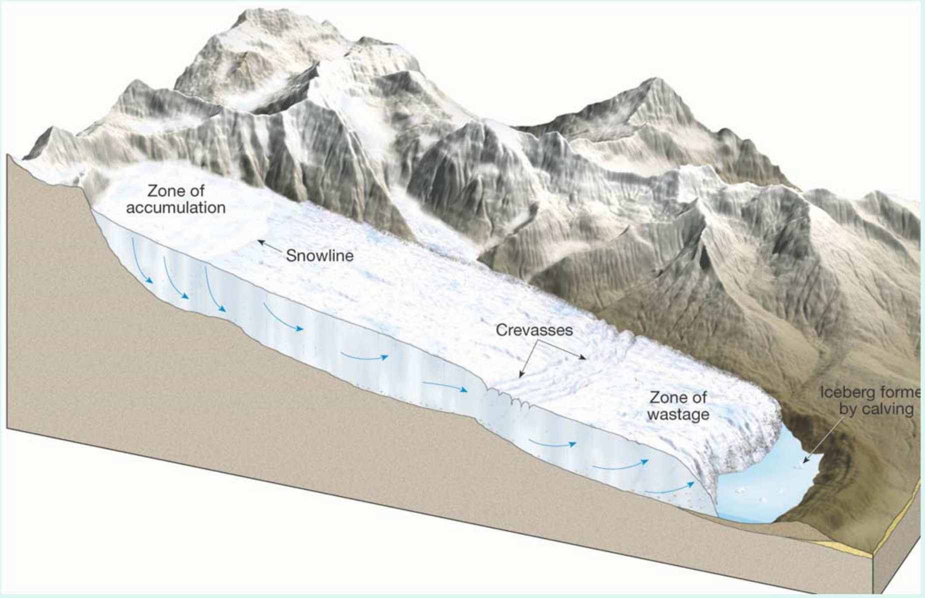
Chapter 5
Plate Tectonics: A Scientific Theory Unfolds

Match the following words with their definition and/or description:

1. J — Seafloor Spreading
2. A — Divergent Boundary
3. I — Plate
4. G — Hot Spot
5. H — Lithosphere
6. E — Transform Fault Boundary
7. B — Plate Tectonics
8. C — Convergent Plate Boundary
9. K — Asthenosphere
10. D — Subduction Zone

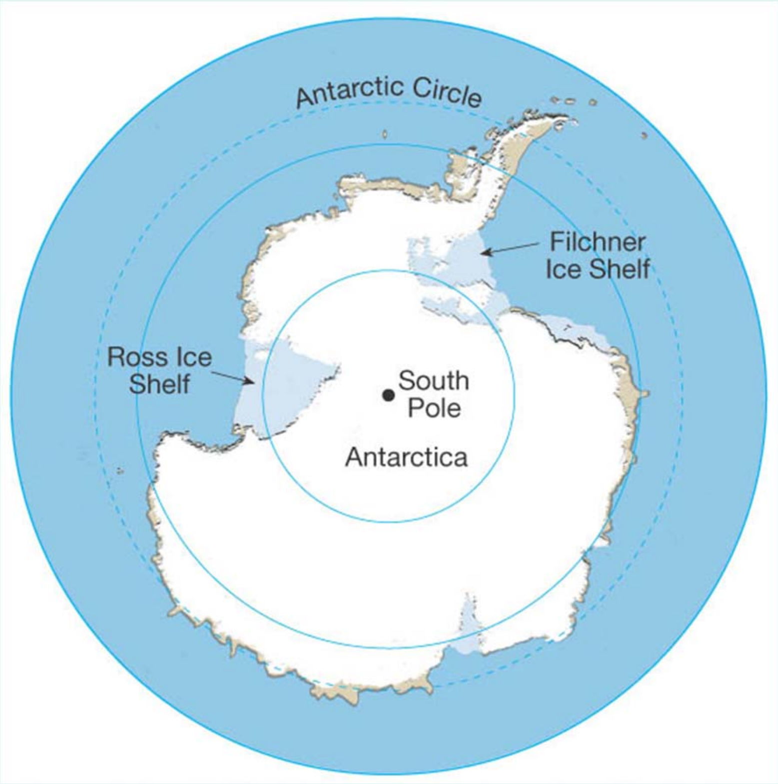
Glaciers

Glacier **—A thick mass of ice that originates on land from the accumulation, compaction, and recrystallization of snow**



Glaciers

- **Types of glaciers**
  - **Ice sheets**
    - **Often called continental ice sheets**
    - **Ice flows out in all directions from one or more snow accumulation centers**



How Glaciers Move

Movement is referred to as flow

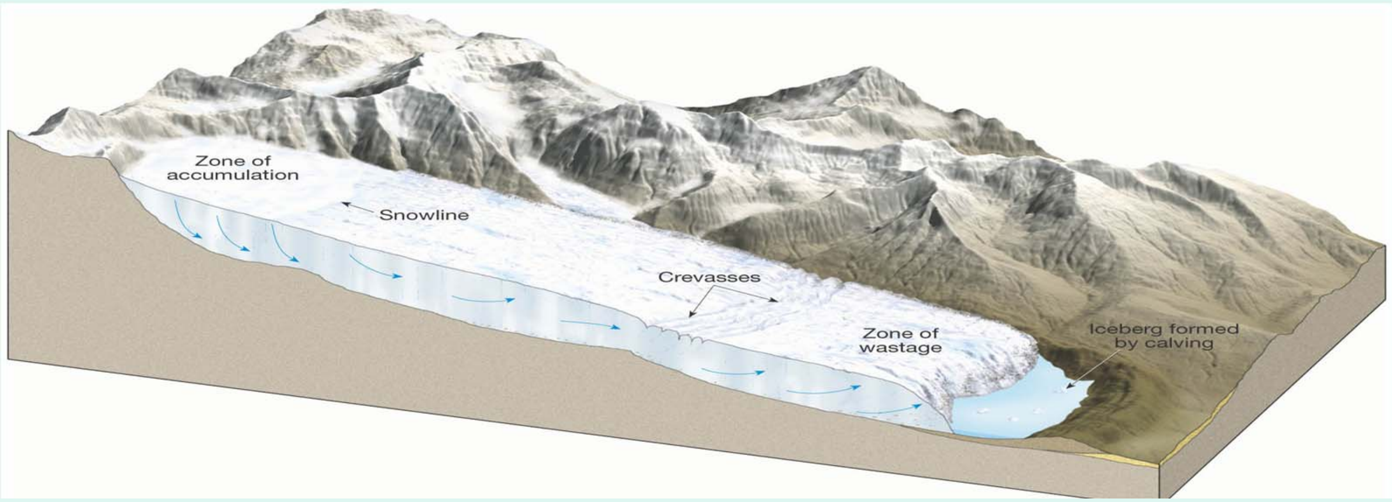
Zone of fracture

Occurs in the uppermost 50 meters

Tension causes *crevasses* to form in brittle ice

Rates of glacial movement

Average velocities vary considerably from one glacier to another

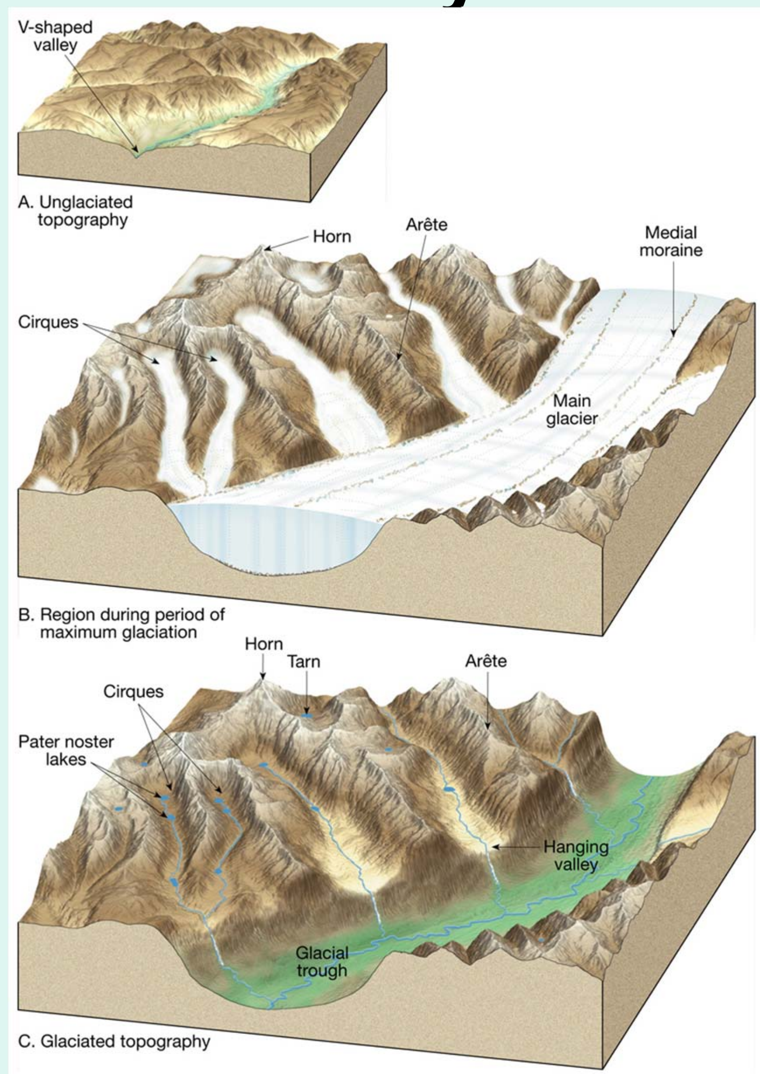


Glacial Erosion

Landforms created by glacial erosion

Erosional features of glaciated valleys

- *U- Shaped Valleys*
- *Hanging valleys*
- *Cirques*
- *Tarns*
- *Fiords*
- *Arêtes*
- *Horns*

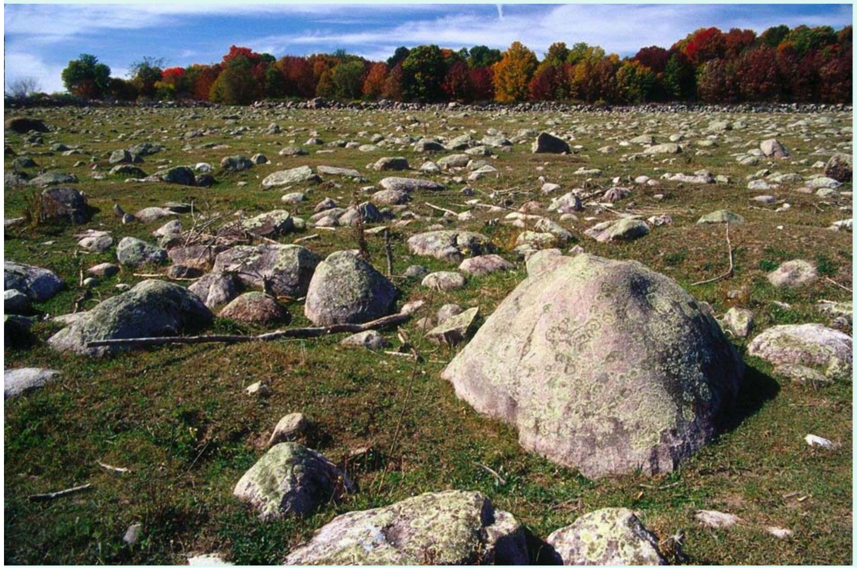


Glaciated Topography

U – Shaped valleys

Glacial Deposits

- **Glacial drift—Refers to all sediments of glacial origin**
  - **Types of glacial drift**
    - ***Till* —Material that is deposited directly by the ice**
    - ***Stratified drift* —Sediments laid down by glacial meltwater**



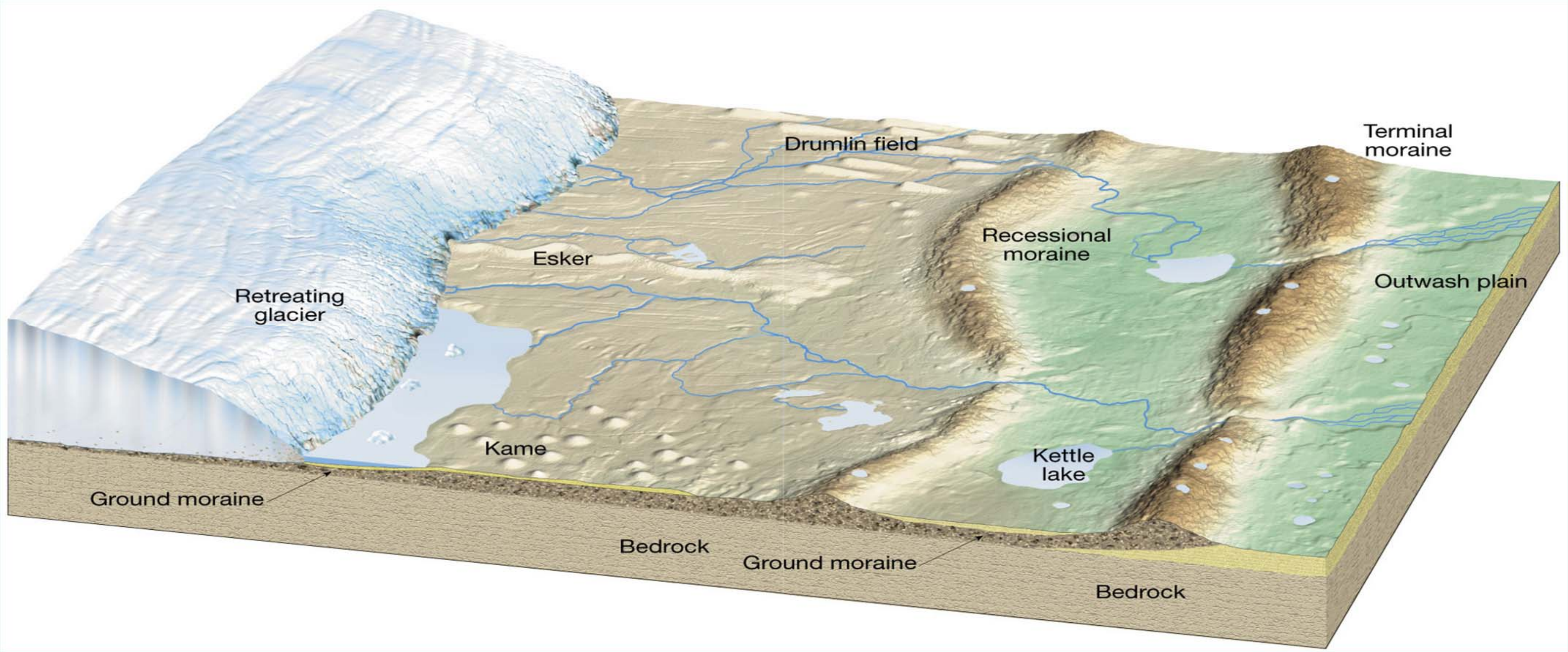
Glacial Deposits

Landforms made of till

- ***Moraines***
  - **Layers or ridges of till**
- **Moraines produced by alpine glaciers**
  - ***Lateral moraine***
  - ***Medial moraine***

Glacial Deposits

- **Landforms made of till**
  - **Other types of moraines**
    - ***End moraine*—Terminal or recessional**
    - ***Ground moraine***



Desert and Steppe Regions of the World

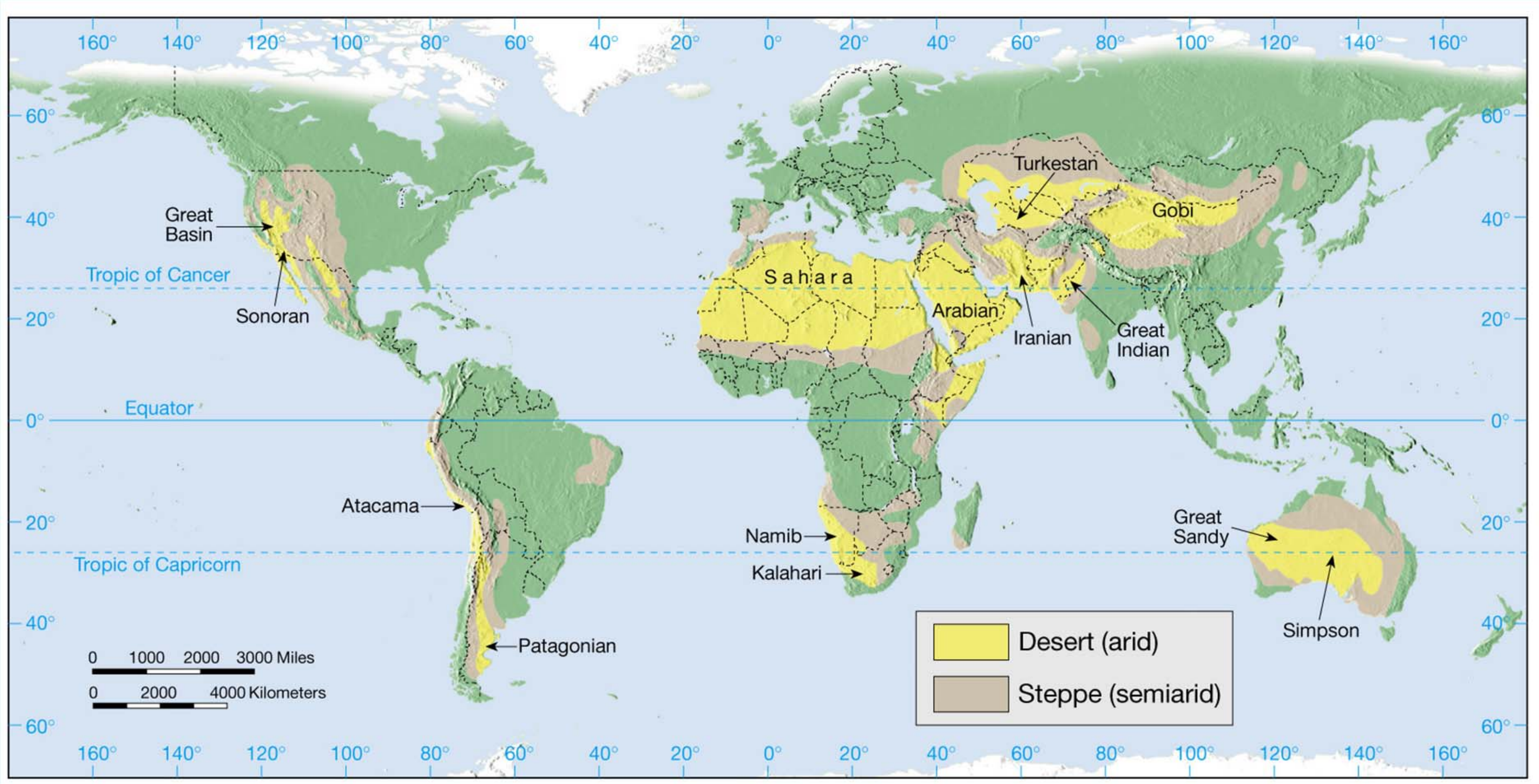
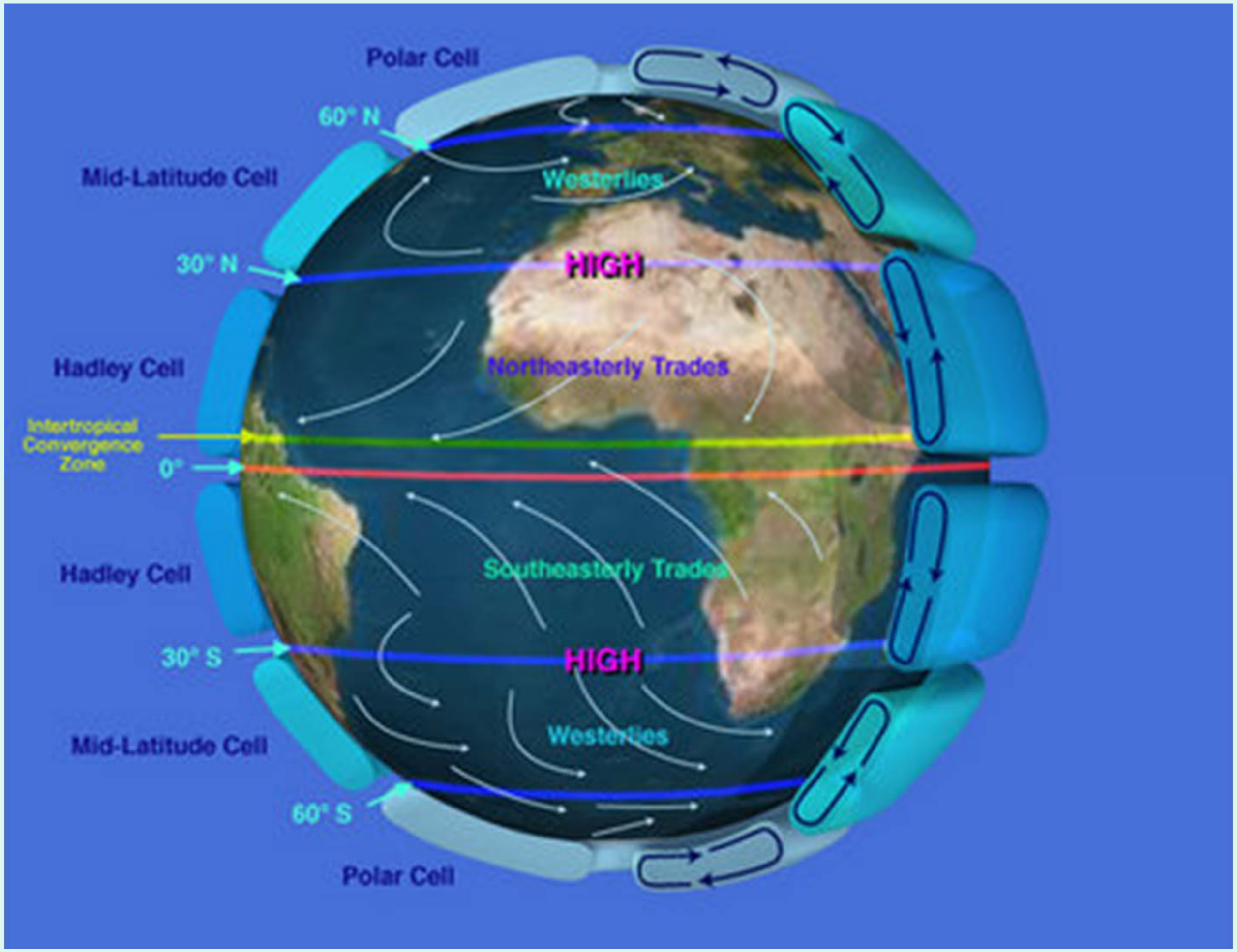


