# Topic 2: The lithosphere and the tectonic system

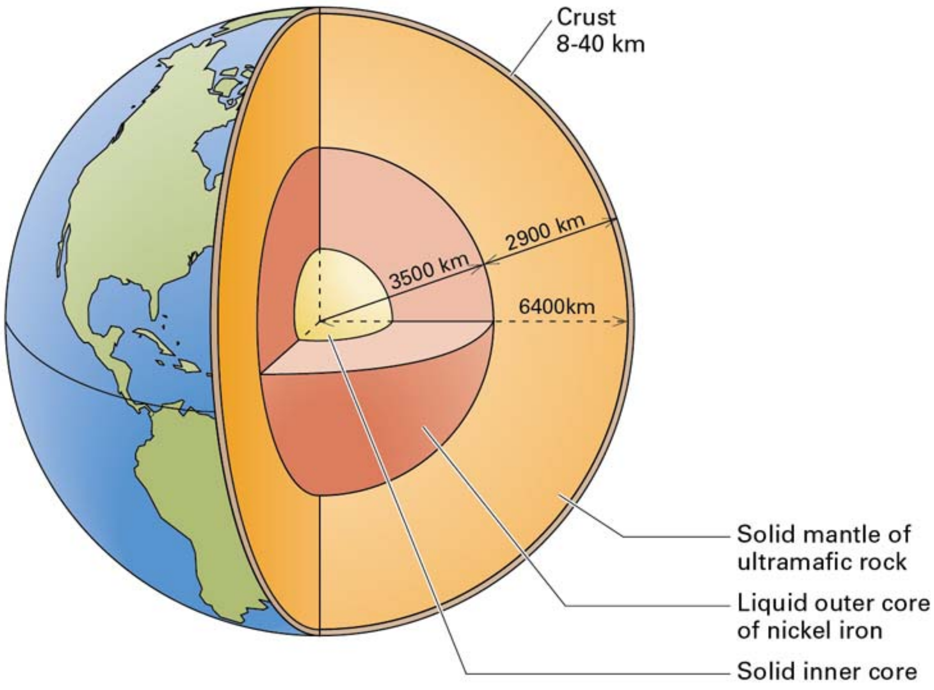
# Outline

- Read chapter 12
- Internal Earth structure
- Geologic timescale and Earth history
- Major relief features of the Earth
- Lithospheric plates, plate movements and boundaries

# Earth internal structure

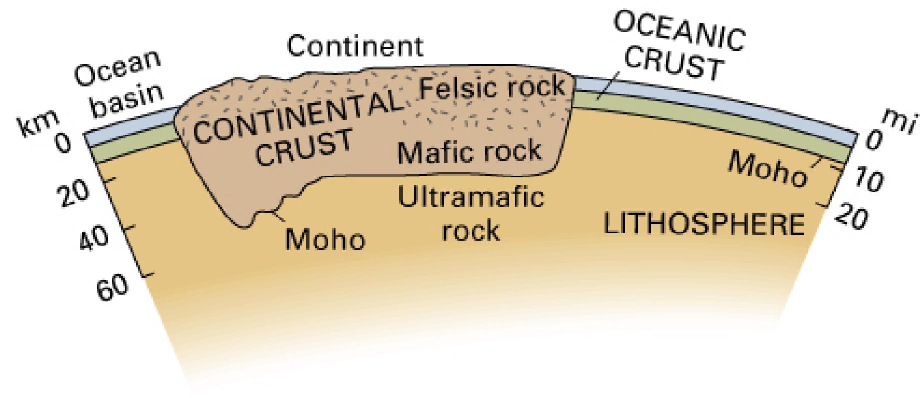
**Three main zones, arranged as roughly concentric shells:**

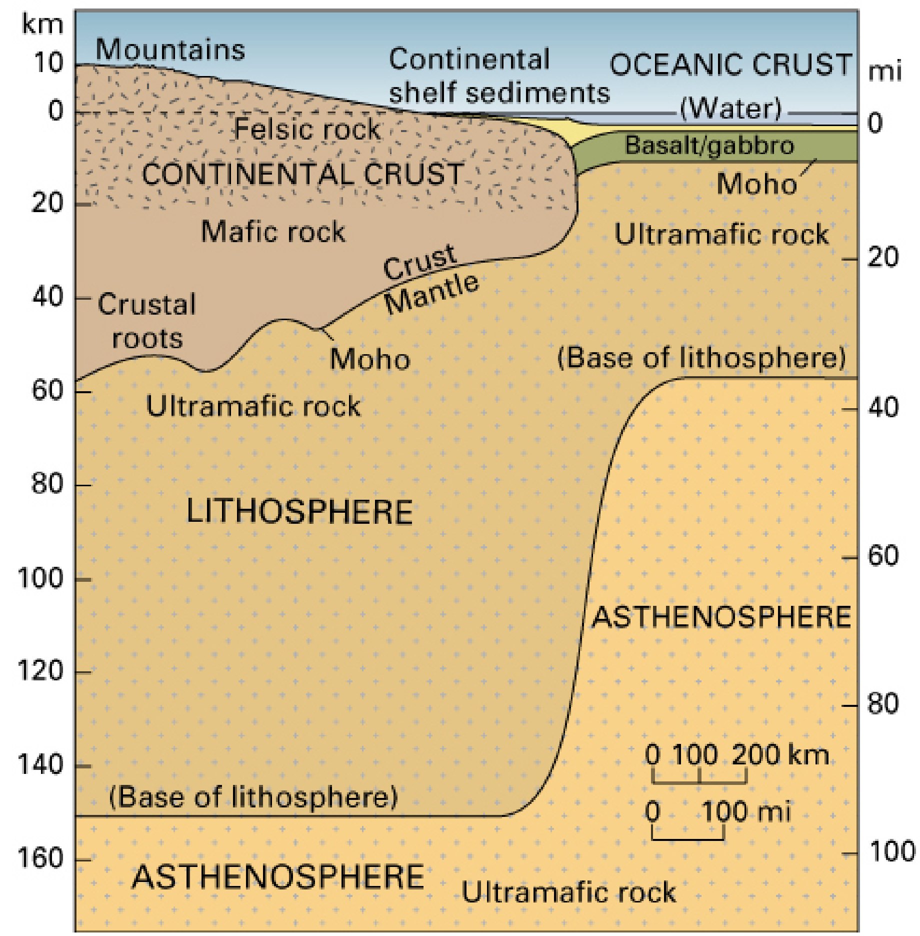
- **Crust/lithosphere**
- **Mantle**
- **Core**



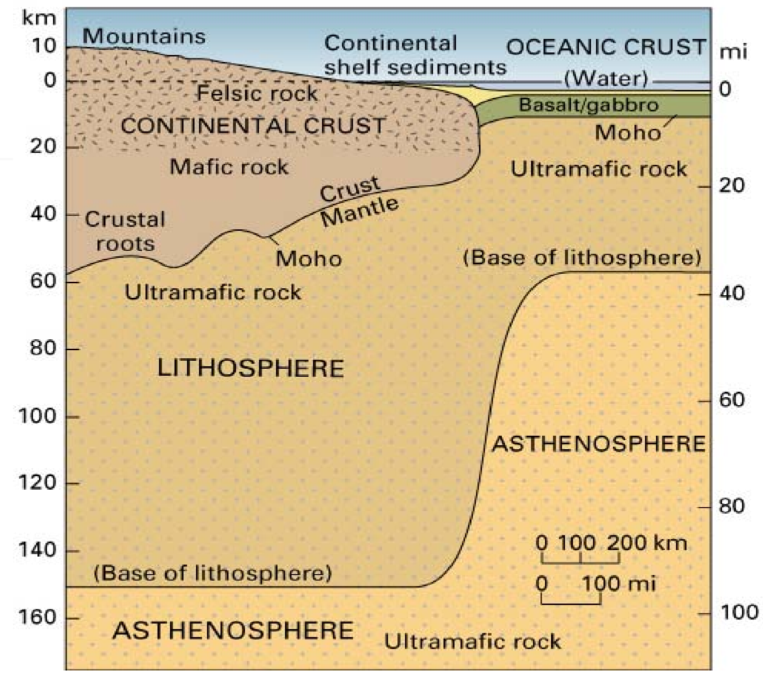
# Crust

- Boundary between crust and mantle is sharp; known as the Mohorovicic Discontinuity (Moho)
- It marks a change in density
- Crustal composition:
  - Continental Crust:
    - ~ 35 km thick
    - Two layers - upper felsic and lower mafic (indistinct boundary between them).
  - Oceanic Crust:
    - ~ 7 km thick
    - Composed of mafic rocks – upper basalt and lower gabbro



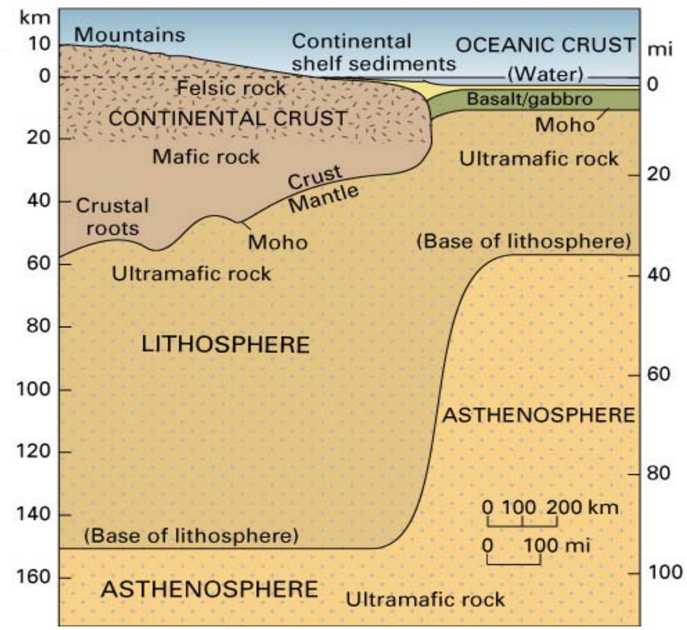
# Lithosphere




- **Complication: There are 2 major layers in outer part of earth**
  - **→ lithosphere and asthenosphere**
  - **They overlap the crust/mantle boundary.**

- ***Lithosphere*:**
  - **Geological term describing the outer, rigid rocky shell of the crust and outer mantle (60-150 km thick)**
  - **Includes felsic, mafic and ultramafic rocks.**

