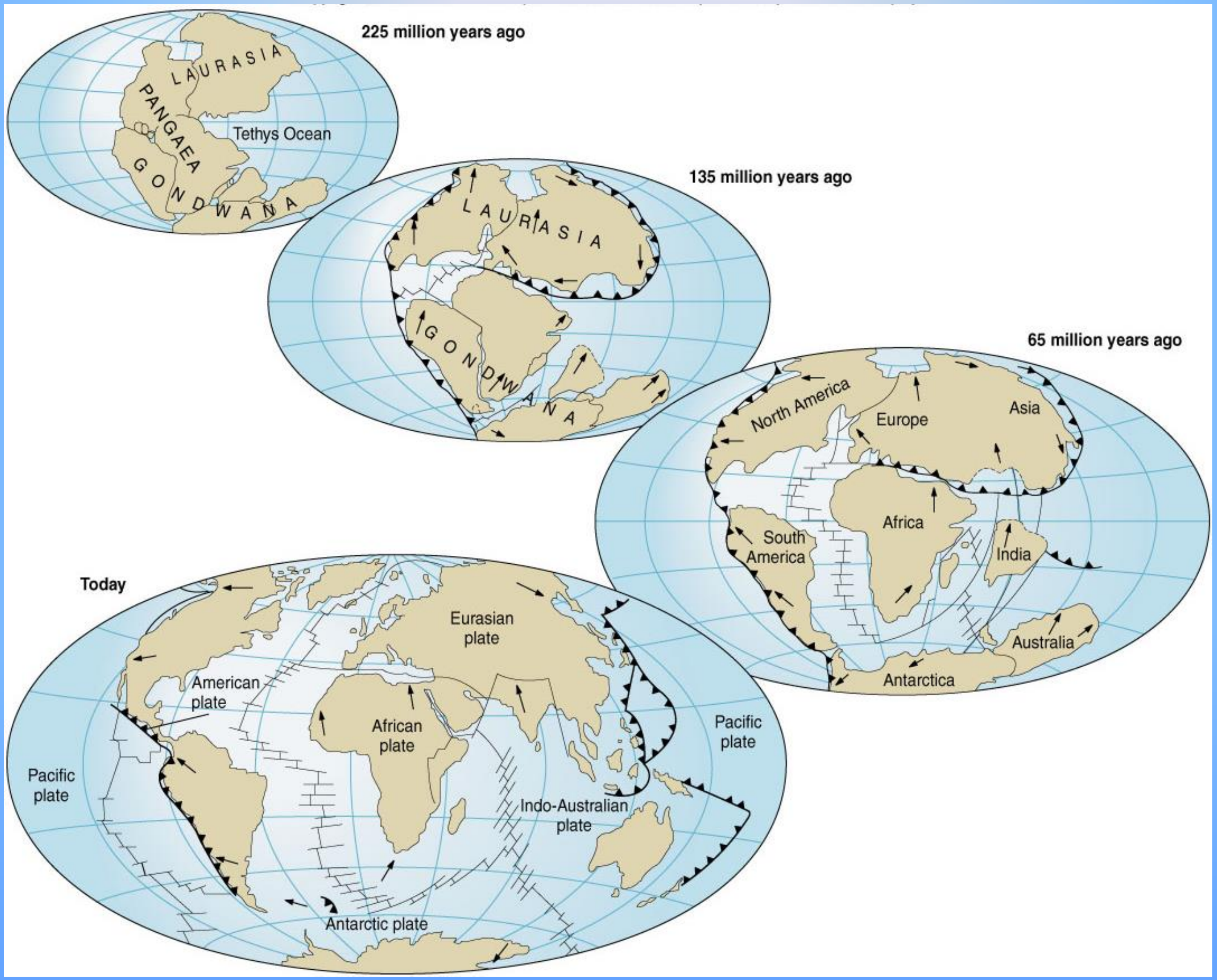
Plate Tectonics and Continental Drift



Tectonics

A. Tectonic Forces are forces generated from within Earth causing rock to become **deformed** .

B. **Tectonics**

1. The study of the origin and arrangement of Earth surface including mountain belts, continents, and earthquake belts.

2. *Plate Tectonics*

a. This is the basic idea that Earths crust is divided into a few large, thick __**plates**__ which are large slabs of the lithosphere.

(1) Plates are part of the__**lithosphere**__ move slowly and change in size.

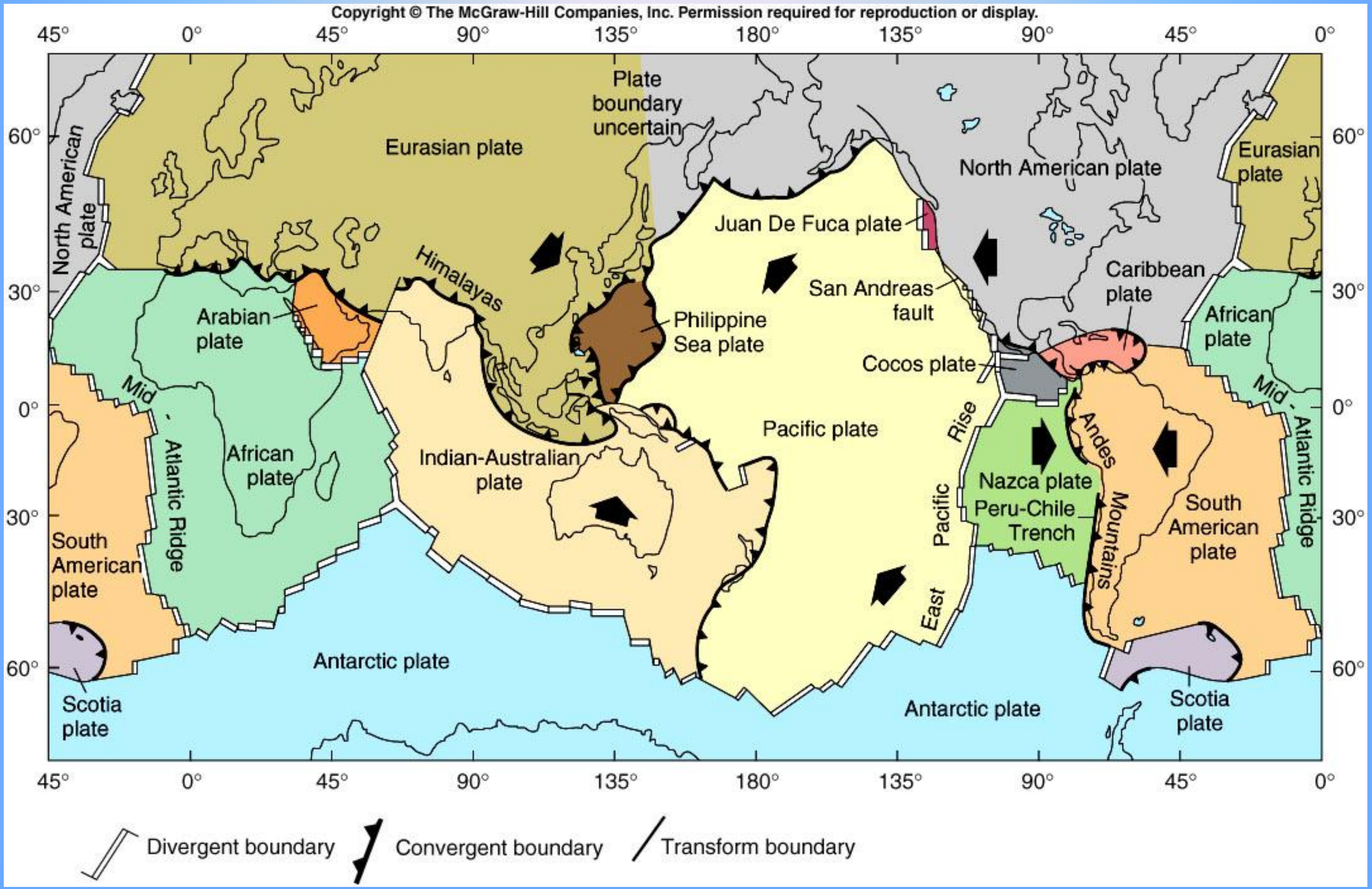
(2) Plates may be:

(a) entirely __**sea floor**__ rock

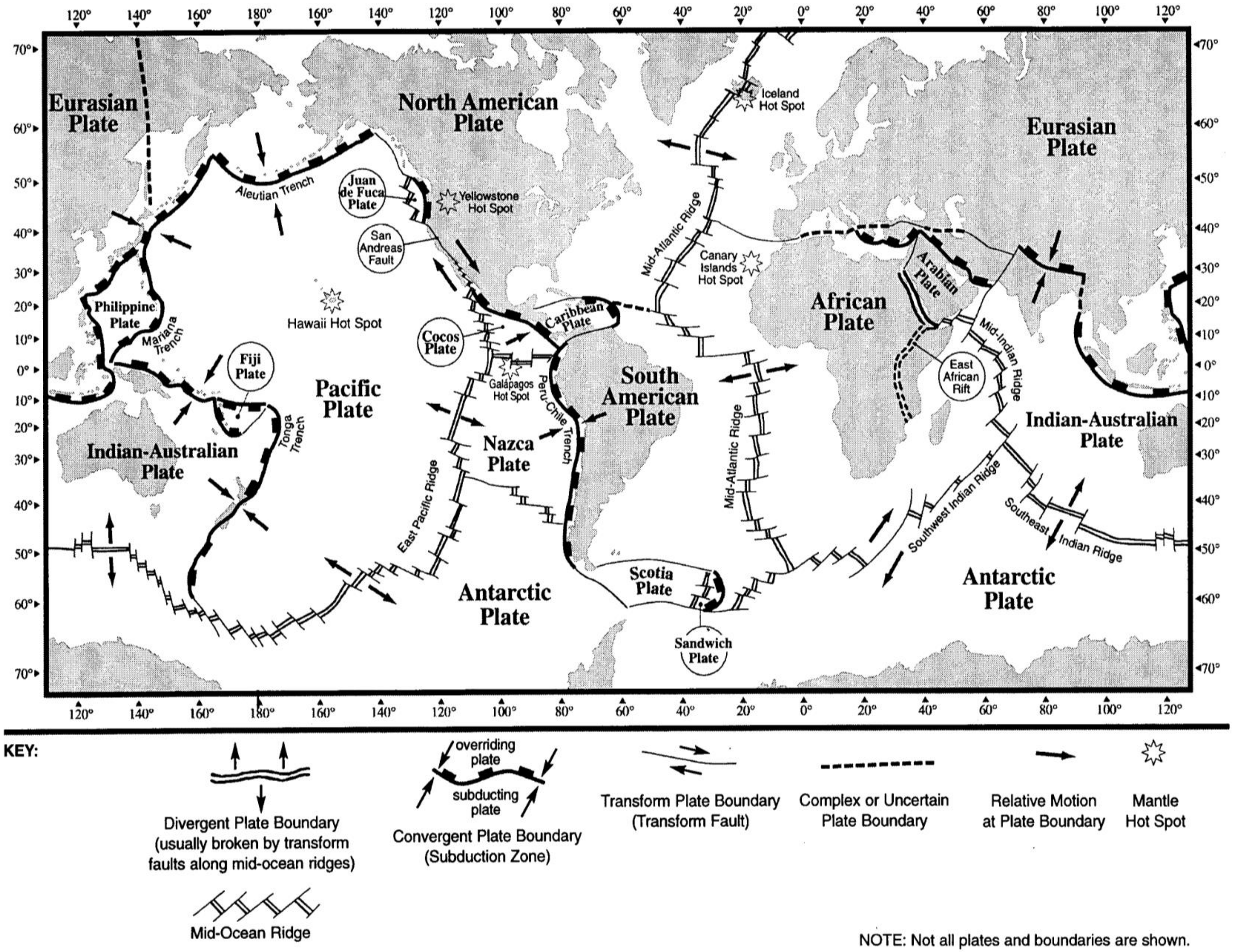
(b) both __**sea floor**__ and __**continental**__ rock

(c) entirely __**continental**__ rock

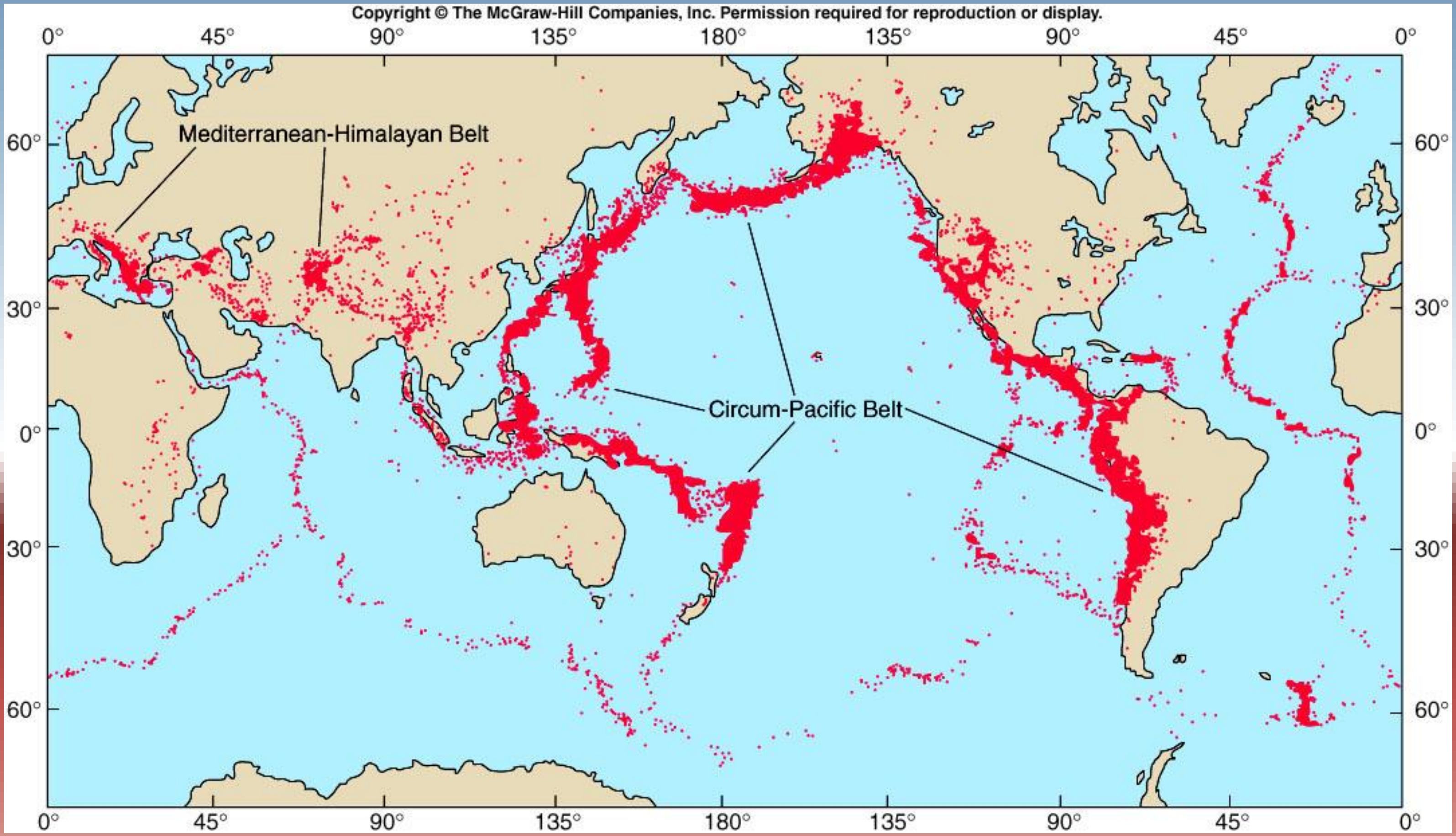
Tectonic Plates



Tectonic Plates

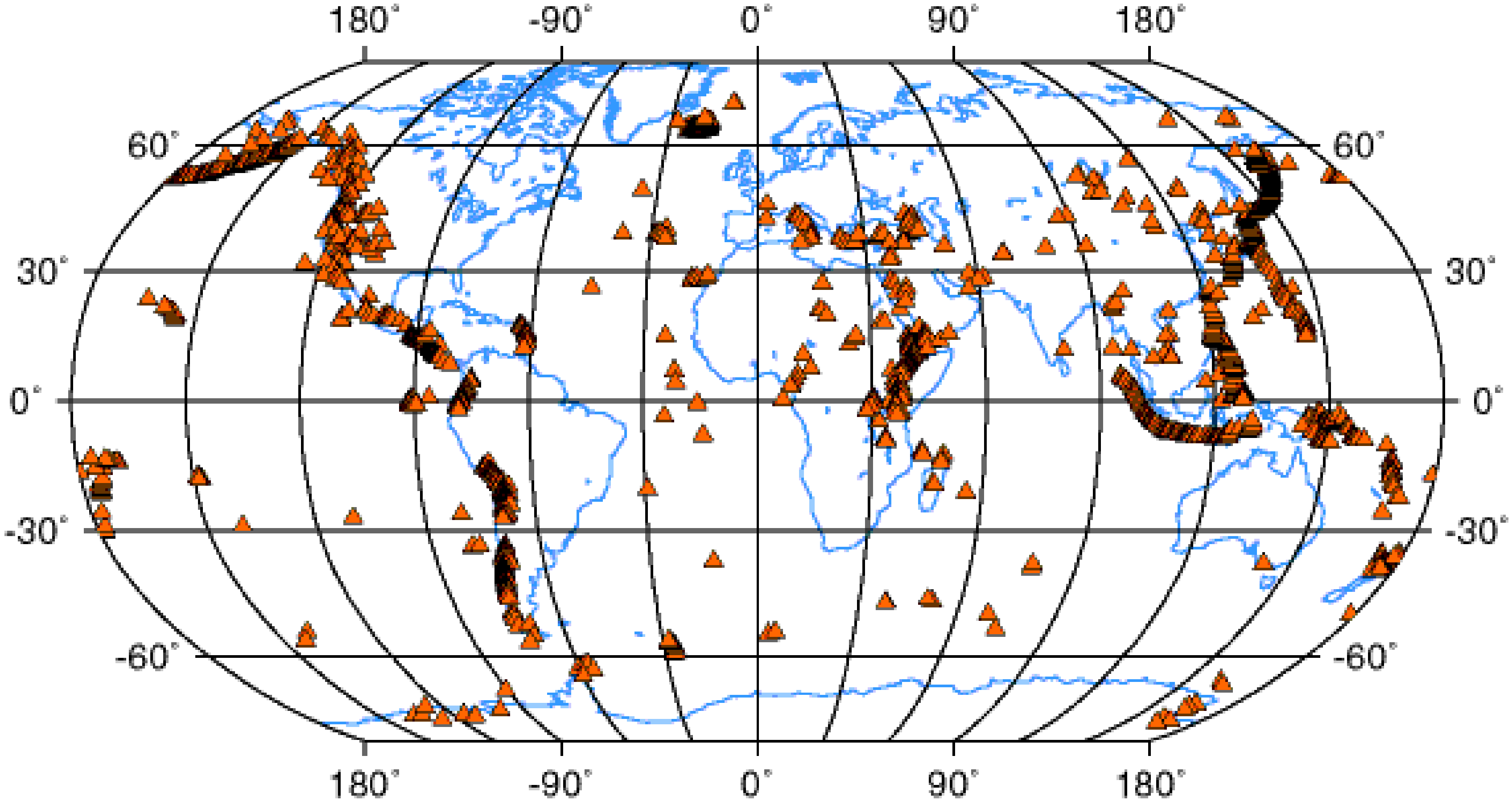


World Distribution of Earthquakes



- Earthquakes with focal depths between 0 and 670 km
- Over a six-year period

Volcanoes



(3) Plate boundaries are geologically active with:

(a) ______earthquakes______

(b) ______volcanoes______

(c) young mountain ranges

b. Plate Tectonics combines two preexisting ideas

(1)___**Continental Drift**_____which is the idea that the continents move freely over Earth's surface, changing their positions relative to one another

(2)**Sea-Floor Spreading** which is the hypothesis that sea floor forms a mid-oceanic ridge crests and then moves horizontally away from the ridge towards oceanic trenches.

Sea Floor Spreading

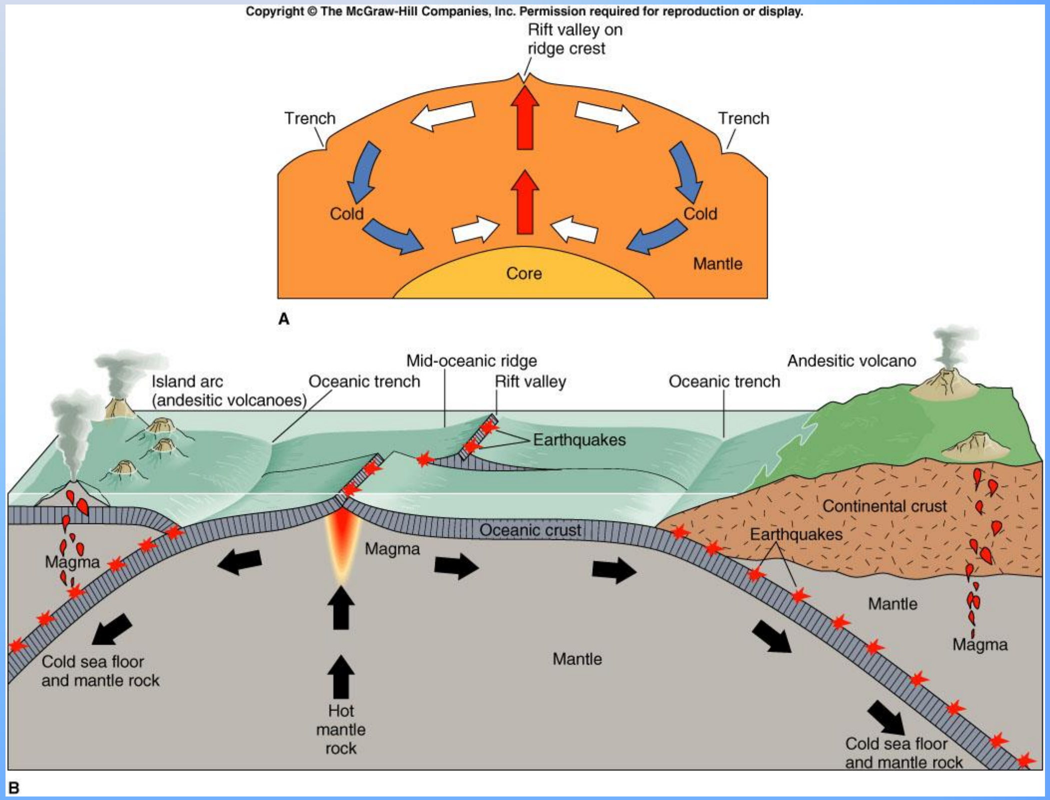
A. This is the hypothesis that:

1. Was originally proposed by Harry Hess, a Princeton University geologist

2. Sea floor forms at the_**Mid-ocean ridge**_

3. The sea floor moves _**horizontally**_ from the ridge crest toward an oceanic trench where it _**subducts**_.

4. The two sides move in _**opposite**_ directions



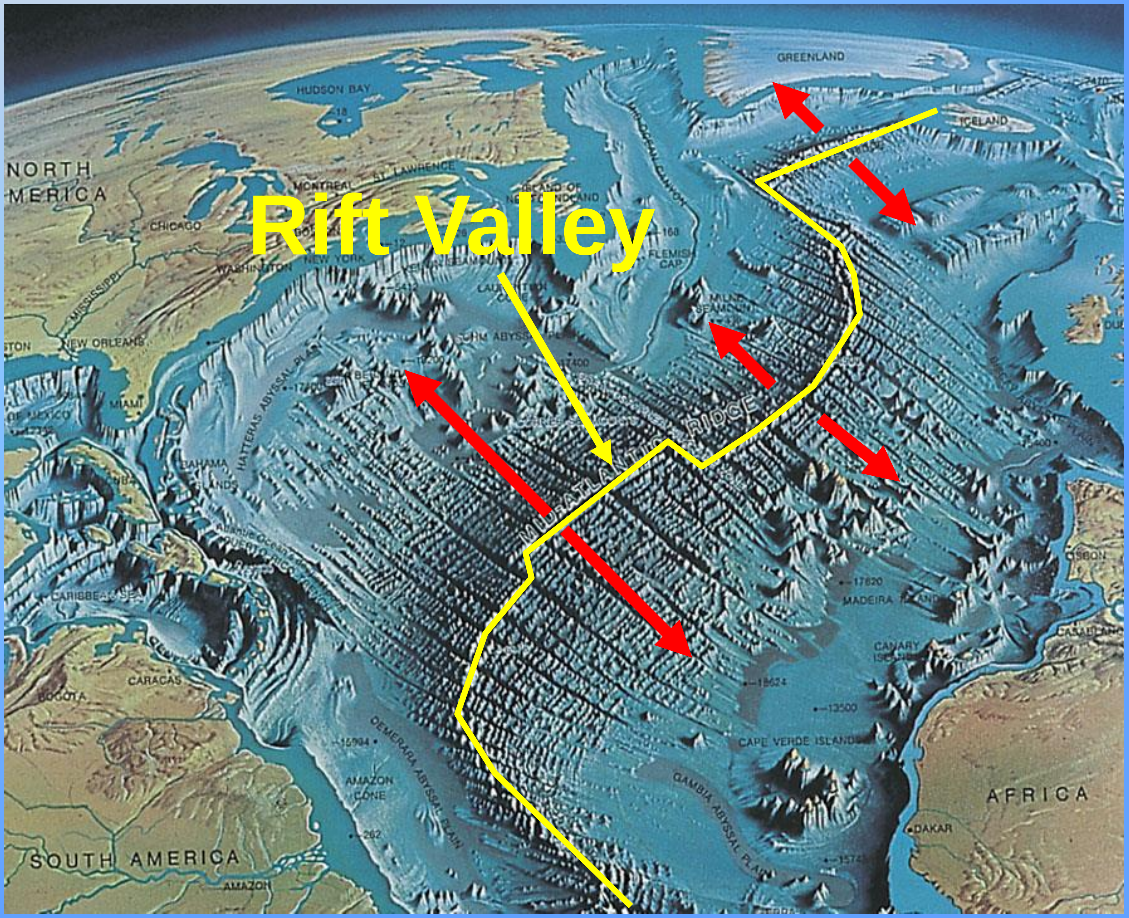
5. _**Convection**_ in the mantle is the driving force.

B. The Mid-Ocean Ridge

1. Hot mantle rock rises beneath the ridge as a result of convection
2. This expains high heat flow and basaltic volcanic eruptions.