Figure 4.19

Deserts

- **Dry lands are concentrated in two regions**



Rainshadow Desert

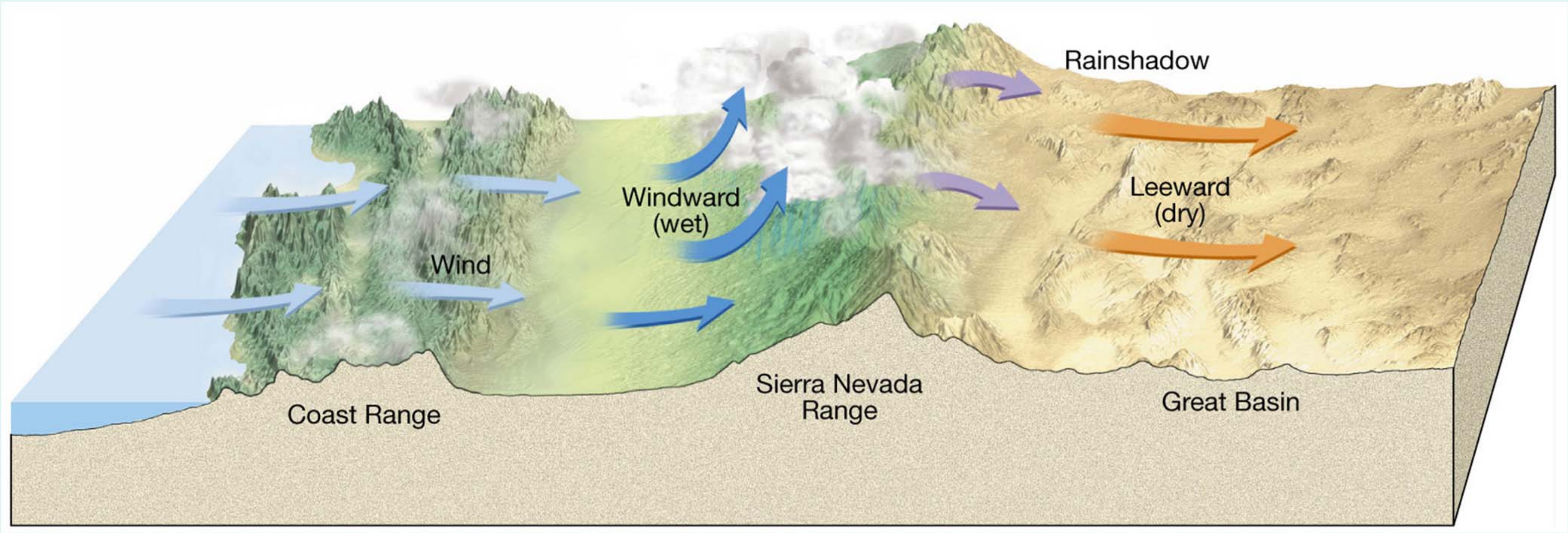


Figure 4.21

A Dry Channel Contains Water Only Following Heavy Rain

A. B. **Figure 4.22**

Plate Tectonics - Review

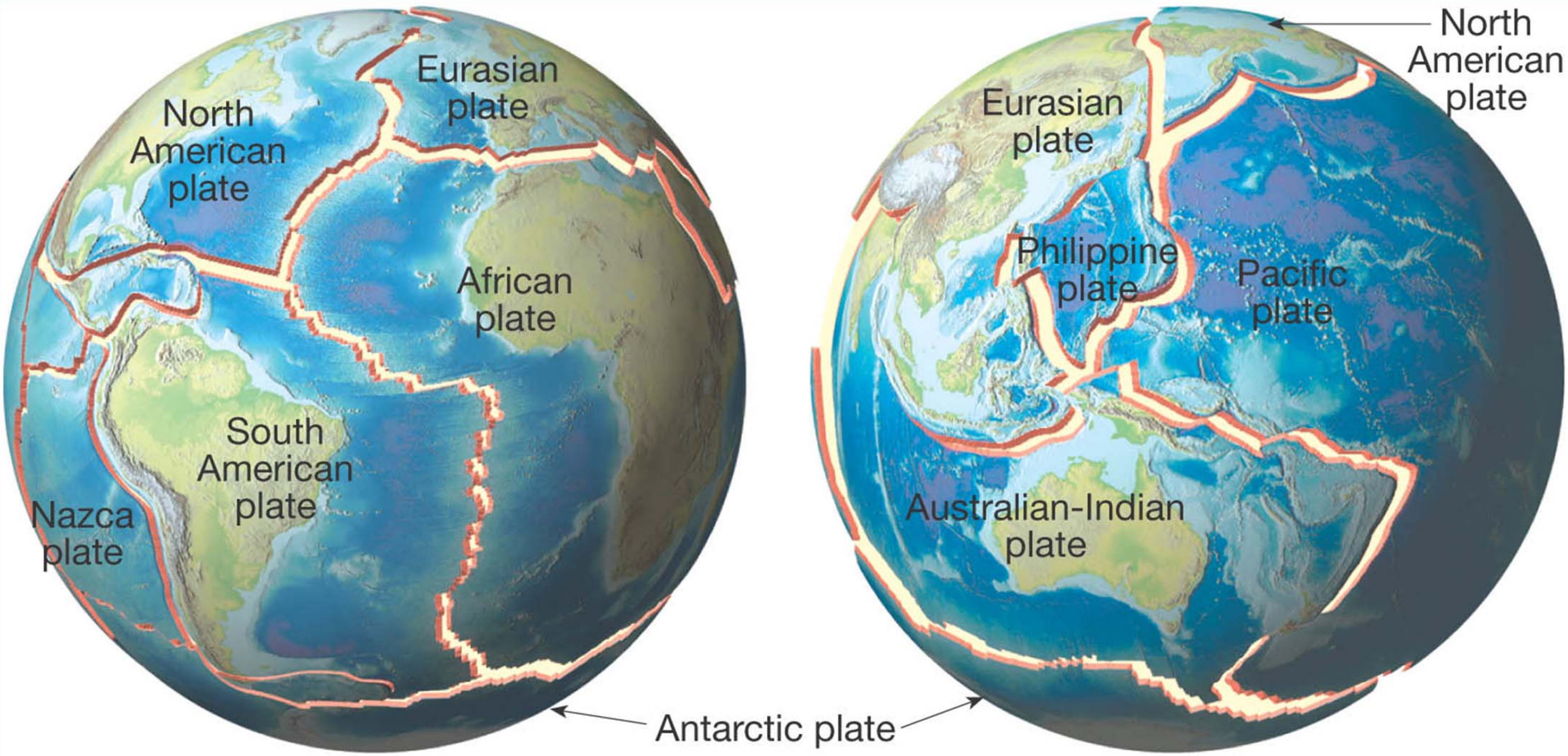


Plate Tectonics - Review

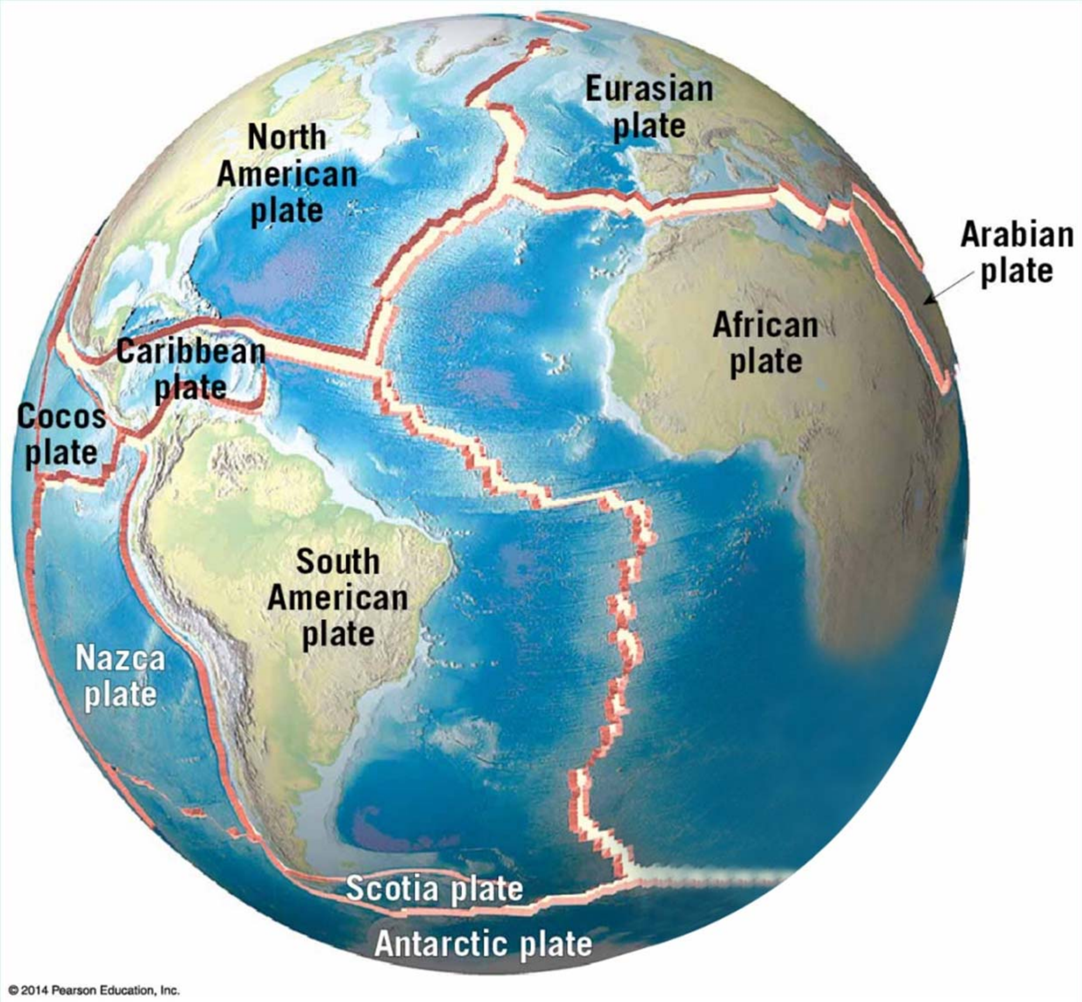
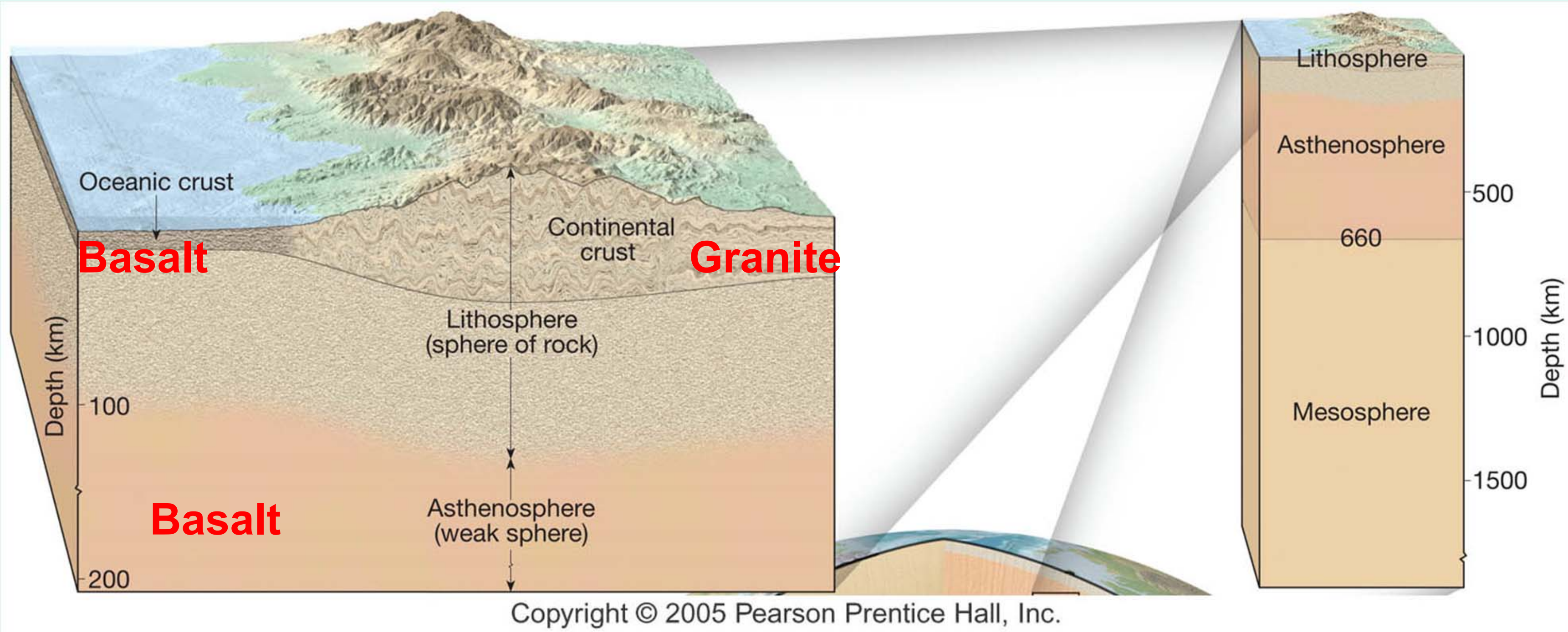


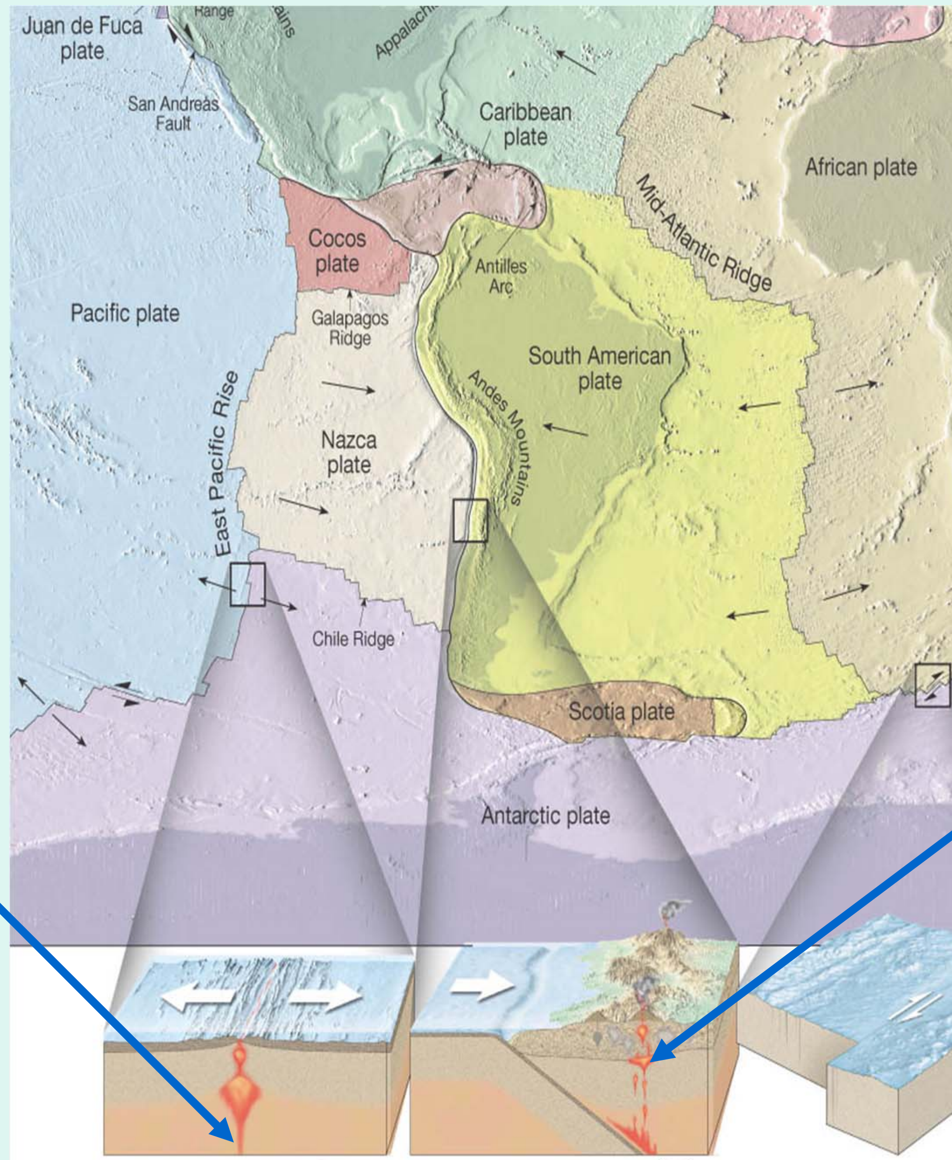
Plate Tectonics - Review



Crust	
Oxygen	47%
Iron	5.5%
Silicon	27%
Magnesium	2.1%
Sulfur	<1%
Aluminum	8%
Calcium	3.7%

	Earth
Oxygen	35%
Iron	24%
Silicon	17%
Magnesium	14%
Sulfur	6%
Aluminum	1%
Calcium	1%

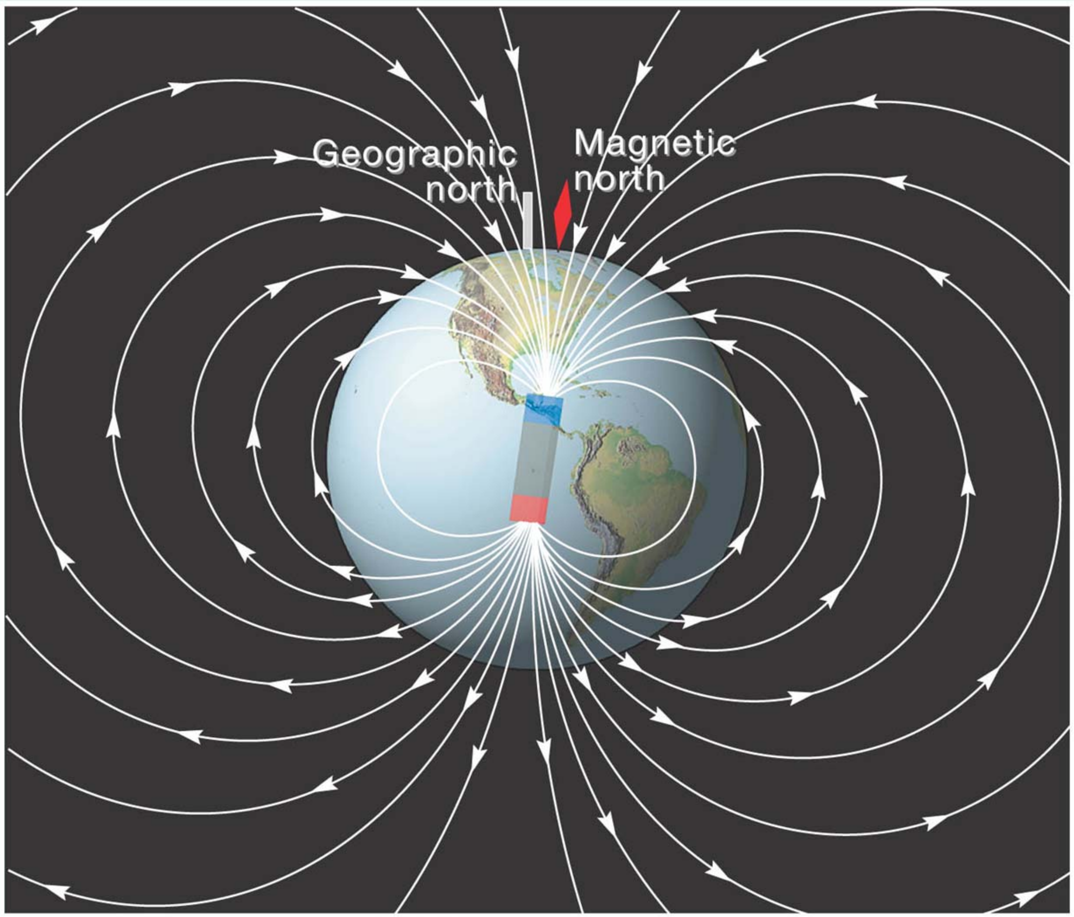
Plate Tectonics - Review



Basaltic Magma

Granitic Magma

Plate Tectonics - Review



Oxygen	35%
Iron	24%
Silicon	17%
Magnesium	14%
Sulfur	6%
Aluminum	1%
Calcium	1%

Continental Drift: An Idea Before Its Time

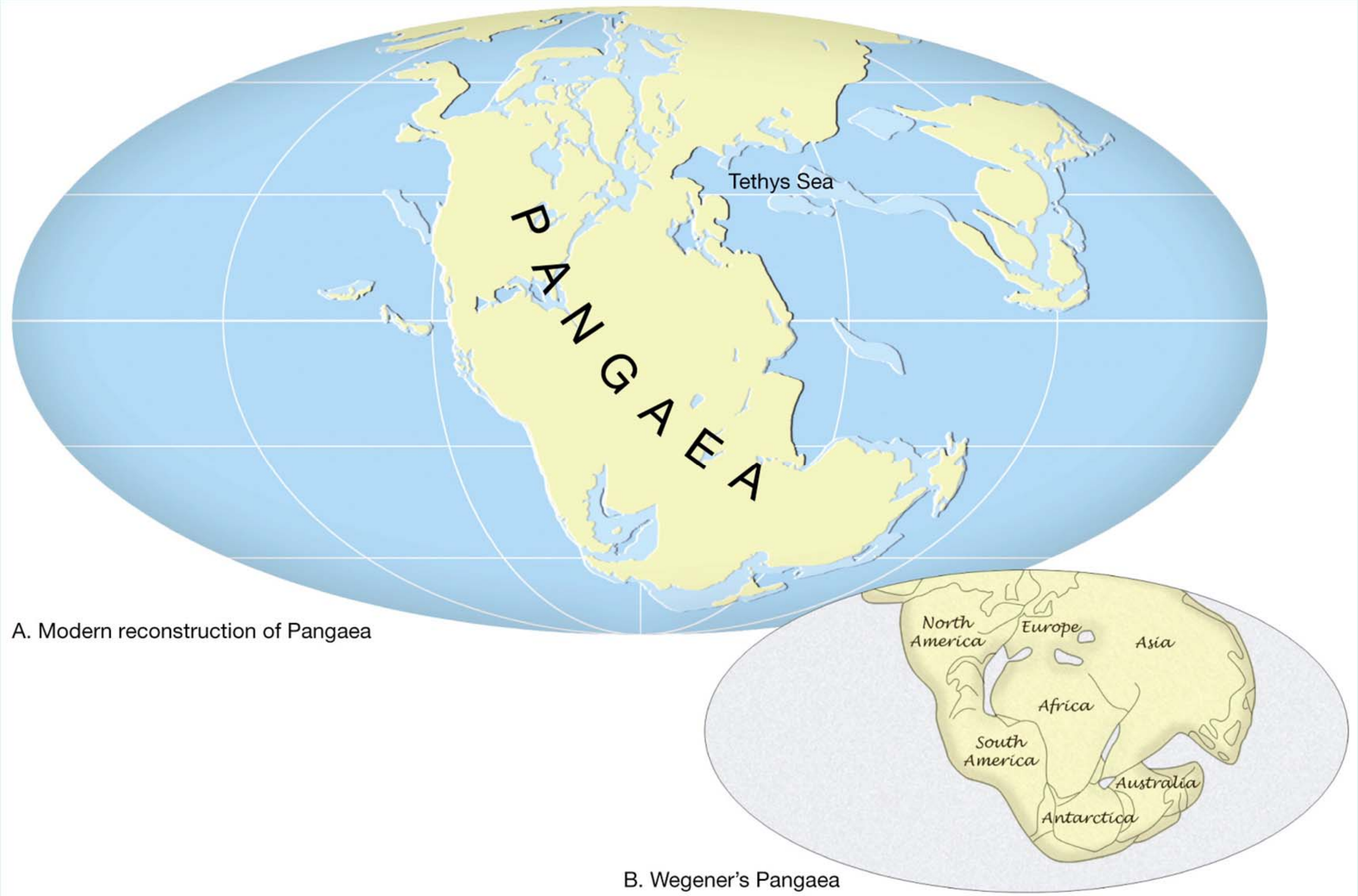
Alfred Wegener

- First proposed his continental drift hypothesis in 1915
- Published *The Origin of Continents and Oceans*