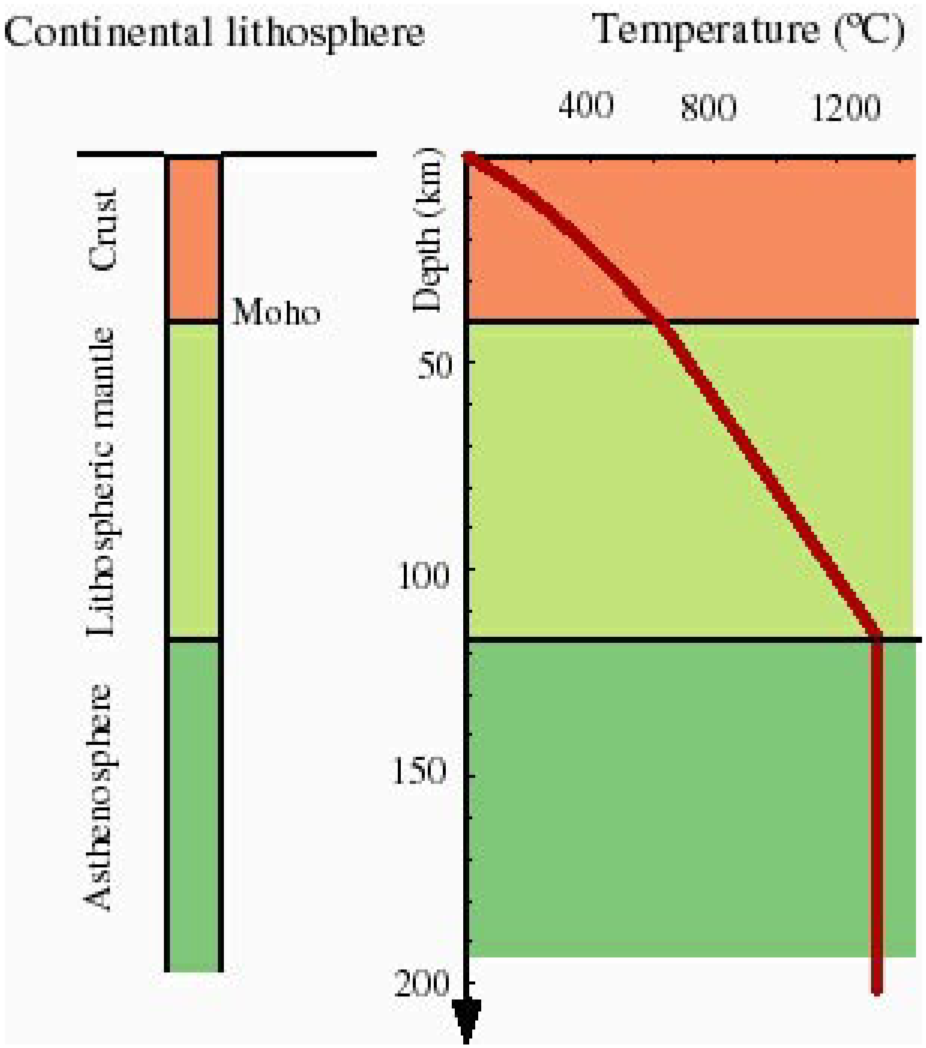
# Asthenosphere

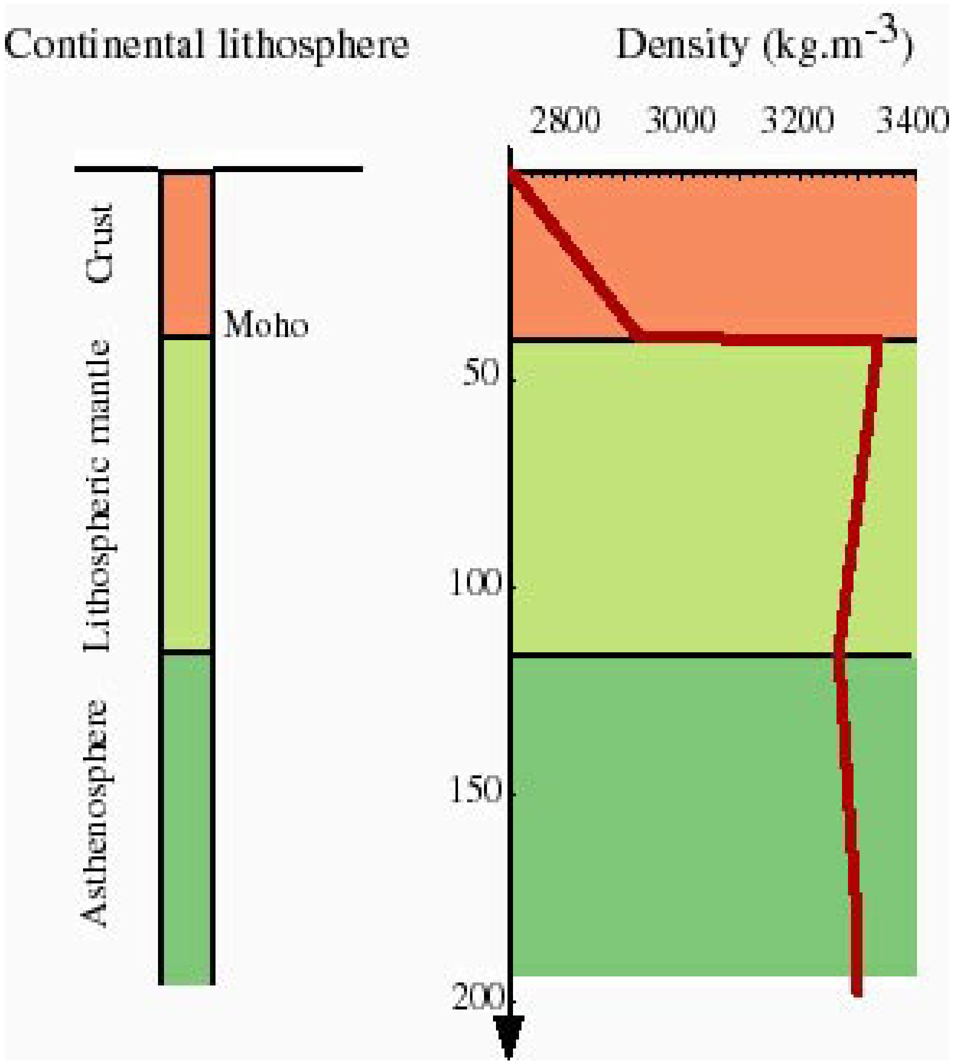



- Heating of rocks below lithosphere results in "plastic" or soft rocks.
- Thin layer between solid lower and upper mantle.
- Rocks are denser (mafic and ultramafic).

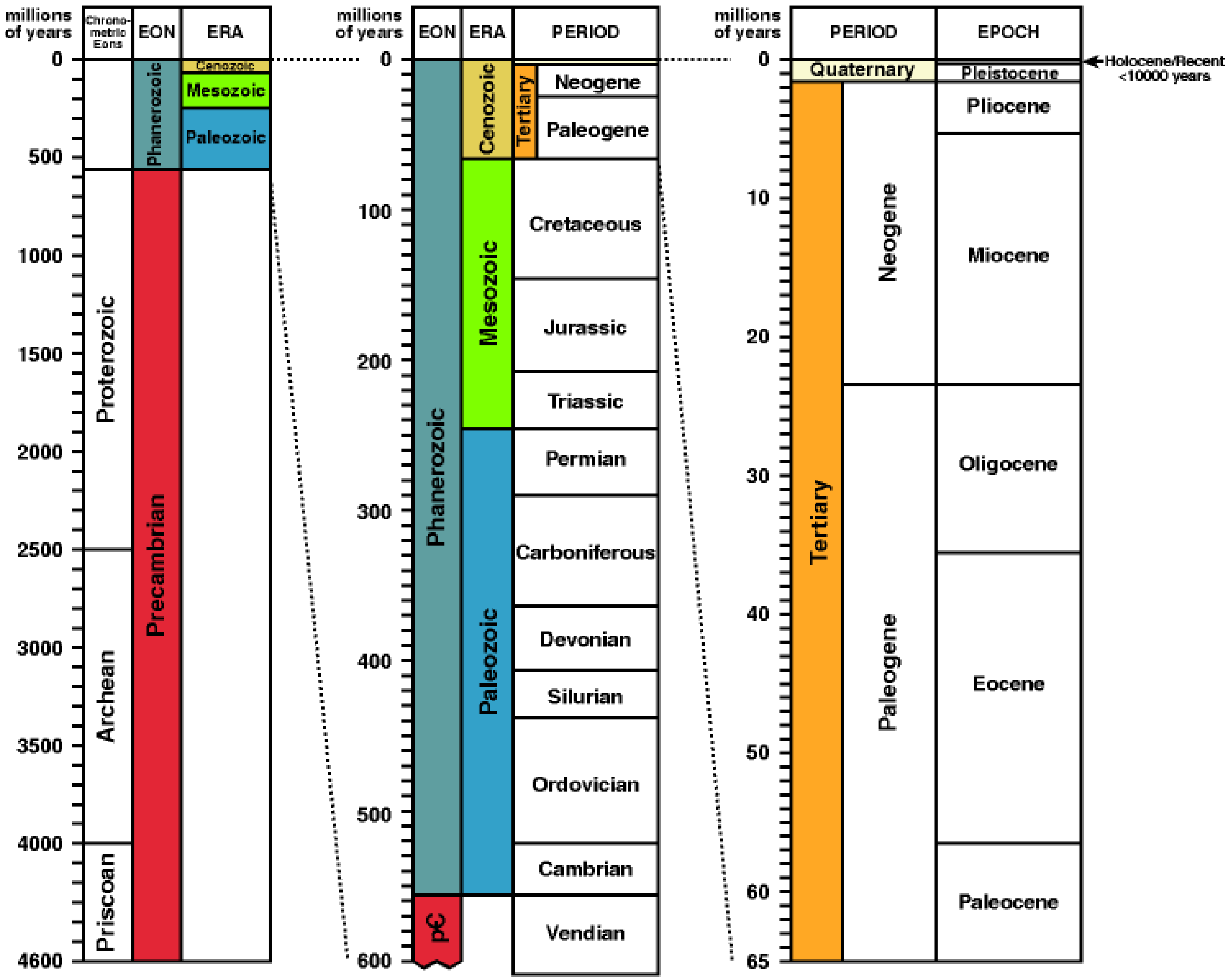
- SCALE NOTE: lithosphere and asthenosphere form a thin (300 km) skin over the earth (about 5% of its total thickness)
- Within this, most of the earth's surface relief (from high mountains to low ocean floors) is contained in upper 10 km – 0.2% of total thickness!

# Lithosphere: temperature and density



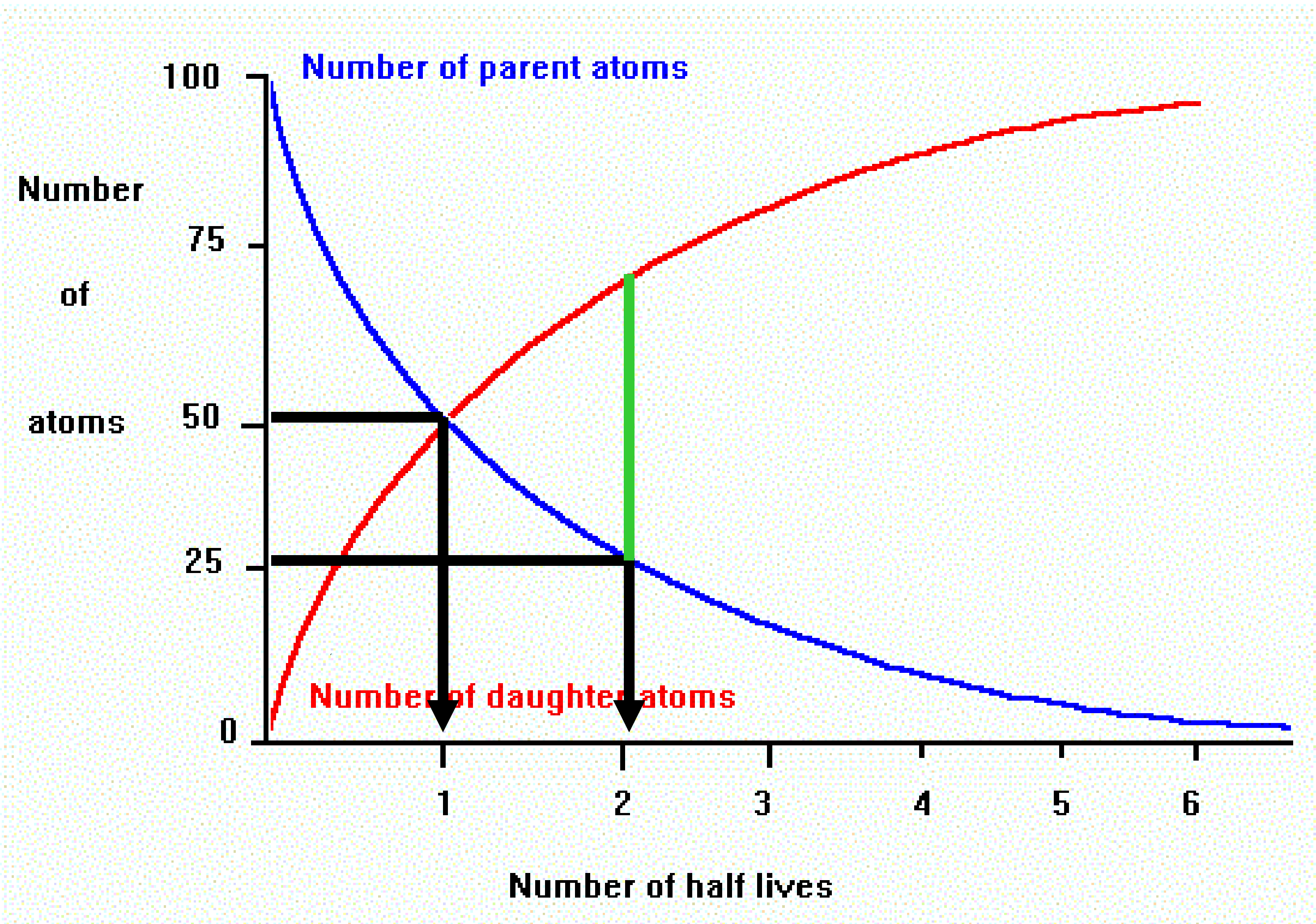
# Geologic Time Scale



# Radiometric dating

- The earth interior is largely heated by decay of radioactive isotopes elements
- Some elements are found in forms with different mass numbers (e.g., uranium $^{248}U$ and $^{235}U$
- Certain isotopes are unstable
  - Leads to an irreversible change
  - This change is called radioactive decay (exponential with time)
  - Example $^{238}U \rightarrow {}^{234}Th$ (thorium)
  - The rate of decay is measured by half life (the time that it take the number of atoms to be reduced by half)

