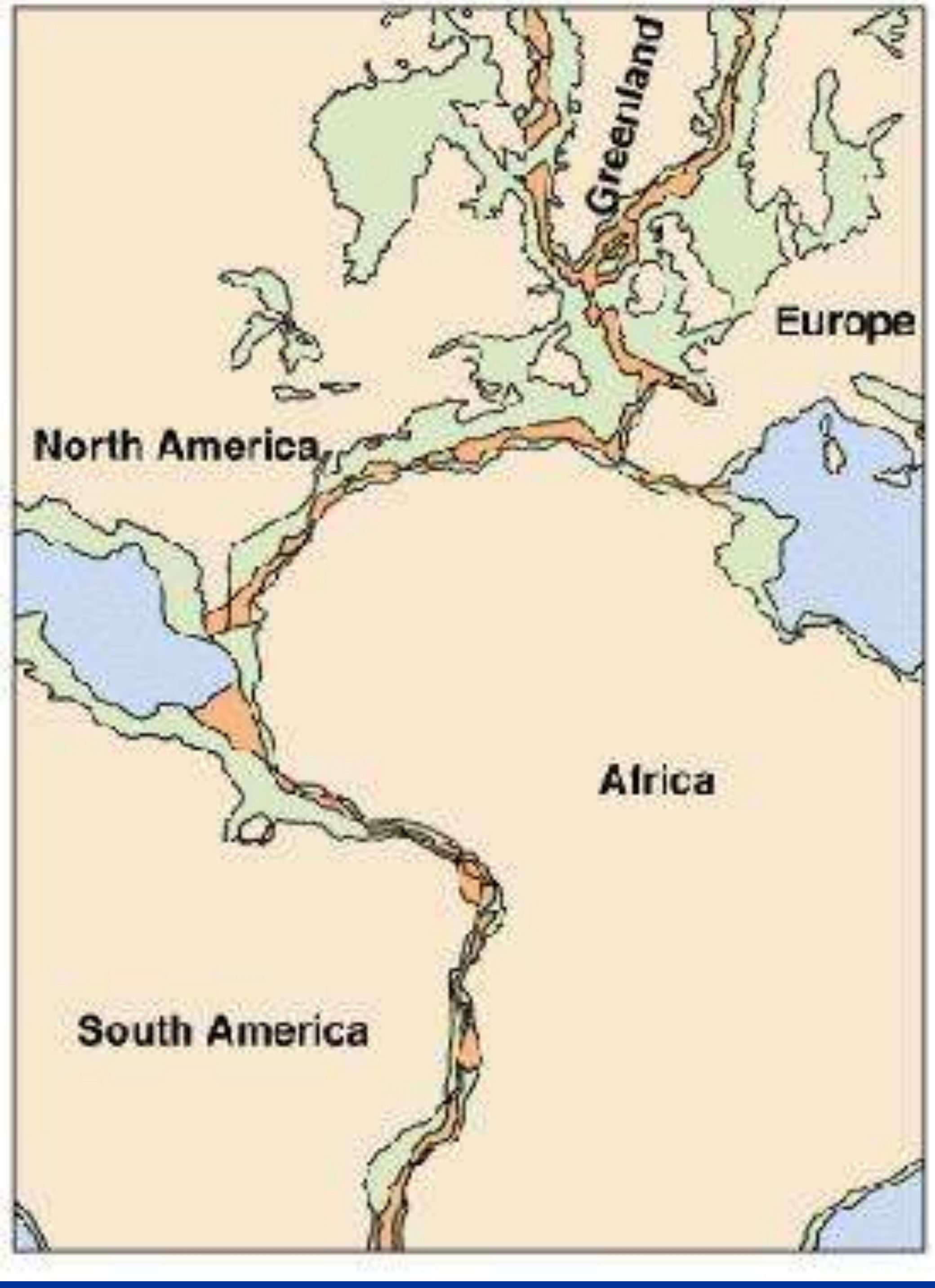
Early Case for Continental Drift

- Continental coastlines would fit together
- Rocks & fossils indicated that continents joined
  - *Pangea*- supercontinent
    - Separated into *Laurasia & Gondwanaland*
- Late Paleozoic glaciation
- Paleoclimatology indicated *polar wandering*
- Skepticism about Continental Drift
  - Problem of mechanism an
  - forces



Fit of continents

1. Shape of the coastlines - the jigsaw puzzle fit of Africa and South America.

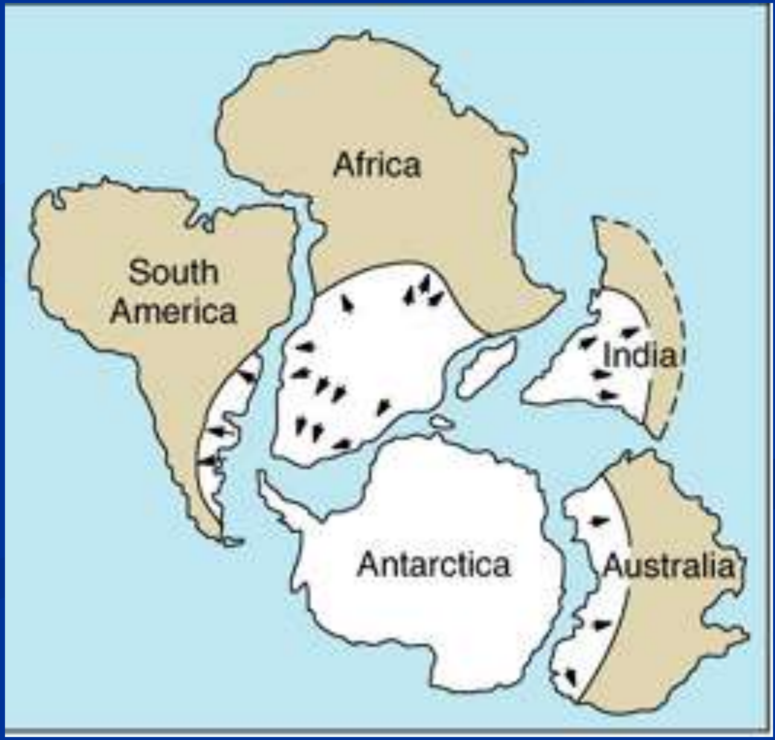


Gondwanaland

- Wegener reassembled continents into the supercontinent ***Pangea***
- Pangea initially separated into *2 large continents*
  - ***Laurasia*** - northern supercontinent containing North America and Asia, minus India
  - ***Gondwanaland*** - southern supercontinent containing South America, Africa, India, Antarctica, and Australia

2. Late Paleozoic glaciation

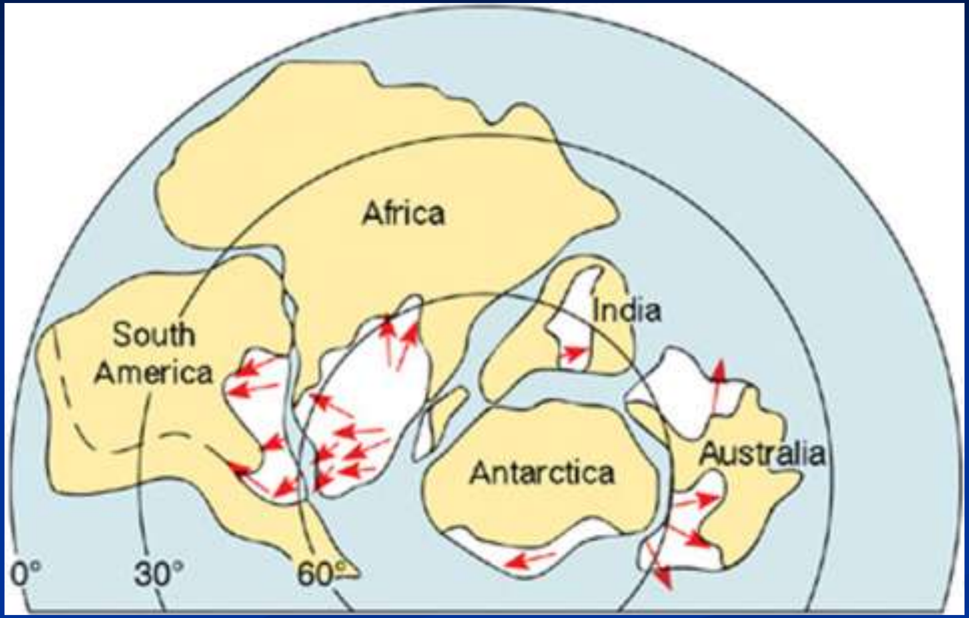
- Wegener reassembled continents into the supercontinent *Pangea*
- Late Paleozoic glaciation patterns on southern continents best explained by their reconstruction into Gondwanaland

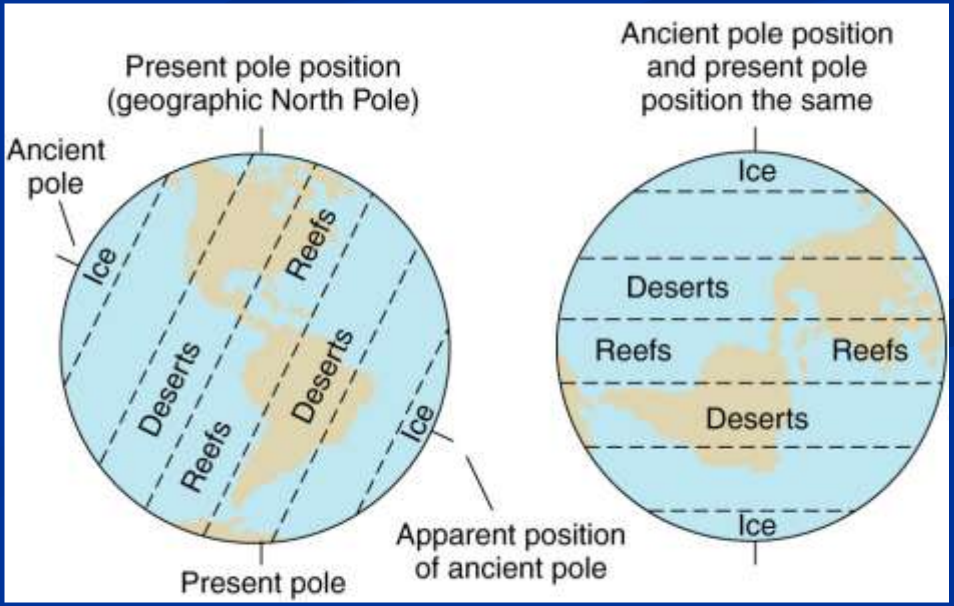


3. Paleoclimate evidence

Paleoclimatic evidence - Ancient climatic zones match up when continents are moved back to their past positions.

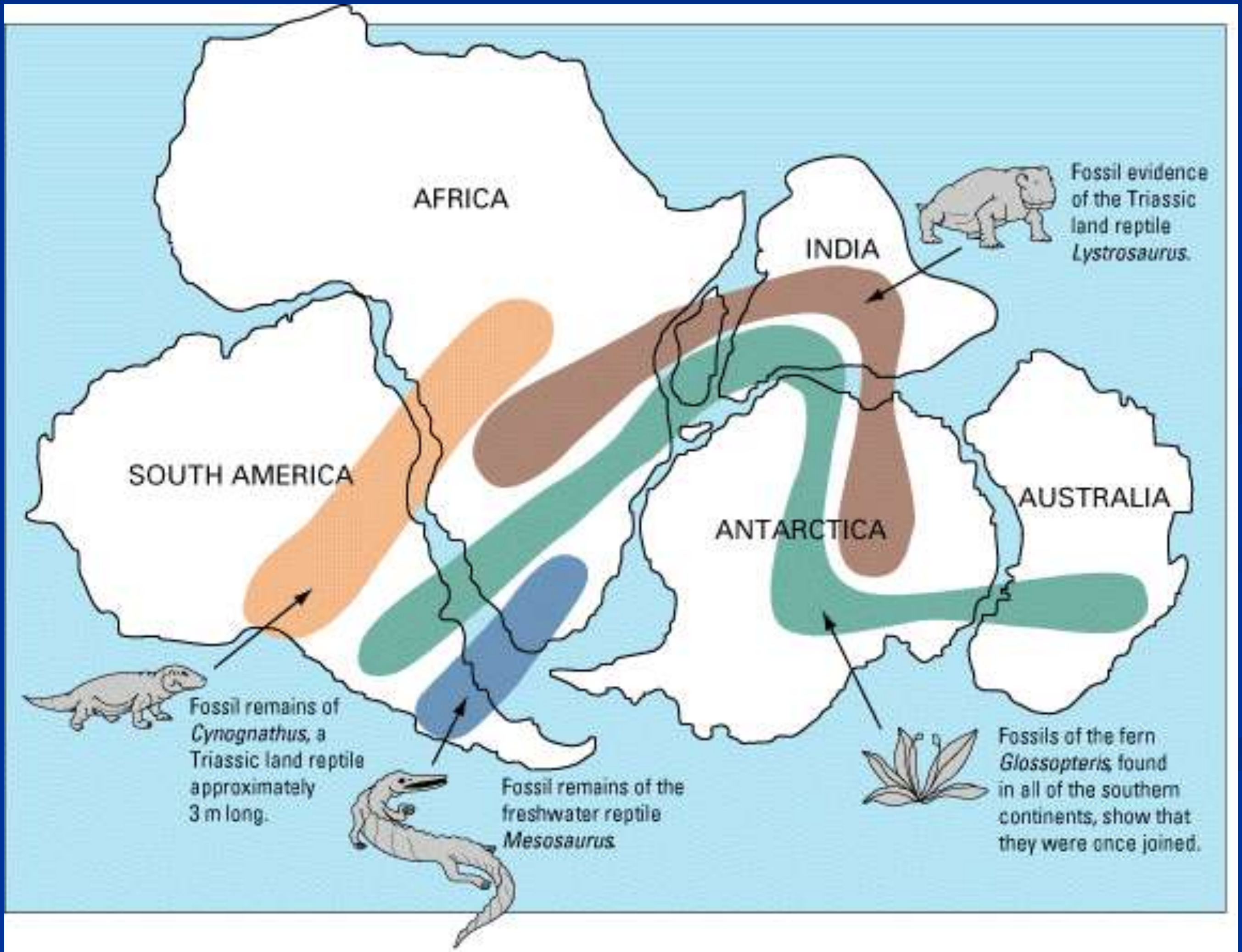
- Glacial tillites
- Glacial striations
- Coal deposits
- Carbonate deposits
- Evaporite deposits





4. Fossil Evidence Supporting Plate Tectonics

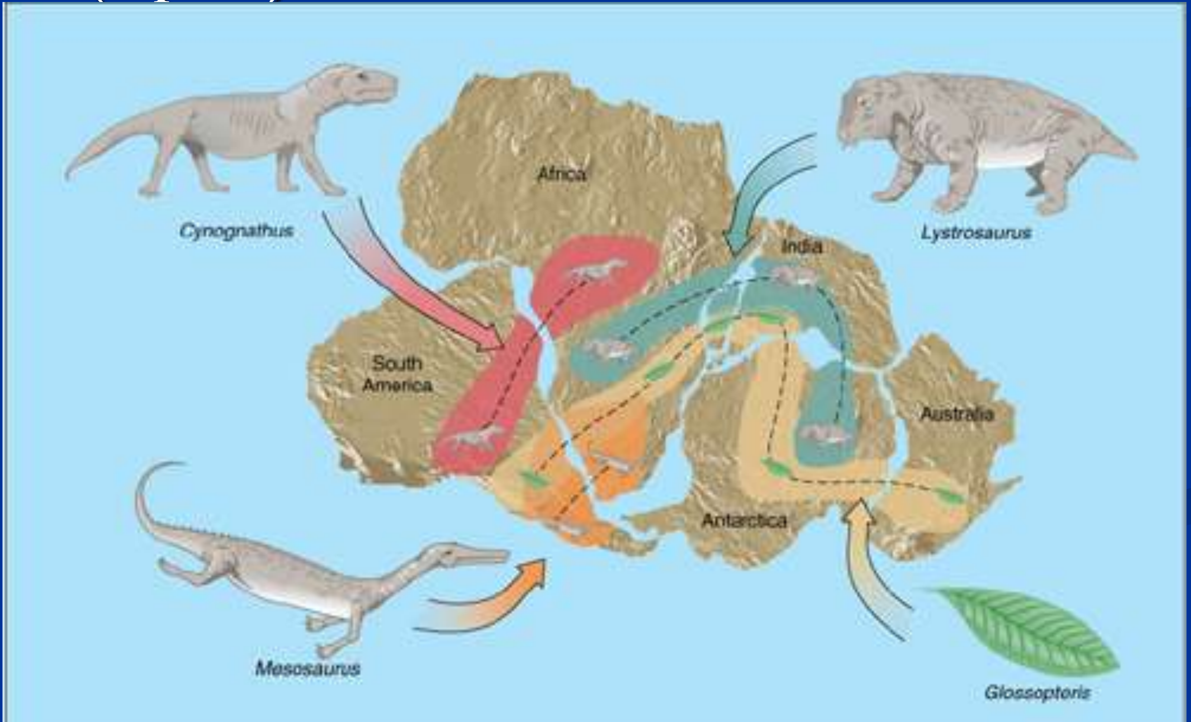
Implies once-continuous land connections between now-separated areas



4. Fossil zones align

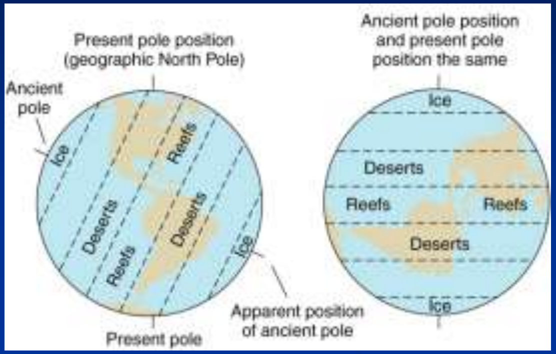
In the early 1900s, ***Alfred Wegener*** noted that South America, Africa, India, Antarctica, and Australia have almost identical late Paleozoic rocks and ***fossils***

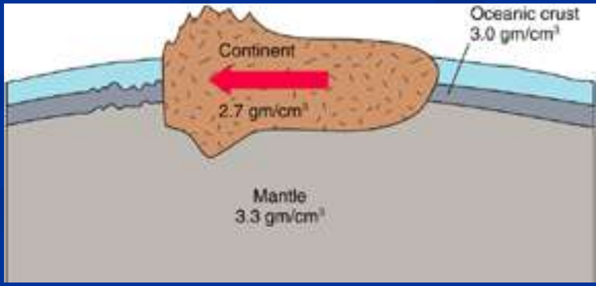
- ***Glossopteris*** (plant), ***Lystrosaurus*** and ***Cynognathus*** (animals) fossils found on all five continents – no way to get across an ocean
- ***Mesosaurus*** (reptile) fossils found in Brazil and South Africa only



Early Case for Continental Drift

- *Coal beds* of North America and Europe support reconstruction into Laurasia
- Reconstructed *paleoclimate* belts indicated *polar wandering*, potential evidence for continental drift over time
- Continental drift hypothesis initially rejected because Wegener could not come up with a viable *driving force*
  - Centrifugal force from Earth's rotation and the Moon's tidal pull are insufficient to plow continents through the sea floor rocks, as he proposed

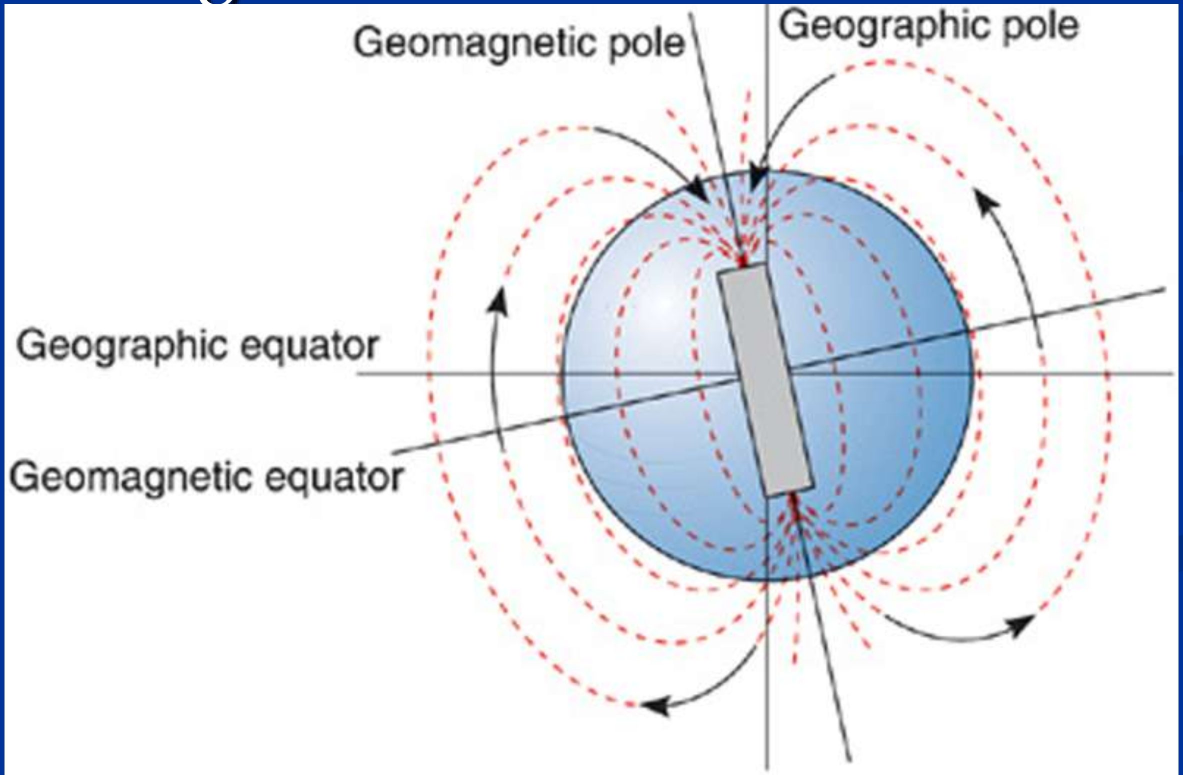




Paleomagnetic lines of force

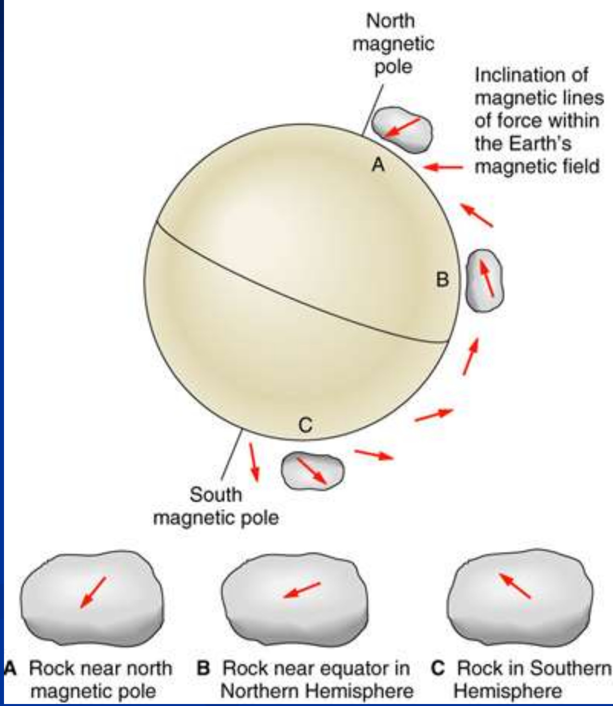
5. Paleomagnetism and Polar Wandering Curves.

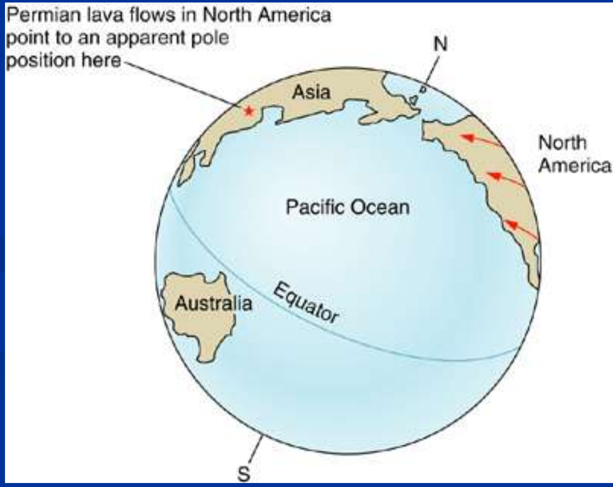
The Earth's magnetic field behaves as if there were a bar magnet in the center of the Earth



5. Paleomagnetism and Pole Locations

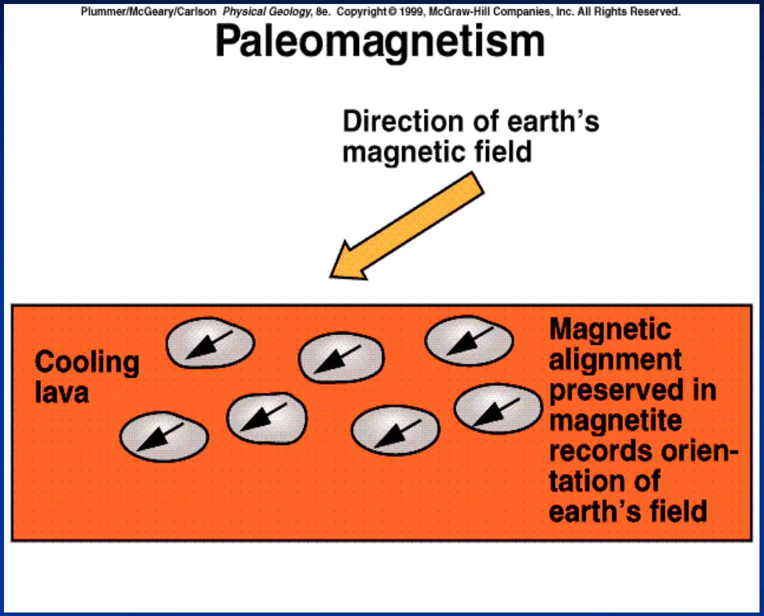
- Studies of *rock magnetism* allowed determination of magnetic pole locations (close to geographic poles) through time
- *Paleomagnetism* uses mineral magnetic alignment direction and dip angle to determine the direction and distance to the magnetic pole
  - Steeper dip angles indicate rocks formed closer to the north magnetic pole
- Rocks with increasing age point to pole locations increasingly far from today's

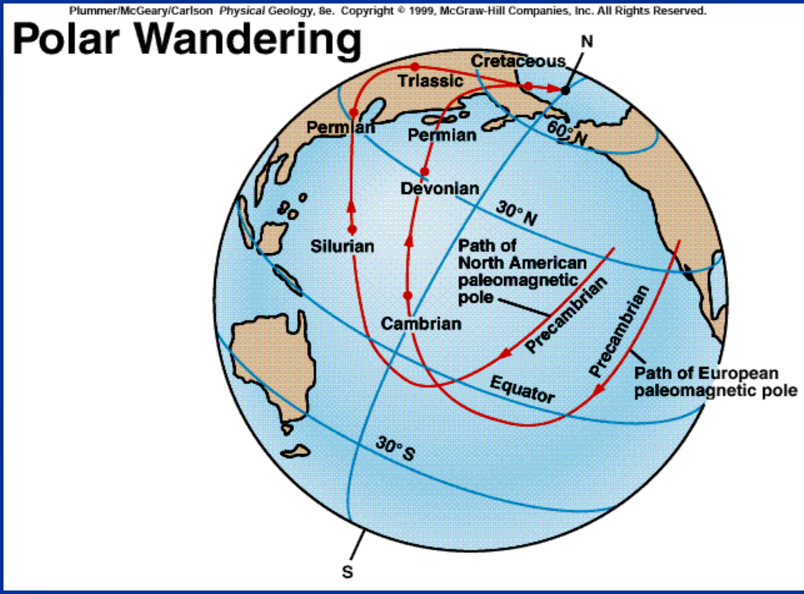




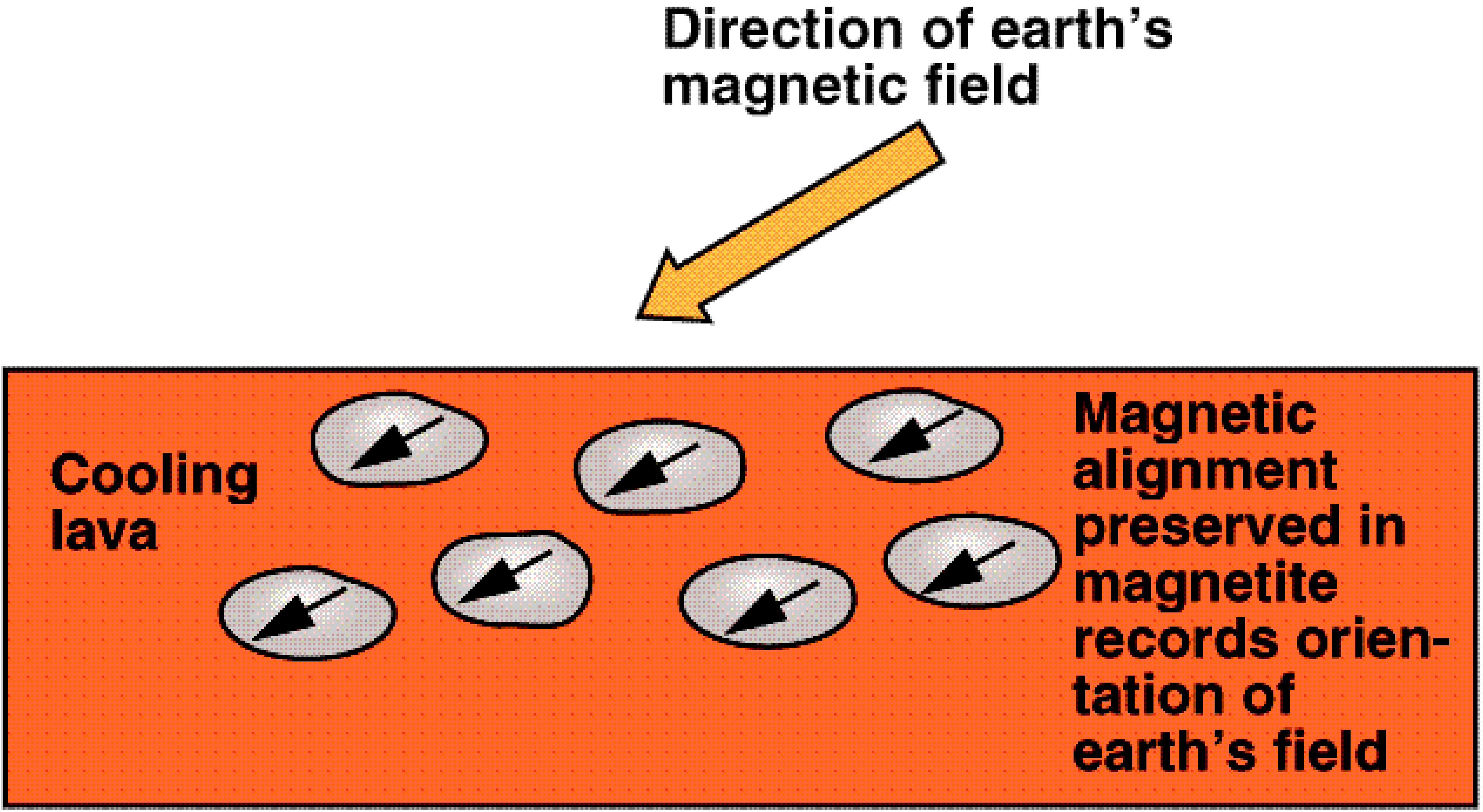
5. Paleomagnetism

- Magnetite aligns on existing magnetic field
- Dip indicates old magnetic pole position
- Apparent motion of north magnetic pole through time
  - Split in path
  - indicates continents split apart