Continental drift hypothesis

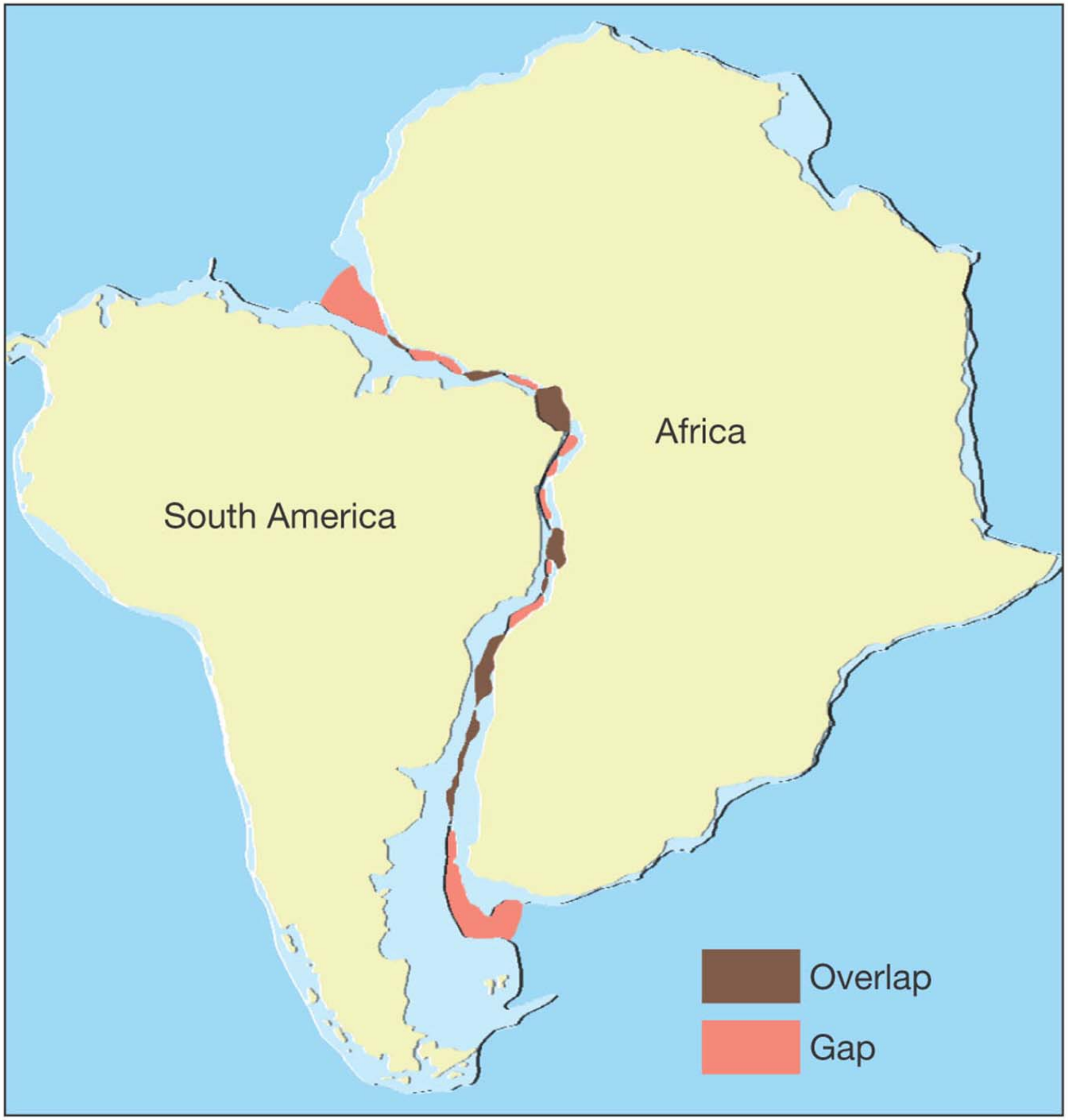
- Supercontinent called *Pangaea* began breaking apart about 200 million years ago

Pangaea Approximately 200 Million Years Ago



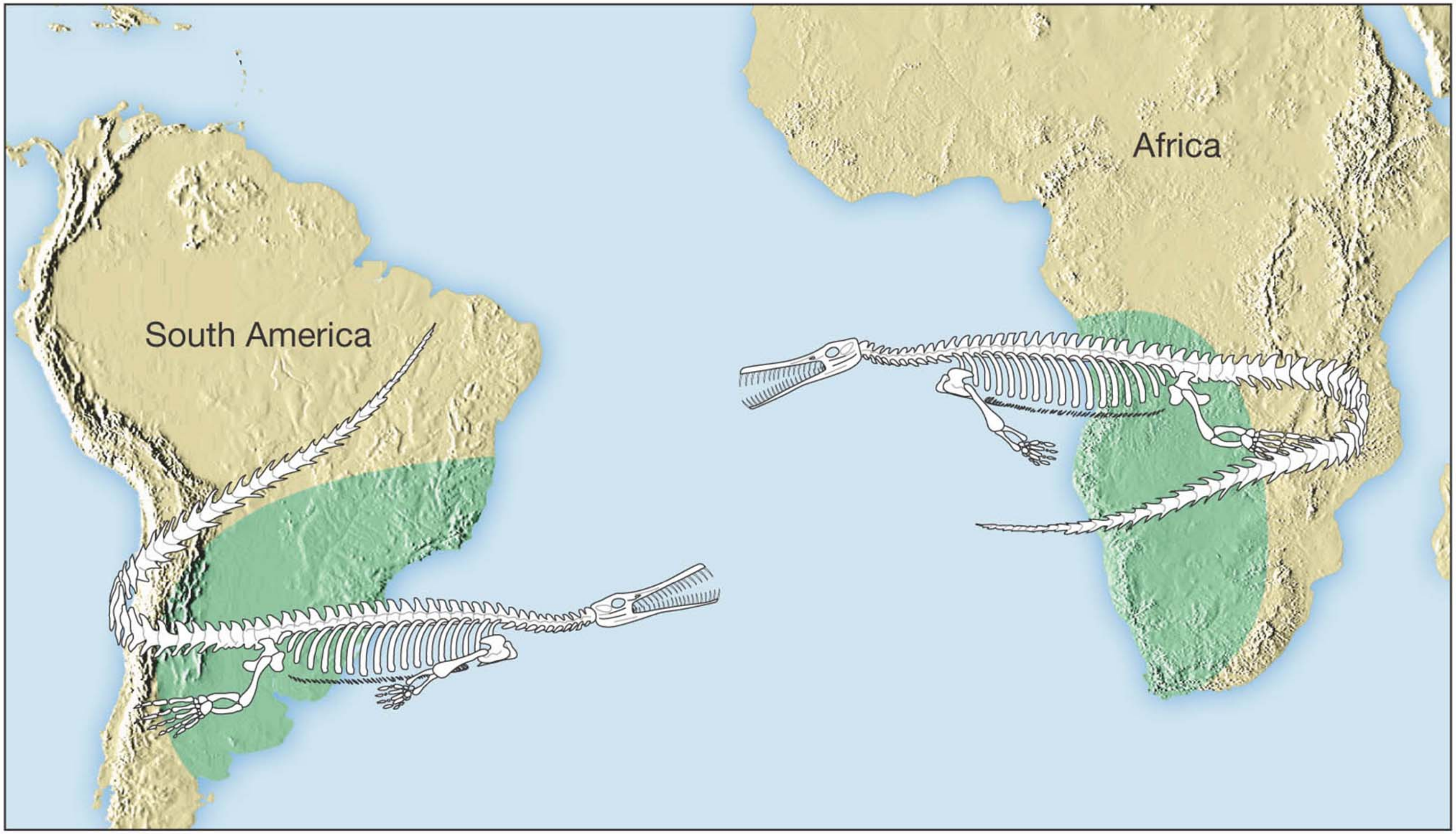
Continental drift: An Idea Before Its Time

- **Continental drift hypothesis**
  - **Continents "drifted" to present positions**
- **Evidence used in support of continental drift hypothesis**
  - **Fit of the continents**
  - **Fossil evidence**
  - **Rock type and structural similarities**
  - **Paleoclimatic evidence**