# Radiometric dating



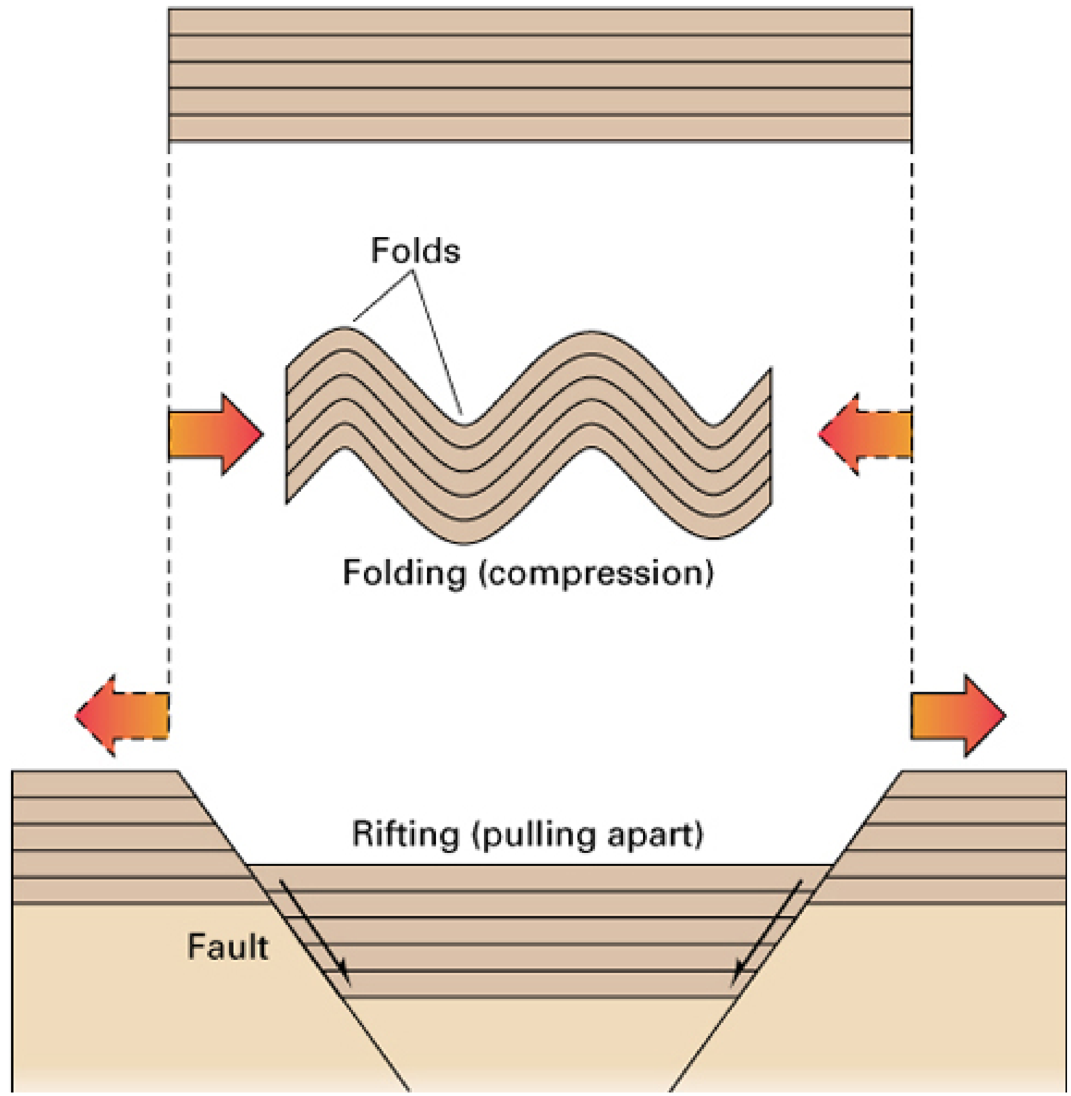
# Some of the principle isotopes used in radiometric dating

| Isotopes | | Half-life of parent (yr) | Effective dating range (yr) | Materials that can be dated |
|---|---|---|---|---|
| Parent | Daughter | | | |
| Uranium 238 | Lead 206 | 4.5 billion | 10 million to 4.6 billion | Zircon, Uraninite, Pitchblende |
| Uranium 235 | Lead 207 | 710 million | 10 million to 4.6 billion | |
| Potassium 40 | Argon 40<br>Calcium 40 | 1.3 billion | 100, 000 to 4.6 billion | Volcanic rocks<br>Biotite, Hornblende |
| Rubidium 87 | Strontium 87 | 47 billion | 10 million to 4.6 billion | Metamorphic rocks<br>Biotite, Muscovite |
| Carbon 14 | Nitrogen 14 | 5730 +- 30 | 100 to 50, 000 | Wood, peat, grain, cloth, shell, bone, goundwater |

# Tectonic activity

- Two basic types of tectonic activity:

1. compression causes folding act at converging boundaries fold the rock → alpine mountain chain
2. extension causes faults by rifting →occurred where mid ocean plates spreading

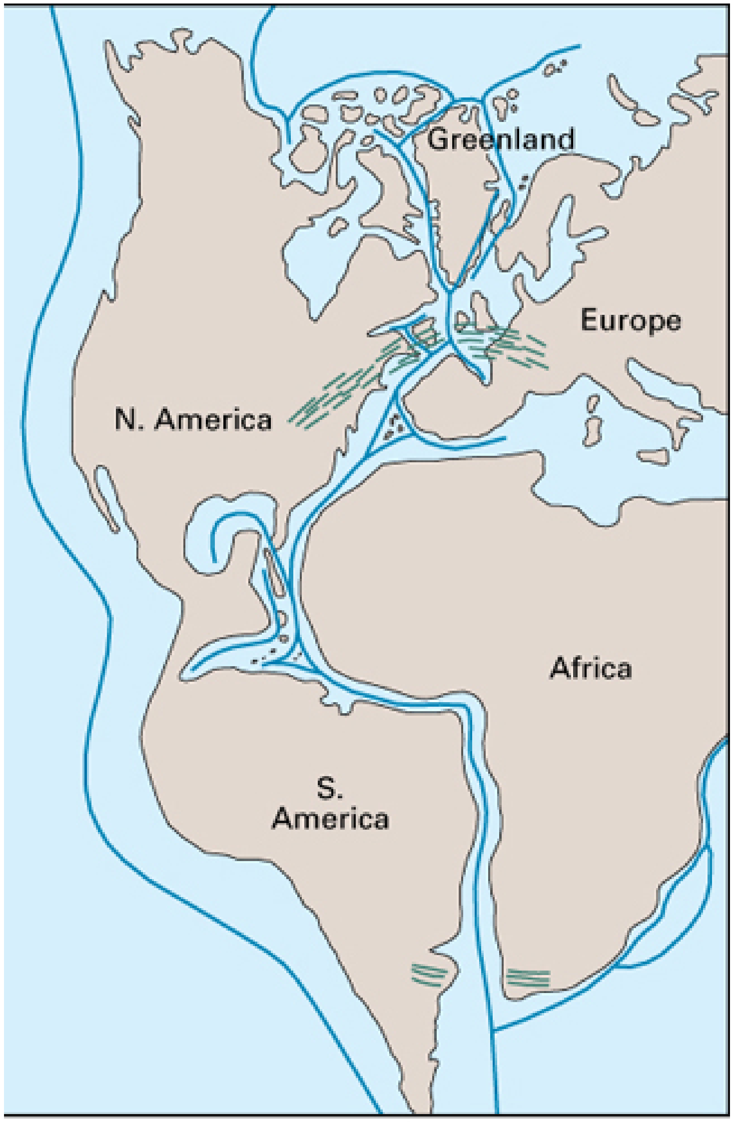


# Continents of the past: Continental Drift 1

- Alfred Wegener (1915) proposed that landmasses were once united as a single great continent, Pangea, surrounded by a single great ocean, Panthalassa.

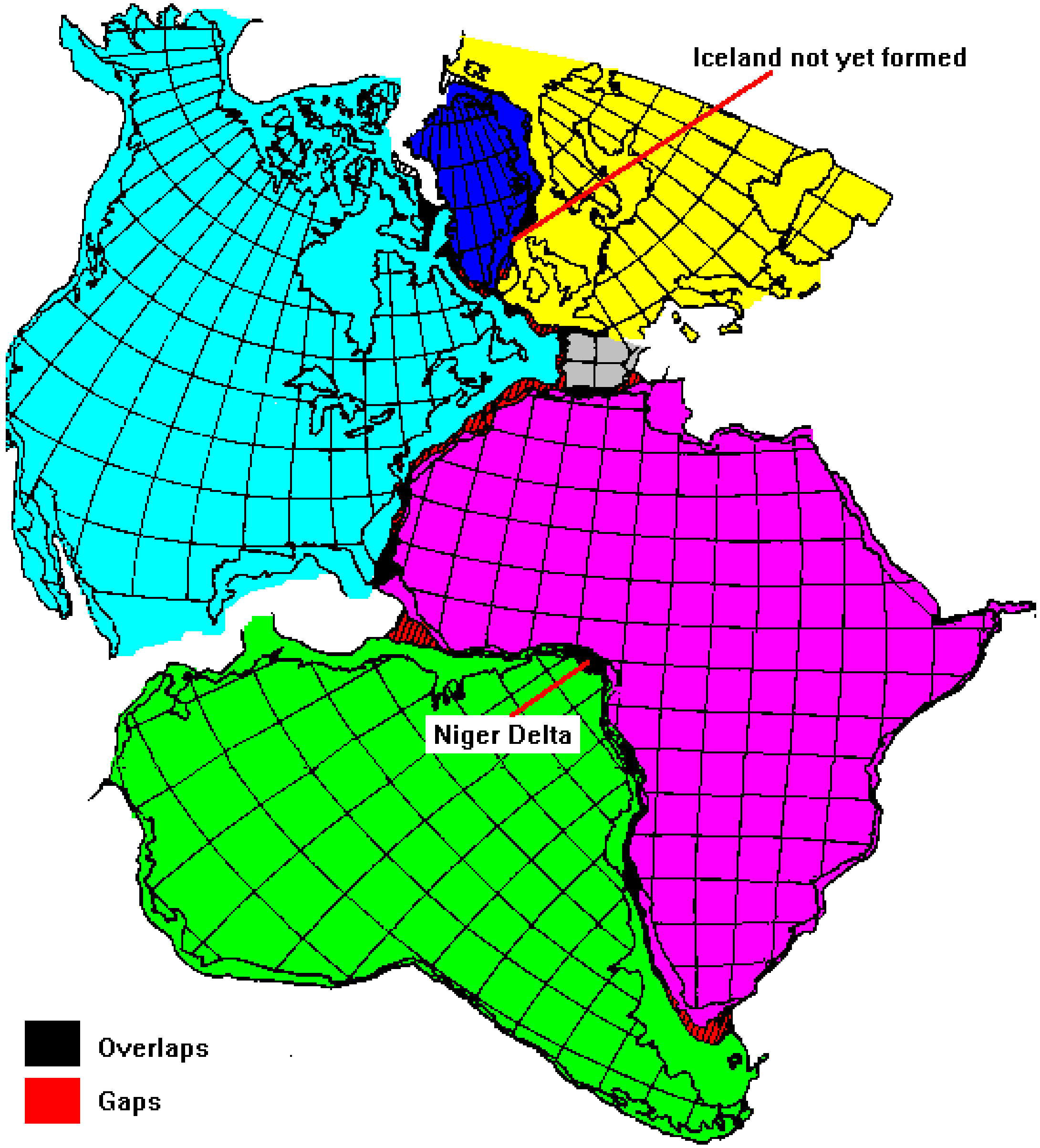
- Pangea broke apart over hundreds of millions of years ago because of development of rift zones within continents.