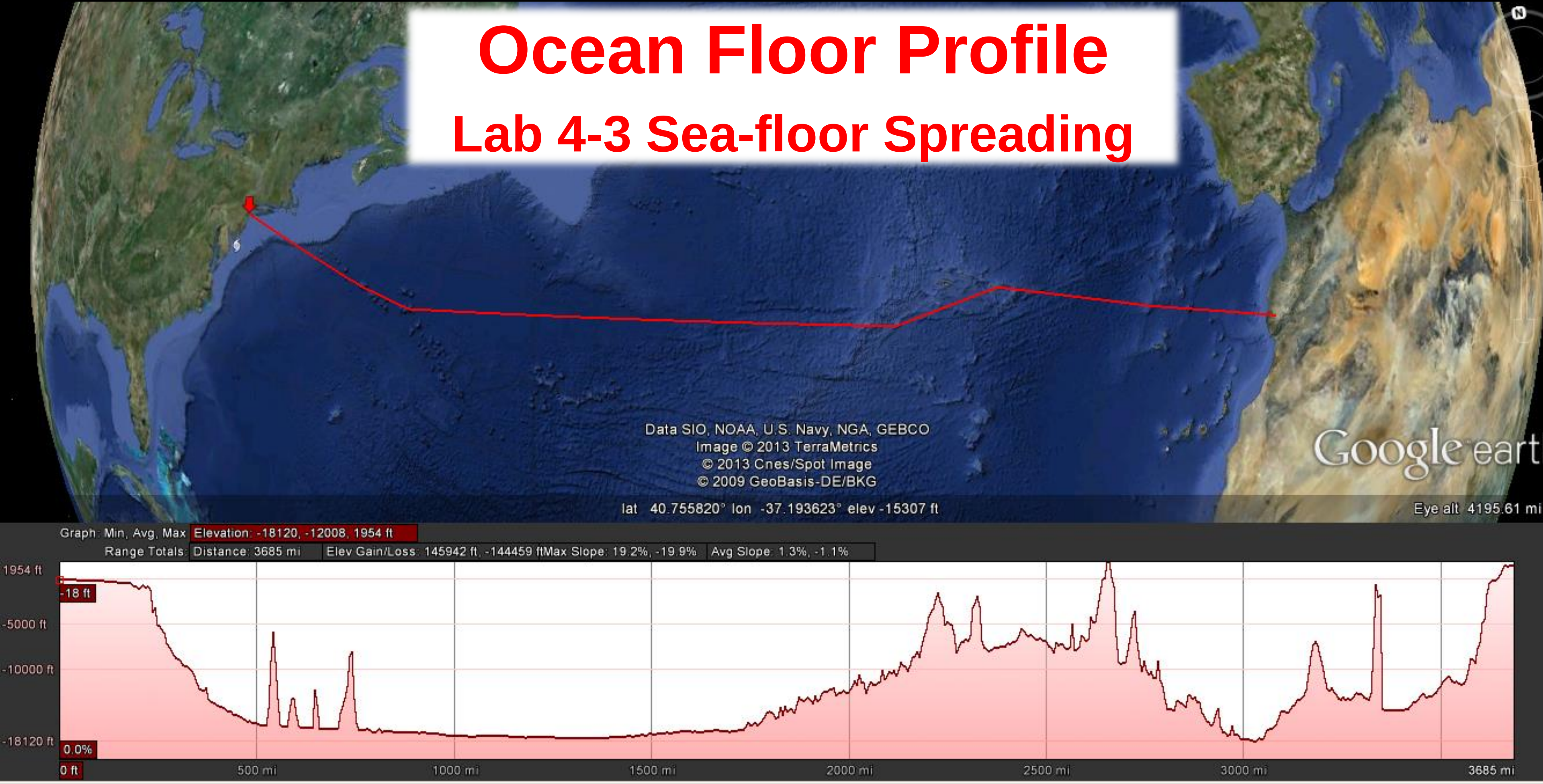
3. a. **Tension** at the ridge crest results in cracking open of oceanic crust to form a **rift valley**

   b. Shallow focus earthquakes



Ocean Floor Profile

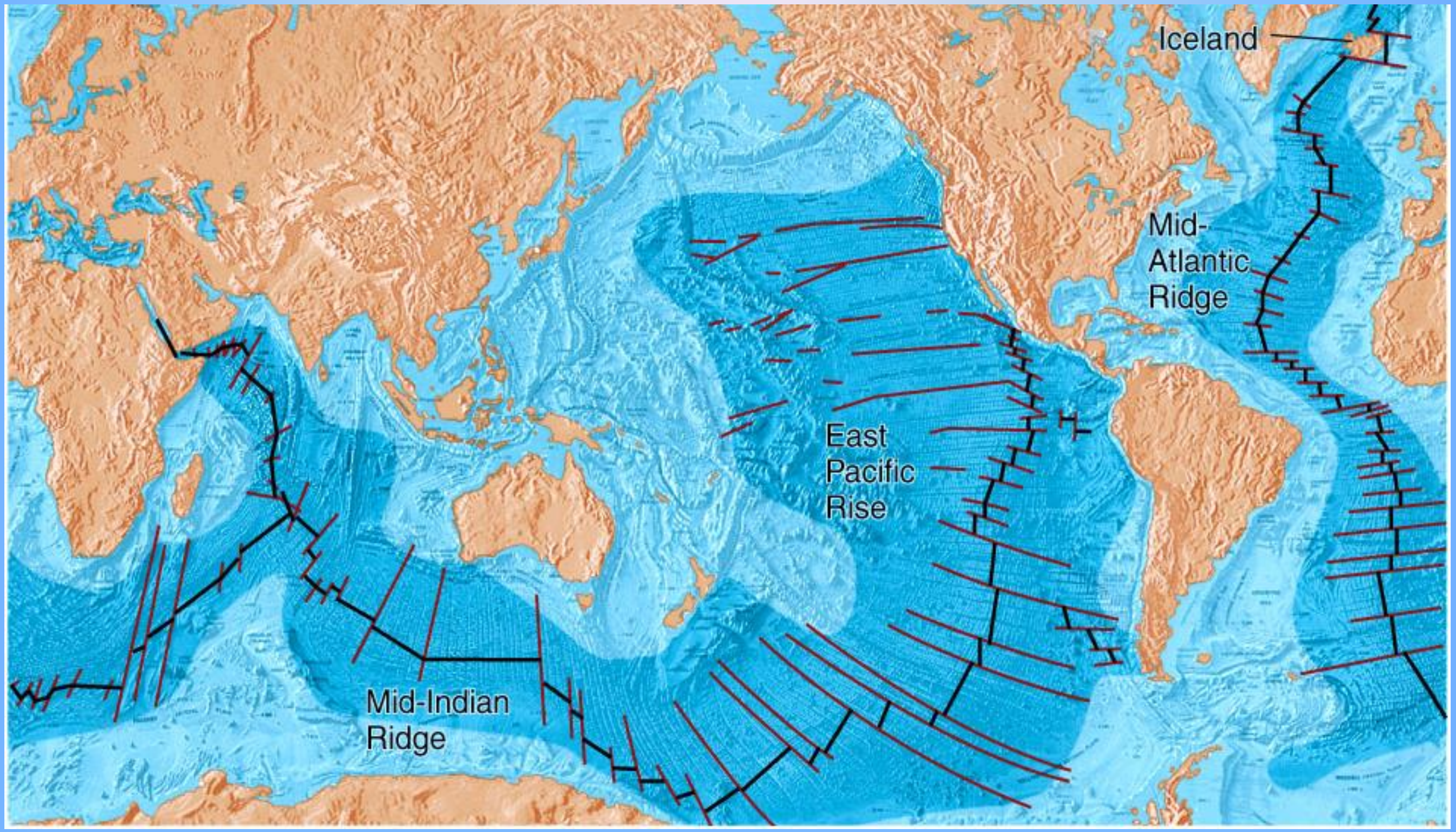
Lab 4-3 Sea-floor Spreading



- Can you identify:

- Deep ocean floor
- continental shelf
- ocean ridge
- seamounts
- island
- rift valley

c. Fracture Zones



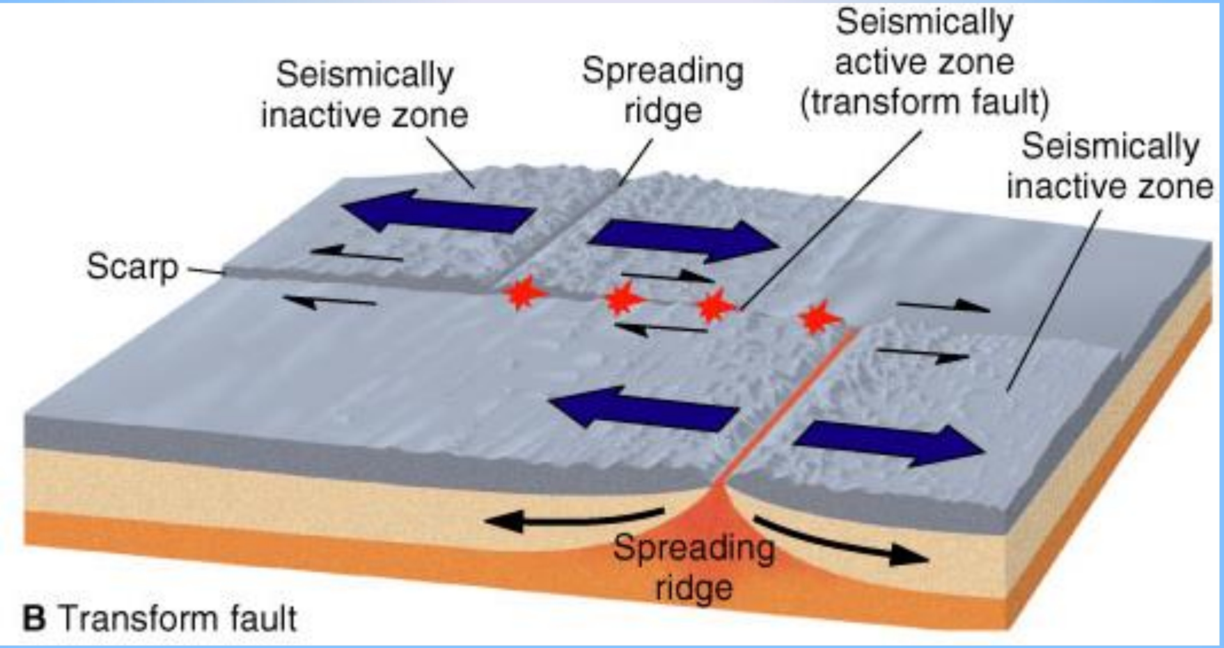
(1) **Major lines of weakness in Earth's crust.**

(2) **Cross the mid-ocean ridge at nearly right angles.**

(3) **Extend for 1000's kilometers across the ocean floor.**

(4) **The mid-ocean ridge was once continuous across the fracture zones but is now offset.**

d. Transform Faults



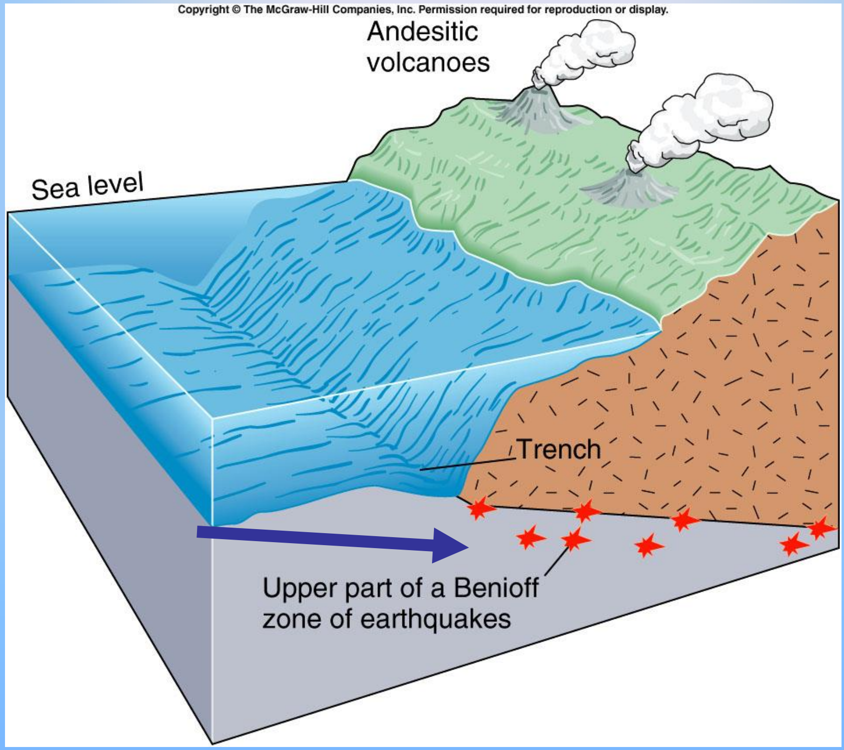
(1) Mid-ocean ridges are offset along fracture zones

(2) Transform motion of rocks on either side is not always in opposite directions.

  (a) Rocks move in opposite directions only in the section between two segments of ridge crest.

  (b) This is the only section that experiences earthquakes instead of along the entire section as would normally be expected.

4. Ocean **Trenches**

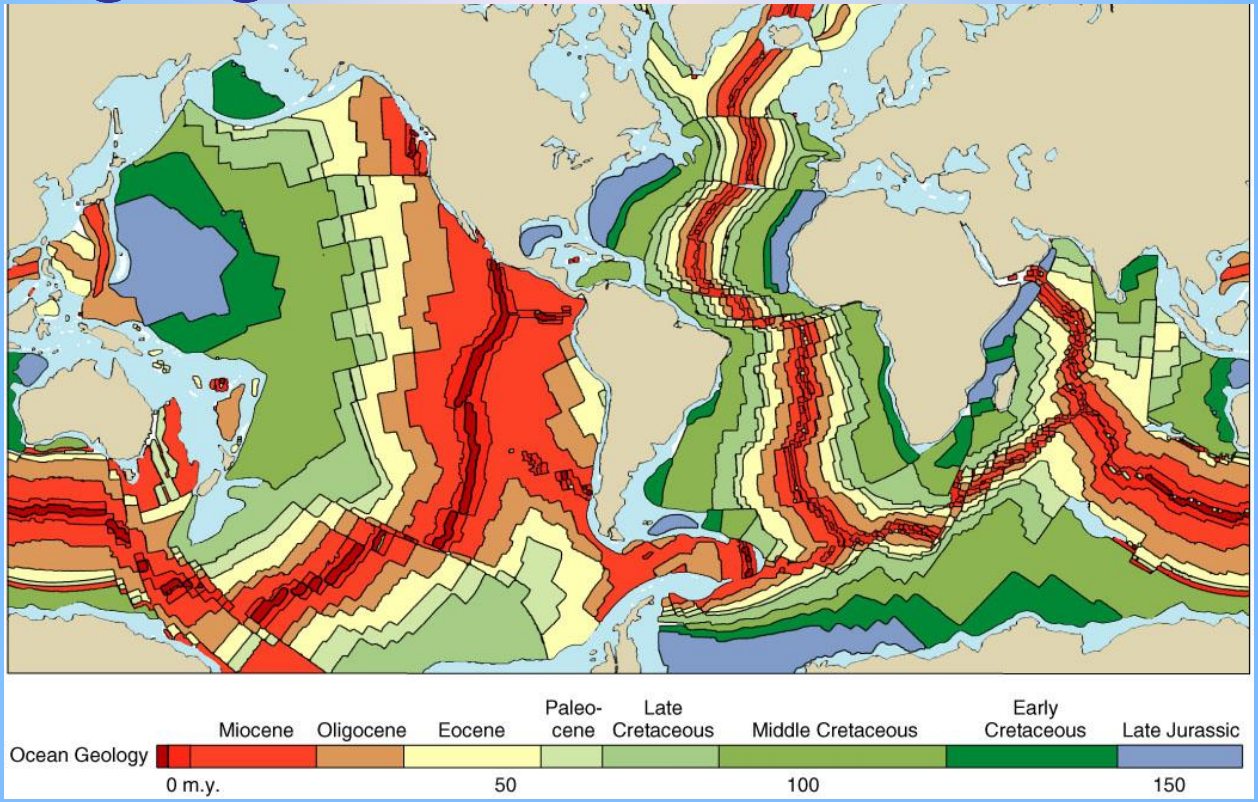


a. **Sea floor moving away from the ridge cools**

b. **It becomes denser and subducts, perhaps sinking back into the mantle.**

c. **Trenches are explained by the downward plunge of cooler rock and explains *negative gravity anomalies*.**

5. Young Age of the Sea Floor



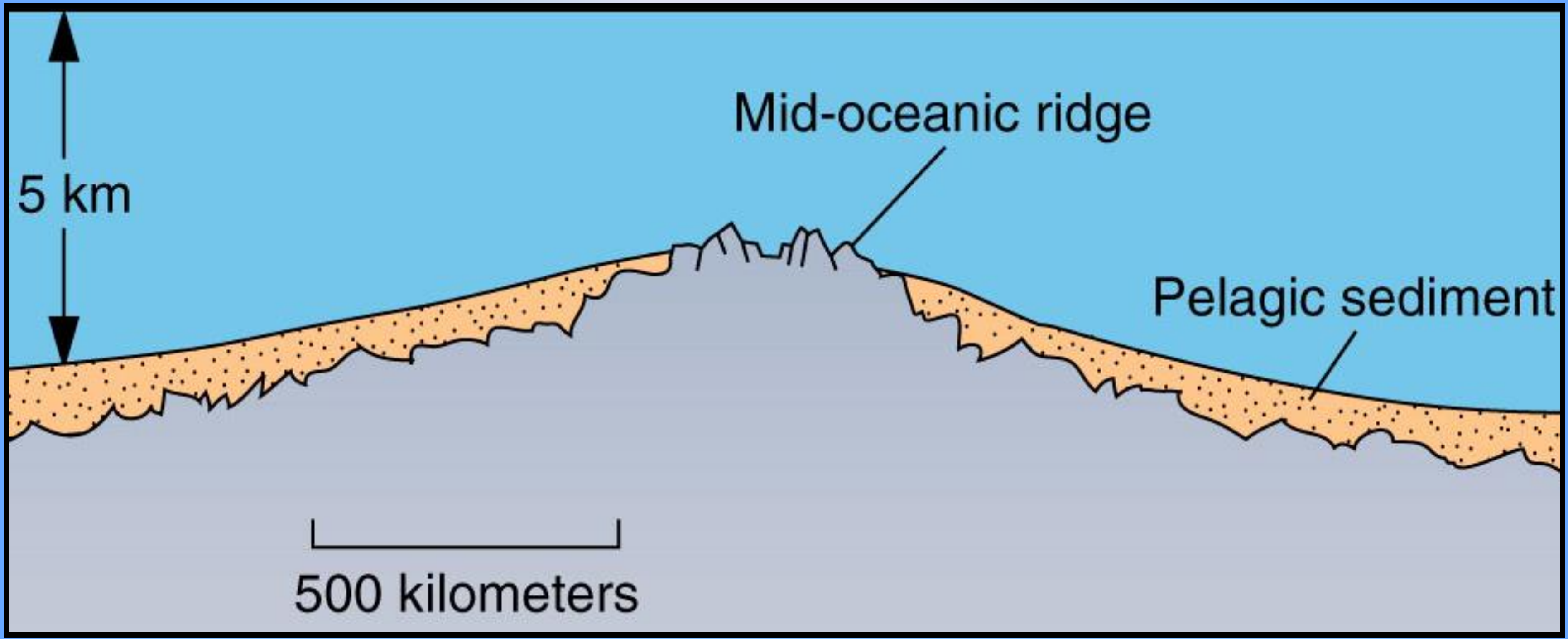
a. Less than **200 million years** old.

b. New sea floor continually is formed by basalt eruptions at the **ridge crests**.

c. Basalt is carried horizontally *away* from the ridge crest where the ***youngest*** rock is found.

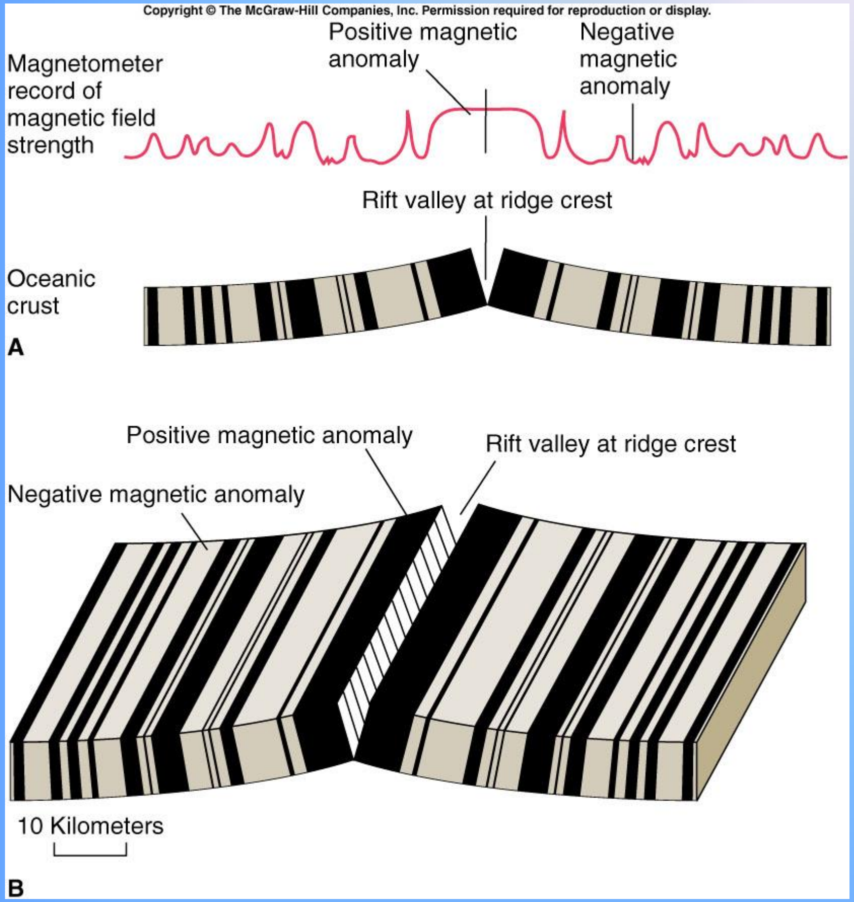
d. Sea floor is continually destroyed by *subduction* into the mantle at the oceanic trenches

Deep Ocean Sediments



- Deep ocean (pelagic) sediment is thin or absent on the crest of the mid-oceanic ridges.
- Sediment becomes thicker away from the ridge.

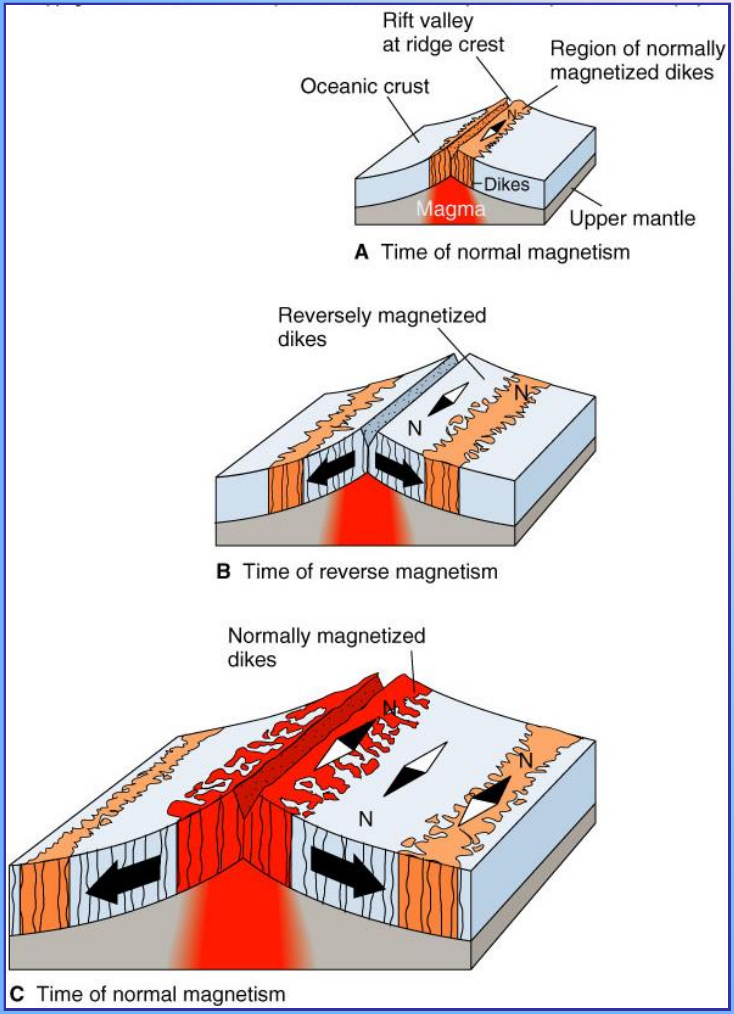
C. **Paleomagnetic** Data at the Ridges

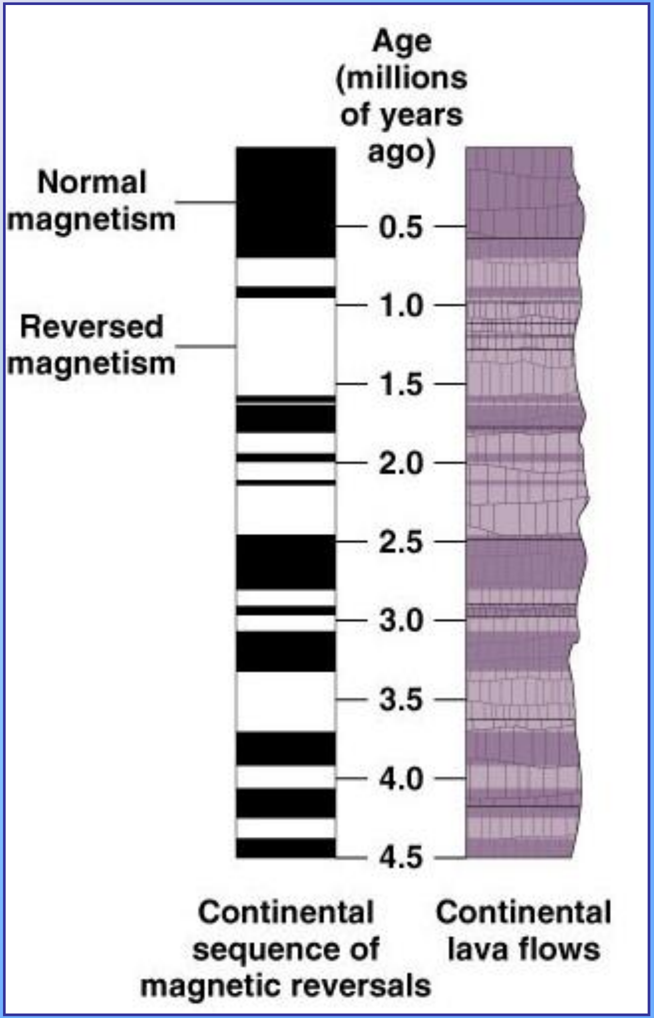


Airborne magnetometer on a U.S. Navy Orion P-3

1. **New** rock formed at the center of the ridge acquires Earth's magnetic polarity at that time.
2. Parallel to the ocean ridges there are long strips with alternating magnetic polarity (magnetic anomalies that are symmetrical about the ridge crest).

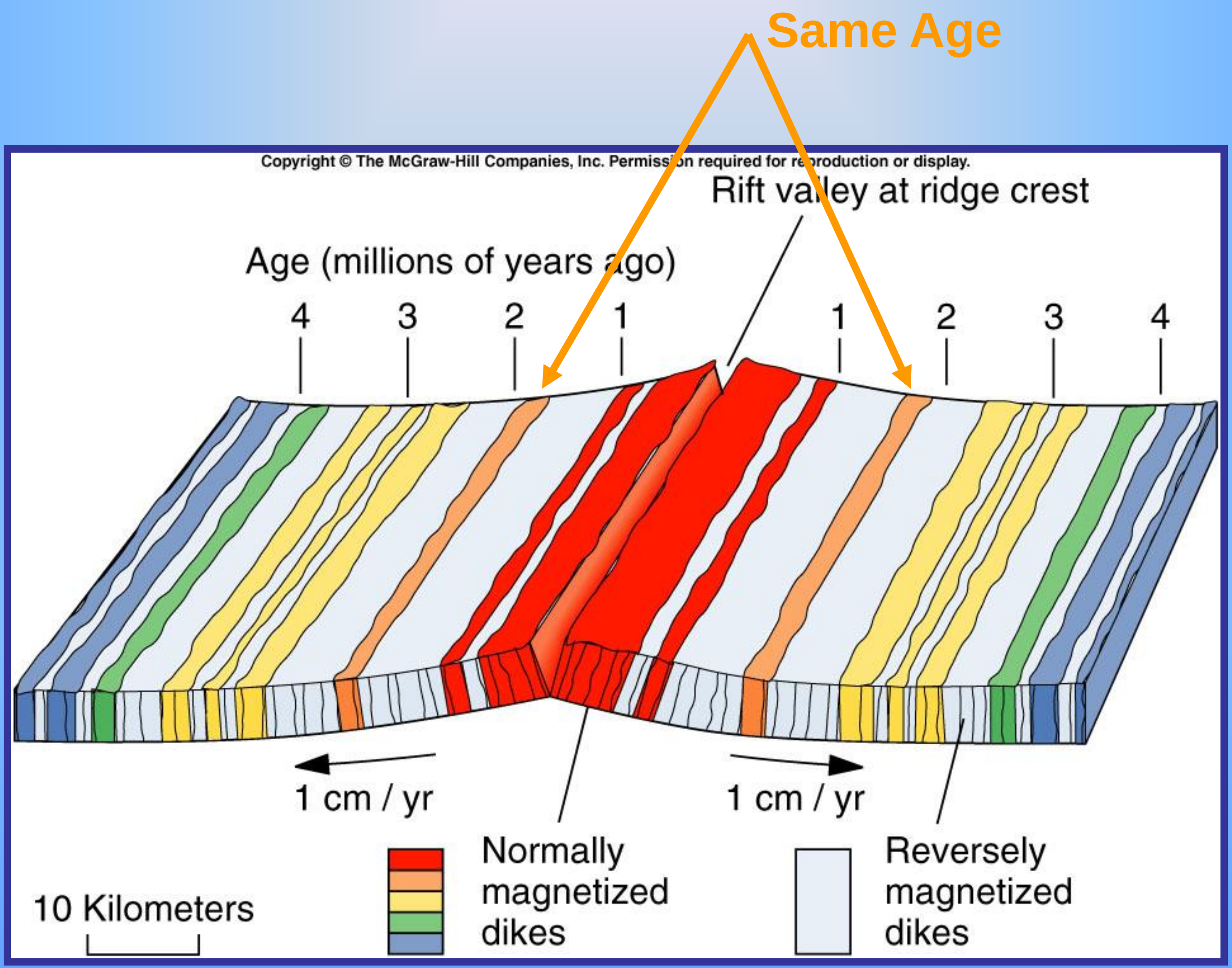
Vine-Matthews Hypothesis





- Developed by British geologists Fred Vine and Drummond Matthews
- Proposes that the magnetic anomalies match the pattern of magnetic reversals of Earth’s magnetic field as measured in continental rocks.