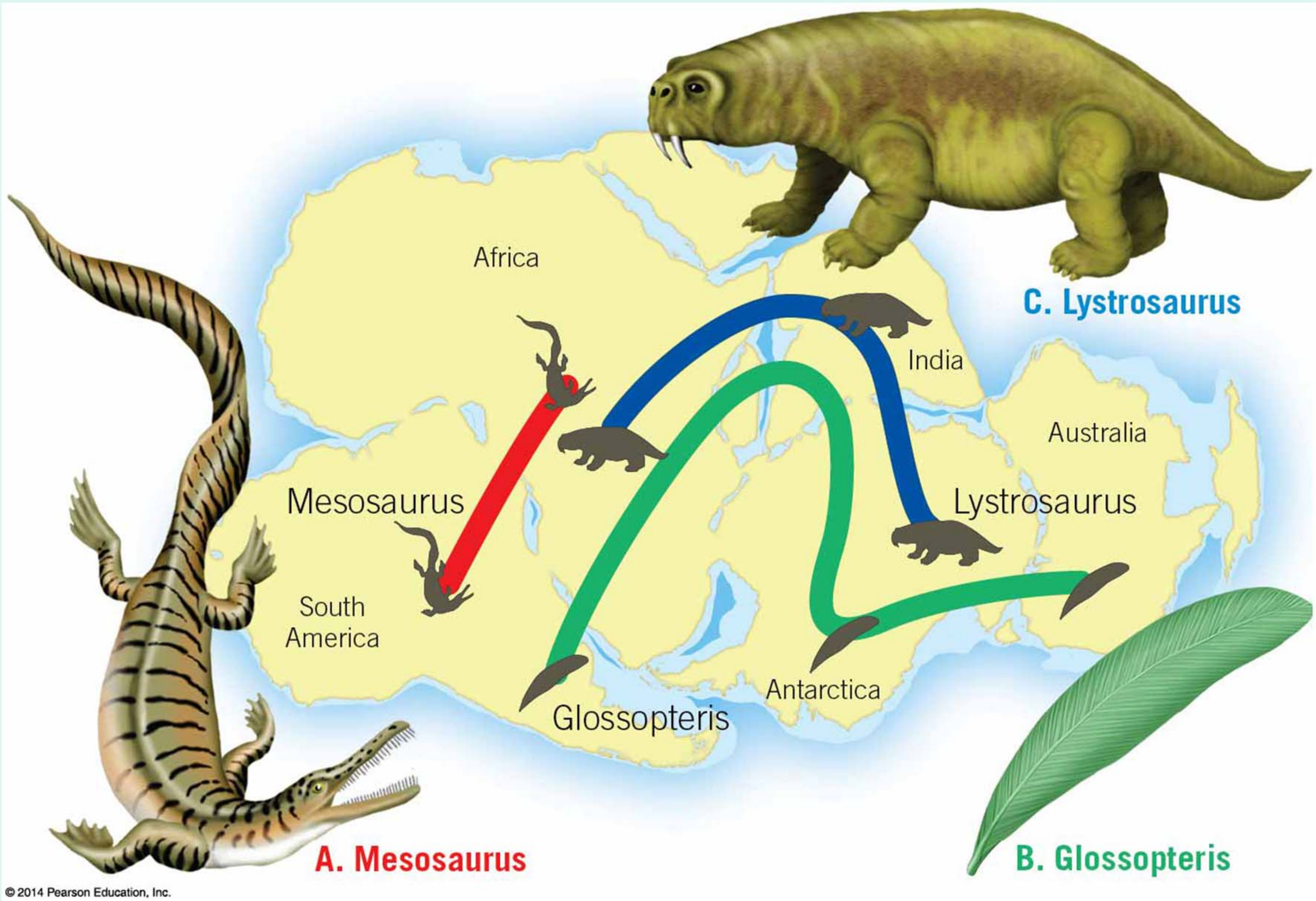


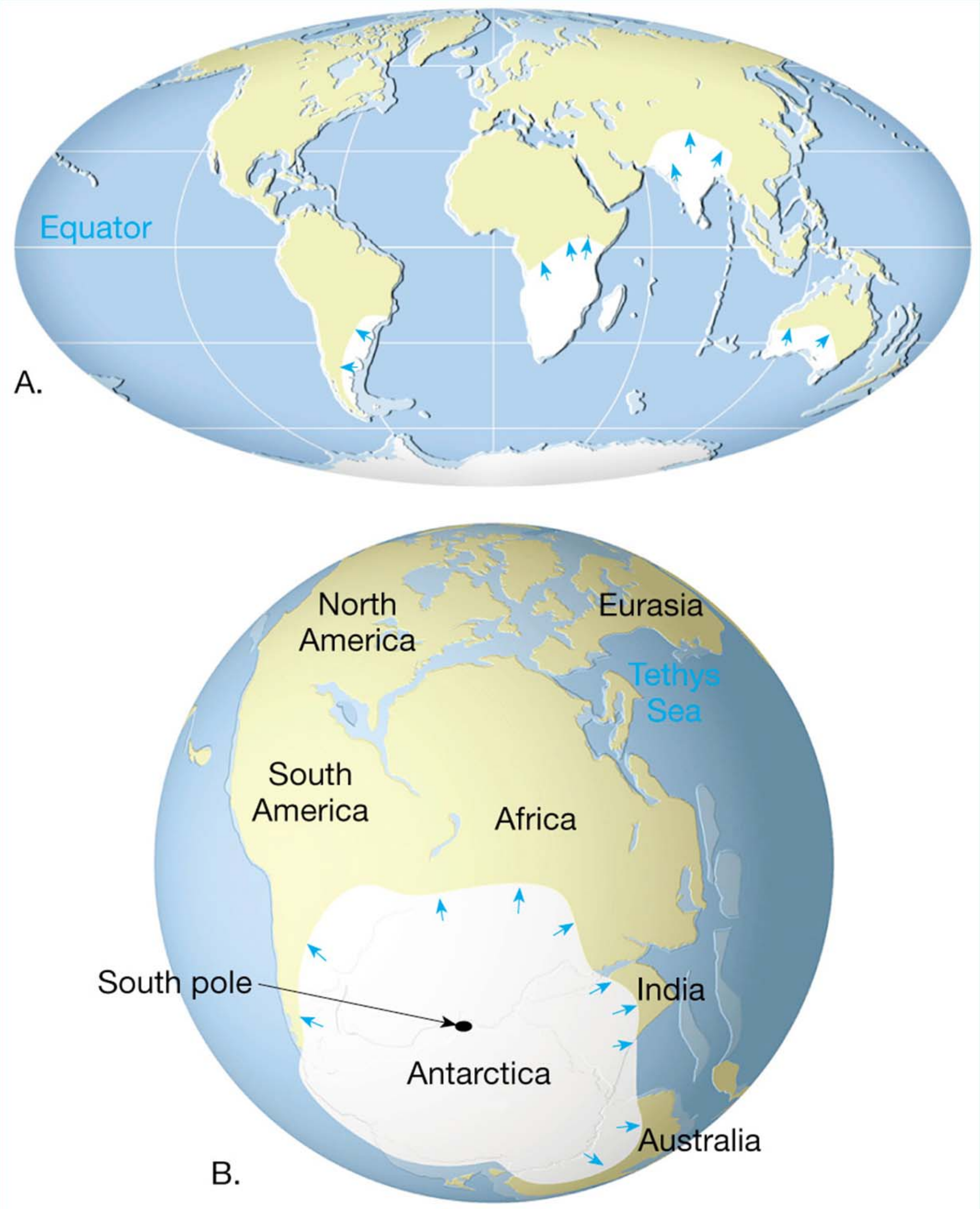
Fit of Continents

Similar Fossils on Different Continents



Similar Fossils on Different Continents

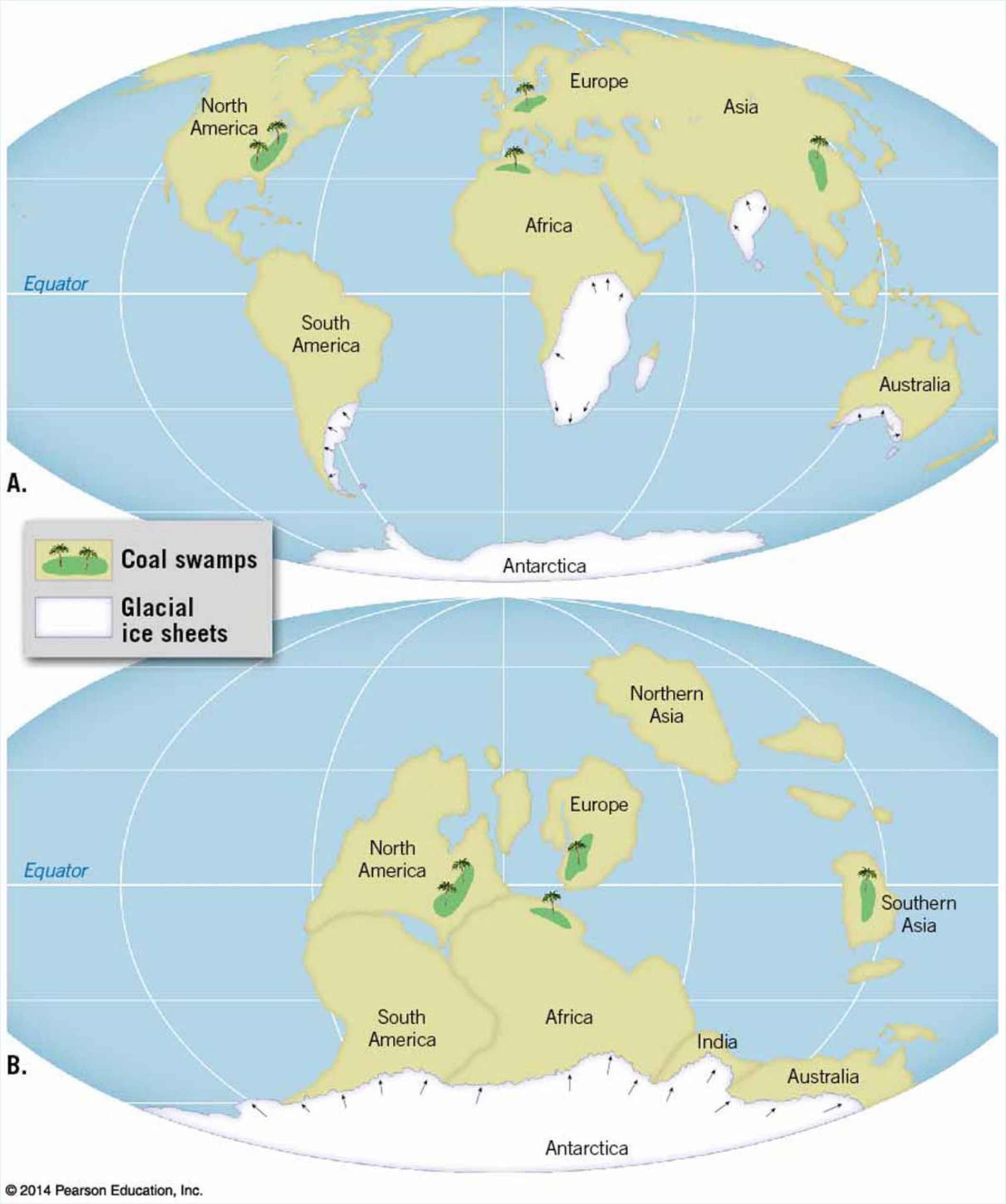




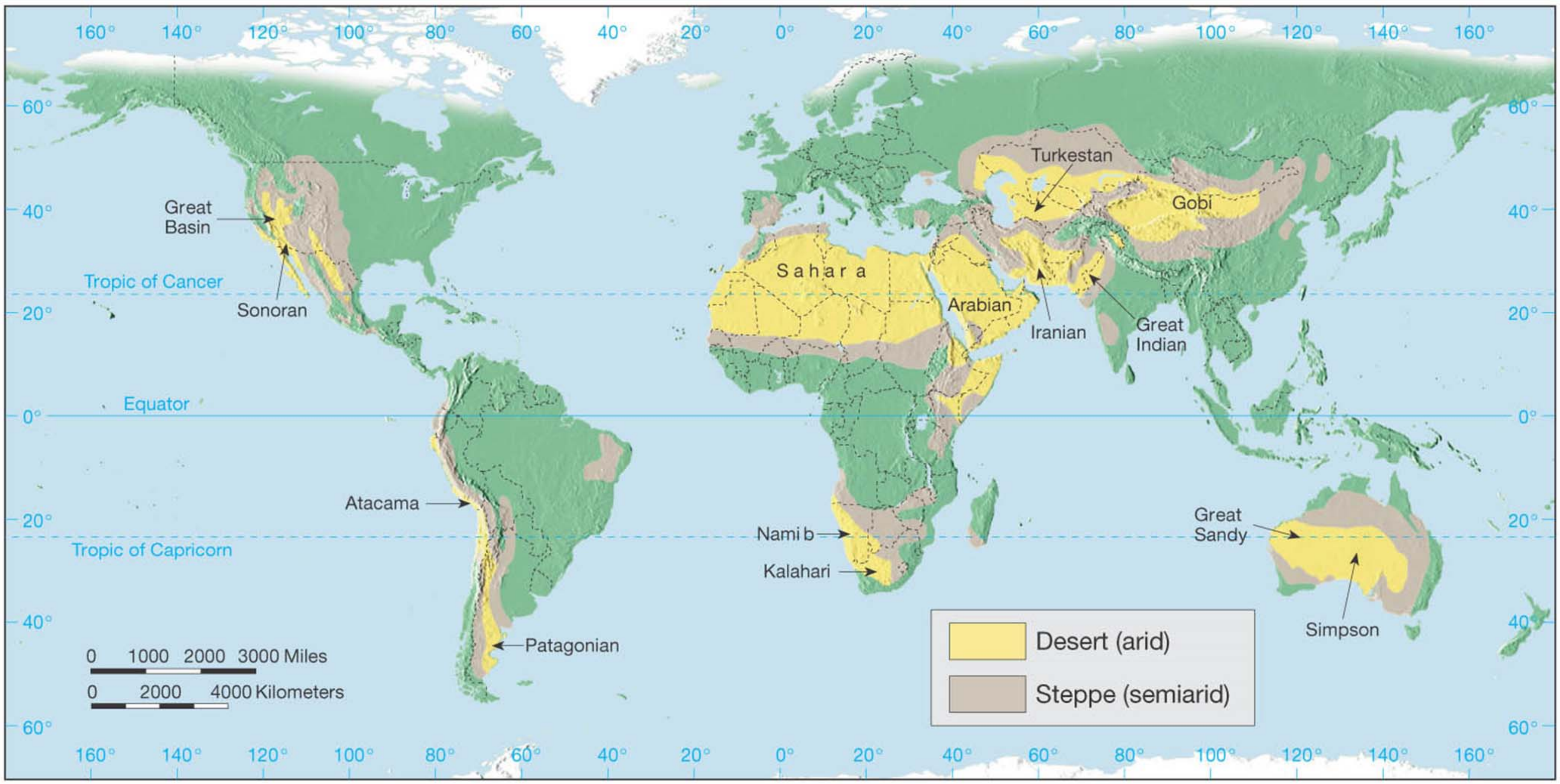
Paleoclimatic Evidence

Glaciers

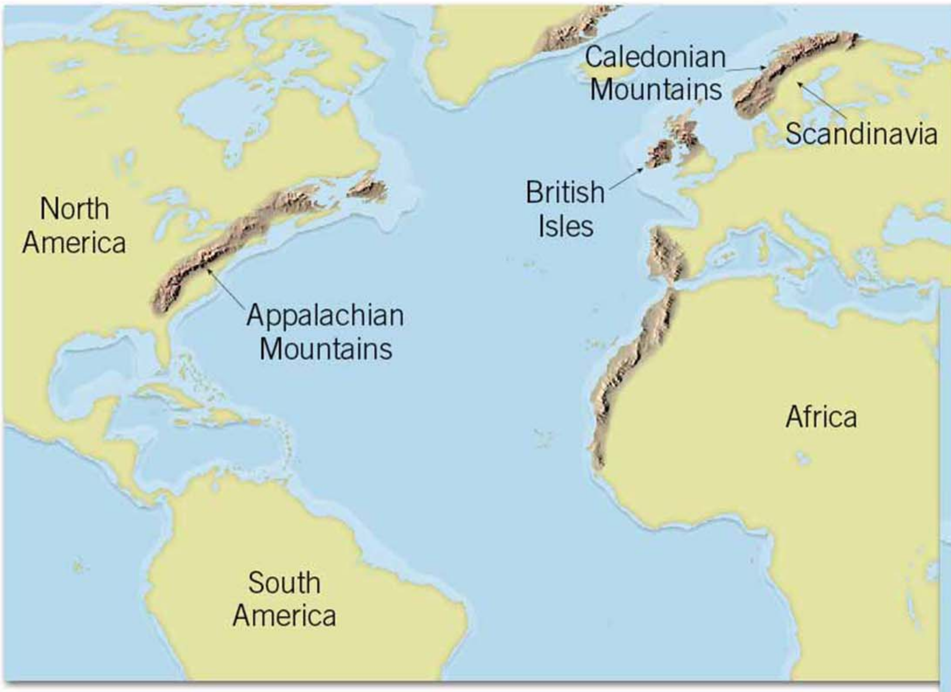
Paleoclimatic Evidence



Paleoclimatic Evidence
Other Evidence: Coal Beds, Deserts, Coral



Matching Mountain Ranges


Caledonian
Mountains
Scandinavia
British
Isles
North
America
Appalachian
Mountains
Africa
South
America

A.


Greenland
Europe
North
America
Africa
South
America

B.

Objections: *The Great Debate*

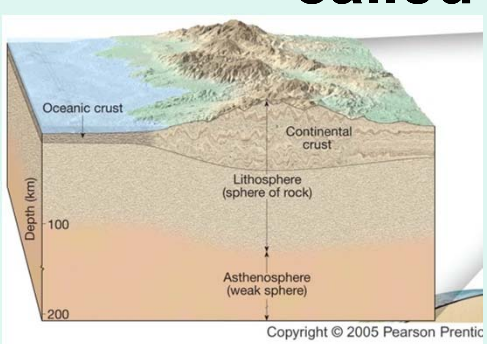
- **Objections to the continental drift hypothesis**
  - **Lack of a mechanism for moving continents**
  - **Wegener incorrectly suggested that continents broke through the ocean crust, much like ice breakers cut through ice**
  - **Strong opposition to the hypothesis from the scientific community**

The Great Debate

- **Continental drift and the scientific method**
  - **Wegener's hypothesis was correct in principle, but contained incorrect details**
  - **A few scientists considered Wegener's ideas plausible and continued the search**

Plate Tectonics: A Modern Version of an Old Idea

- **Earth’s major plates**
  - **Associated with Earth's strong, rigid outer layer**
    - **Known as the *lithosphere***
    - **Consists of uppermost mantle and overlying crust**
    - **Overlies a weaker region in the mantle called the *asthenosphere***



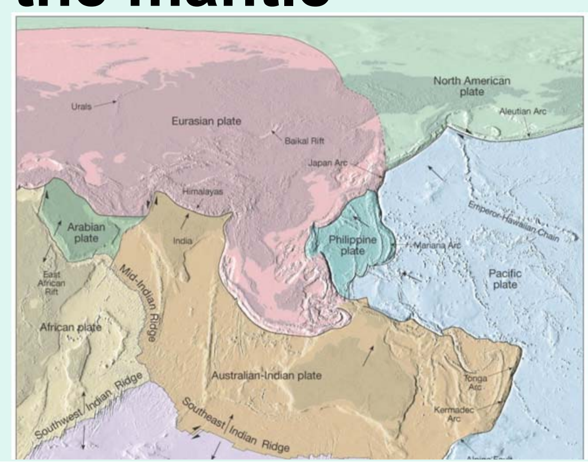


Plate Tectonics: A Modern Version of an Old Idea

- **Earth's major plates**
  - **Seven major lithospheric plates**
  - **Plates are in motion and continually changing in shape and size**
  - **Largest plate is the Pacific plate**
  - **Several plates include an entire continent plus a large area of seafloor**

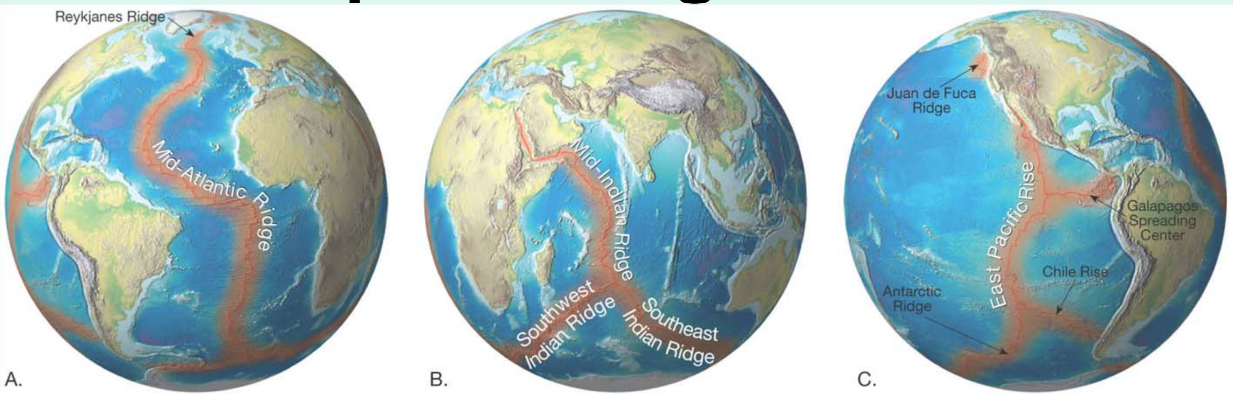


Plate Tectonics: A Modern Version of an Old Idea

- **Earth's major plates**
  - **Plates move relative to each other at a very slow but continuous rate**
    - **Cooler, denser slabs of oceanic lithosphere descend into the mantle**

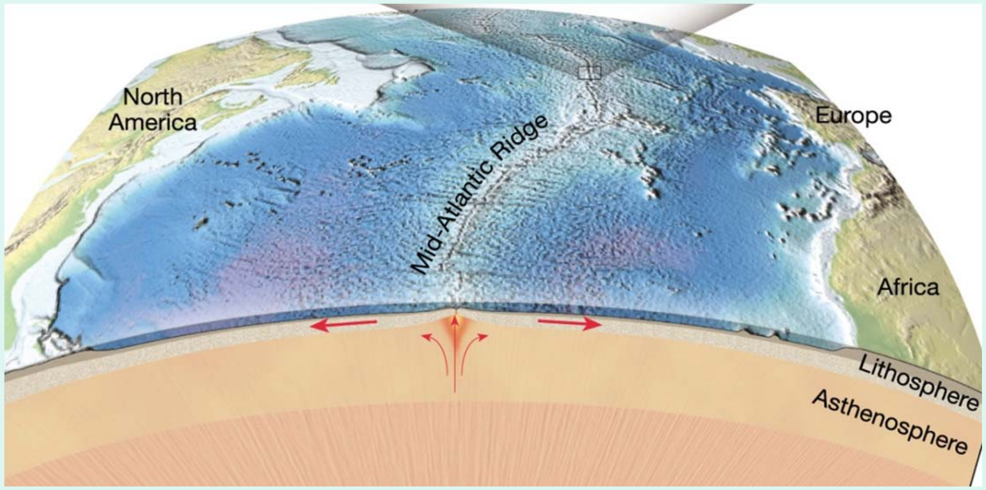


Plate Tectonics: A Modern Version of an Old Idea

Plates move about 5 centimeters (2 inches) per year

Plate Tectonics: A Modern Version of an Old Idea

Plate boundaries - Interactions among individual plates occur along their boundaries

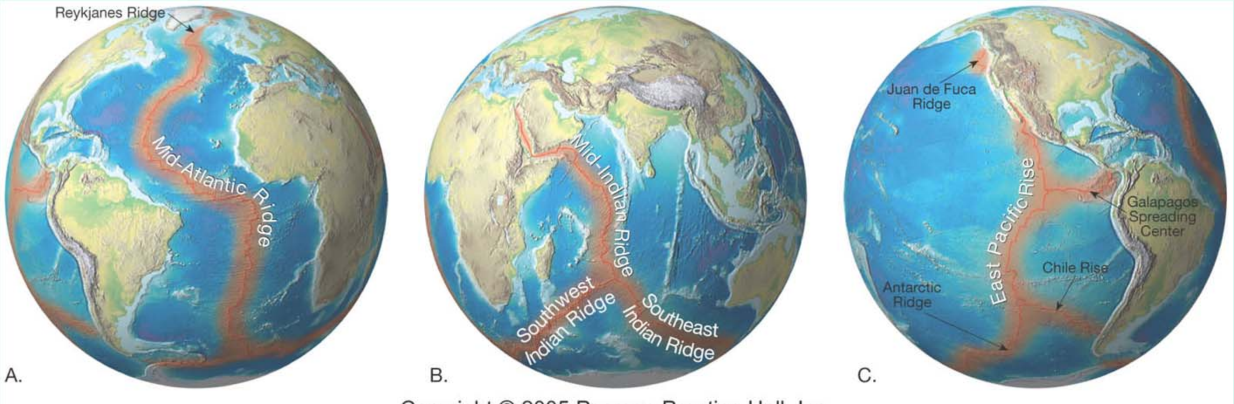


Plate Tectonics: 3 Types of Plate Boundaries

1) ***Divergent plate boundaries*** **(constructive margins)**

2) ***Convergent plate boundaries*** **(destructive margins)**

3) ***Transform fault boundaries*** **(conservative margins)**

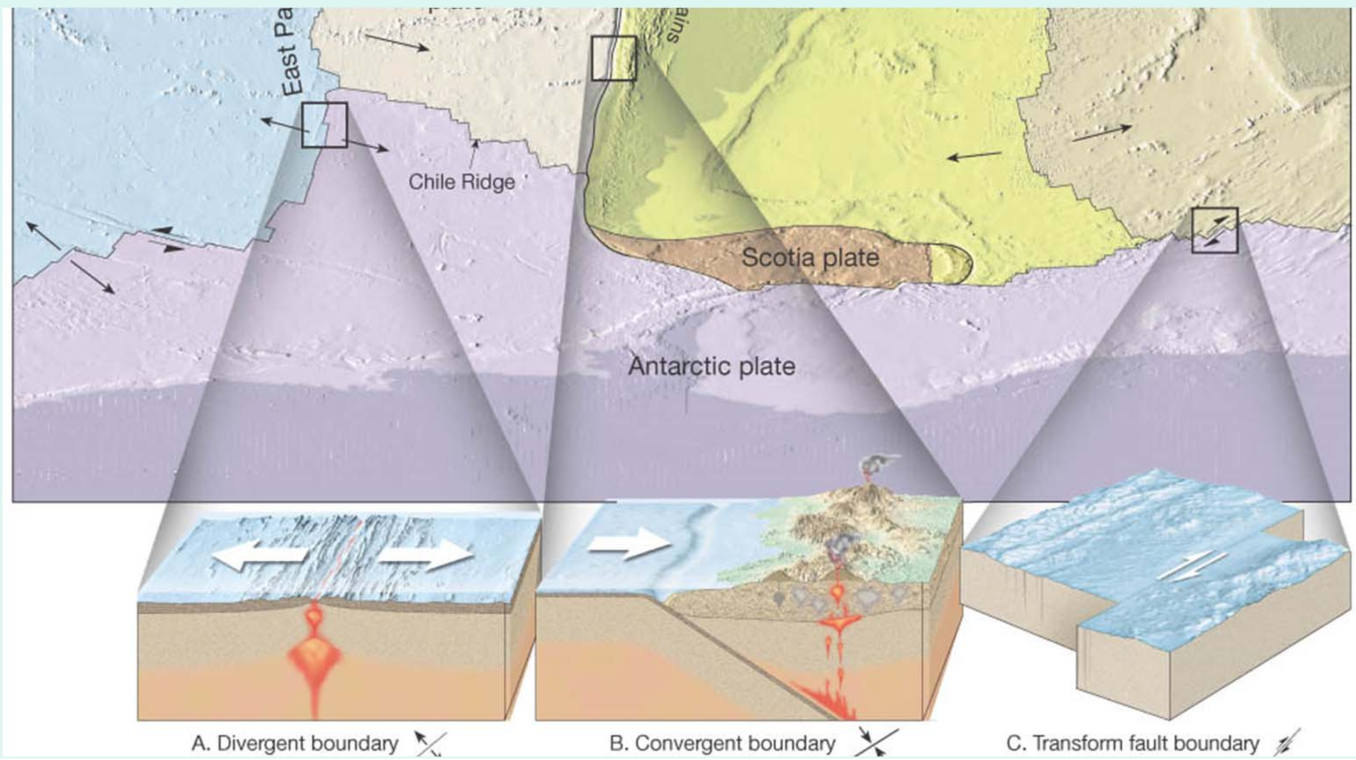
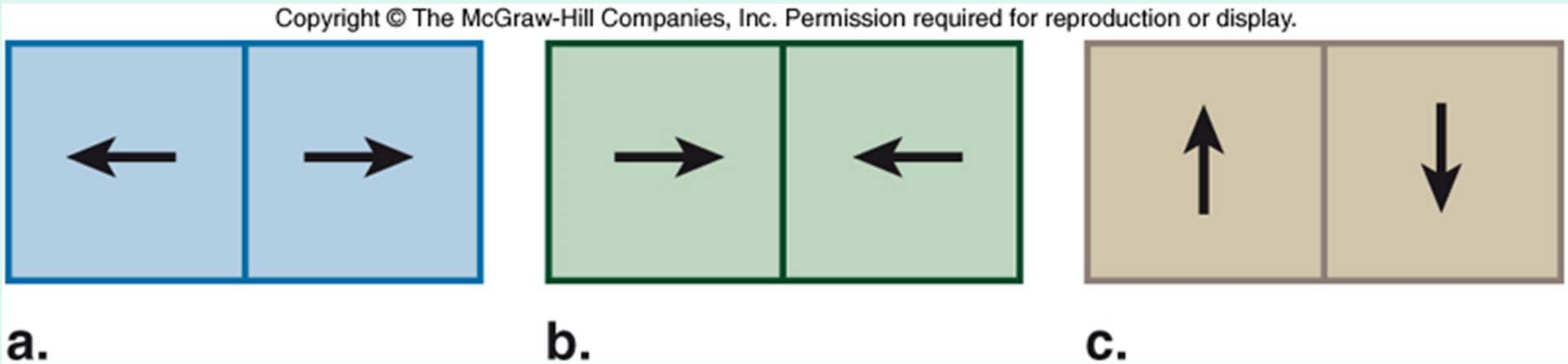


Plate Boundaries

Three types of plate boundaries



Divergent
- plates move apart (e.g. oceanic ridges)

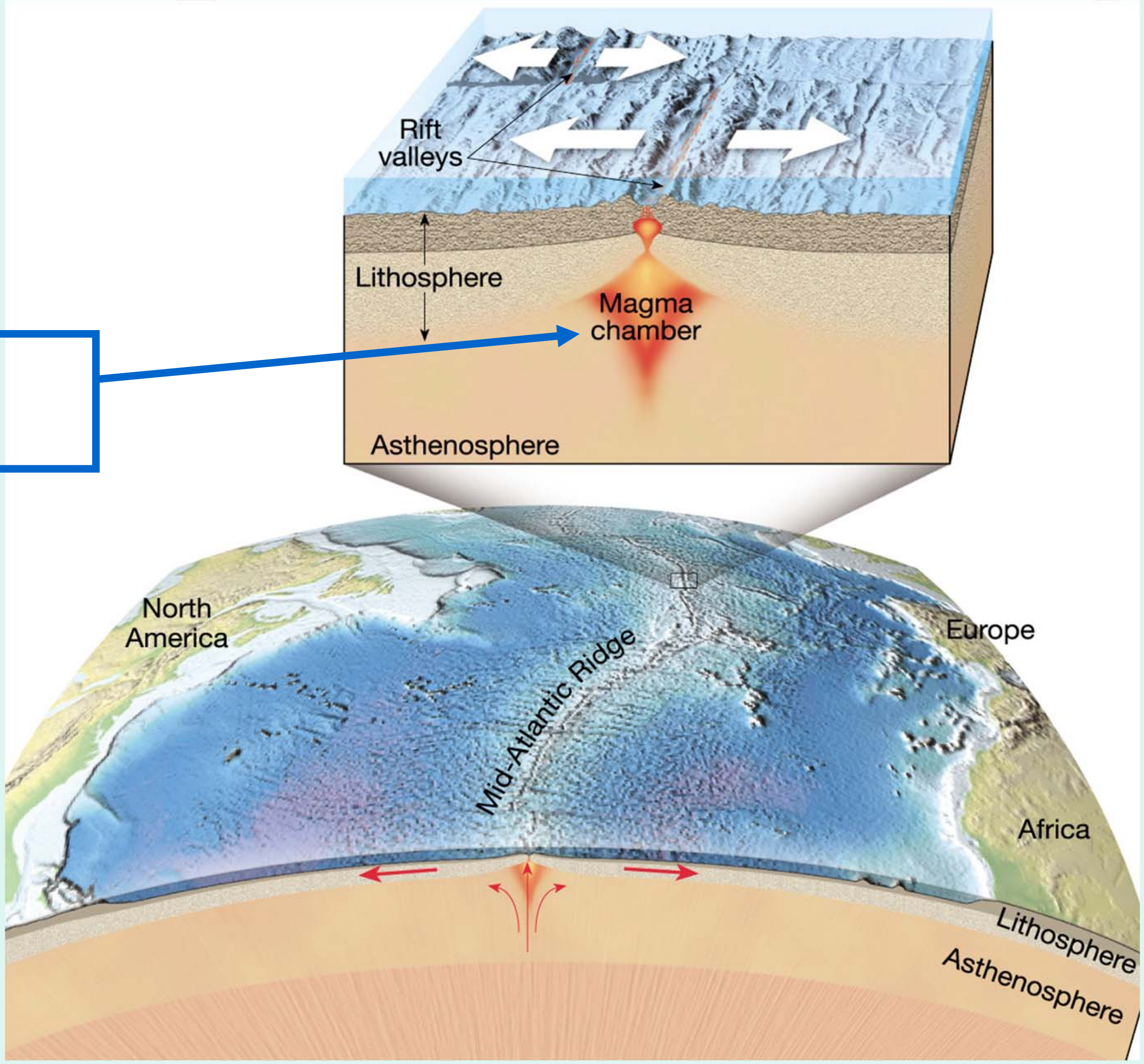
Convergent
- plates move toward each other (e.g. subduction zones)

Transform
- plates slide past each other (e.g. San Andreas fault, CA)

Divergent Plate Boundaries

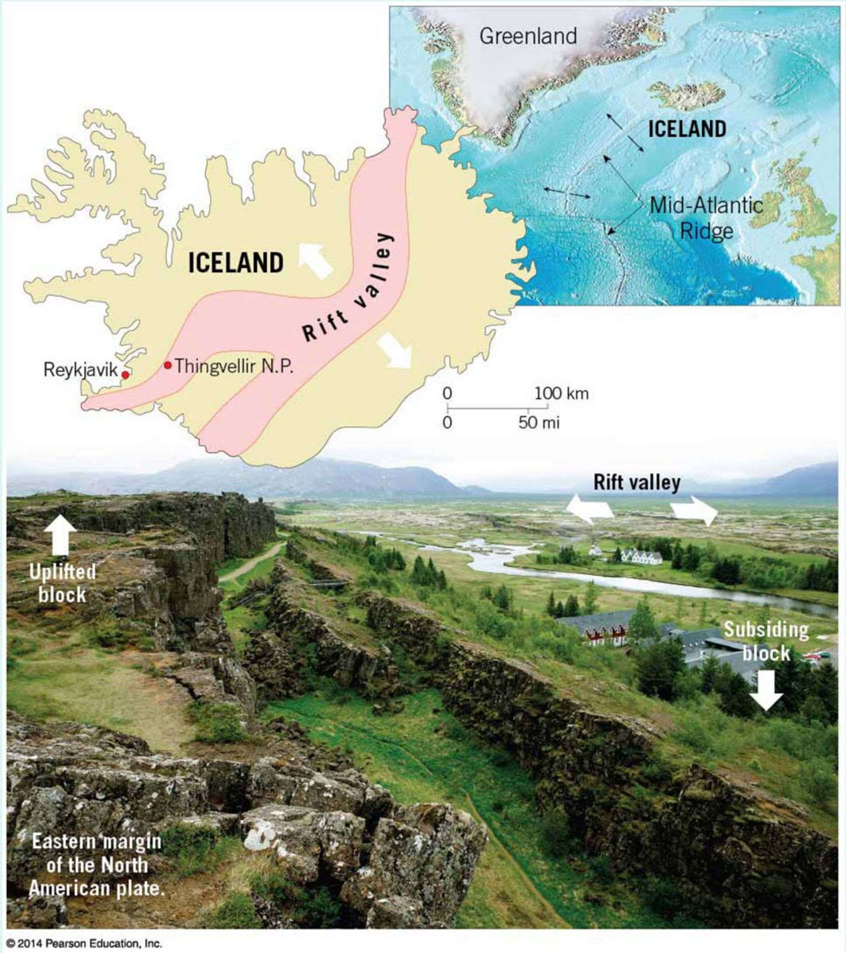
- **Most are located along the crests of oceanic ridges**
- **New Crust is formed at these boundaries**
- **Oceanic ridges and seafloor spreading**
  - **Along well-developed divergent plate boundaries, the seafloor is elevated forming oceanic ridges**