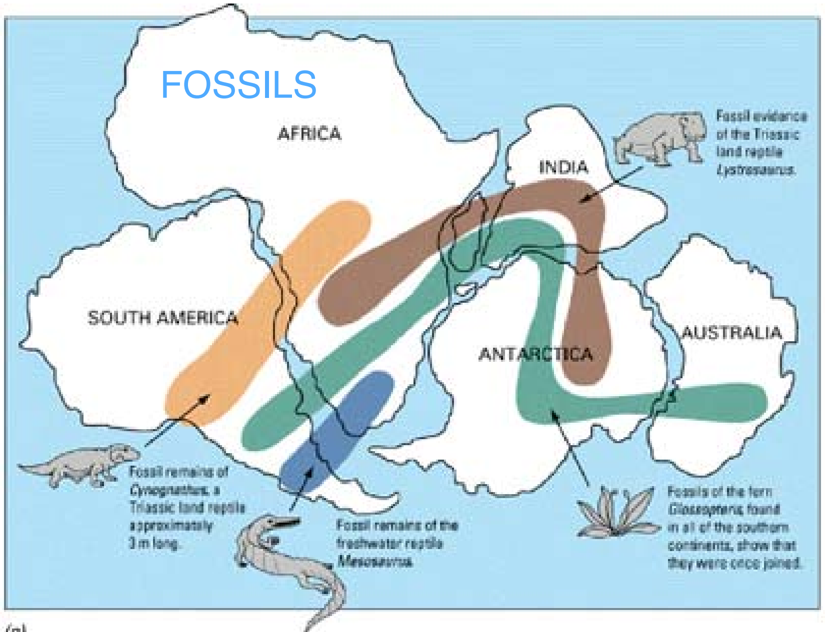
- Continents spread apart and ocean basins developed by process of sea-floor spreading.



# Continental Drift 2

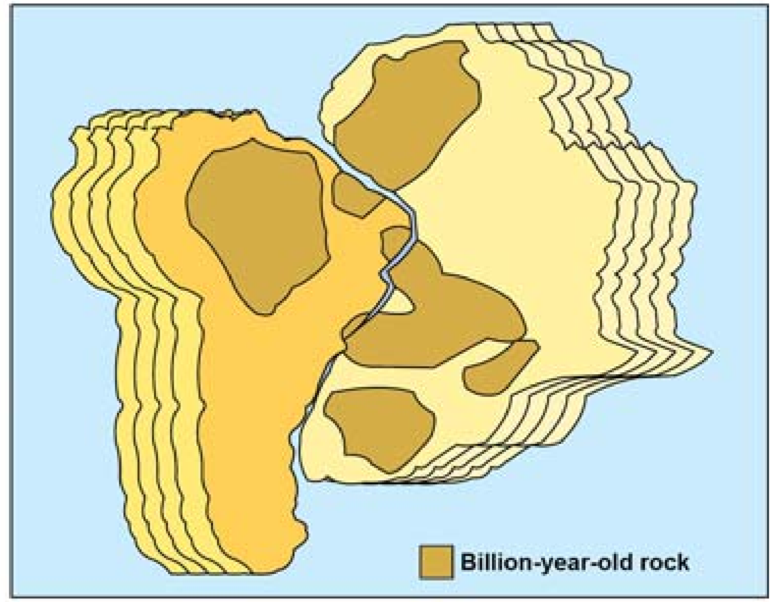
## Fit of continents across the Atlantic






(a)

ROCK FORMATIONS

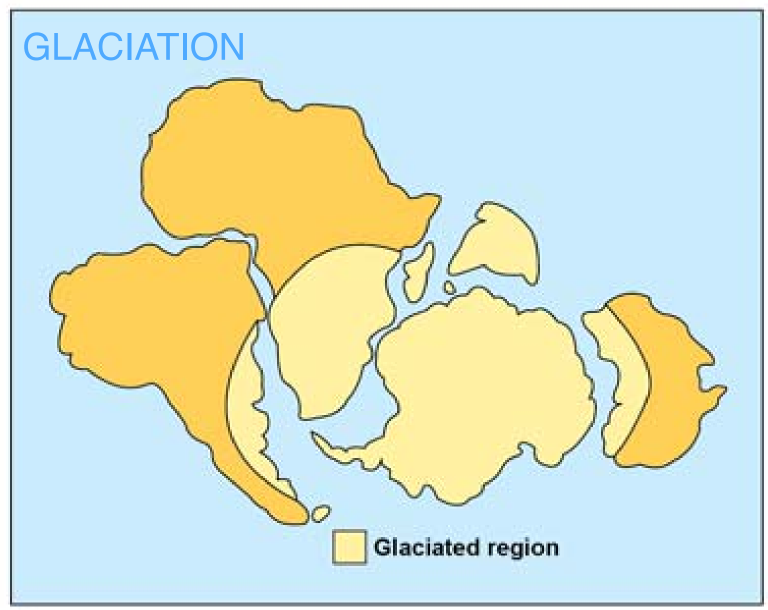



(b)


(c)

# More evidence!

OF CONTINENTIAL DRIFT

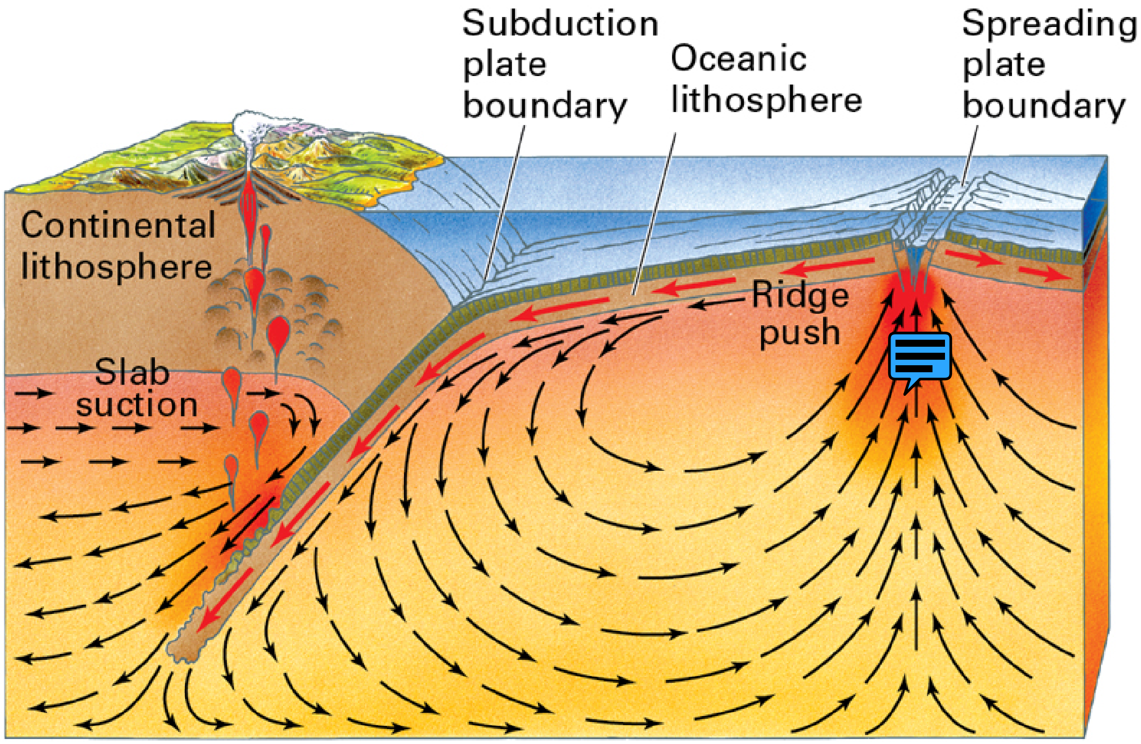



(d)

# Concept of a lithospheric ‘plates’

- **Rigid lithospheric rocks are "floating" on the denser, plastic asthenosphere.**
- Individual ‘slabs’ of lithosphere have typical thickness of 40 – 80 km, whereas plate lateral extent is of the order 100s to 1000s of km.
- **The lithosphere is broken into large or plates (AKA ‘tectonic’ plates)**
  - **Oceanic plates: consist of relatively thin, dense oceanic lithosphere (~ 60 km)**
  - **Continental plates: made of thick, light continental lithosphere (~ 150 km)**
- **Plates are both flexible and brittle → fractures are known as "faults"**

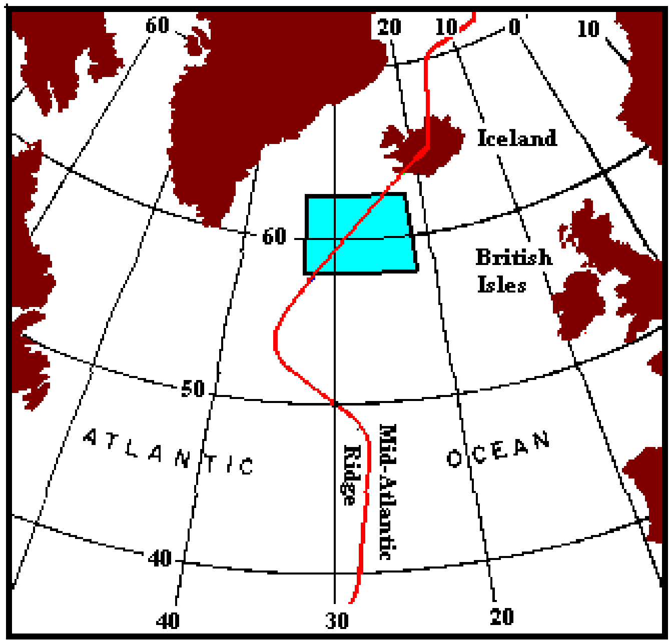
# Plate Boundary Types:  Divergent

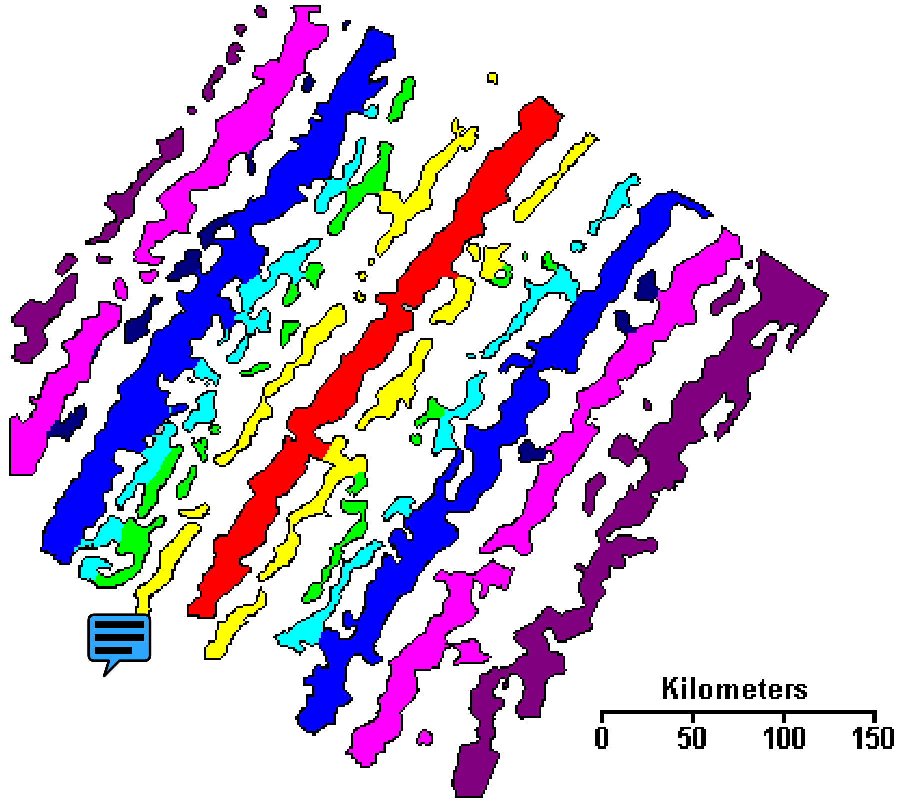



Principally located at Mid-Ocean Ridges.  Zones where upwelling of hot mantle material causes melting, stretching, and rifting of a plate.

Rift faults allow mantle material (ultramafic and mafic magma) to be extruded to form new ocean floor material along mid-ocean ridges.  Ocean basin gradually gets wider over millions of years.

