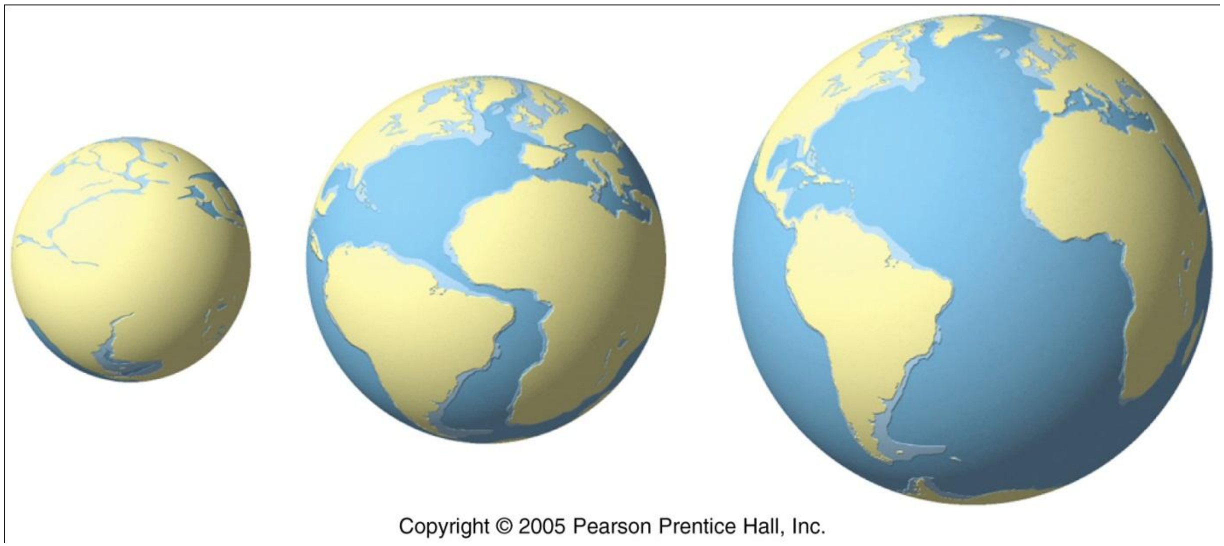
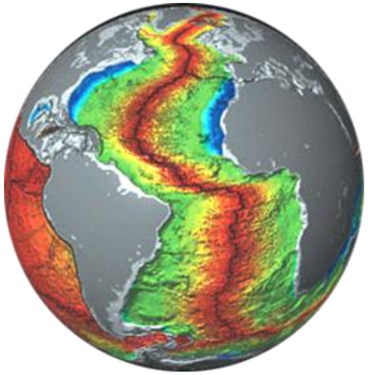
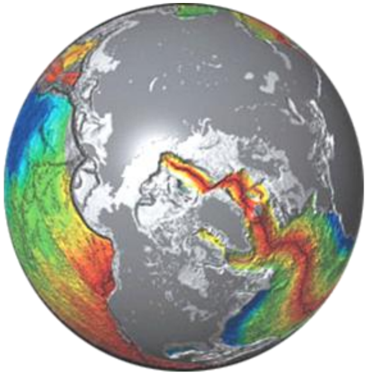
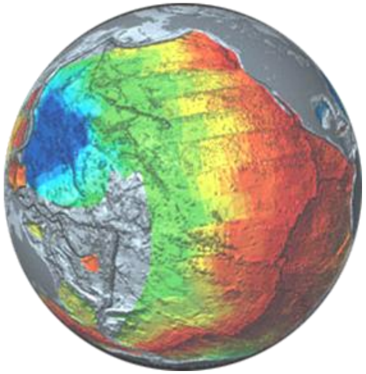
Plate Tectonics (Geo 380)