Divergent Plate Boundary



Basaltic Magma

Divergent Plate Boundary



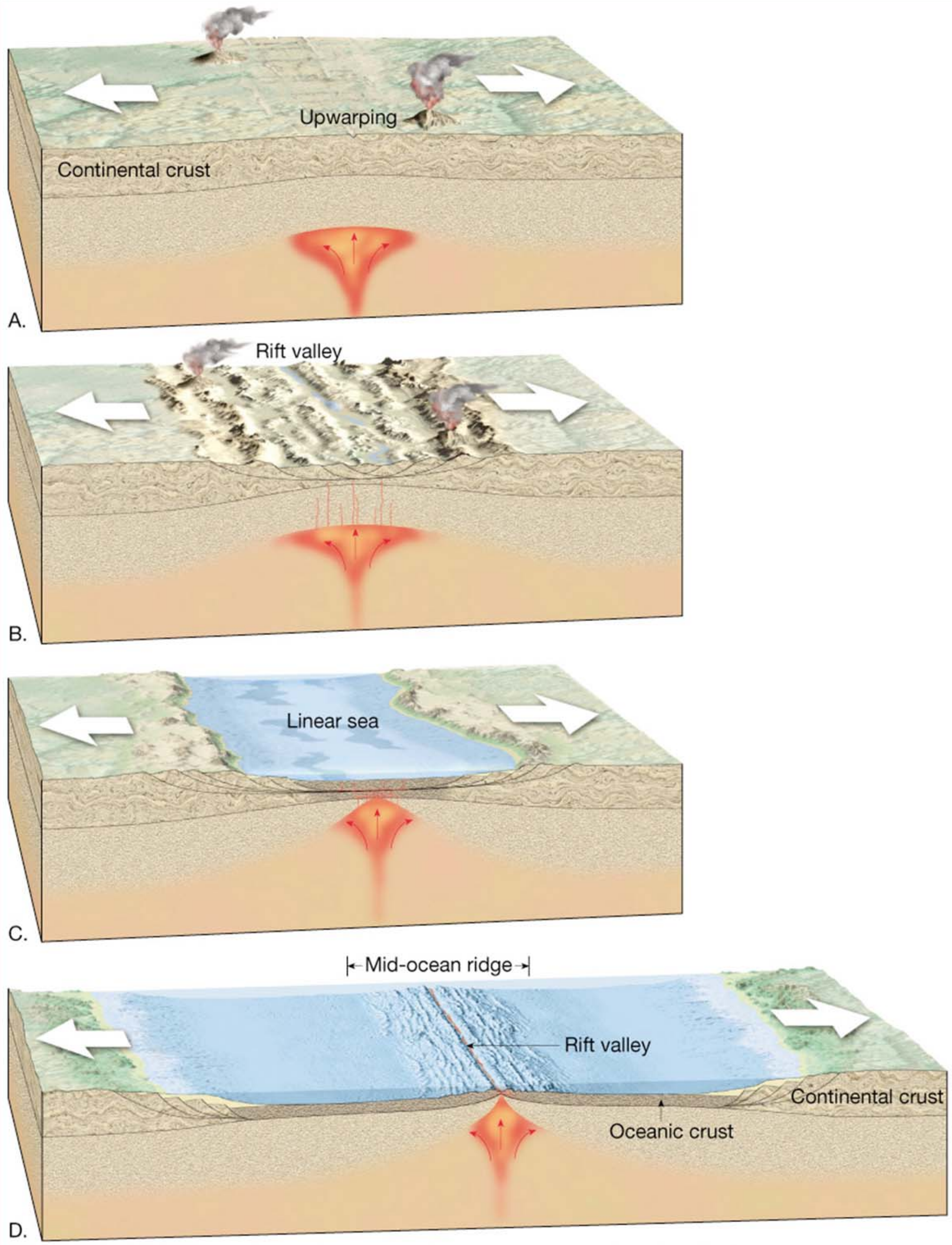
Divergent plate boundaries

- Oceanic ridges and seafloor spreading
  - Seafloor spreading occurs along the oceanic ridge system
- Spreading rates and ridge topography
  - Ridge systems exhibit topographic differences
  - These differences are controlled by spreading rates

Divergent Plate Boundaries

Continental rifting

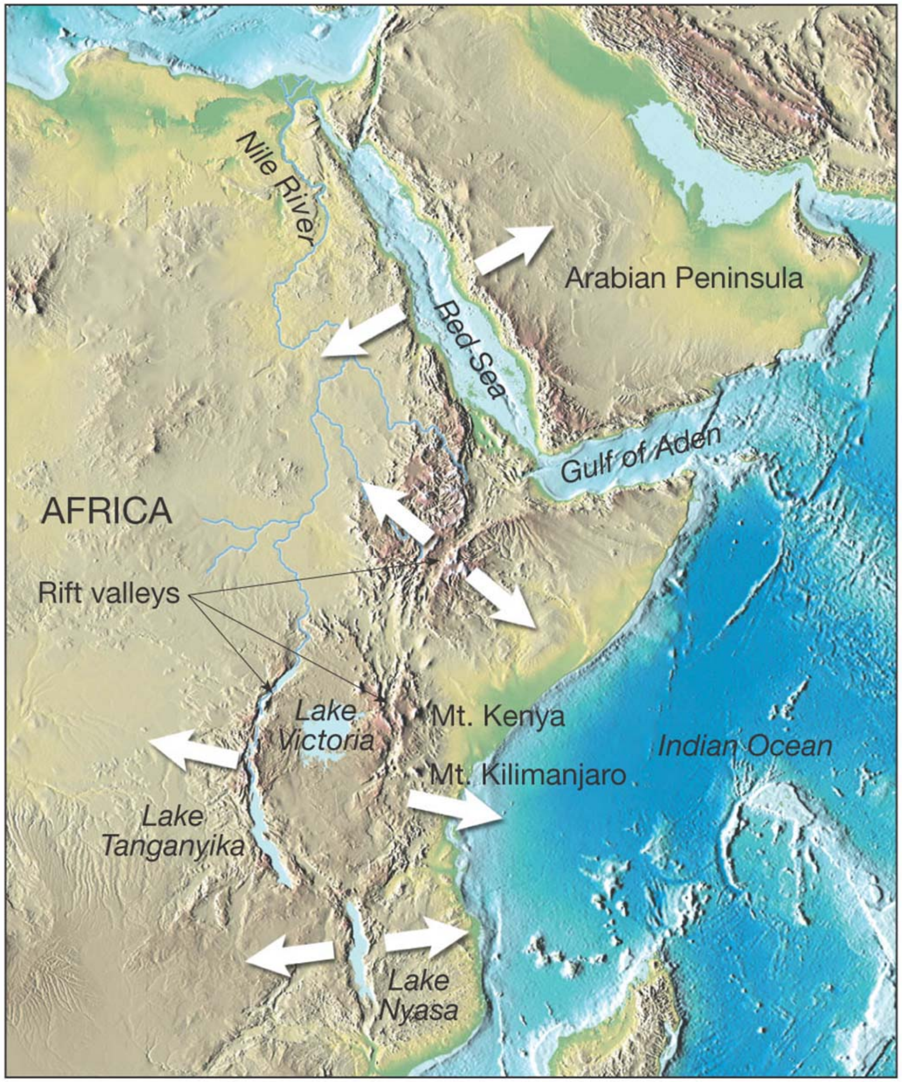
- **Splits landmasses into two or more smaller segments along a *continental rift***
- **Examples include the East African rift valleys and the Rhine Valley in northern Europe**
- **Produced by extensional forces acting on lithospheric plates**



Continental Rifting

Figure 5.11

Continental Rifting

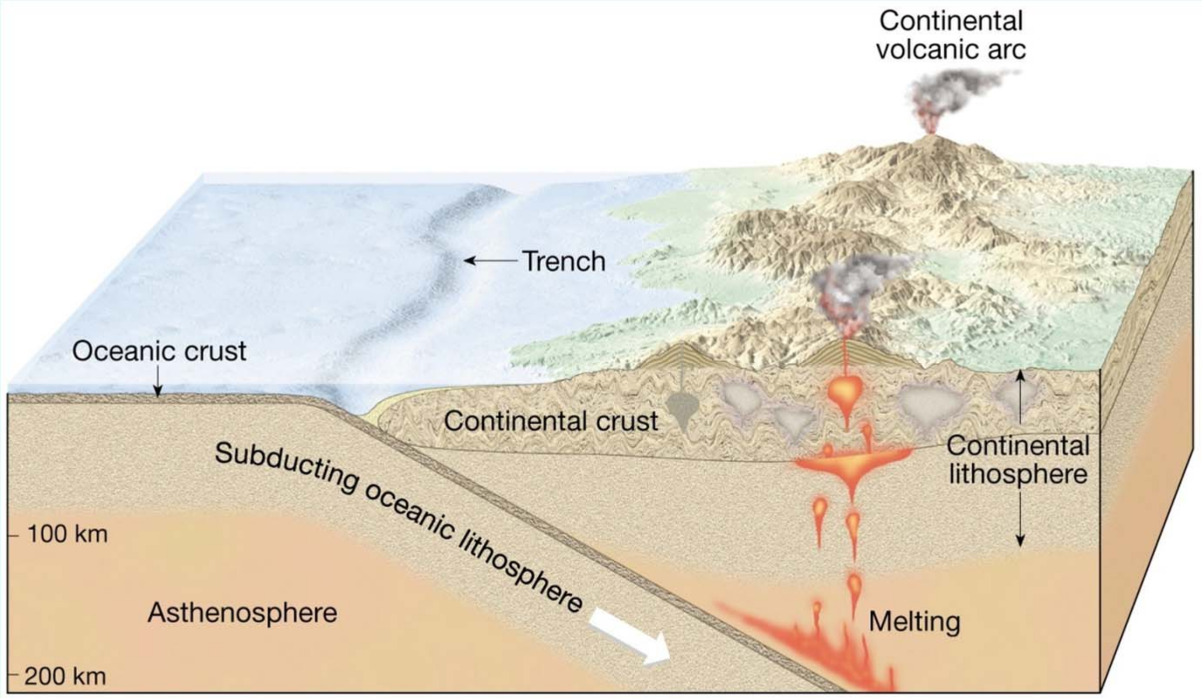


Convergent Plate Boundaries

- **Plates can be destroyed at Convergent Boundaries**
- **Older portions of oceanic plates are returned to the mantle in these destructive plate margins**

Convergent Plate Boundaries

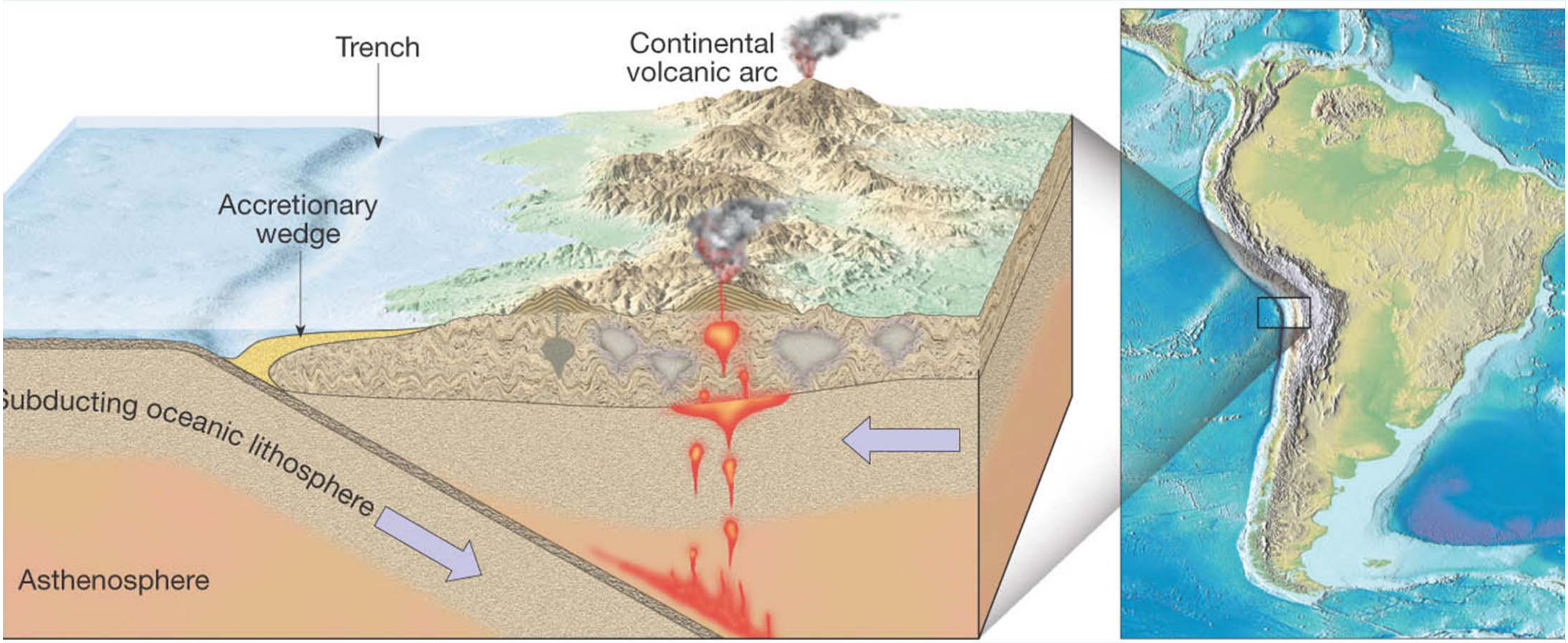
- Surface expression of the descending plate is an *ocean trench*
- Also called *subduction zones*
- Average angle of subduction = 45°



Convergent Plate Boundaries

- **Types of convergent boundaries**
  - **Oceanic-continental convergence**
    - **Denser oceanic slab sinks into the asthenosphere**
    - **Along the descending plate partial melting of mantle rock generates magma**
    - **Resulting volcanic mountain chain is called a *continental volcanic arc* (Andes and Cascades)**

Oceanic-Continental Convergence



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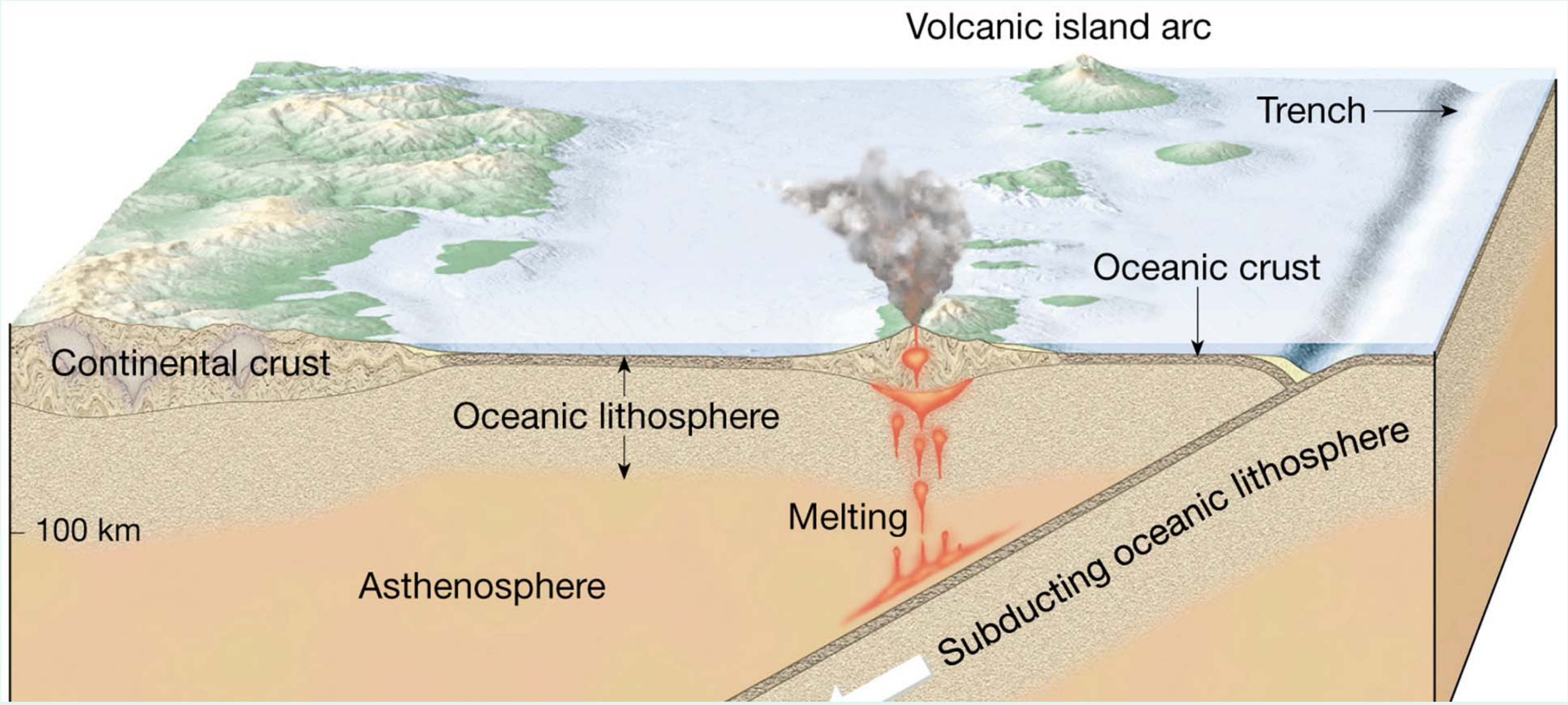
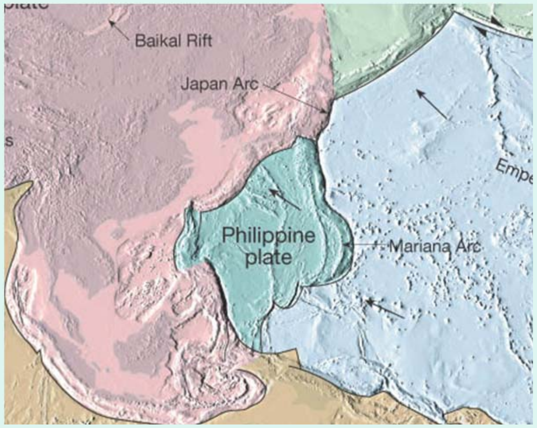
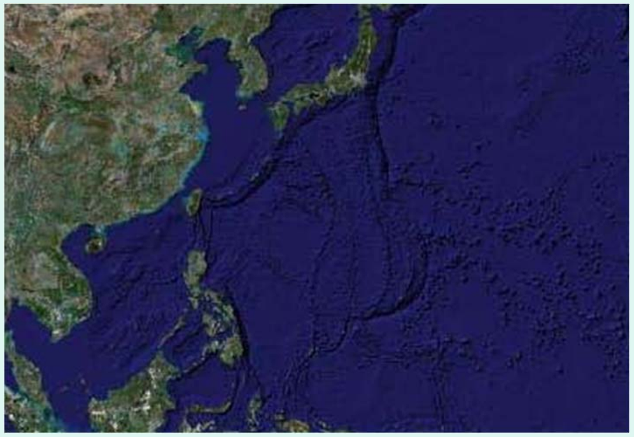
Convergent Plate Boundaries

- **Types of convergent boundaries**
  - **Oceanic-oceanic convergence**
    - **When two oceanic slabs converge, one descends beneath the other**
    - **Often forms volcanoes on the ocean floor**
    - **If the volcanoes emerge as islands, a volcanic *island arc* is formed (Japan, Aleutian islands, Tonga islands)**

Oceanic-Oceanic Convergence



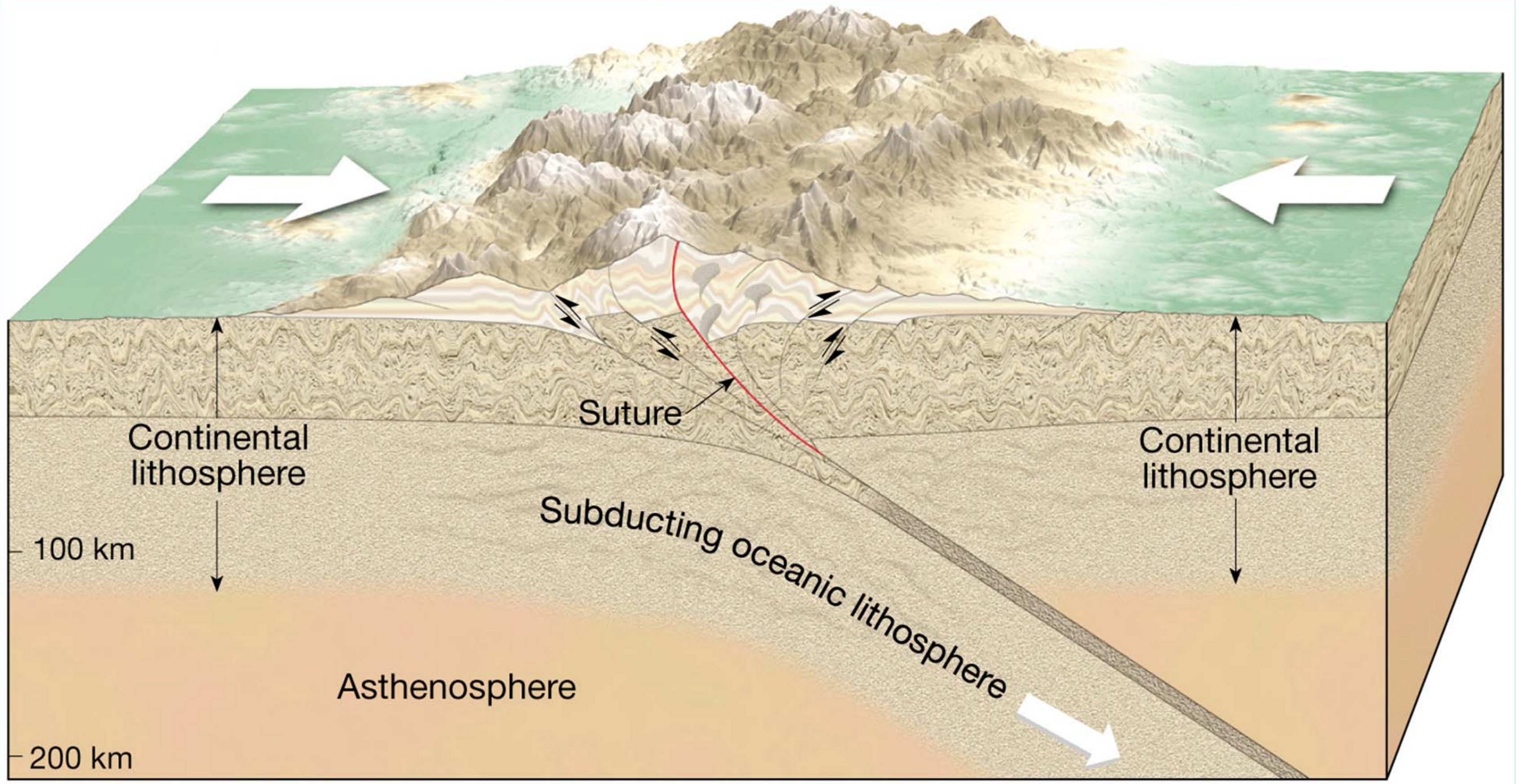




Convergent Plate Boundaries

- **Types of convergent boundaries**
  - **Continental-continental convergence**
    - **Less dense, buoyant continental lithosphere does not subduct**
    - **Resulting collision between two continental blocks produces mountains (Himalayas, Alps, Appalachians)**