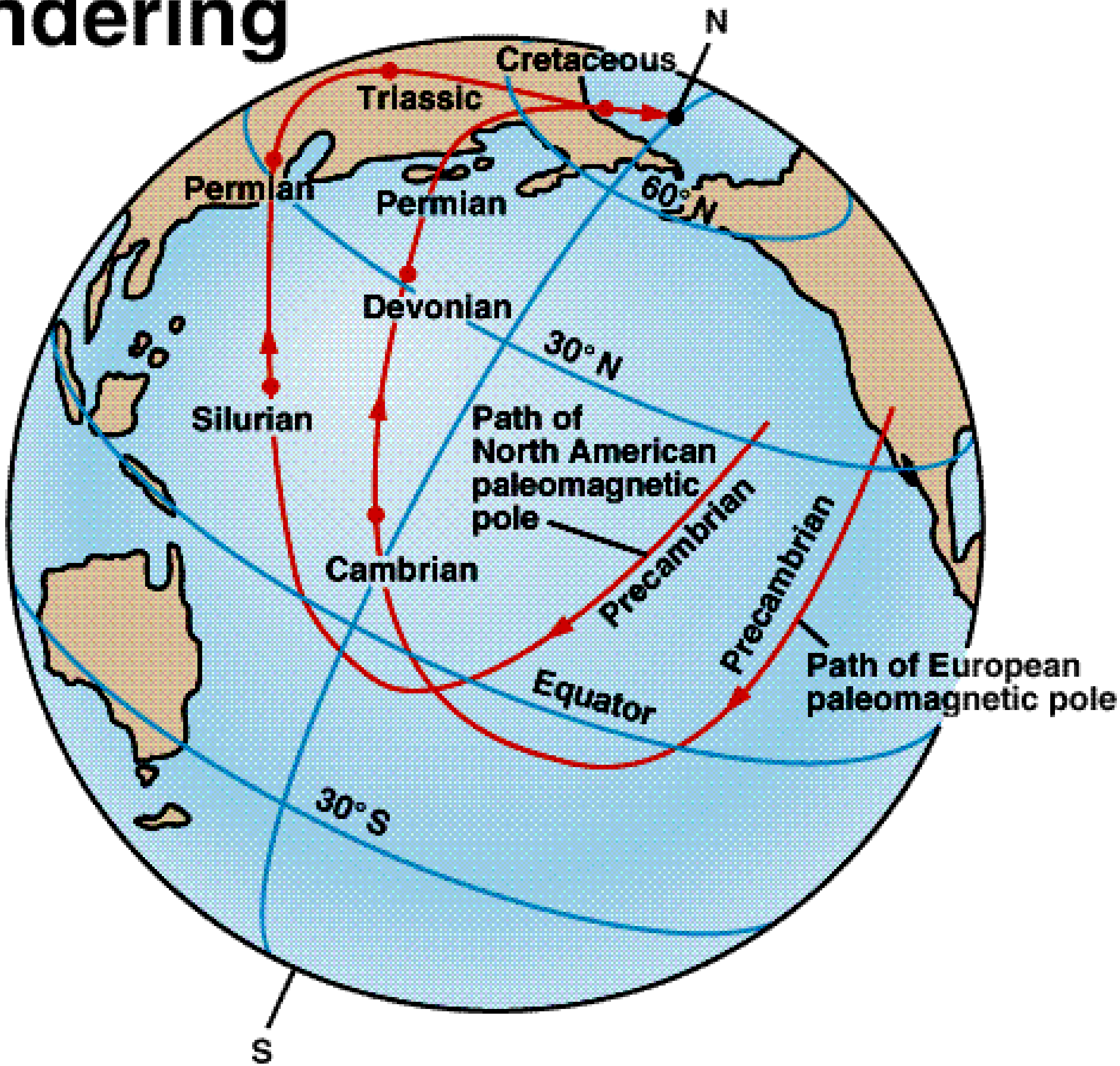




Paleomagnetism

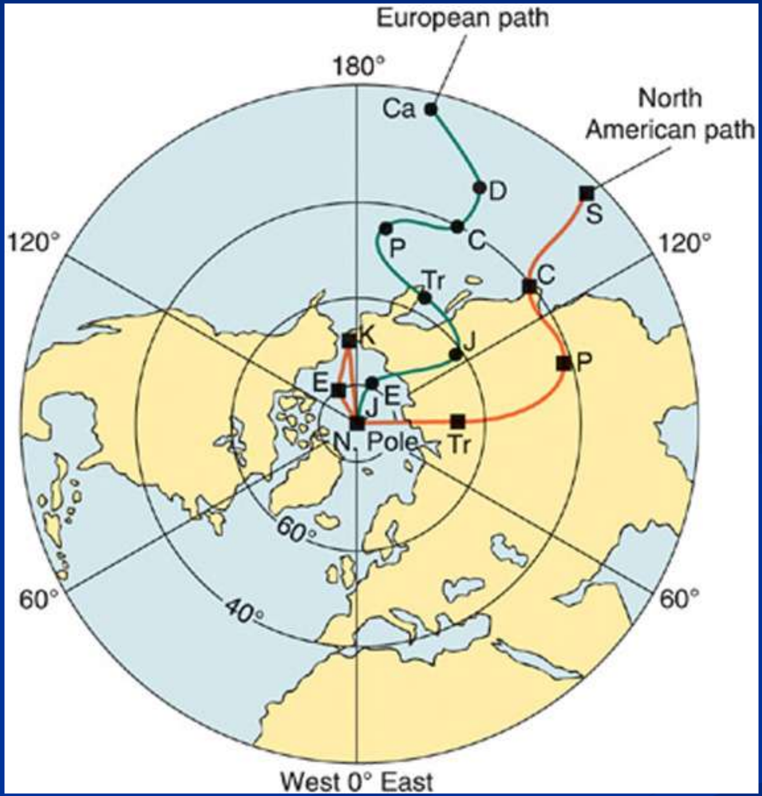


Polar Wandering



5. Apparent Polar Wandering

- Different polar wandering paths are seen in rocks of different continents.
- Put continents back together (like they were in the past) and the polar wandering curves match up.

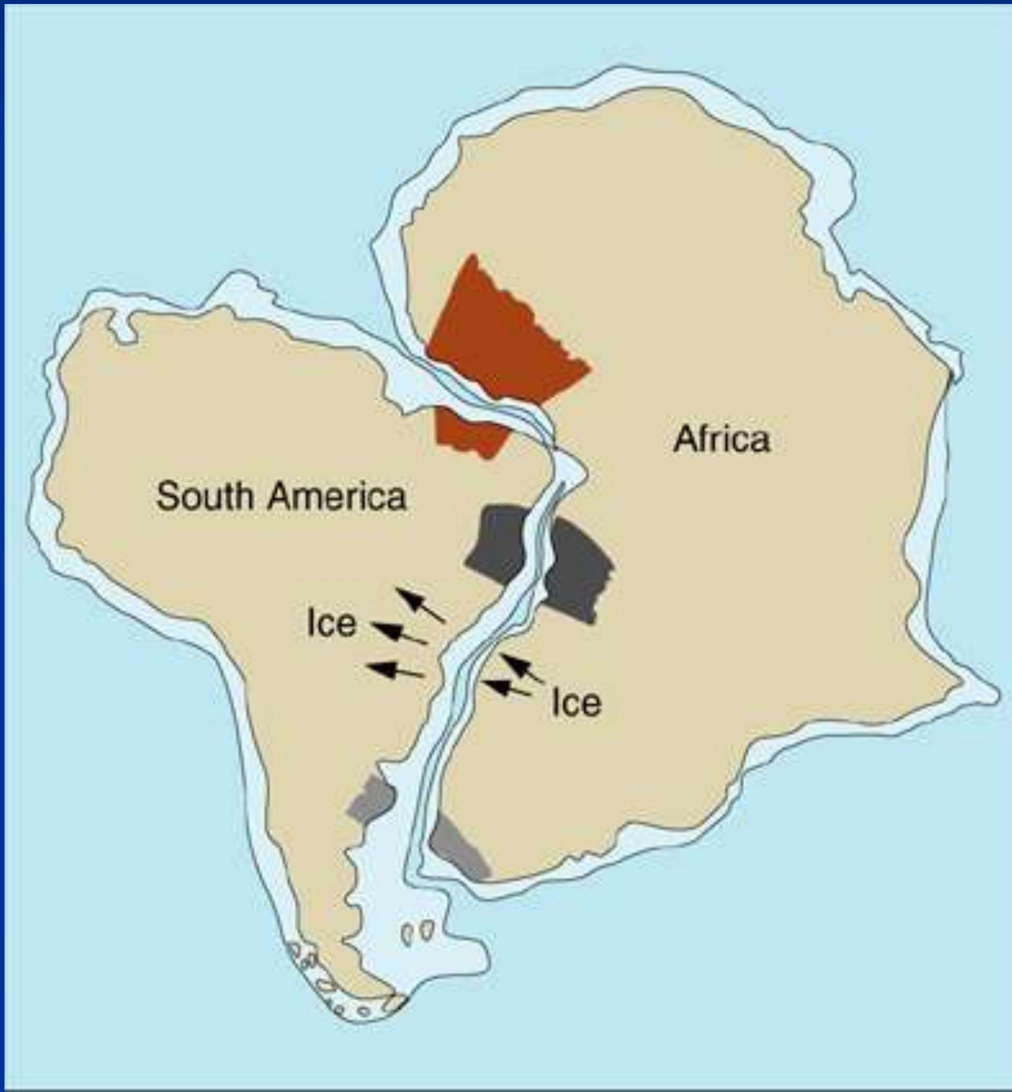


5. Apparent Polar Wandering

- Paleomagnetic data confirm that the continents have moved continuously.
- When ancient magnetic pole positions are plotted on maps, we can see that they were in different places, relative to a continent, at different times in the past.
- This is called apparent polar wandering. The poles have not moved. The continents have moved.

6. Fit of rock units

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



Evidence in Support of the Theory of Plate Tectonics

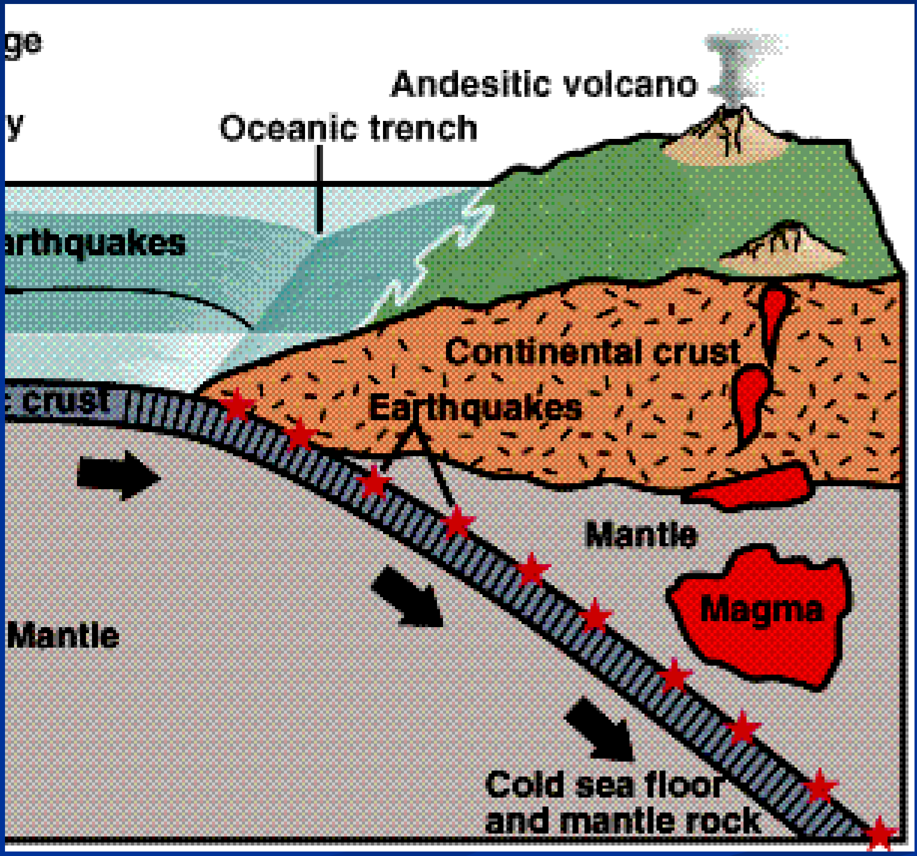
6. Geologic similarities between South America, Africa, and India
   - Same stratigraphic sequence (same sequence of layered rocks of same ages in each place)
   - Mountain belts and geologic structures (trends of folded and faulted rocks line up)
   - Precambrian basement rocks are similar in Gabon (Africa) and Brazil.

Evidence in Support of the Theory of Plate Tectonics

6. Geologic similarities between Appalachian Mountains and Caledonian Mountains in British Isles and Scandinavia.

7. Seismic Evidence

- Inclined zones of earthquake foci dip at about a 45° angle, near a deep-sea trench. Benioff Zones, (or Wadati-Benioff Zones).
- The zone of earthquake foci marks the movement of the subducting plate as it slides into the mantle.
- The Benioff Zone provides evidence for subduction where one plate is sliding beneath another, causing earthquakes.

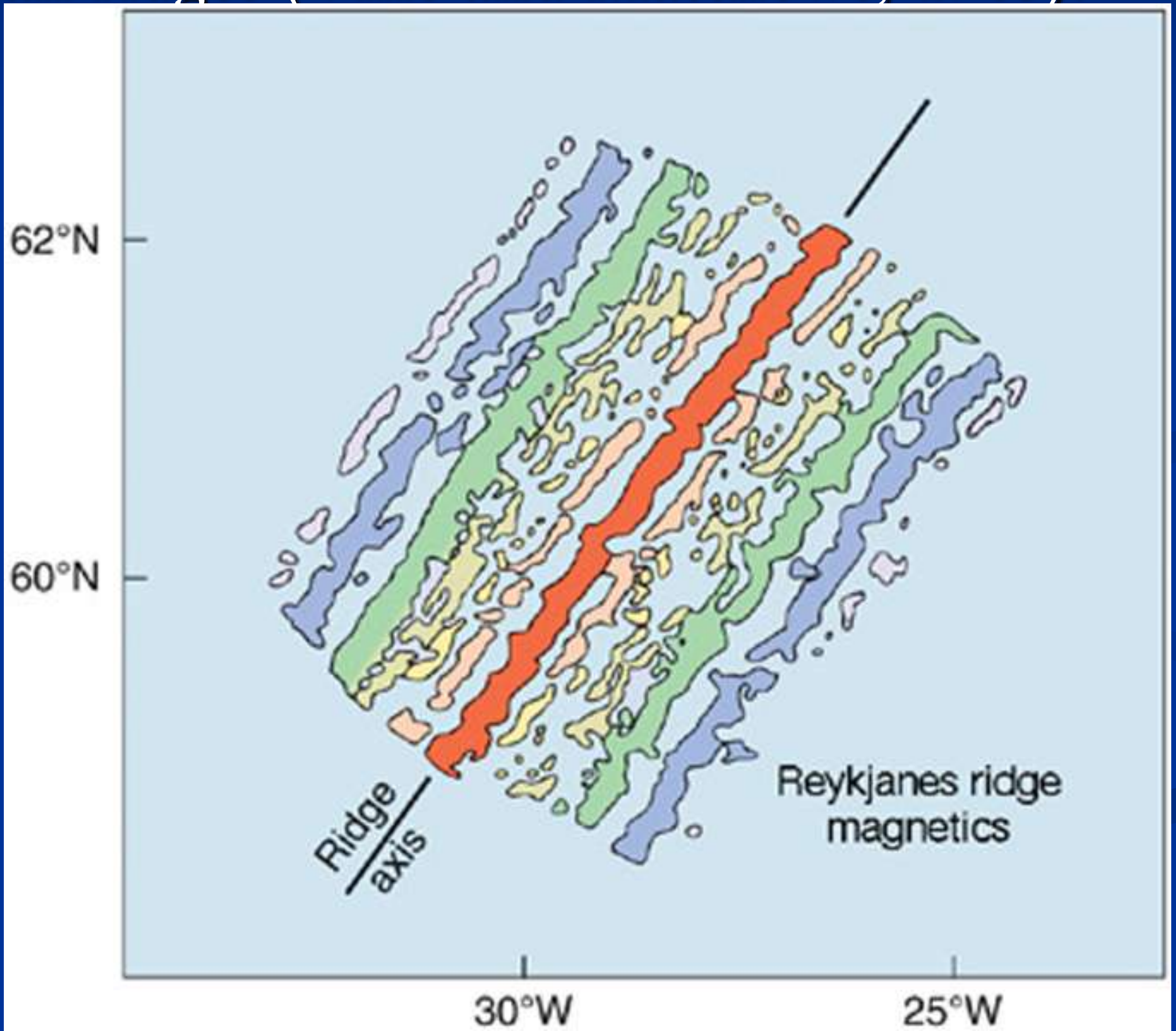


Lithosphere and Asthenosphere

- Lithosphere = rigid, brittle crust and uppermost mantle.
- Asthenosphere = partially molten part of upper mantle, below lithosphere.
- Rigid lithospheric plates "float" on flowing asthenosphere.
- Convection in asthenosphere moves tectonic plates.

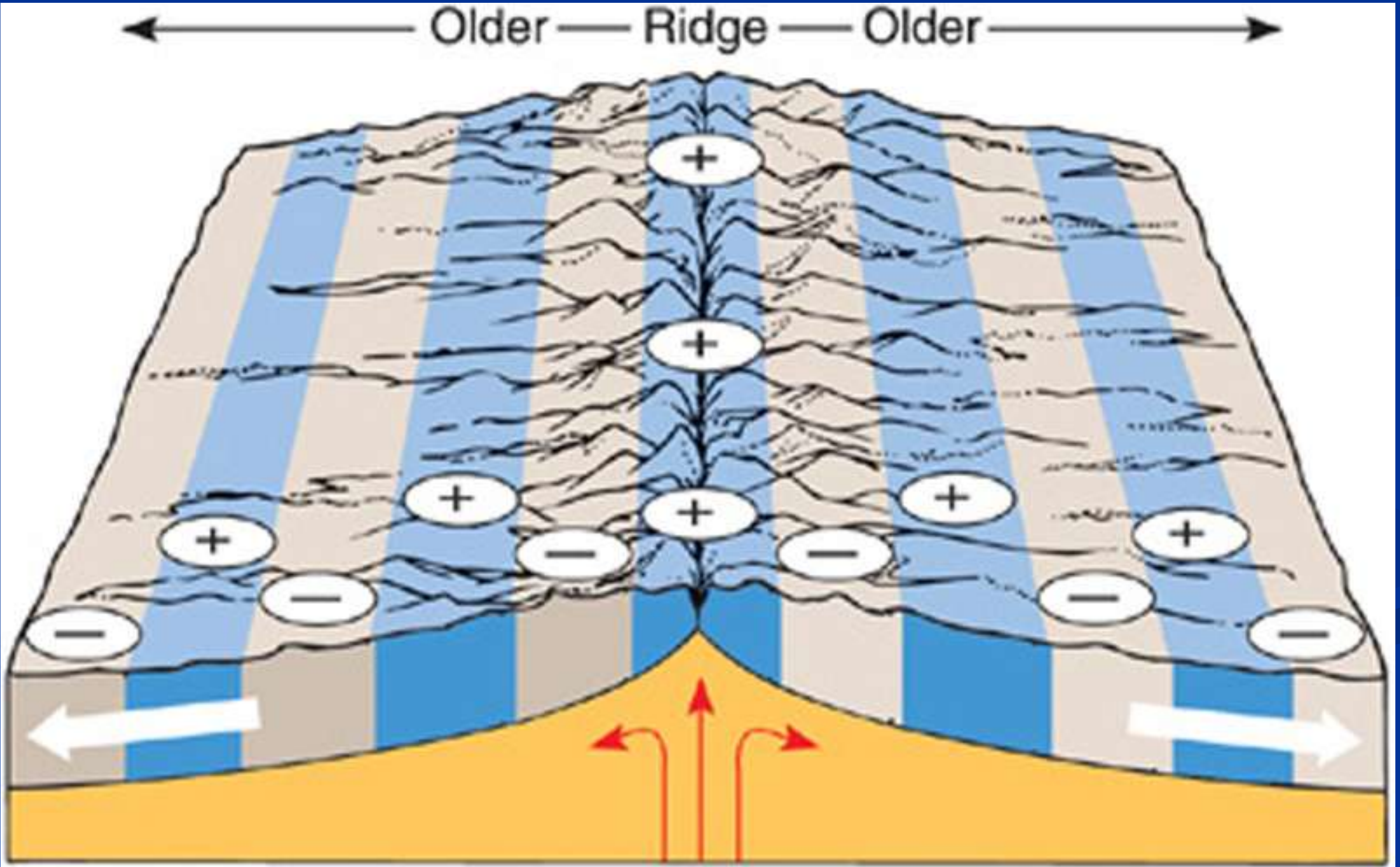
8. Paleomagnetic Evidence

Magnetic stripes on the sea floor are symmetrical about the mid-ocean ridges (Vine and Matthews, 1963).

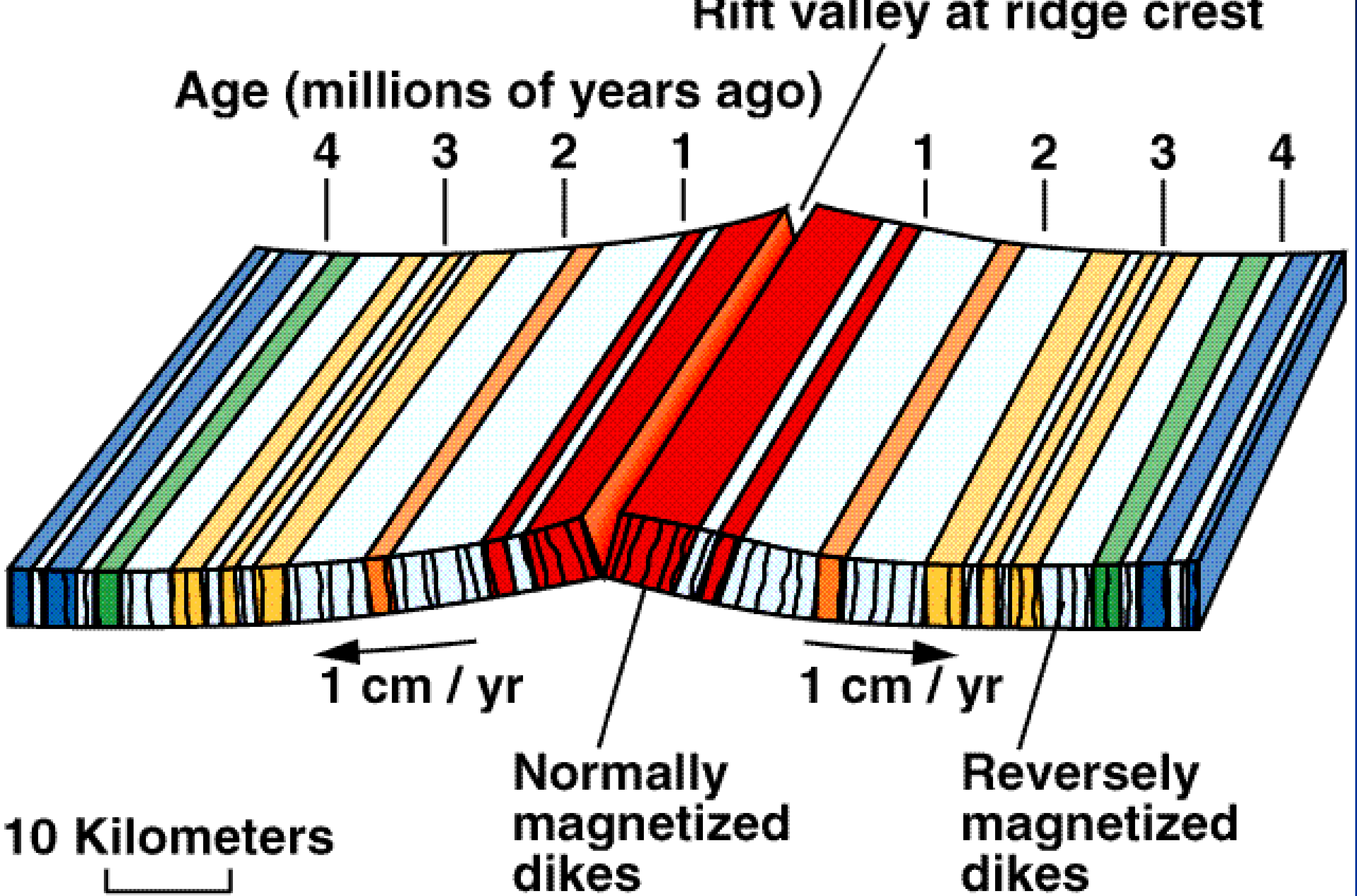


Paleomagnetic Evidence

Normal (+) and reversed (-) magnetization of the seafloor about the mid-ocean ridge. Note the symmetry on either side of the ridge.