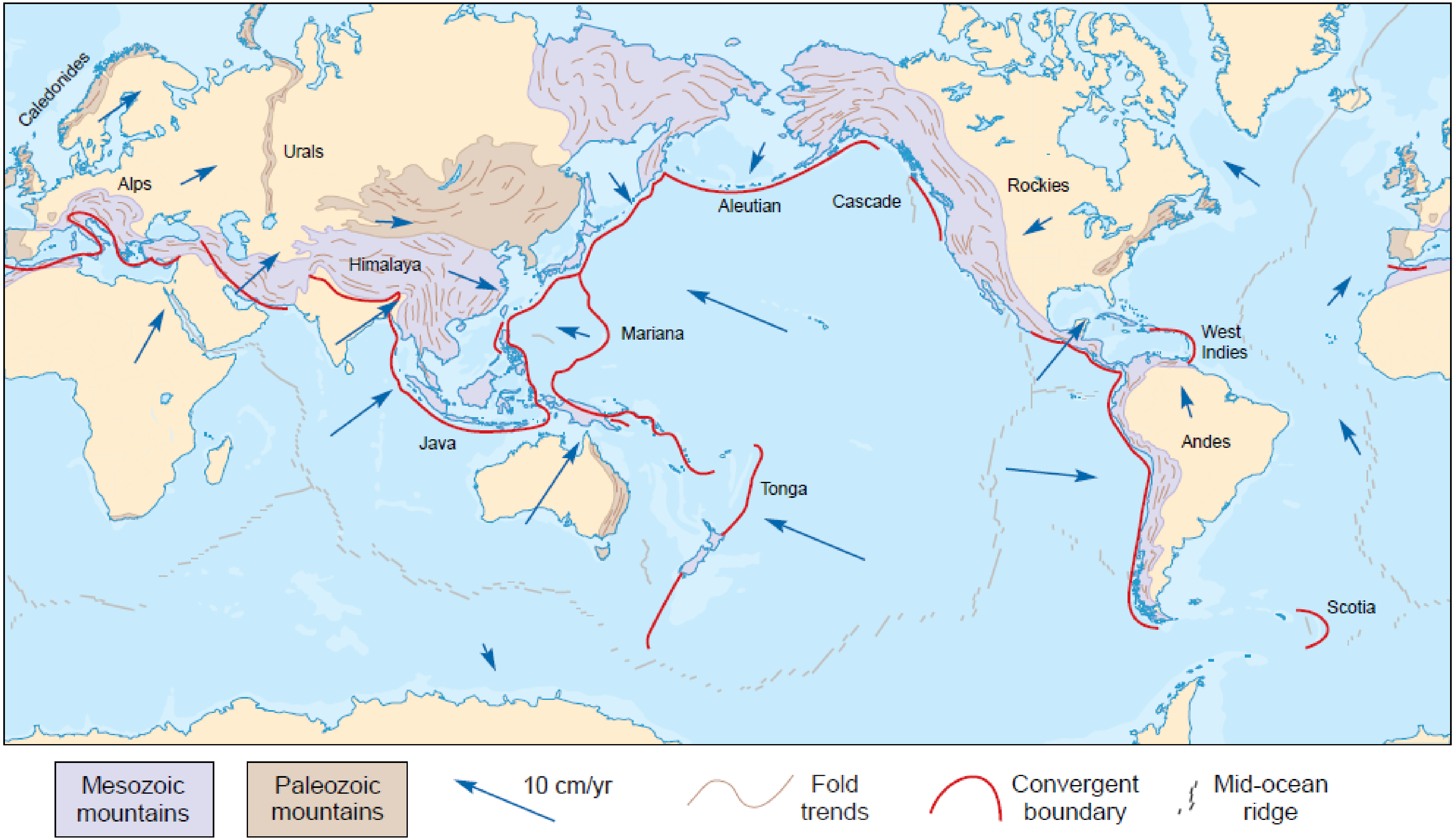


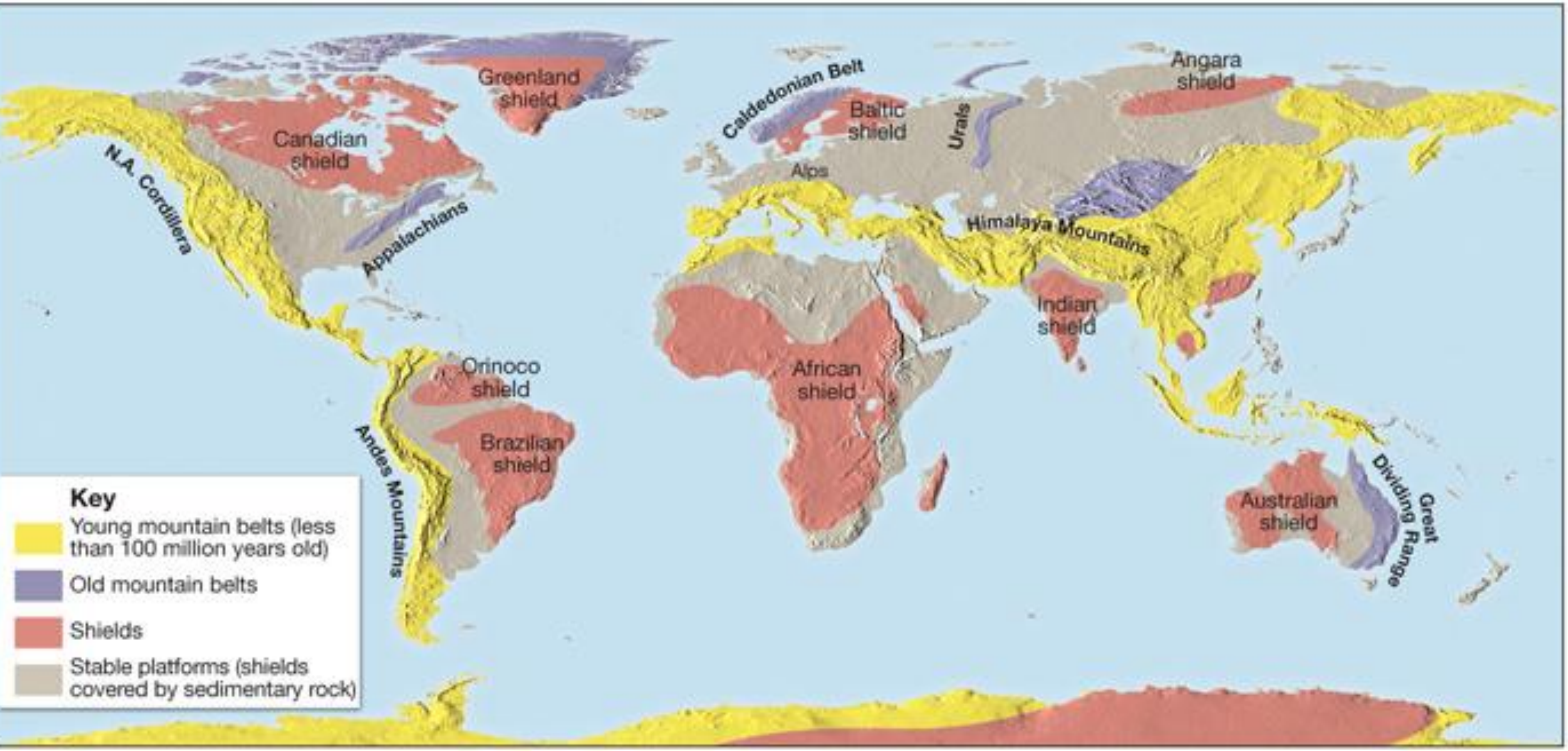




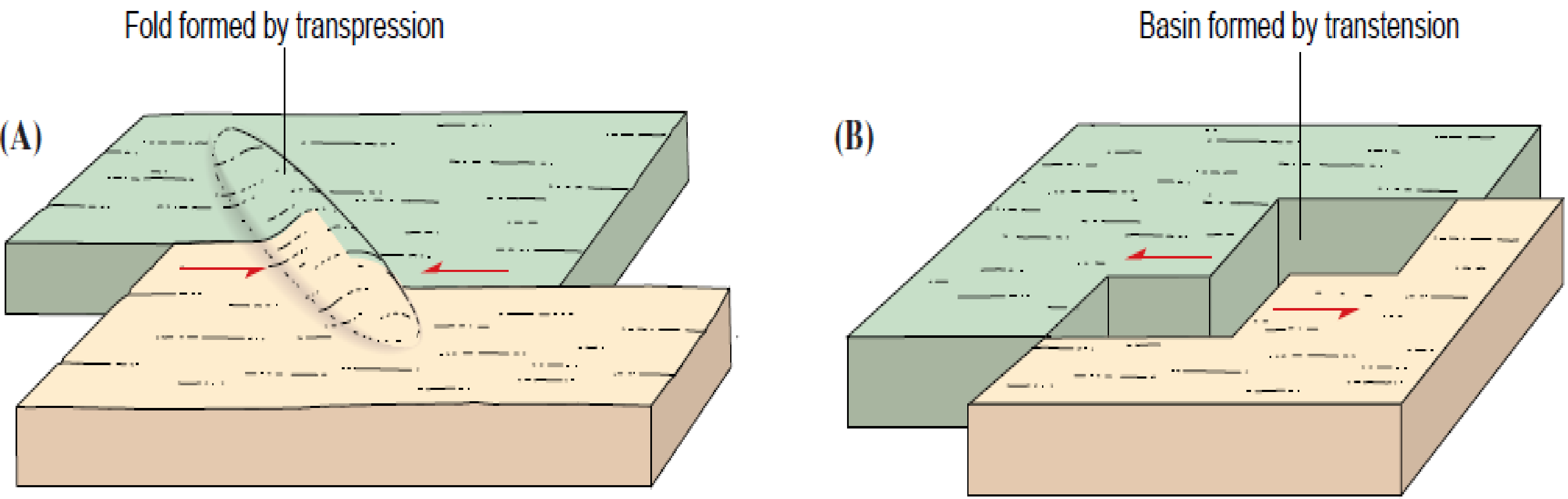


Mountain chains

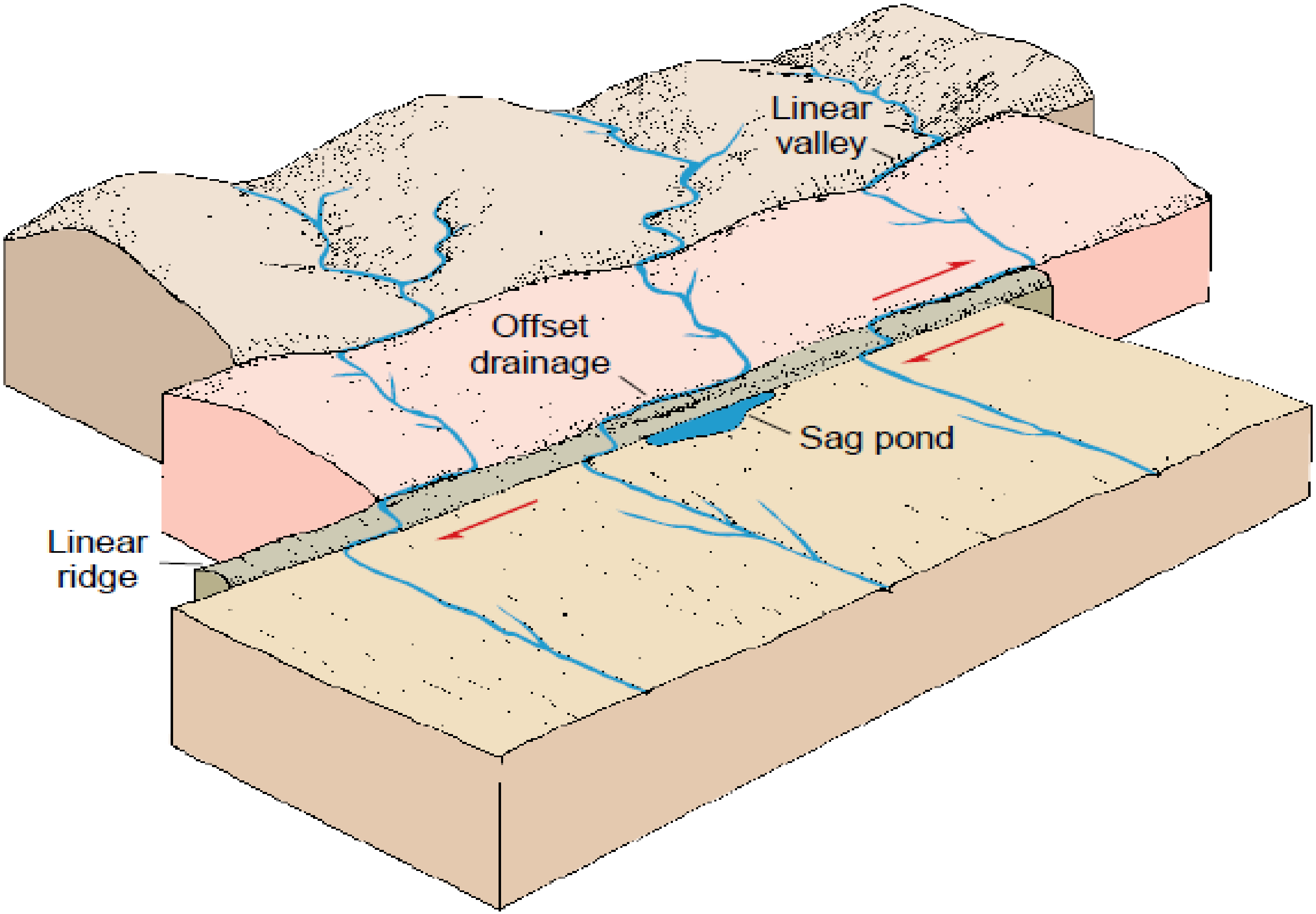



Greenland shield
Canadian shield
N.A. Cordillera
Appalachians
Caledonian Belt
Baltic shield
Urals
Alps
Angara shield
Himalaya Mountains
Indian shield
Orinoco shield
Brazilian shield
Andes Mountains
African shield
Australian shield
Great Dividing Range
Key
Young mountain belts (less than 100 million years old)
Old mountain belts
Shields
Stable platforms (shields covered by sedimentary rock)