Continental-Continental Convergence



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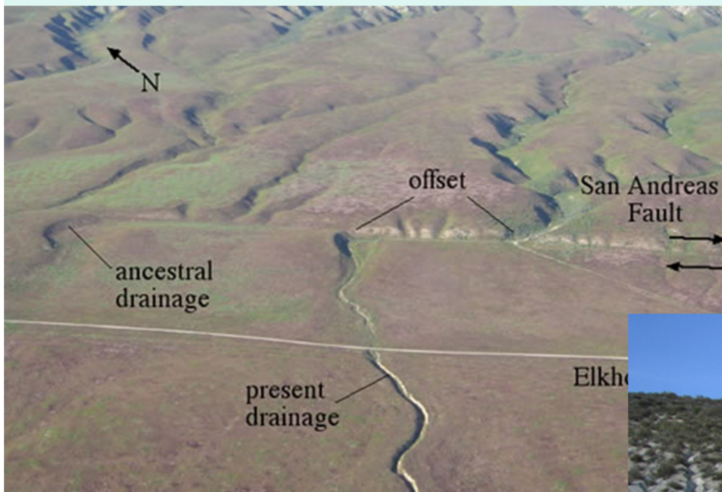
Transform Fault Boundaries

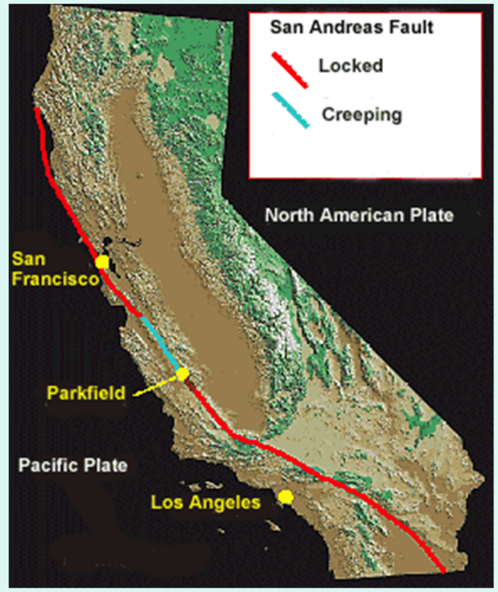
- **Plates slide past one another and no new lithosphere is created or destroyed**
- **Transform faults**
  - **Most join two segments of a mid-ocean ridge along breaks in the oceanic crust known as *fracture zones***

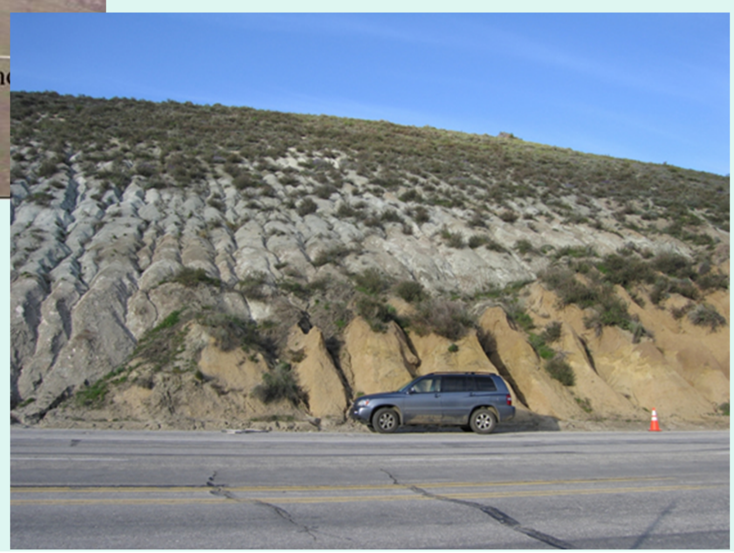
Transform Fault Boundaries

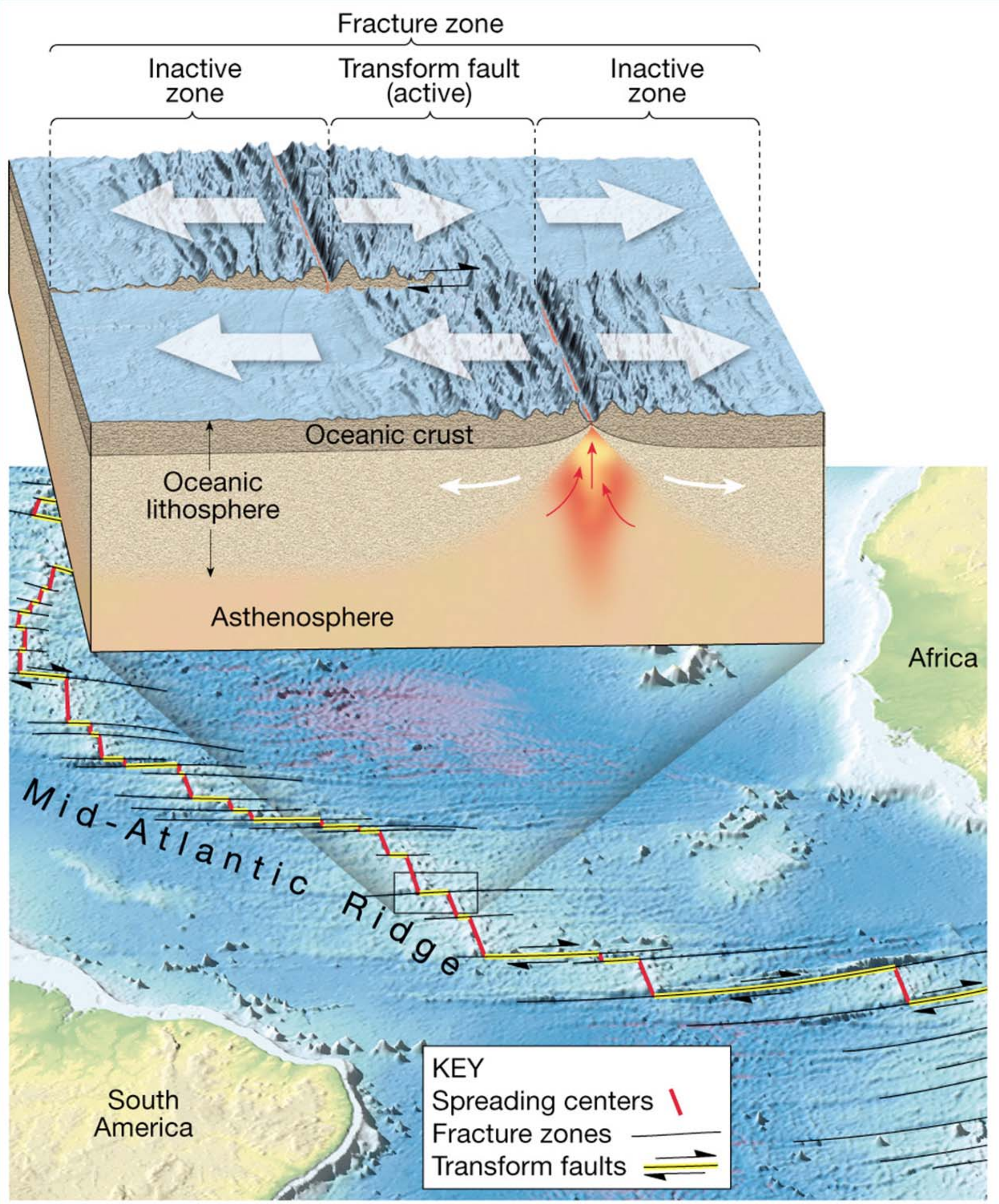
Transform faults

A few (the San Andreas fault and the Alpine fault of New Zealand) cut through continental crust









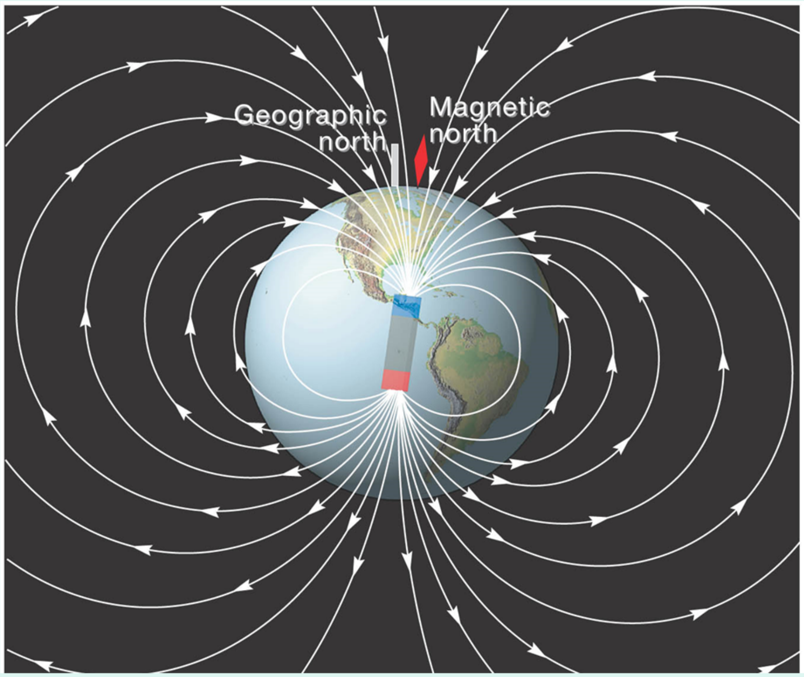
Transform Faults

Figure 5.16

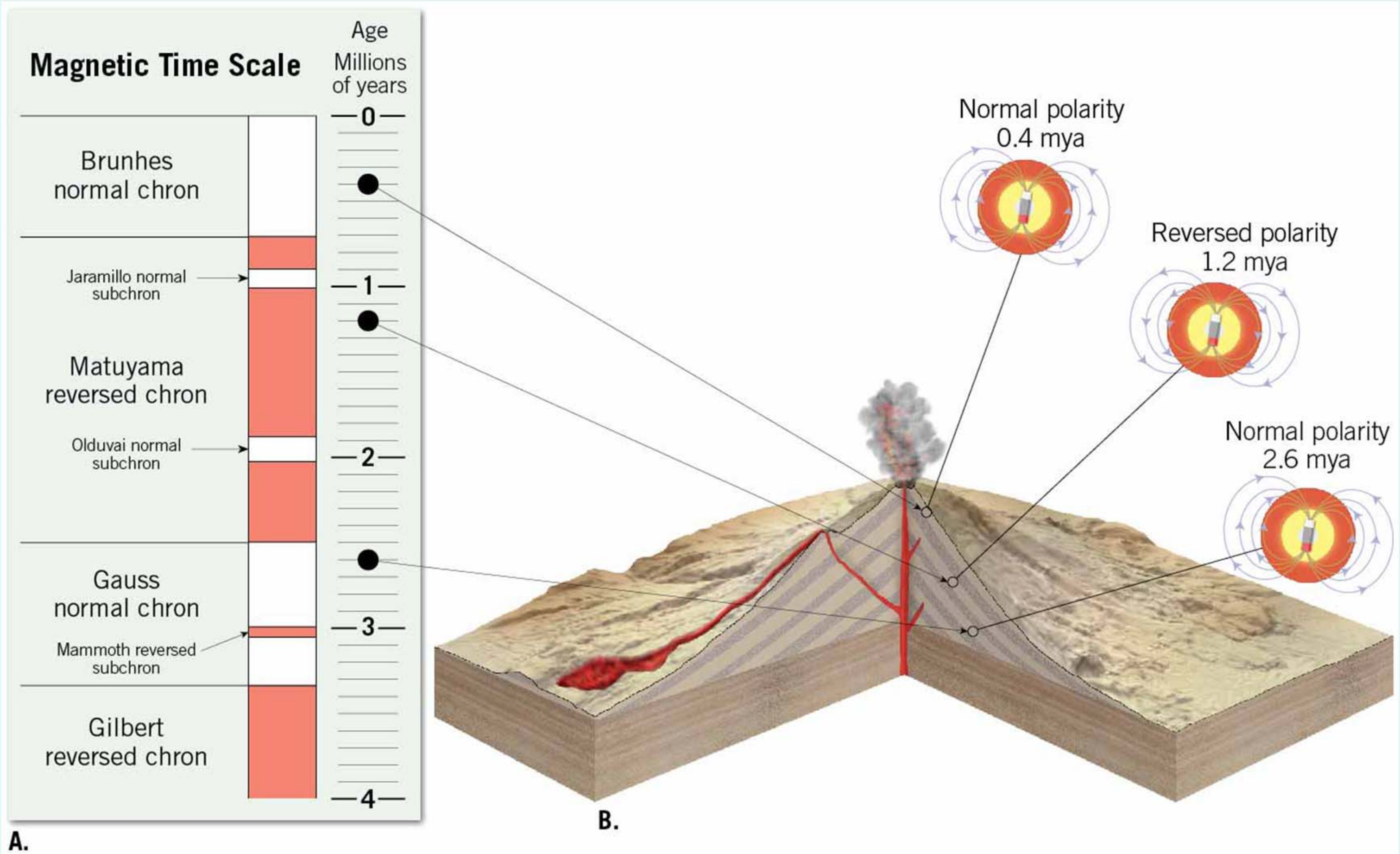
Testing the Plate Tectonic Model

Paleomagnetism

- Iron-rich minerals become magnetized in the existing magnetic field as they crystallize
- Rocks that formed millions of years ago contain a “record” of the direction of the magnetic poles at the time of their formation



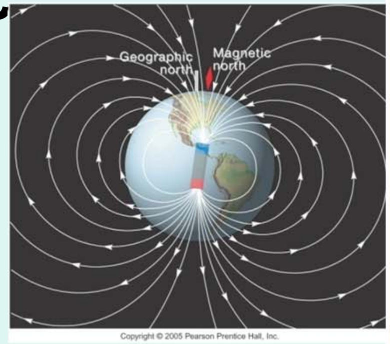
Paleomagnetism

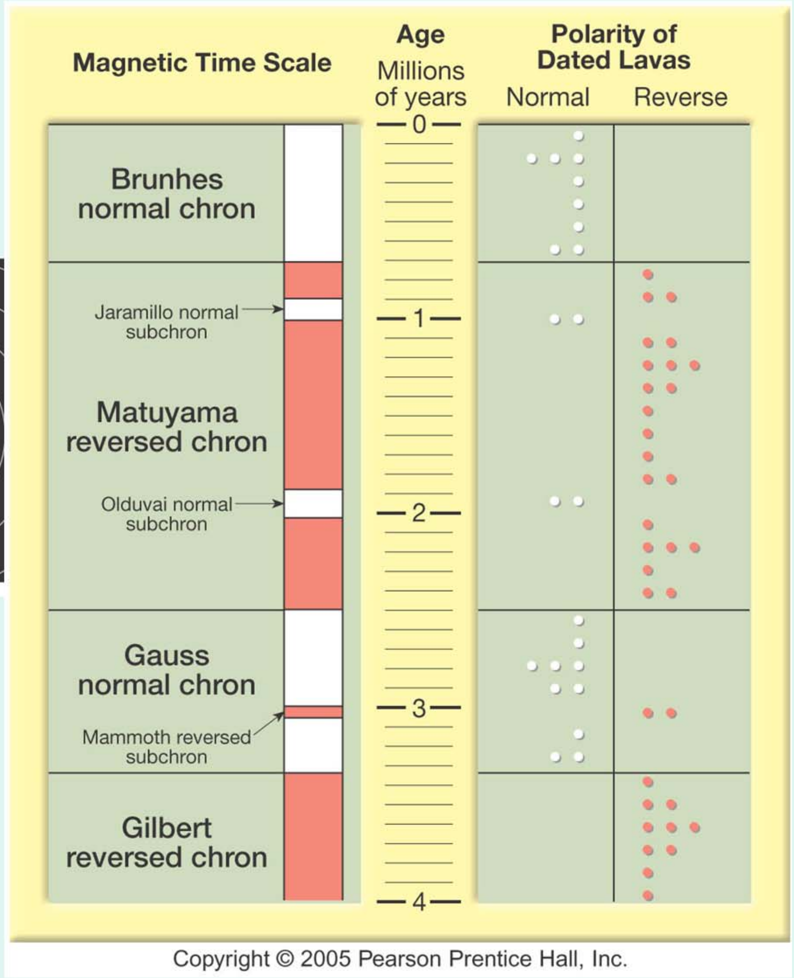


Testing the Plate Tectonics Model

Geomagnetic reversals:

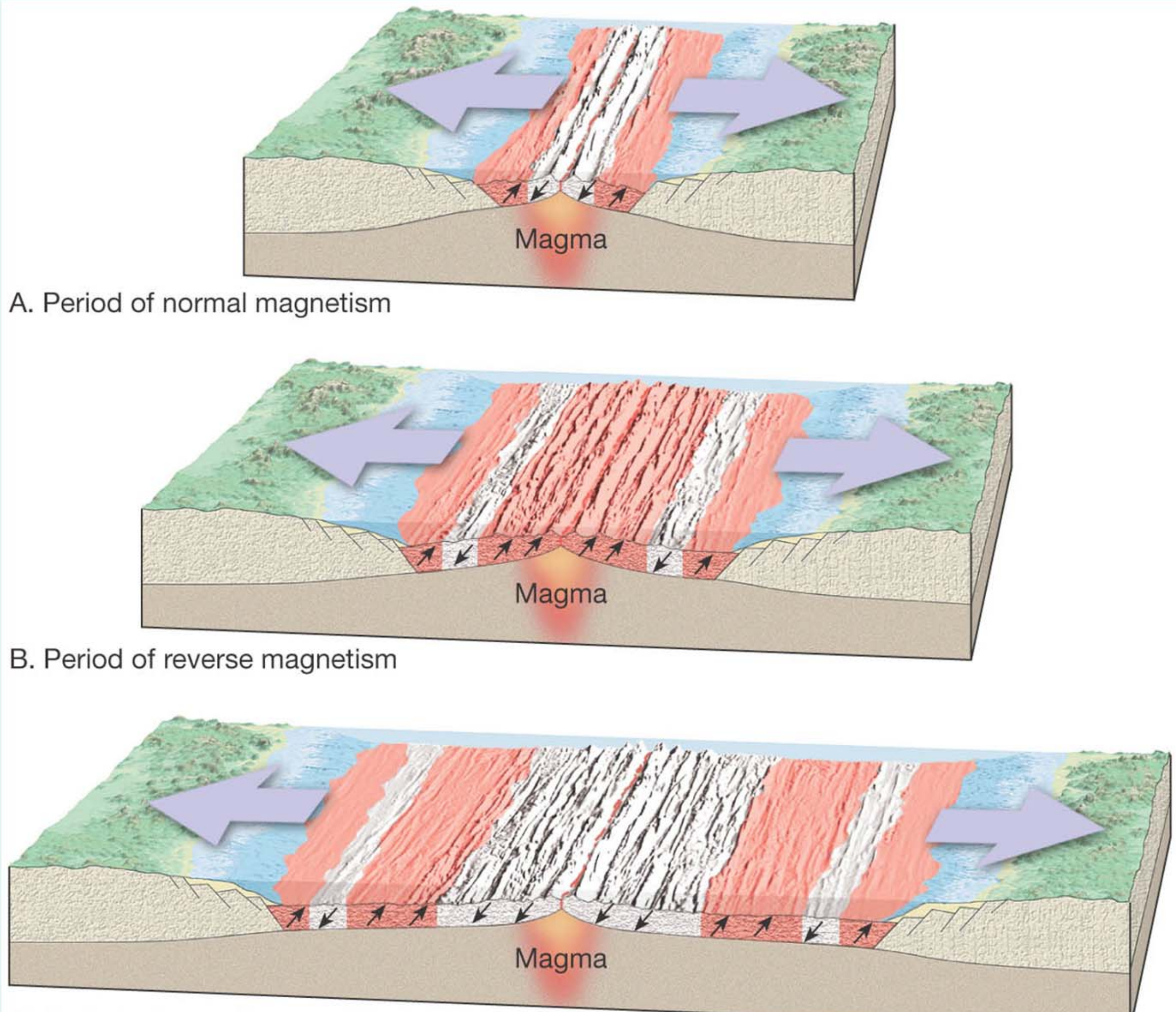
- **1) Earth's magnetic field periodically reverses polarity—The north magnetic pole becomes the south magnetic pole, and vice versa**
- **2) Dates when the polarity of Earth's magnetism changed were determined from lava flows**