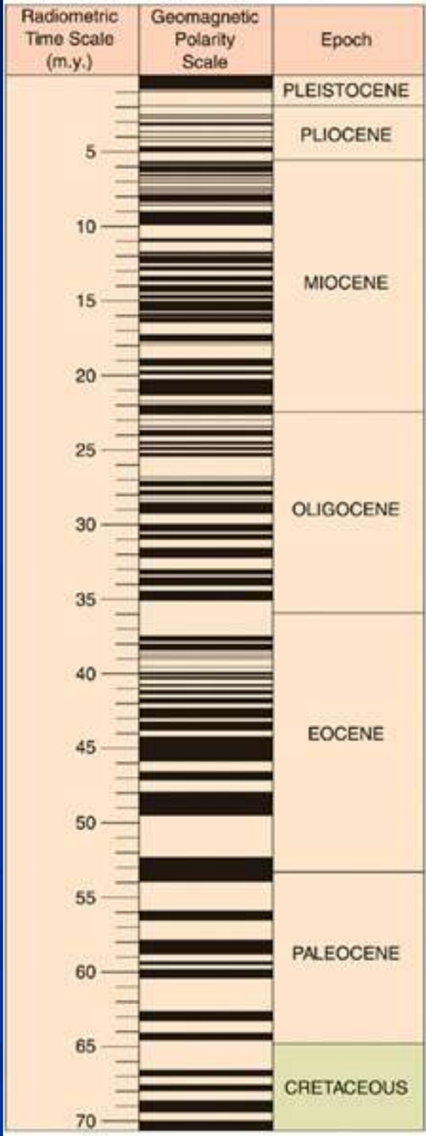


Dating of Magnetic Anomalies



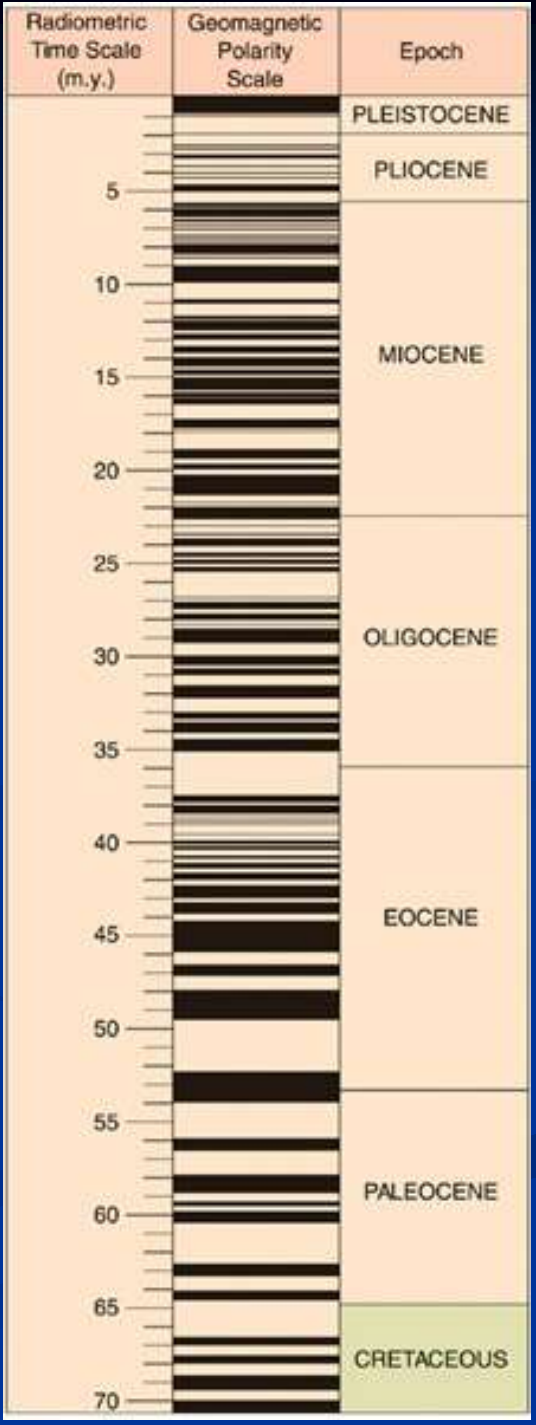
Paleomagnetic Evidence

- Magnetic reversals have occurred relatively frequently through geologic time.
- Recently magnetized rocks show alignment of magnetic field consistent with Earth's current magnetic field.
- Magnetization in older rocks has different orientations (as determined by magnetometer towed by a ship).

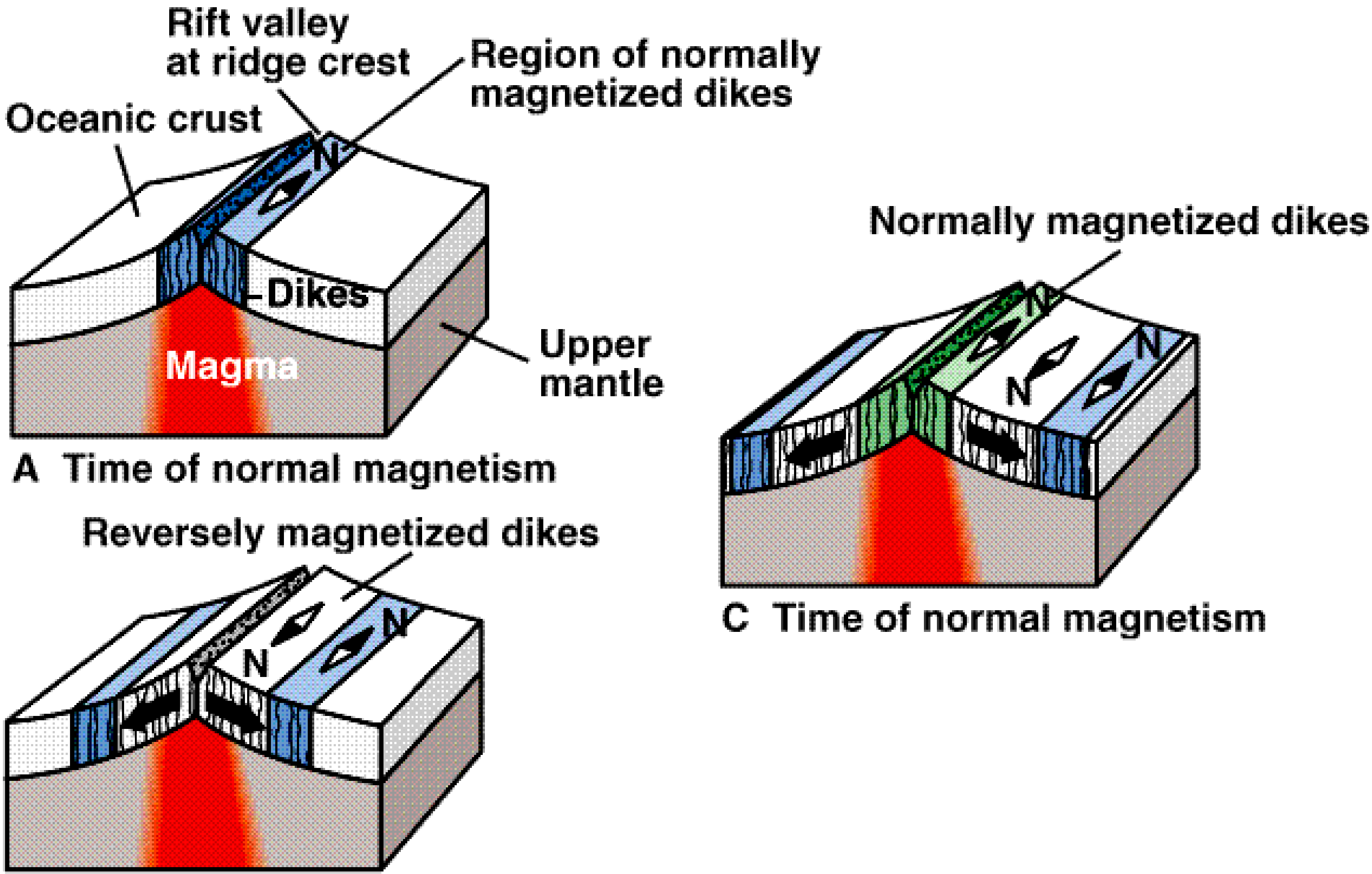


Magnetic Reversal Time Scale

- Reversals in magnetic north in sea floor basalts match the reversal time scale determined from rocks exposed on land.
- Continental basalts were dated radiometrically and correlated with the oceanic basalts.
- Using this method, magnetic reversals on the sea floor were dated.



Origin of Magnetic Anomalies



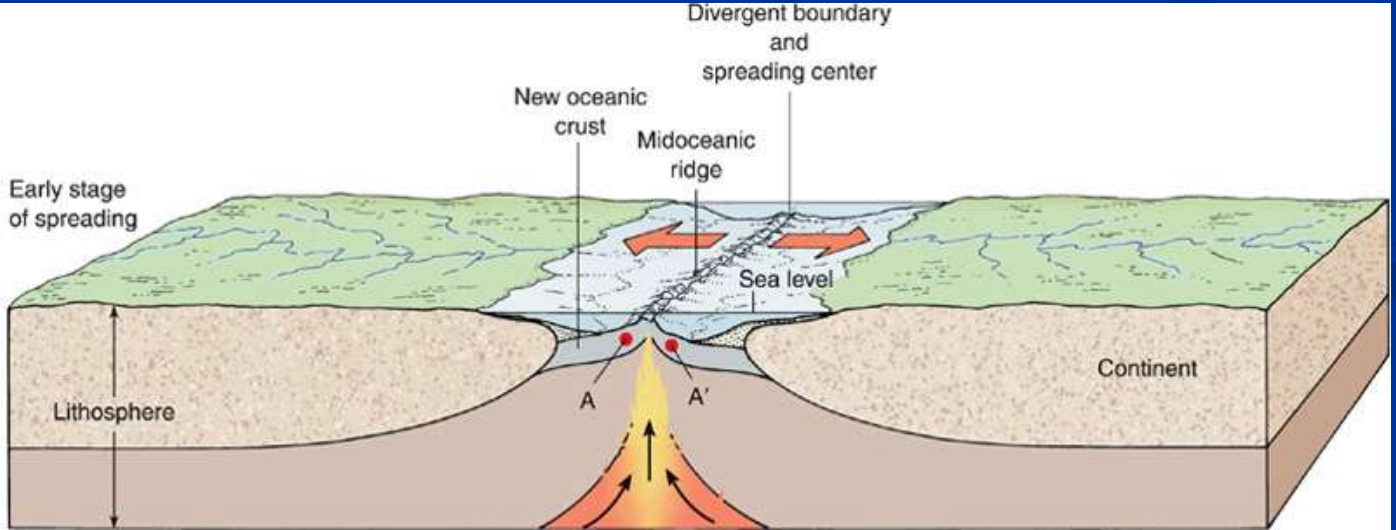
A Time of normal magnetism

B Time of reverse magnetism

C Time of normal magnetism

SEA-FLOOR SPREADING

- Sea-floor moves away from mid-oceanic ridge
- Plunges beneath continent or island arc-*subduction*
- Rate of 1 to 6 (or more) cm/year
- Driving force
  - Originally regarded as mantle convection

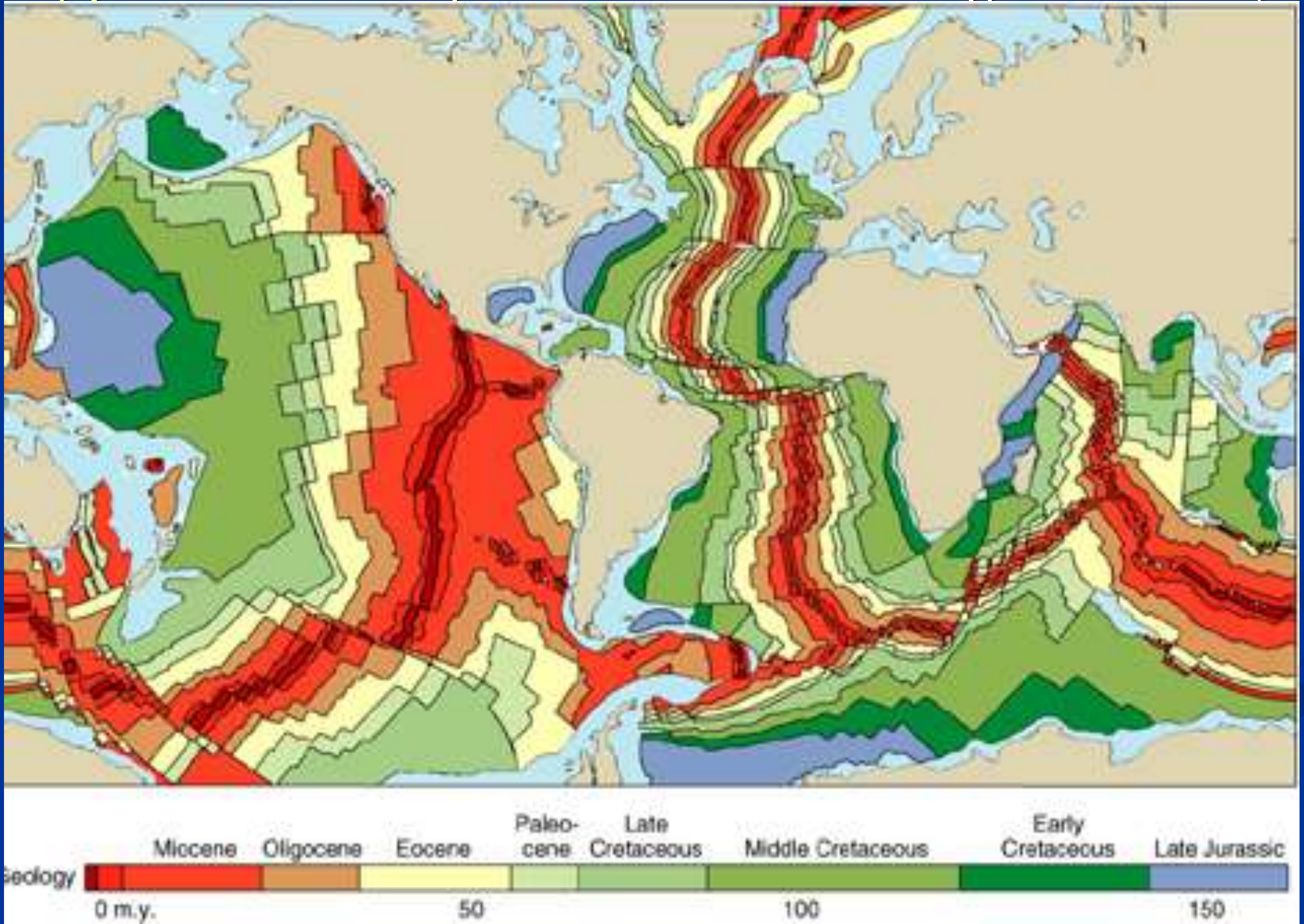


Calculating Rates of Seafloor Spreading

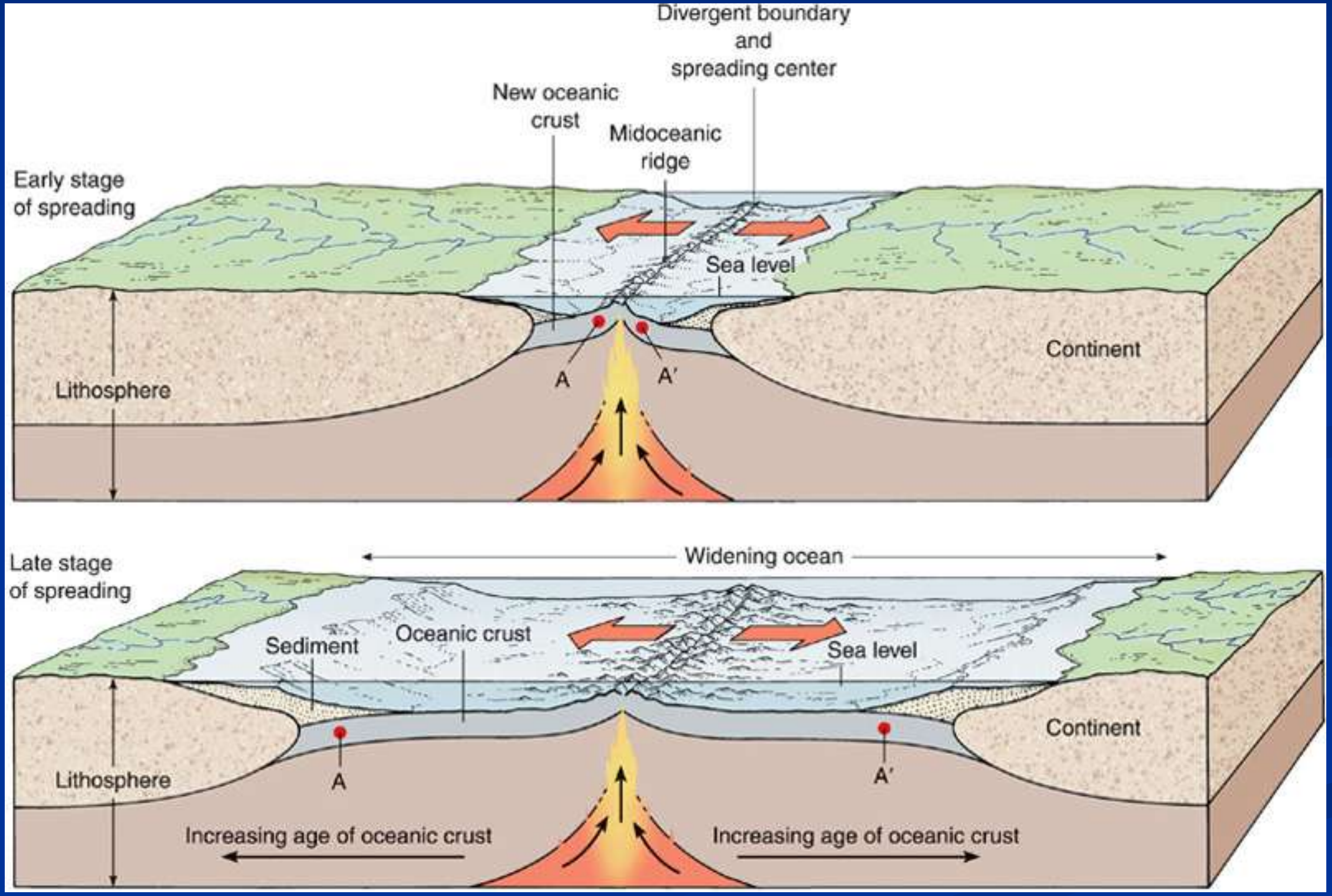
- Width of magnetic stripes on sea floor is related to time.
  - Wide stripes = long time
  - Narrow stripes = short time
- Knowing the age of individual magnetic stripes, it is possible to calculate rates of seafloor spreading and former positions of continents.

Evidence of Plate Motion

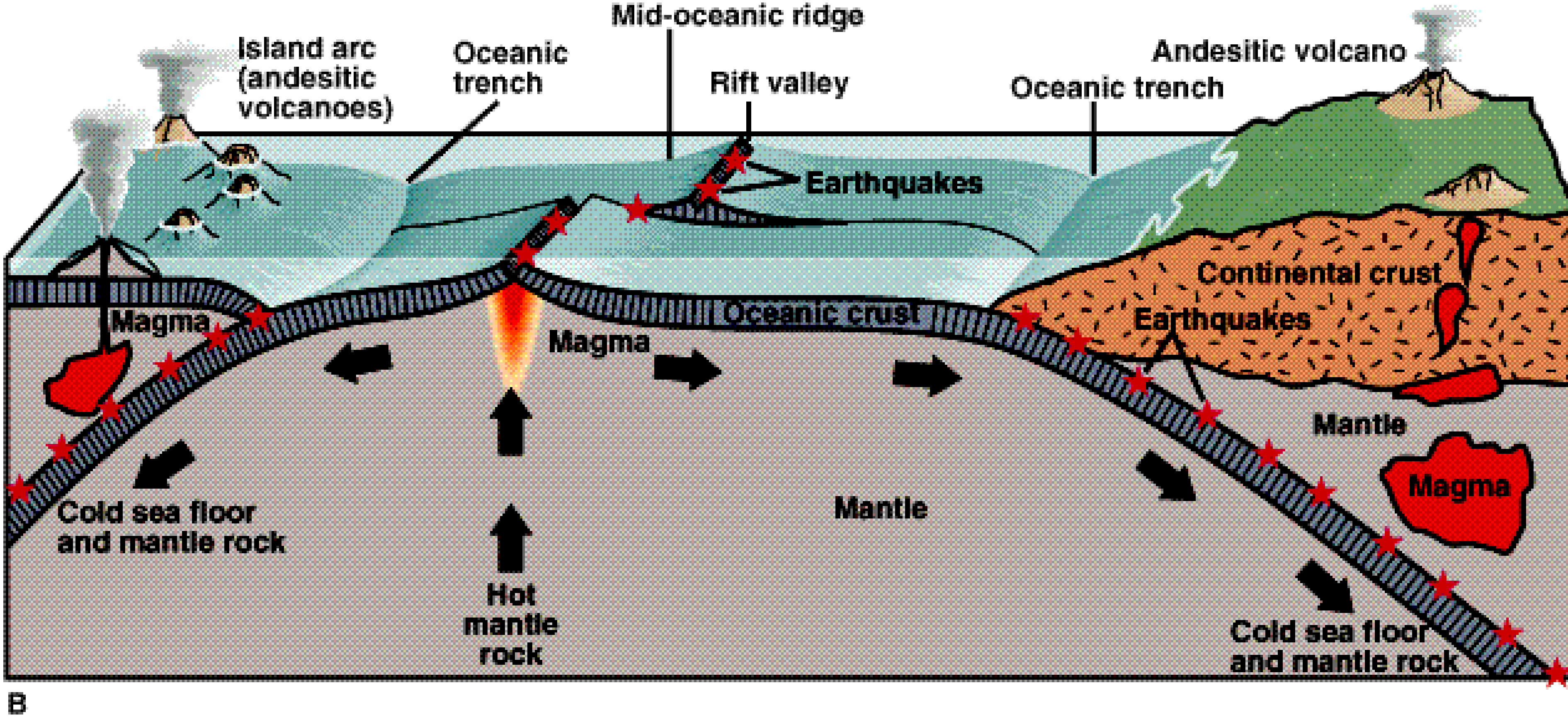
- Seafloor age *increases with distance* from mid-oceanic ridge
  - *Rate of plate motion* equals distance from ridge divided by age



Seafloor Spreading at Divergent Plate Boundary



Sea-Floor Spreading

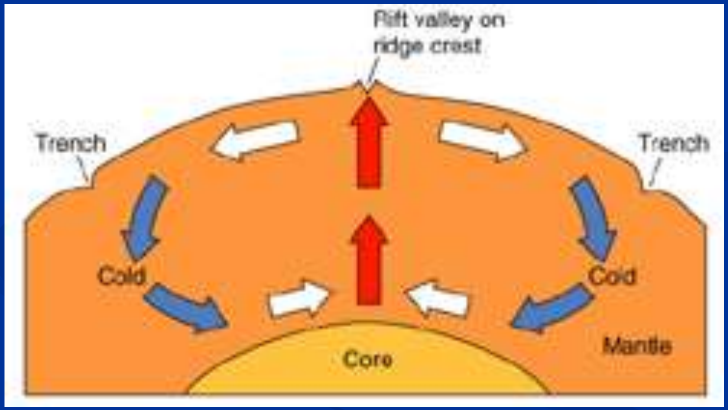


Core and Magnetic Field

- Convection in liquid outer core plus spin of solid inner core generates Earth's magnetic field.
- Magnetic field is also evidence for a dominantly iron core.

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



Youth of Ocean Basins and Sea Floor

- Only a thin layer of sediment covers the sea floor basalt.
- Sea floor rocks date to less than 200 million years (most less than 150 million years).
- No seafloor rocks are older than 200 million years.

Types of plate boundaries

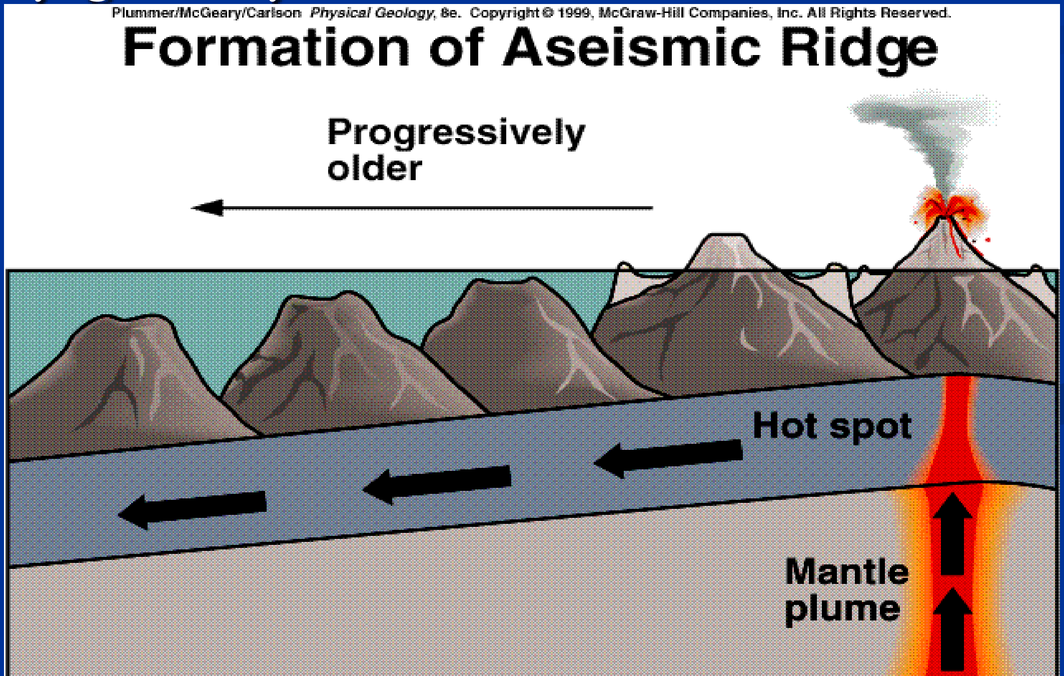
- **Divergent** - The plates move apart from one another. New crust is generated between the diverging plates.
- **Convergent** - The plates move toward one another and collide. Crust is destroyed as one plate is pushed beneath another.
- **Transform** - The plates slide horizontally past each other. Crust is neither produced nor destroyed.

Characteristics of Divergent Boundaries

9. Mid-ocean ridges are sites of sea floor spreading. They have the following characteristics:
   - High heat flow.
   - Seismic wave velocity decreases at the ridges, due to high temperatures.
   - A valley is present along the center of ridge.
   - Volcanoes are present along the ridge.
   - Earthquakes occur along the ridge.

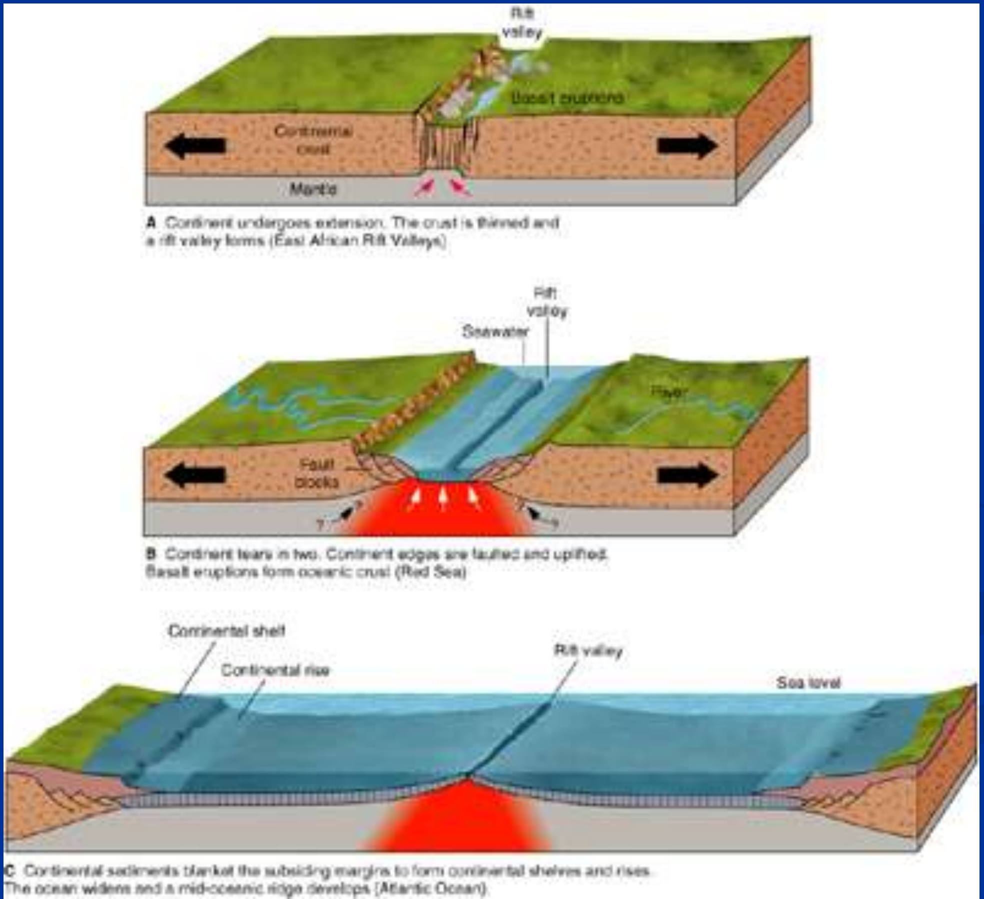
Ocean floor evidence

9. Evidence for subsidence in oceans
   - Guyots - flat-topped sea mounts (erosion when at or above sea level).
   - Chains of volcanic islands that are older away from site of current volcanic activity - Hawaiian Islands and Emperor Sea Mounts (also *subsiding* as they go away from site of current volcanic activity).