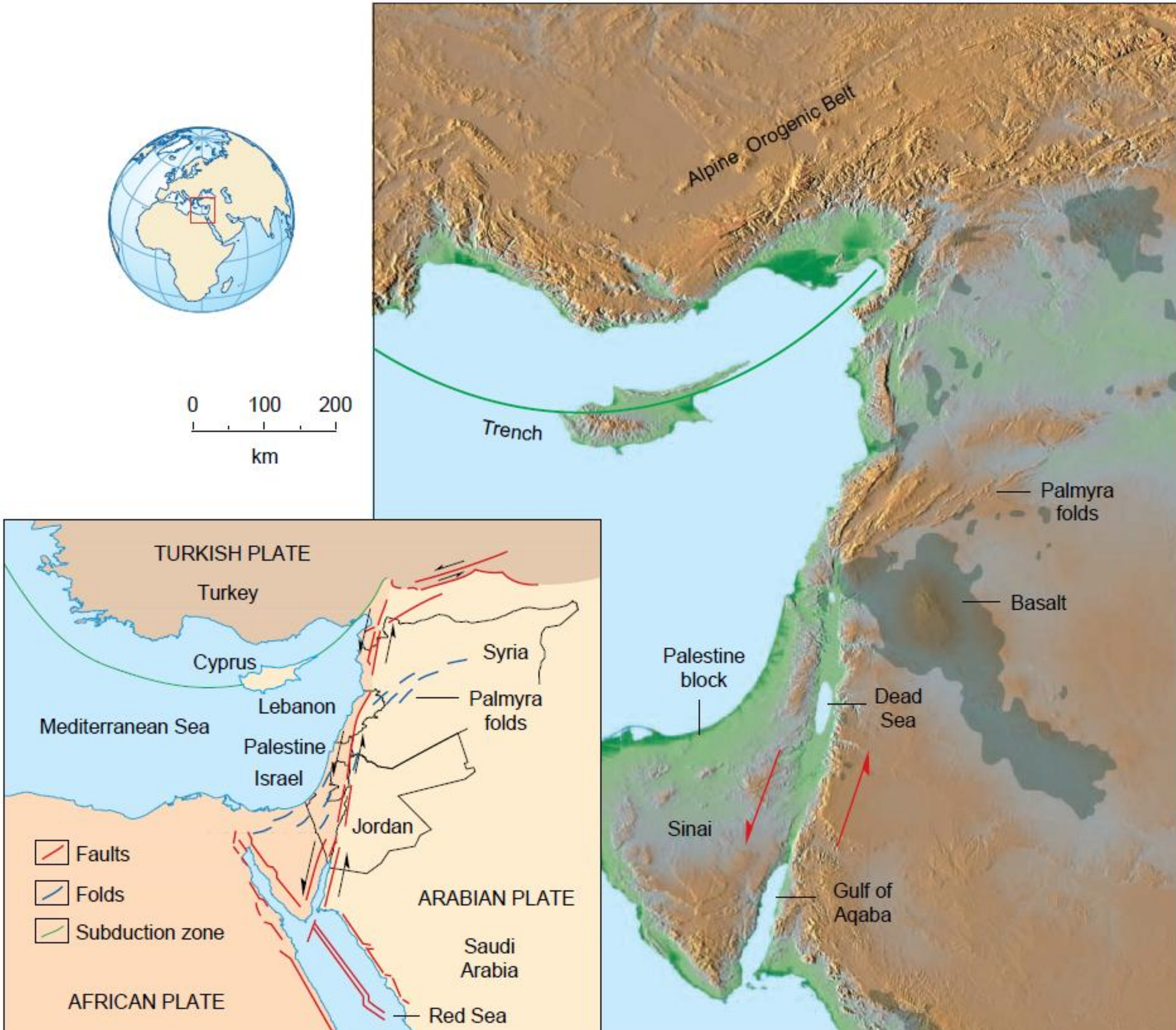
Lineagenic Movements



Lineagenic Movements

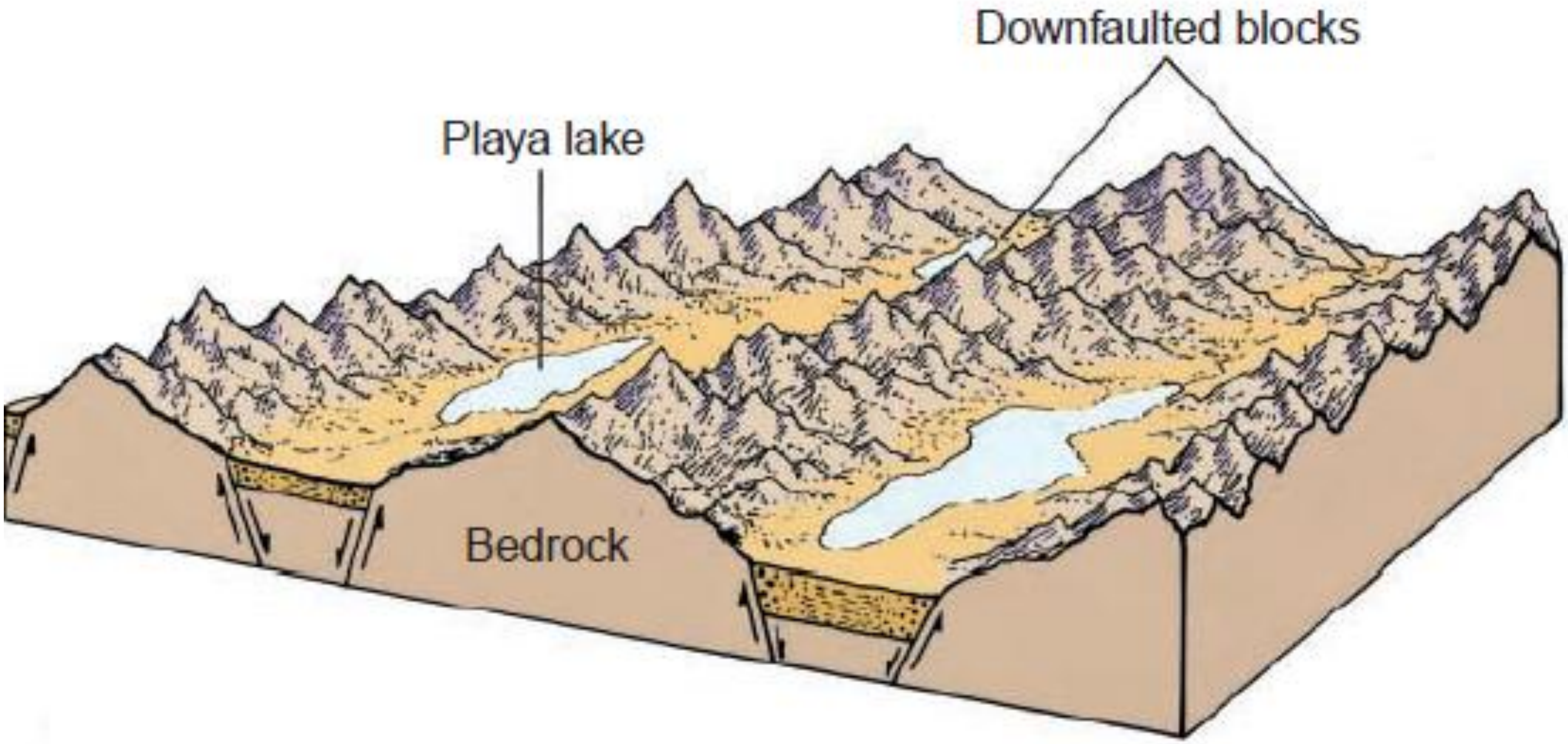


(B) The San Andreas Fault slices through California, marking the transform boundary between moving tectonic plates. The great scar along the fault line is marked by linear valleys, sharp contrast in landforms, and displaced drainage.

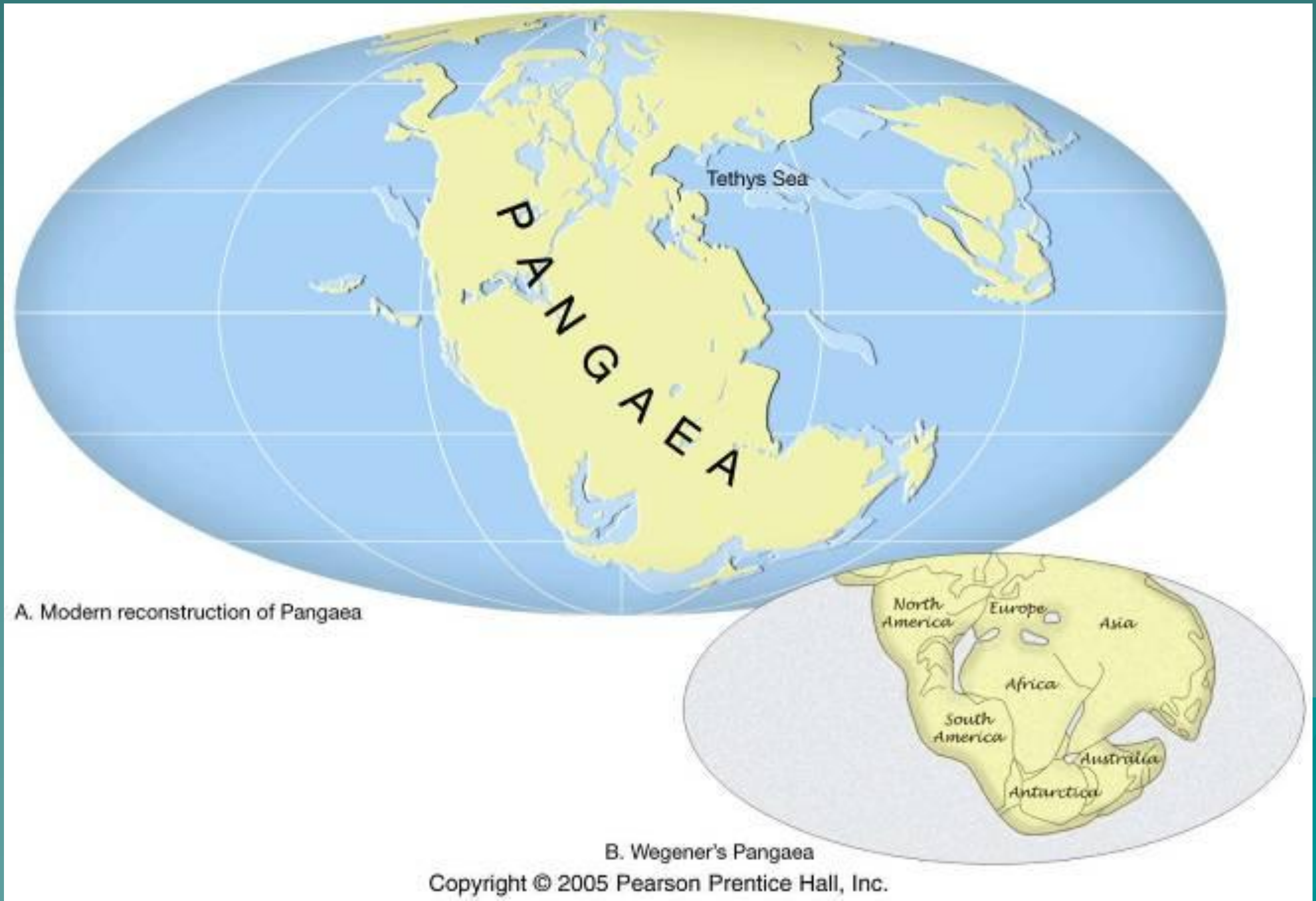

Alpine Orogenic Belt
Trench
0 100 200
km
Palmyra folds
Basalt
Palestine block
Dead Sea
Sinai
Gulf of Aqaba
TURKISH PLATE
Turkey
Cyprus
Syria
Lebanon
Palmyra folds
Mediterranean Sea
Palestine
Israel
Jordan
Faults
Folds
Subduction zone
ARABIAN PLATE
Saudi Arabia
AFRICAN PLATE
Red Sea