Testing the Plate Tectonics Model

Geomagnetic reversals are symmetrically recorded in the seafloor



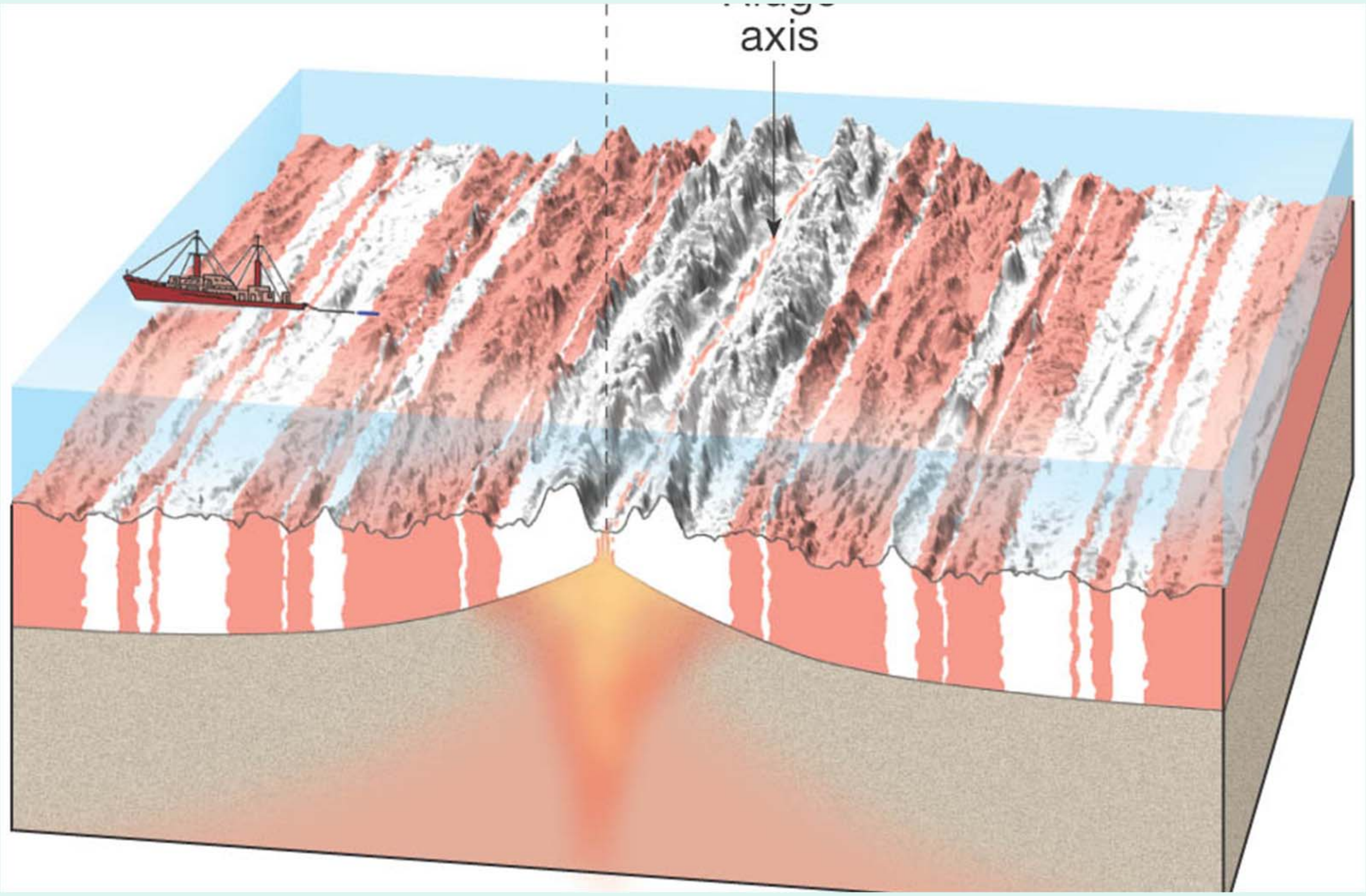
A. Period of normal magnetism

B. Period of reverse magnetism

C. Period of normal magnetism

Testing the Plate Tectonics Model

Geomagnetic reversals are symmetrically recorded in the seafloor



A scientific revolution begins

- **Geomagnetic reversals**
  - **Geomagnetic reversals are recorded in the ocean crust**
  - **In 1963 Vine and Matthews tied the discovery of magnetic stripes in the ocean crust near ridges to Hess's concept of seafloor spreading**

Paleomagnetic Reversals Recorded in Oceanic Crust

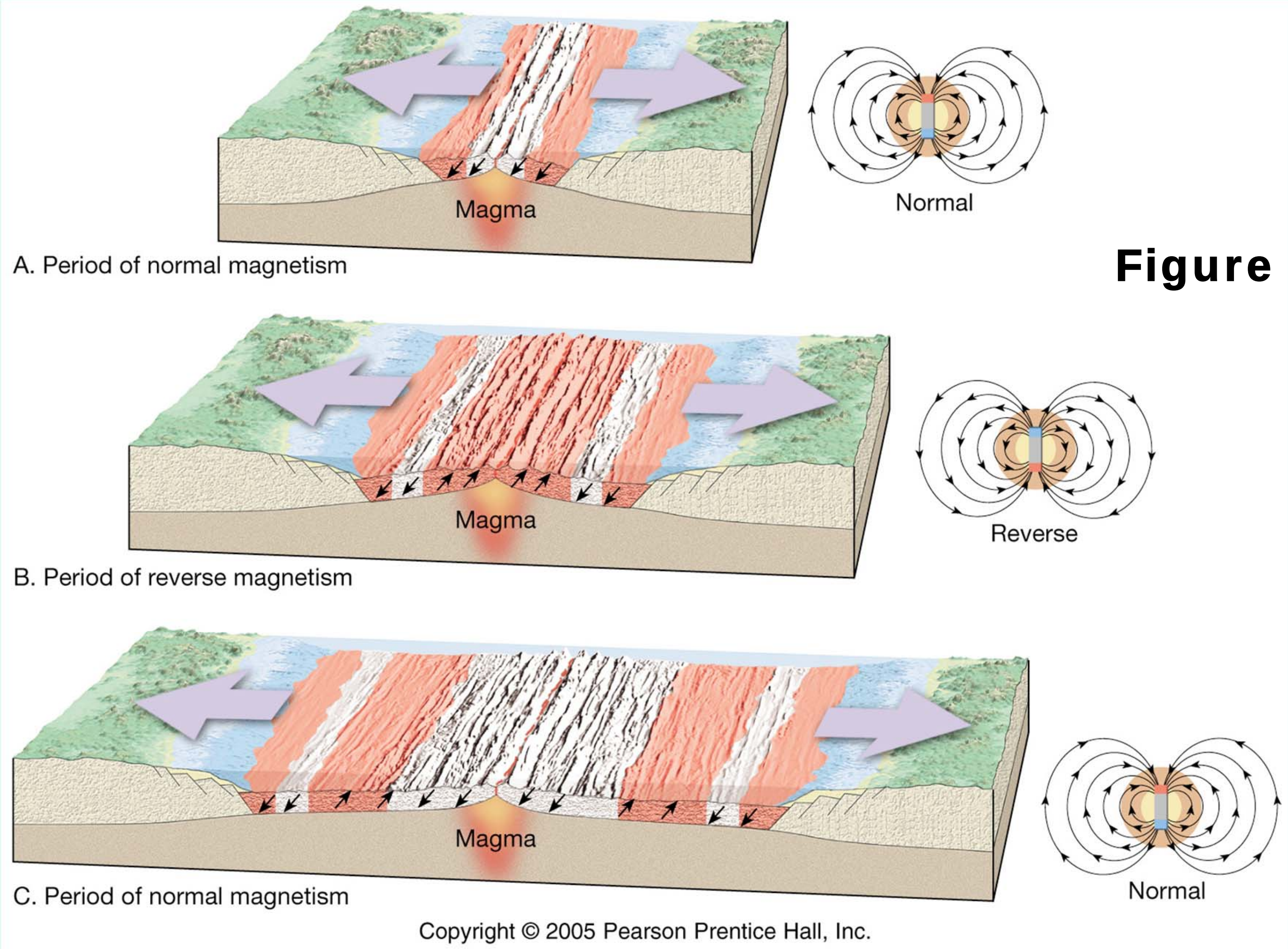
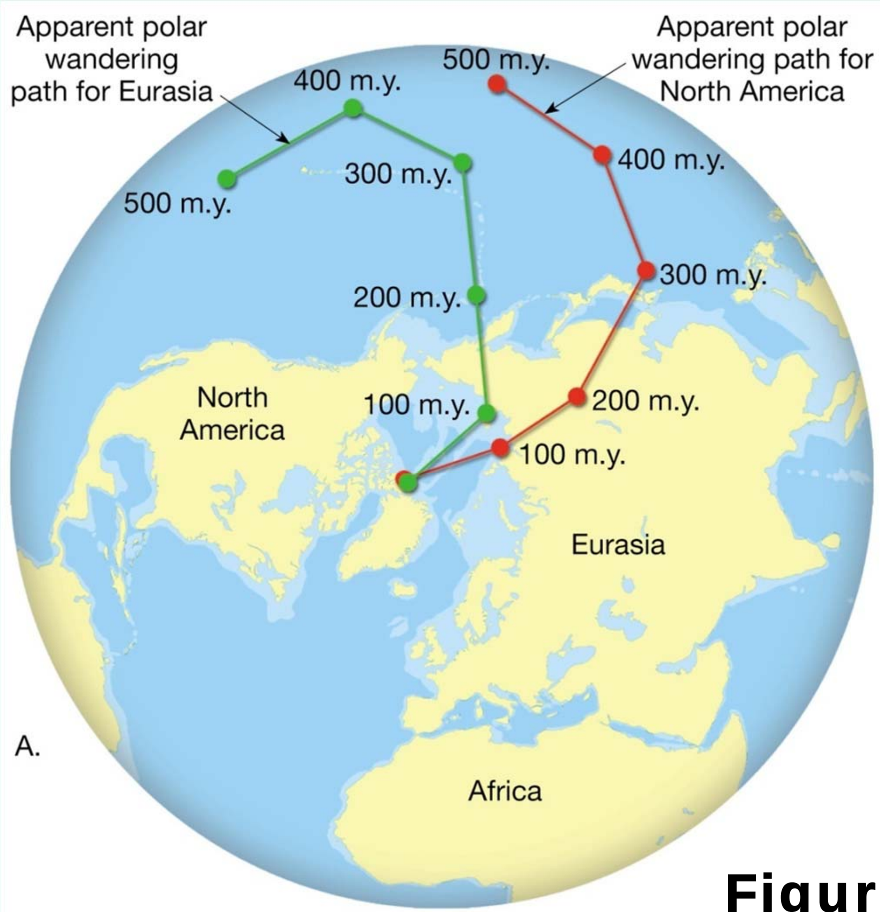


Figure 5.24

Testing the Plate Tectonics Model

- **Apparent polar wandering**
  - **Lava flows of different ages indicated several different magnetic poles**
  - **Polar wandering paths are more readily explained by the theory of plate tectonics**

Polar-Wandering Paths for Eurasia and North America



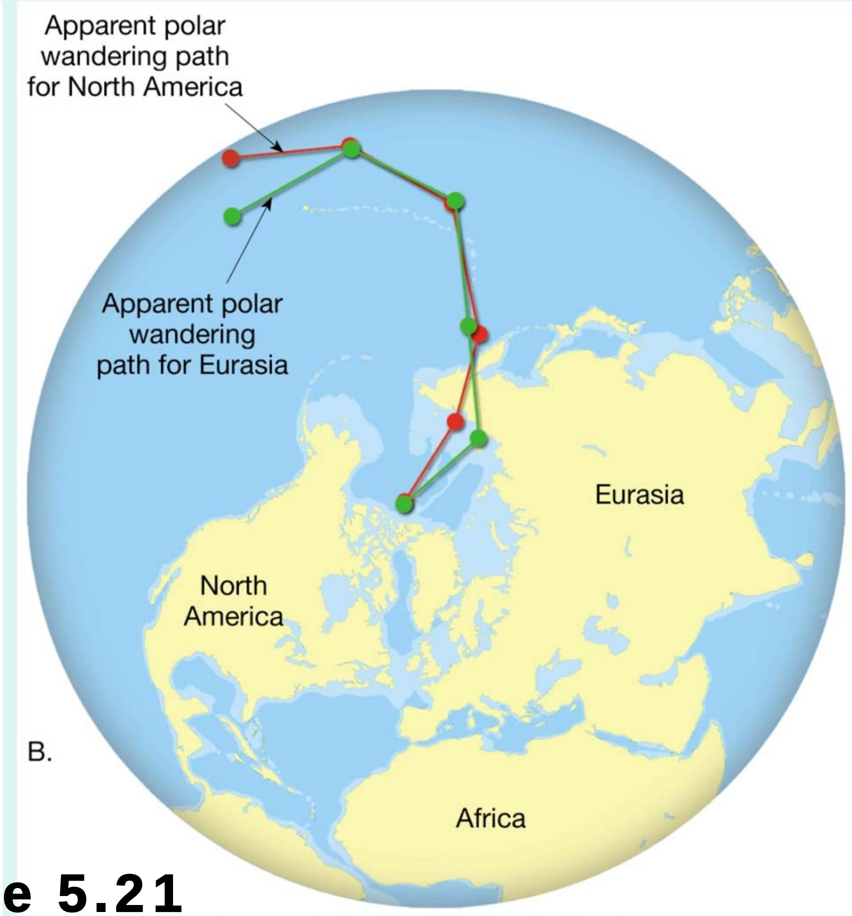
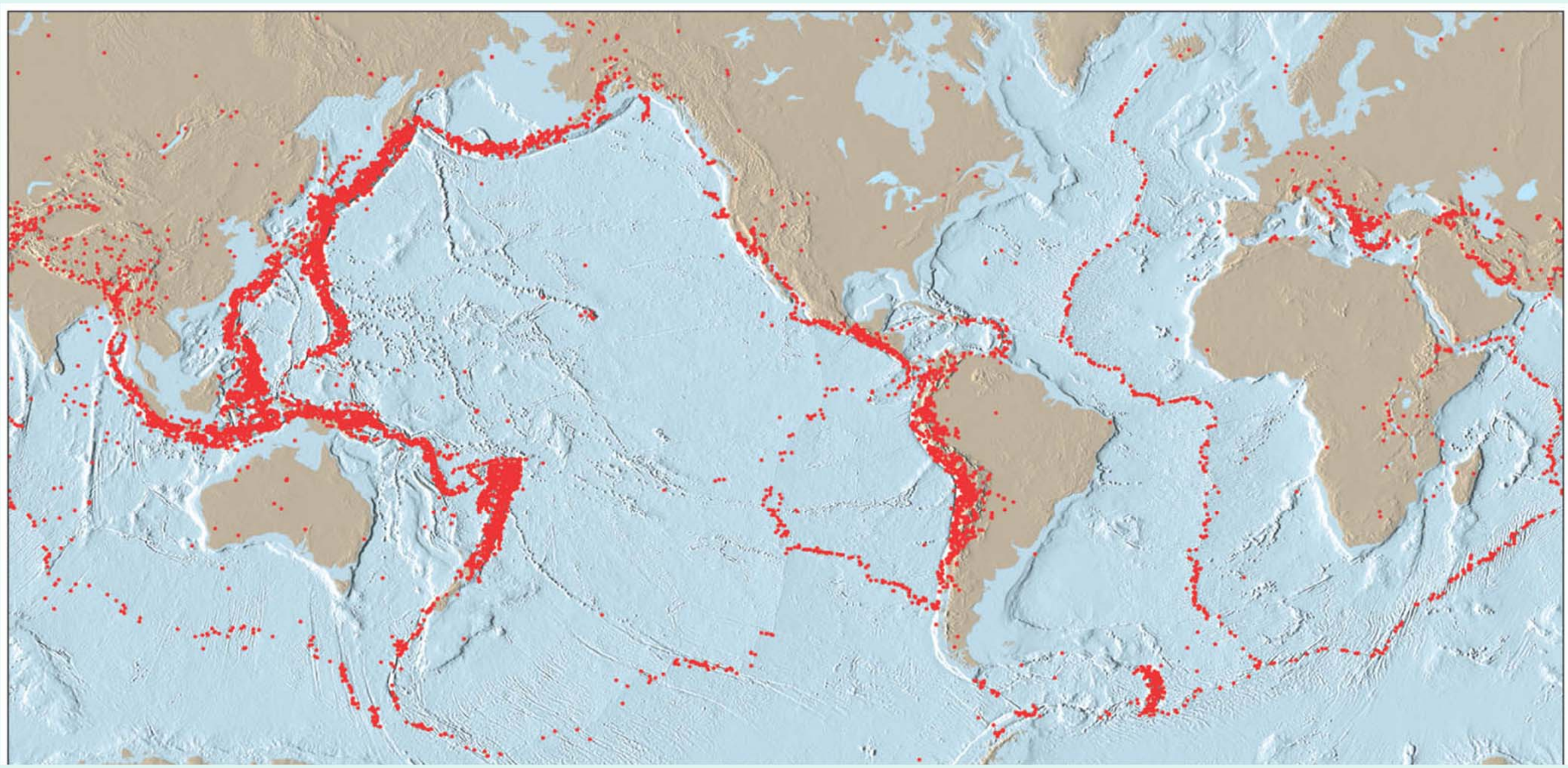


Figure 5.21

Testing the Plate Tectonics Model

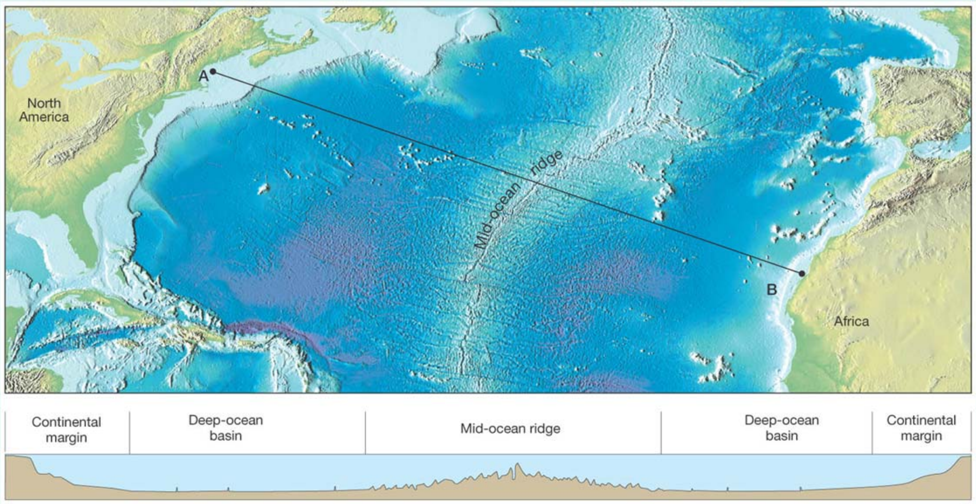
Earth Quake Patterns



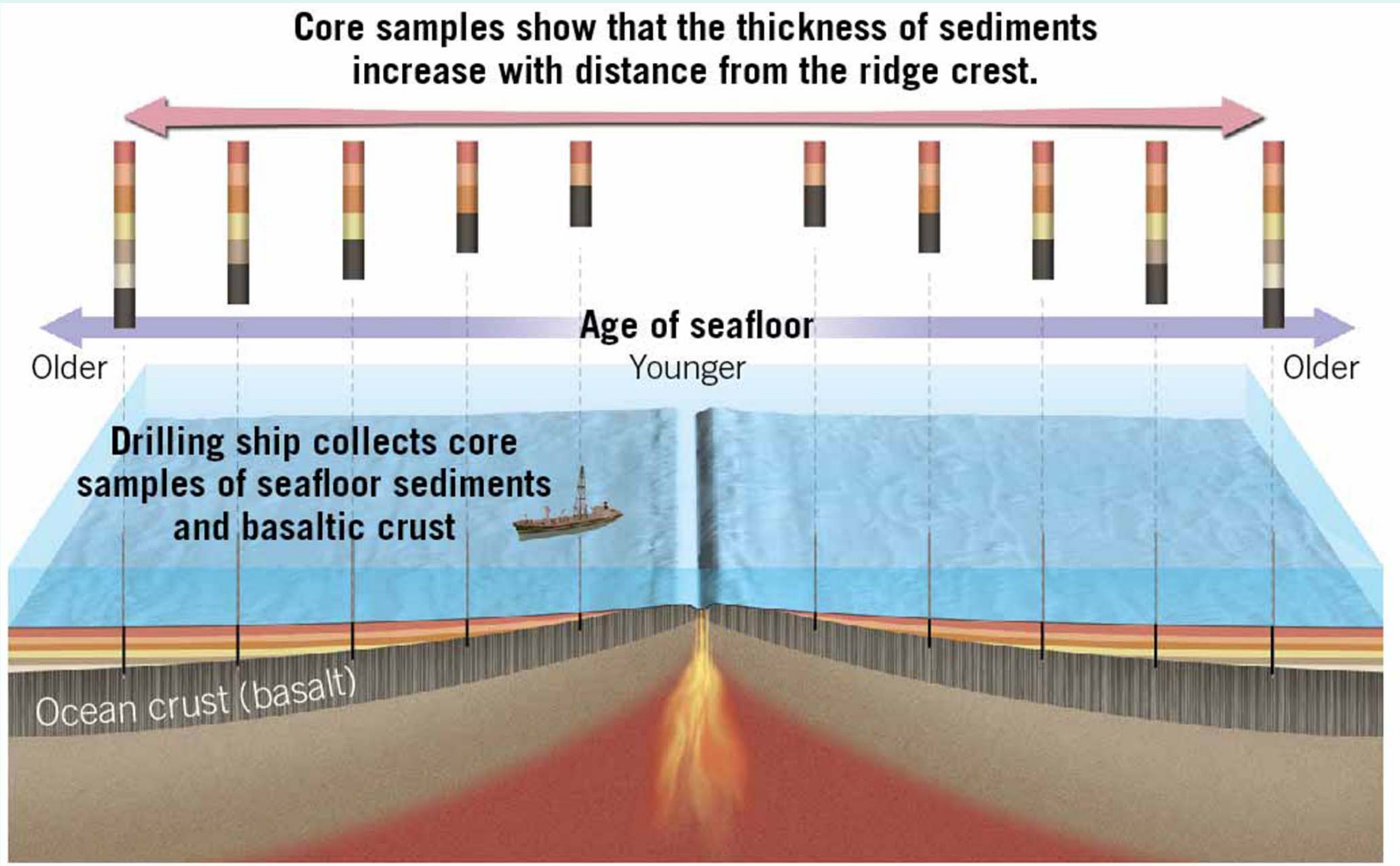
Testing the Plate Tectonics Model

Evidence from ocean drilling

- Some of the most convincing evidence confirming seafloor spreading has come from drilling directly into ocean-floor sediment
  - Age of deepest sediments
  - Thickness of ocean-floor sediments verifies seafloor spreading



Testing the Plate Tectonics Model



Testing the Plate Tectonics Model

- ***Hot spots*** **and** ***mantle plumes***
  - **Caused by rising plumes of mantle material**
  - **Volcanoes can form over them (Hawaiian Island chain)**
  - **Mantle plumes**
    - **Long-lived structures**
    - **Some originate at great depth, perhaps at the mantle-core boundary**