# Geological evidence for sea-floor spreading

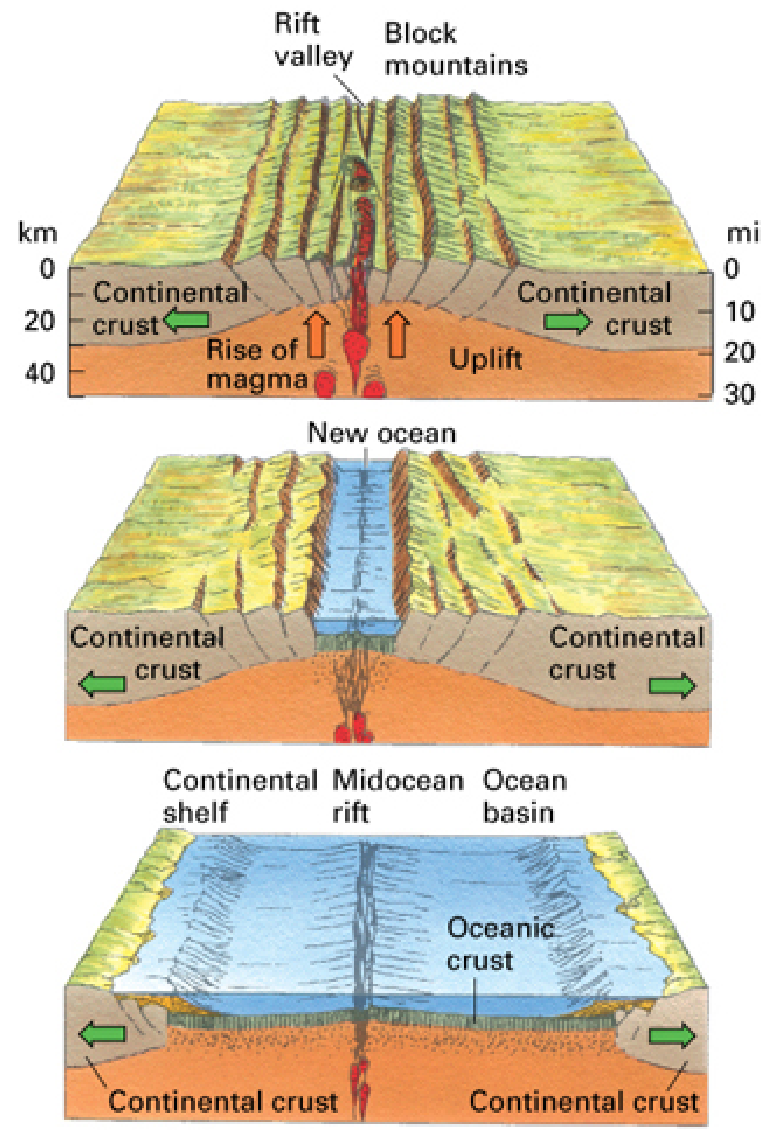



1. **Various colours indicate oceanic basaltic materials of different age.**
2. **Most recent lavas (red) occur along the presently active ridge. Note symmetrical arrangement of zones of similar age on each side of the ridge. <u>This is *prima facie* evidence of sea-floor spreading</u>.**
3. **Lavas of different ages have <u>differing magnetic polarity</u>, due to periodic reversals of Earth's geomagnetic field.**

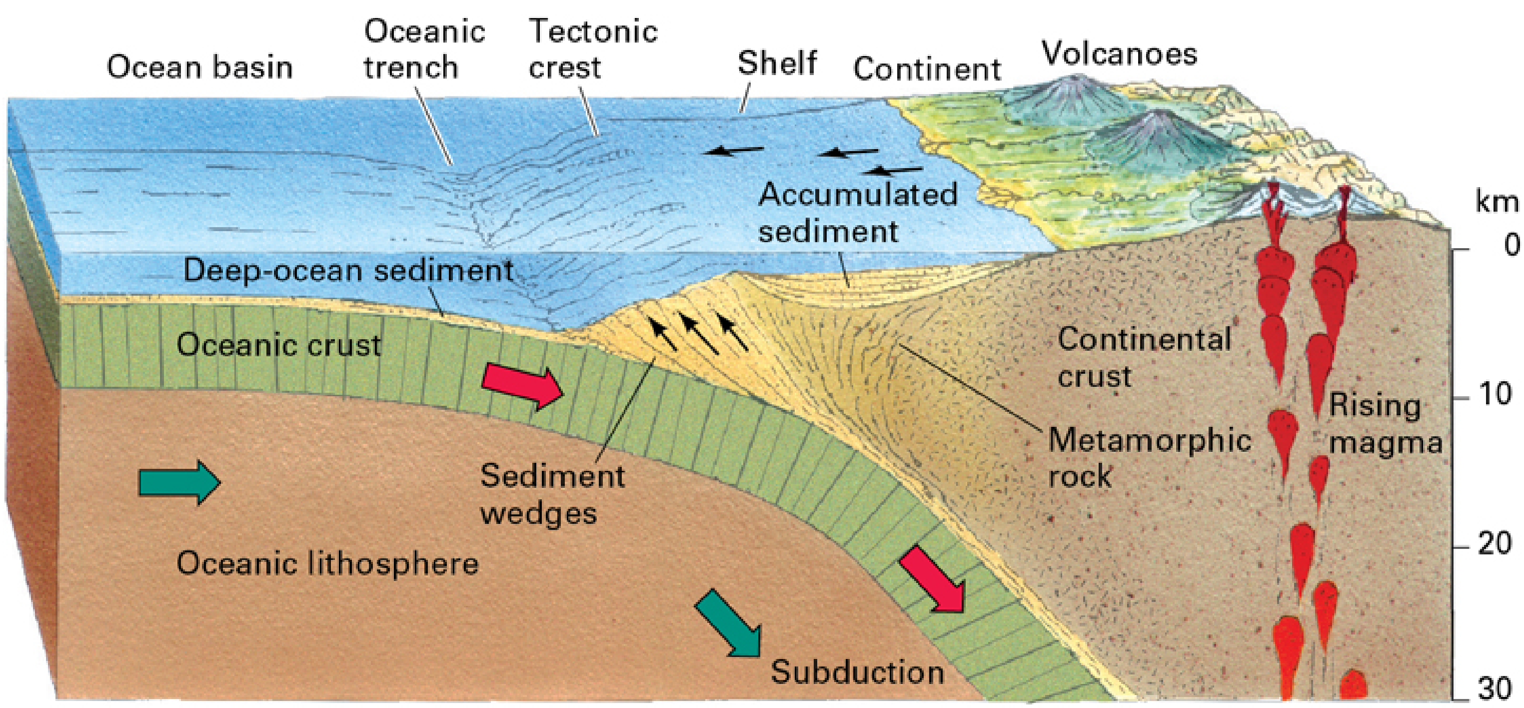
# Spreading boundaries

- Continental rupture and new ocean basins:
- Continental crust is uplifted and cracked by convective movements in asthenosphere
- Long narrow rift valley forms, widens as the two new plates begin to move apart at the new spreading boundary.
- Blocks of crust slide up or down
- Ocean invades the new valley.
- New oceanic crust formed along the mid ocean rift, and ocean basin widens.
- Examples: East African Rift / Red Sea; Mid-Atlantic Ridge



# Plate Boundary Types:  Convergent

- Zones where lithospheric plates move towards one another and are compressed.  The thinner, denser oceanic plate is subducted beneath the thicker, more rigid, less dense continental plate.
- Subducting plate melts, causing igneous intrusion at depth and volcanic activity at the surface of the continental plate.  Marine rocks  near the plate boundary are compressed and deformed, with metamorphism at depth.  Large earthquakes along subduction zone.

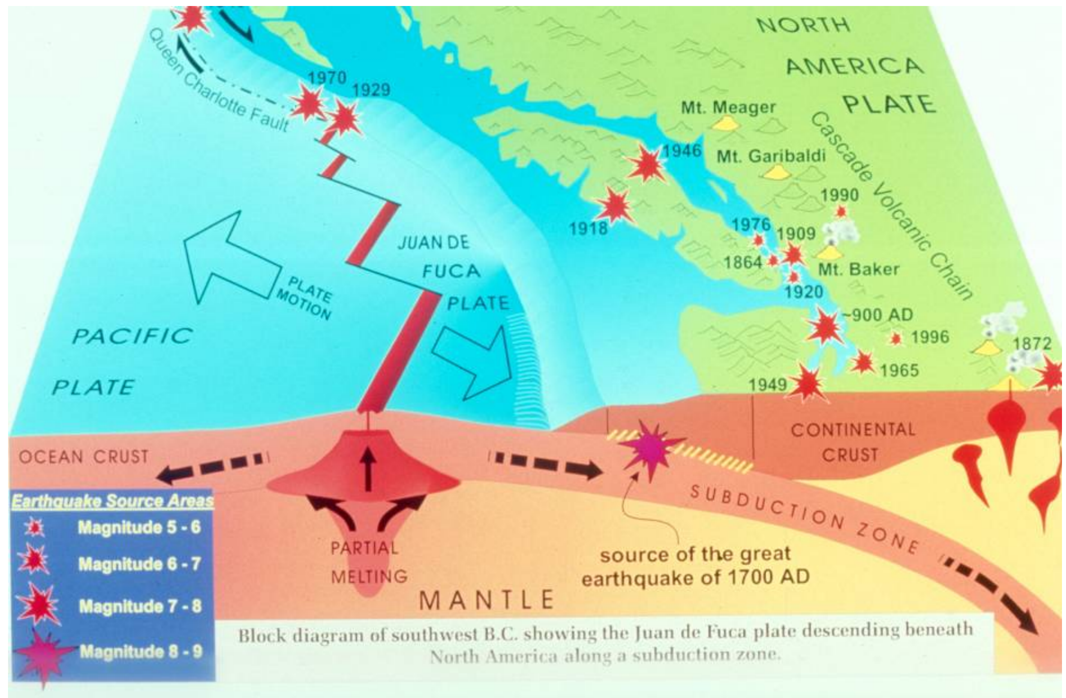


# Cascadia Subduction Zone between the Juan de Fuca Plate and North America Plate


From 'Geoscape Vancouver'

# Plate tectonic setting of western N. America

- The Juan de Fuca is currently being subducted beneath the N. American continent
- Cascade subduction zone
- The San Andreas and Queen Charlotte faults lies adjacent to the coastline
- Seismic activity along this fault

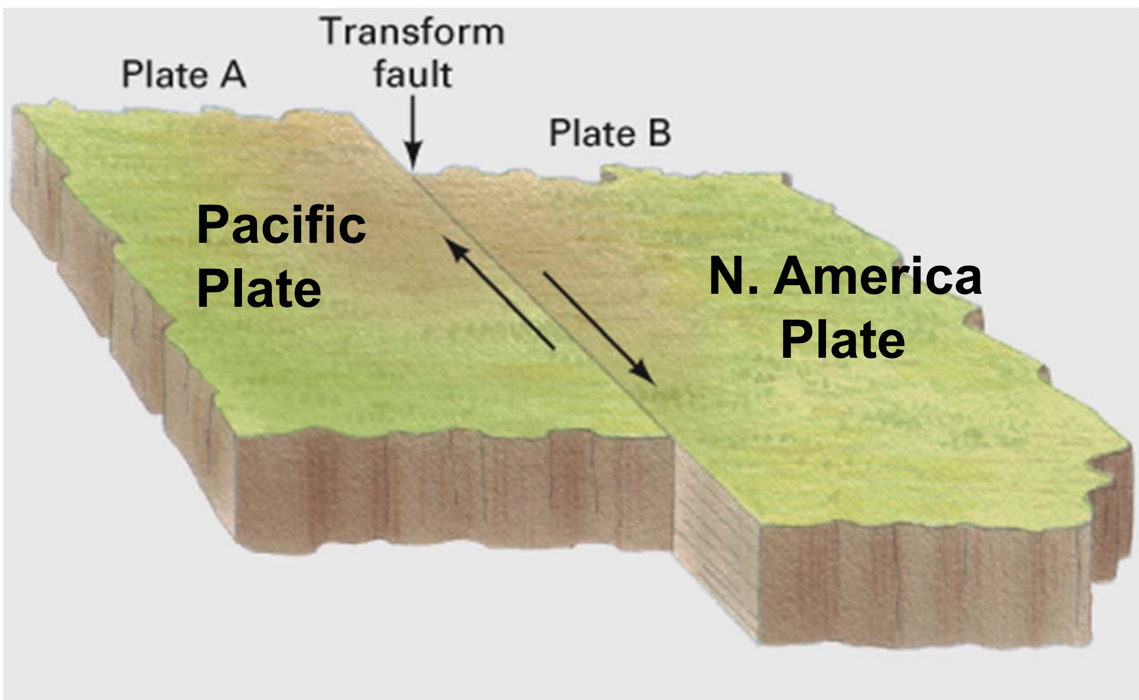


Block diagram of southwest B.C. showing the Juan de Fuca plate descending beneath North America along a subduction zone.