Elat
Sinai

Taphrogenic movement



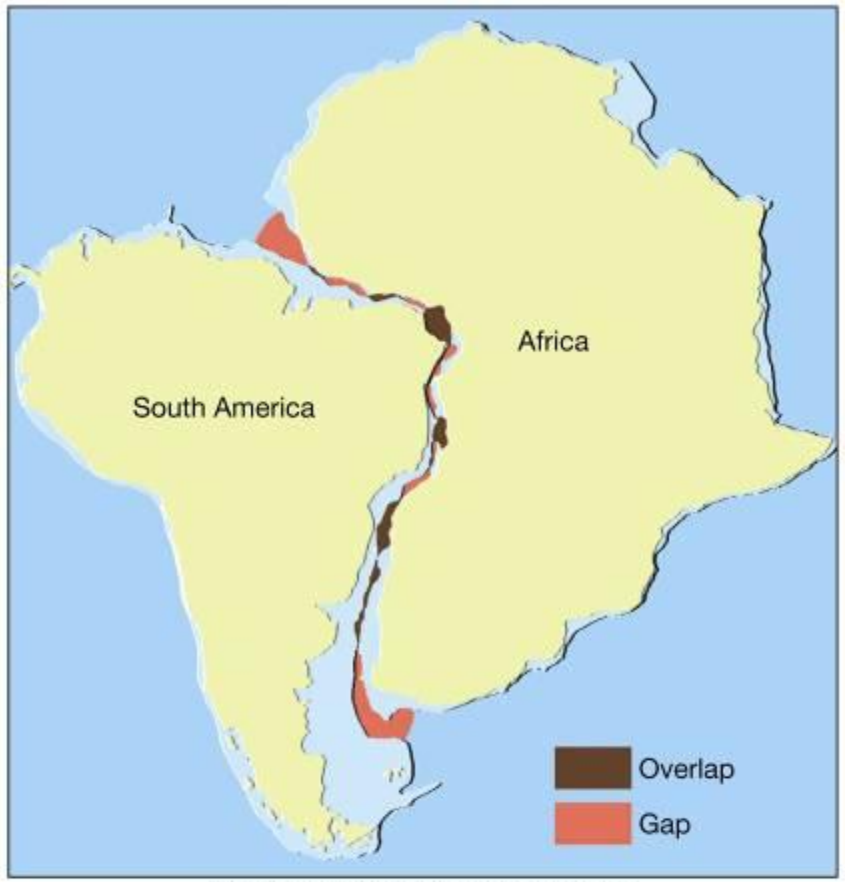
Continental Drift



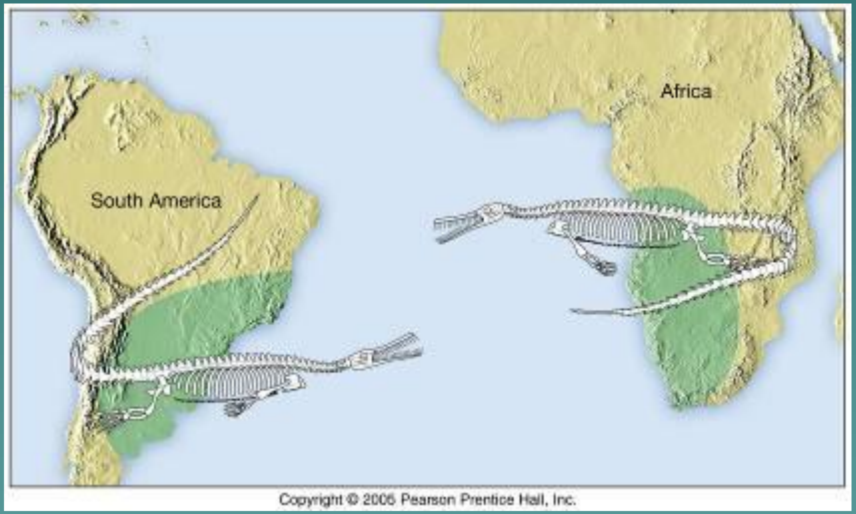
Evidence for Continental Drift

- Jigsaw Puzzle fit of continents

Alfred Wegener during Greenland expedition



More evidence



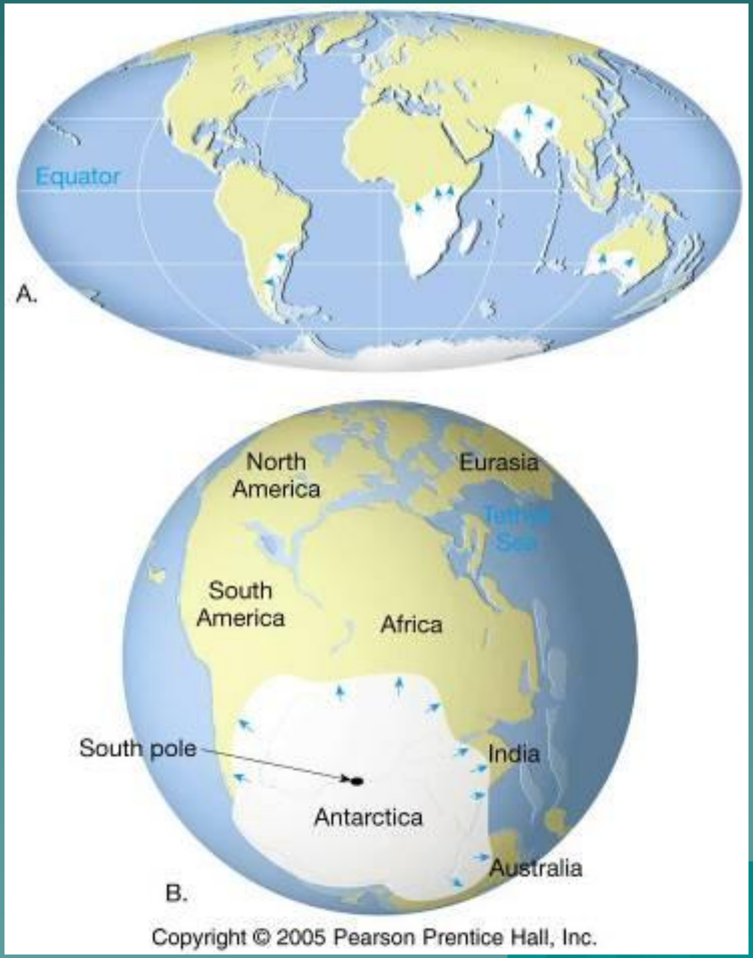
- Matching fossils on continents now located thousands of miles apart. Example = Mesosaurus, a freshwater reptile
- Many others

More evidence

- Matching geologic structures including:
  - Mountain chains
  - Ore deposits
  - Same rocks of same age

More evidence

- Climate change evidence
  - Glacial deposits at current equator
  - Fossilized palm trees in Greenland
- Map shows why according to the placements of current continents within Pangaea