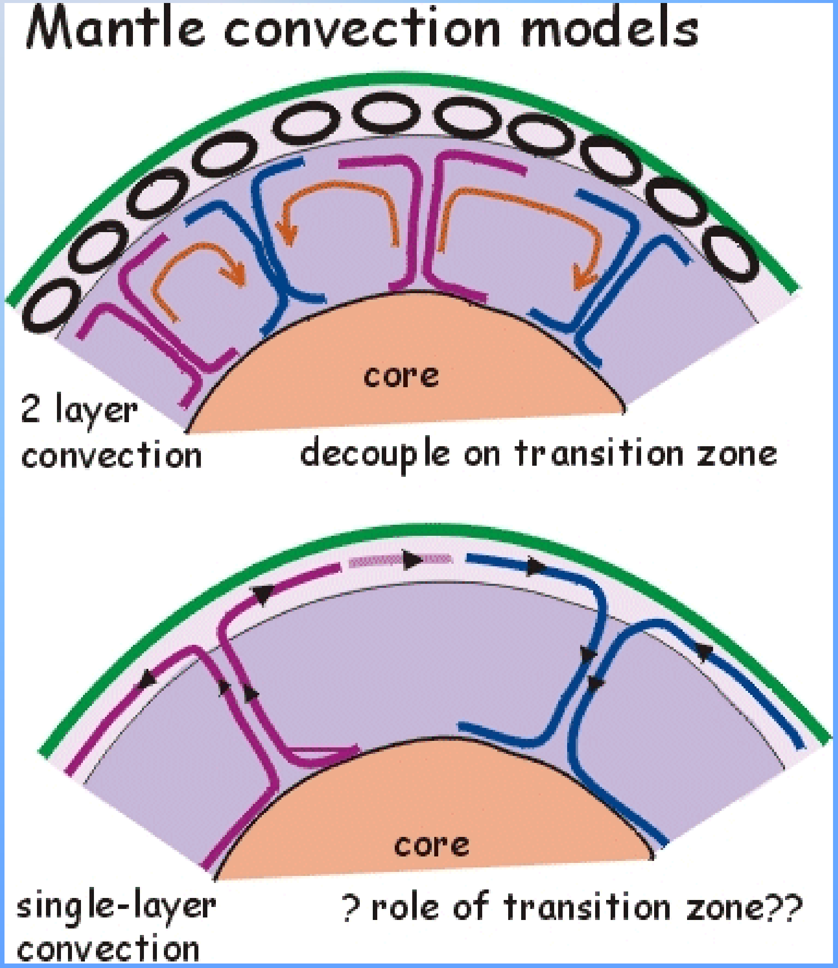
Correlation of Magnetic Anomalies with Magnetic Reversals



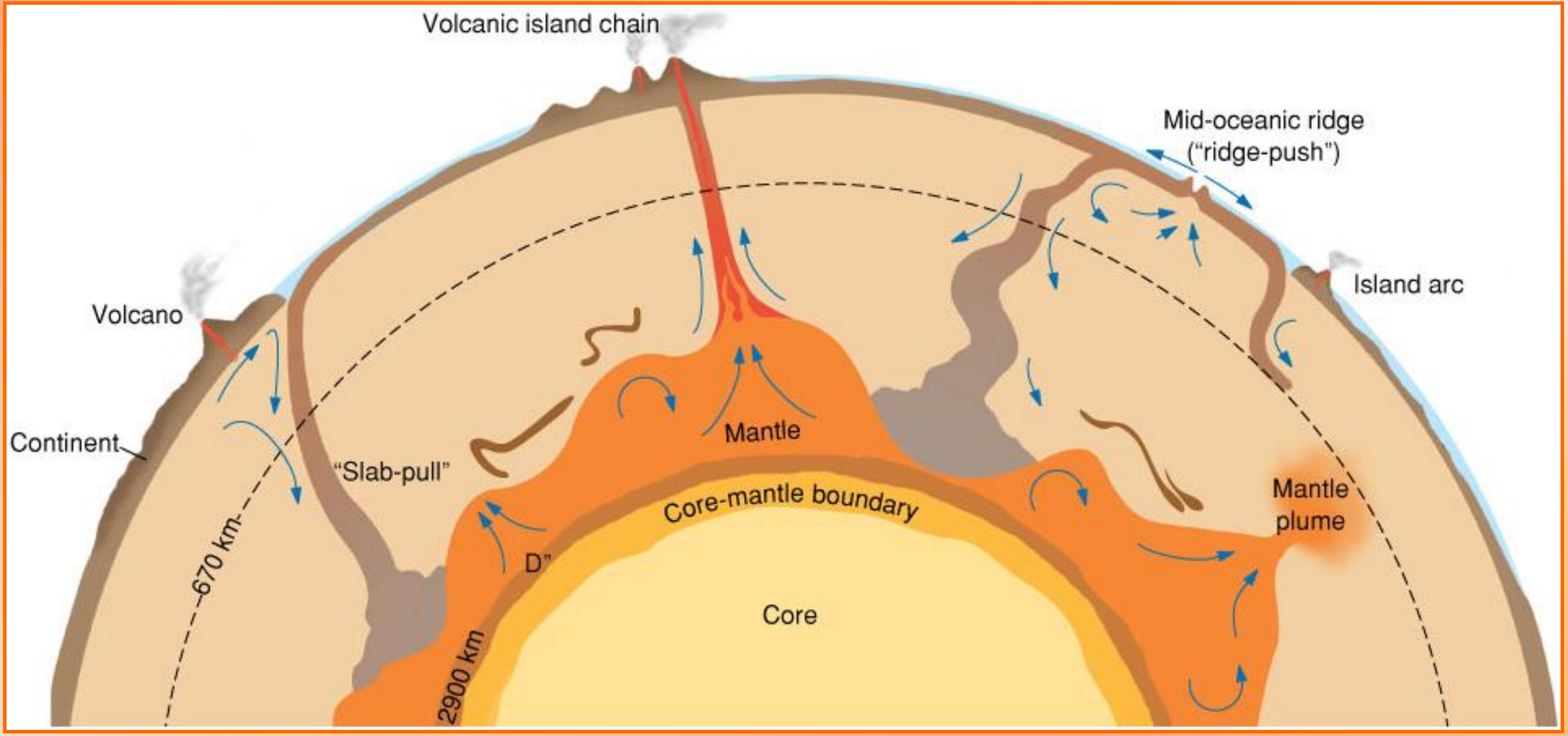
III. Causes of Plate Motion

B. Mantle Convection

- On a human time scale convection is slow
  - Rate of fingernail growth
  - A clock's hour hand moves 10,000 times faster
- Geologically it's fast
  - 58 million years from bottom to top of mantle
- Patterns are not fully understood.
  - There are several models



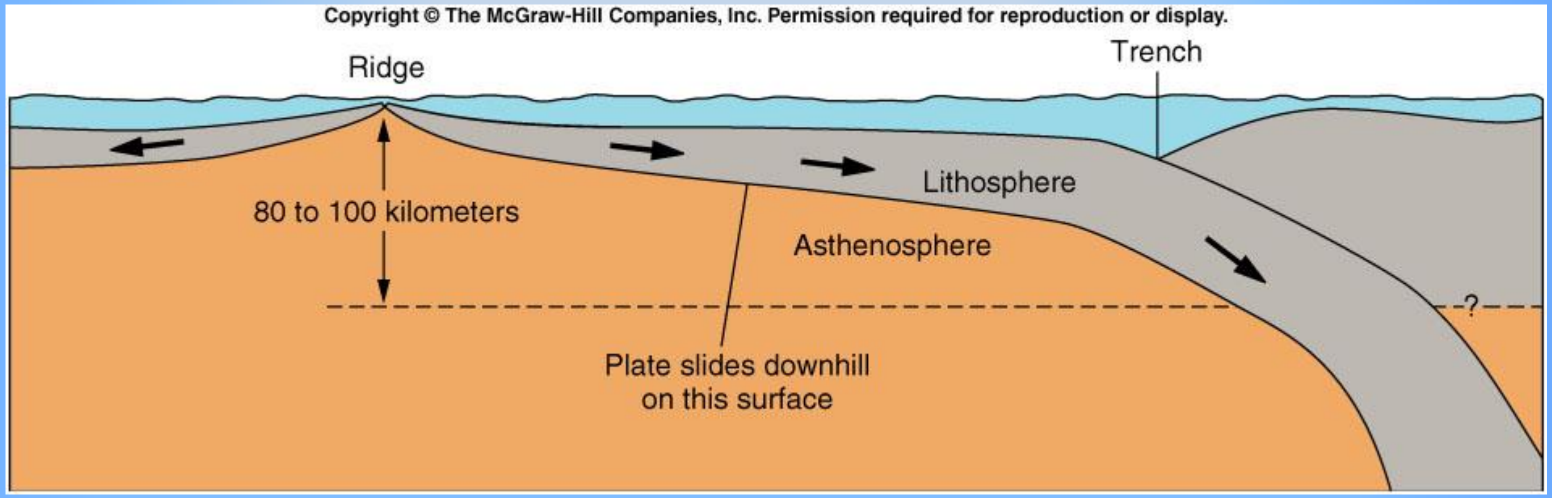
Convection Model that Includes “Ridge Push” and “Slab Pull”



C. *Ridge-Push* and *Slab-Pull*

Contradict convection models that assume the plates are dragged Along by movement of underlying mantle rock

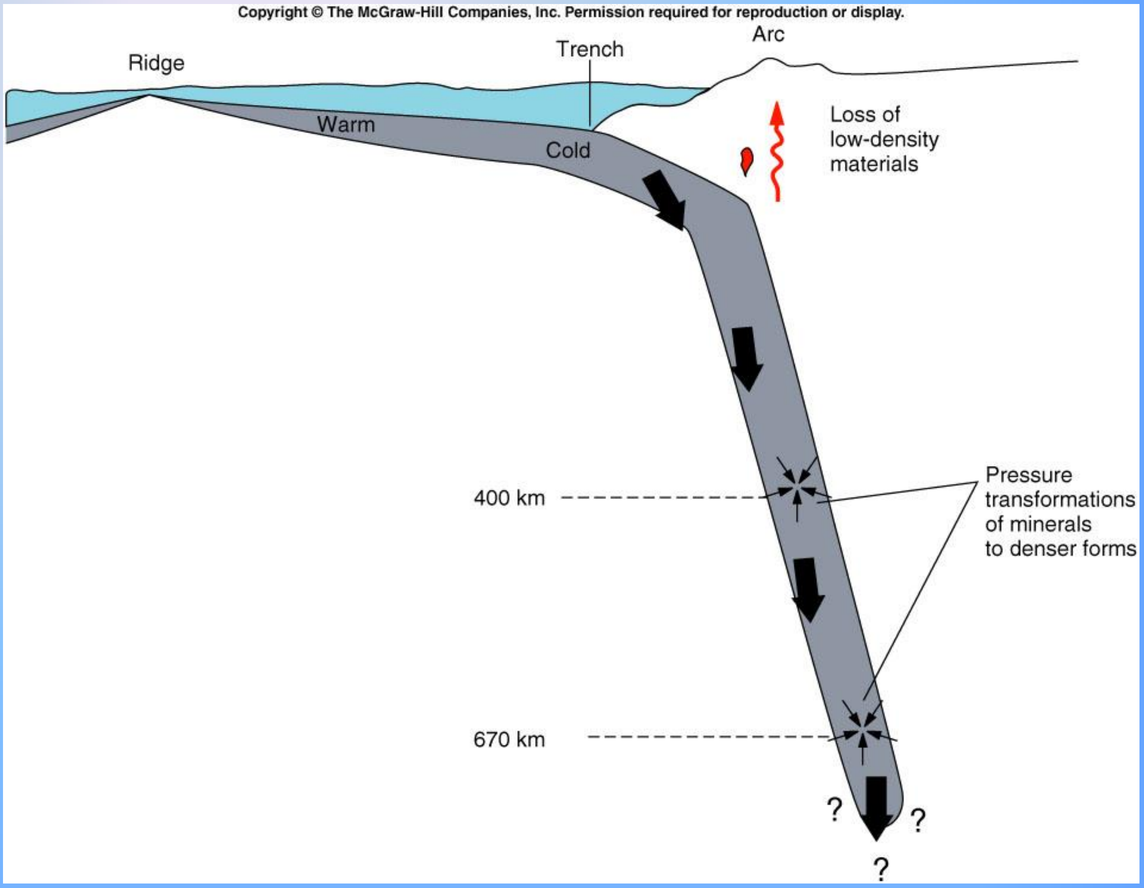
1. _**Ridge**_ - *Push*



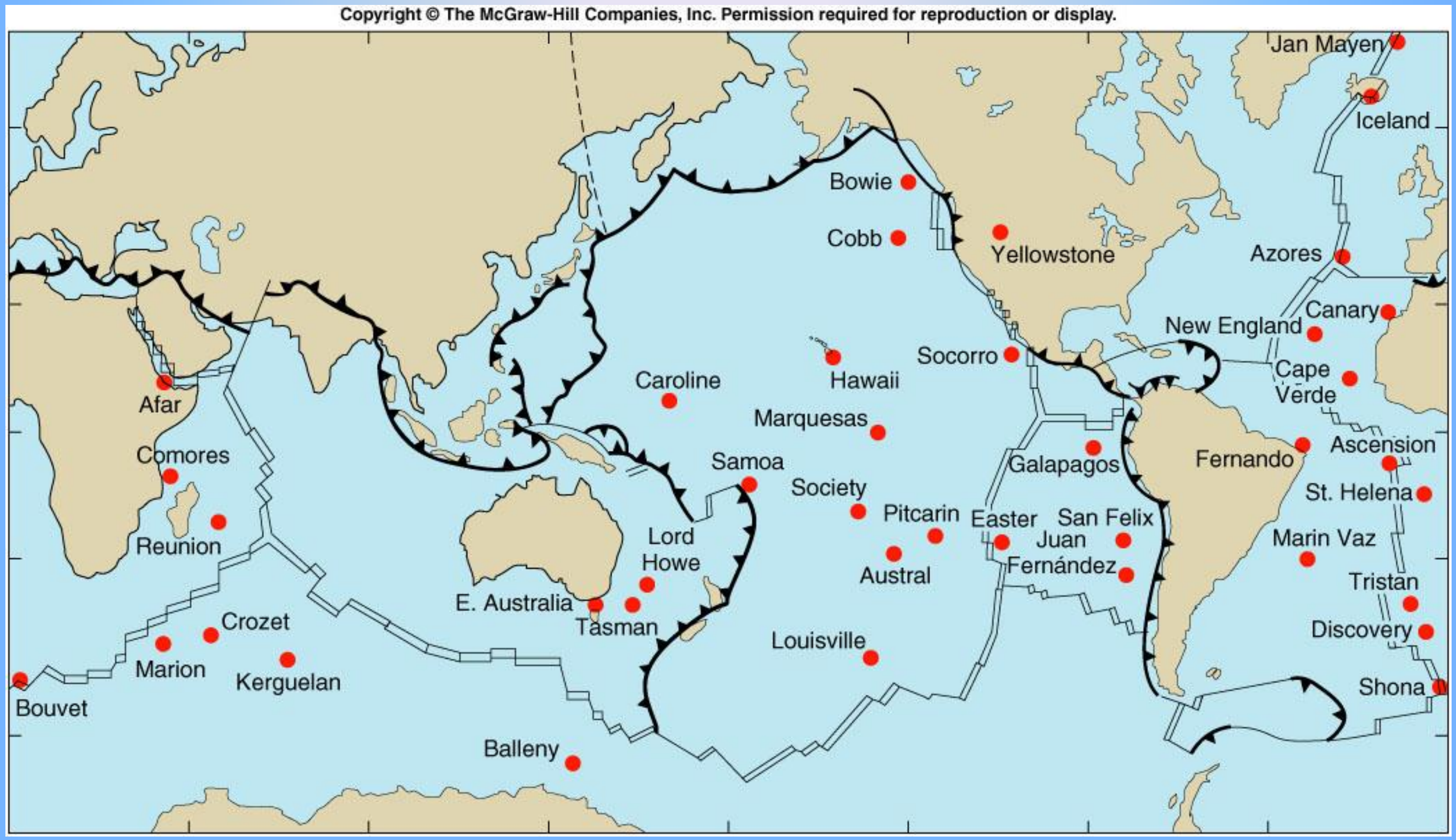
- **Spreading centers stand high on the sea floor**
- **As a plate moves away from a divergent boundary it cools and thickens causing the sea floor to subside as it moves, forming the broad side slops of the ridge.**
- **As the asthenospheric mantle cools it thickens creating a slope.**
- **Lithosphere slides down.**
- **Due to higher elevation at the ridge, a *push* is imparted to the tectonic plate.**

2. Slab - *Pull*

- The dense, leading edge of a subducting plate pulls the rest of the plate along.
- Density increases
  - Cooling
  - Loss of water
  - Phase transitions of minerals
- Motion is rapid along a steep slope

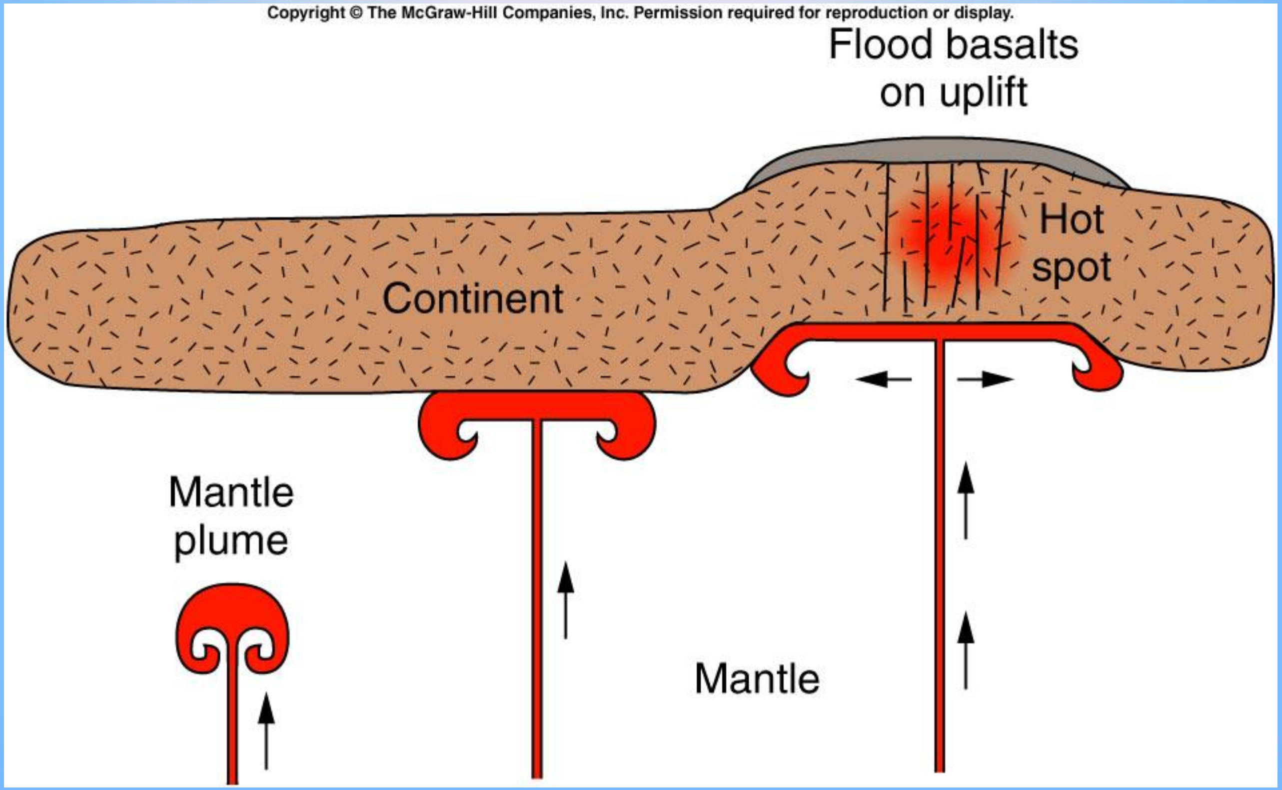


C. Mantle Plumes and Hot Spots



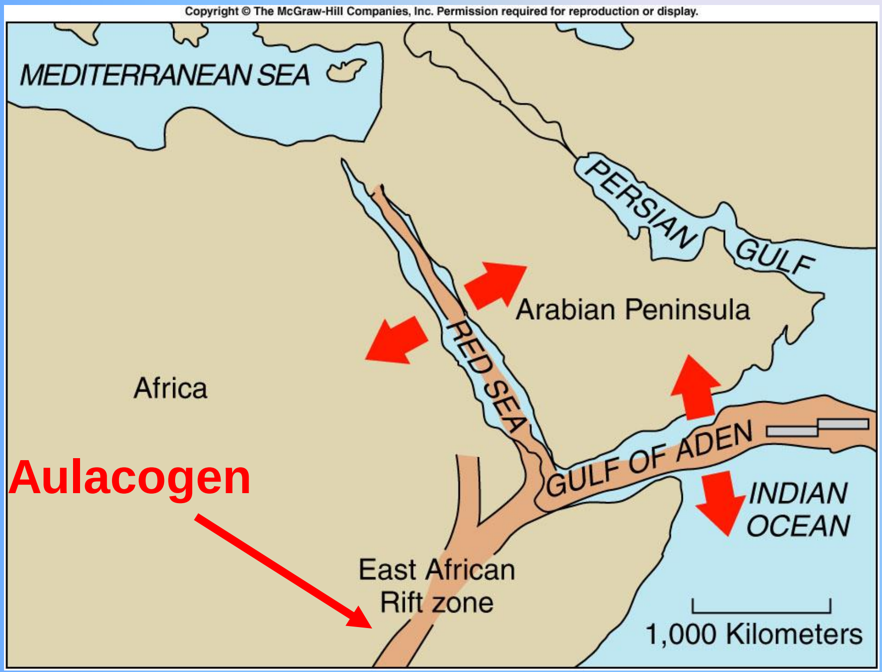
1. Mantle Plumes: Narrow columns of hot mantle rock that rise through the mantle.
2. Hot Spots: Regions of active volcanism at Earth's surface above plumes

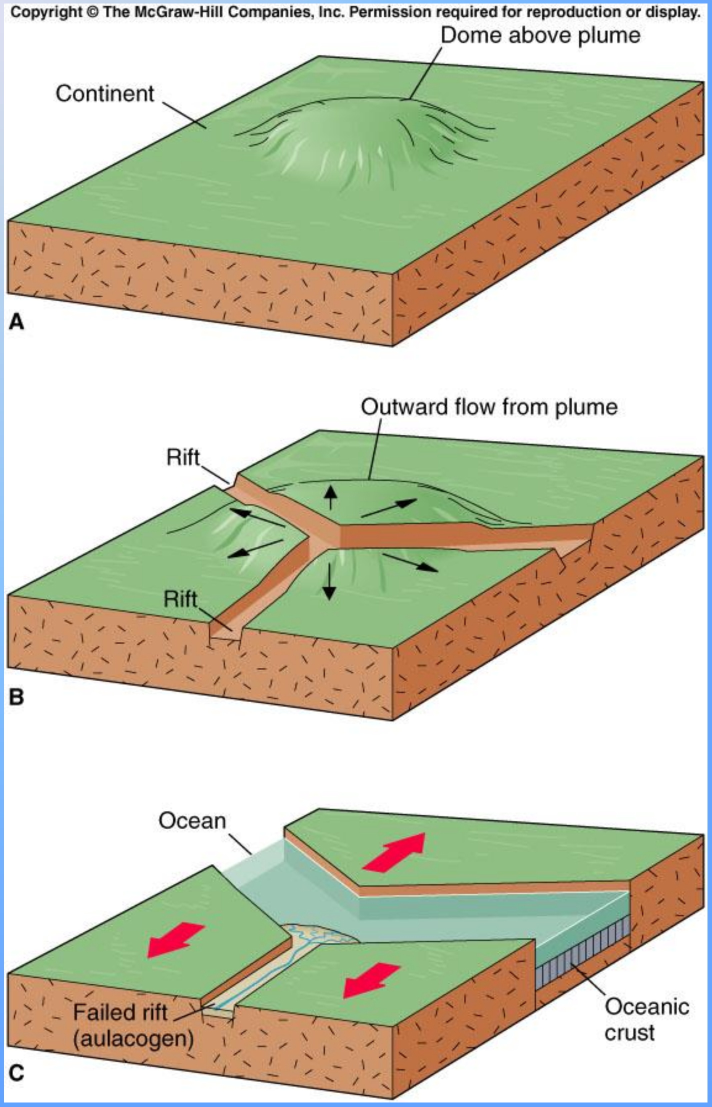
Flood Basalts and the "Superplume" Hypotheses



- Uplift and the eruption of vast fields of flood basalts when the head of a large plume nears the surface.
- Widening of the head below the crust results in crustal stretching and the flood-basalt area widens.

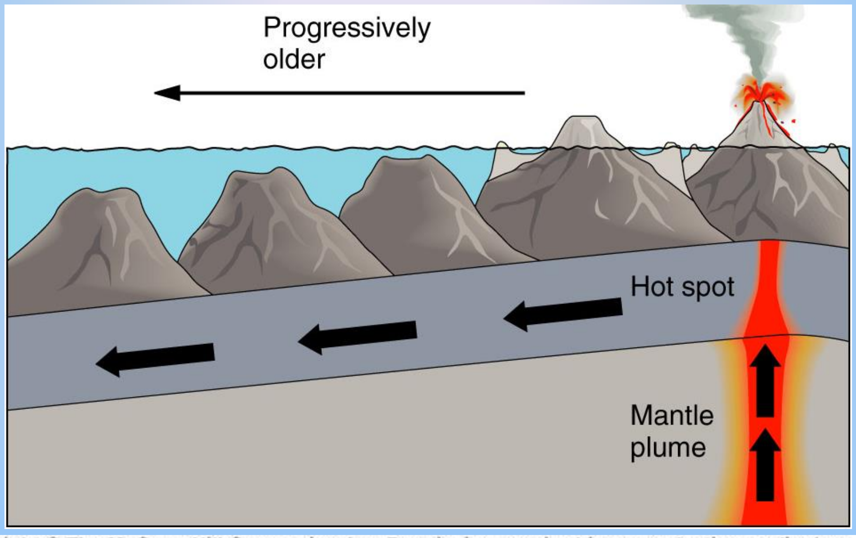
Continental Rifting

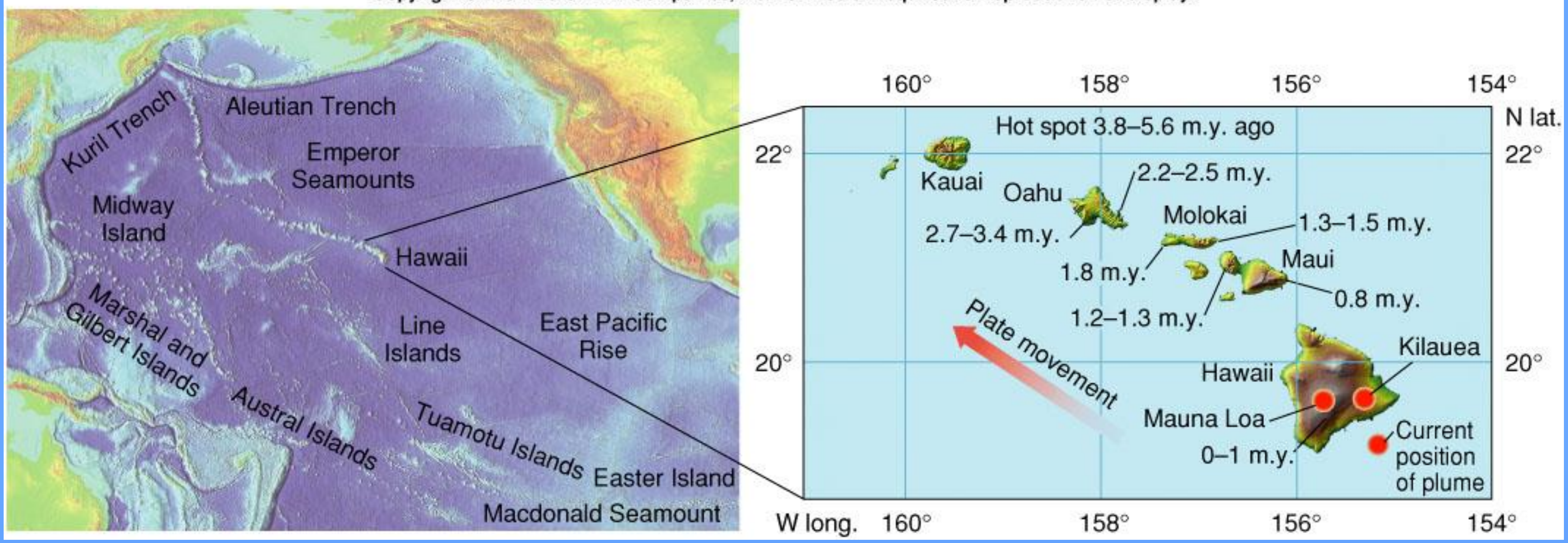




- **A plume causes a dome that breaks in a three-pronged pattern.**
- **The plume separates the crust along two of the three fractures**
- **The third fracture become inactive and eventually fills with sediment (called a *failed rift* or *aulacogen.*)**

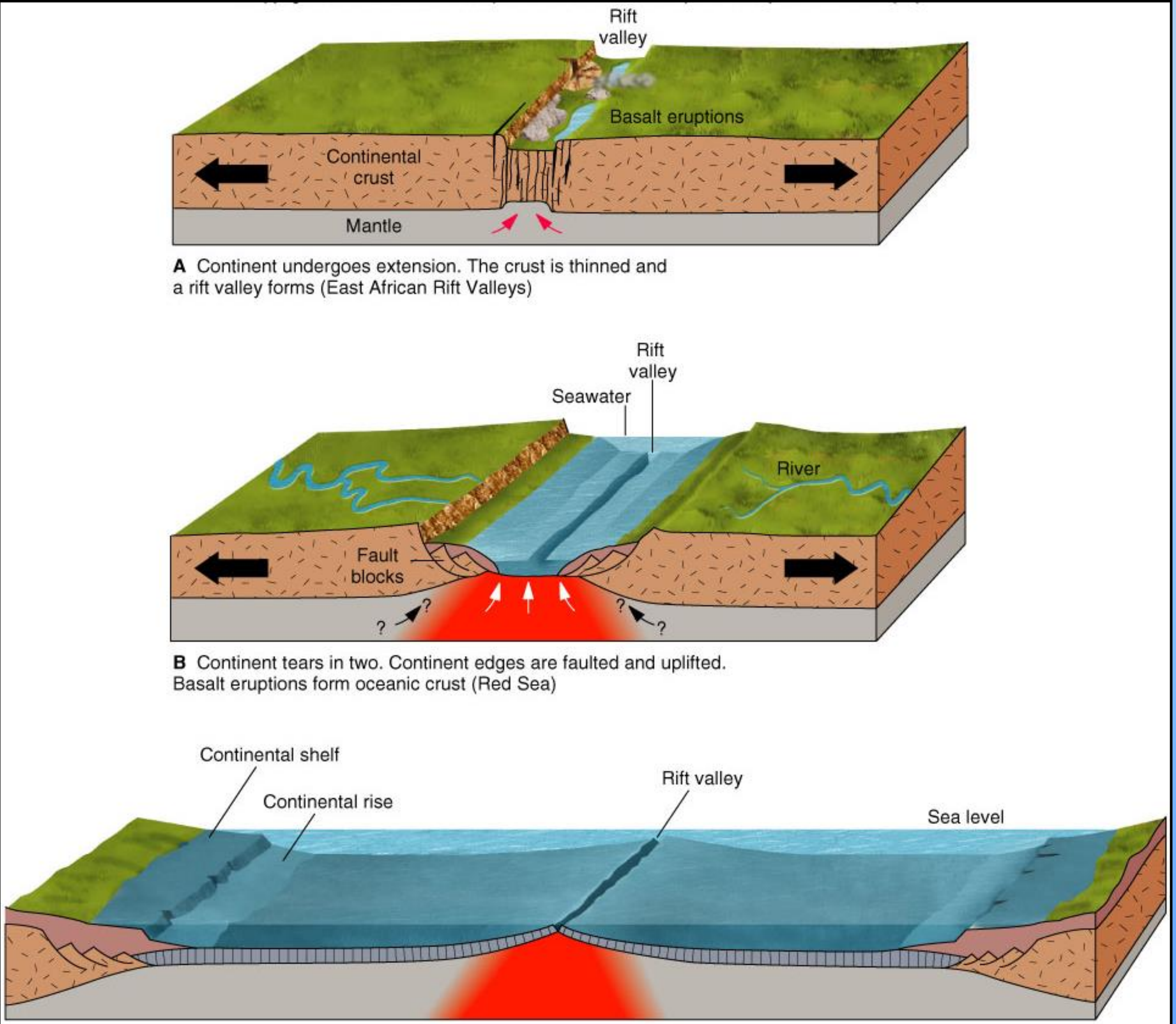
Hawaiian Volcanism





IV. Types of Plate Boundaries

A. ___Divergent___ Boundaries



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

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

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

Summary of Divergent Boundaries

1. Plates moving __**away**______ from each other.
2. Marked by rifting, basaltic volcanism, and uplift.
3. Tension causes shallow-focus earthquakes along normal faults along which the crust is stretched and thinned.
4. In a continent a _**rift valley**_ forms as a central valley.
5. Found at:
   a. _**Mid-ocean**_ ridges
   b. **Continental** rift valleys (East African Rift)
      (1) After widening of the rift, eventually the plates separate and seawater floods into the linear basin between the two divergent continents.
      (2) Eventually opens into an ocean with a mid-ocean ridge in the center.

B. __Transform__ Boundaries

1. One plate slides __horizontally__ past another.
2. Sites of shallow-focus earthquakes and less likely to have volcanic activity
3. Strike-slip motion is common.
4. No new surface is formed or consumed
5. Locations of transform motion.