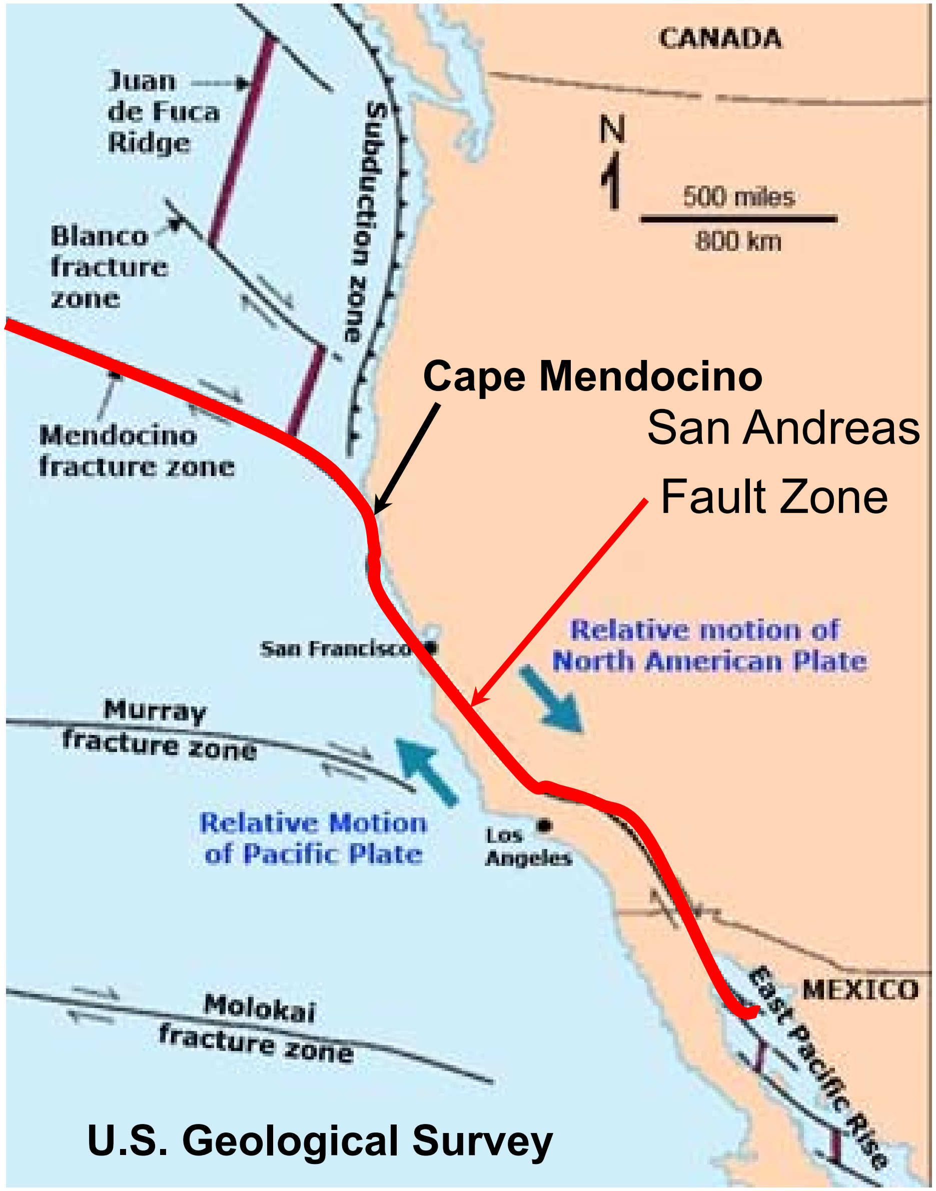
# Plate Boundary Types:  Transform Fault

- Zones where two lithospheric plates move past one another with primarily horizontal displacements.  Example shown is a right-lateral transform fault, since plate on other side of fault has relative motion to the right.
- San Andreas Fault Zone of California is an example of a right-lateral transform fault.

MOVES SIDE BY SIDE

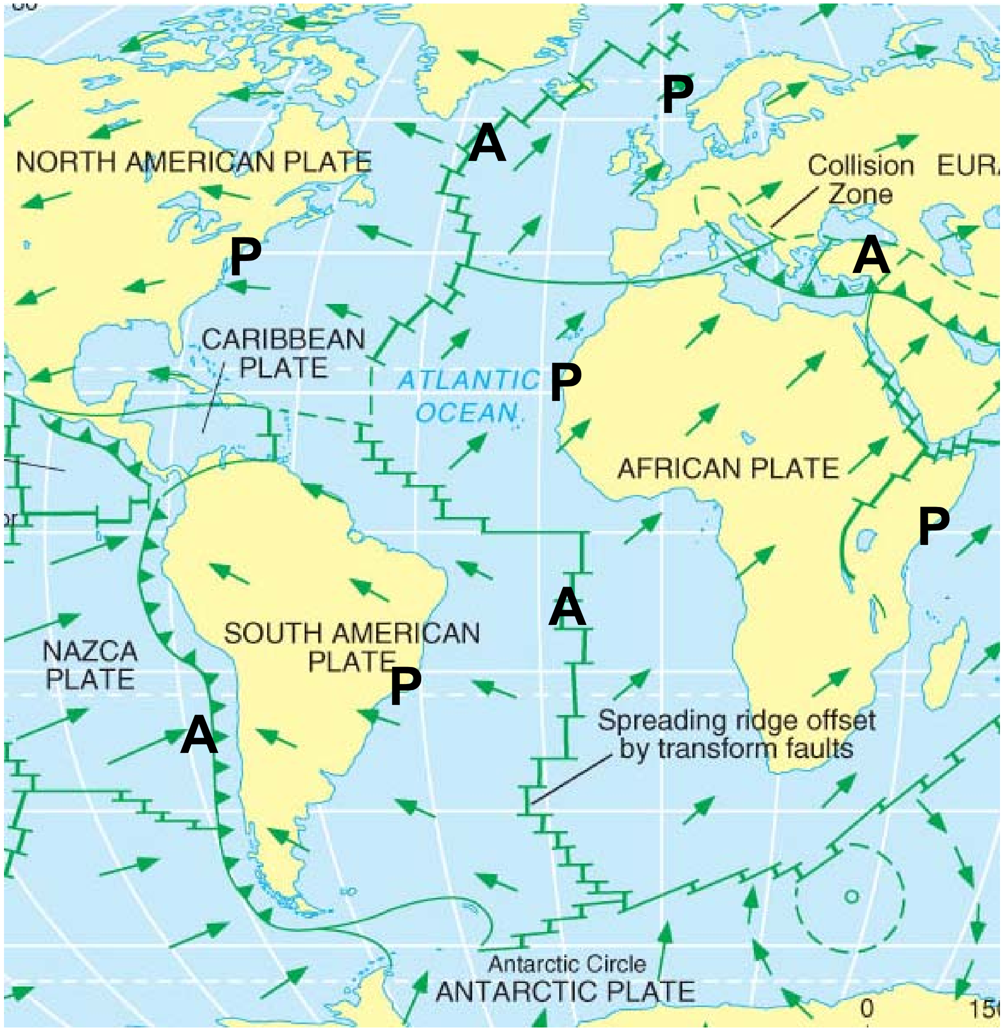


# San Andreas Transform Fault Zone




Actual motion of North America Plate is to the west. Pacific Plate moves to northwest. These movements cause huge compression along the San Andreas Fault and a right-lateral displacement along the fault. Many sub-parallel faults comprise the fault zone. It isn't a single fault. Note that Baja California and most of coastal California is on the Pacific Plate!

**Active versus Passive Plate Margins**



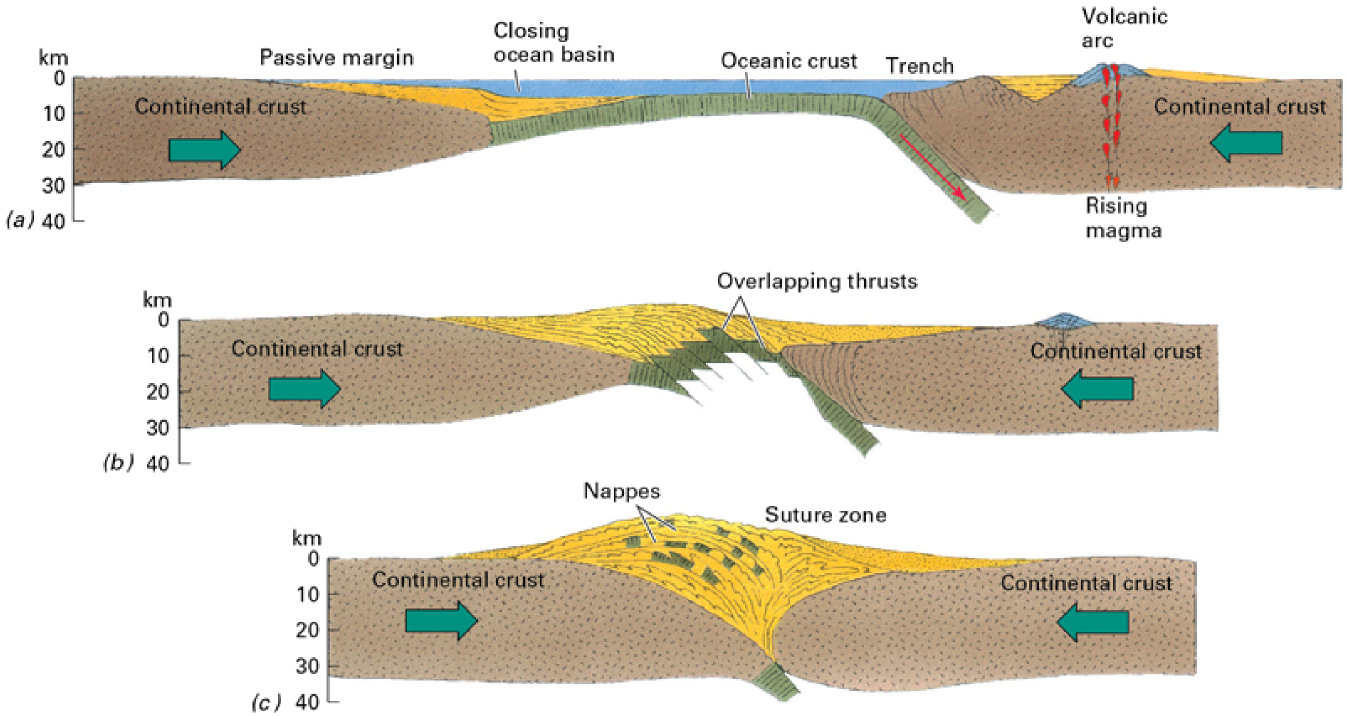

**A = active margin**

**P = passive margin**

**Active margins**: refers to spreading ridges or subduction/collision zones.

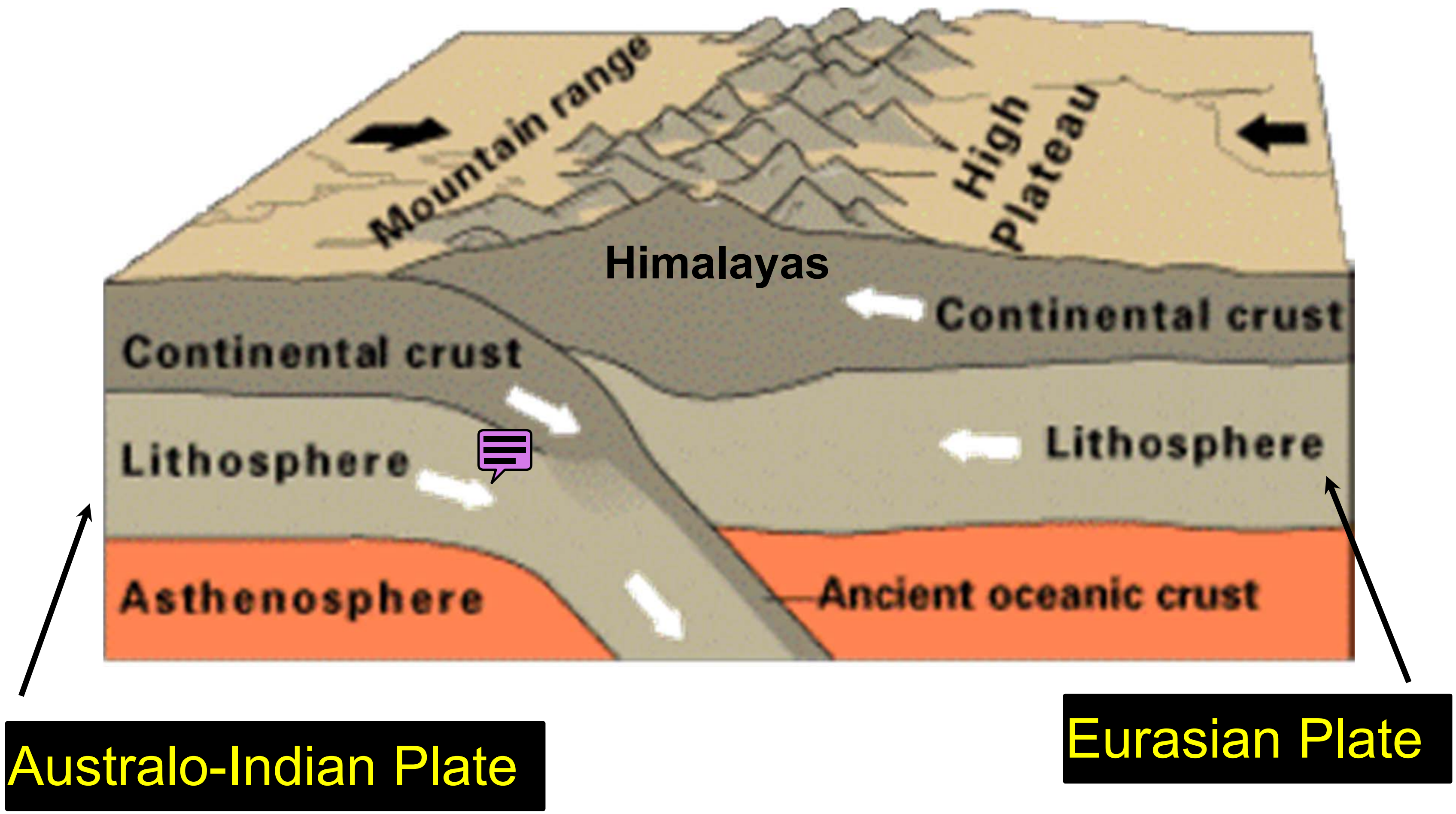
**Passive margins:** refers to continental margins which have rifted apart but not experienced subsequent tectonic compression, e.g. N and E coasts of S. America, western margin of Africa, eastern North America, most of Australia. These are tectonically quiet zones.