Glacial Deposits……

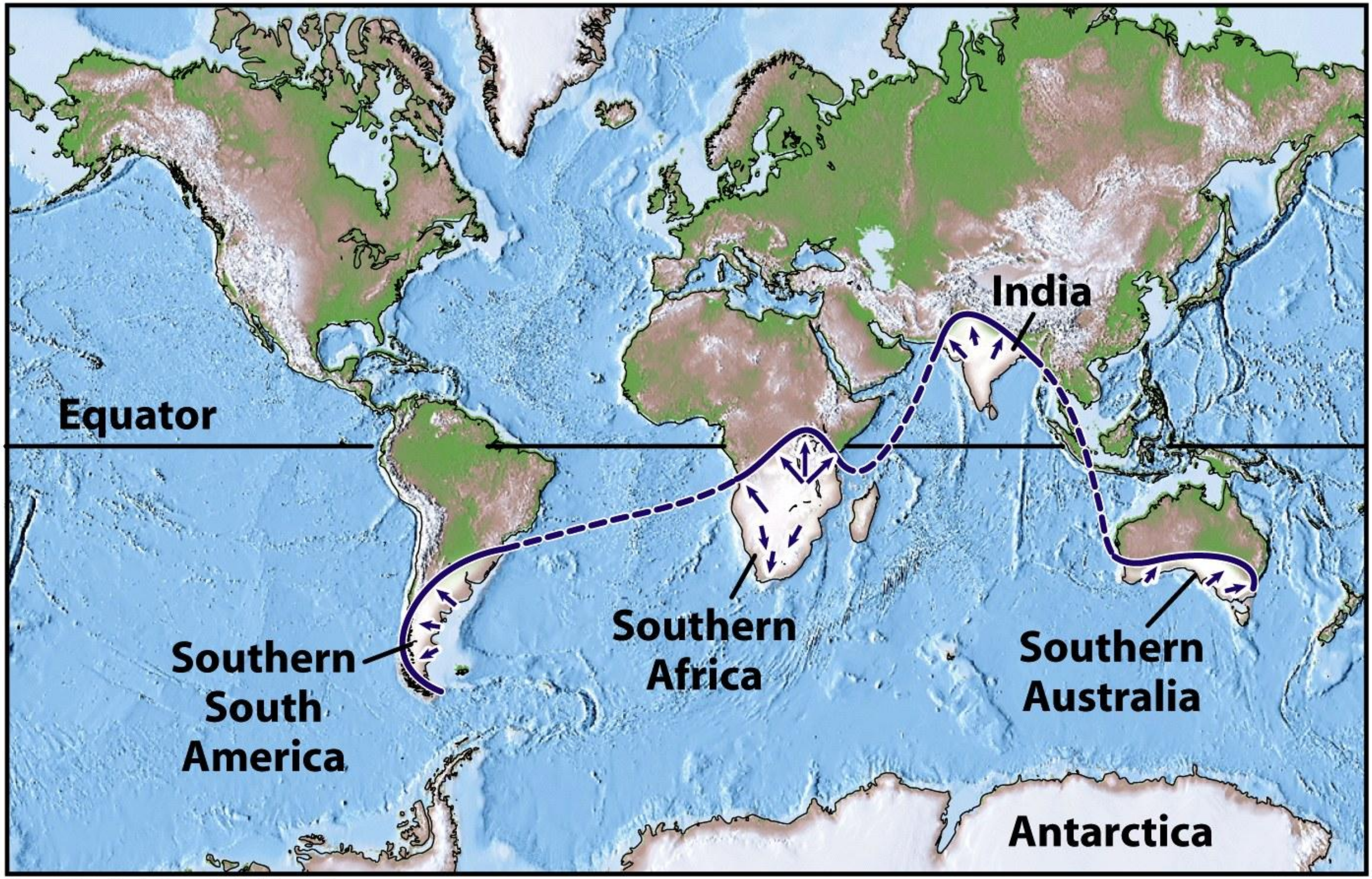


Figure 3-3a Earth: Portrait of a Planet 3/e

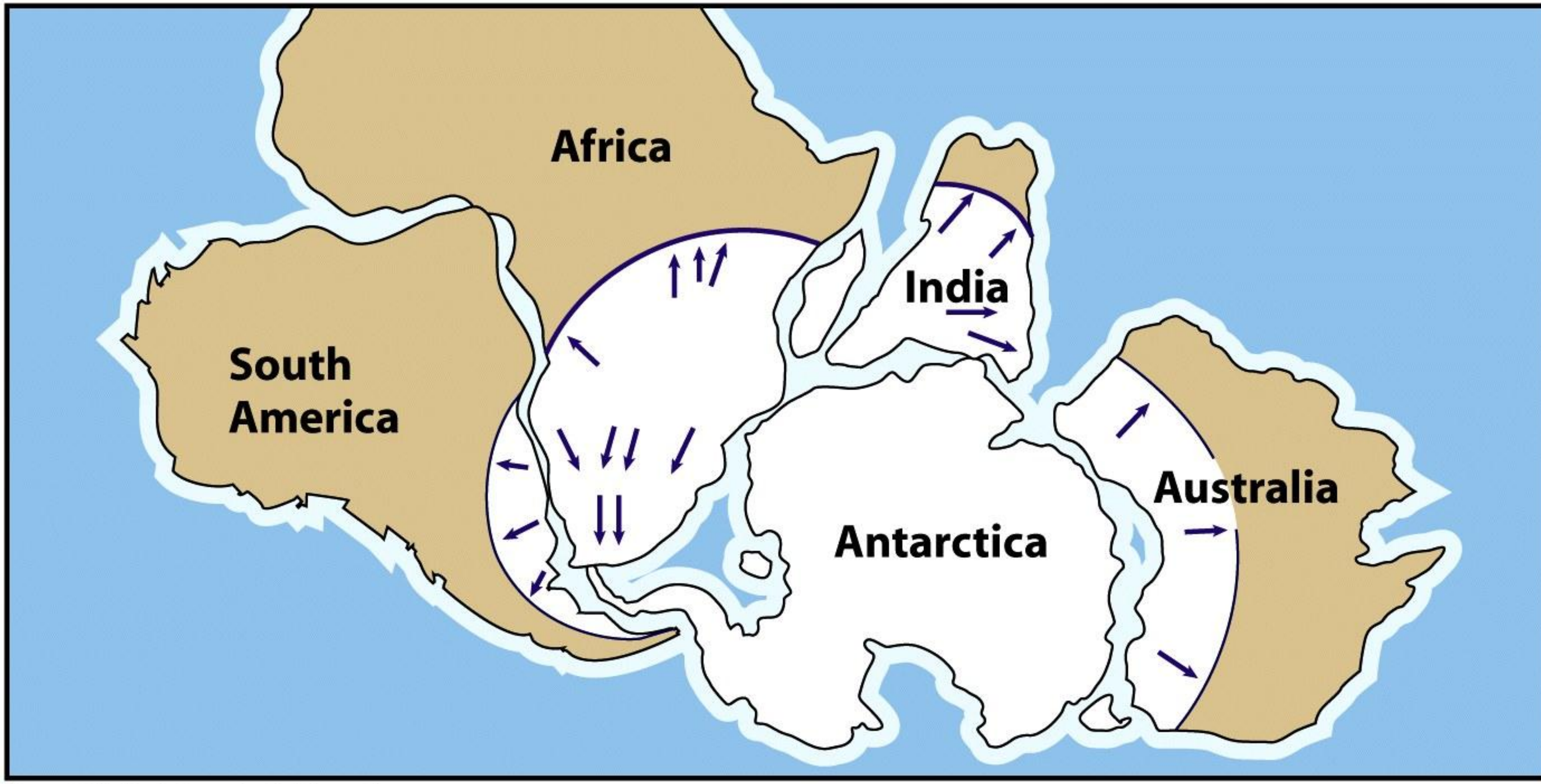


Figure 3-3b Earth: Portrait of a Planet 3/e

Matching Geology

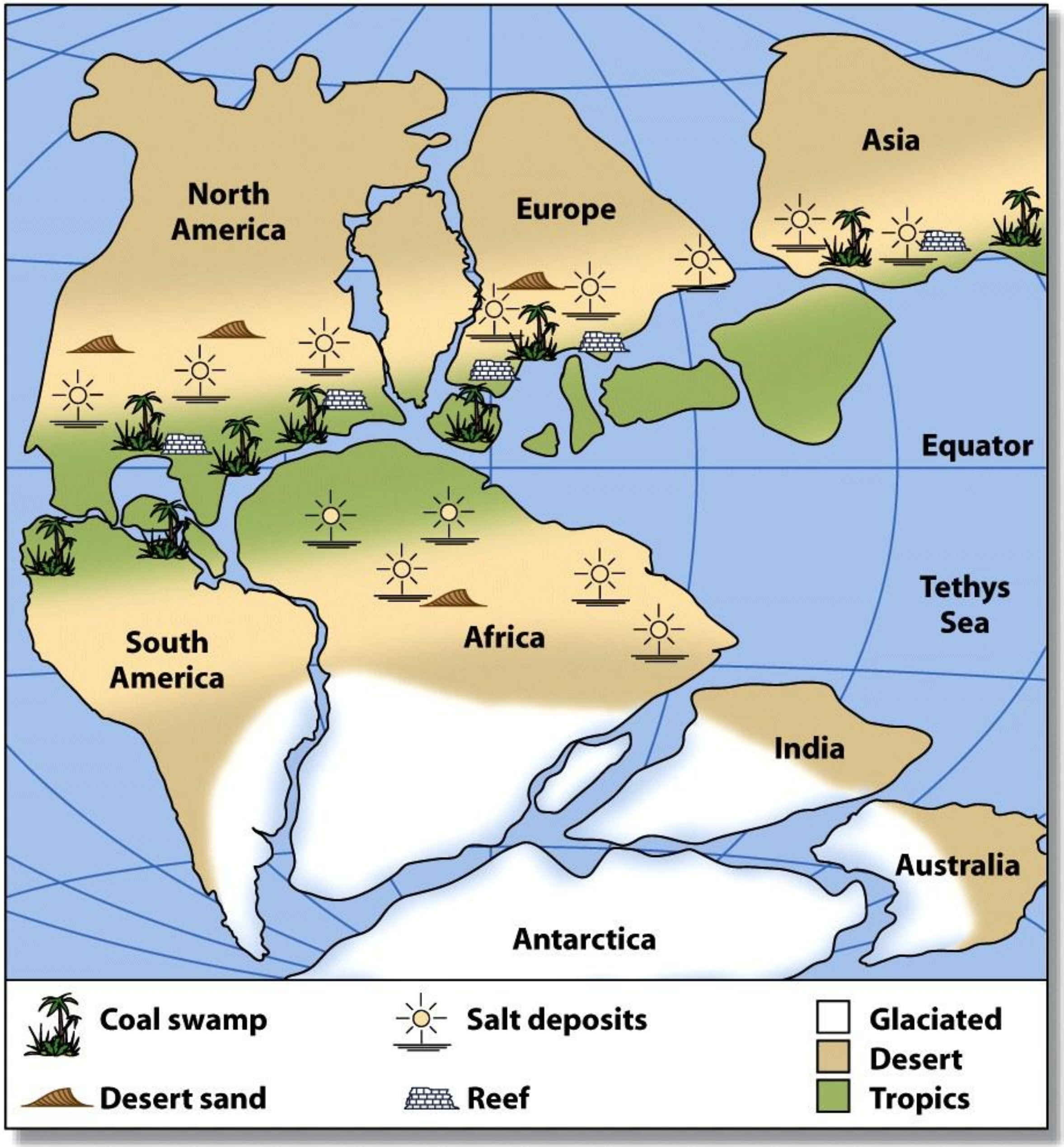


Figure 3-4 Earth: Portrait of a Planet 3/e
Modified from American Association of Petroleum Geologists

Matching fossils

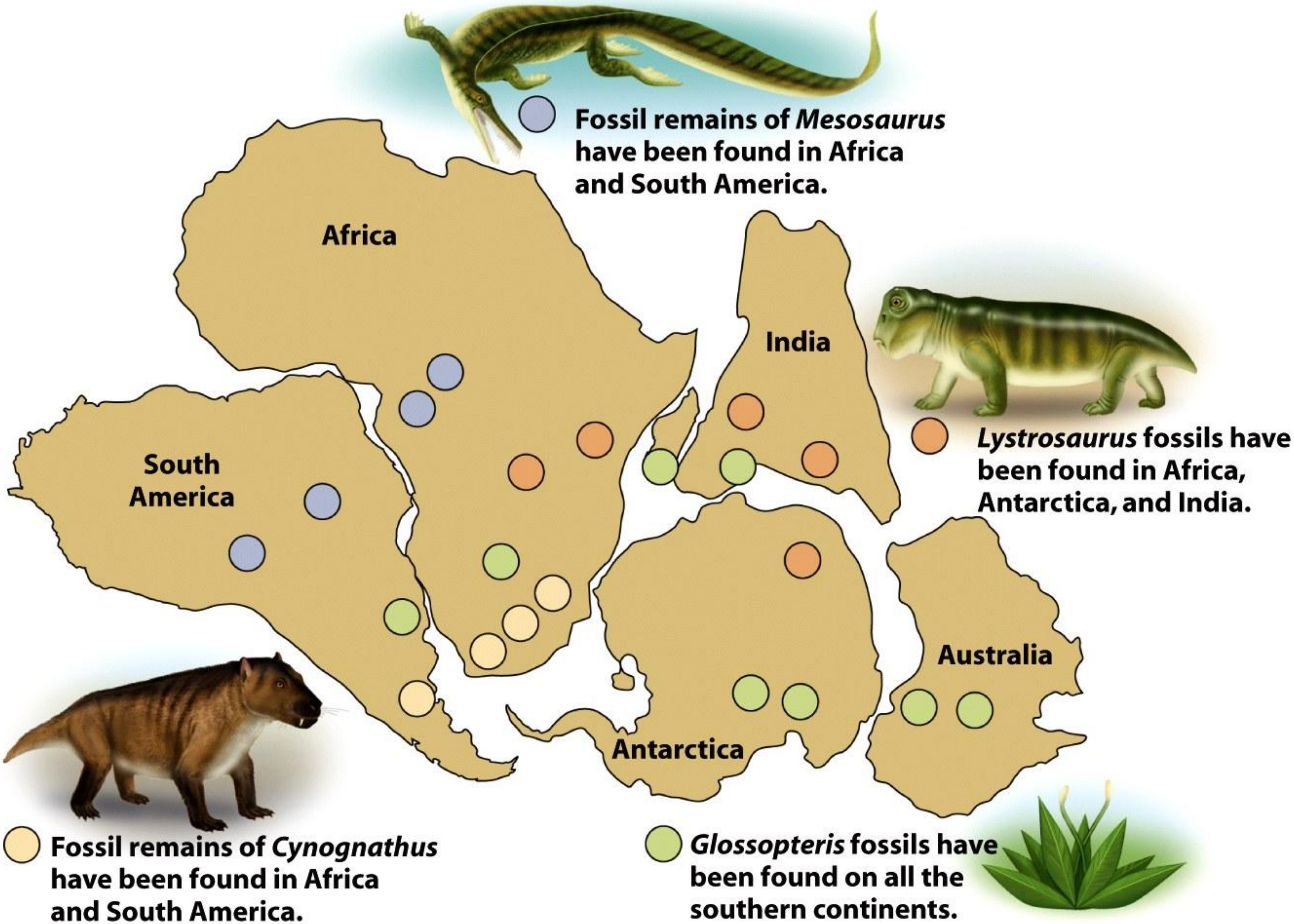


Figure 3-5 Earth: Portrait of a Planet 3/e

Wegener not believed

- Why? -
  - What could possibly force the continents to move across the ocean floor in this way. They would be crushed.
  - He was a meteorologist, not a geologist

Developments 50s and 60s

- World war 2 submarines found mountains under the oceans – the midocean ridges
- Sea floor drilling showed rocks younger than expected and youngest towards the center of the mid ocean ridge
- Theory of seafloor spreading suggested by Princeton professor Dr. Harry Hess

Alfred Wegener needed a mechanism to move the continents……….

<u>Sea Floor Spreading</u>

Paleomagnetism

…..measuring the components (inclination and declination) of Earth’s magnetic field preserved in rocks of different ages……