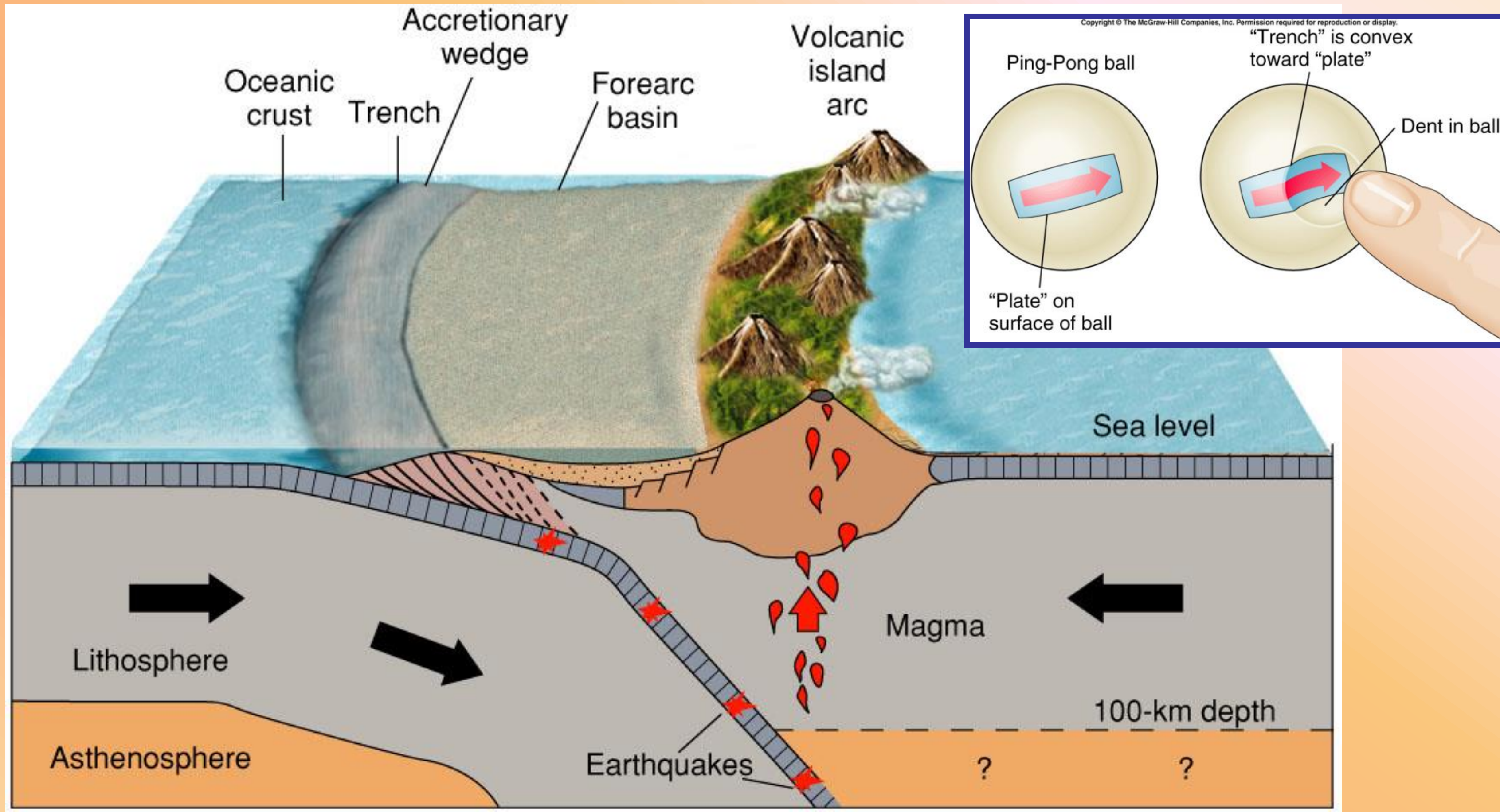
a. __San Andreas Fault__ in California (between the North American Plate and the Pacific Plate)

b. At **mid-ocean ridge** __fracture zones__ (**not plate boundaries**)

C. **Convergent** Plate Boundaries

Tectonic Plates Collide

1. Ocean-Ocean Convergence



a. Two plates capped by sea floor converge

b. One plate ____**subducts**____ beneath the other.

   (1) The subducting plate bends downward forming the outer wall of an oceanic trench

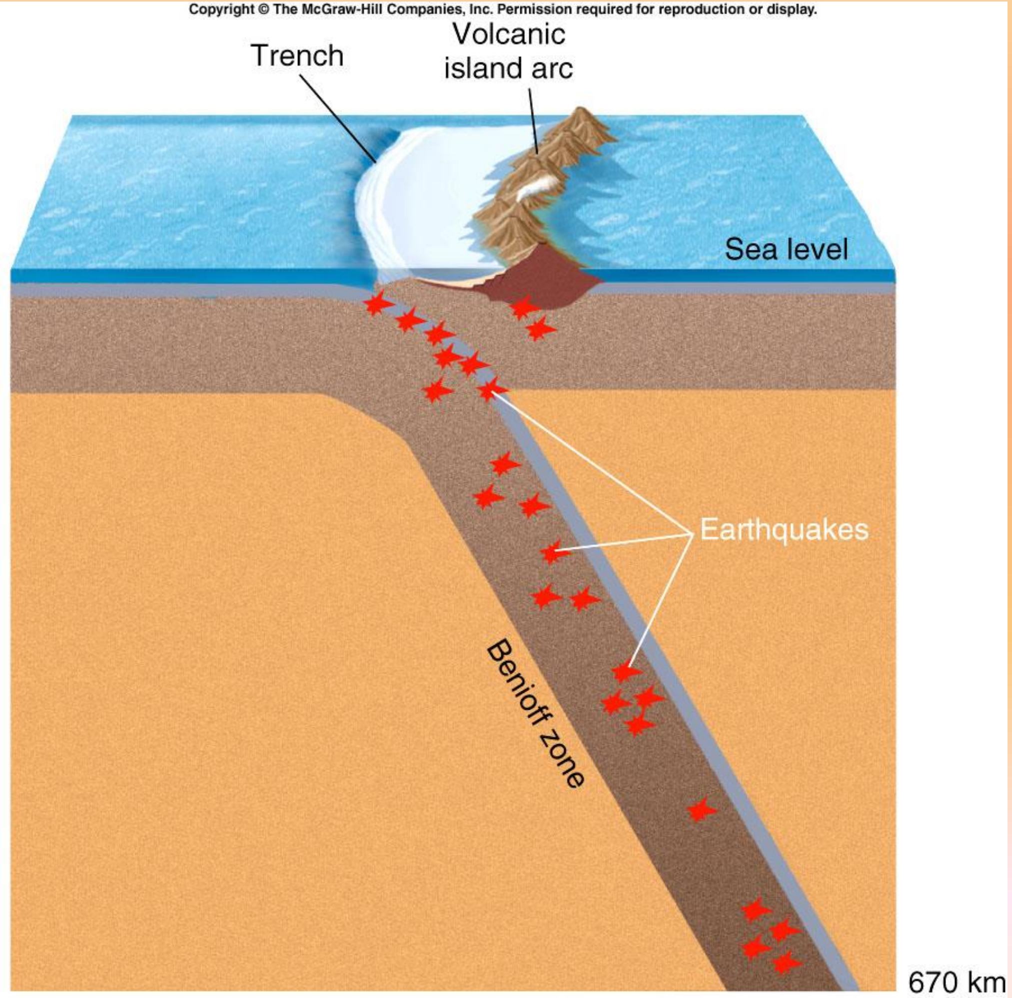
   (2) The trench forms a broad curve *convex* to the subducting plate due to Earth's rounded surface.

(3) Benioff Zones Form

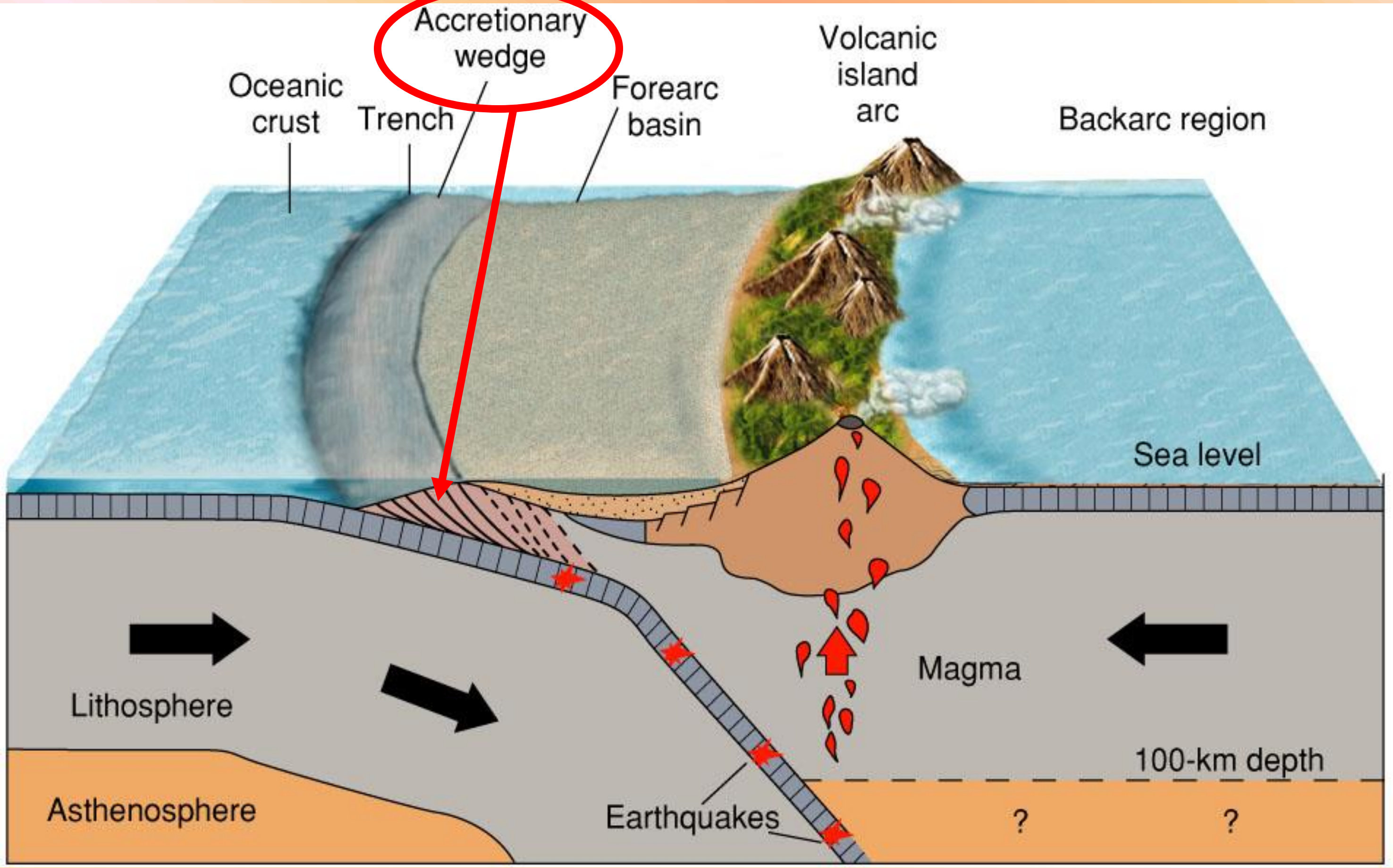
- Inclined zone of seismic activity.
- Subduction angle of 30º to 60º.

(4) Above the Benioff Zone

- String of volcanic islands
- In a curved line
- parallel to the trench

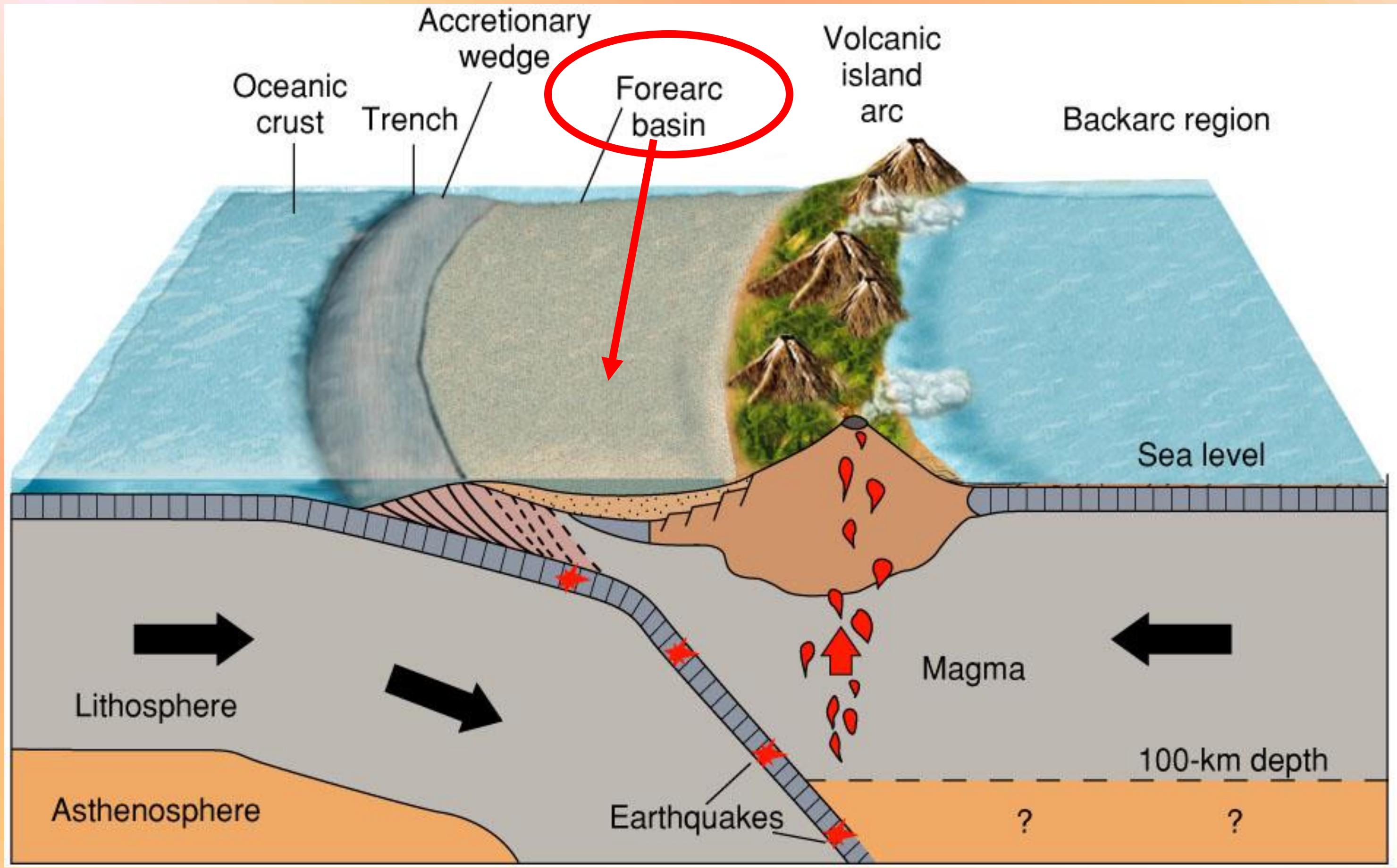


5. Accretionary Wedge



- Inner wall of a trench that is towards the arc
- Thrust faulted and folded marine sediment along with pieces of ocean crust.
- "Snowplowed" off the subducting plate by the overlying plate.

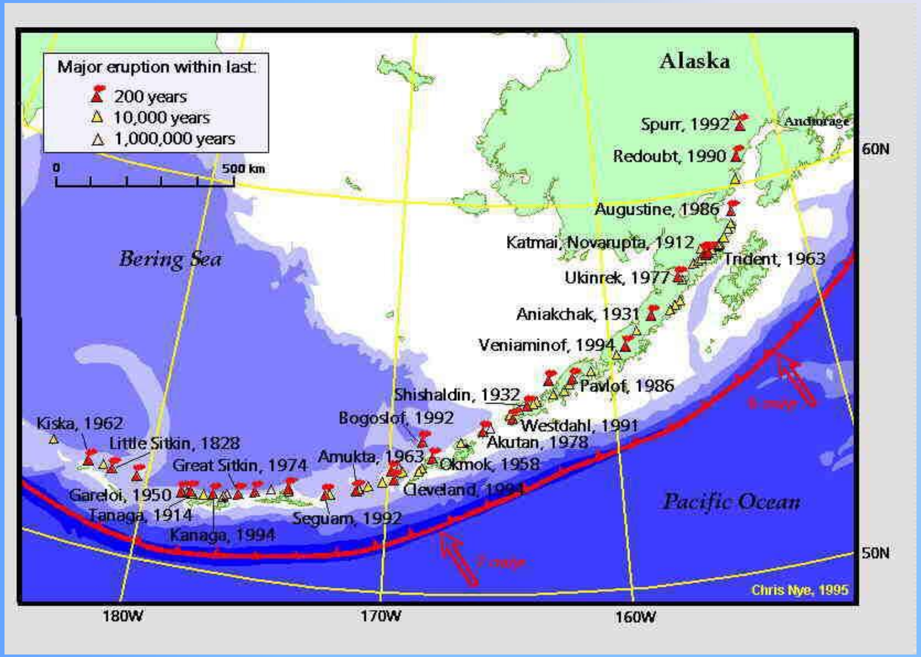
6. Forearc Basin

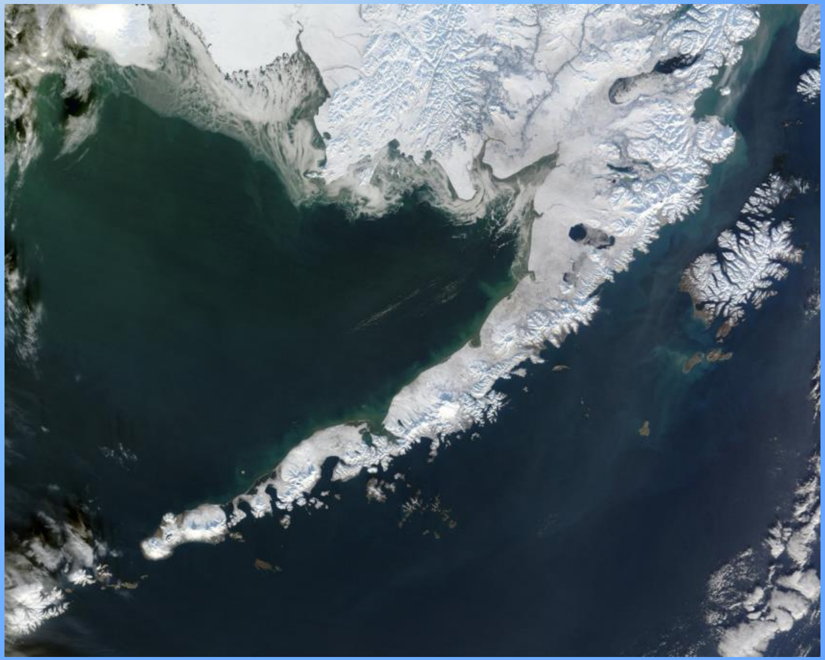


- **Lies between the accretionary wedge and the volcanic arc**
- **Relatively undeformed**

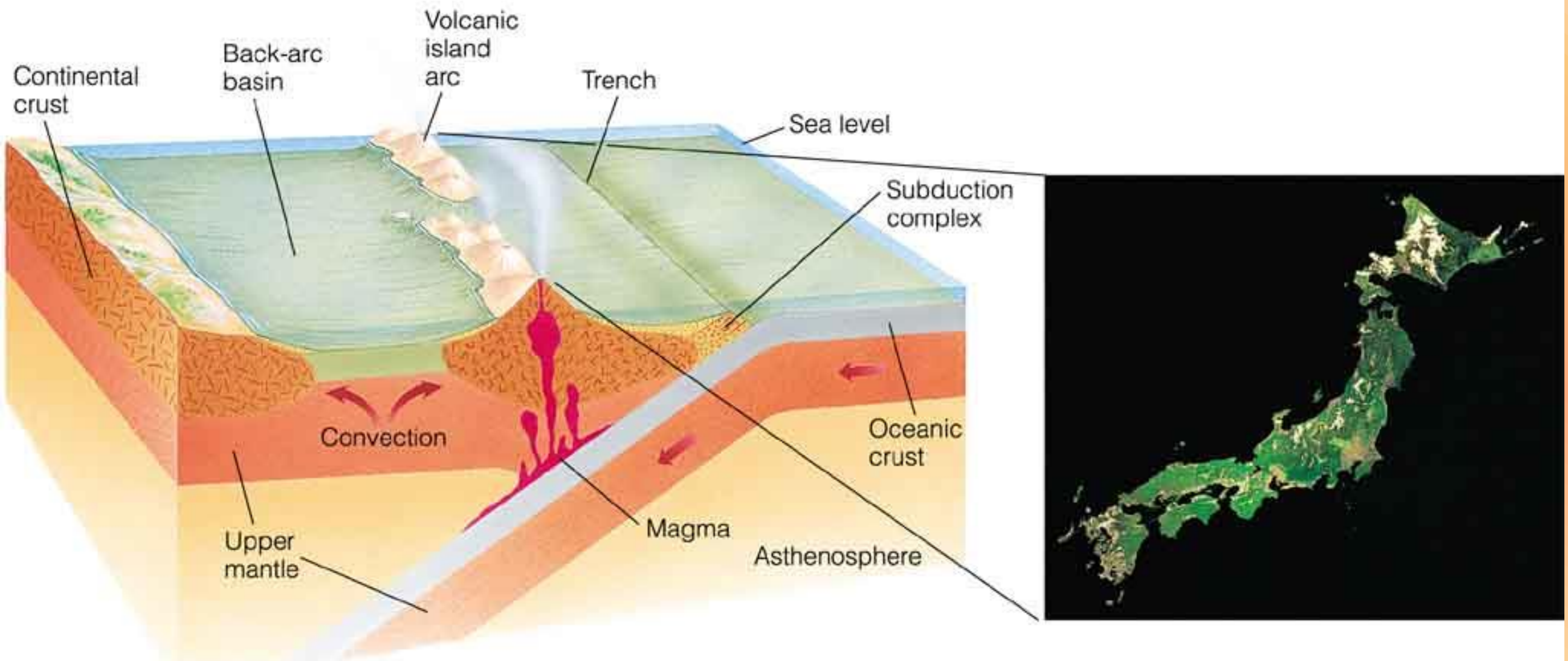
Examples

Alaska’s Aleutian Islands

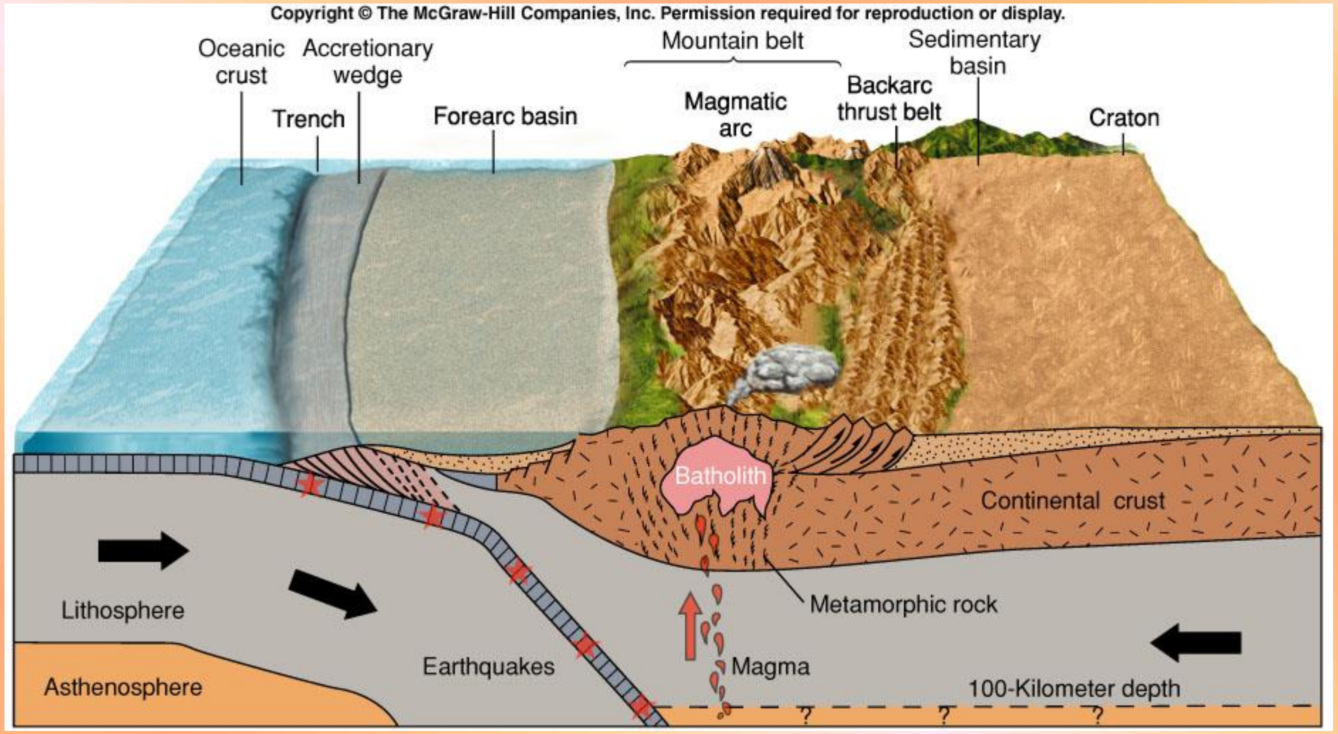




Japanese Island Arc

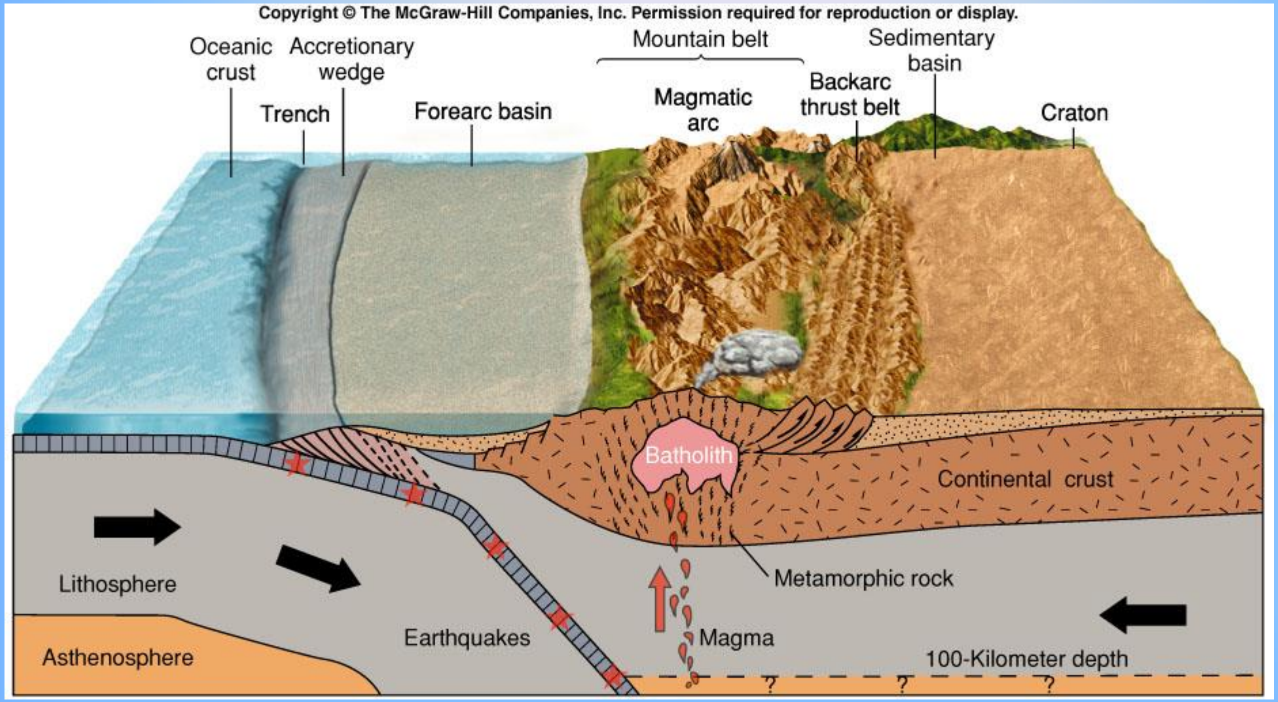


2. Ocean-Continent Convergence



a. Oceanic crust is subducted under continental lithosphere resulting in an *active continental margin.*
b. A __**benioff**_____ zone of earthquakes dips under the edge of the continent.
c. A new mountain belt is formed.

2. Ocean-Continent Convergence

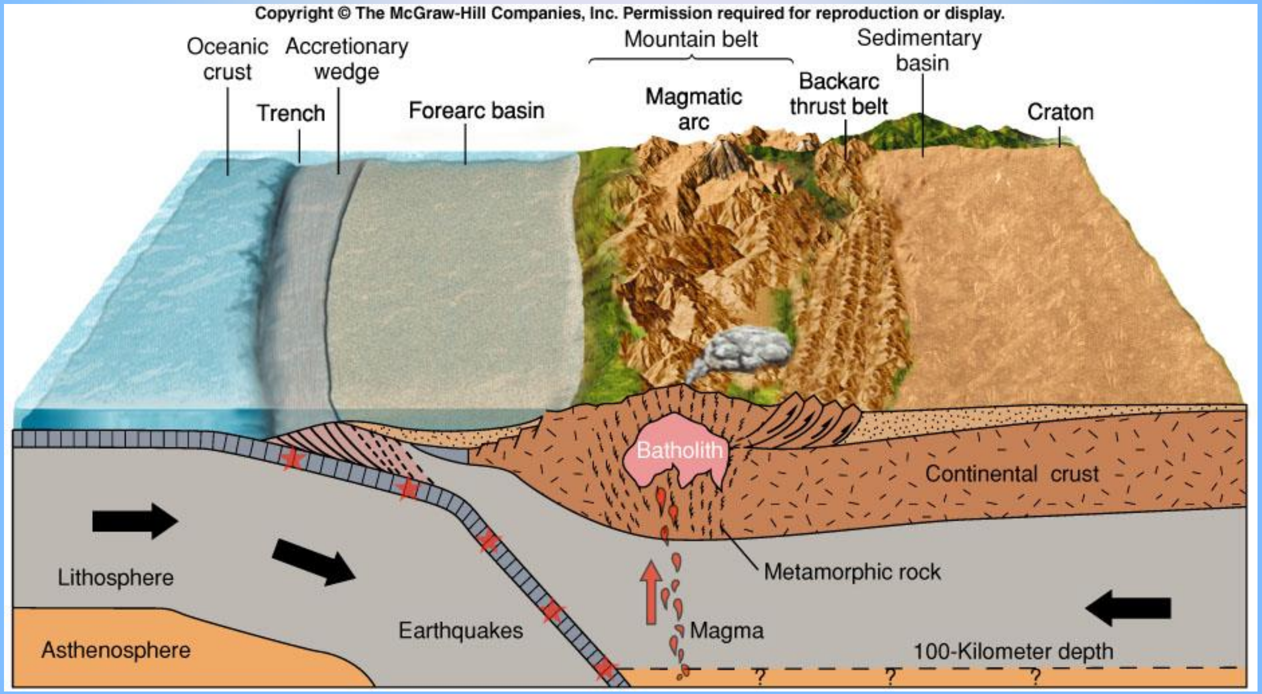


d. Magma rises forming a *magmatic arc* with the continent.

e. Andesitic volcanism occurs.

f. Beneath the the volcanoes are large plutons in thickened crust, seen on land as batholiths when exposed by extensive erosion.