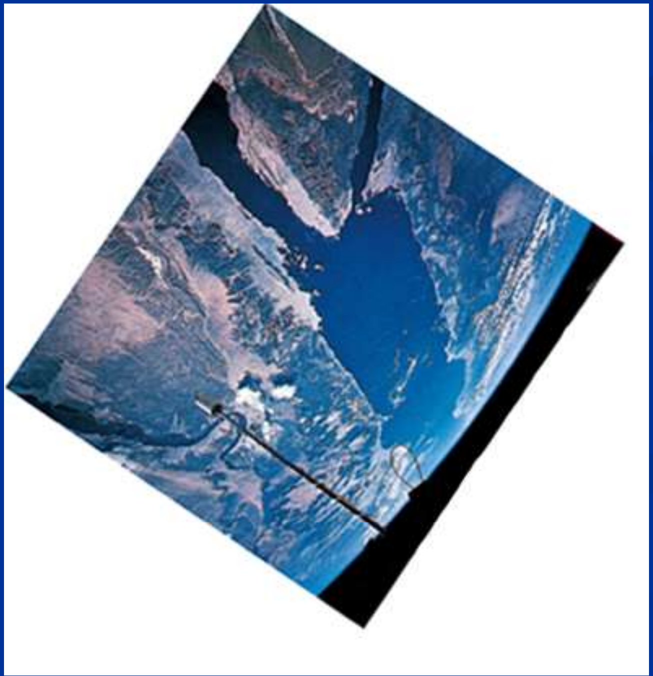
Divergent Plate Boundaries

- 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



Divergent Plate Boundaries

- Marked by *rifting*, basaltic volcanism, and uplift
  - During rifting, crust is stretched and thinned
  - Graben valleys mark rift zones
  - Volcanism common as magma rises through thinner crust along normal faults
  - Uplift is due to thermal expansion of hot rock

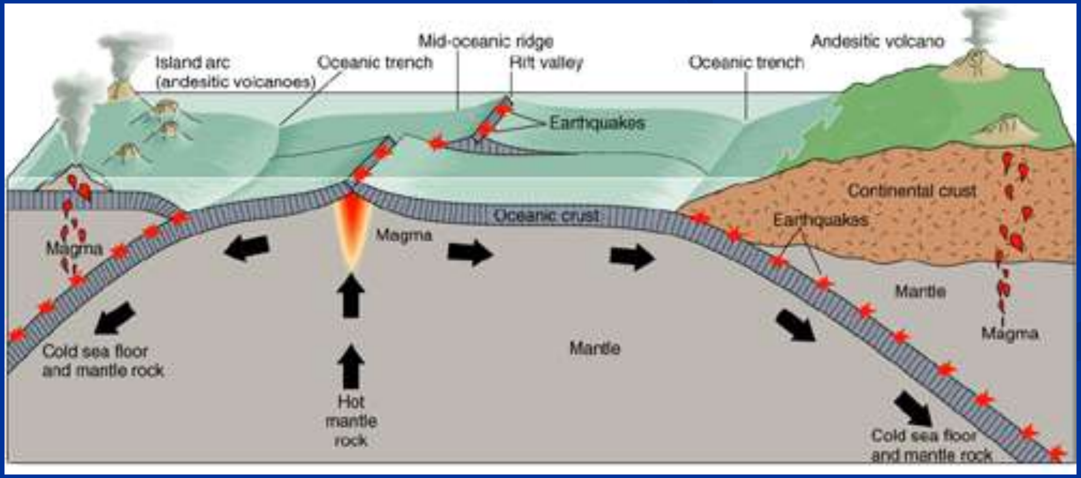


SEA-FLOOR SPREADING

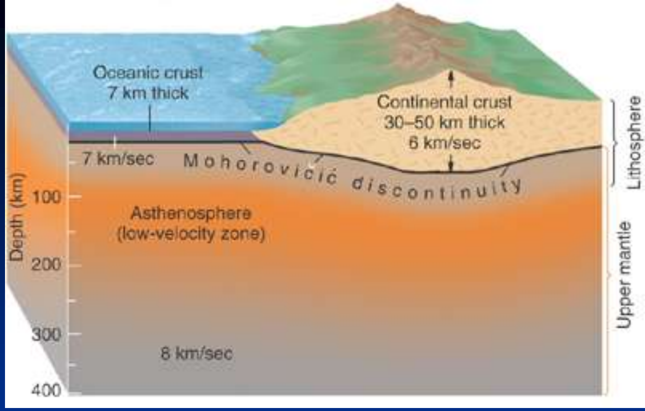
- Explanations
  - Mid-oceanic ridge
    - Hot mantle rock beneath ridge
      - High heat flow
      - Basalt eruptions
    - Rift valley
    - Shallow-focus earthquakes

Seafloor Spreading

- Seafloor rocks, and mantle rocks beneath them, cool and become *more dense* with distance from mid-oceanic ridge
- When sufficiently cool and dense, these rocks may sink back into the mantle at *subduction zones*
  - Downward plunge of cold rocks gives rise to oceanic trenches and the very low heat flow associated with them
- Overall young age for sea floor rocks (everywhere <200 million years) is explained by this model

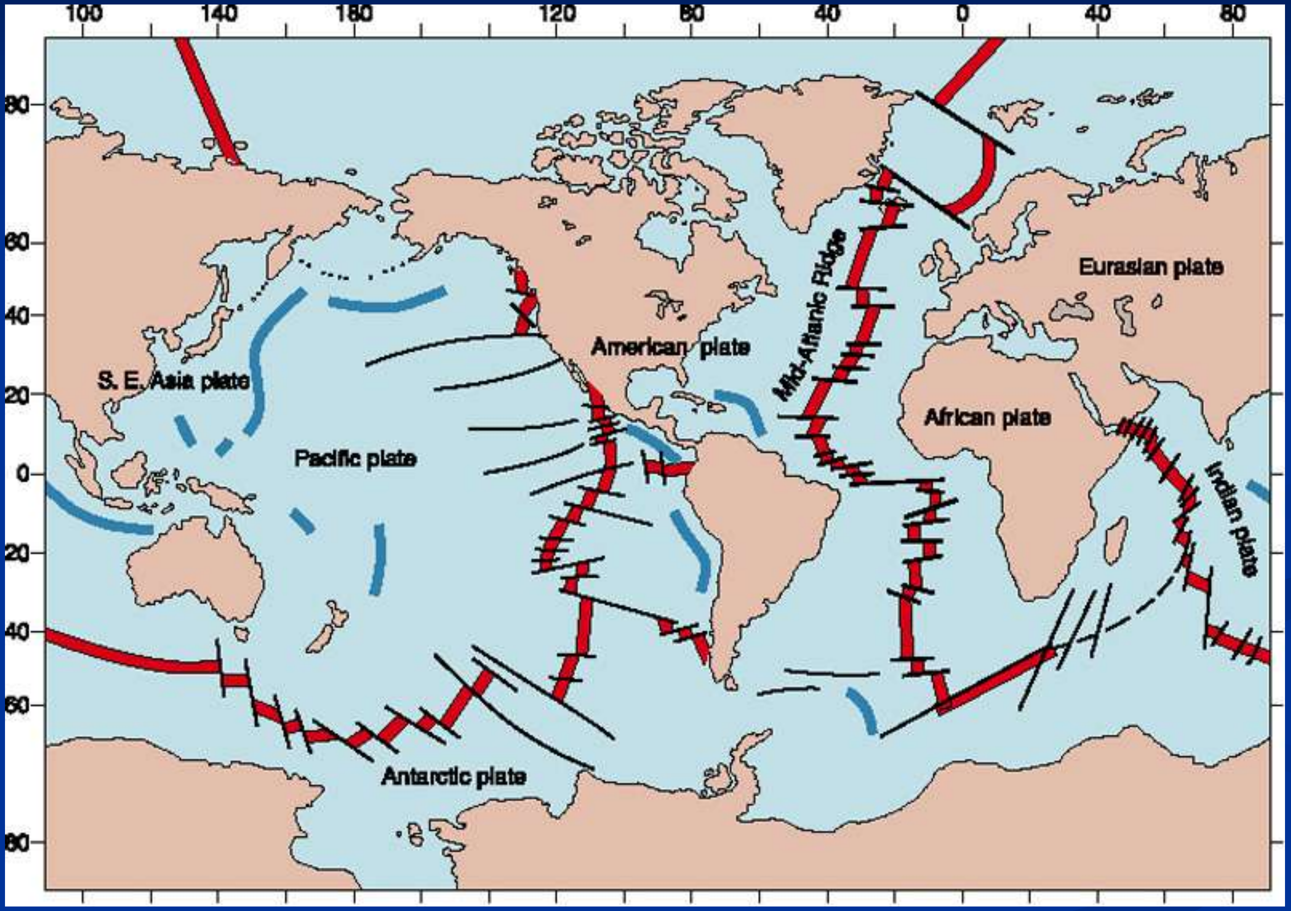


Plates and Plate Motion



- Tectonic plates are composed of the relatively rigid *lithosphere*
  - Lithospheric thickness and age of seafloor *increase with distance* from mid-oceanic ridge
- 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 Boundaries

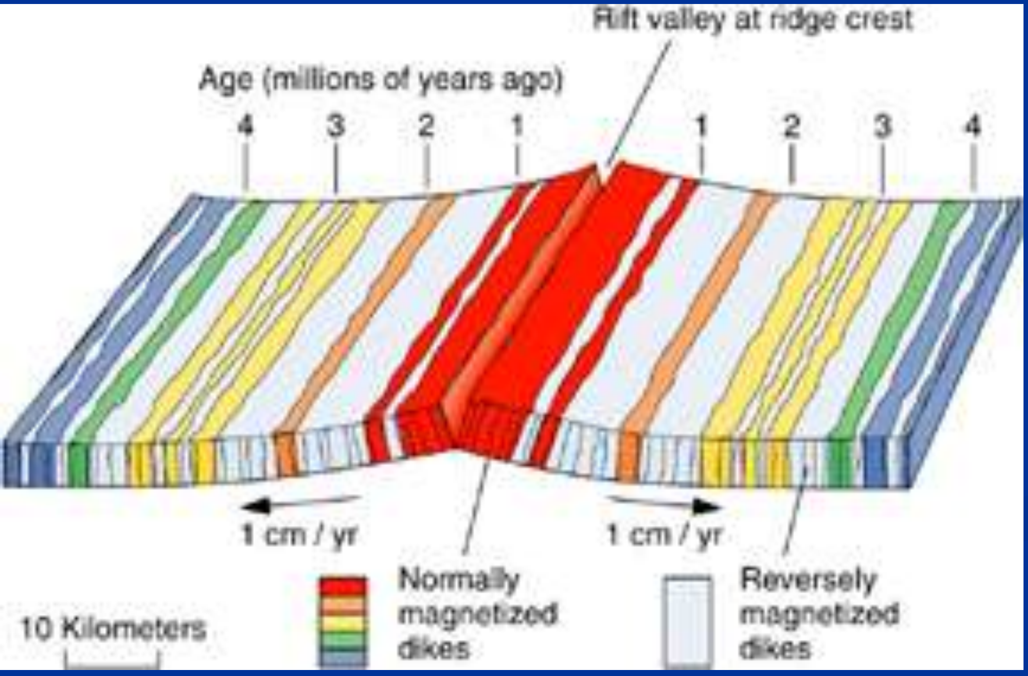


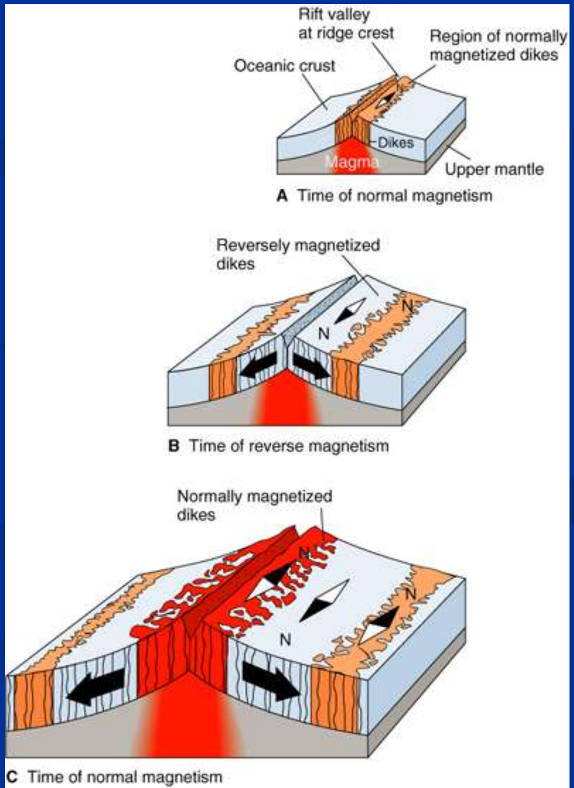
Red = Midoceanic ridges Blue = Deep-sea trenches

Black = Transform faults

Evidence of Plate Motion

- *Marine magnetic anomalies* are bands of stronger and weaker than average magnetic field strength
  - Parallel mid-oceanic ridges
  - Field strength related to basalts magnetized with same and opposite polarities of current global magnetic field
  - Symmetric "bar-code" anomaly pattern reflects plate motion away from ridge coupled with magnetic field reversals





Divergent Plate Boundaries

- Plates move apart from one another
- Tensional stress
- Rifting occurs
- Normal faults
- Igneous intrusions, commonly basalt, forming new crust

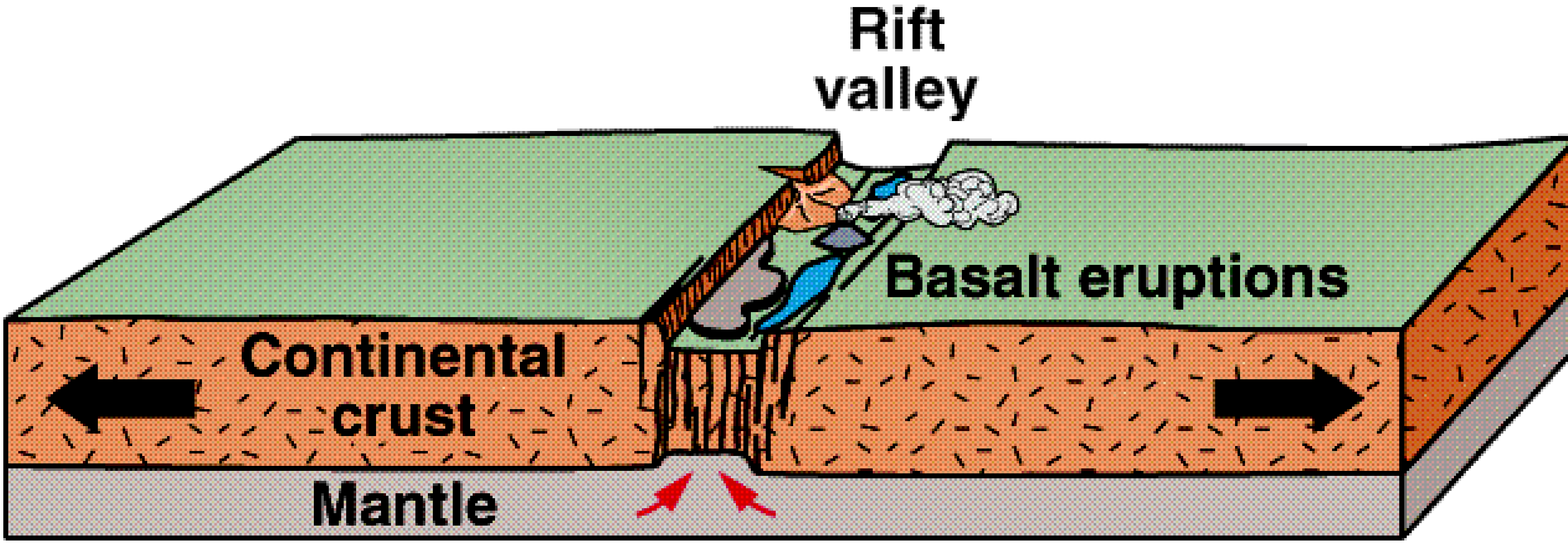
DIVERGENT BOUNDARIES

- During break up of a continent
  - Rifting, basaltic eruptions, uplift
  - Extension- normal faults, rift valley (graben) forms
  - Shallow focus earthquakes
- Continental crust separates
  - Fault blocks along edges
  - Oceanic crust created
  - Rock salt may develop in rift

DIVERGENT BOUNDARIES

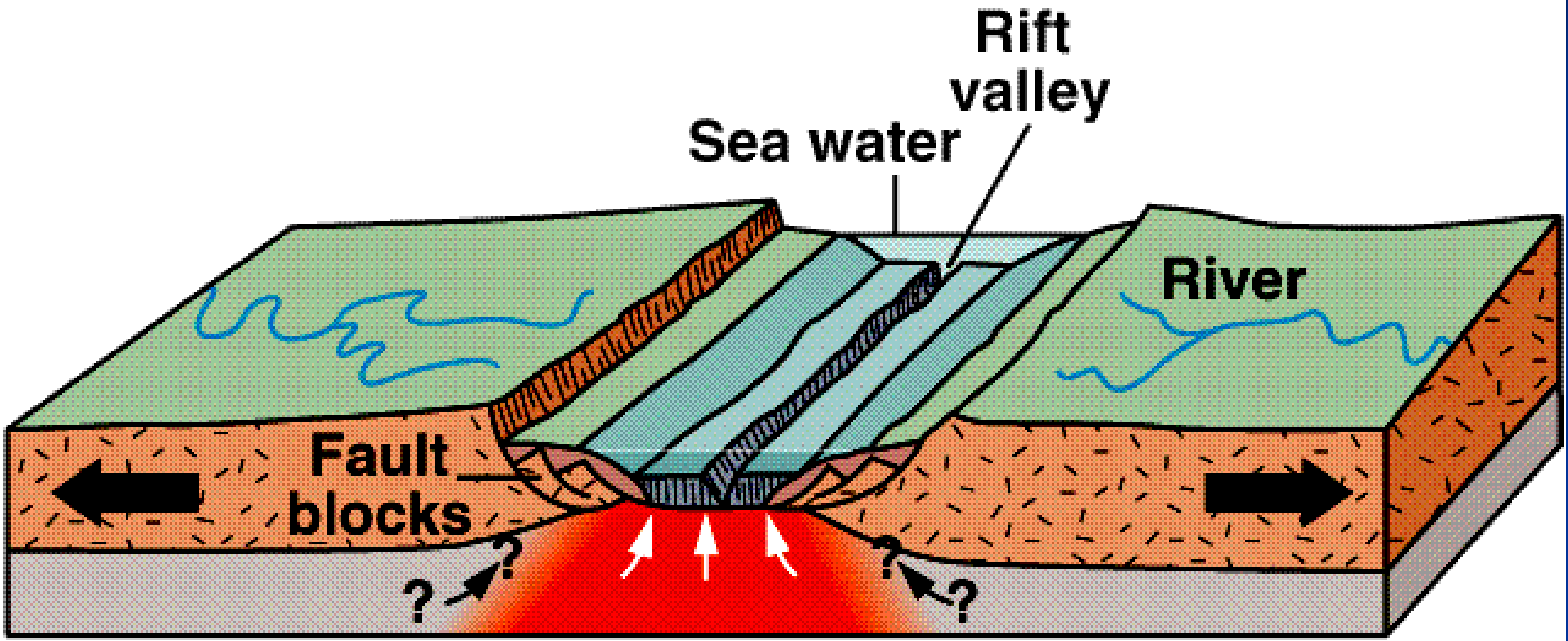
- Continuing divergence
  - Widening sea
  - Mid-oceanic ridge
  - Marine sediment covers continental edges
  - Passive continental margin
  - New crust formed at mid-oceanic ridge
    - Pillow basalt and dikes

Continent Undergoes Extension



A Continent undergoes extension. The crust is thinned and a rift valley forms (East African Rift Valleys).

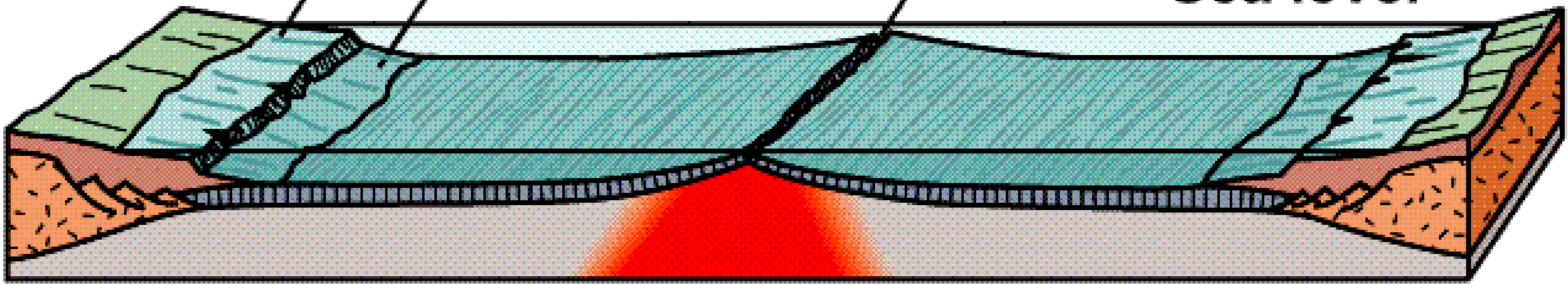
Continent Tears in Two



B Continent tears in two. Continent edges are faulted and uplifted. Basalt eruptions form oceanic crust (Red Sea).

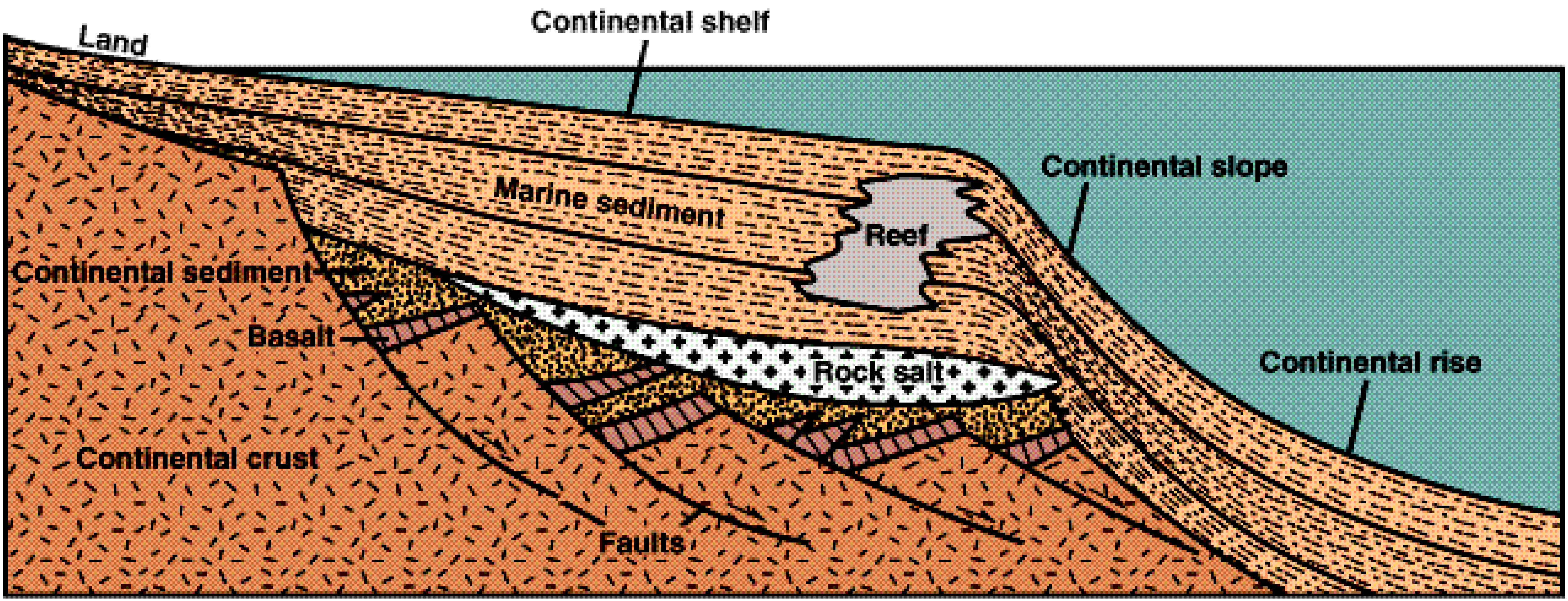
Red Sea

Divergent Plate Boundary Formed

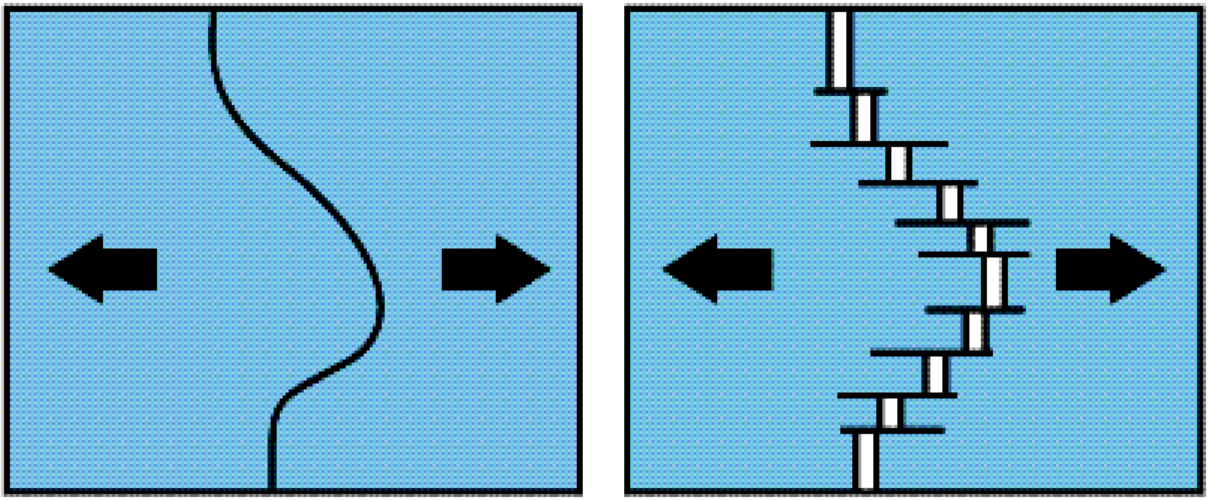


C Continental sediments blanket the subsiding margins to form continental shelves and rises. The ocean widens and a mid-oceanic ridge develops (Atlantic Ocean).