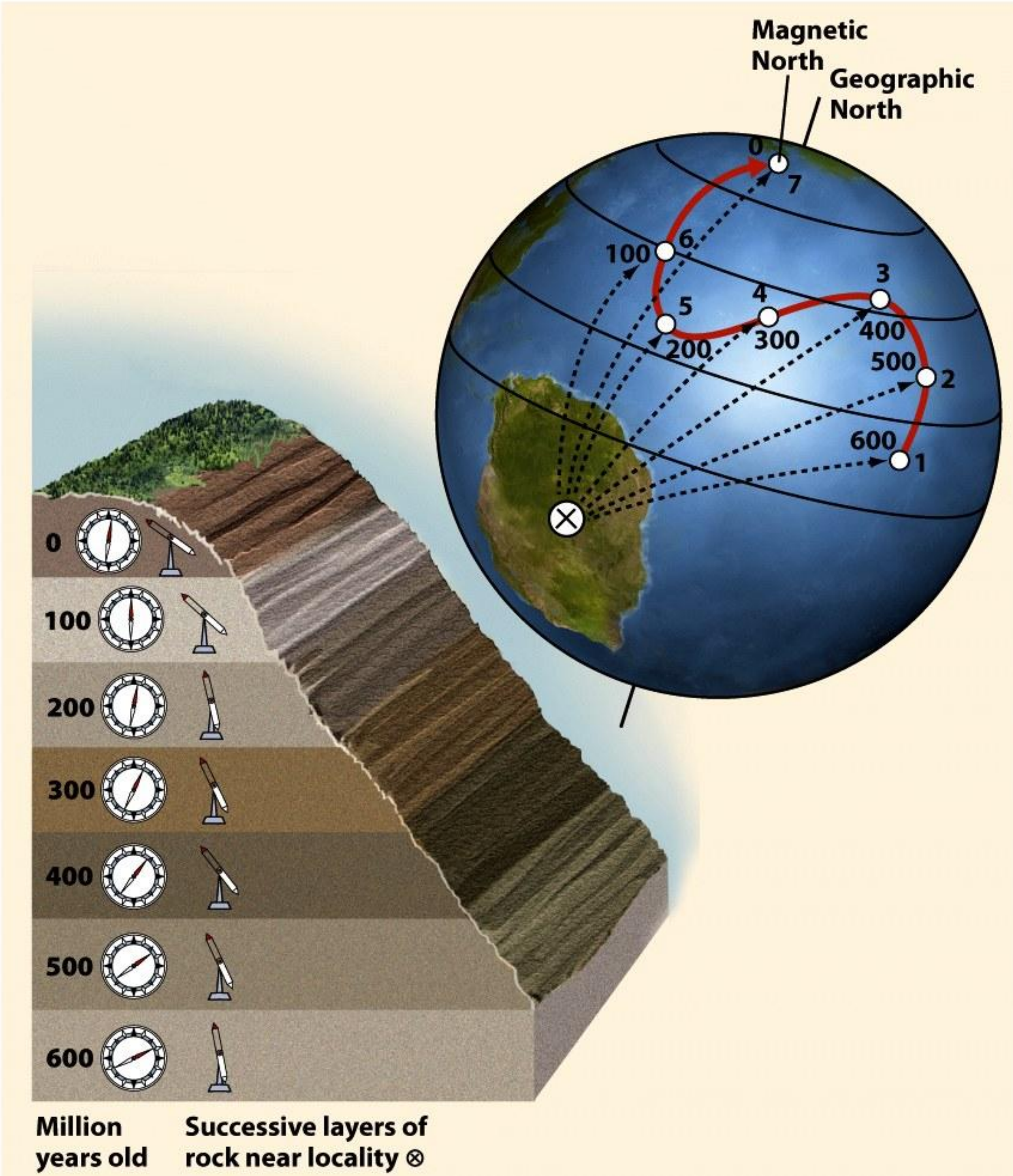
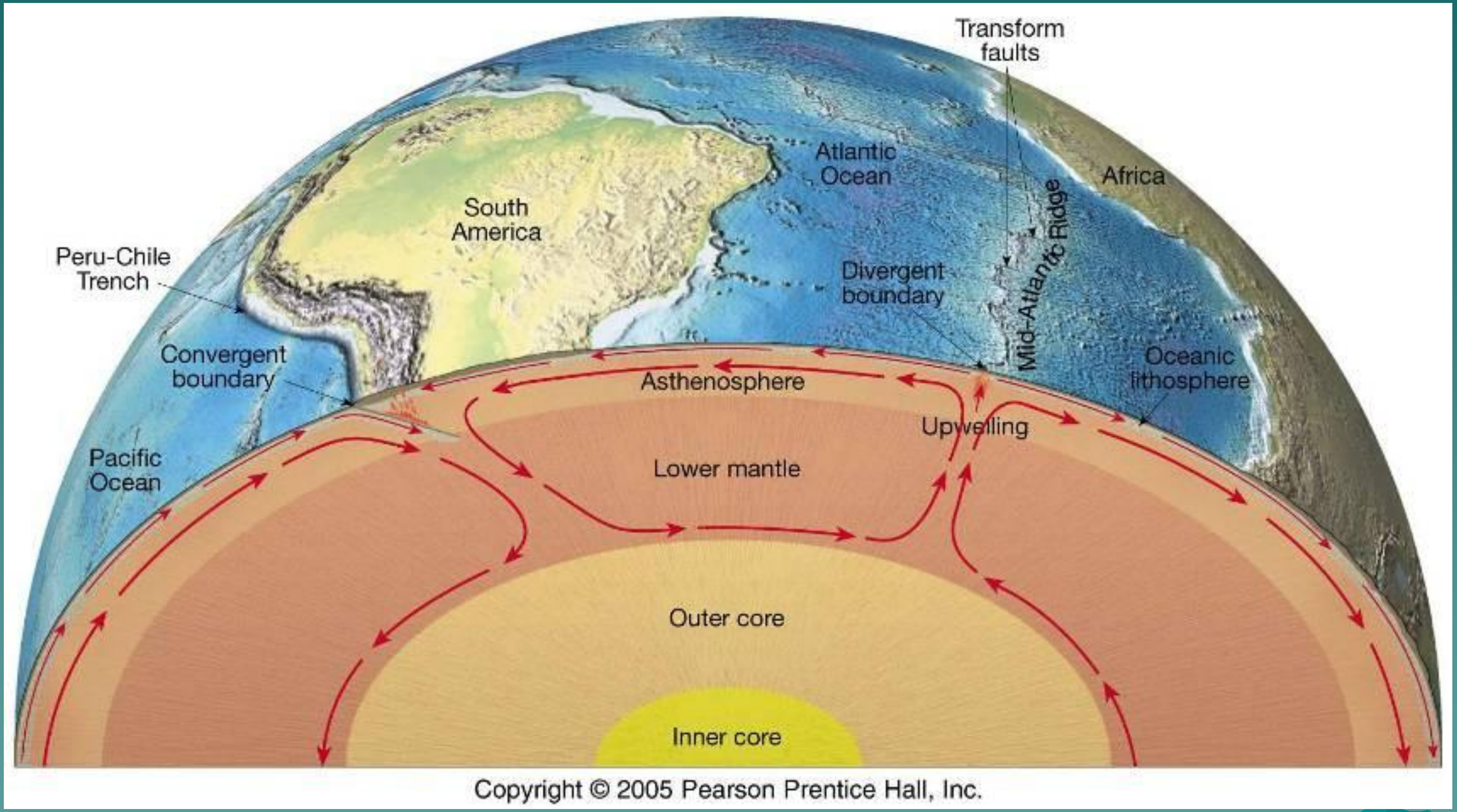


Figure A-9 Earth: Portrait of a Planet 3/e

First assumption by scientists: <u>the North Pole was moving.</u>

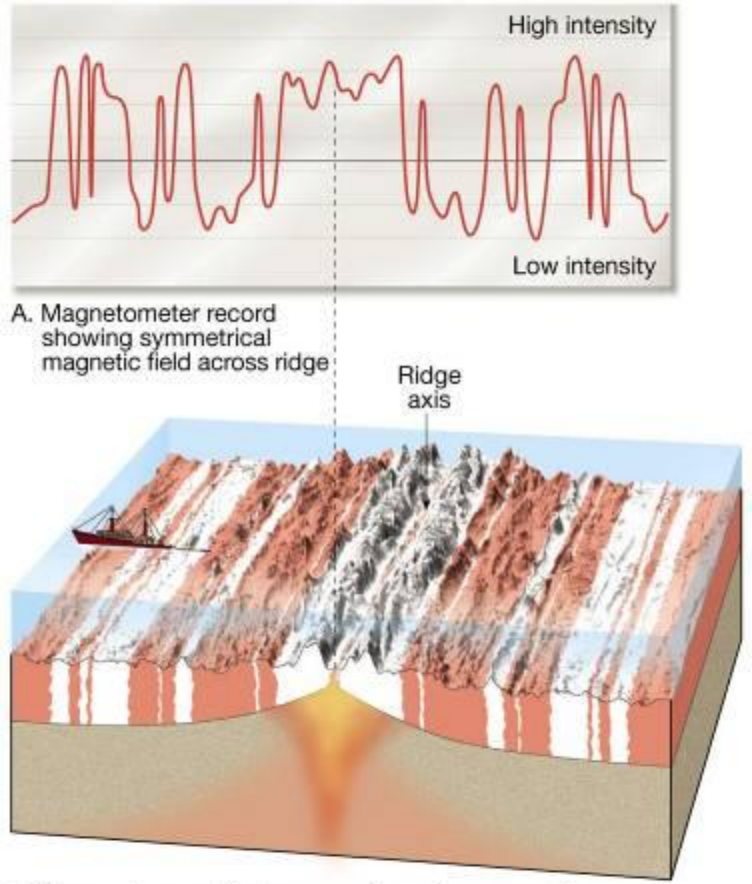
Seafloor spreading



First look at the earth's layers as shown here. Let's draw them. How do we know about them? Animation and Video

Evidence for sea floor spreading

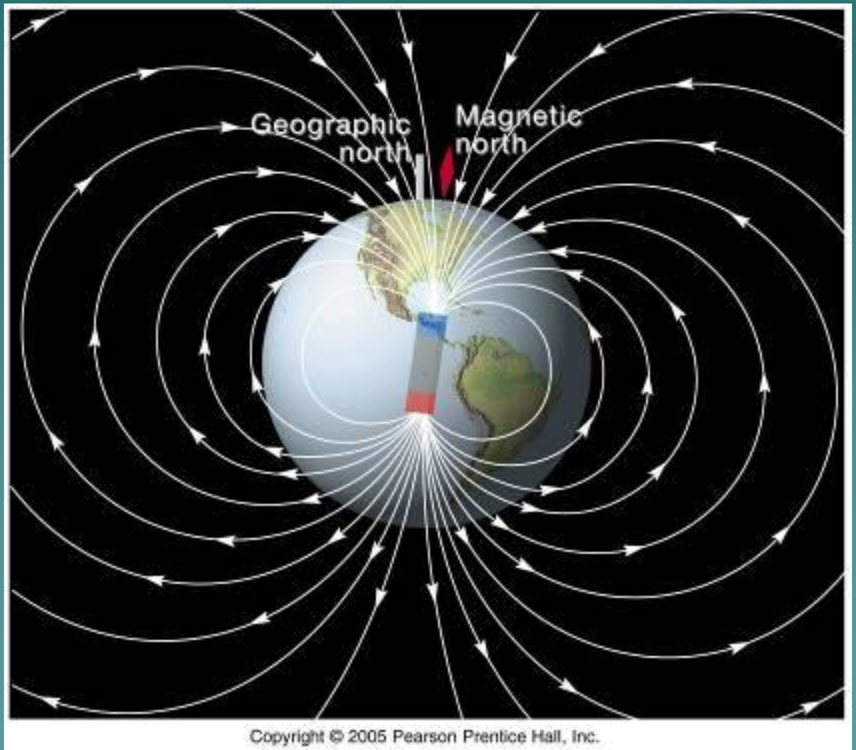
- Cracks and lava showing spreading and volcanism at mid ocean ridges
- Indian Ocean sea floor showed matching stripes of reversing polarities on either side of ridge – what caused these?
  - Lava spreading during alternating magnetic periods