2. Ocean-Continent Convergence



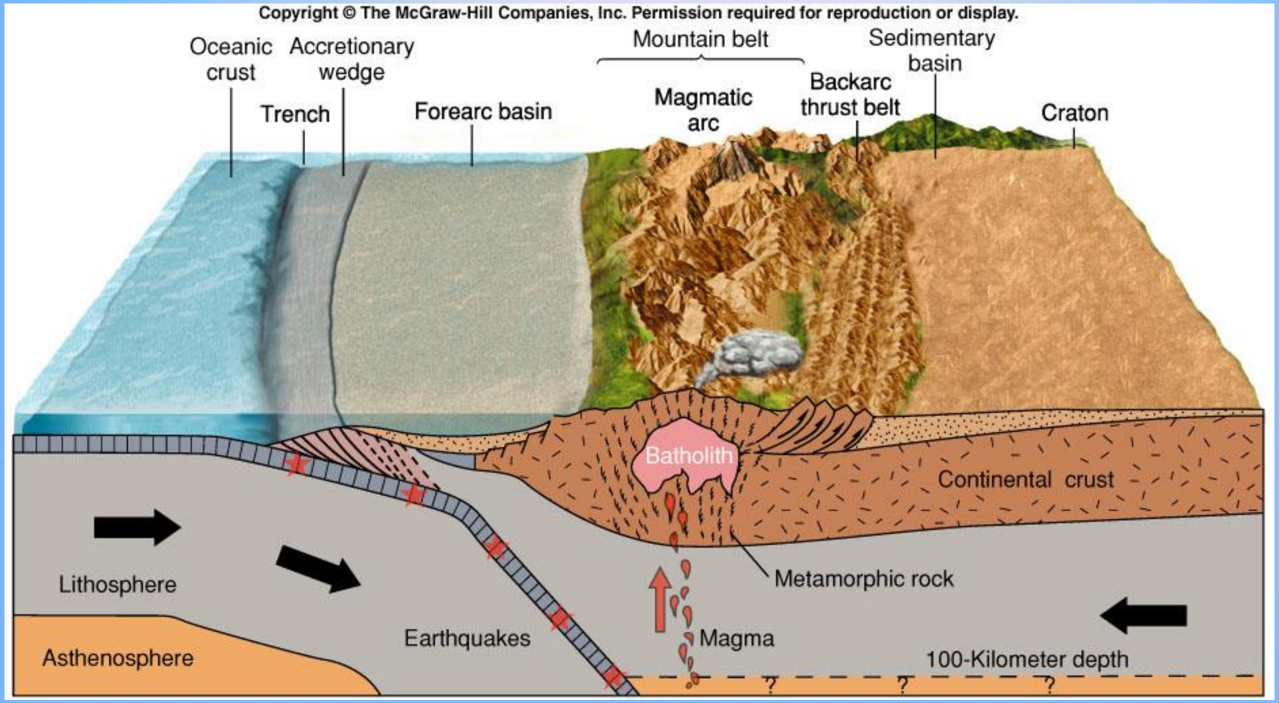
g. The more buoyant and continental plate experiences intense deformation, metamorphisms, and melting.

(1) crust thickens

(2) also rises isostatically

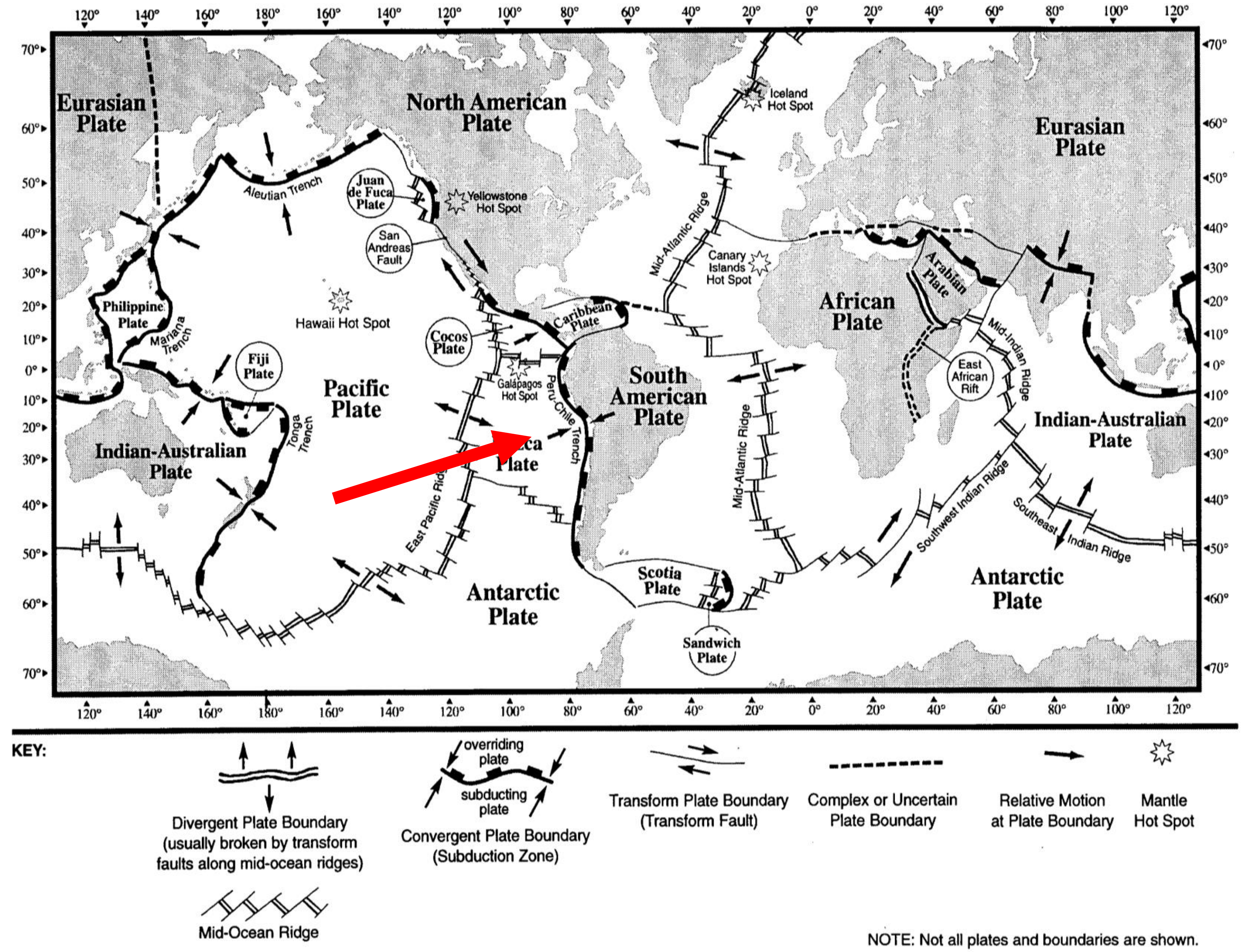
(3) Thrust faults, associated with folds, move slivers of mountain-belt rocks landward over the continental interior.

2. Ocean-Continent Convergence

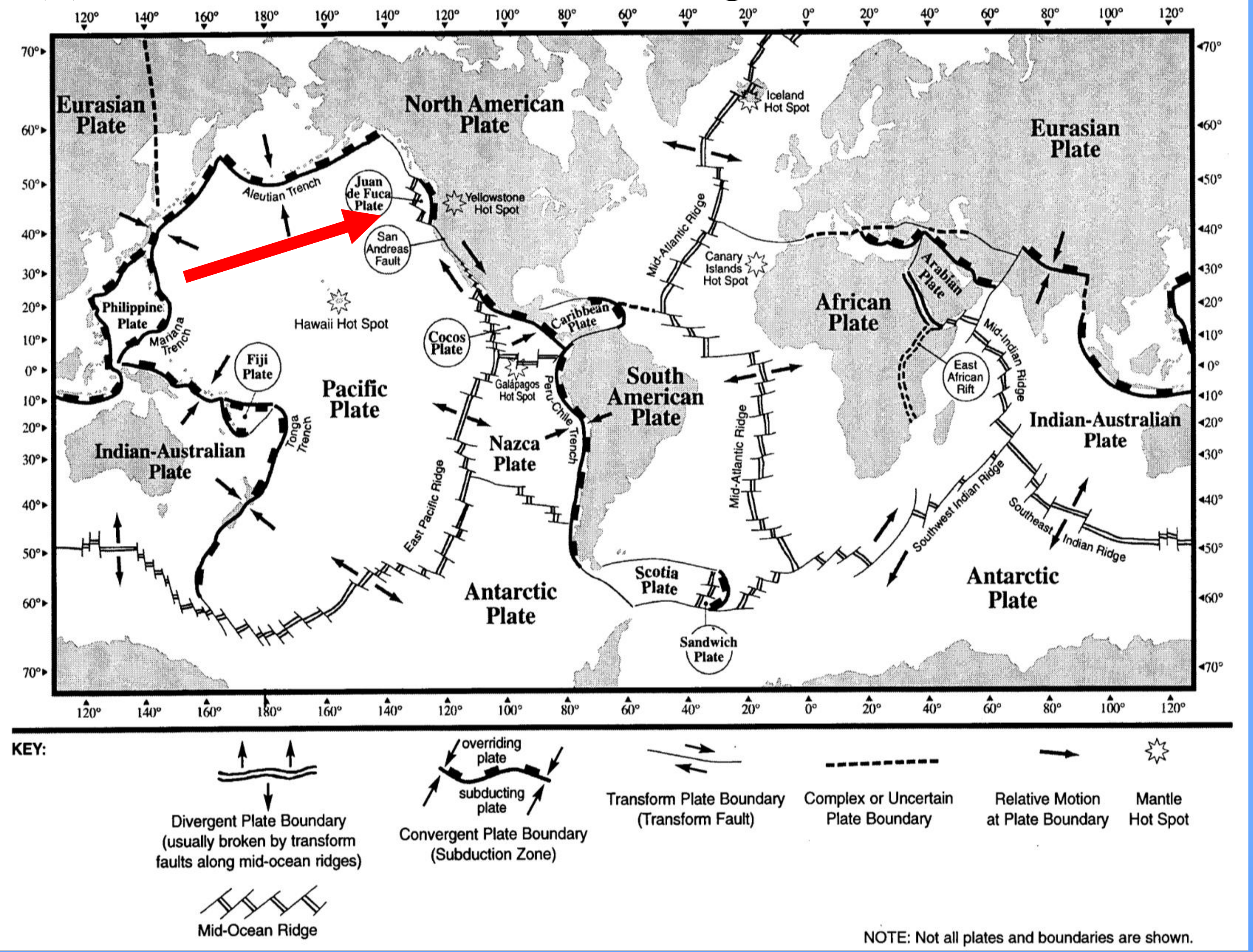


h. Today, this is occurring where:

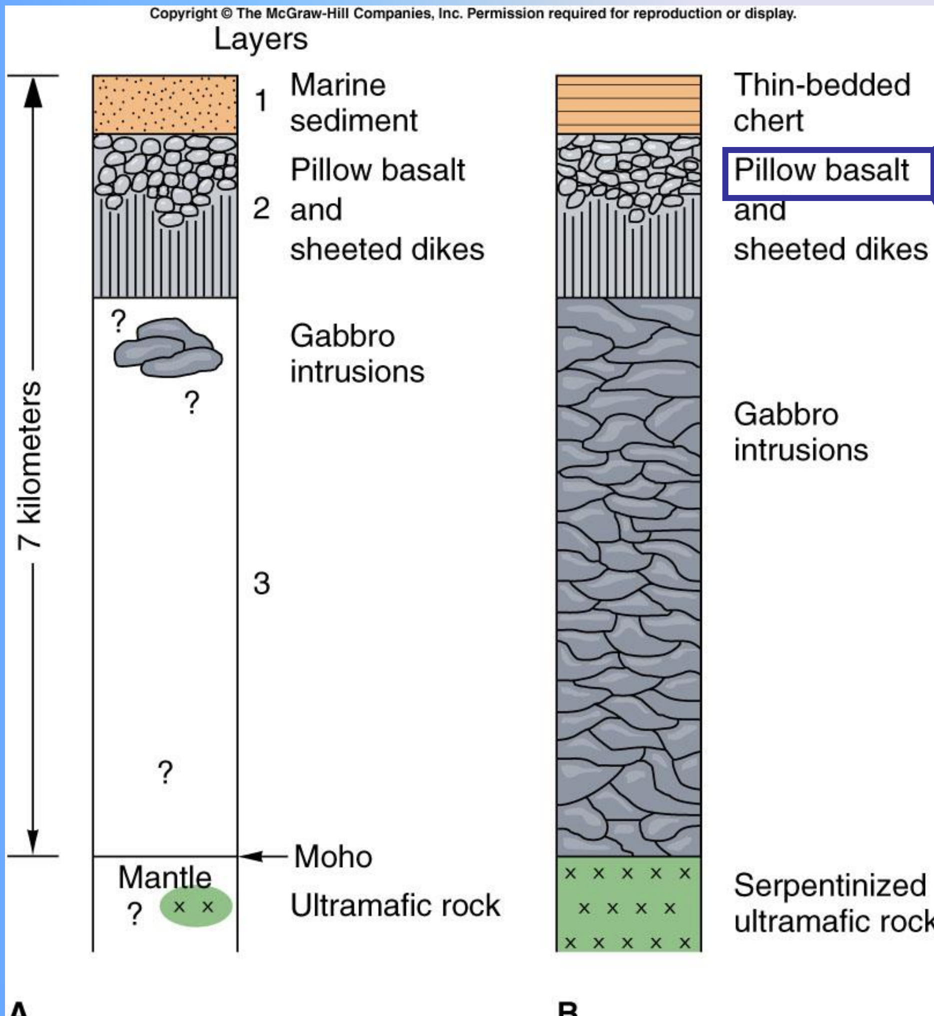
(1) The Nazca Plate is subducting under North America



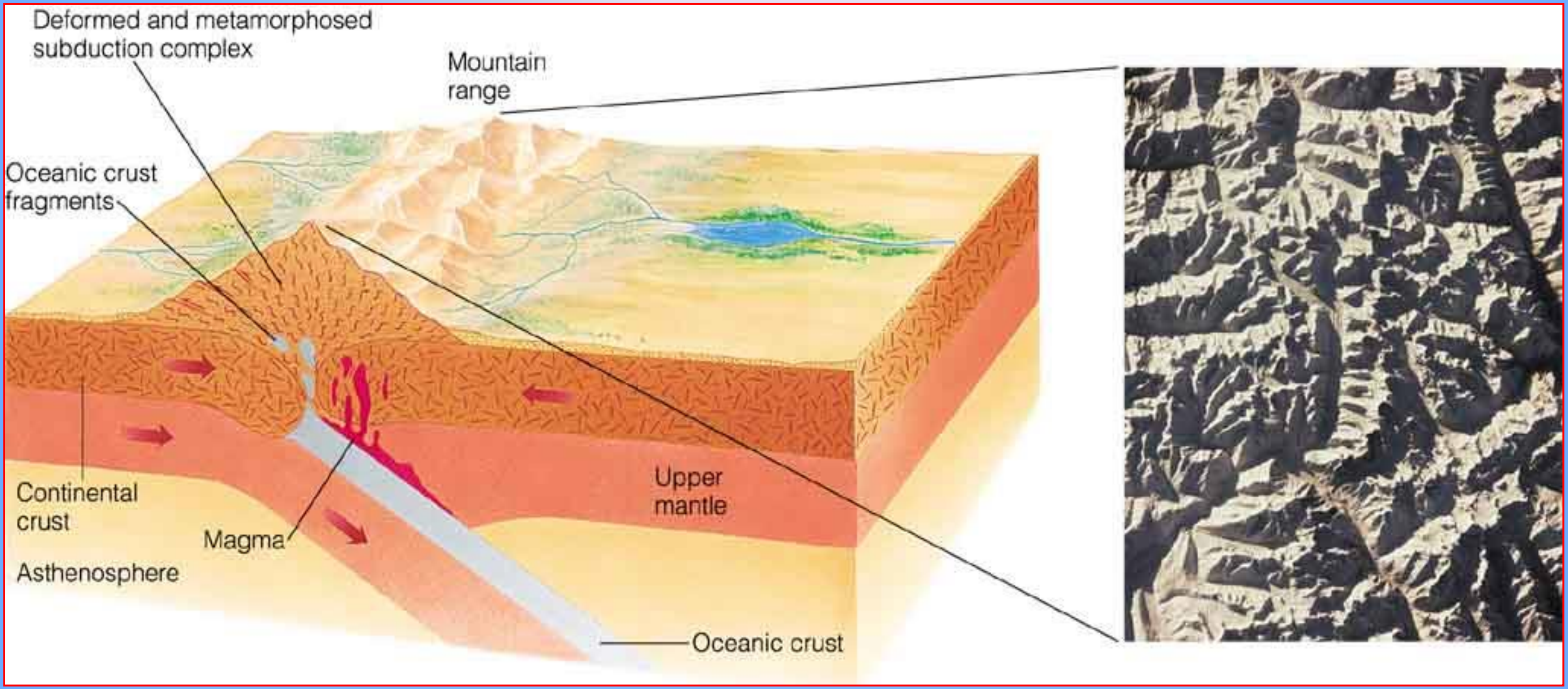
(2) The Pacific Plate is subducting under South America.



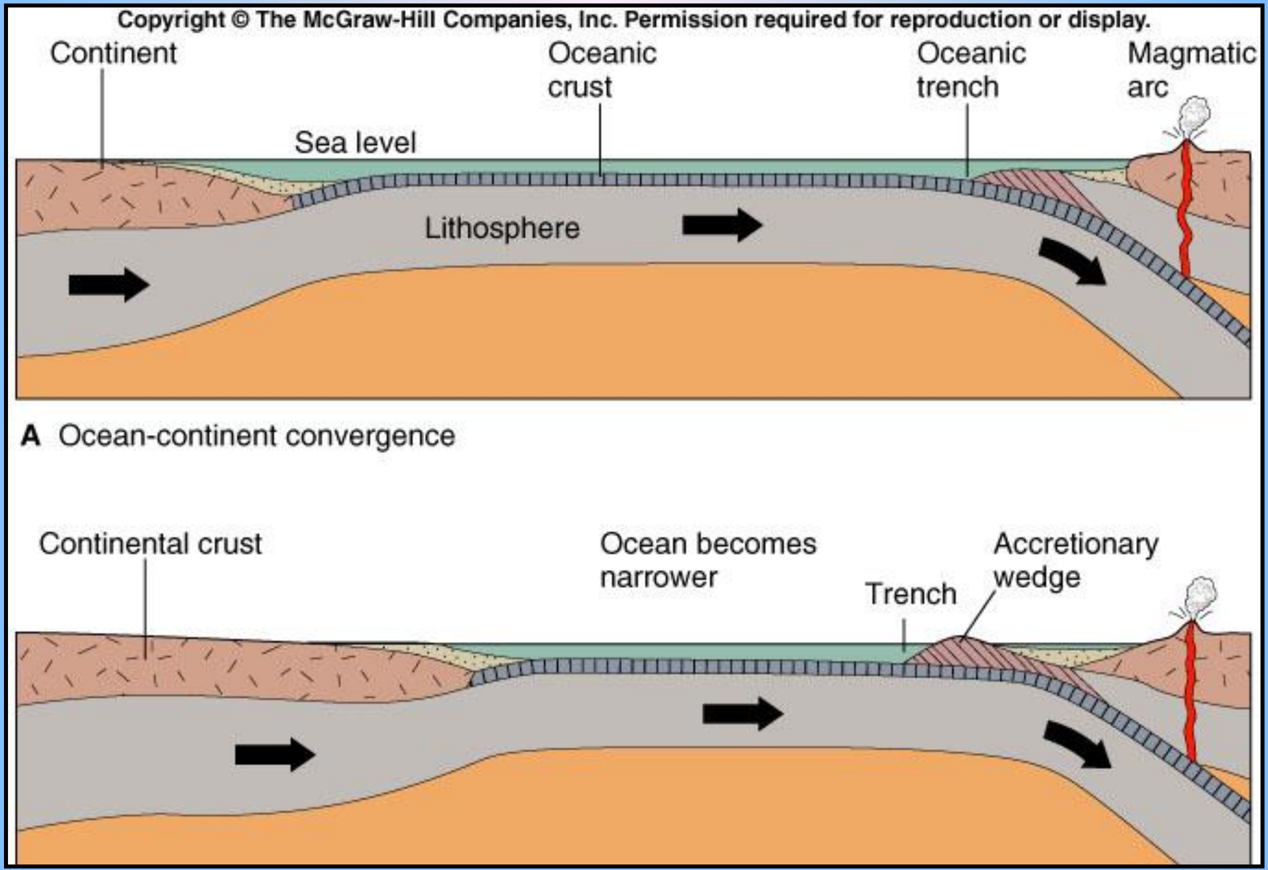
i. Ophiolites: Evidence of an Ancient Convergent Boundary



3. Continent-Continent Convergence



a. Two continents ___collide___.
b. Continents become welded together along a dipping ___suture___ zone.
c. A mountain belt forms at the interior of the new continent. Examples:
   (1) Himalayas between Eurasia and India
   (2) Appalachians - Formed when Pangaea collided with North America



d. Originally separated by ocean floor that is being subducted

e. When the two continents collide the lithosphere can't subduct.

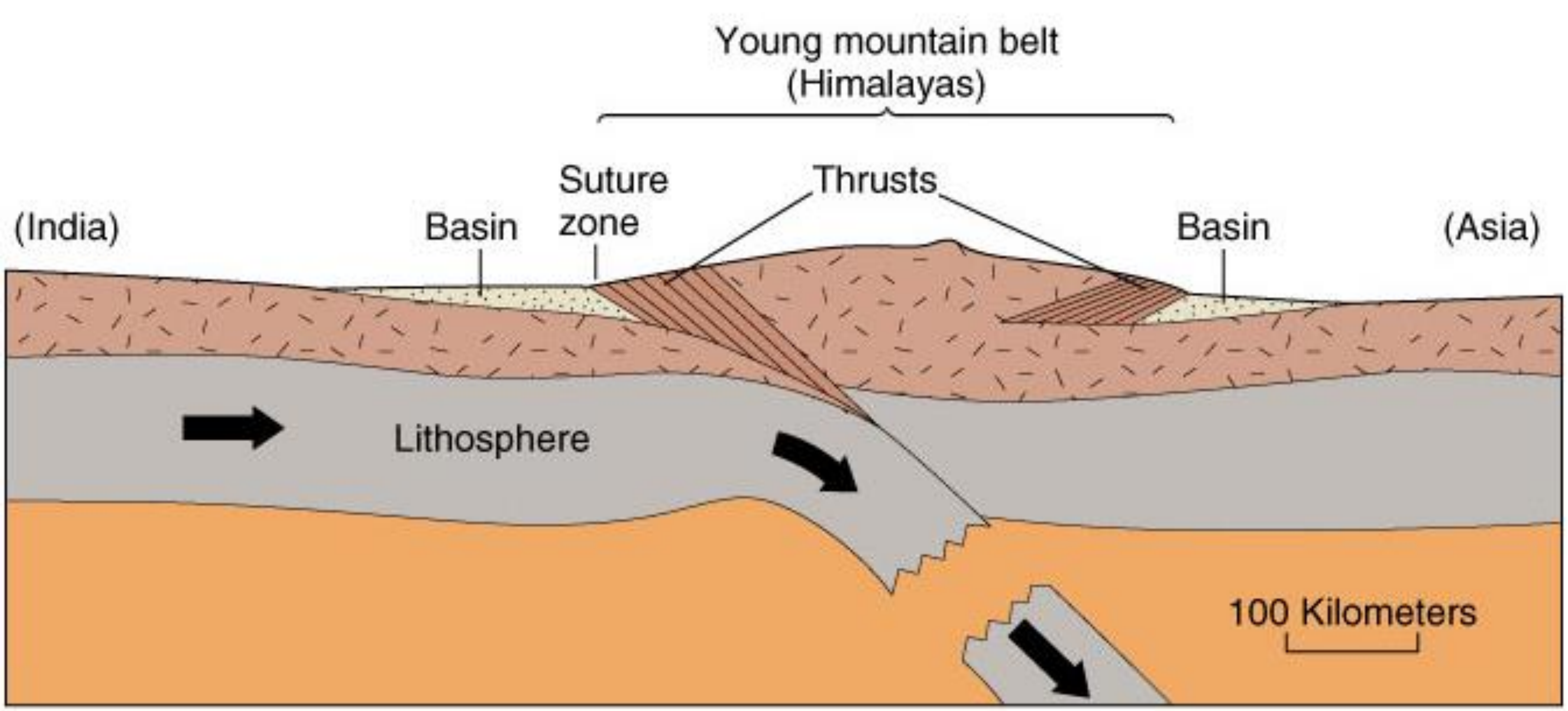
(1) it's density is too low

(2) One plate may partially slip below the other

f. Crust thickens by:

(1) orignal arc thickening the crust at the site of impact.

(2) Shallow underthrusting of one continent beneath the other.



C Continent-continent collision

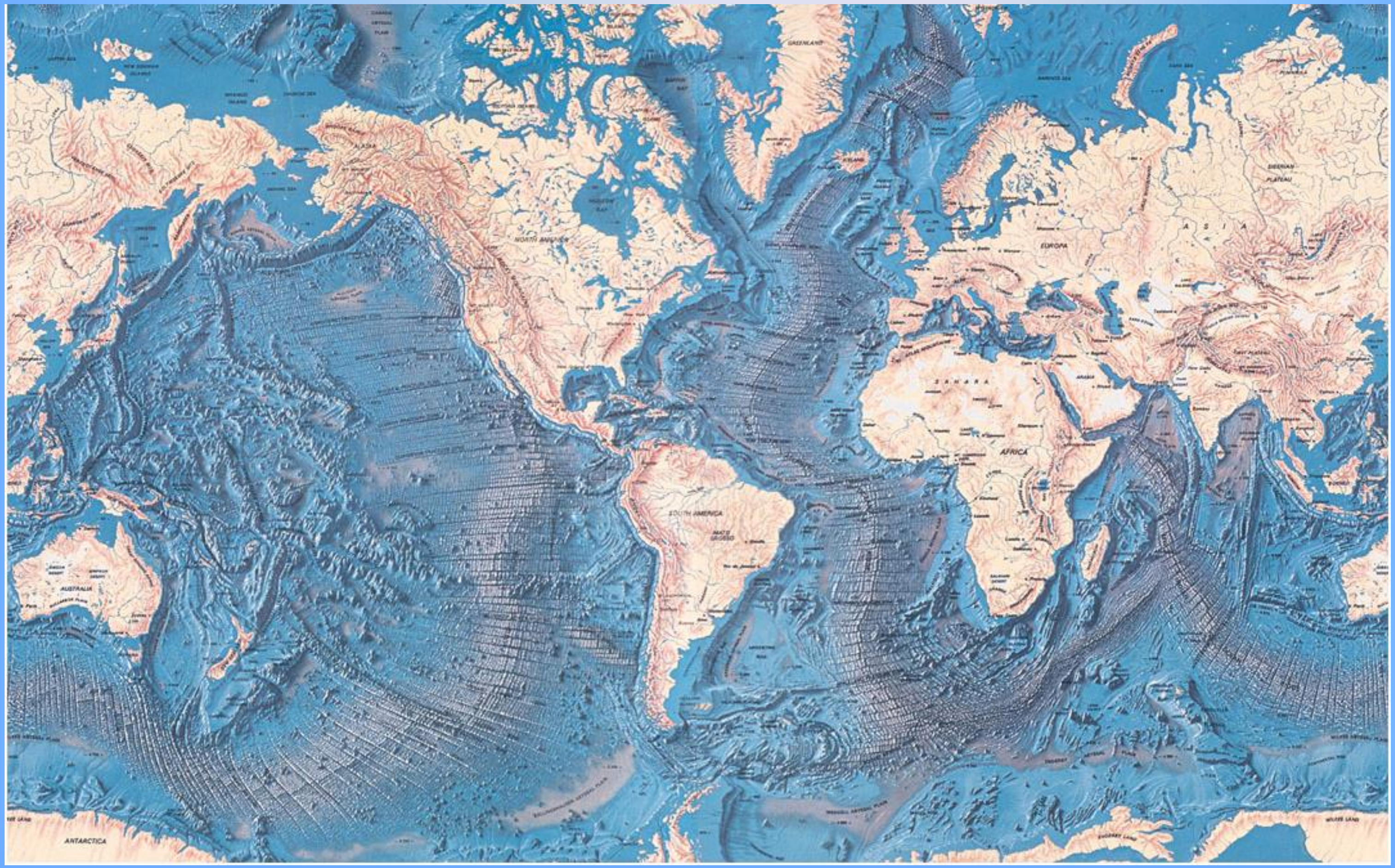
Alfred Wegener and the Continental Drift Hypothesis

- German meteorologist
- Credited with hypothesis of continental drift

B. Wegener's Evidence For Continental Drift

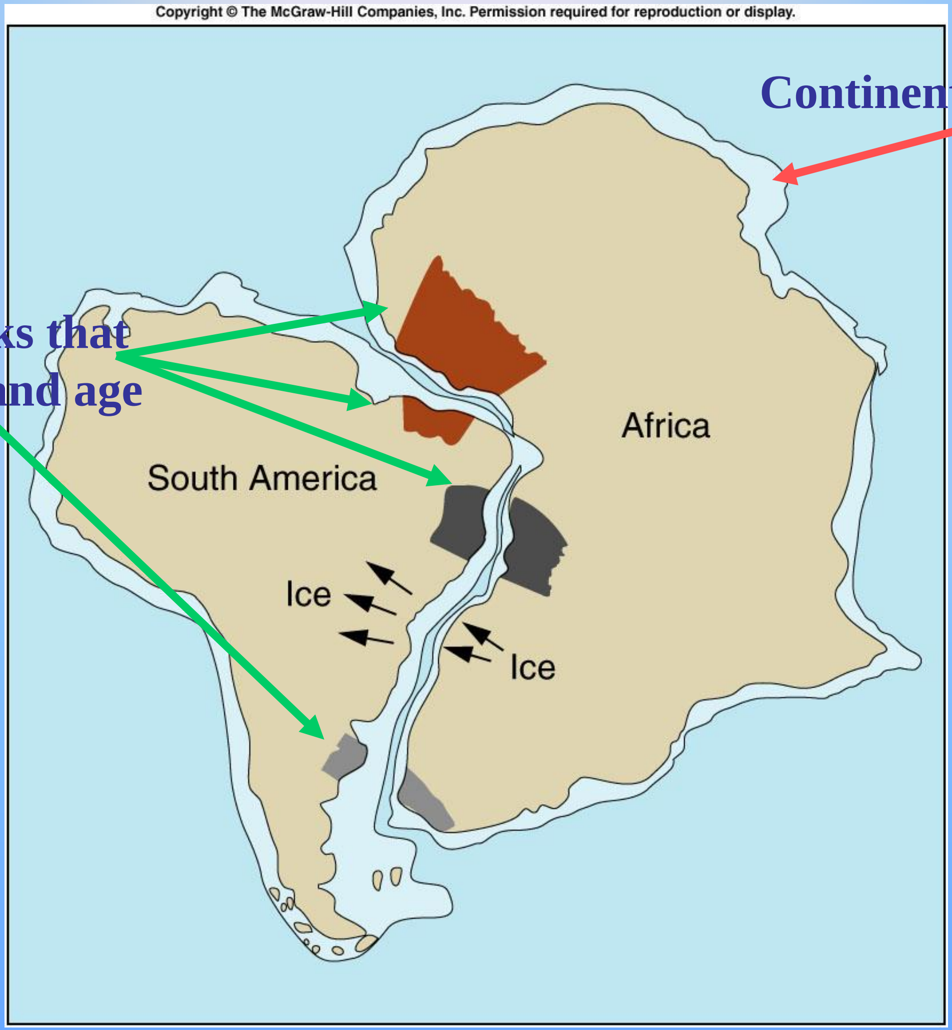
1. **Pangaea**
   a. Wegener proposed the presence of a giant continent, *Pangaea* (also spelled *Pangea*), which literally translated means "all lands."
   b. When it split apart it separated into two parts with the proto-Atlantic between them (called *Tethys Sea*).
      (1) **Laurasia** was the northern supercontinent that contained present-day North America and Eurasia (not including India
      (2) **Gondwanaland** (also called *Gondwana*) was the southern supercontinent, composed of all present-day southern hemisphere continents and India.