# Special Case: Continent-continent collision



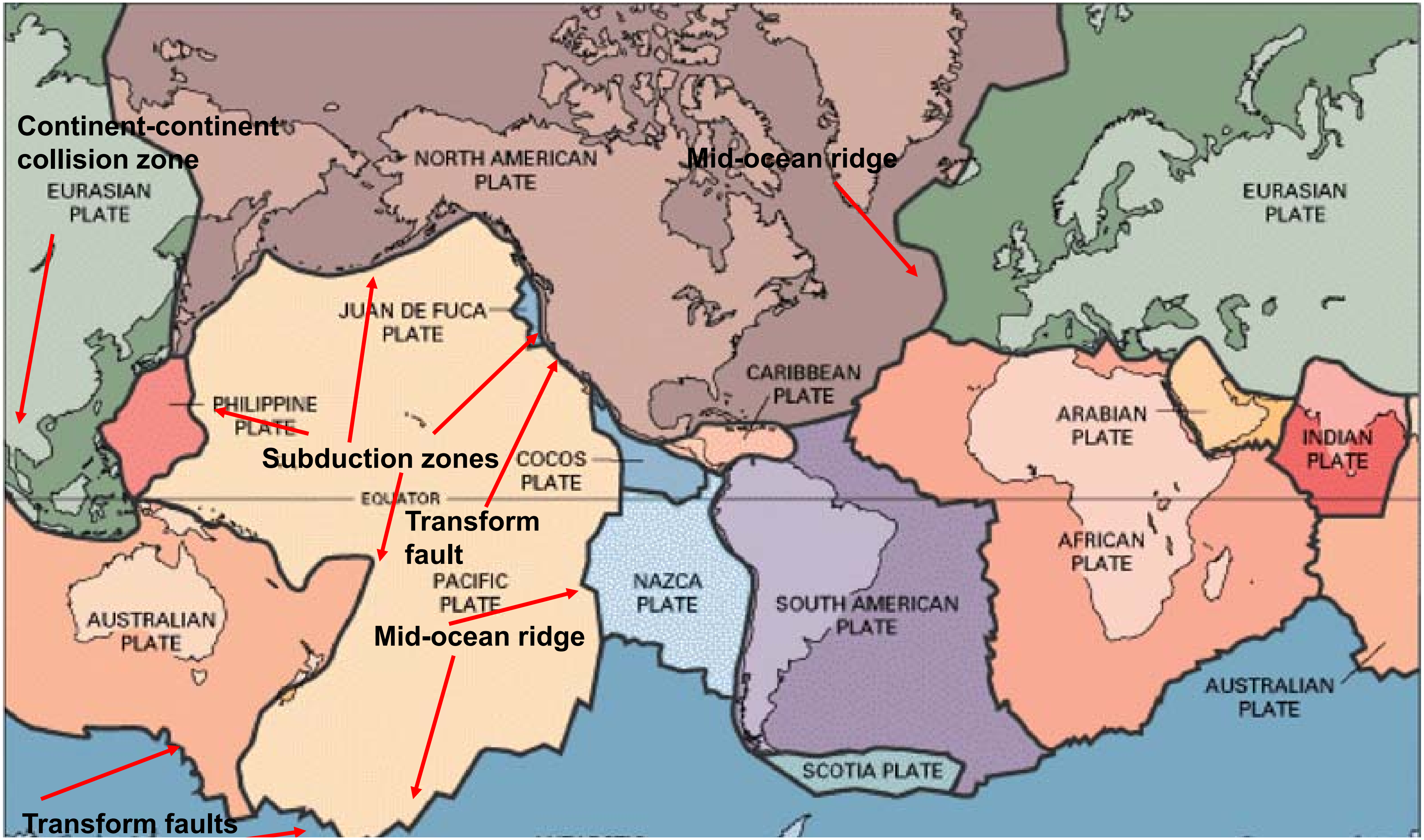

- Convergence of two continental plates with subduction.
- Passive margin is eventually compressed as ocean basin closes.
- Large-scale folding and faulting and massive uplift of marine sedimentary rocks at collision zone of continental plates.
- Large-scale uplift of 'slices' of material (nappes) along major thrust faults.
- 'Suturing' together of plates, leading to igneous activity and metamorphism at depth as tectonic compression builds up.

**Schematic cross-section through Himalayan 'Collision' Zone**

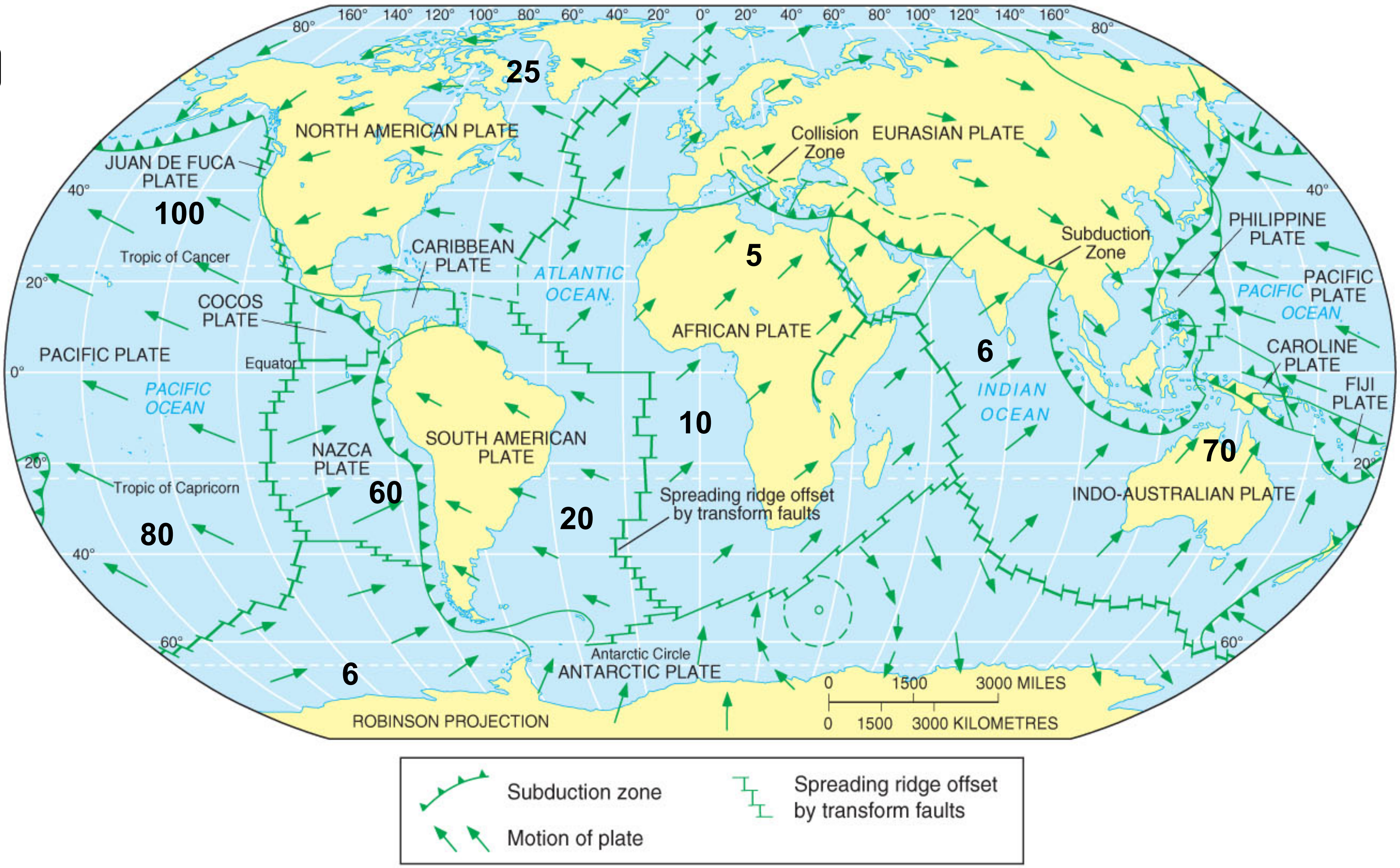



Uplift of the Himalayas is ongoing due to continued convergent pressure from the Australo-Indian plate.

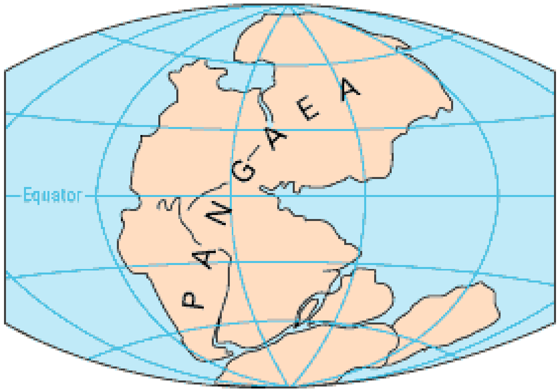
# Major plate boundaries Figure 12.2



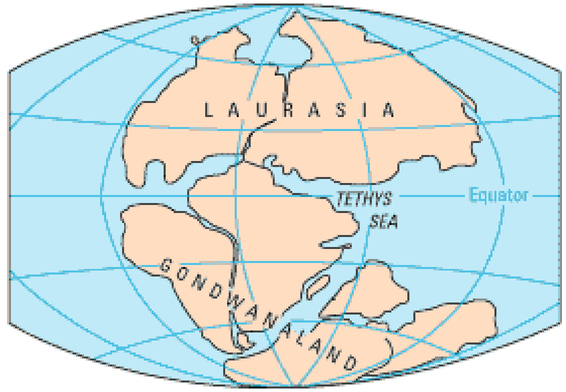
# Modern movement rates of major plates



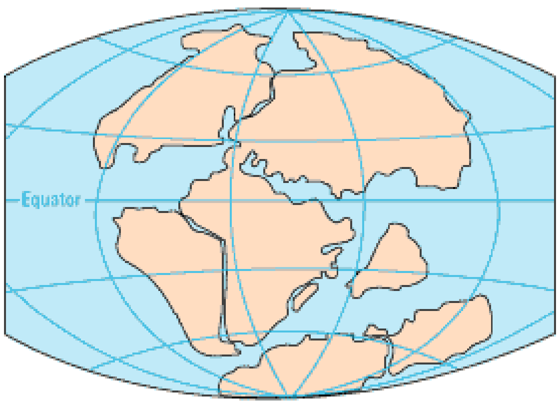

**Numbers indicates rate of movement (mm/a). Long arrows indicate rapid movement.**



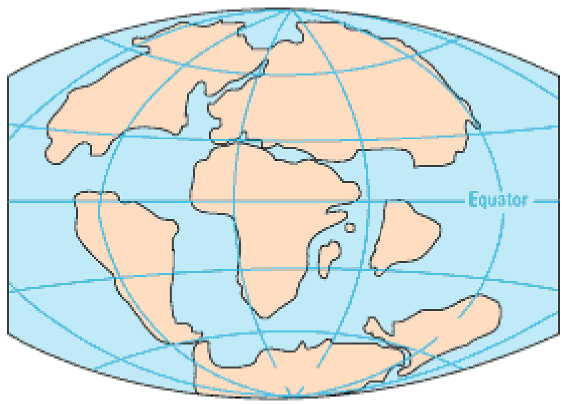

**225 Ma**



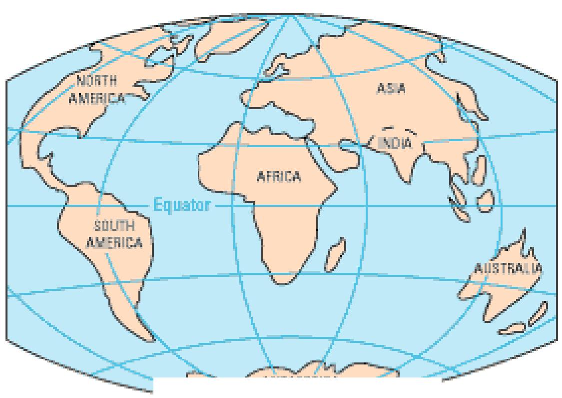

**200 Ma**




**135 Ma**




**65 Ma**




**Present**

Successive stages of continental drift over the past 225 Ma.