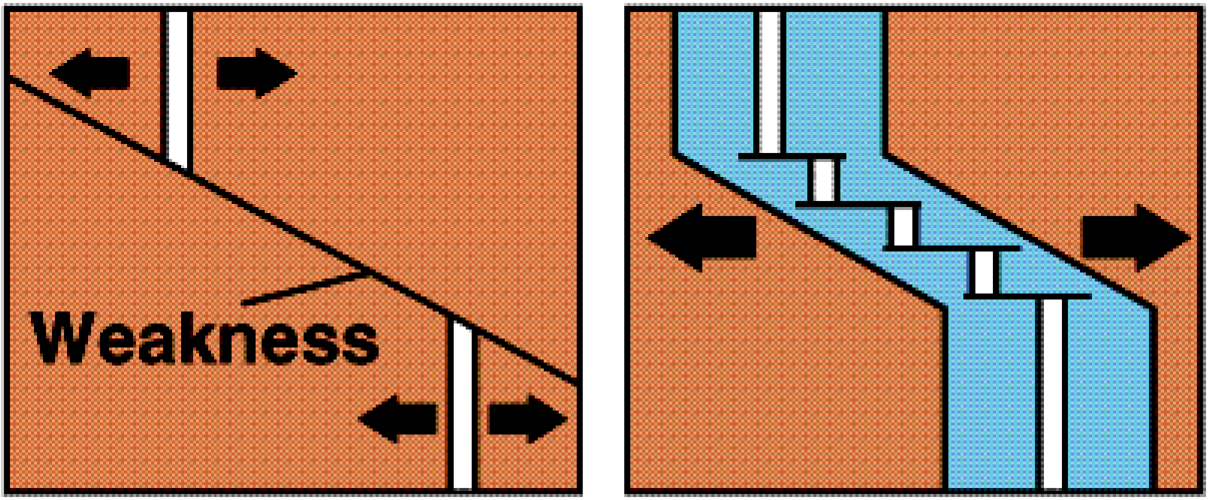
Passive Continental Margin



Divergent Plate Boundaries



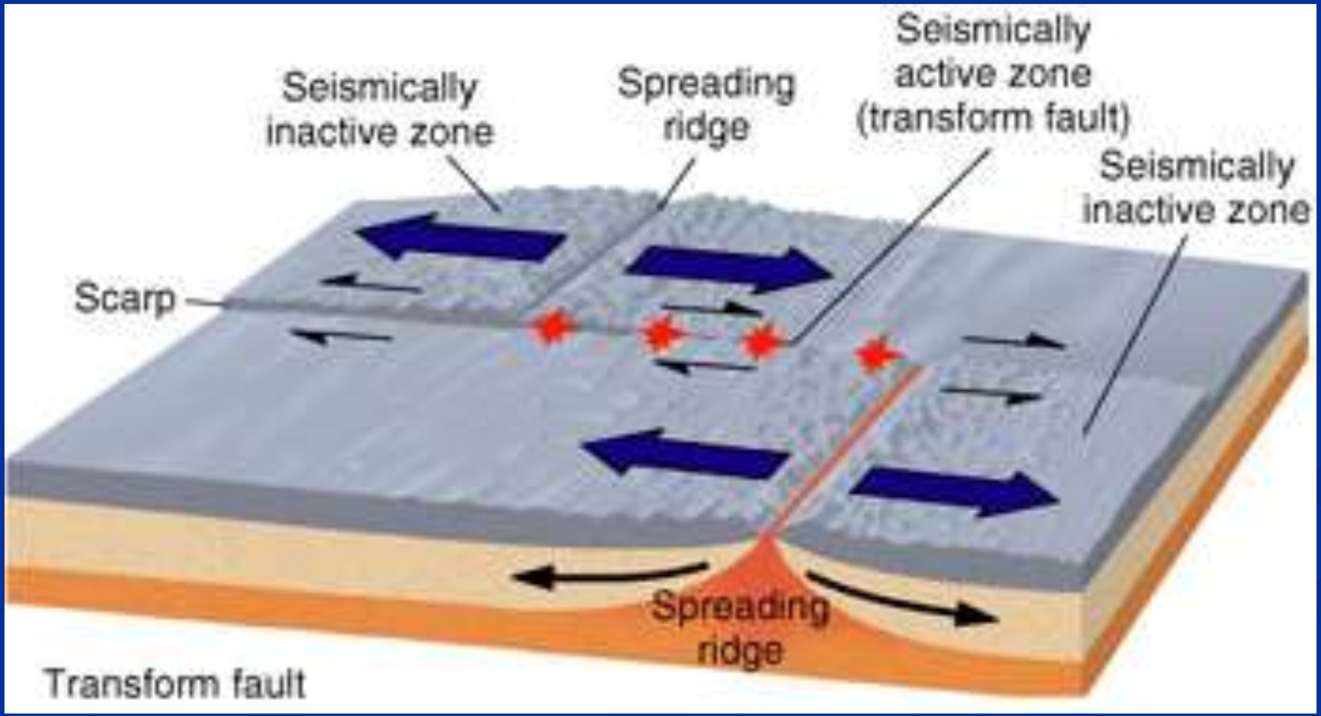
A



B

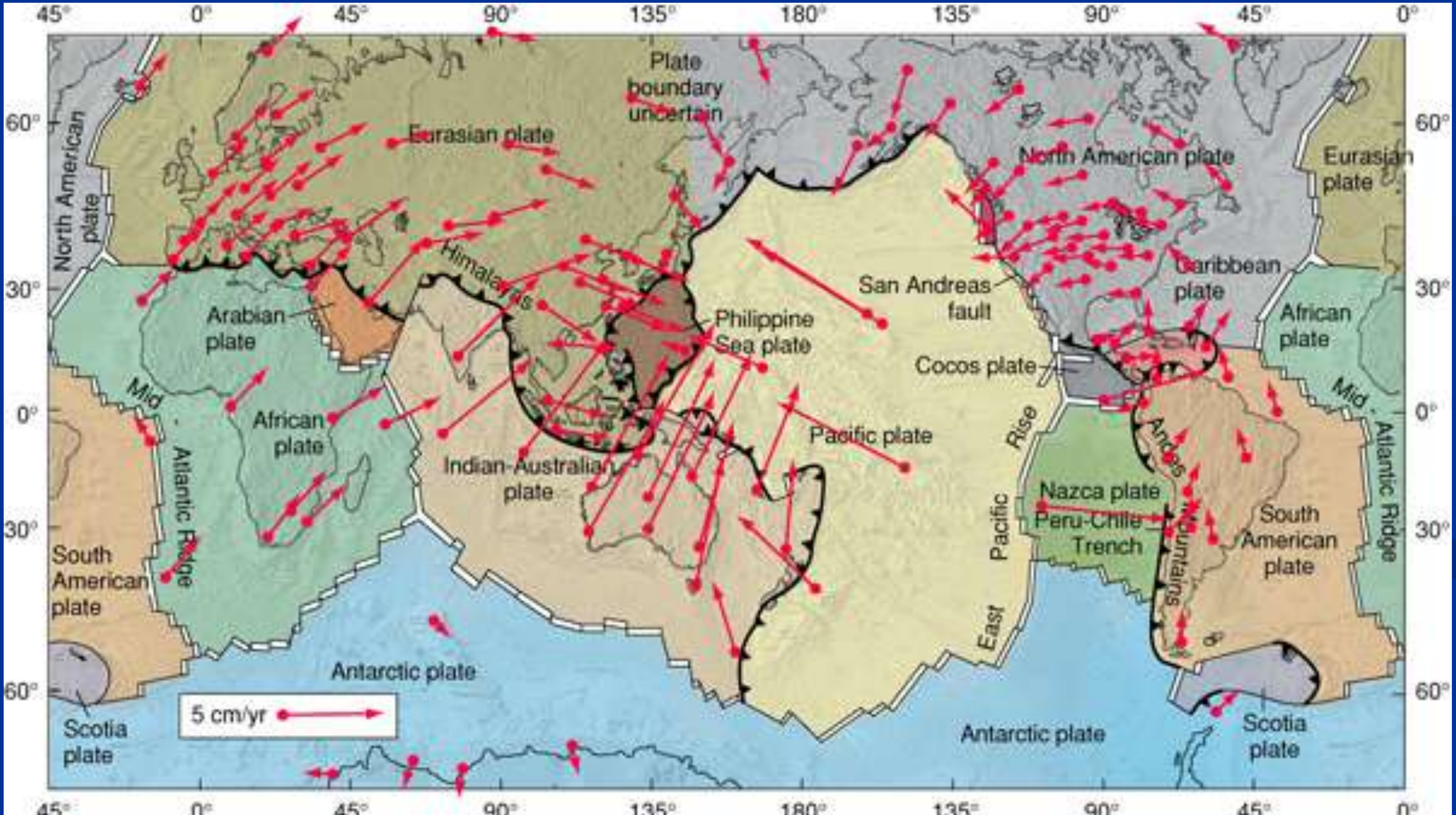
Evidence of Plate Motion

- *Mid-oceanic ridges* are offset along fracture zones
  - The segment of the fracture zone between the offset ridge crests is a seismically active *transform fault*
  - Relative motion along fault is result of seafloor spreading from adjacent ridges



Evidence of Plate Motion

- Plate motion can be directly measured using satellites, radar, lasers and ***global positioning systems***
  - Measurements accurate to within 1 cm
  - Motion rates closely match those predicted using seafloor magnetic anomalies



Rates of Seafloor Spreading

The velocity of plate movement varies around the world.

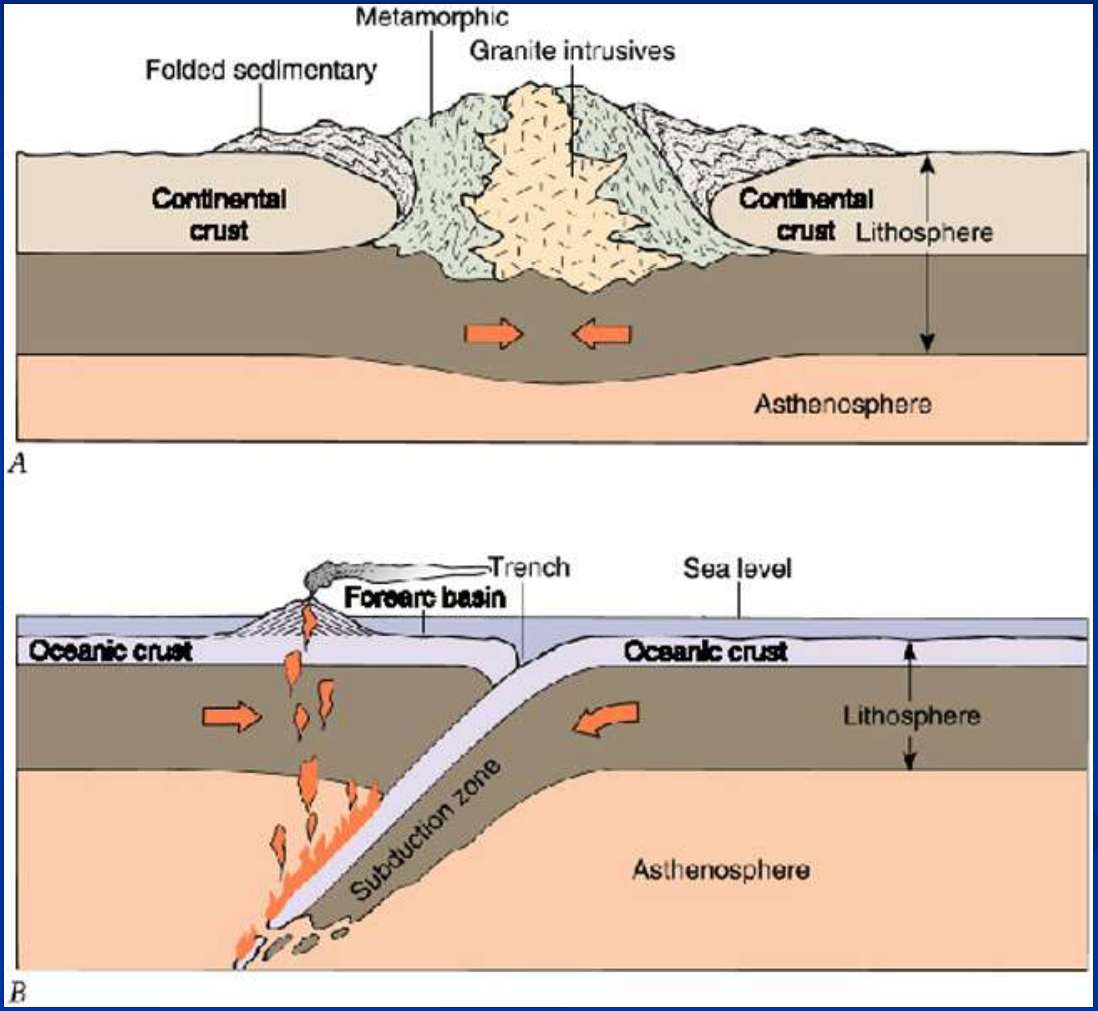
- Plates with large continents tend to move more slowly (up to 2 cm per year).
- Oceanic plates move more rapidly (averaging 6-9 cm per year).

Subduction

- An oceanic plate is pushed beneath another plate, forming a deep-sea trench.
- Rocks and sediments of downward-moving plate are subducted into the mantle and heated.
- Partial melting occurs. Molten rock rises to form:
  - Volcanic island arcs
  - Intrusive igneous rocks

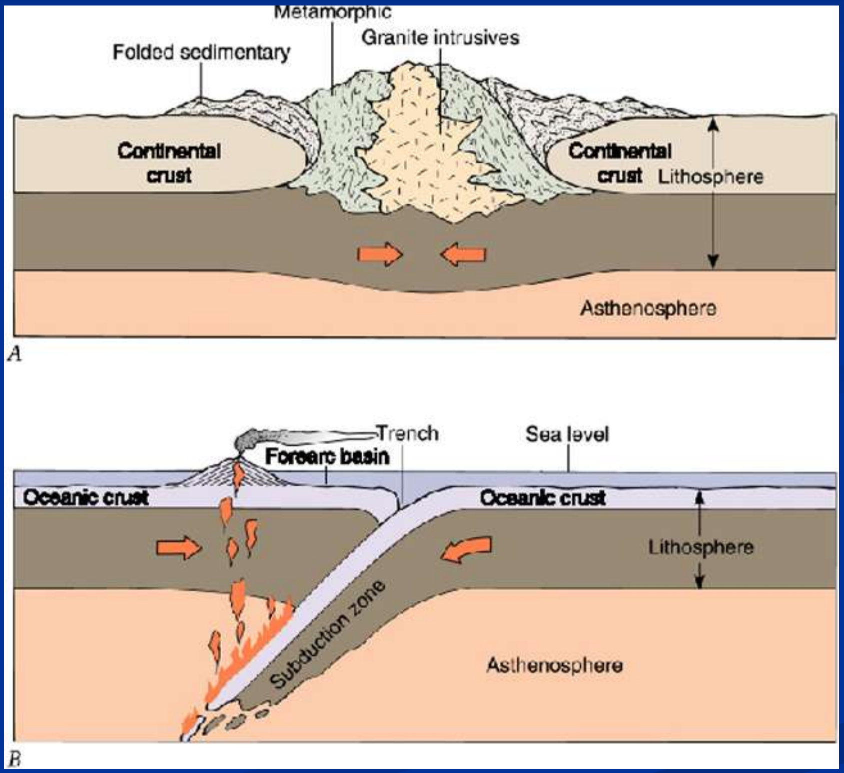
Convergent Plate Boundaries

A. Continent-continent collision
B. Subduction – oceanic plate beneath oceanic plate = island arc

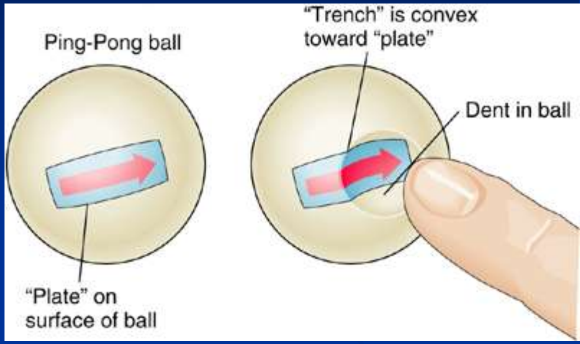


Convergent Plate Boundaries

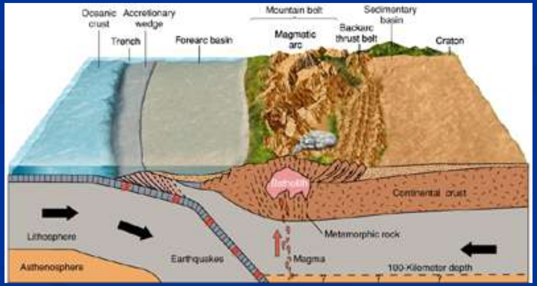
- Plates move toward one another
- One plate overrides the other
- Compressional stress
- Continental collision
- Subduction

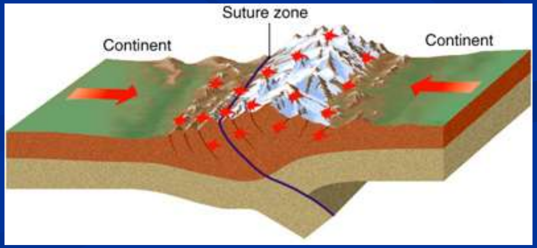


Convergent Plate Boundaries



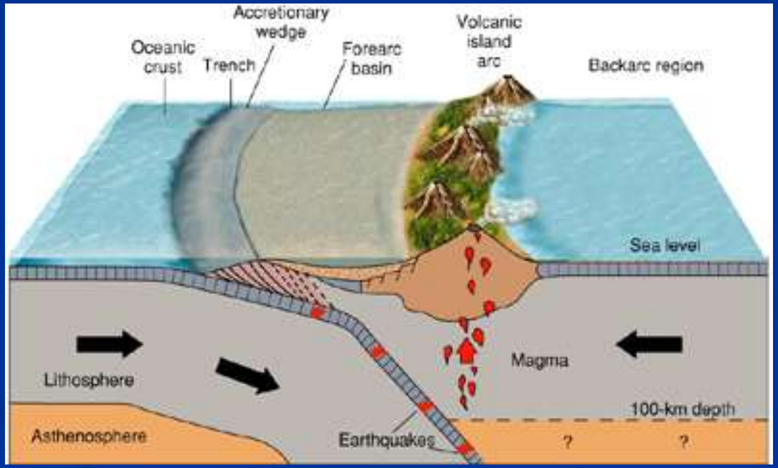
- At ***convergent plate boundaries***, plates move toward one another
- Nature of boundary depends on plates involved (oceanic vs. continental)
  - ***Ocean-ocean plate convergence***
    - Marked by ***ocean trench***, ***Benioff zone***, and ***volcanic island arc***
  - ***Ocean-continent plate convergence***
    - Marked by ocean trench, Benioff zone, ***volcanic arc***, and ***mountain belt***
  - ***Continent-Continent plate convergence***
    - Marked by mountain belts and ***thrust faults***



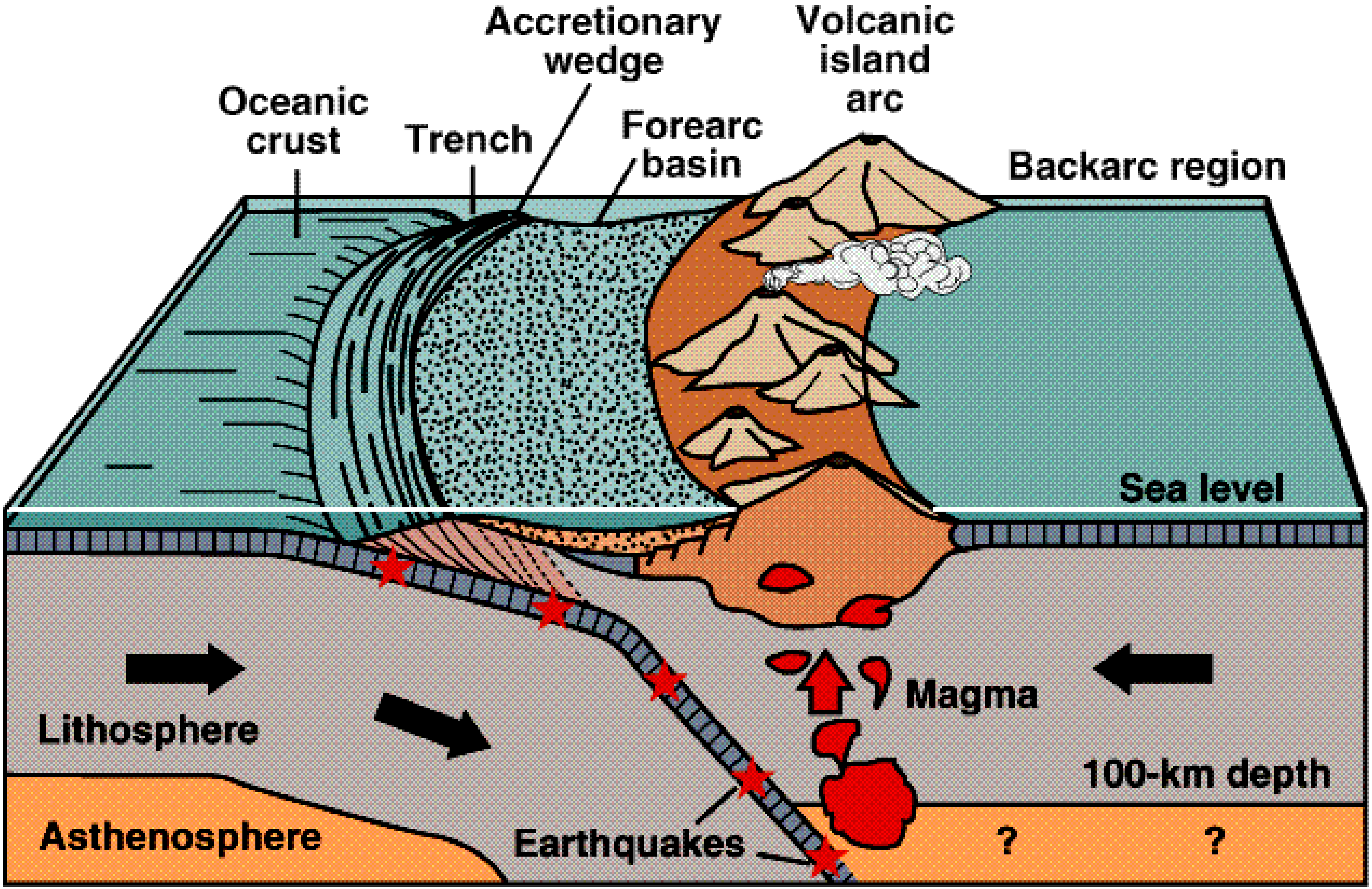


Ocean-Ocean CONVERGENCE

- Oceanic-Oceanic Convergence
  - Oceanic trench
    - curved convex to subducting plate
  - Beniofff zone
  - Magma generated at depth
    - Andesitic volcanism
  - Island arc forms
    - Angle of subduction determines distance of arc from trench
  - Accretionary wedge
  - trench migration in time



Ocean-Ocean Convergence



Ocean-to-Ocean Subduction

An oceanic plate is subducted beneath another oceanic plate, forming a deep-sea trench, with an associated basaltic volcanic island arc.

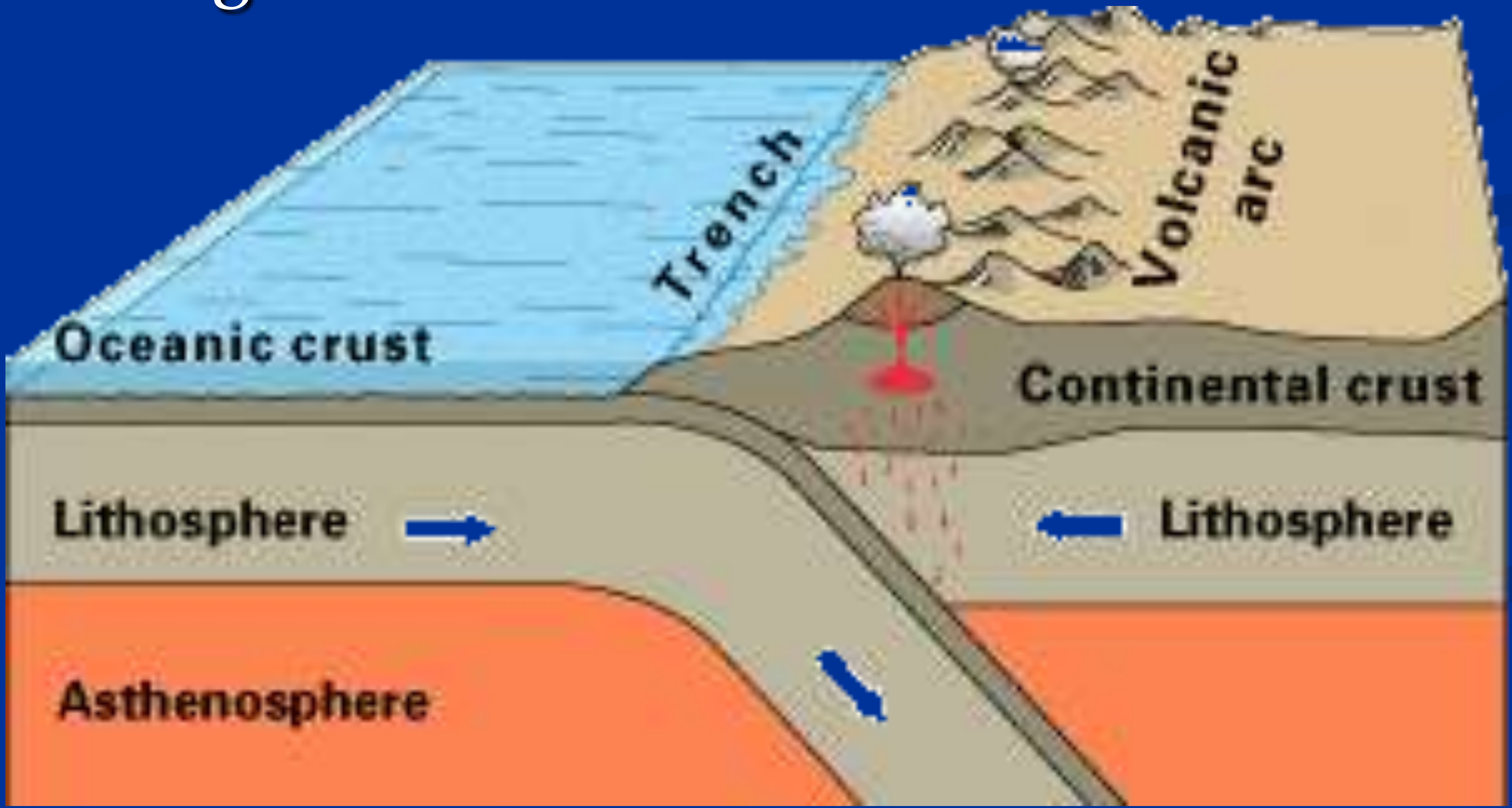
Oceanic-oceanic convergence

Ocean-to-Continent Subduction Zone Includes:

3. Ophiolite suite - Piece of descending oceanic plate that was scraped off and incorporated into the accretionary wedge. Contains:
   - Deep-sea sediments
   - Submarine basalts (pillow lavas)
   - Metamorphosed mantle rocks (serpentinized peridotite)
4. Blueschists – metamorphic minerals (glaucophane and lawsonite) indicating high pressures but low temperatures.

Ocean-to-Continent Subduction

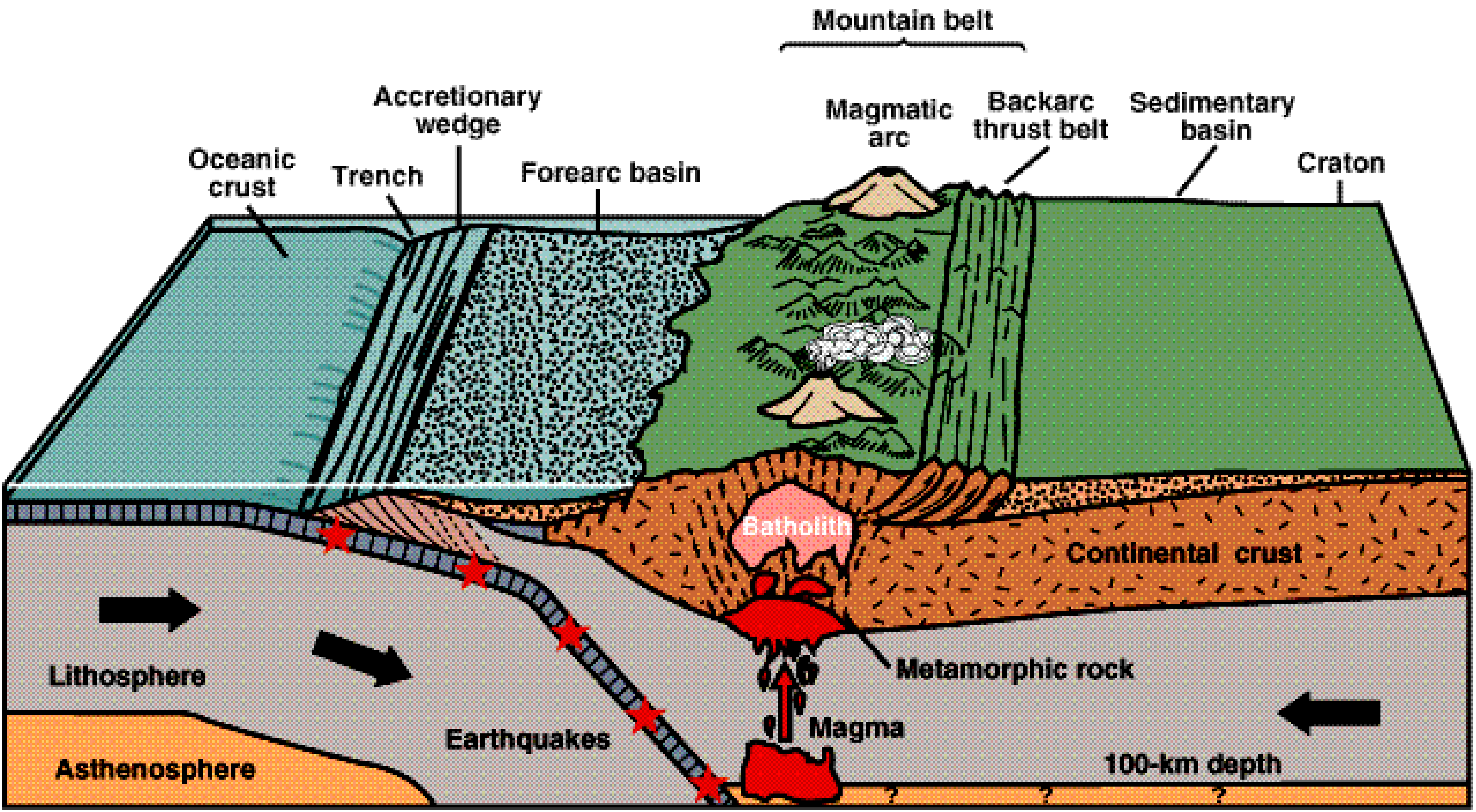
An oceanic plate is subducted beneath a continental plate, forming a trench adjacent to a continent, and volcanic mountains along the edge of the continent.