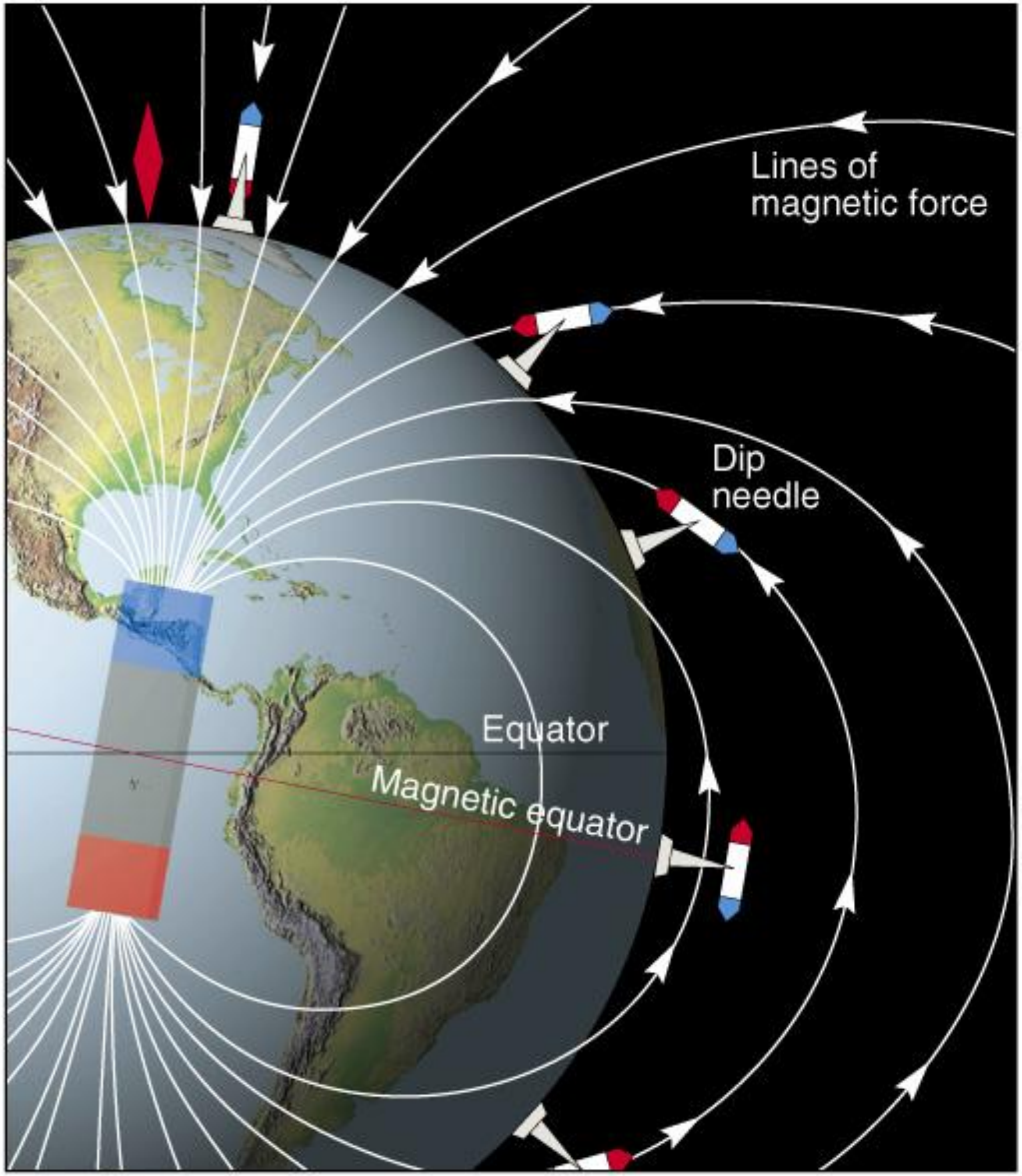


B. Research vessel towing magnetometer across ridge crest

The Earth's magnetic field

- It is produced by the outer core of the earth which is made of liquid iron and nickel
- This moving magnetic material produces a moving magnetic field. It is a dynamo!
- Earth's magnetic field varies over time and it protects us from cosmic radiation





Magnetite crystals align with magnetic field

Away from equator and poles they dip toward the North or south poles

When the Earths polarity switches, new lavas adjacent older, point in opposite directions

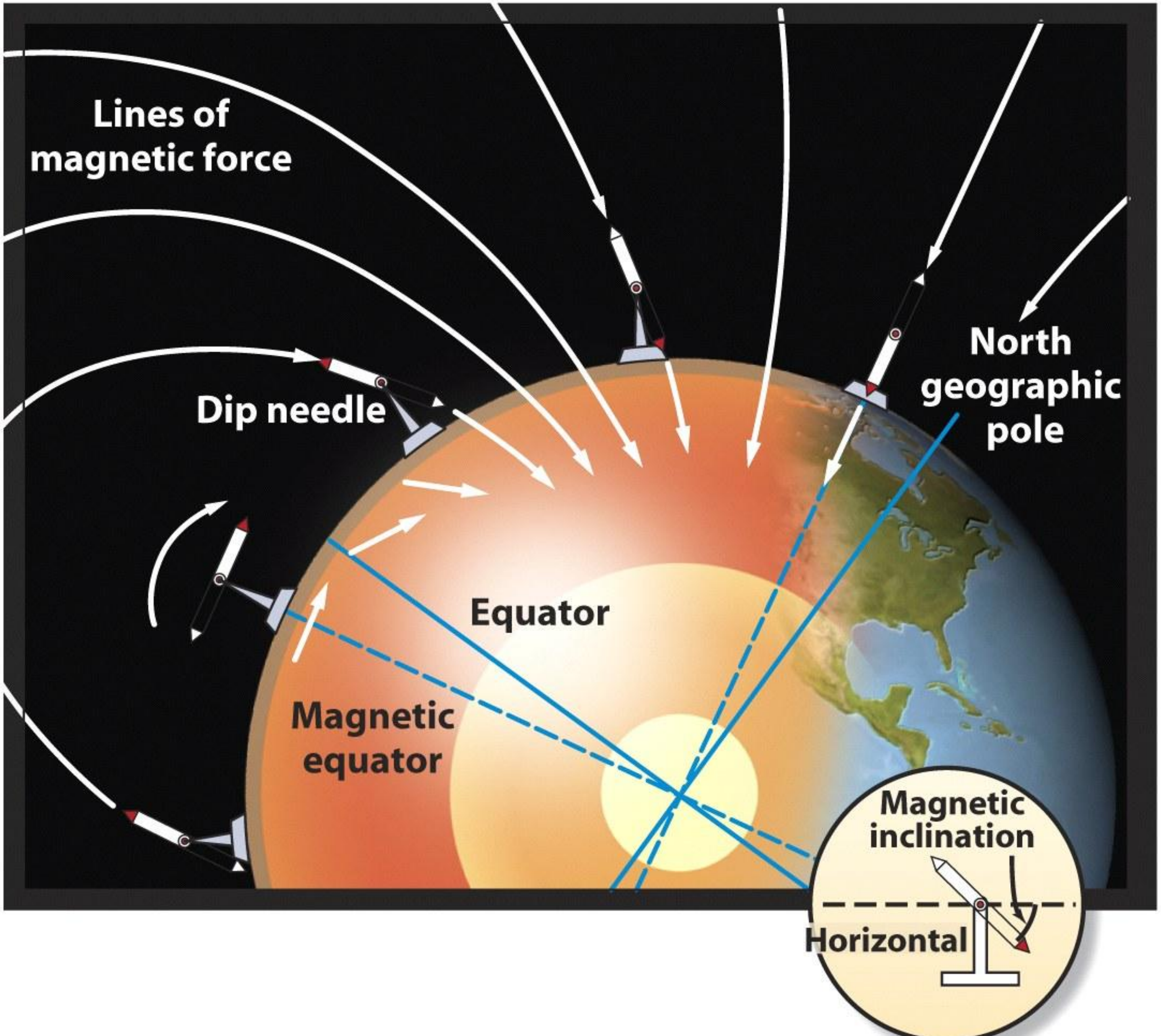
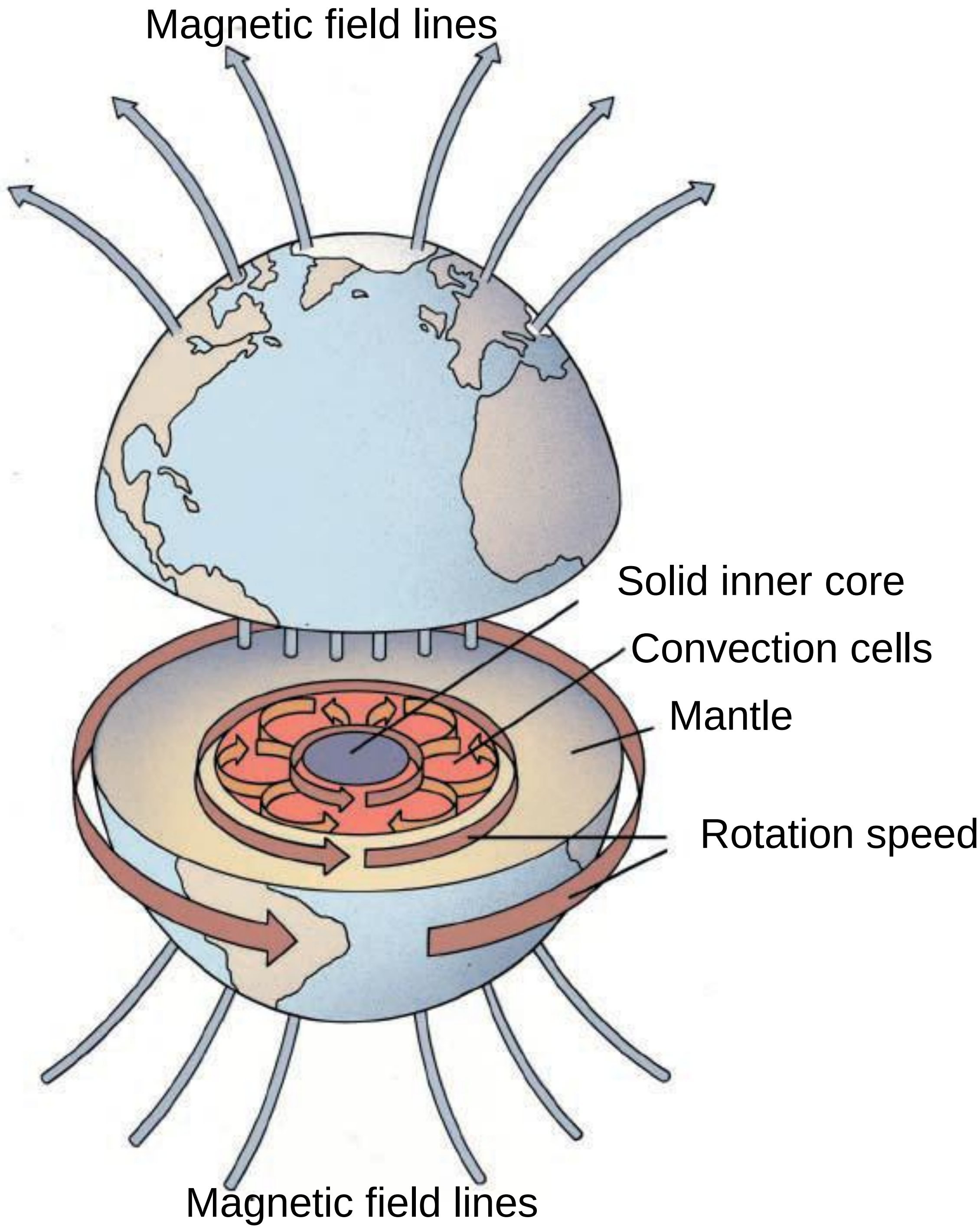


Figure A-4 Earth: Portrait of a Planet 3/e


Magnetic field lines
Solid inner core
Convection cells
Mantle
Rotation speed
Magnetic field lines