The Hawaiian Islands

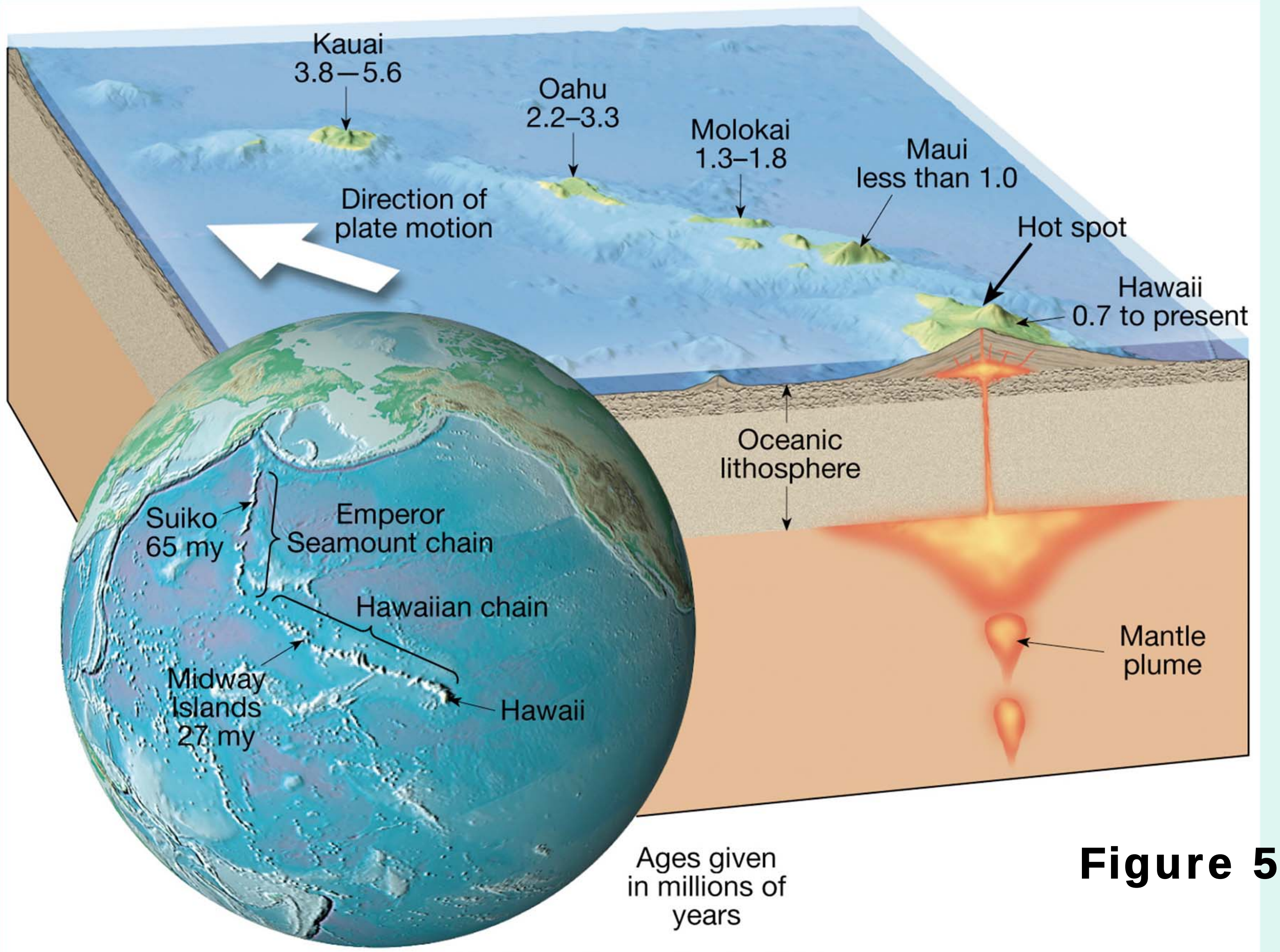
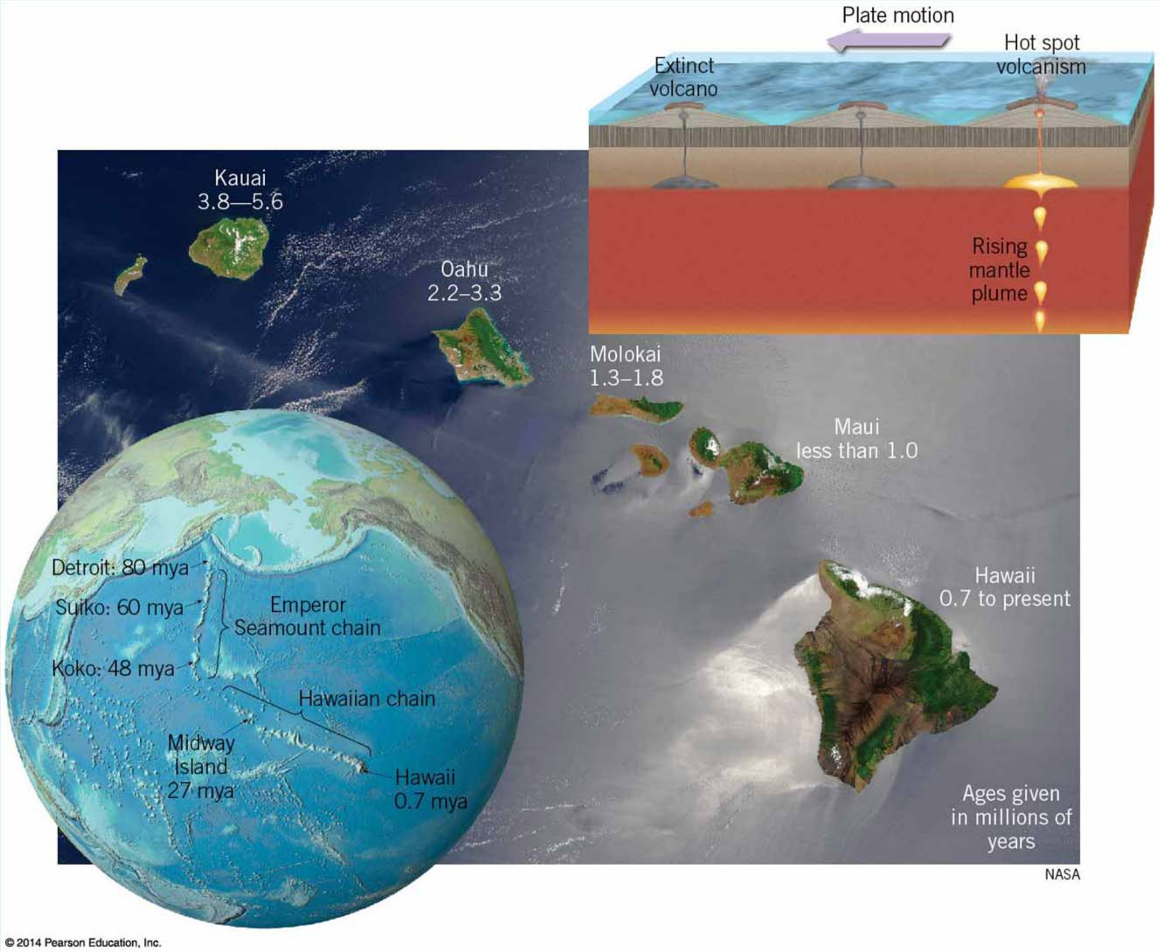


Figure 5.19

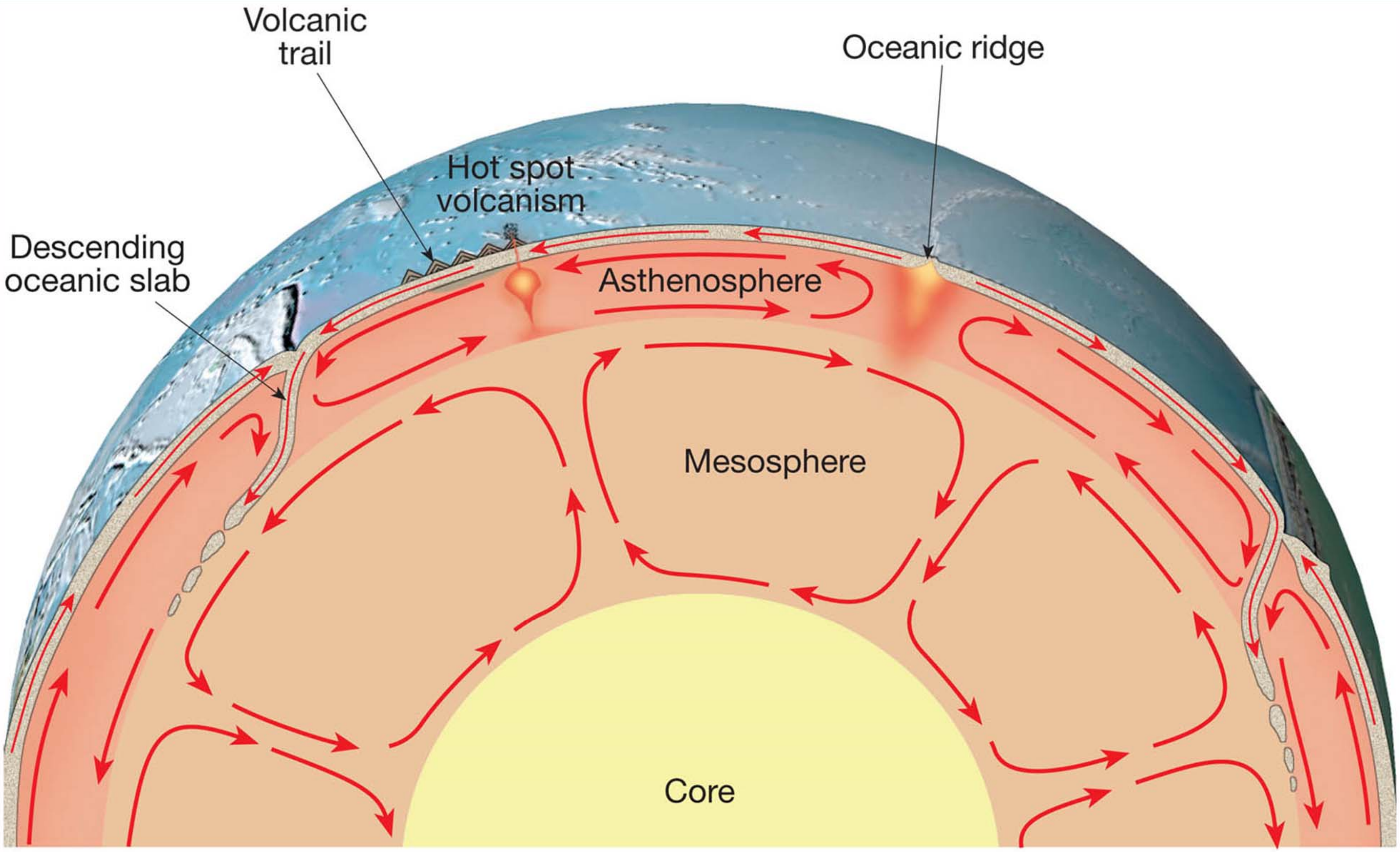
The Hawaiian Islands



What Drives Plate Motions

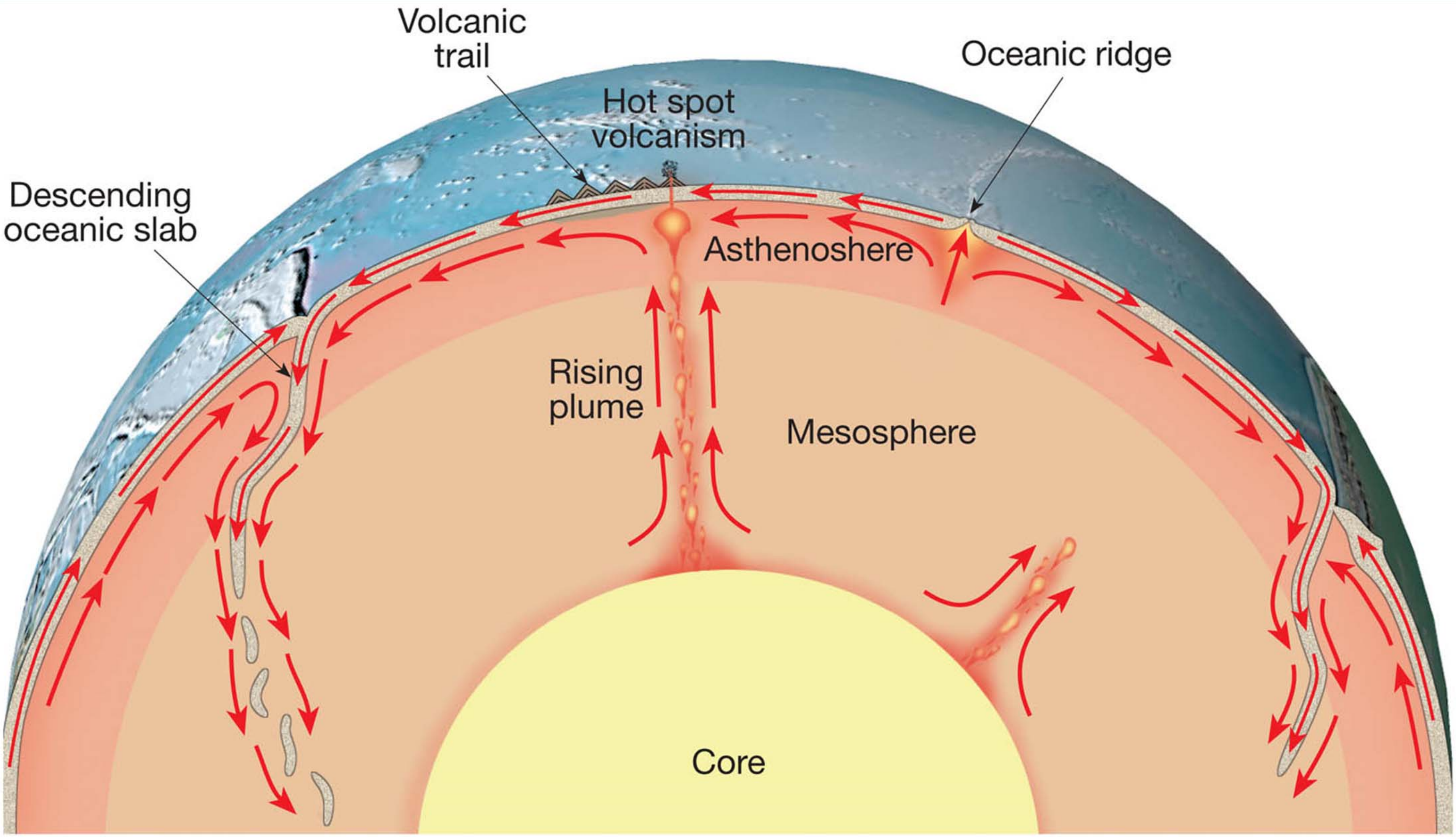
- **Researchers agree that convective flow in the mantle is the basic driving force of plate tectonics**
- **Forces that drive plate motion**
  - ***Slab-pull***
  - ***Ridge-push***
  - ***Slab suction***

Convection Cells



A. Layering at 660 kilometers

Convection Cells



B. Whole-mantle convection

Forces Driving Plate Motions

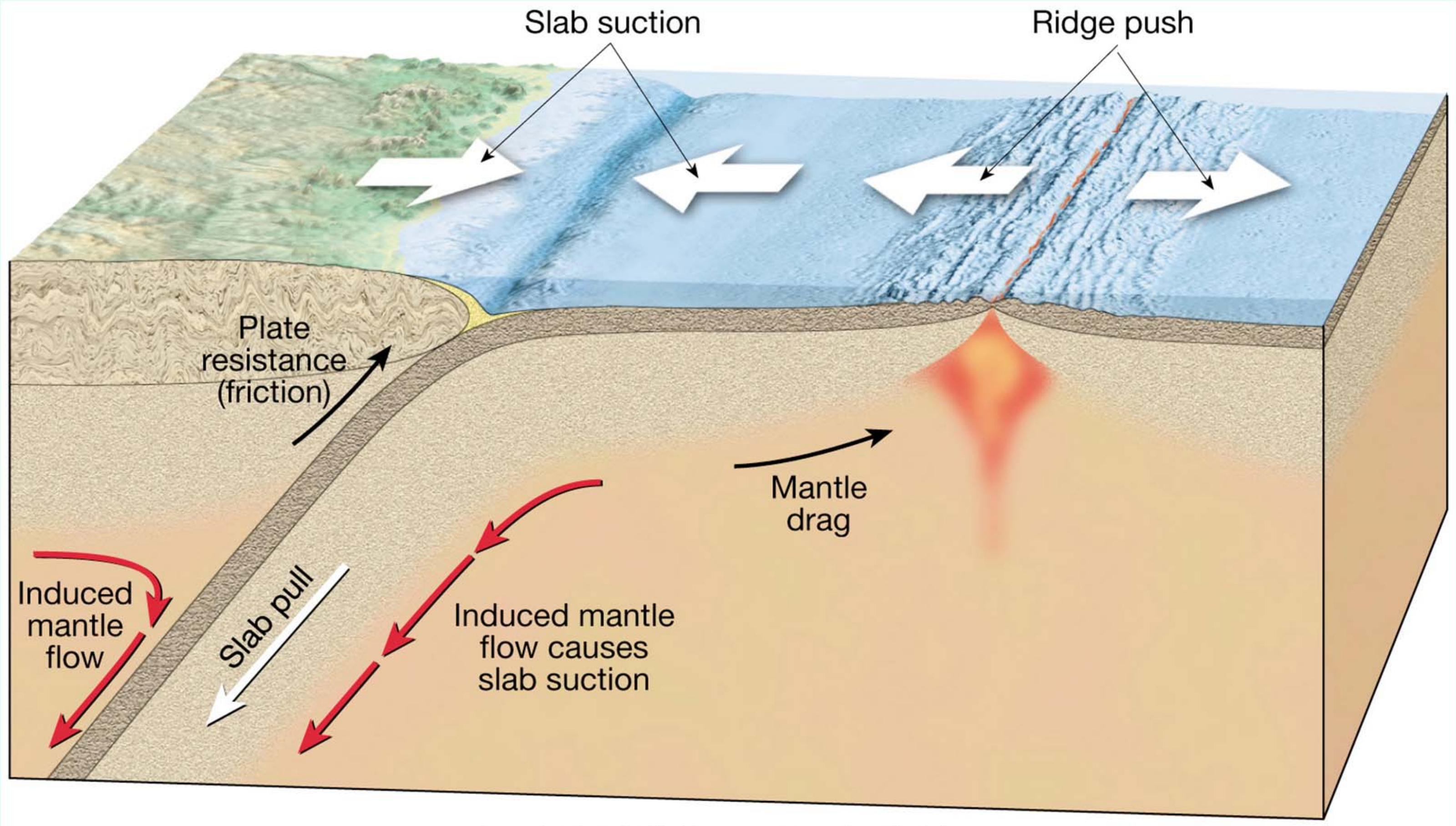
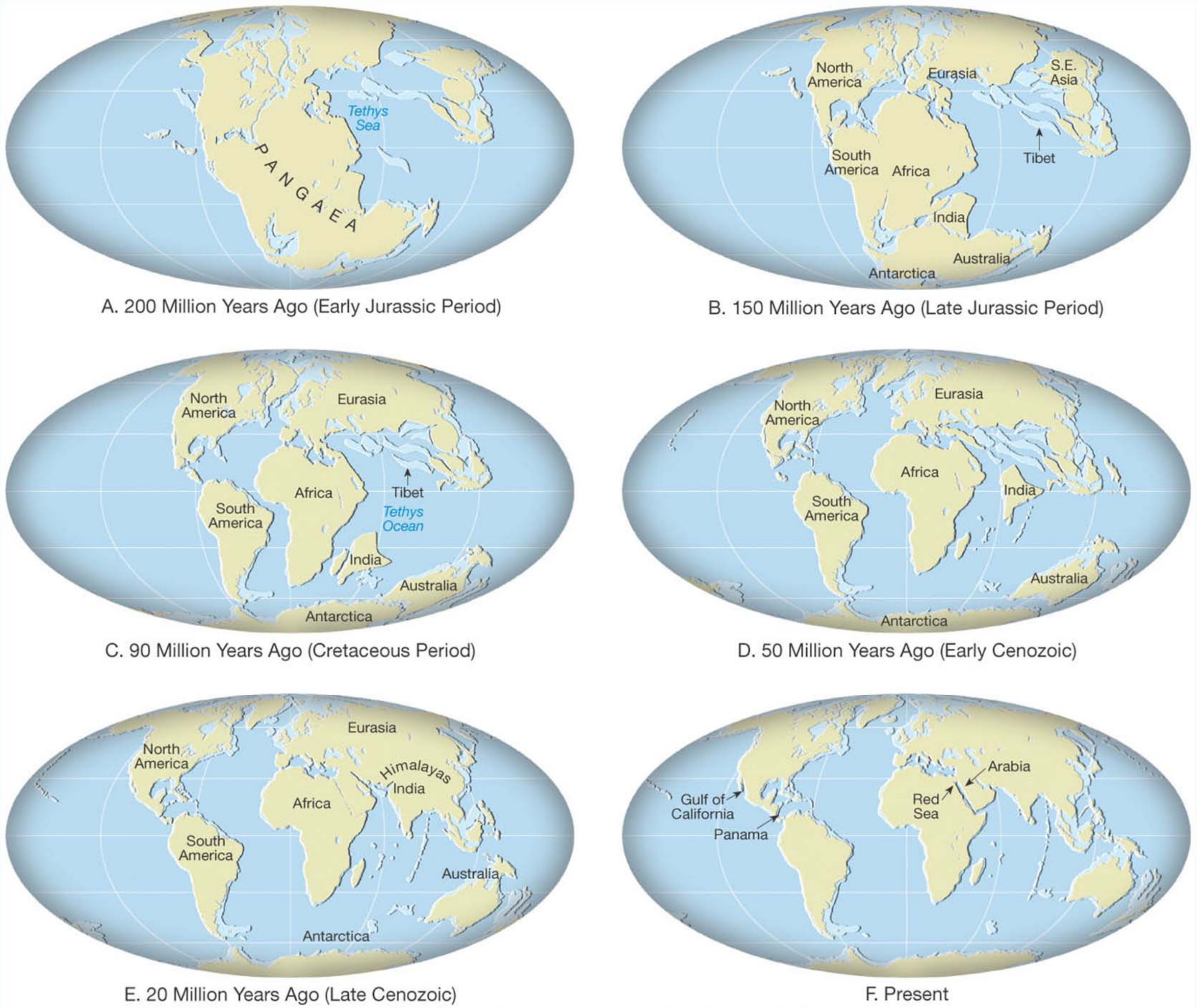


Figure 5.27

Past Plate Positions



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End of Chapter 5