Ocean - Continent CONVERGENCE

- Active continental margin
  - Subduction of oceanic lithosphere beneath continental lithosphere
  - Accretionary wedge & forearc basin
- Magmatic arc- volcanoes & plutons
- Crustal thickening and mountain belts
- Regional metamorphism
- Thrust faulting & folding on continental side
  - Backarc basin

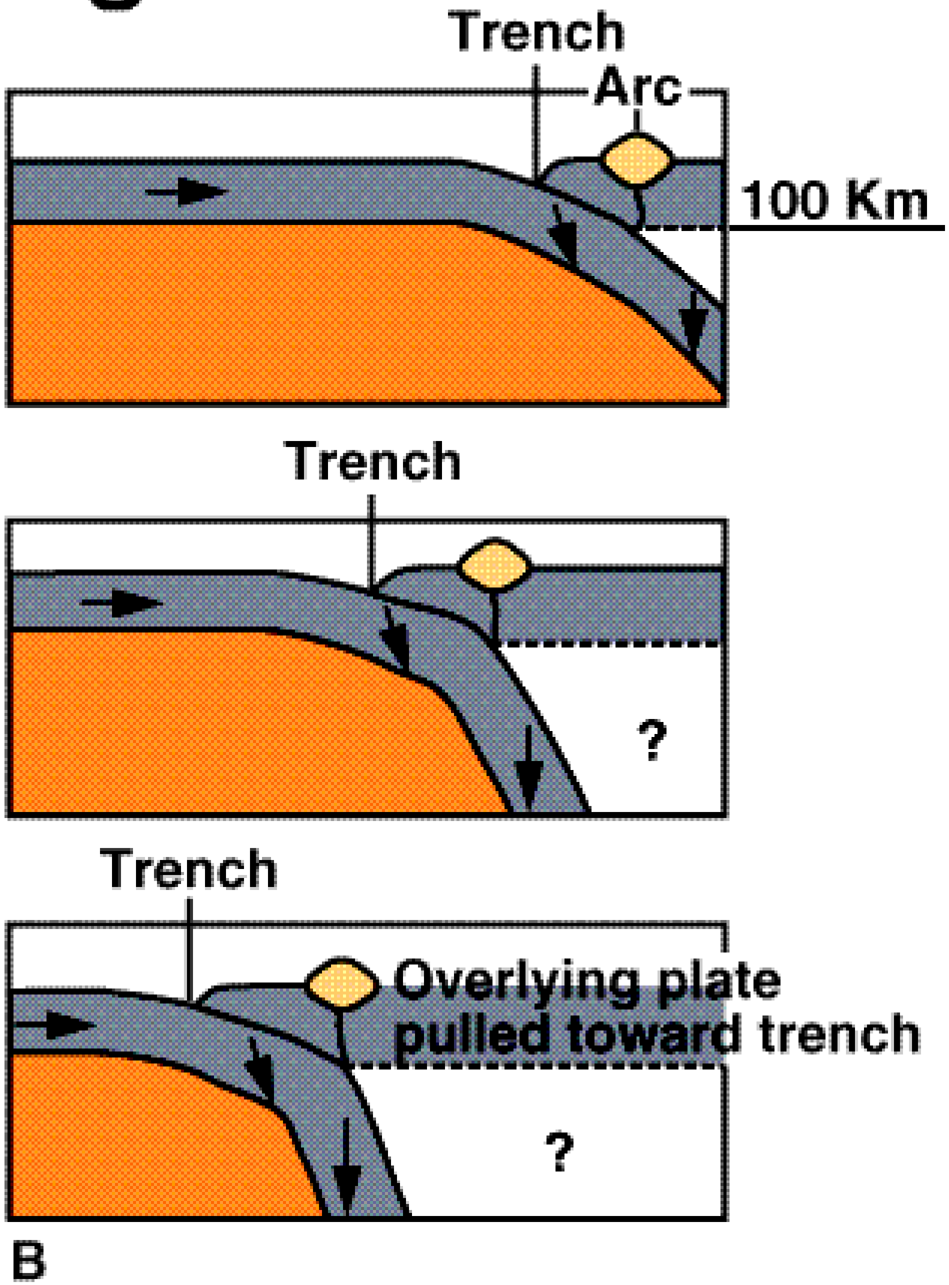
Ocean-Continent Convergence



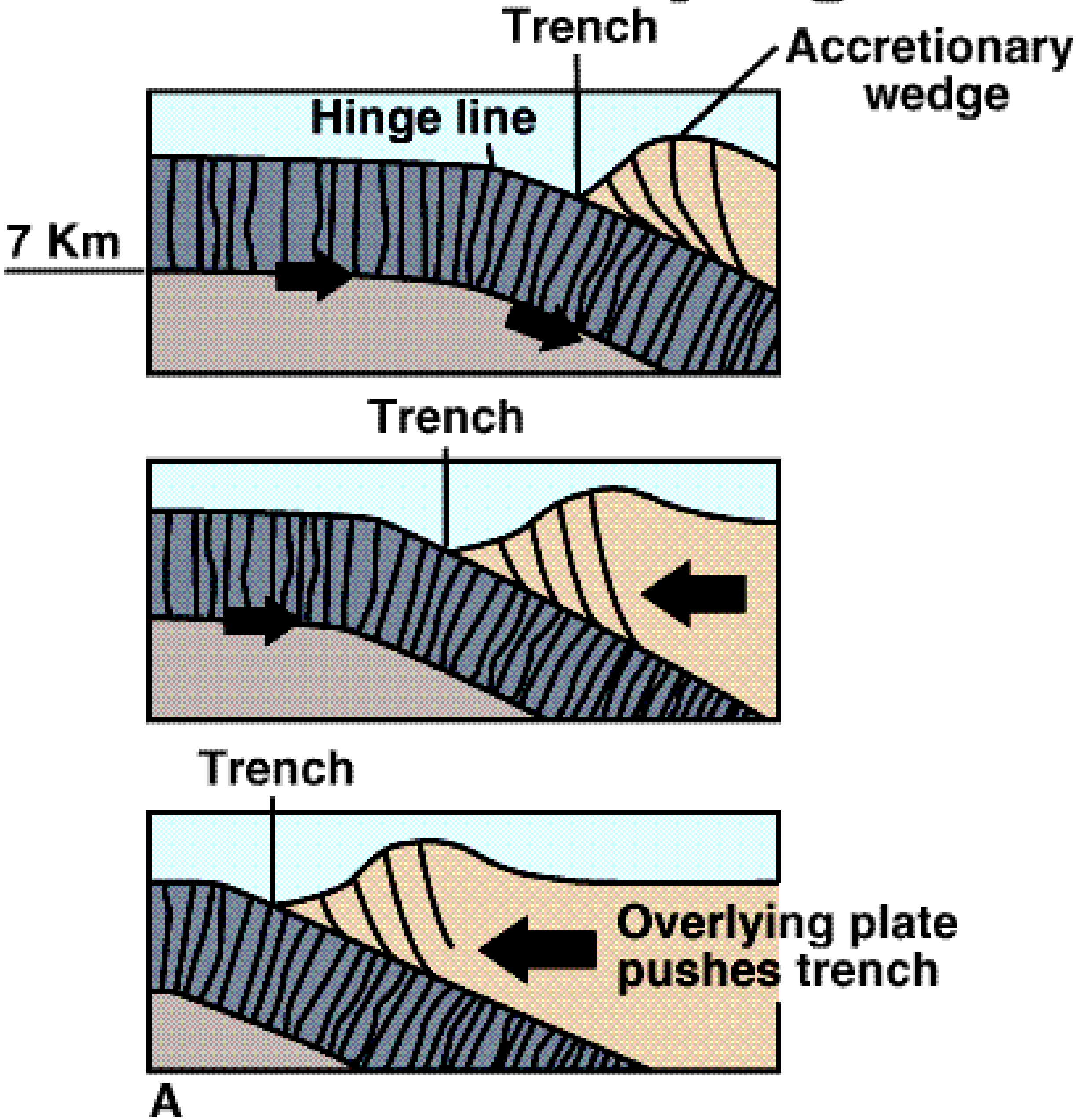
Ocean-to-Continent Subduction Zone Includes:

1. Accretionary prism or accretionary wedge - Highly contorted and metamorphosed sediments that are scraped off the descending plate and accreted onto the continental margin.
2. Mélange - A complexly folded jumble of deformed and transported rocks.

Migration of Trench

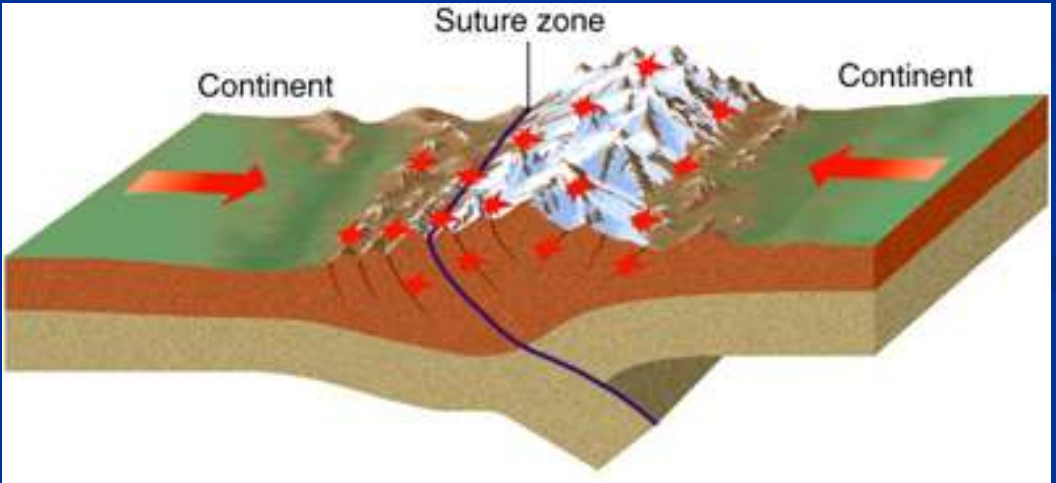


Motion of Overlying Plates



Continent – Continent CONVERGENCE

- Continental-Continental convergence
  - Two continents approach each other and collide
    - Sea floor subducted on one side
    - Ocean becomes narrower and narrower
    - Continent wedged into subduction zone but not carried down it
    - Suture zone
  - Crust thickened - thrust belts
  - Mountain belt in interior of continent

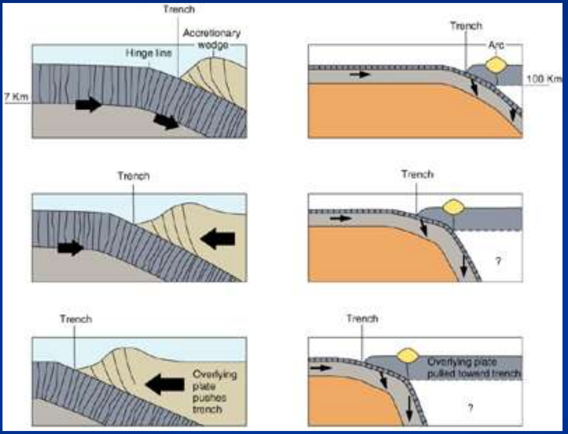


Continental Collision

- Continental collisions form mountain belts with:
  - Folded sedimentary rocks
  - Faulting
  - Metamorphism
  - Igneous intrusions
- Slabs of continental crust may override one another
- Suture zone = zone of convergence between two continental plates

Movement of Plate Boundaries

- ***Plate boundaries*** can move over time
  - Mid-oceanic ridge crests can migrate toward or away from subduction zones or abruptly jump to new positions
  - Convergent boundaries can migrate if ***subduction angle steepens*** or overlying plate has a trenchward motion of its own
    - ***Back-arc spreading*** may occur, but is poorly understood
  - Transform boundaries can shift as slivers of plate shear off
    - San Andreas fault shifted eastward about five million years ago and may do so again



Transform Plate Boundaries

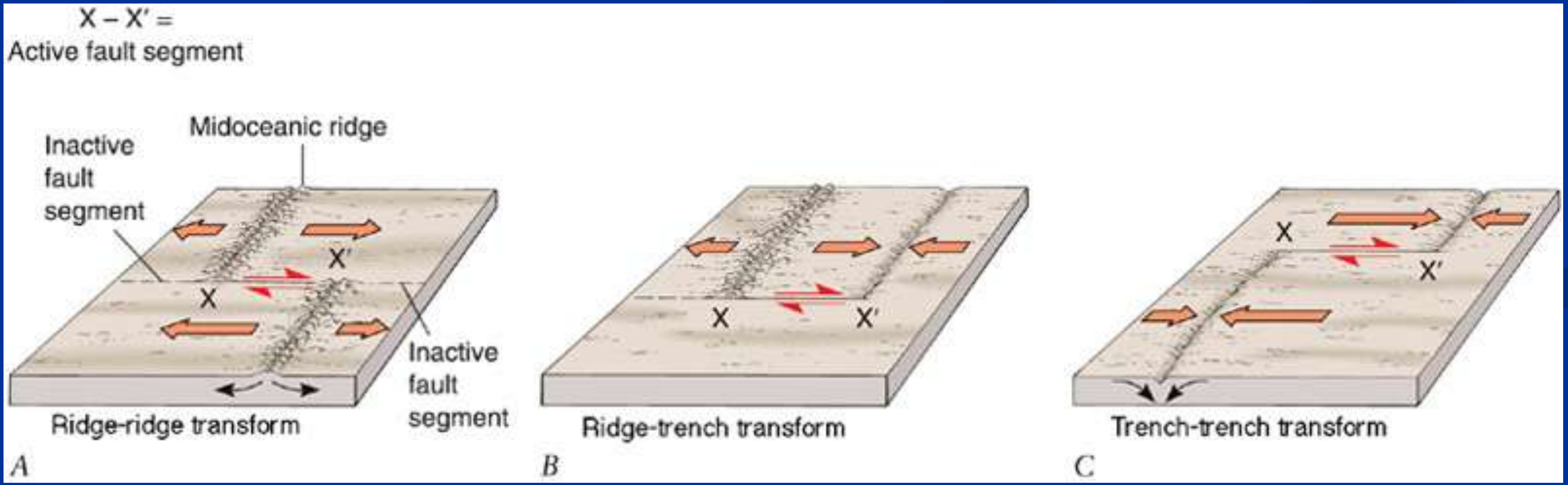
- Plates slide past one another
- Shear stress
- Transform faults cut across and offset the mid-ocean ridges
- A natural consequence of horizontal spreading of seafloor on a curved globe
- *Example*: San Andreas Fault

TRANSFORM BOUNDARIES

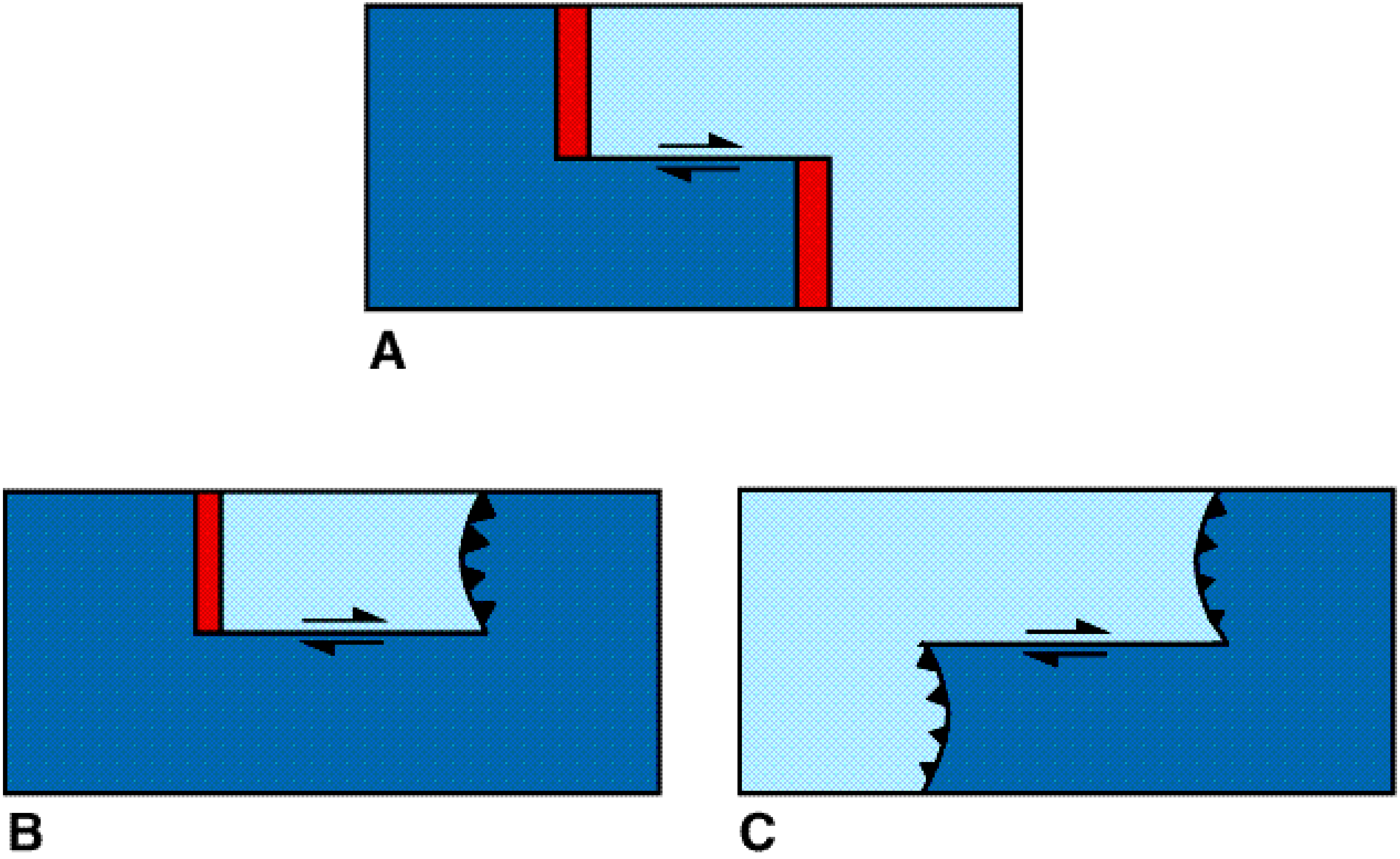
- Two plates slide past each other
- Usually between mid-oceanic ridge segments
  - Can also connect ridge and trench
  - Or trench to trench
- Origin of offset of ridges

Types of Transform Faults

Because seafloor spreads outward from mid-ocean ridge, relative movement between offset ridge crests is opposite of that in ordinary strike-slip faults. Note arrows showing direction of movement.

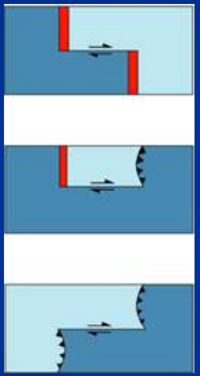


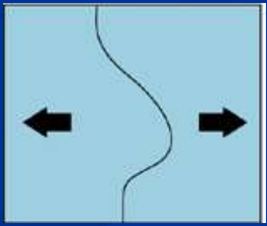
Transform Boundaries

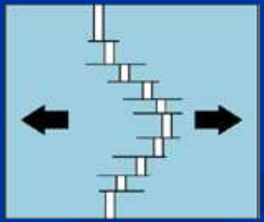


Transform Plate Boundaries

- At ***transform plate boundaries***, plates slide horizontally past one another
  - Marked by ***transform faults***
  - Transform faults may connect:
    - Two offset segments of mid-oceanic ridge
    - A mid-oceanic ridge and a trench
    - Two trenches
  - Transform offsets of the mid-oceanic ridges allow a series of straight-line segments to approximate the curved boundaries required by a ***spheroidal Earth***



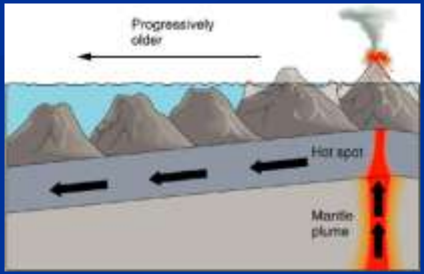


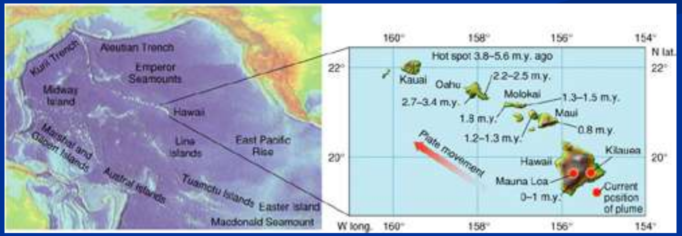


San Andreas fault

Mantle Plumes and Hot Spots

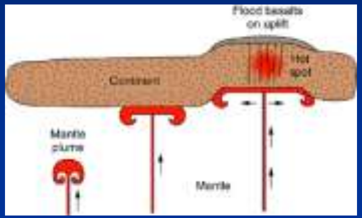
- Mantle plumes may form *"hot spots"* of active volcanism at Earth's surface
  - Approximately 40 known hotspots
- When hot spots occur in the interior of a plate, a *volcanic chain* will be produced
  - *Orientation* of the volcanic chain shows *direction* of plate motion over time
  - *Age* of volcanic rocks can be used to determine *rate* of plate movement
  - Hawaiian islands are a good example

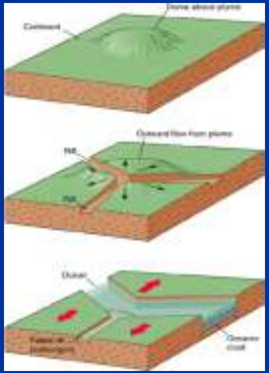


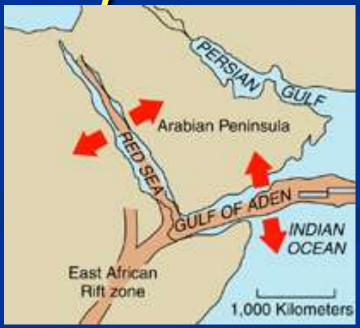


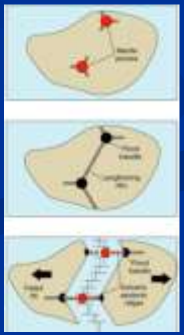
Mantle Plumes and Hot Spots

- *Mantle plumes* are a modified version of convection where narrow columns of hot mantle rock rise through the mantle
  - Thought to have large spherical or mushroom-shaped heads above a narrow rising tail
  - Stationary with respect to moving plates
  - *Large mantle plumes may spread out … tear apart the overlying plate*
    - Flood basalt eruptions
    - Rifting apart of continental land masses
  - New divergent boundaries may form





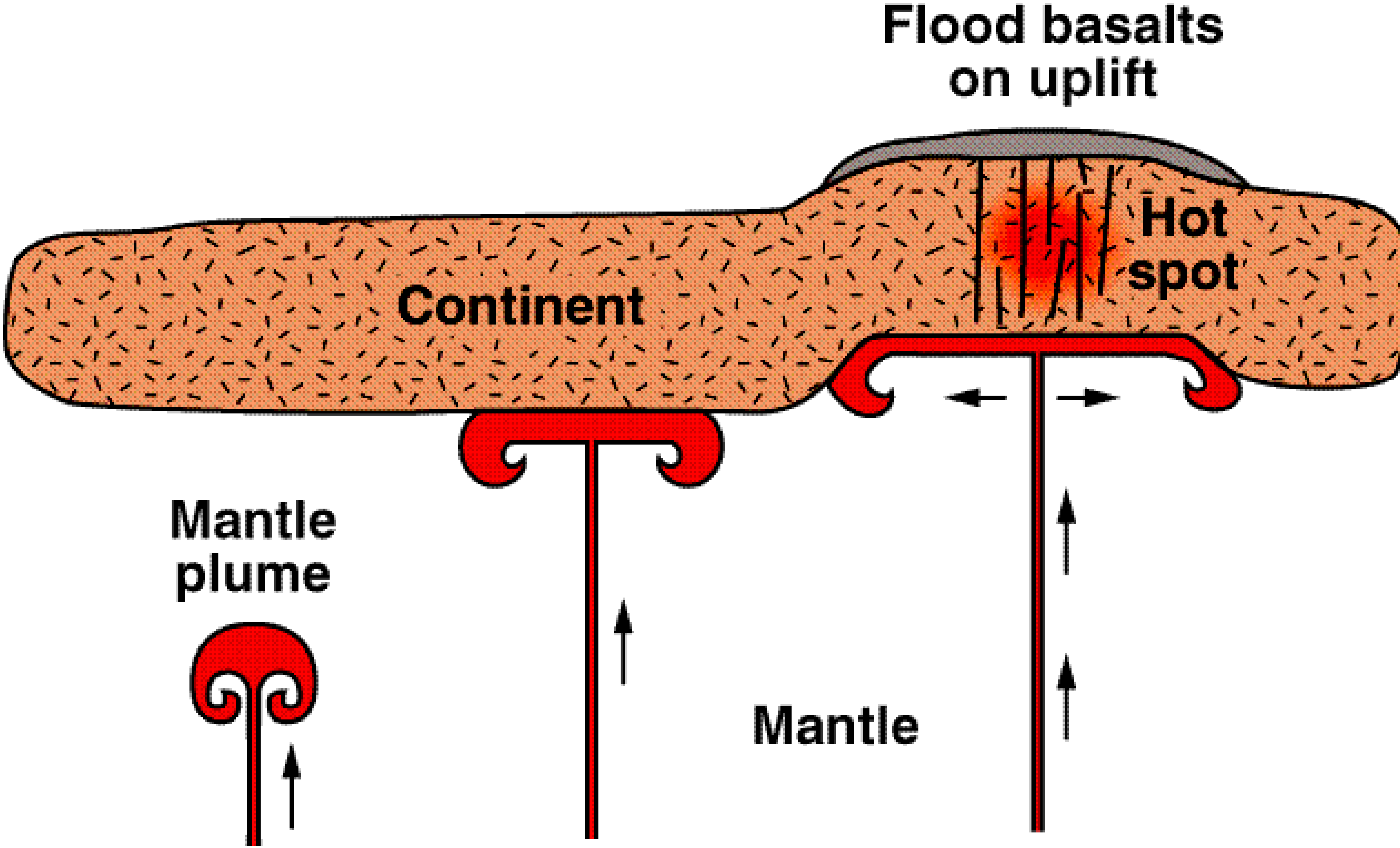




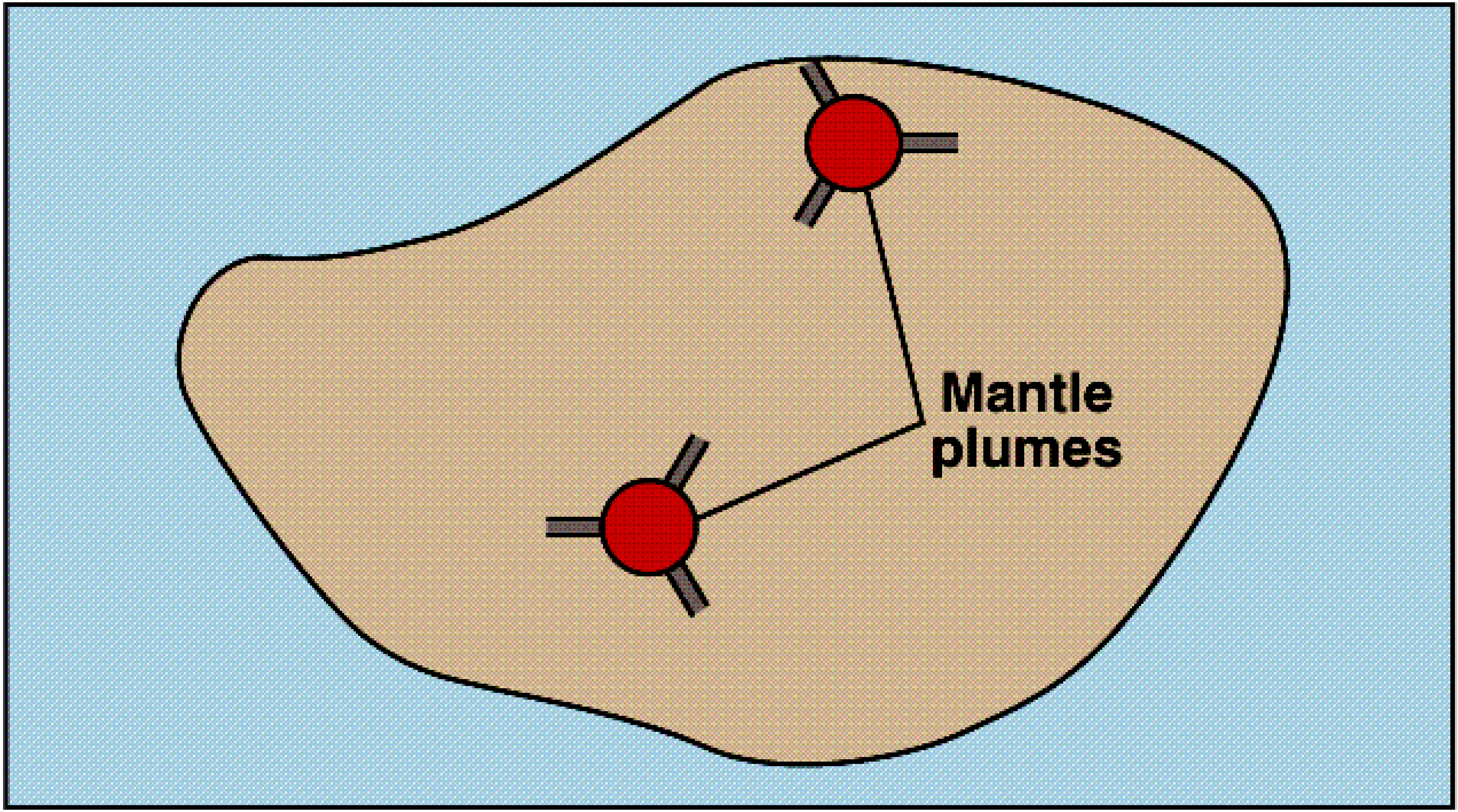
Thermal Plumes

- Thermal plumes do not all produce triple junctions.
- Hot spots are present across the globe. If the lava from the thermal plume makes its way to the surface, volcanic activity may result.
- As a tectonic plate moves over a hot spot (at a rate as high as 10 cm per year), a chain of volcanoes is formed.