2. Jig-Saw Fit of Continents



Shorelines of continents seem to fit together

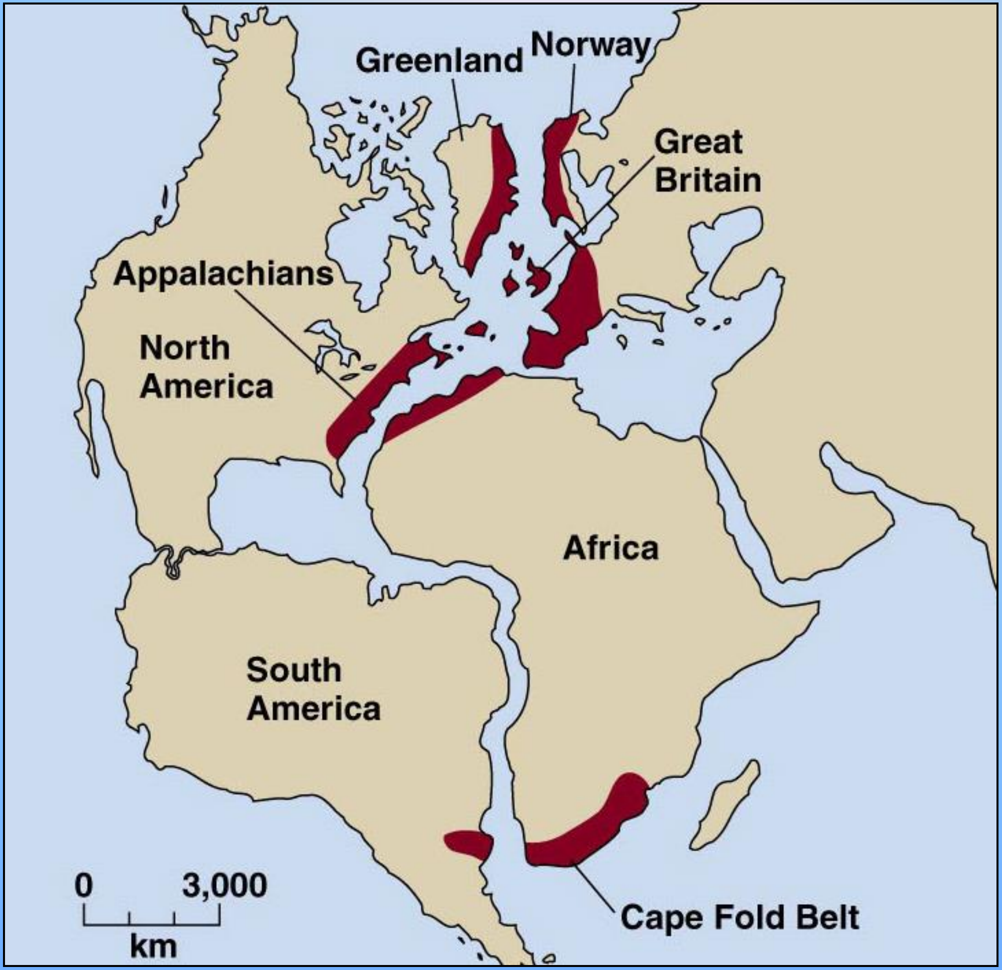
3. Matching Rock Types Between Continents



Continental Shelf (light blue)

Broad belts of rocks that Correlate in type and age

4. Matching Mountain Ranges



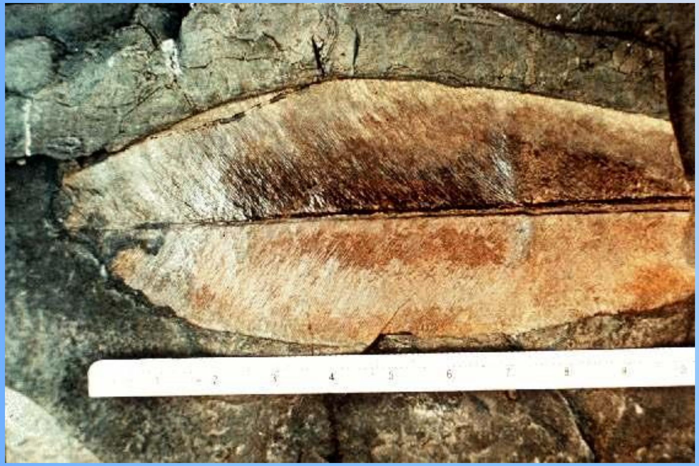
When continents are brought together, their mountain ranges form a single continuous range of the same age and style of deformation.

5. __Fossil__ Evidence

a. Almost identical late Paleozoic fossils in South America, Africa, India, Antarctica, and Australia.

b. Bones of land reptiles have been found in Antarctic rocks. Antarctica is now completely separate and isolated from other continents.

c. ***Glossopteris***



(1) A Late Paleozoic plant found in rocks on all five continents.

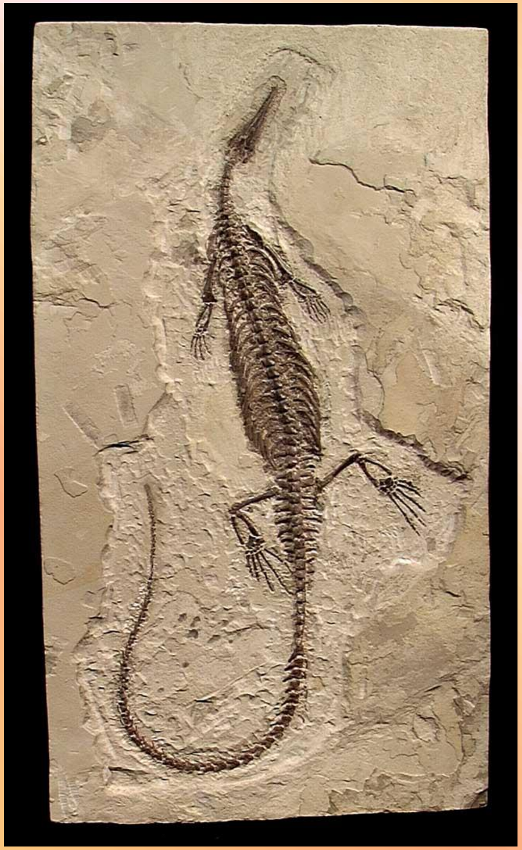
(2) When the land areas are joined, similarity can be seen.

d. Extinct Reptiles

- **Areas where found reveal narrow, sharply defined habitats extending across:**
  - **three continents and**
  - **the subcontinents of Madagascar and India.**

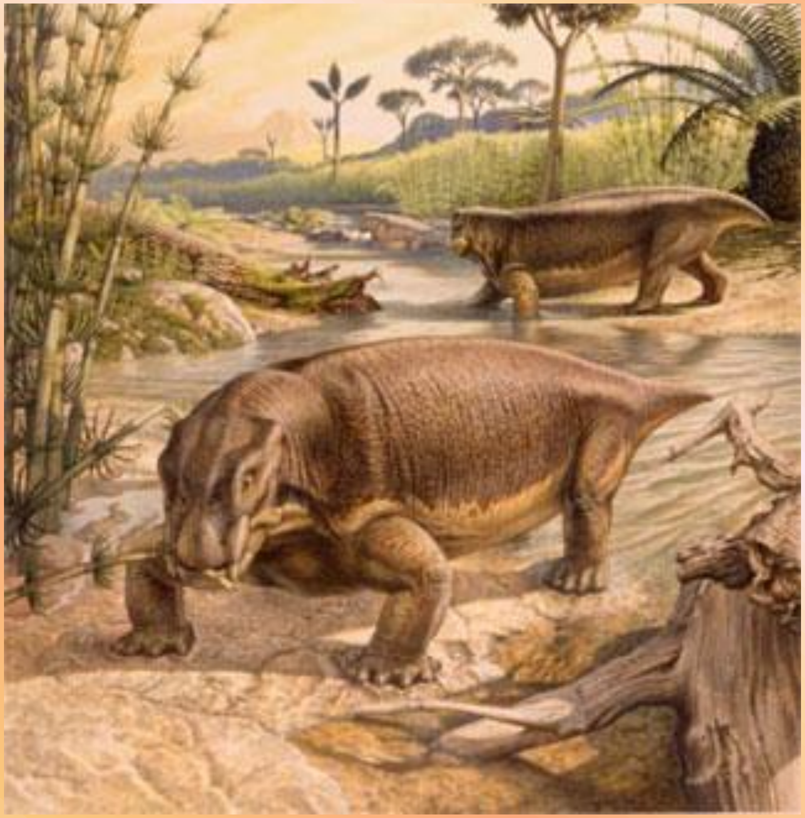
- **The shape of the animals ranges can best be explained by assuming that these lands were once united as one landmass.**

Mesosaurus



- A freshwater carnivorous reptile; 50 cm long
- Fossils found in Permian-aged rocks in Brazil and Africa

Lystrosaurus

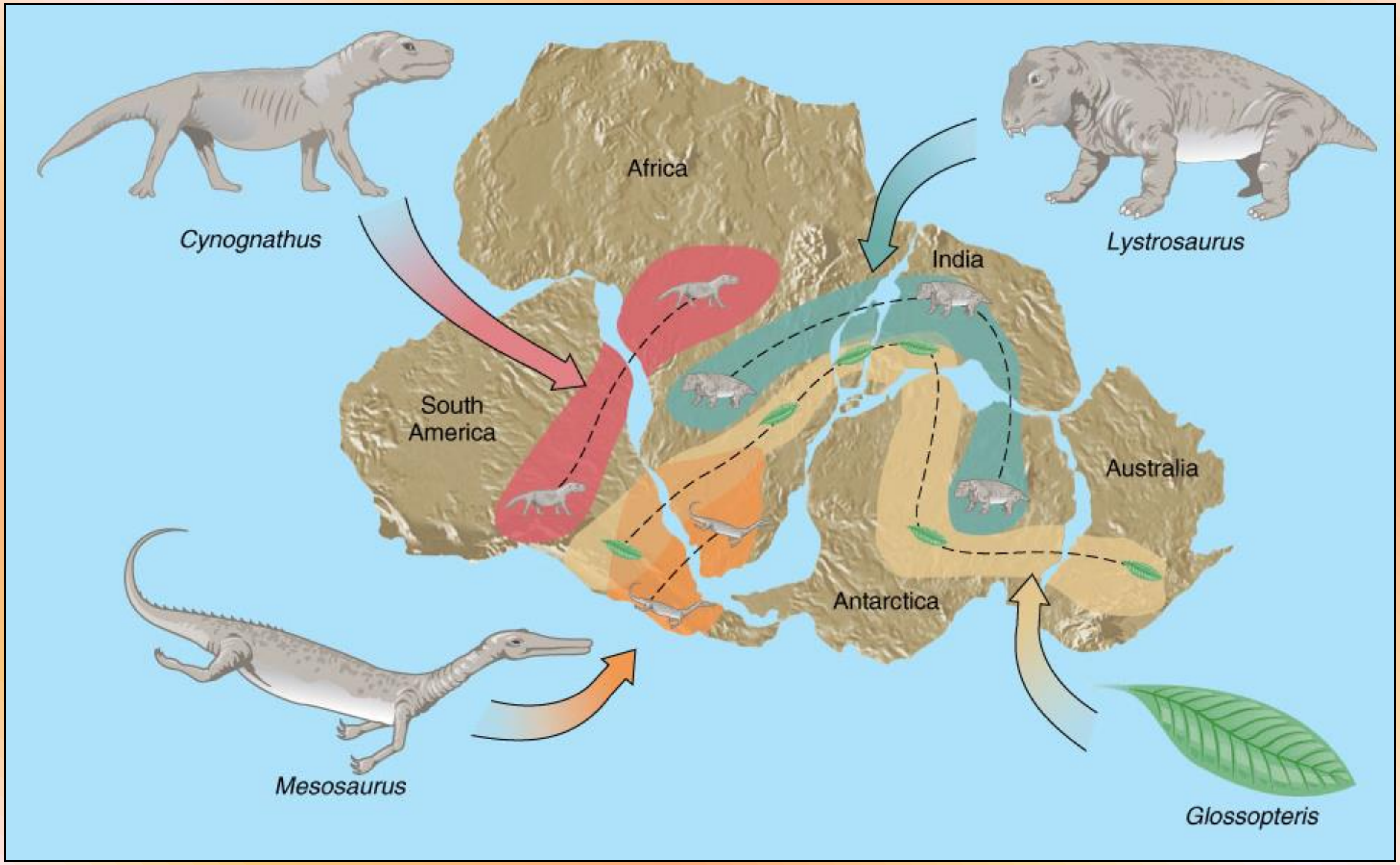


- Early Triassic terrestrial mammal-like reptile
- About 1 meter long with two long teeth protruding from the upper jaw
- Fossils found in Africa, India, and Antarctica

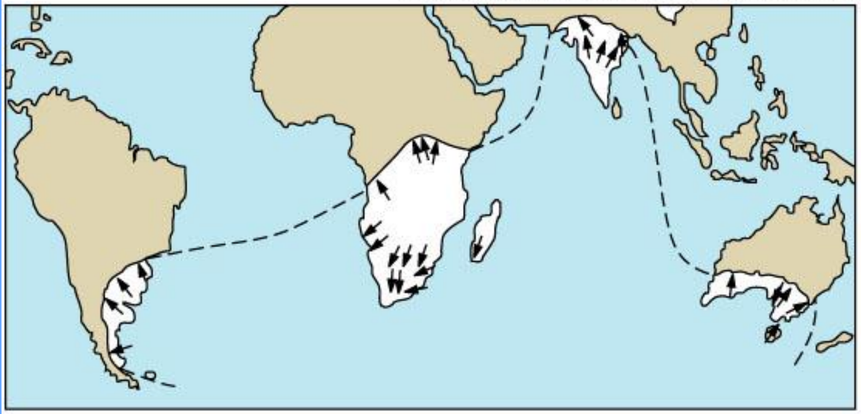
Cynogathus

- Early Triassic terrestrial mammal-like reptile
- About 1 meter in length
- Fossils found in Brazil and Africa

Fossil Evidence

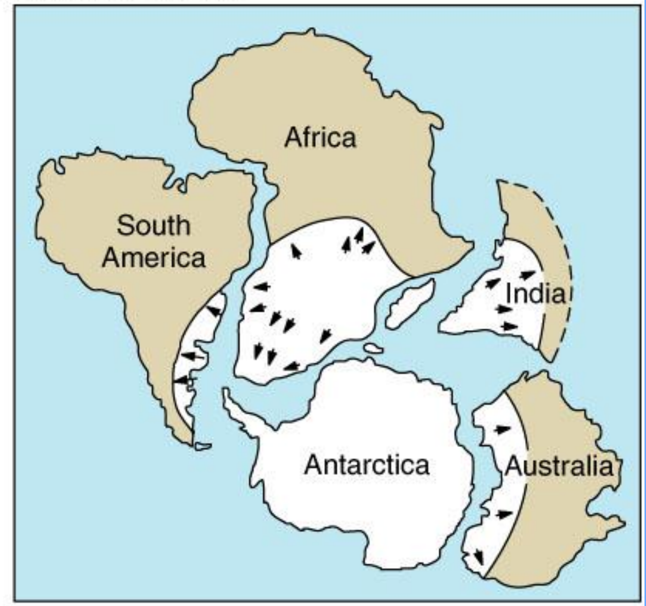


6. Late Paleozoic **Glaciation**



A

Glacial evidence shows the Origin of the glaciers in the Atlantic



B

Boulders in S. America traced to a source in Africa

- Distribution of Late Paleozoic continental glacial evidence on the Gondwanaland continents can only be explained by a supercontinent.

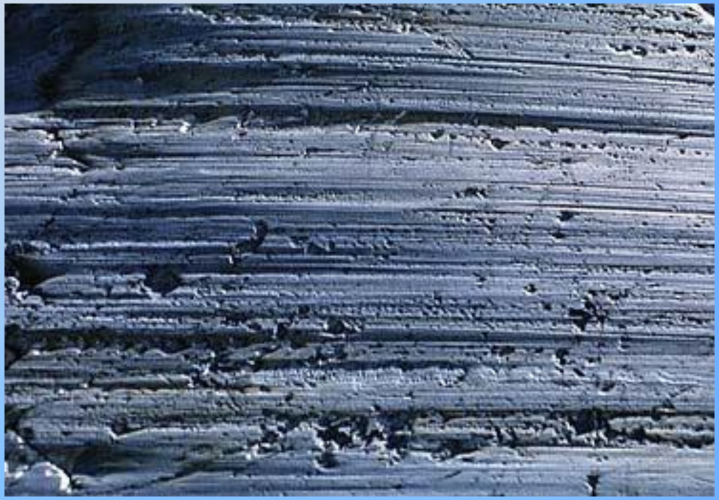
7. **Paleoclimates** (Ancient Climates)

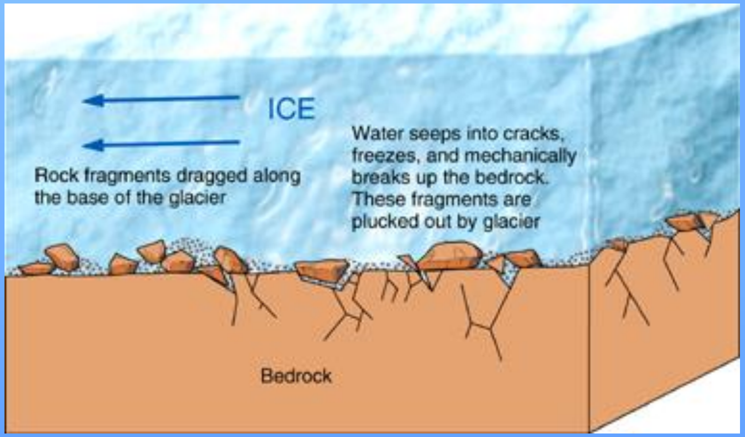
a. Inferring the Location of the Poles

- If it is assumed that ancient climates had the same geographic distribution as present-day climates,
- then the distribution of sedimentary rocks can be used to infer the locations of the ancient poles and the paleoequator.

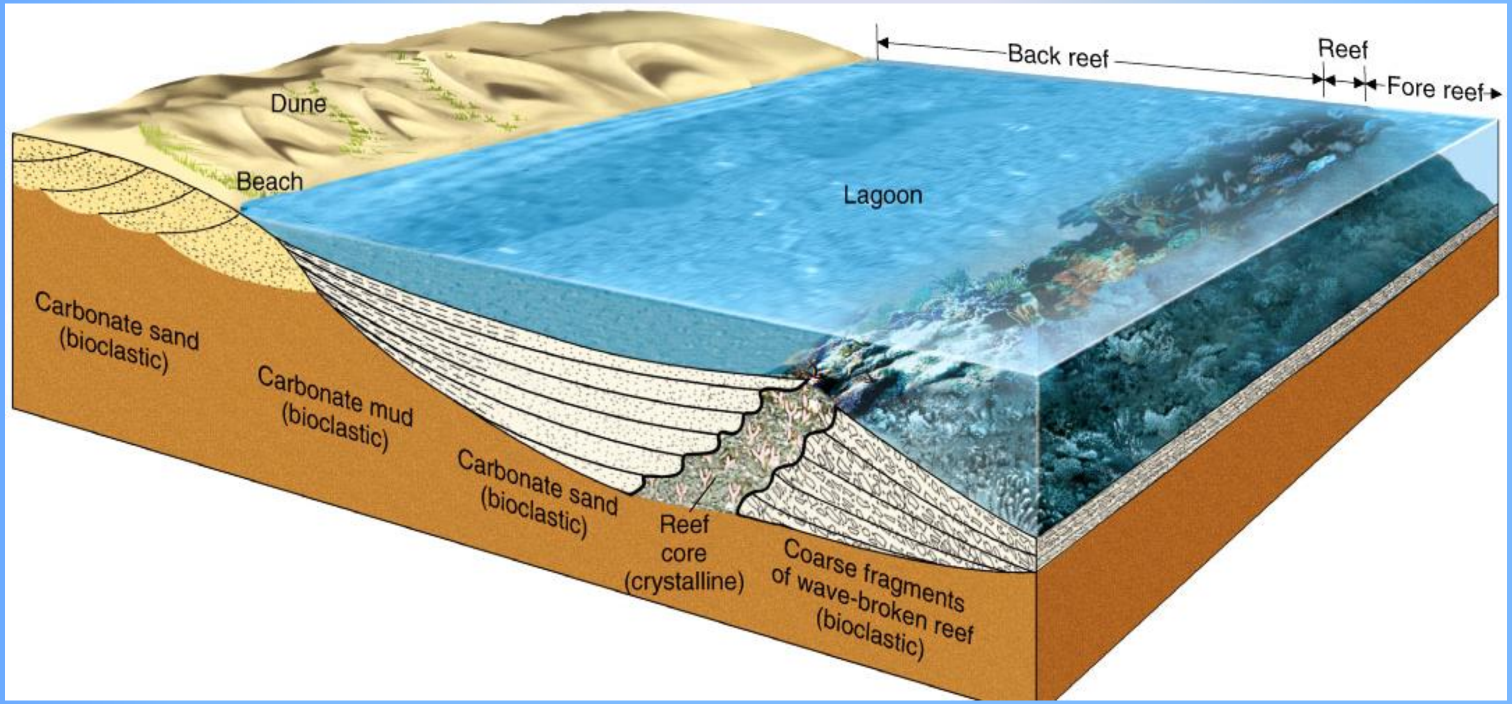
Glacial Evidence

(1) Glacial _**till**_ (soil) and _**striations**_ (scratches) on bedrock are found in cold polar climates.



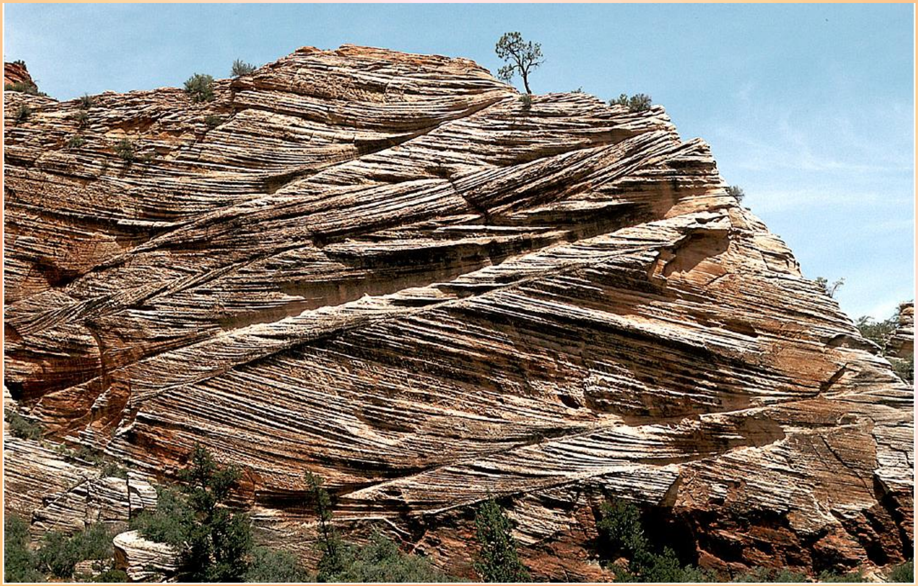


Coral Reefs



- Coral reefs are found in tropical regions (as far as 30^0 north or south of the equator)

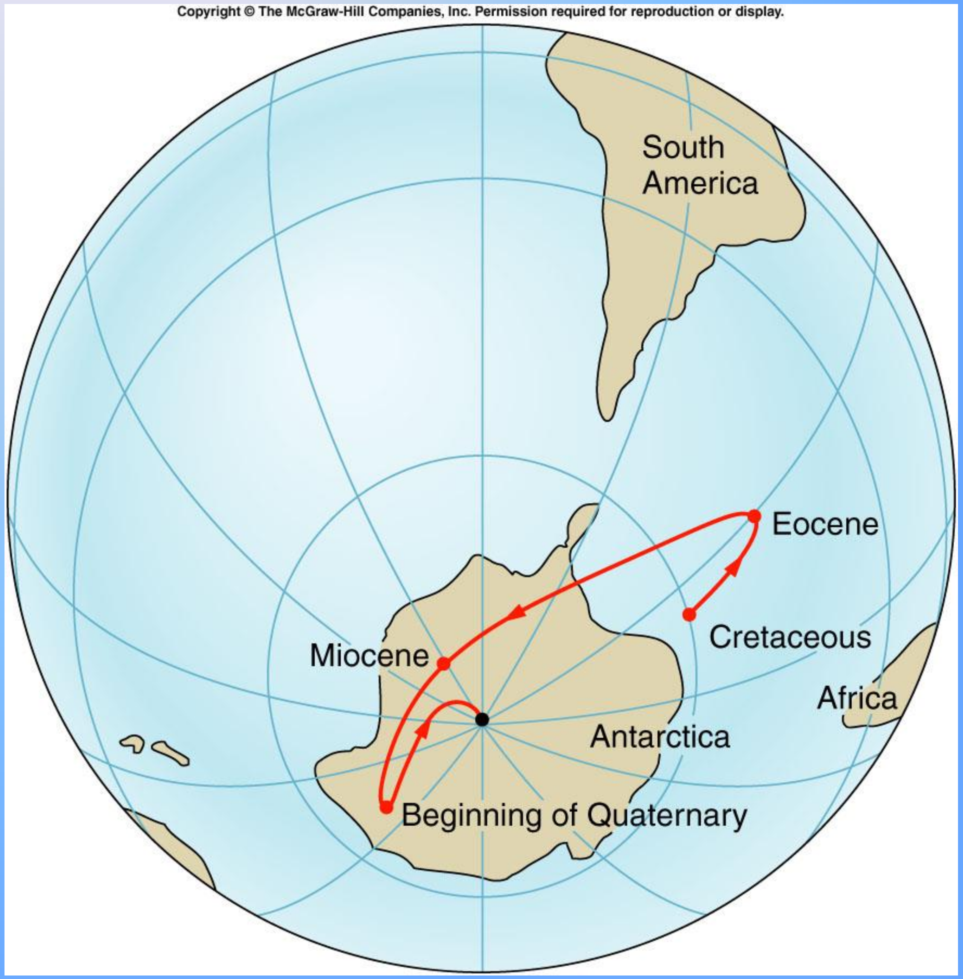
Cross-Bedded Sandstones



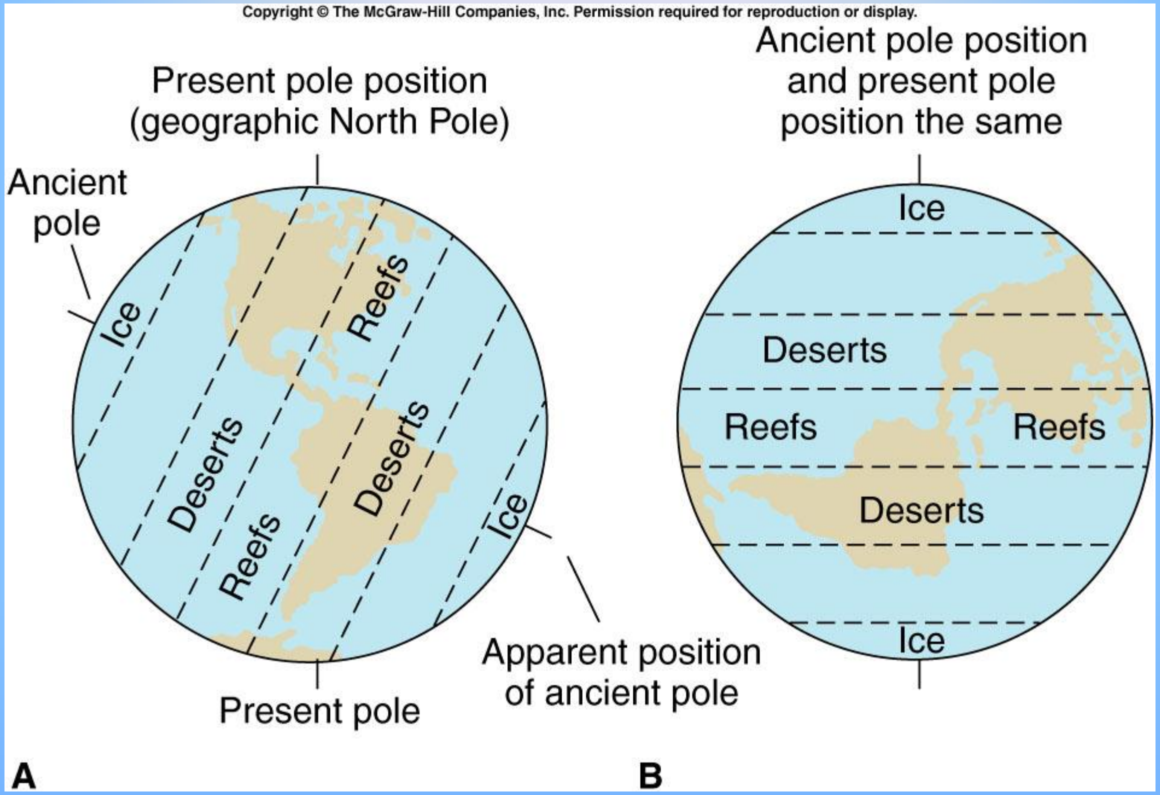
- Indicate the locations of ancient deserts
- Latitudes of 30^{o}

(2) **Polar Wandering**

- Wegener inferred that the ancient poles were in different positions that the present-day poles.
- This apparent change in positions of the poles is termed *polar wandering*.