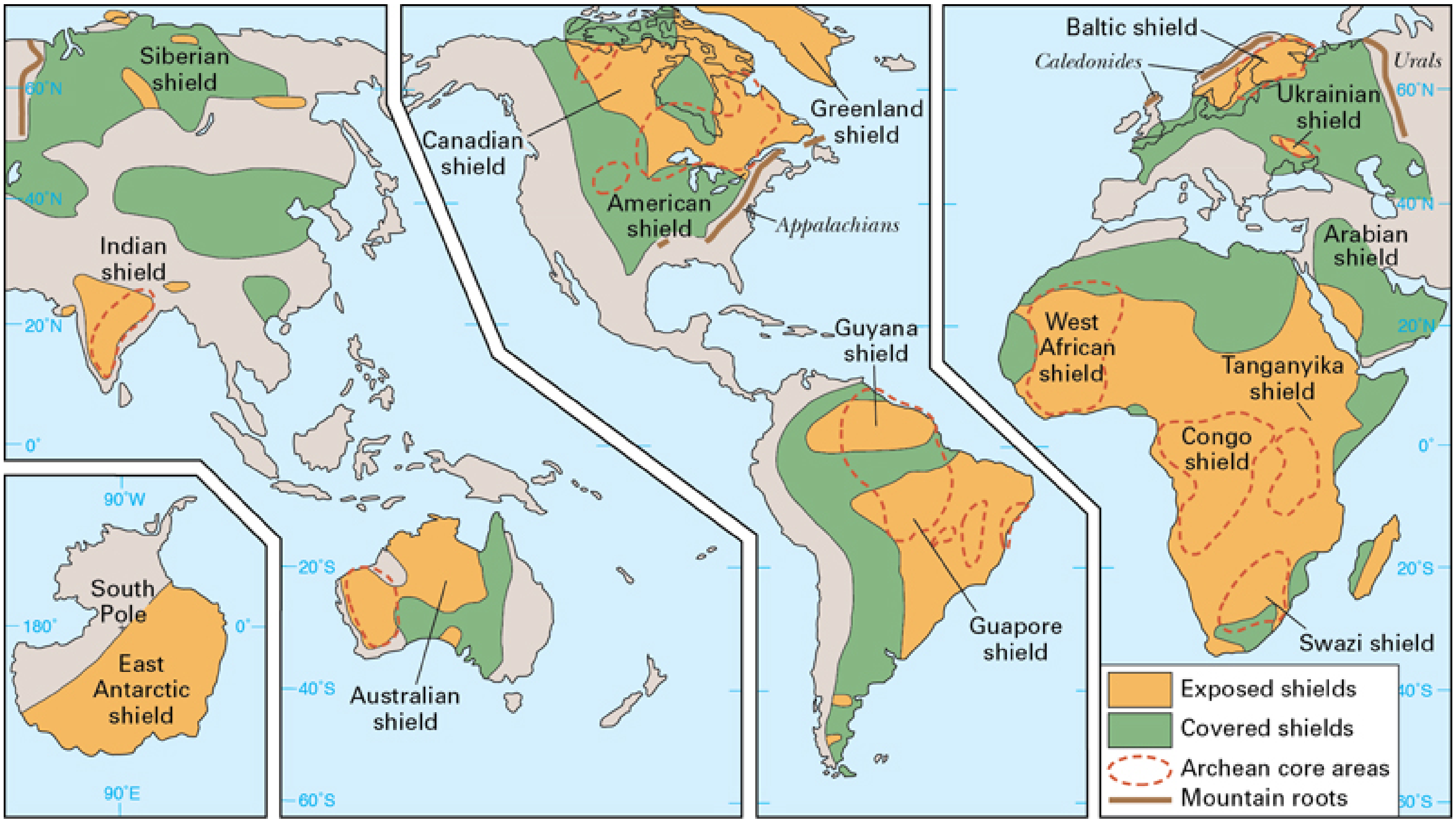
(Fig 11.18 equiv.)

Note: Ma means ‘mega annum’, or millions of years ago.

# Summary of Main Evidence for Continental Drift

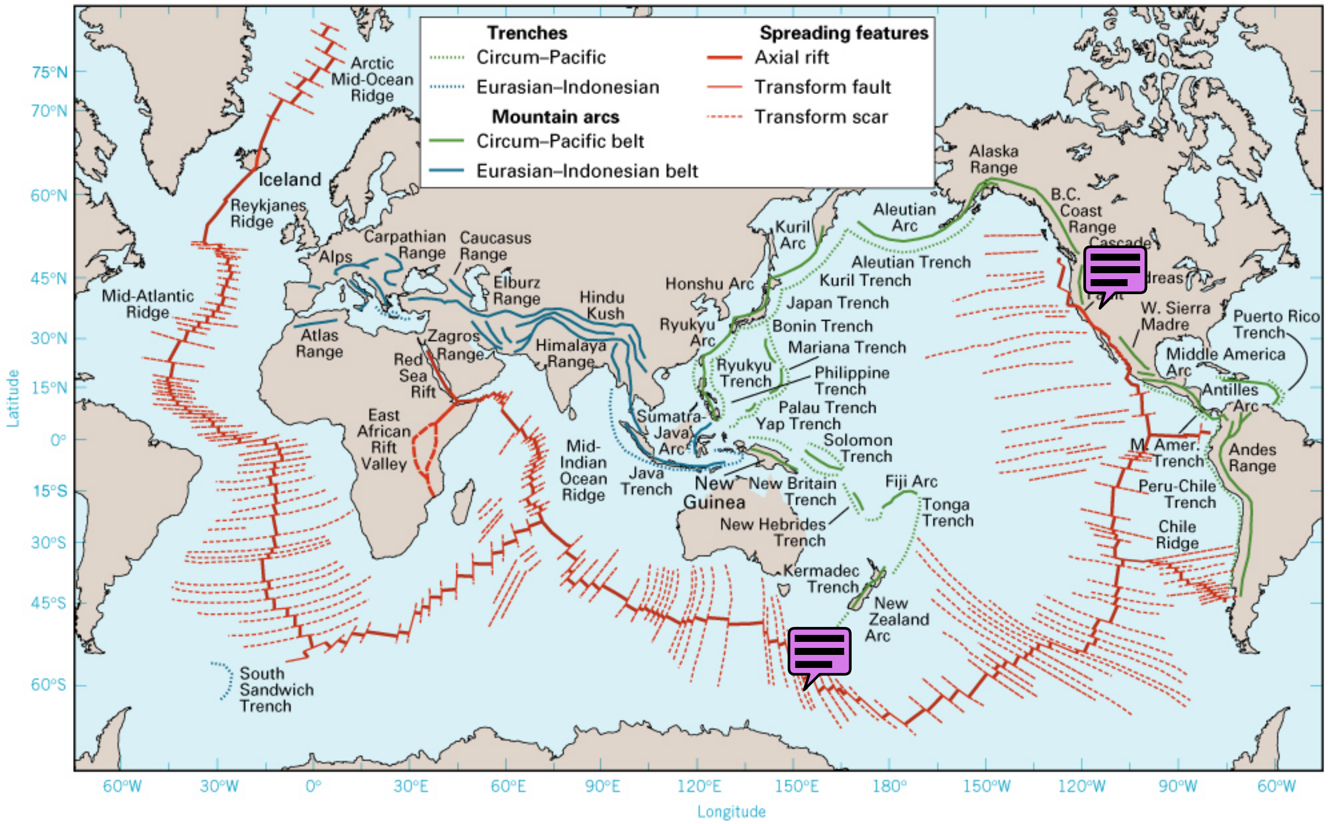
- Approximate 'jigsaw fit' matching of some continental boundaries (only works for passive margins.)
- Approximate continuity of tectonic trends (fold belts, faults) and rock types between adjacent continents (e.g., Eastern Canada and Northwest Europe). South America and South Africa.
- Symmetric age pattern of volcanic rocks on either side of mid-ocean ridges.

Present Distribution of Ancient Continental Shields




Continental 'shields' are large areas of ancient continental lithosphere which formed 1 – 2 billion years ago, then rifted apart over the past 200 Ma. They comprise complex assemblages of igneous and metamorphic rocks.

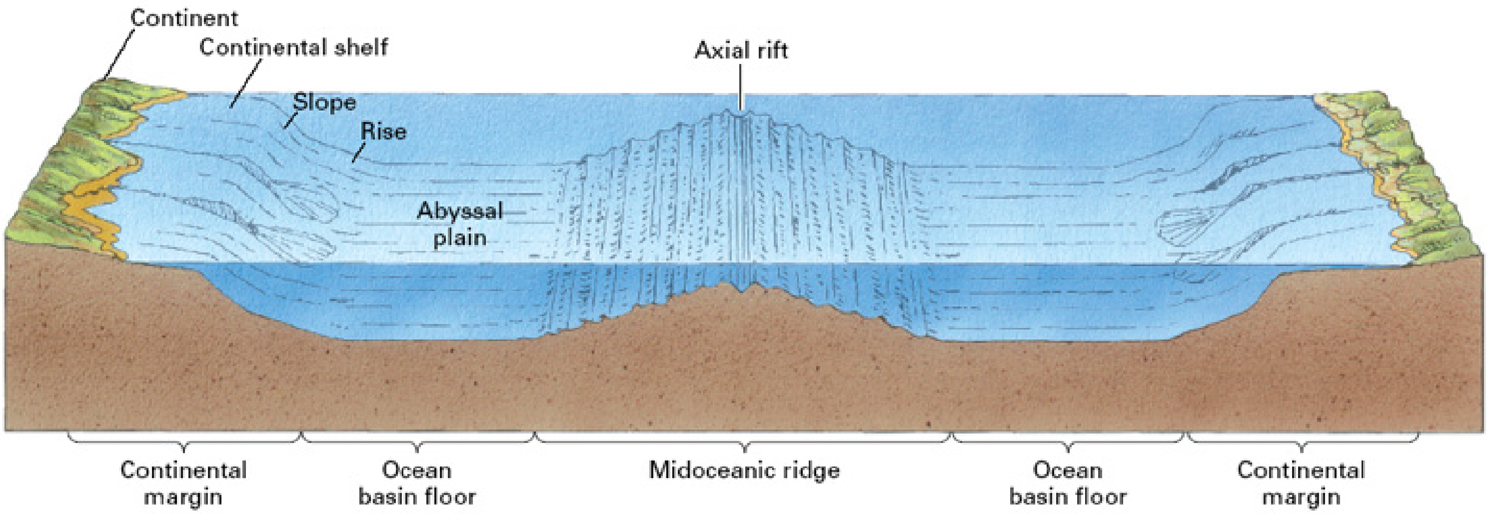
# Principle mountain arcs, island arcs, and trenches




- **Continents: young (dynamic alpine belts); old (stable continental shields – old mountain belts)**

Young develop through volcanic activity

# Relief Features of the Ocean Basins




- Mid ocean ridge and ocean basin floor
  - mid ocean ridge with Axial rift at the centre
  - ocean basin floor are deep plains (Abyssal plains)
  - some include small hills (Abyssal hills)
- Continental Margins
  - where ocean and continental lithospheres meet
  - Continental rise - steep slope
  - Continental shelf - gentle slope