Mantle Plumes

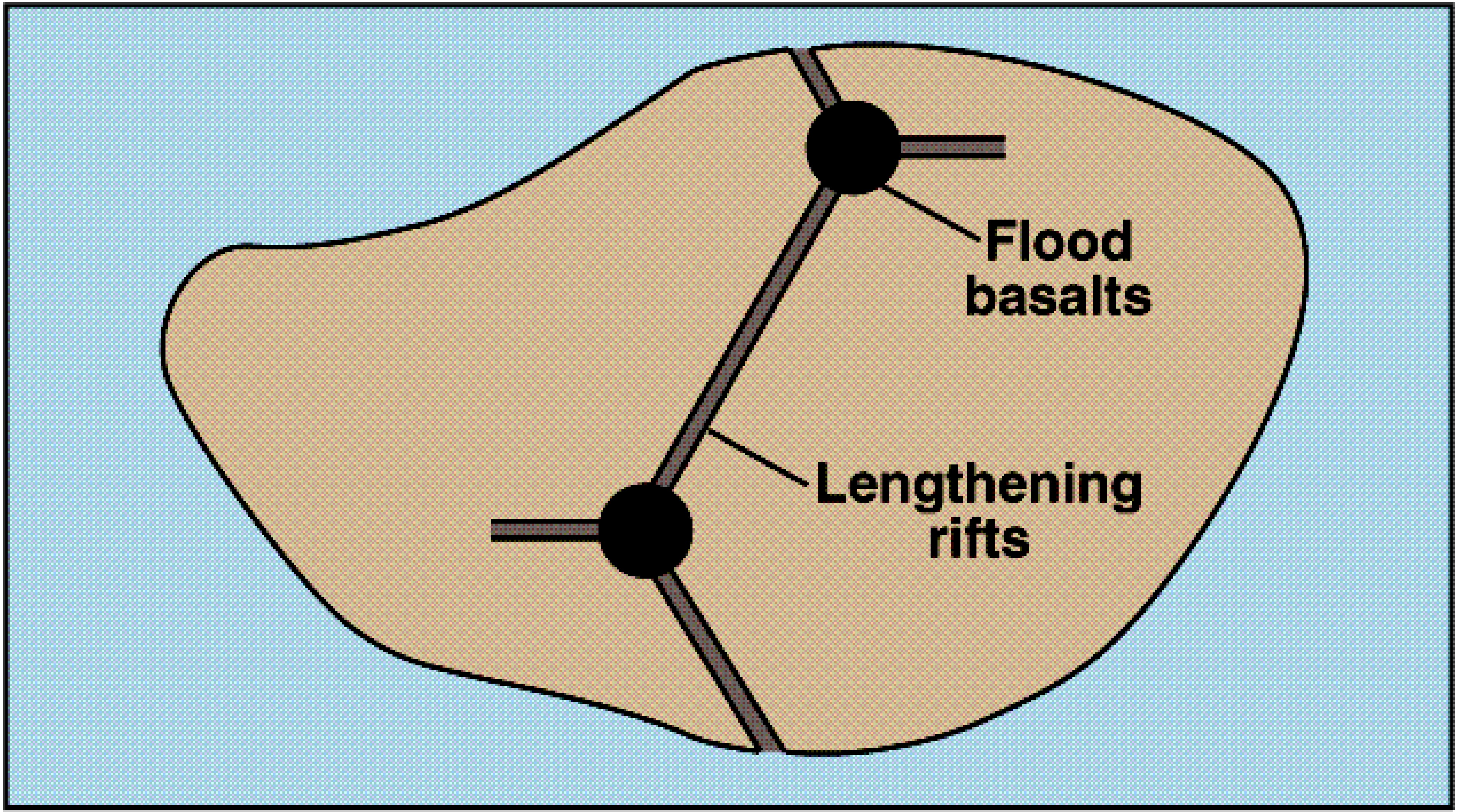


Two Mantle Plumes



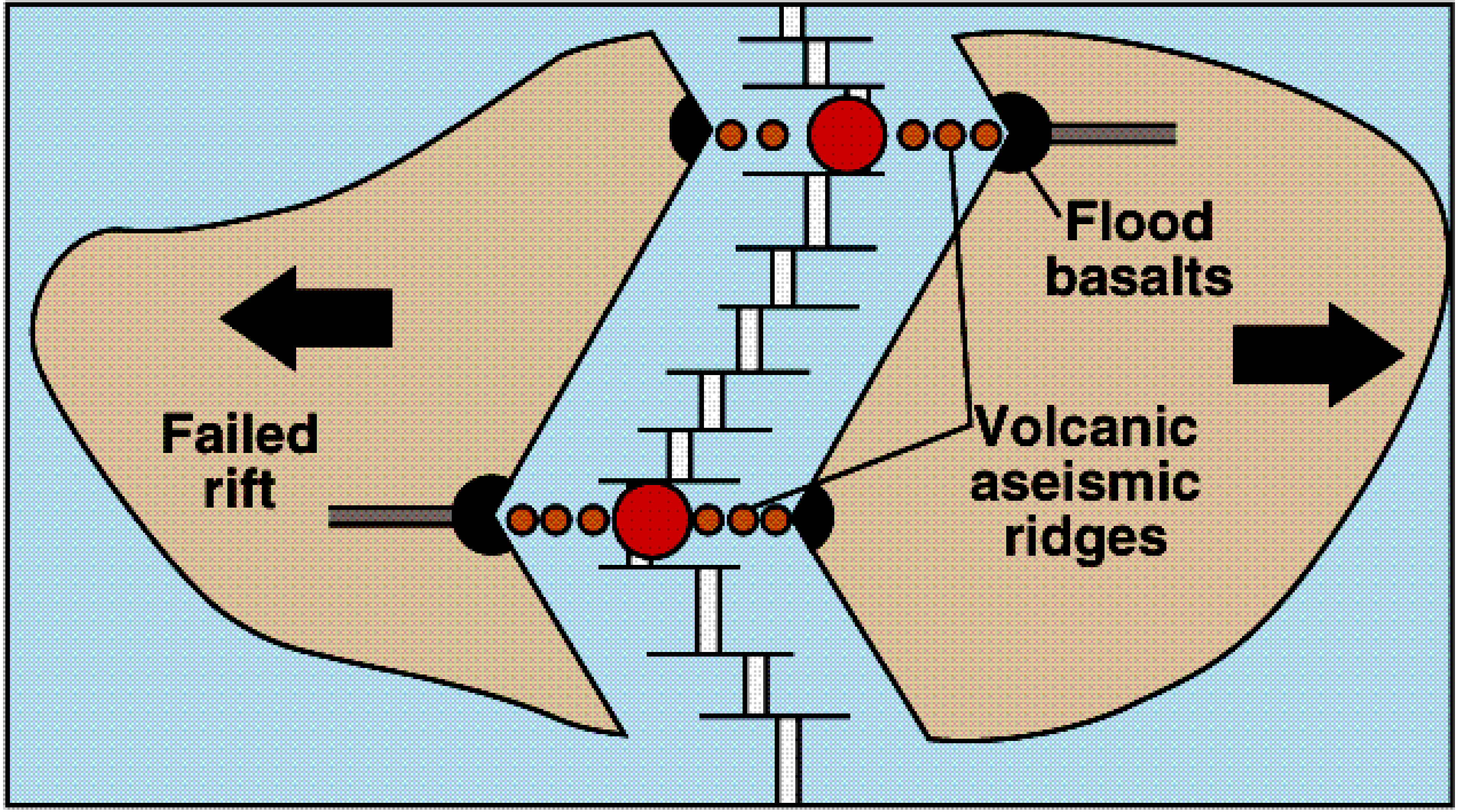
A

Rifts Lengthen



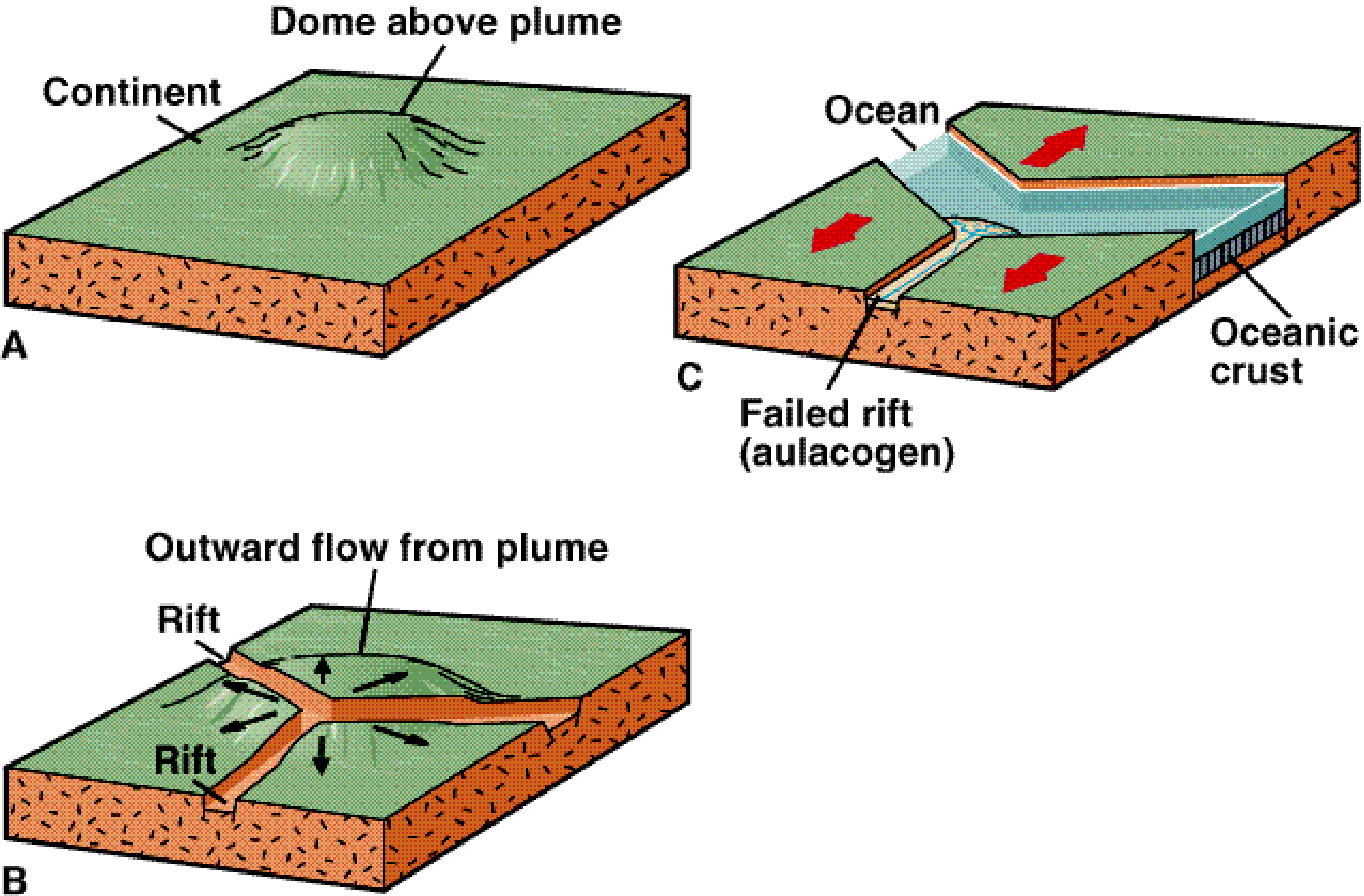
B

Continent Splits



C

Continental Breakup from Plume

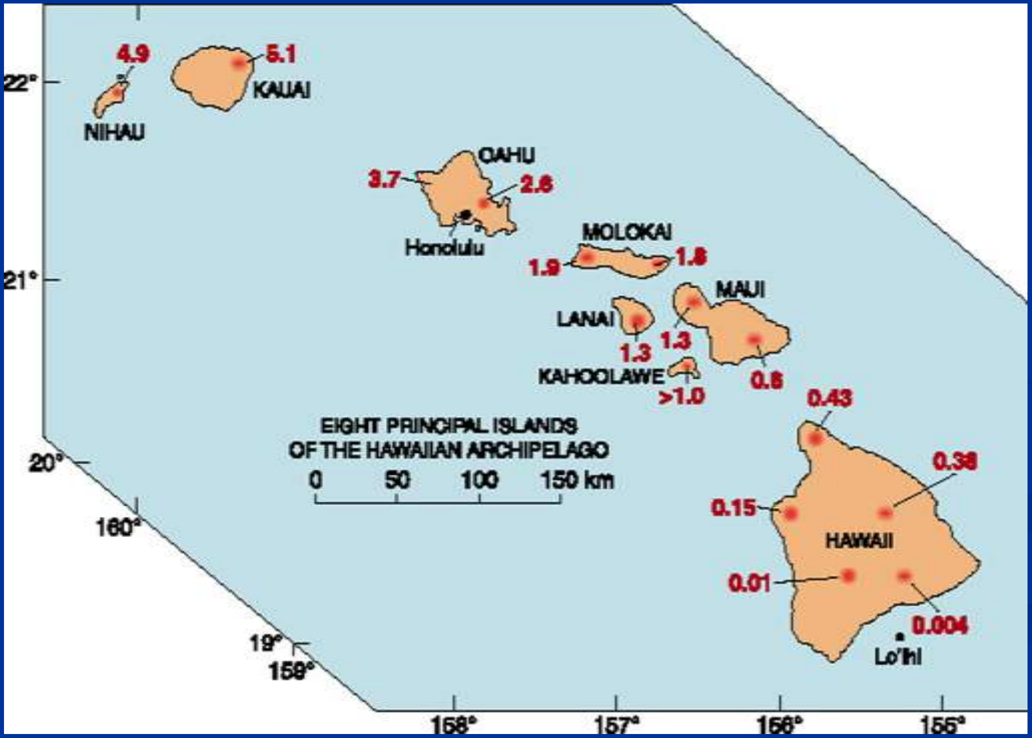


Thermal Plumes, Hot Spots and Hawaii

- Volcanoes develop over hot spots or thermal plumes.
- As the plate moves across the hot spot, a chain of volcanoes forms.
- The youngest volcano is over the hot spot.
- The volcanoes become older away from the site of volcanic activity.
- Chains of volcanic islands and underwater sea mounts extend for thousands of km in the Pacific Ocean.

Thermal Plumes, Hot Spots and Hawaii

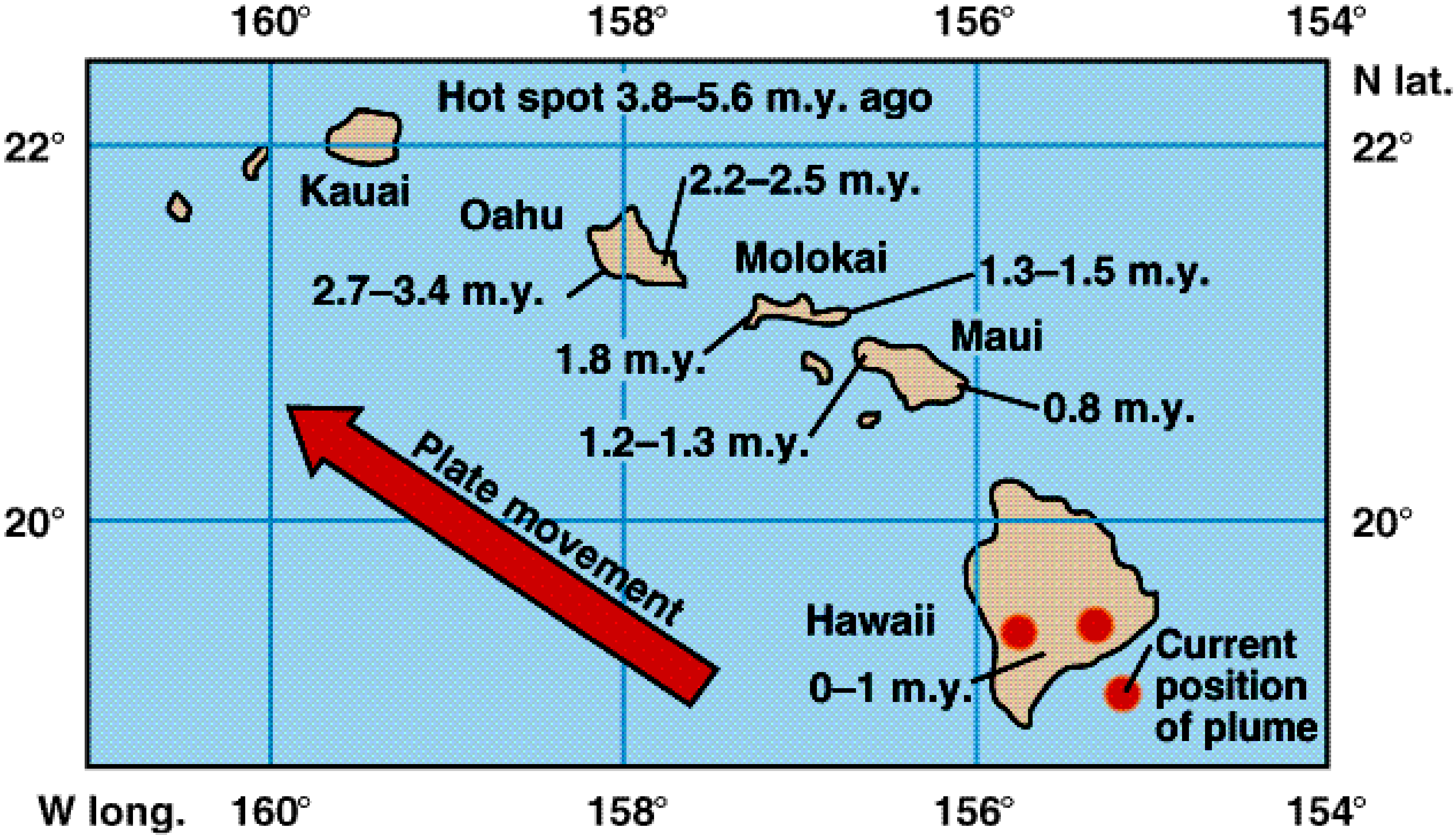
A new volcano, Lo'ihi, is forming above the hot spot, SE of the island of Hawaii. The Hawaiian islands are youngest near the hot spot, and become older to the NW.



Thermal Plumes

- Thermal plumes are concentrated areas of heat rising from near the core-mantle boundary. **Hot spots** are present on the Earth's surface above a thermal plume.
- The lithosphere expands and domes upward, above a thermal plume. The uplifted area splits into three radiating fractures, forming a **triple junction**. Rifting occurs, and the three plates move outward away from the hot spot.

Ages of Hawaiian Volcanic Rock



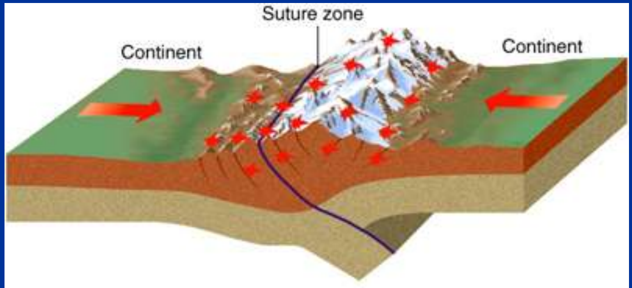
Thermal Plumes, Hot Spots and Hawaii

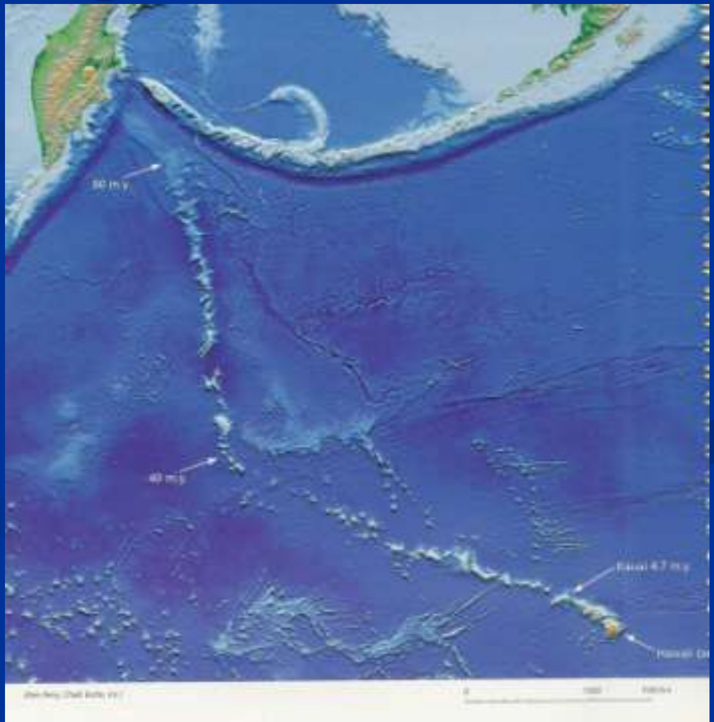
This chain of volcanoes extends NW past Midway Island, and then northward as the Emperor Seamount Chain. The volcanic trail of the Hawaiian hot spot is 6000 km long. A sharp bend in the chain indicates a change in the direction of plate motion about 43 million years ago.

What happened at 43 Ma?

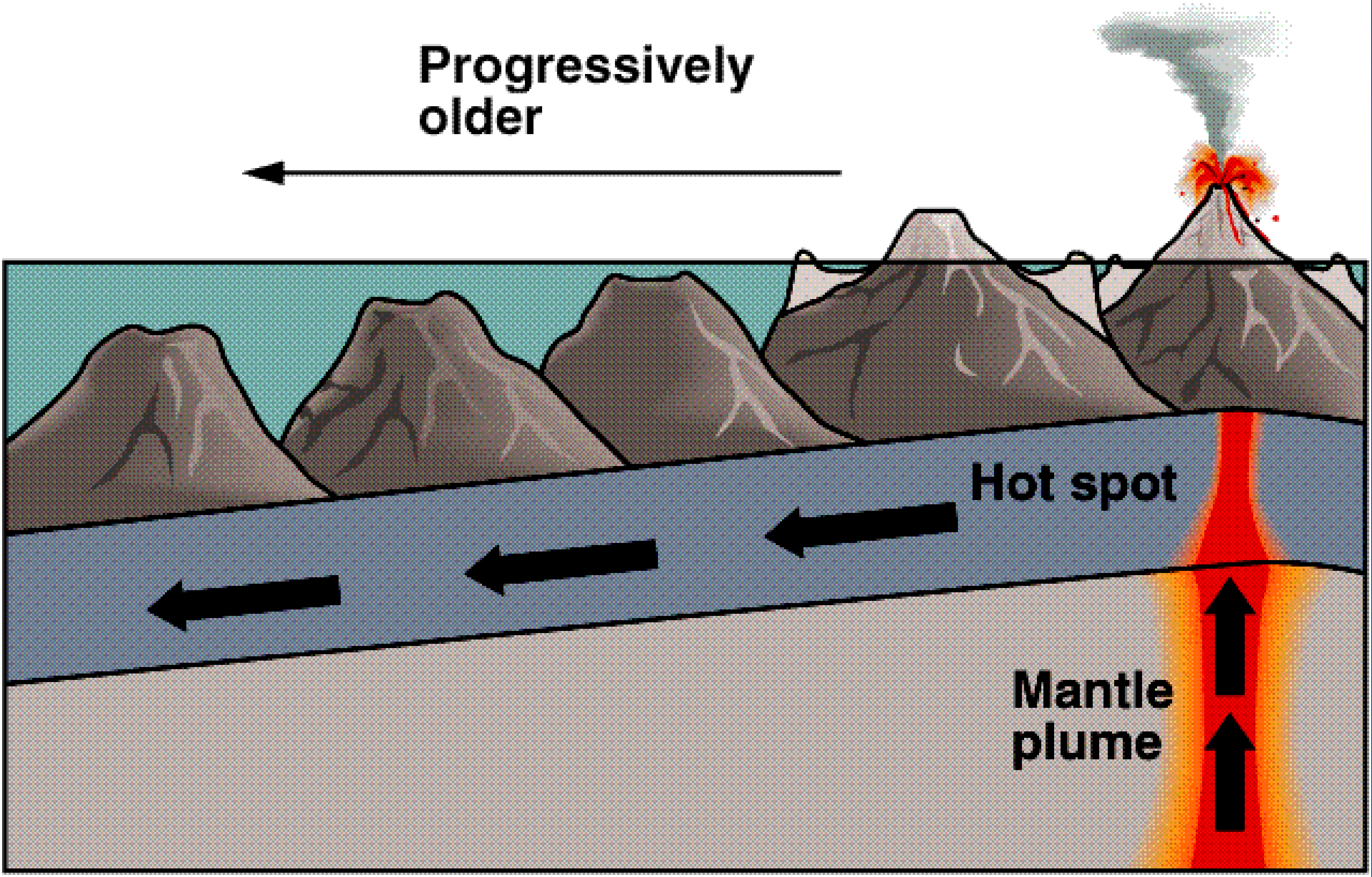
collision of India into Asia

caused plate readjustment

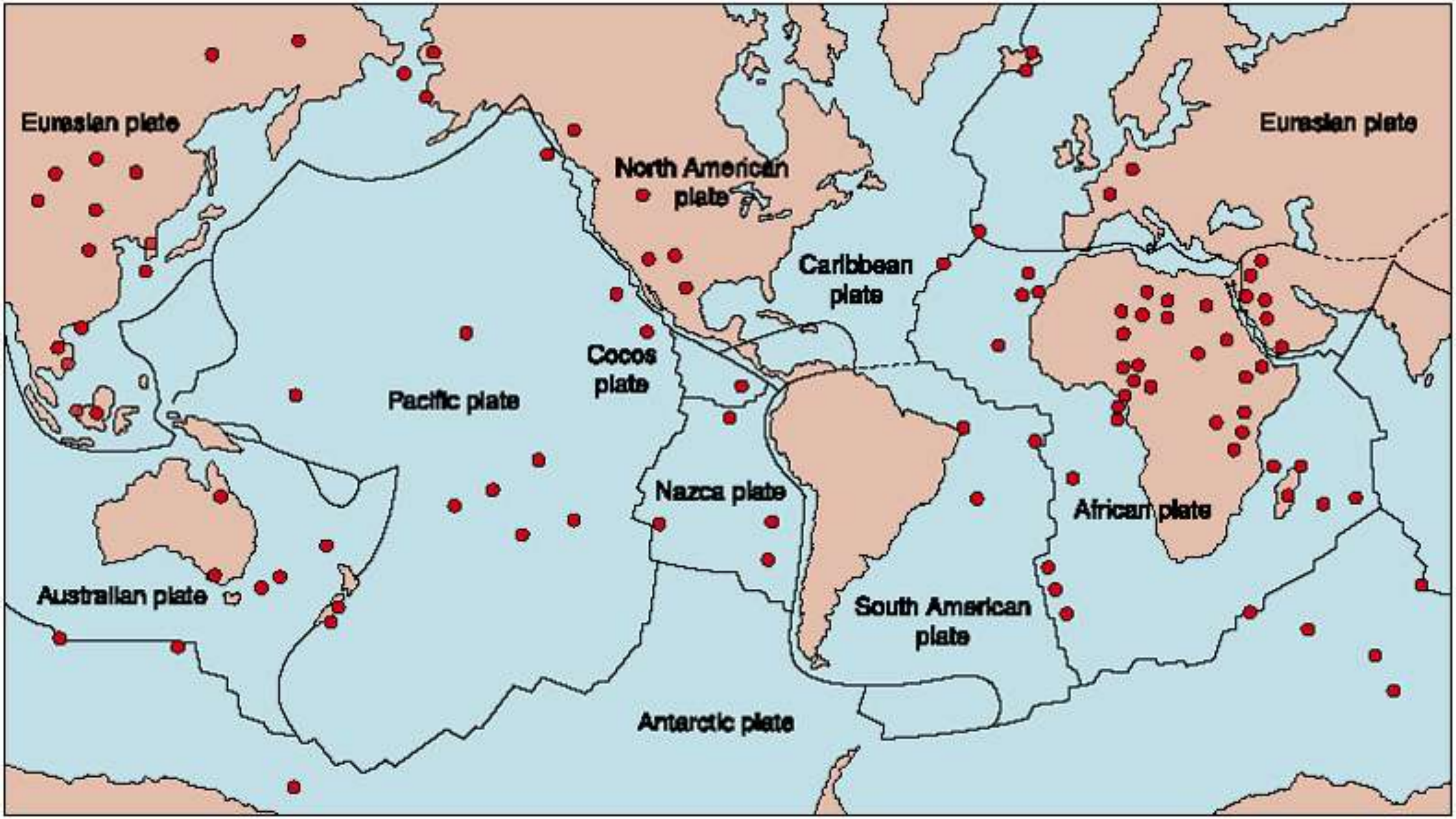




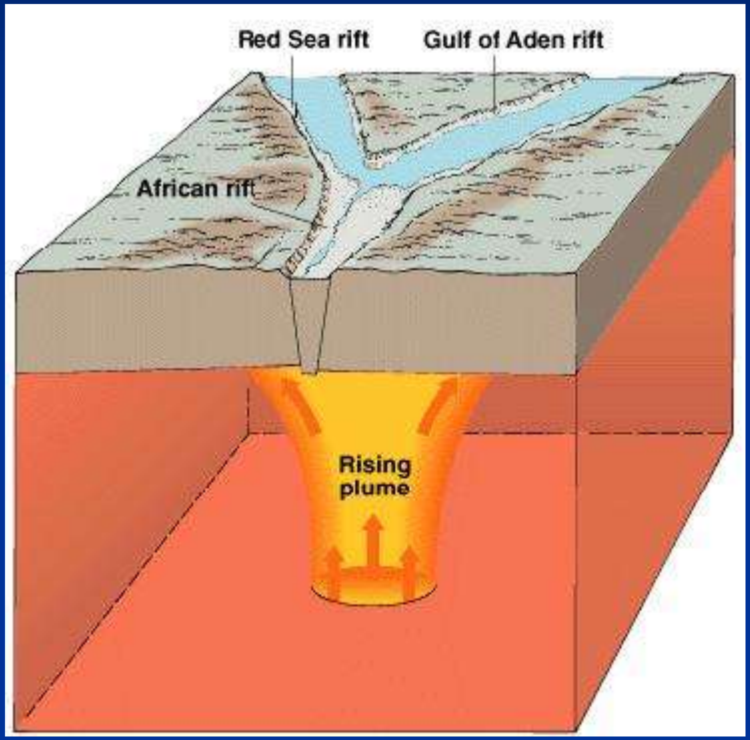
Formation of Aseismic Ridge

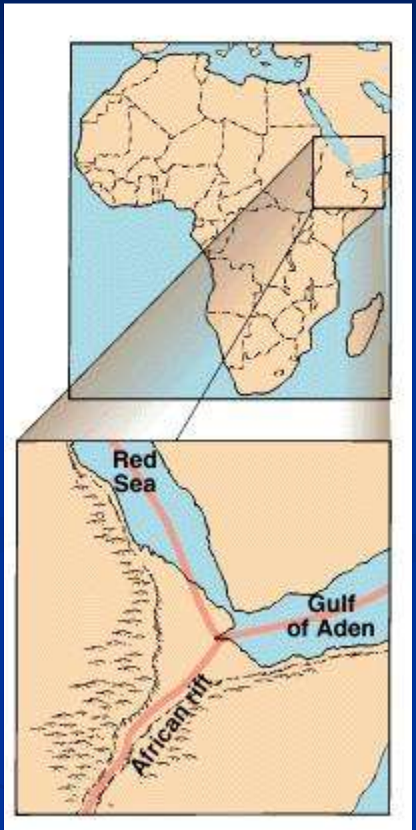


Map of Major Hotspots



Thermal Plumes





A triple junction over a thermal plume. Afar Triangle.