Explaining Polar Wandering

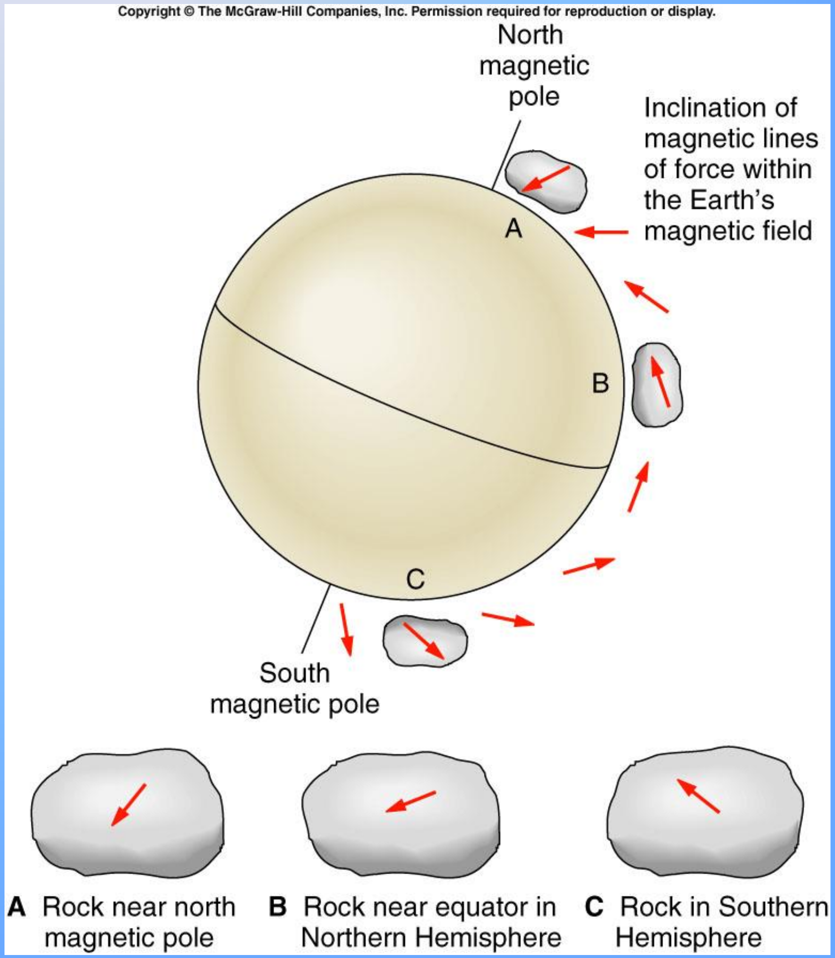


(A) Continents remain stationary and the poles actual change position

(B) Poles remain stationary and the continents change position

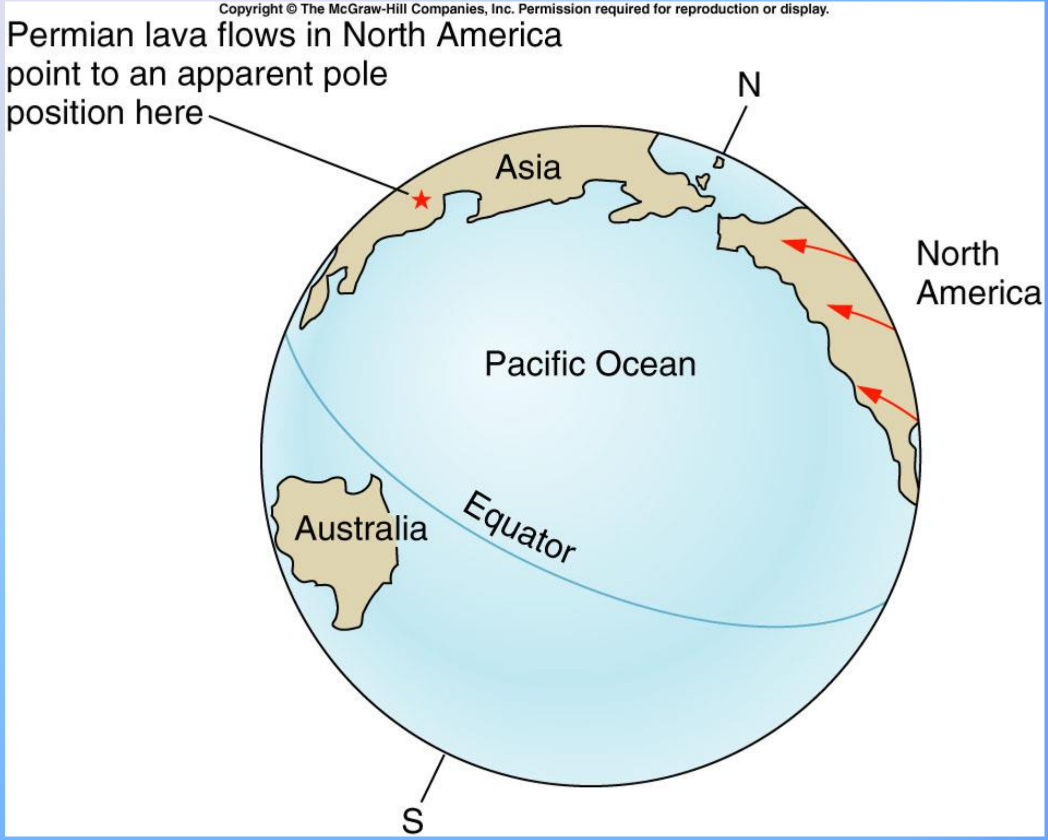
Paleomagnetic Evidence for Continental Drift

- Magnetic dip of magnetite crystals increases towards the North magnetic pole.
- Aligned with magnetic lines of force



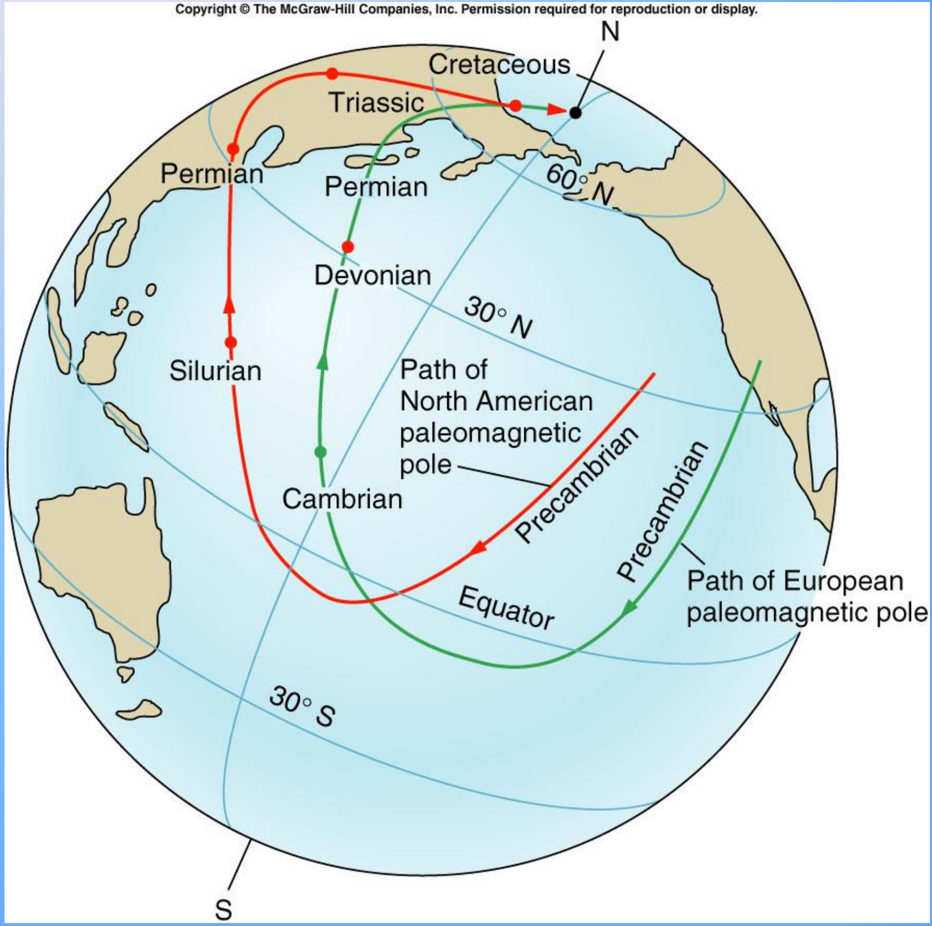
The Permian North Pole

- Permian rocks in N. America point to a pole position in eastern Asia
- Rocks in Europe point to a different position
  - Every continent shows a different Permian pole position

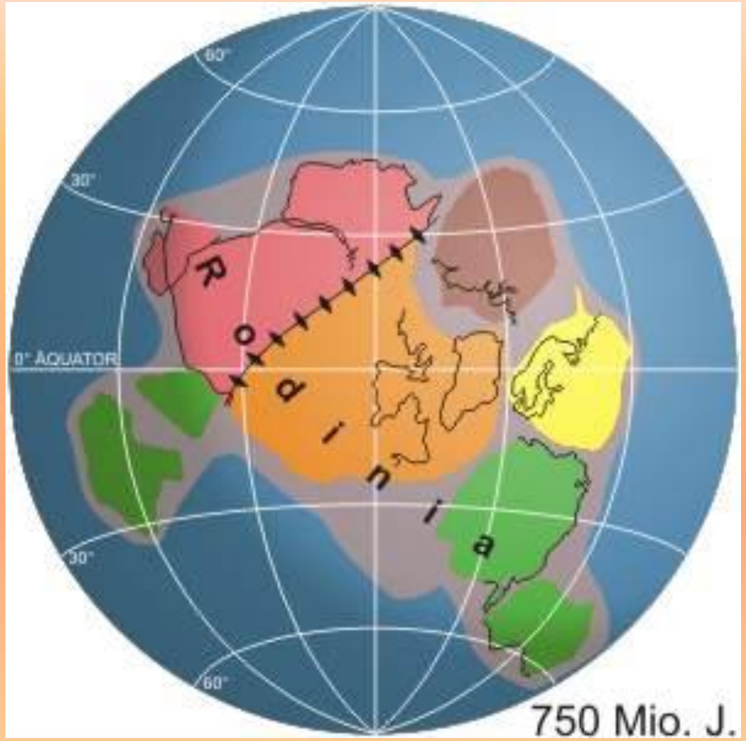


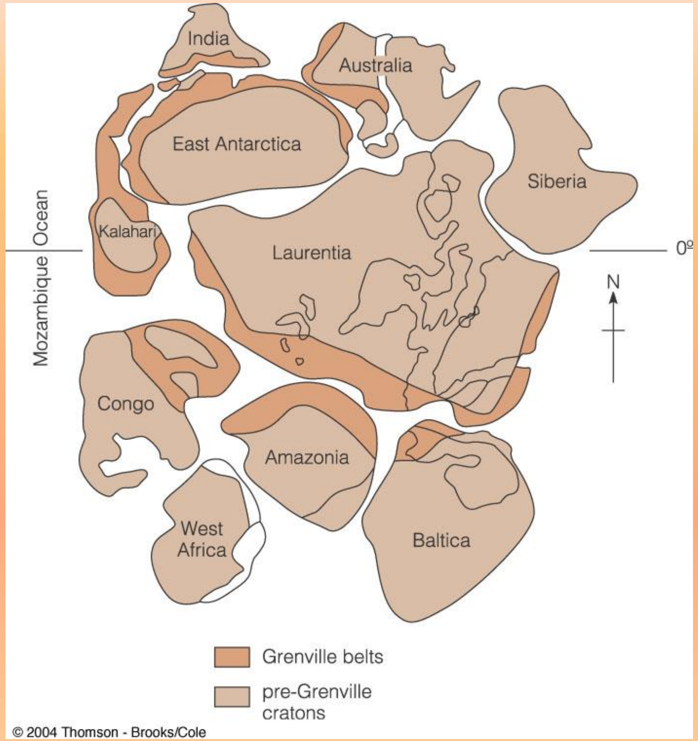
Polar Wandering

- Paths of polar wandering have similar shapes
- If North America is theoretically pushed back towards Europe, its polar wandering path lies exactly on the path for Europe
- Suggests
  - one north magnetic pole
  - The continents were joined.



Rodinia – The Late Proterozoic Supercontinent





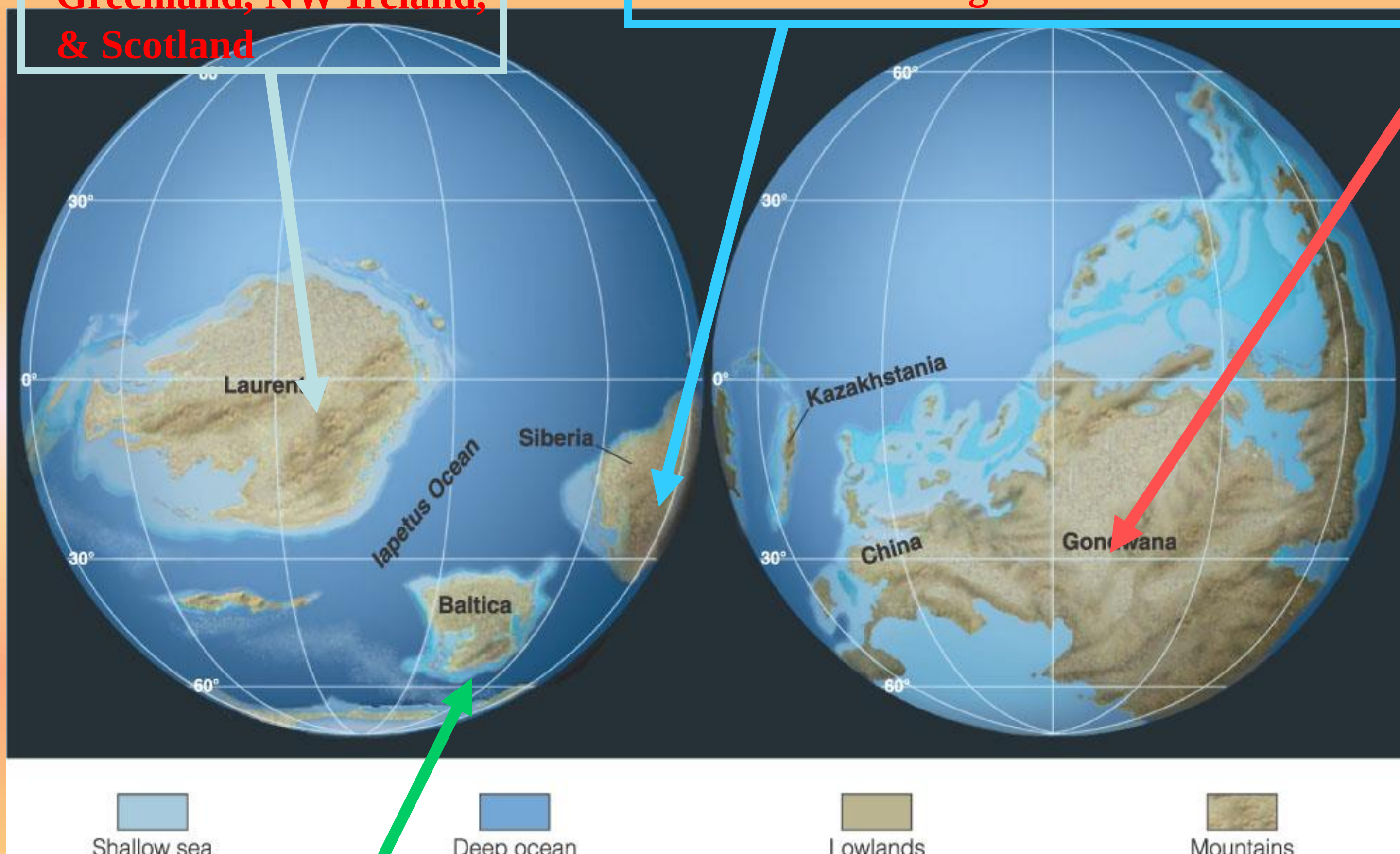
- **Assembled between 1.3 and 1.0 billion years ago**
- **Began fragmenting 750 million years ago**
- **Pieces formed another supercontinent, *Pannotia*, about 650 million years ago**

Late Cambrian Paleogeography

Most of N. America, Greenland, NW Ireland, & Scotland

Russia east of Ural Mts. Asia north of Kazkhsstan And south of Mongolia

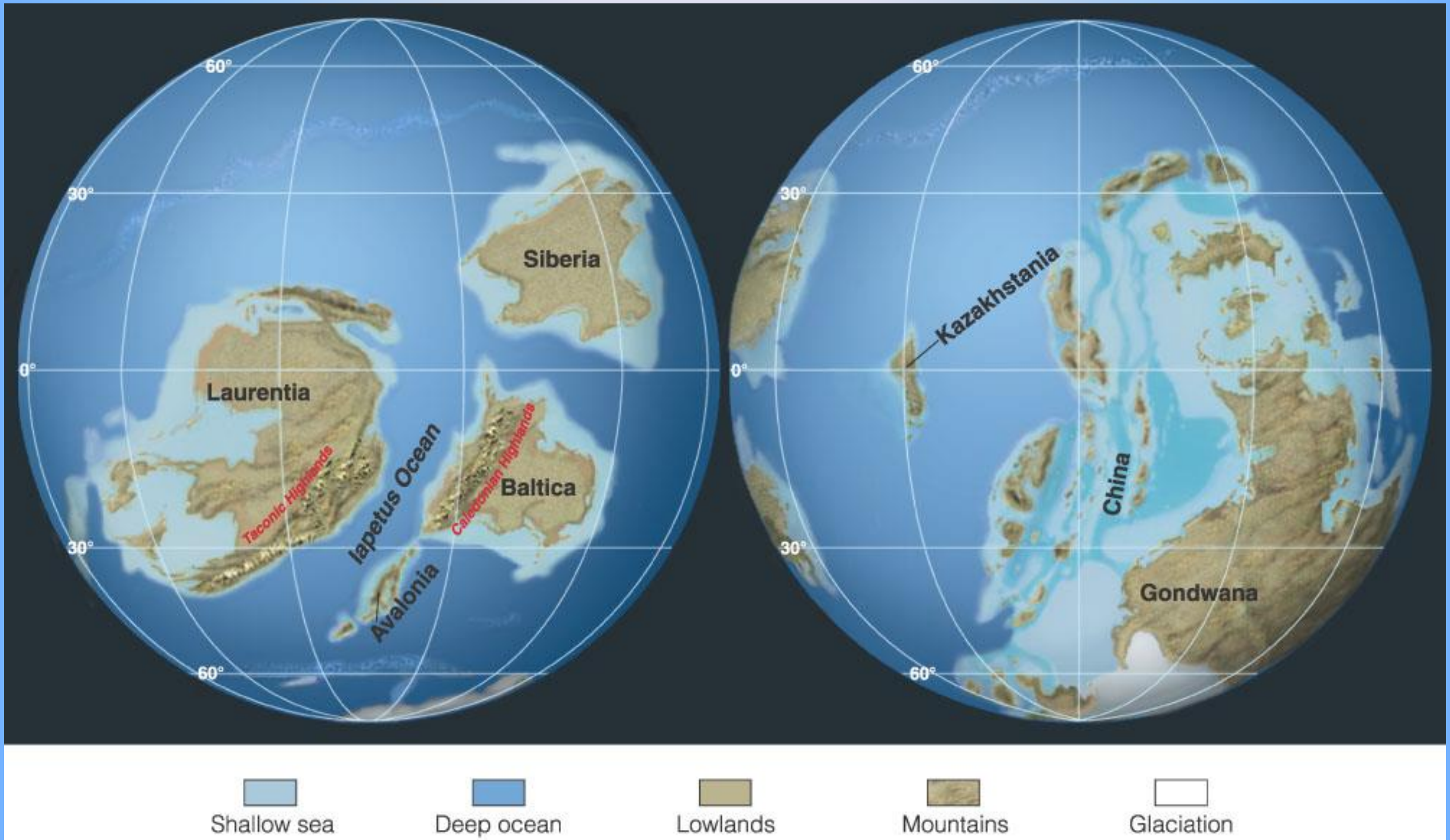
Africa, Antarctica, Australia, Florida, India, Madagascar, and parts of Middle East & southern Europe



(a) Late Cambrian Period

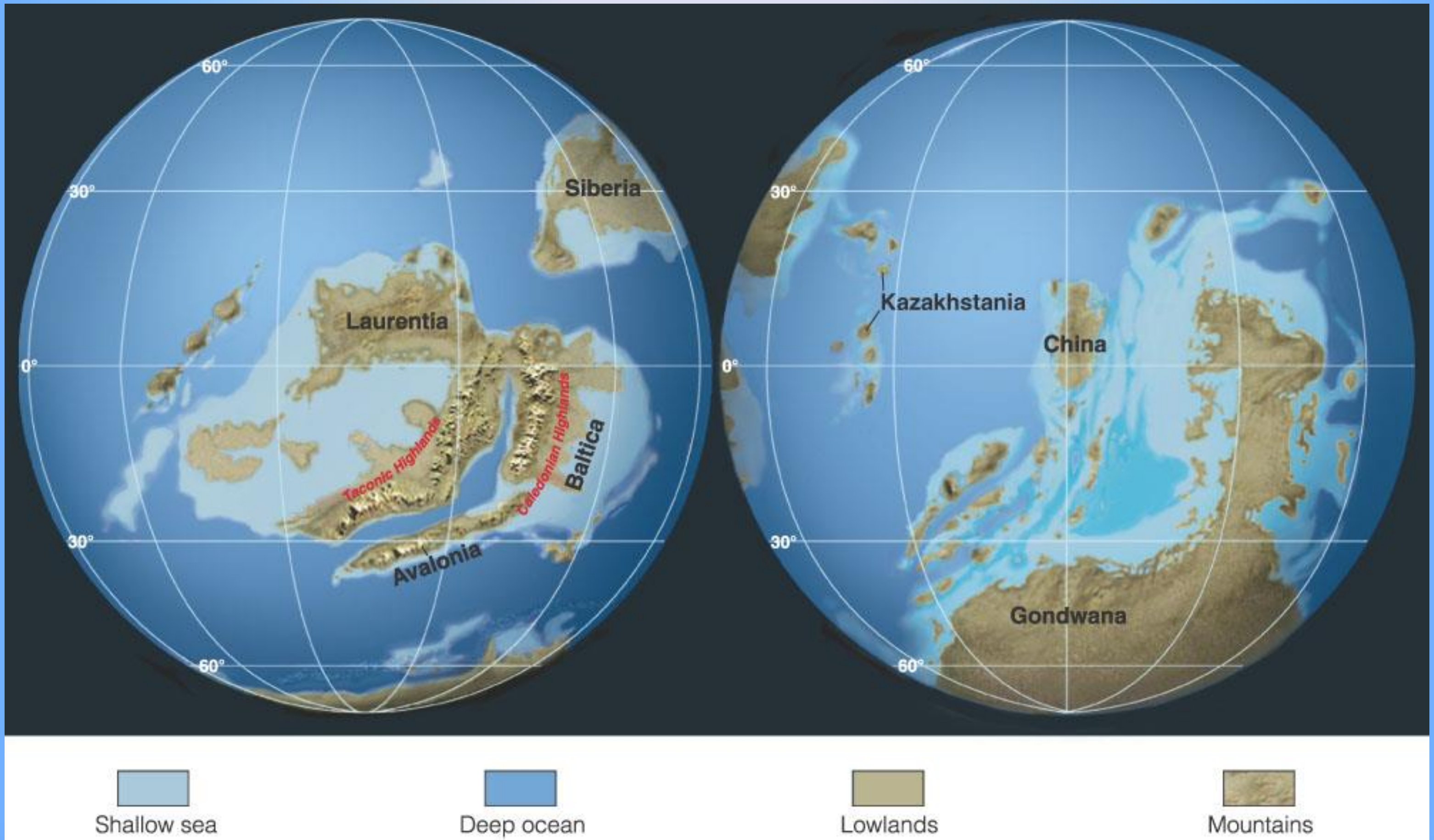
Russia west of Ural Mts., major part of N. Europe

Late Ordovician Paleogeography



(b) Late Ordovician Period

Middle Silurian Paleogeography

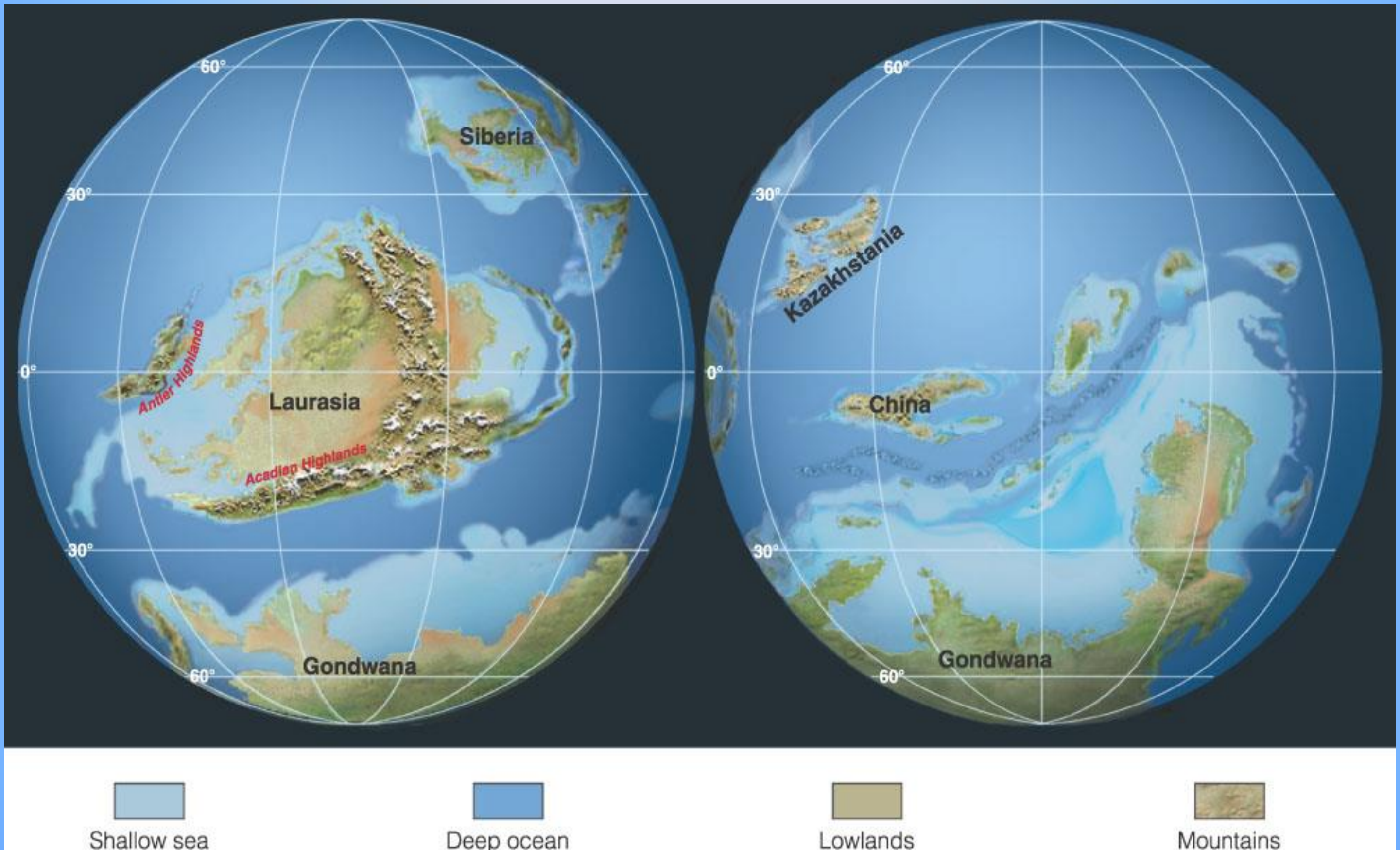


(c) Middle Silurian Period

Early Paleozoic Era Continental Drift Summary(Cambrian – Silurian)