Relationship between plate tectonics & ore deposits

- At divergent boundaries
  - Hot springs in rift valleys deposit metallic minerals in mounds
- Sea floor spreading carries deposits away from ridge crest
  - Perhaps subducted

Formation of Metallic Ores

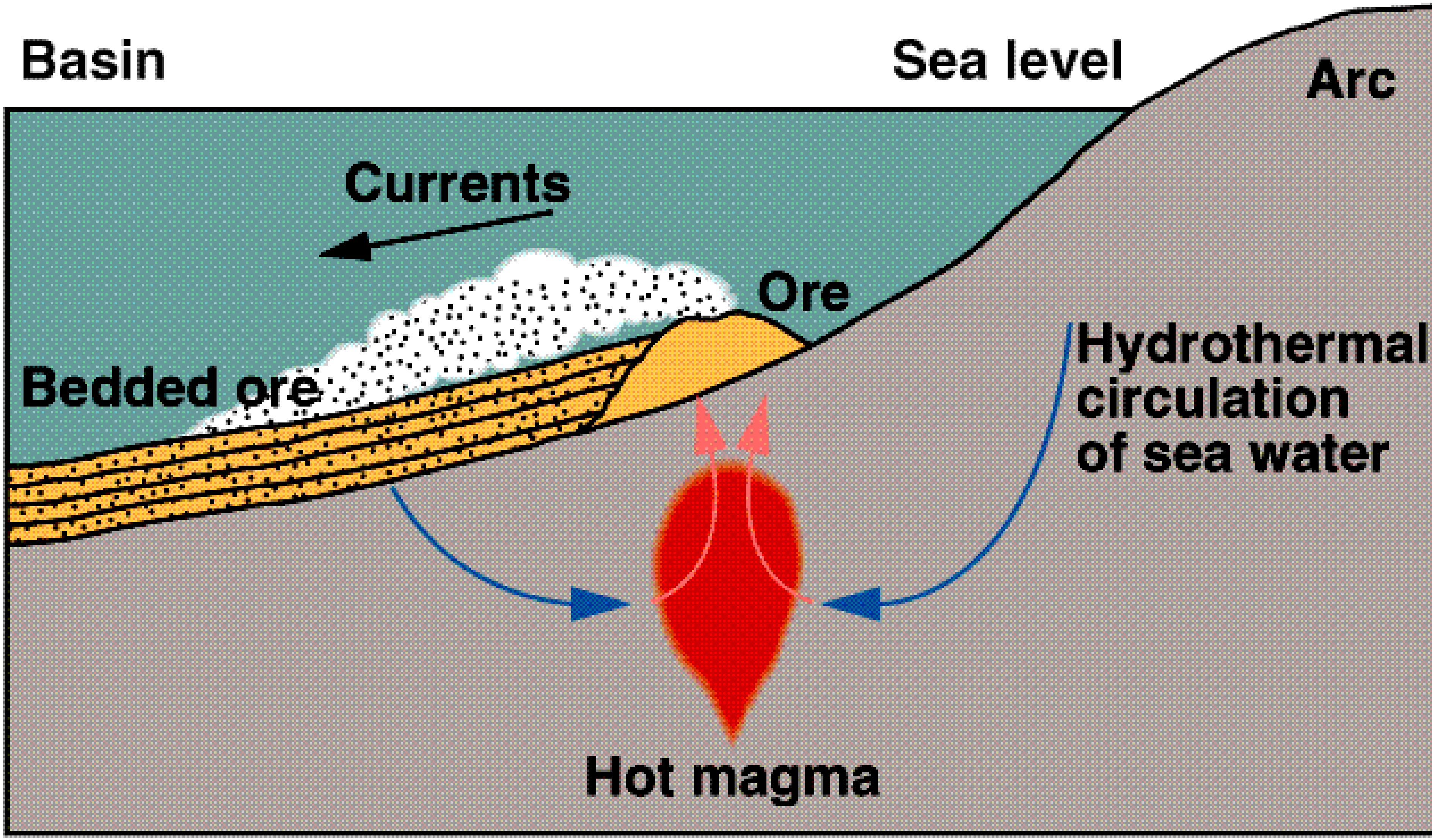
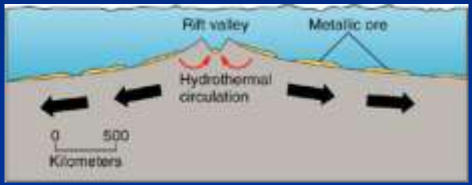
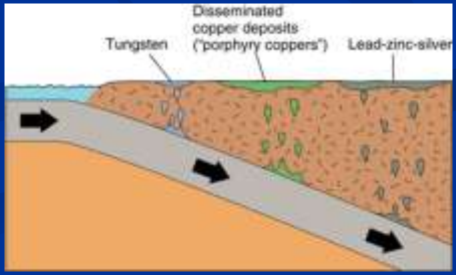


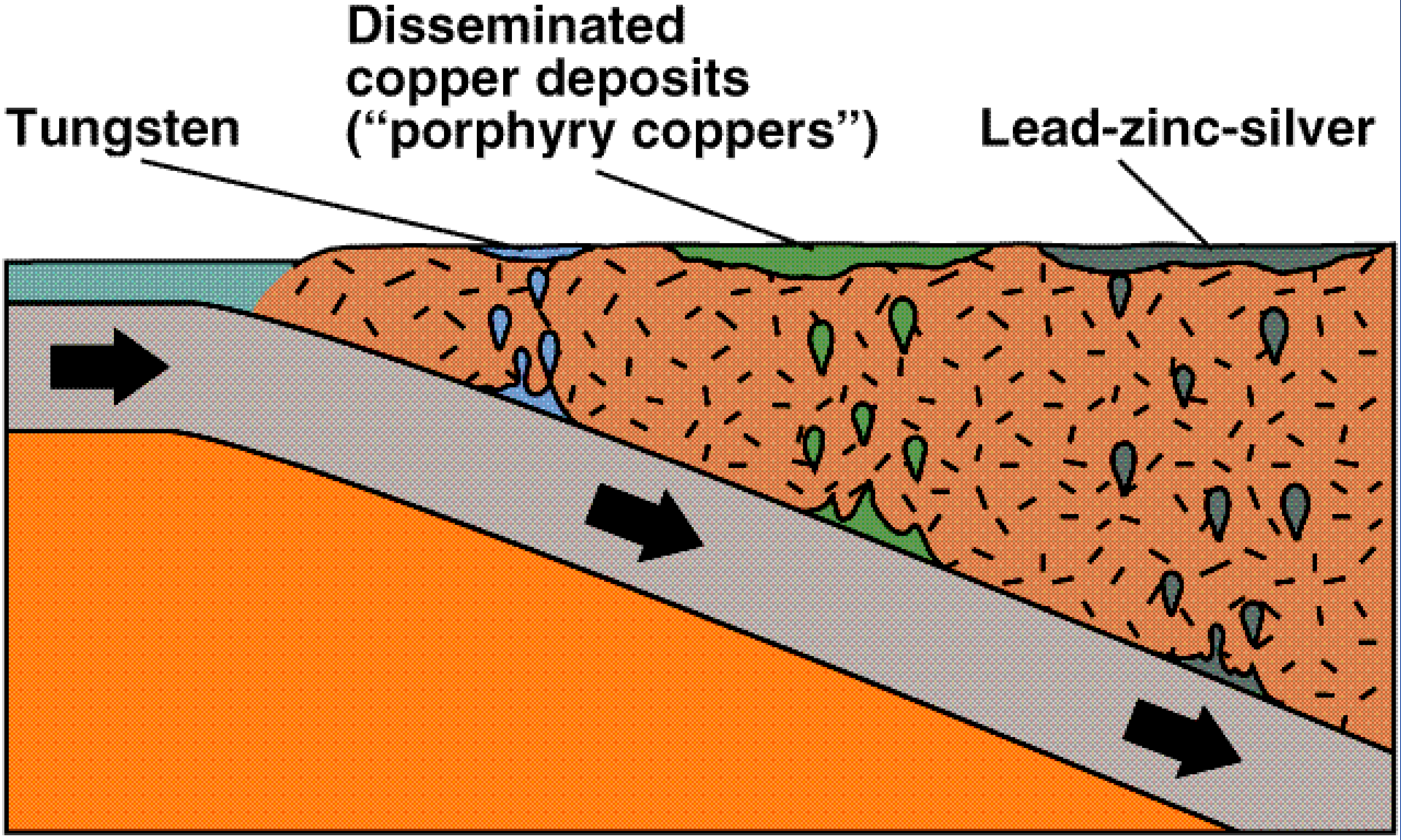
Plate Tectonics and Ore Deposits

- Metallic *ore deposits* are often located near plate boundaries
  - Commonly associated with igneous activity
- Divergent plate boundaries often marked by lines of hot springs on sea floor
  - Mineral-rich hot springs (*black smokers*) deposit metal ores on sea floor after hitting cold water
- Subducting plates at convergent boundaries may produce metal-rich magmatic fluids
  - Different metallic ores originate at different depths along the subducting plate





Generation of Metallic Ores



What Forces Drive Plate Tectonics?

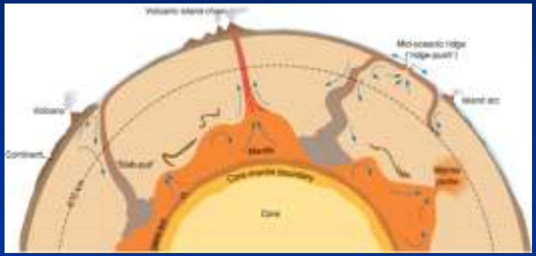
The tectonic plates are moving, but with varying rates and directions.

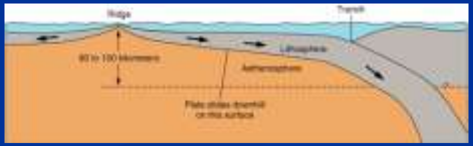
What hypotheses have been proposed to explain the plate motion?

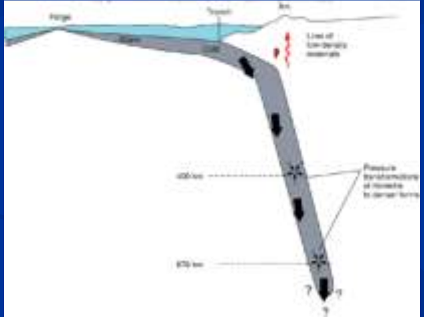
- Convection Cells in the Mantle
- Ridge-Push and Slab-Pull Model
- Thermal Plumes

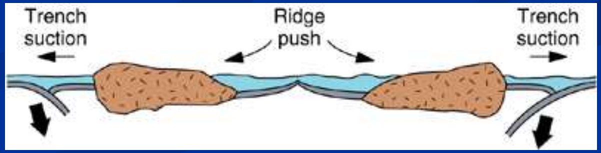
What Causes Plate Motions?

- Causes of plate motion are not yet fully understood, but any proposed mechanism must explain why:
  - Mid-oceanic ridges are hot and elevated, while trenches are cold and deep
  - Ridge crests have tensional cracks
  - The leading edges of some plates are subducting sea floor, while others are continents (which cannot subduct)
- *Mantle convection* may be the cause or an effect of circulation set up by *ridge-push* and/or *slab-pull*









What Causes Plate Motions?

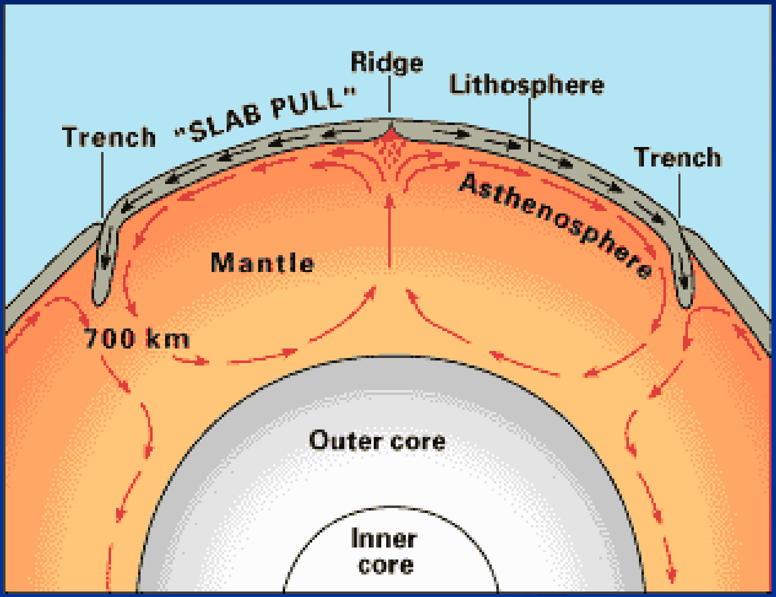
- Convection in mantle
  - Convection a *result* of plate motion
    - Ridge push
    - Slab pull
    - Trench suction

Convection Cells in the Mantle

- Large-scale thermal convection cells in the mantle may move tectonic plates.
- Convection cells transfer heat in a circular pattern. Hot material rises; cool material sinks.
- Mantle heat probably results from radioactive decay.

Image courtesy of U.S. Geological Survey.

Convection Cells in the Mantle



Rising part of convection cell = rifting (mid-ocean ridge)

Descending part of convection cell = subduction (deep sea trench)

Image courtesy of U.S. Geological Survey.

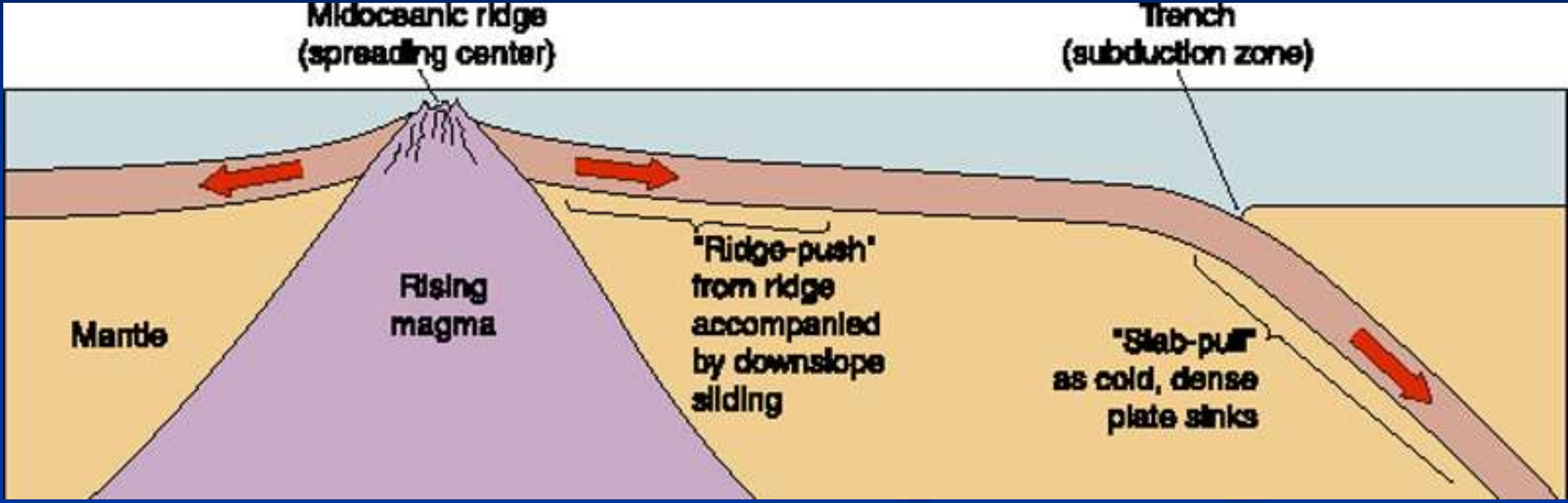
What Causes Plate Motions?

- Need to explain:
  - Mid-oceanic ridges = hot & elevated; trenches = cold & deep
  - Ridge crests have tensional cracks
  - Leading edges of some plates = subducting sea floor
  - Leading edges of other plates are continents
- Convection in mantle (3 hypotheses)
  - Deep mantle convection
  - Two-layer convection

What Causes Plate Motions?

- Mantle Plumes and Hot Spots
  - Mantle plumes form “hot spots”
  - Active volcanism
  - Outward, radial flow of head may start plates moving
    - Three-pronged rift
  - Explains Yellowstone volcanism, Hawaiian volcanism and aseismic ridges

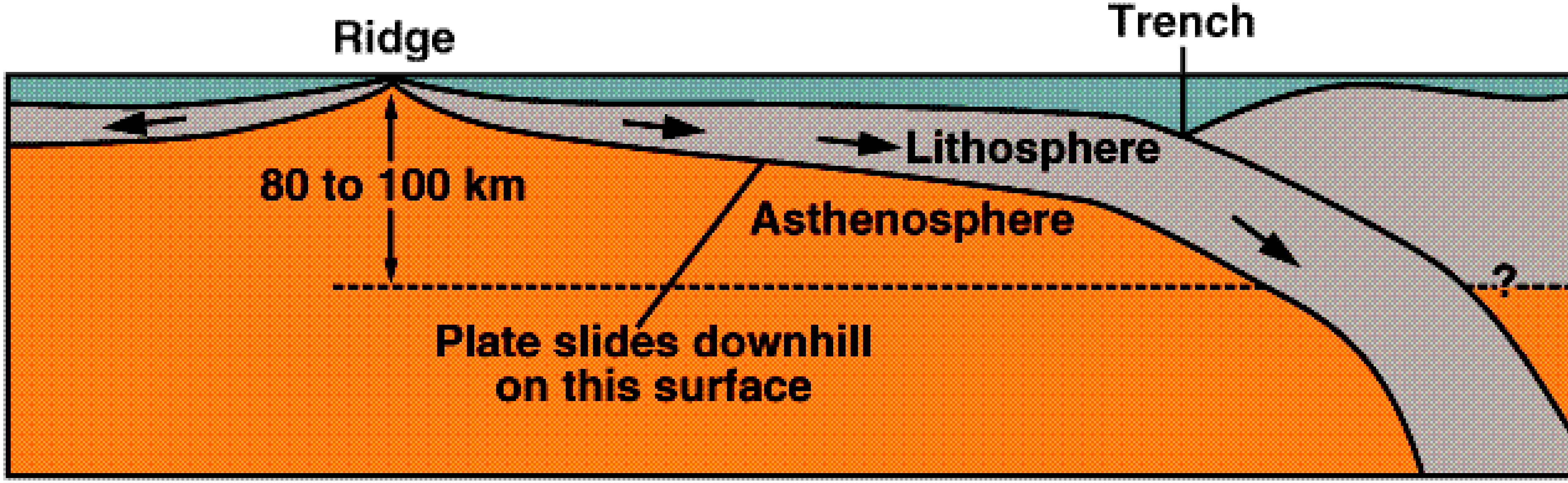
Ridge-Push and Slab-Pull Model



Crust is heated and expands over a mid-ocean ridge spreading center. Crust tends to slide off the thermal bulge, pushing the rest of the oceanic plate ahead of it.

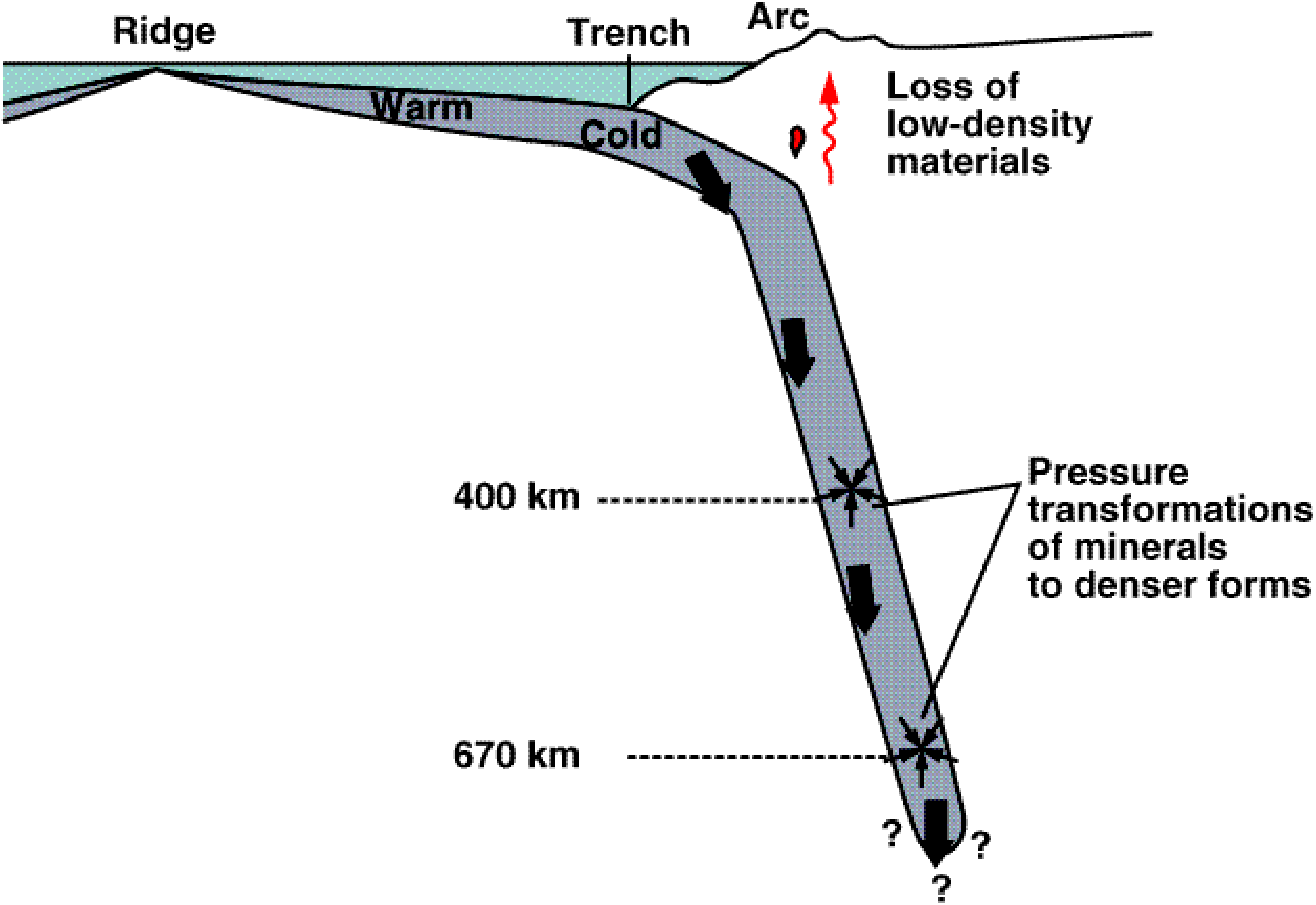
This is called **ridge-push**.

Ridge-Push



Ridge
Trench
Lithosphere
80 to 100 km
Asthenosphere
?
Plate slides downhill
on this surface

Slab-Pull


Ridge
Trench
Arc
Warm
Cold
Loss of low-density materials
400 km
670 km
Pressure transformations of minerals to denser forms
?
?
?

Exotic Terranes

- Small pieces of continental crust surrounded by oceanic crust are called microcontinents.
- *Examples*: Greenland, Madagascar, the Seychelles Bank in the Indian Ocean, Crete, New Zealand, New Guinea.

Exotic Terranes

- Microcontinents are moved by seafloor spreading, and may eventually arrive at a subduction zone.
- They are too low in density and too buoyant to be subducted into the mantle, so they collide with (and become incorporated into the margin of) a larger continent as an exotic terrane.

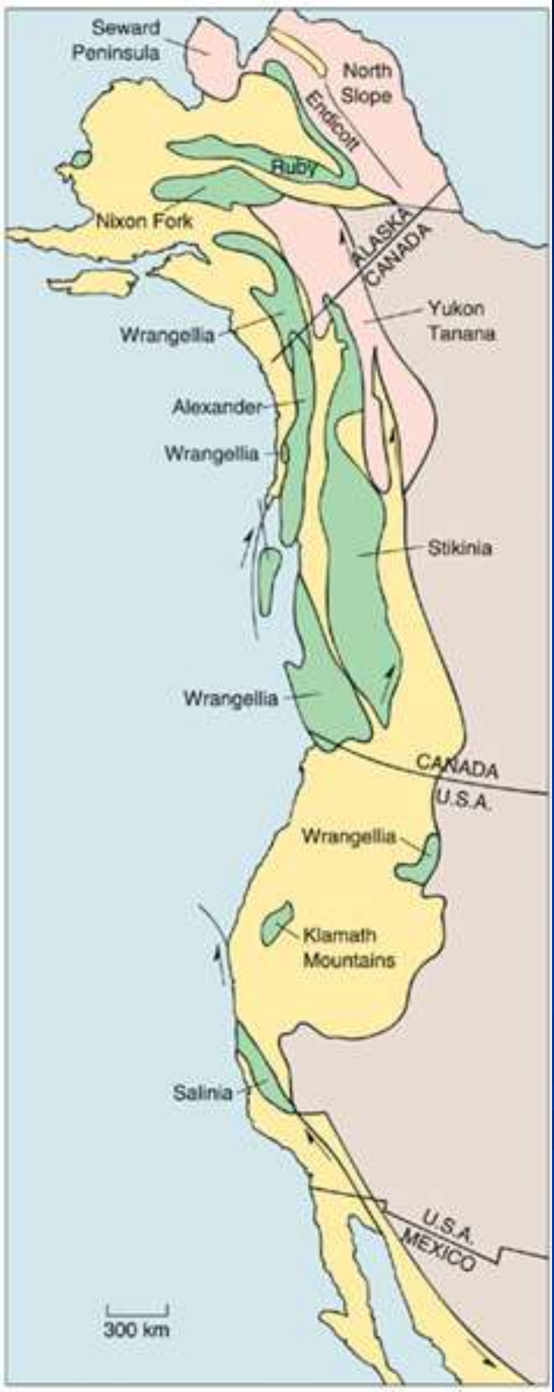
Exotic Terranes

Exotic terranes are present along the margins of every continent.

They are fault-bounded areas with different structure, age, fossils, and rock type, compared with the surrounding rocks.

Exotic Terranes

- Green terranes probably originated as parts of other continents.
- Pink terranes may be displaced parts of North America.
- The terranes are composed of Paleozoic or older rocks accreted during the Mesozoic and Cenozoic Eras.



Wilson Cycles

Plate tectonic model for opening and closing of an ocean basin over time.

1. Opening of new ocean basin at divergent plate boundary
2. Seafloor spreading continues and subduction begins
3. Final stage of continental collision

Wilson Cycles Stage 1

1. Opening of a new ocean basin at a divergent plate boundary.

   Sedimentary deposits include:

   a. Quartz sandstones
   b. Shallow-water platform carbonates
   c. Deeper water shales with chert

Wilson Cycles Stage 2

2. Expansion of ocean basin as seafloor spreading continues and subduction begins. Sedimentary deposits include:

   a. Graywacke
   b. Turbidites
   c. Volcanic rocks

   Also mélange, thrust faults, and ophiolite sequences near the subduction zone.

Wilson Cycles Stage 3

3. Final stage of continental collision.

Sedimentary deposits include:

- Conglomerates
- Red sandstones
- Shales

Deposited in alluvial fans, rivers, and deltas as older seafloor sediments are uplifted to form mountains, and eroded.

Measurement of Plate Tectonics from Space

- Lasers
- Man-made satellites in orbit around Earth - Global Positioning System
- By measuring distances between specific points on adjacent tectonic plates over time, rates of plate movement can be determined.

Isostasy

- Buoyancy and floating of the Earth's crust on the mantle.
- Denser oceanic crust floats lower, forming ocean basins.
- Less dense continental crust floats higher, forming continents.
- As erosion removes part of the crust, it rises isostatically to a new level.