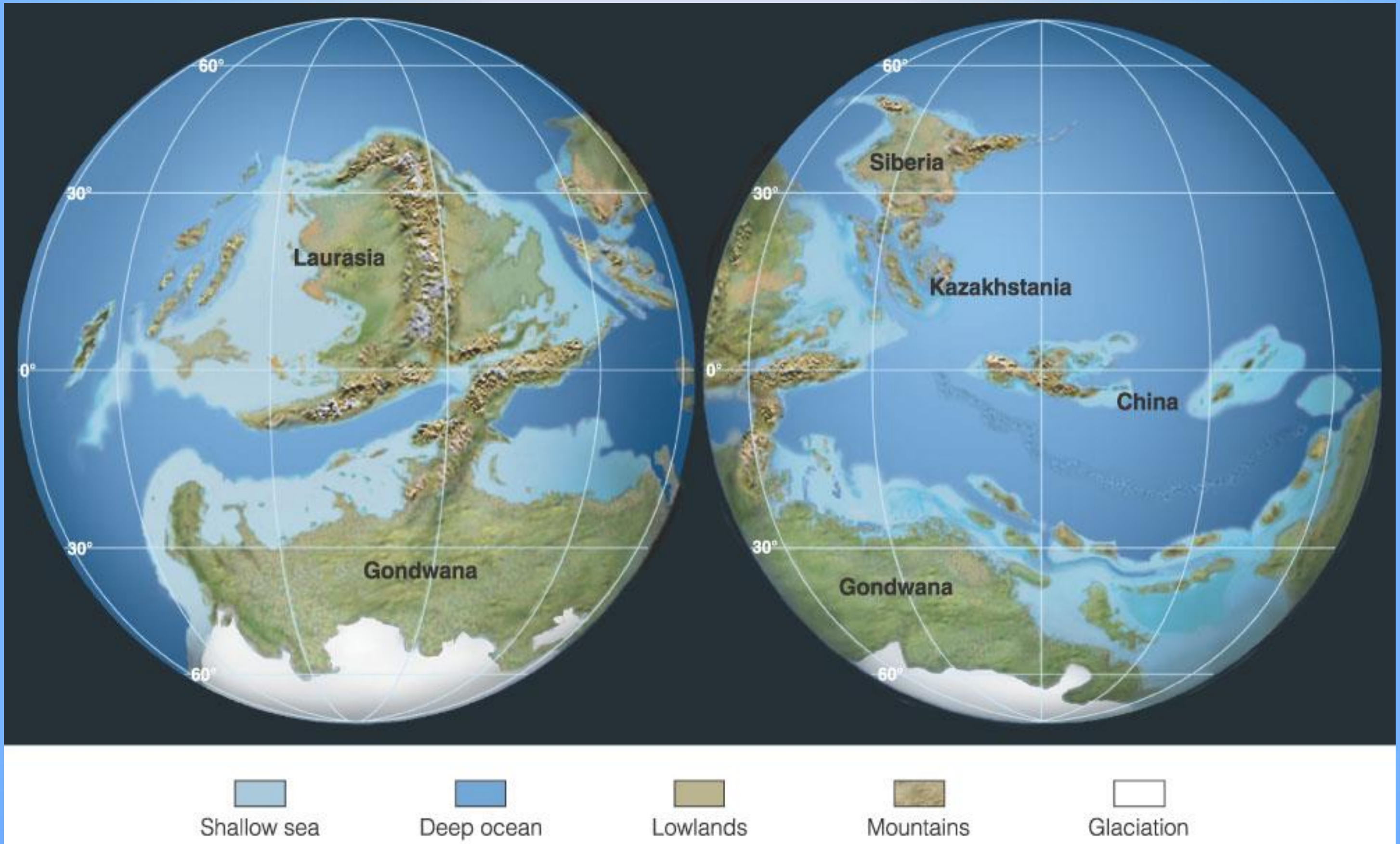
- Six major continents
  - Four were located near the paleoequator
- Laurentia moved northward
- Gondwana moved to a south polar location

Late Devonian Period Paleogeography



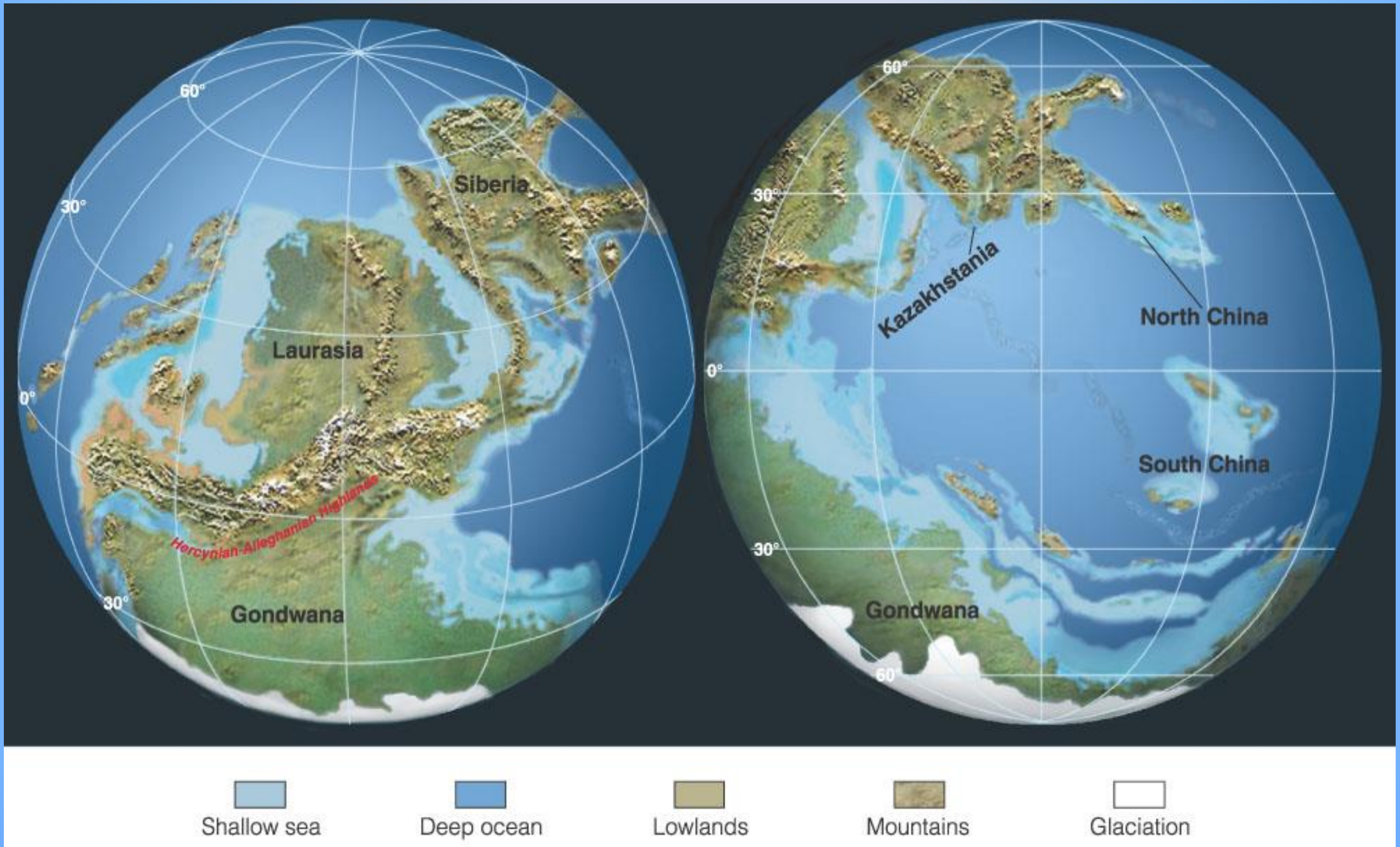
(a) Late Devonian Period

Early Carboniferous Period Paleogeography



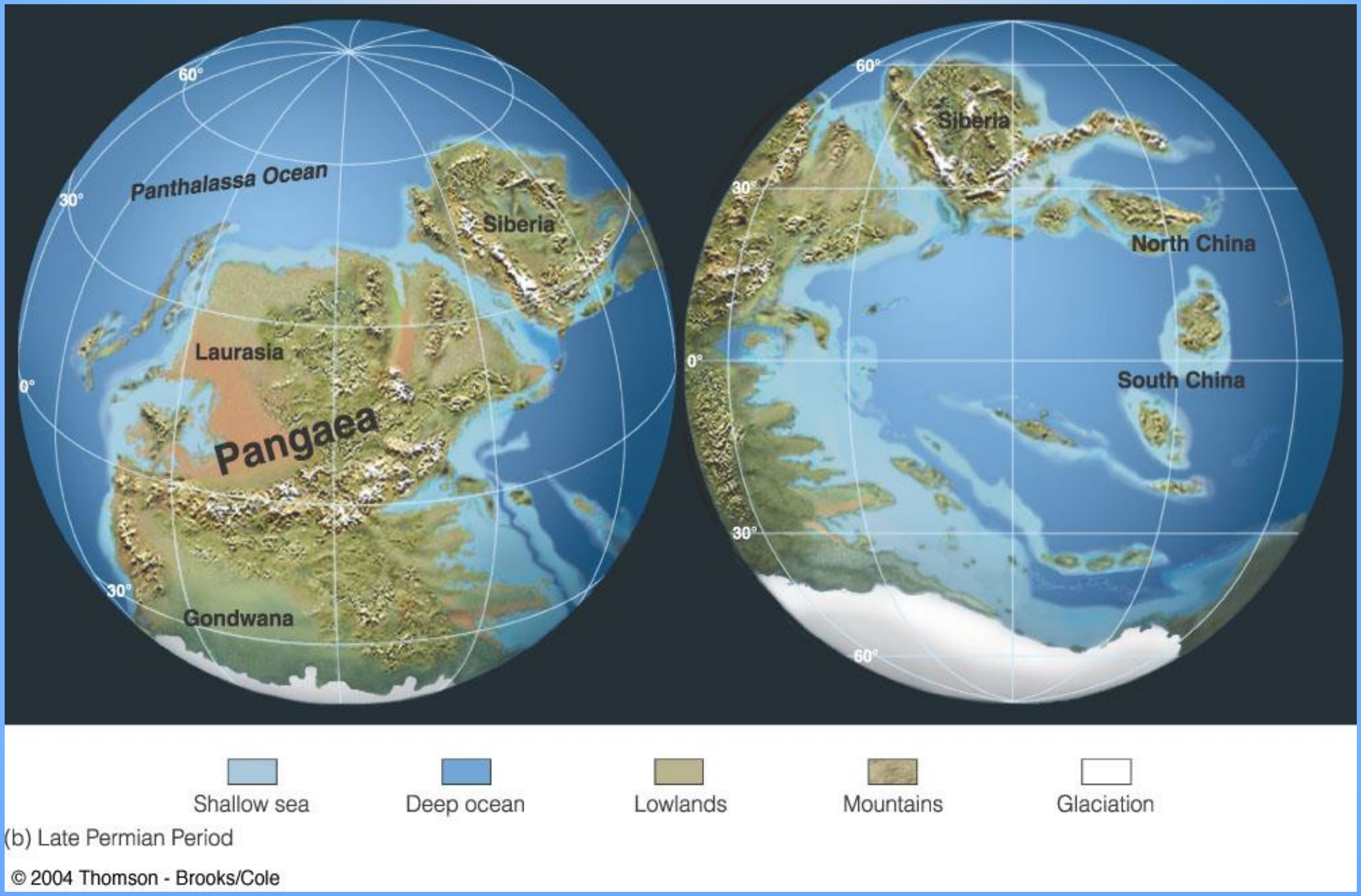
(b) Early Carboniferous Period

Late Carboniferous Period Paleogeography



(a) Late Carboniferous Period

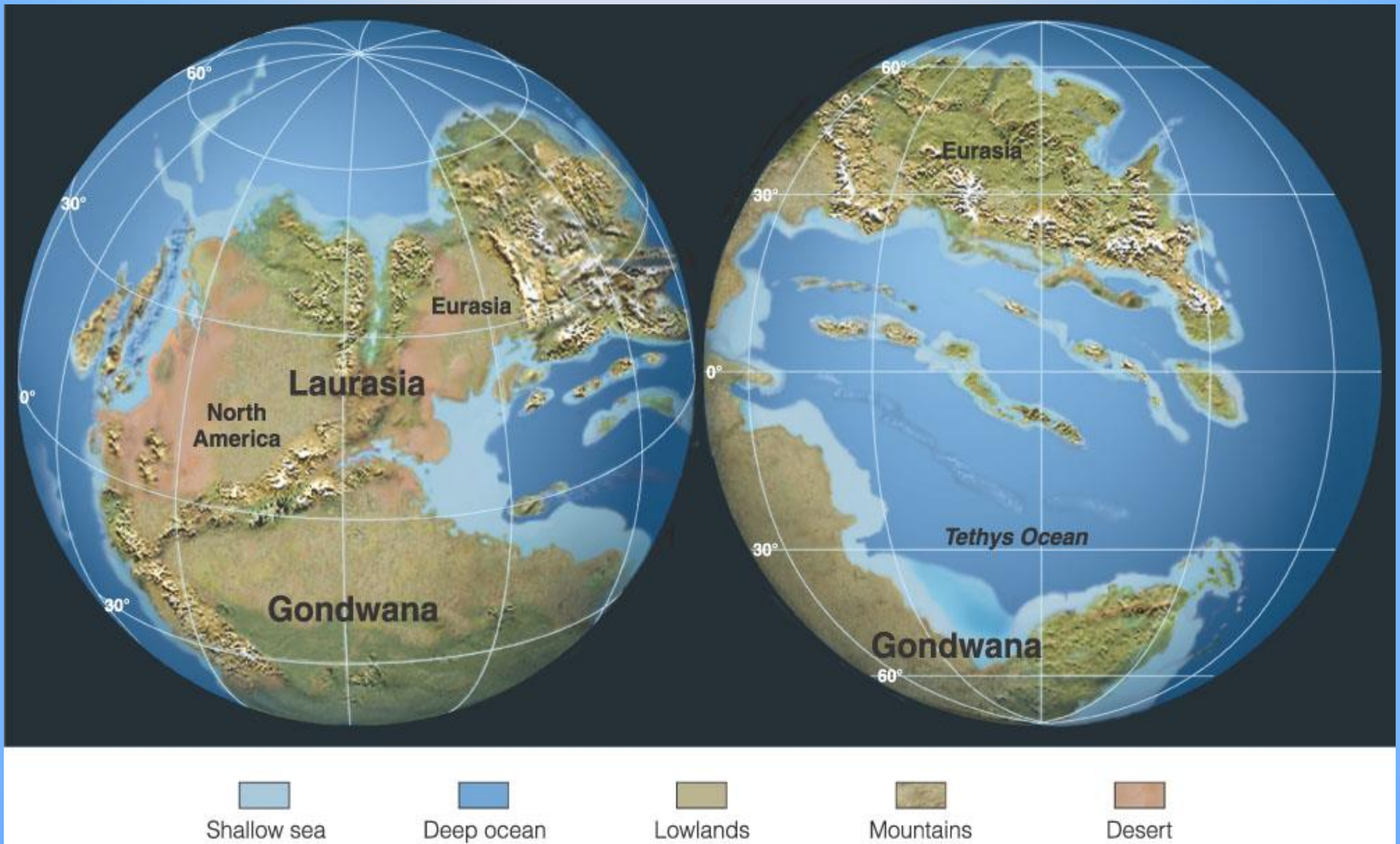
Late Permian Period Paleogeography



Late Paleozoic Continental Drift Summary (Cambrian – Silurian)

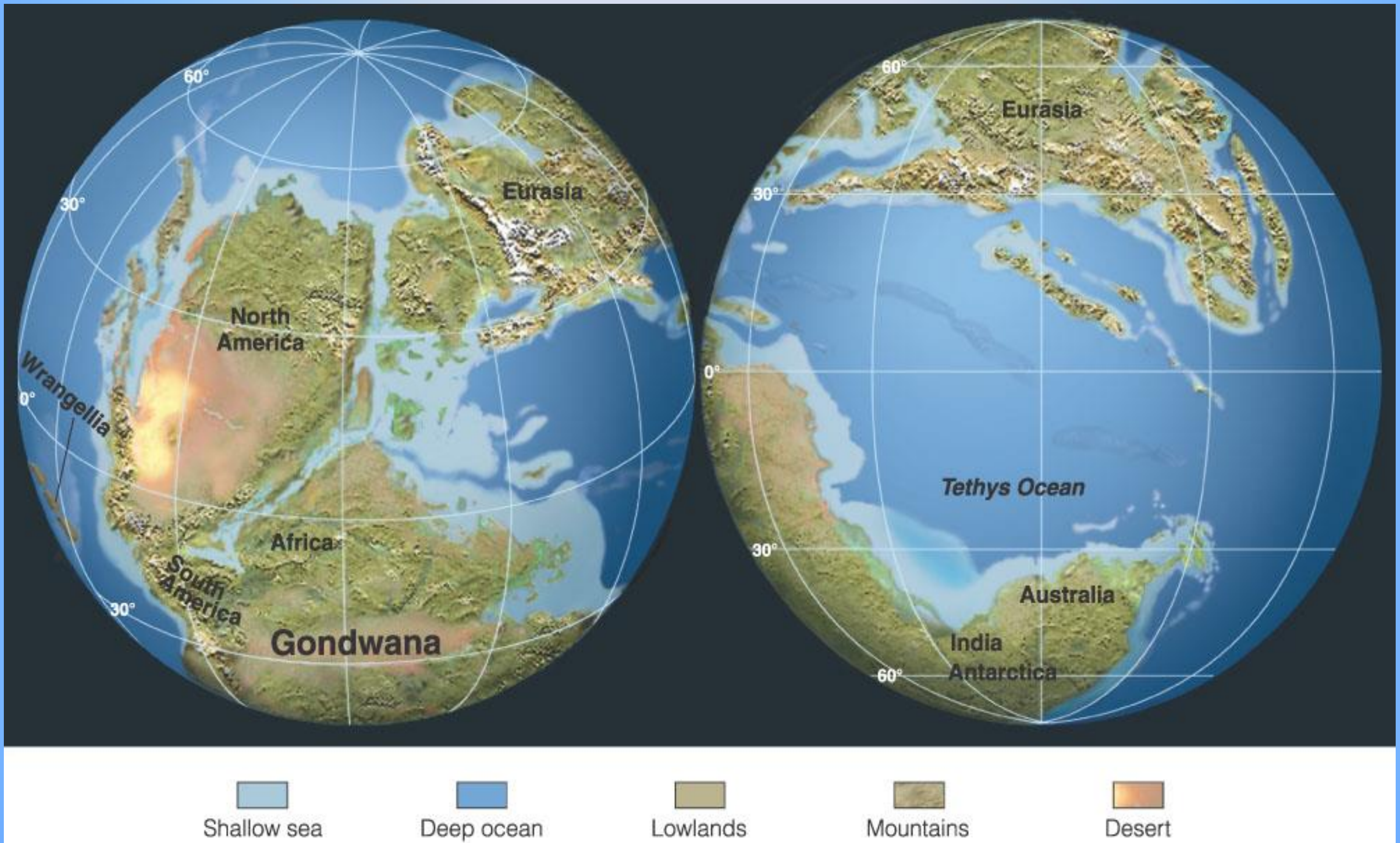
- Baltica and Laurentia collided, forming Laurasia
- Siberia and Kazakhastania . . .
  - Collided
  - Became sutured to Laurasia
- Gondwana moved over the South Pole
- During the Permian . . .
  - the formation of **Pangaea** was completed
  - **Panthalassa**, a global ocean, surrounded the supercontinent

Mesozoic Era Paleogeography
The Triassic Period



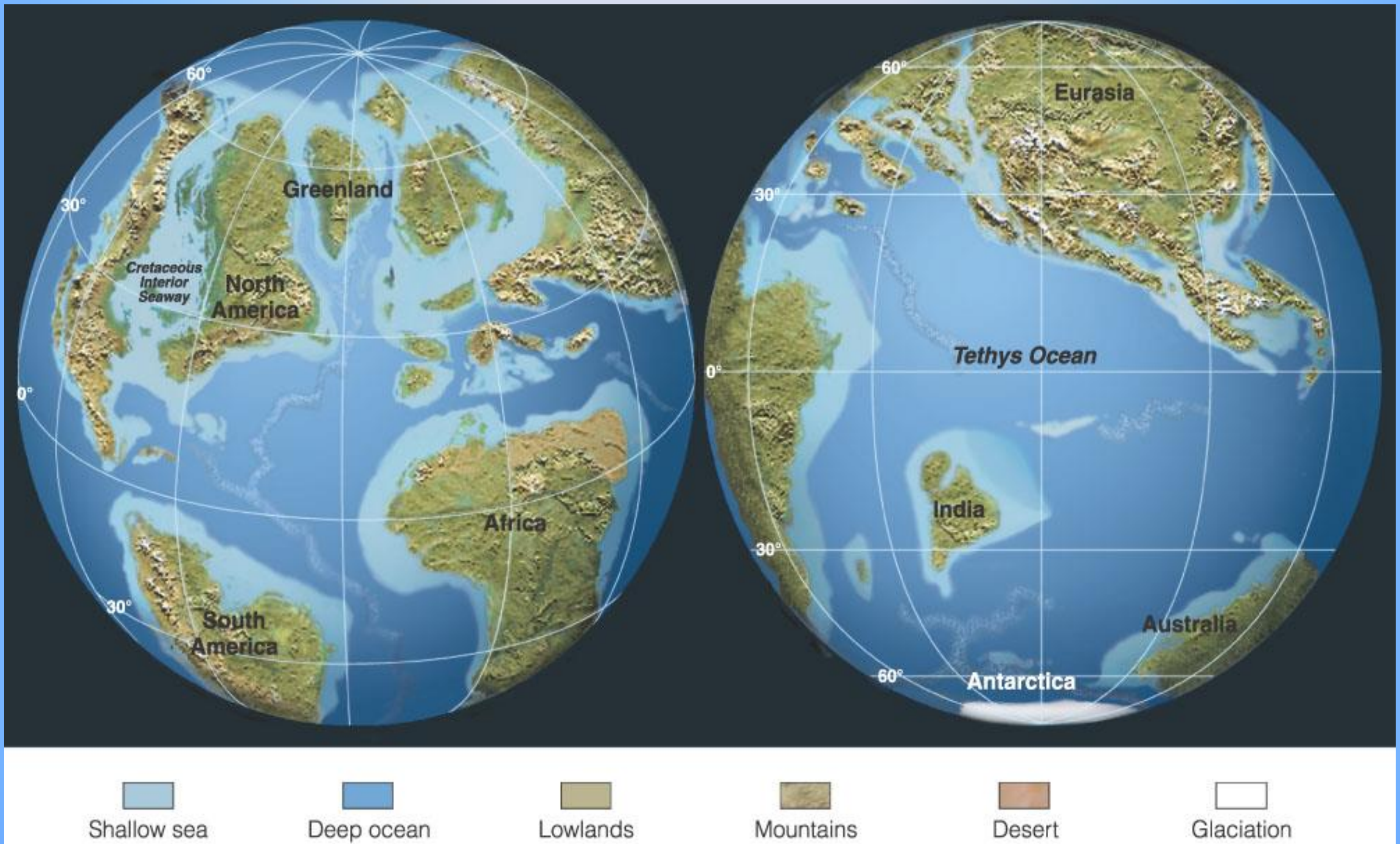
(a) Triassic Period

Mesozoic Era Paleogeography
The Jurassic Period



(b) Jurassic Period

Mesozoic Era Paleogeography
The Cretaceous Period



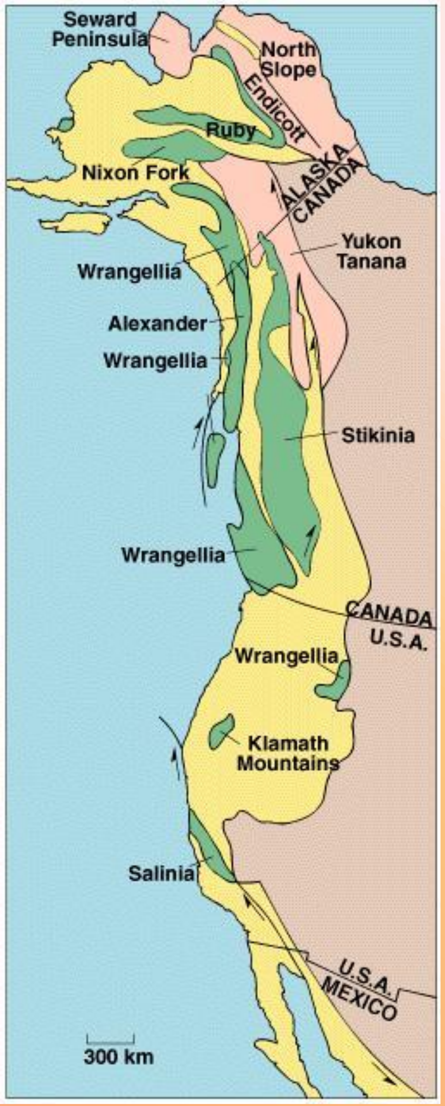
(c) Late Cretaceous Period

Allochthonous Terranes in Western North America

- Microcontinents incorporated into the crumpled margin of a larger continent.
- Called:
  - *Allochthonous terranes*
  - *Suspect terranes*
  - *Alien terranes*

Green terranes are probably from continents other than N. America

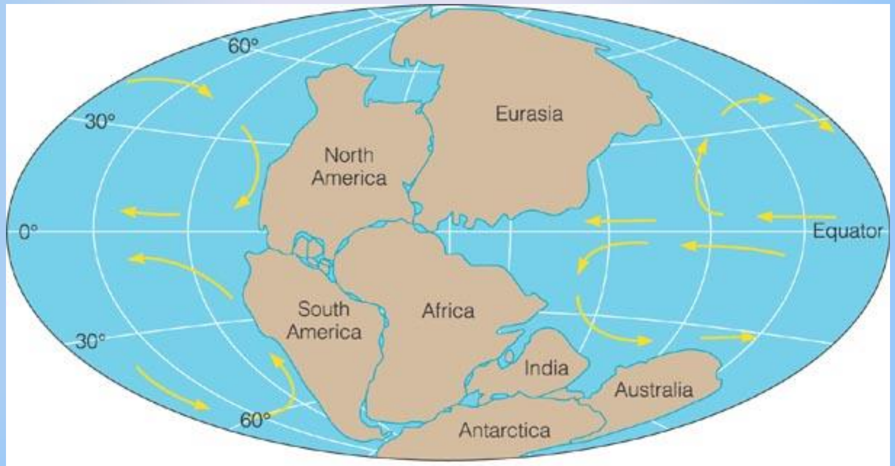
Pink terranes are probably from displaced parts of North America



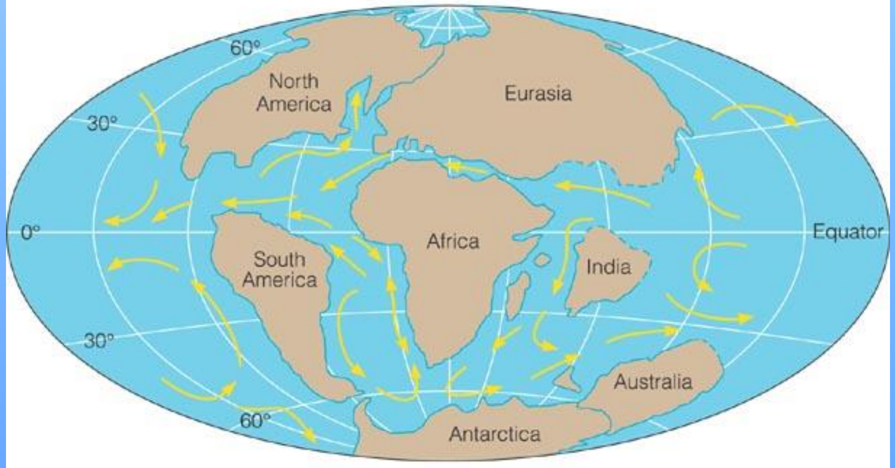
Early Mesozoic Evaporites

- Rifting of Pangaea opened the Proto-Atlantic Ocean
- Evaporites accumulated in shallow basins

Change in Oceanic Circulation



(a) Triassic Period

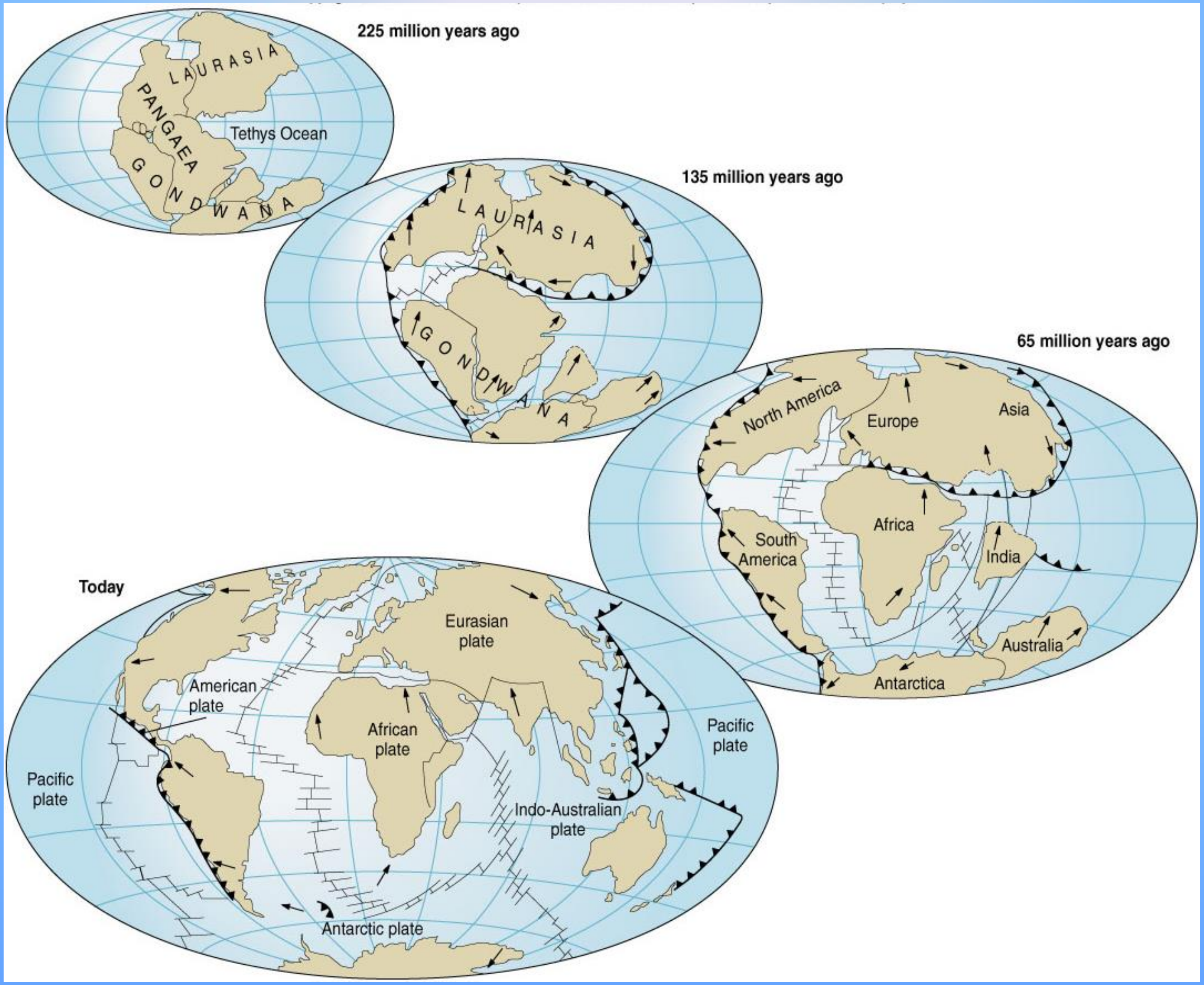


(b) Cretaceous Period

Mesozoic Era Continental Drift Summary

- The main event was the breakup of Pangaea.
- The breakup of Pangaea influenced global climatic and atmospheric circulation patterns

Pangaea Breakup and Continental Drift



“Pangaea Ultima”