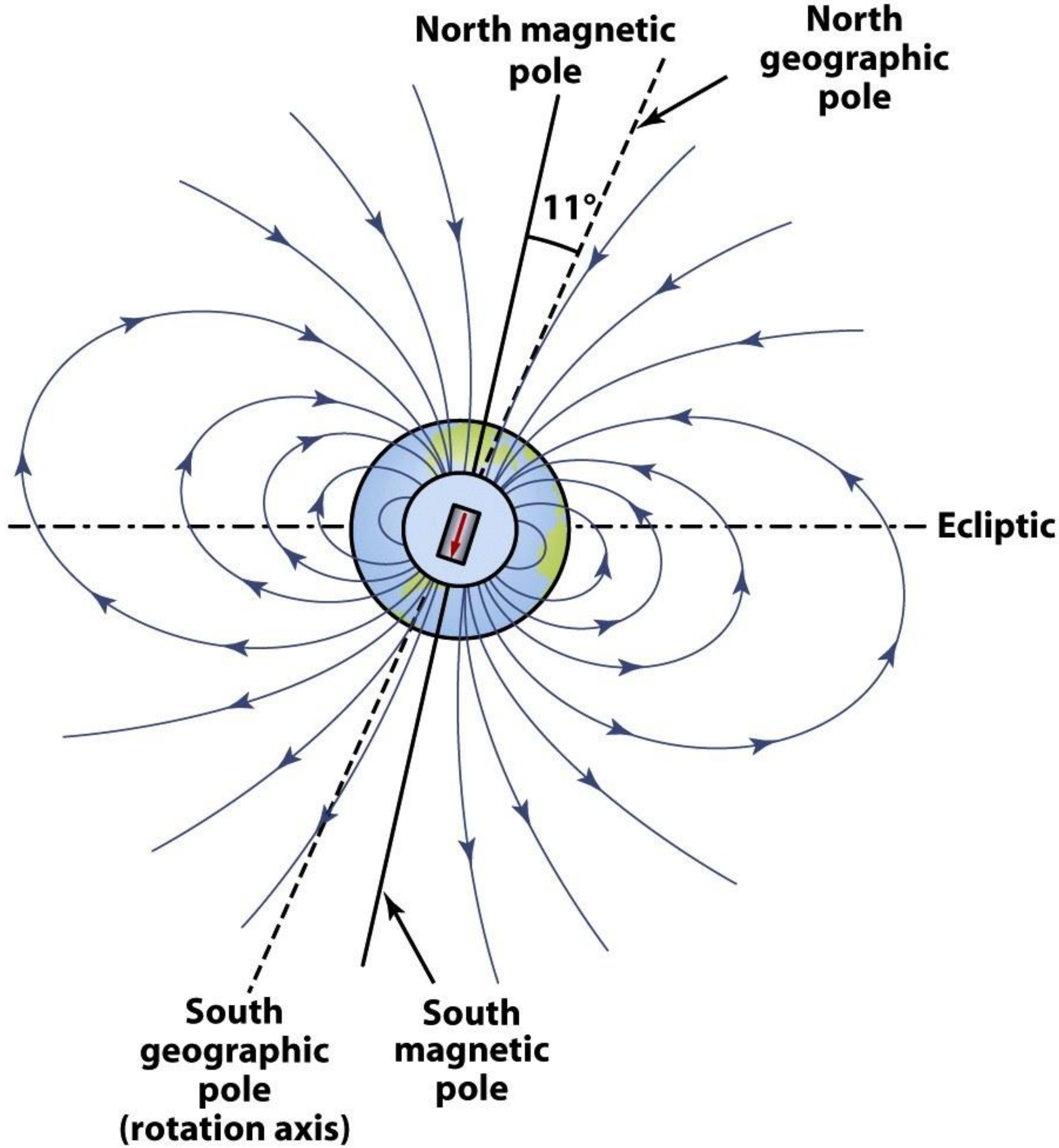
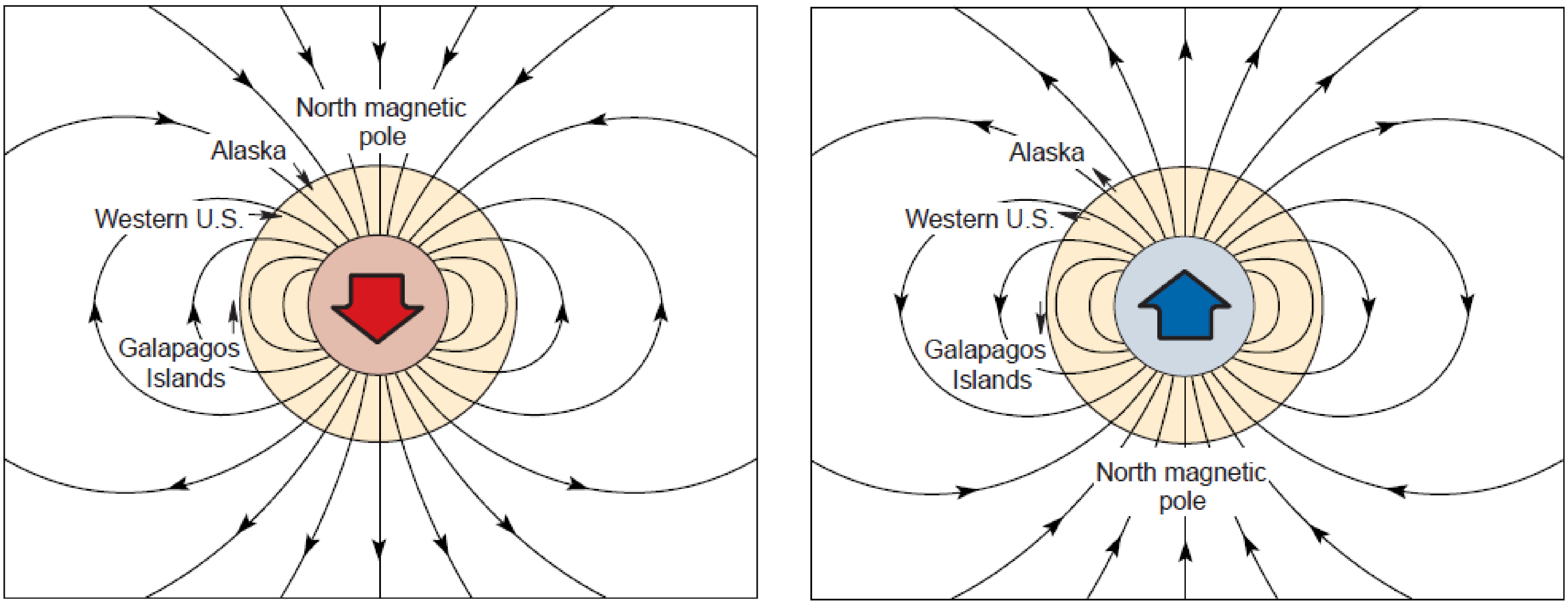


Figure A-2b Earth: Portrait of a Planet 3/e



(A) Normal polarity

(B) Reverse polarity

Paleomagnetism – magnetic signature locked in rocks

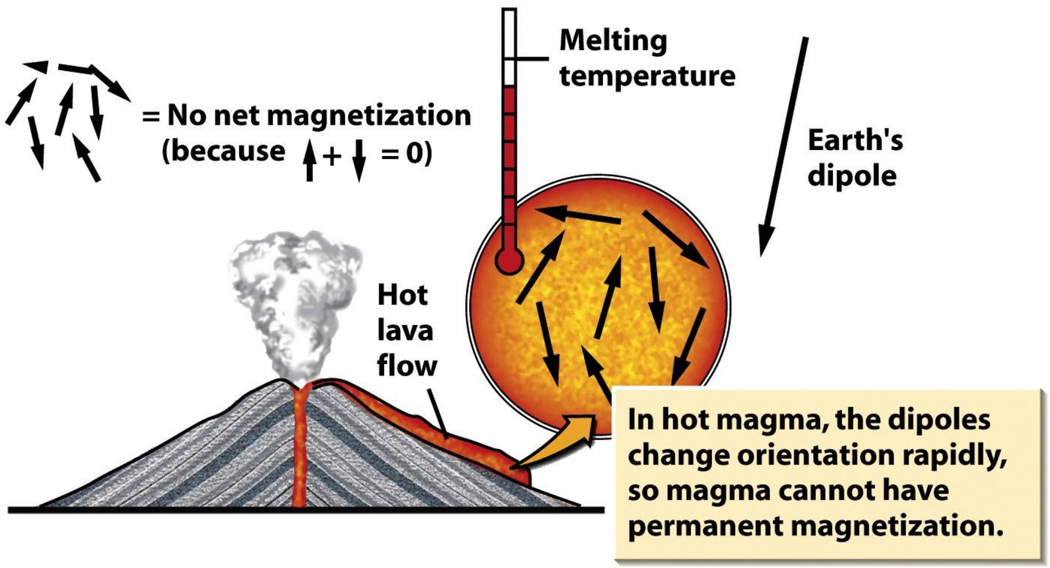


Figure A-5a Earth: Portrait of a Planet 3/e

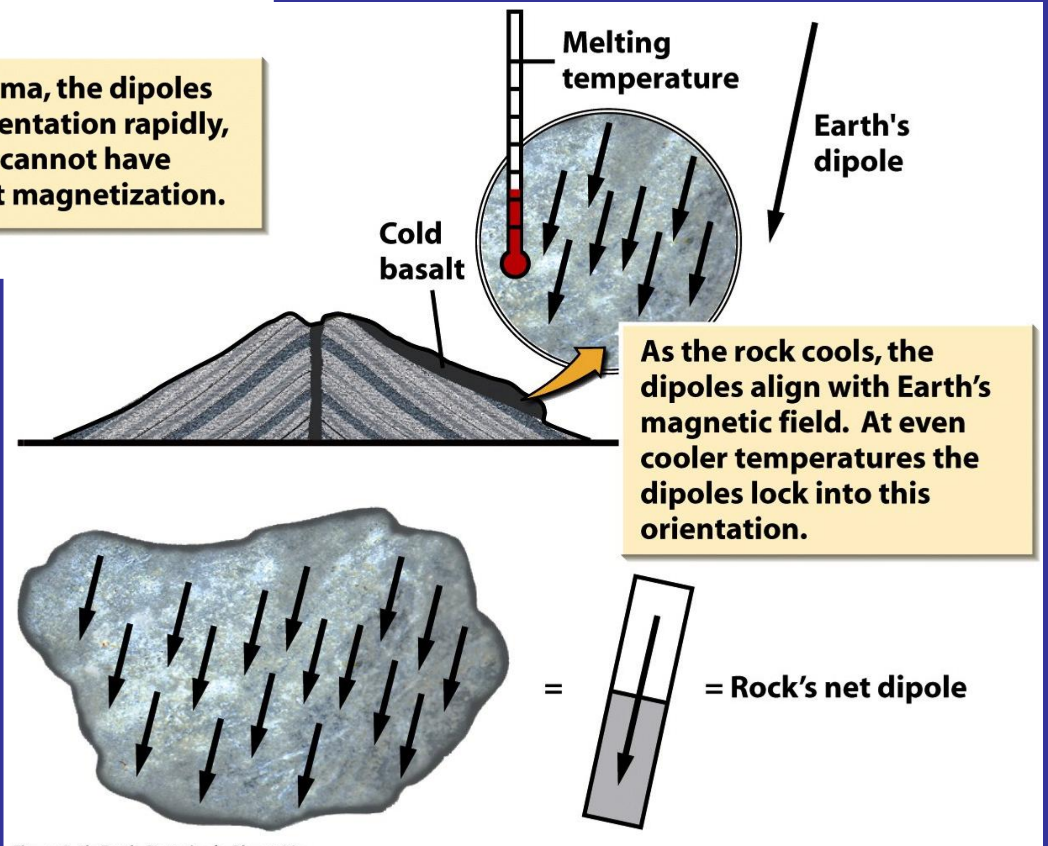
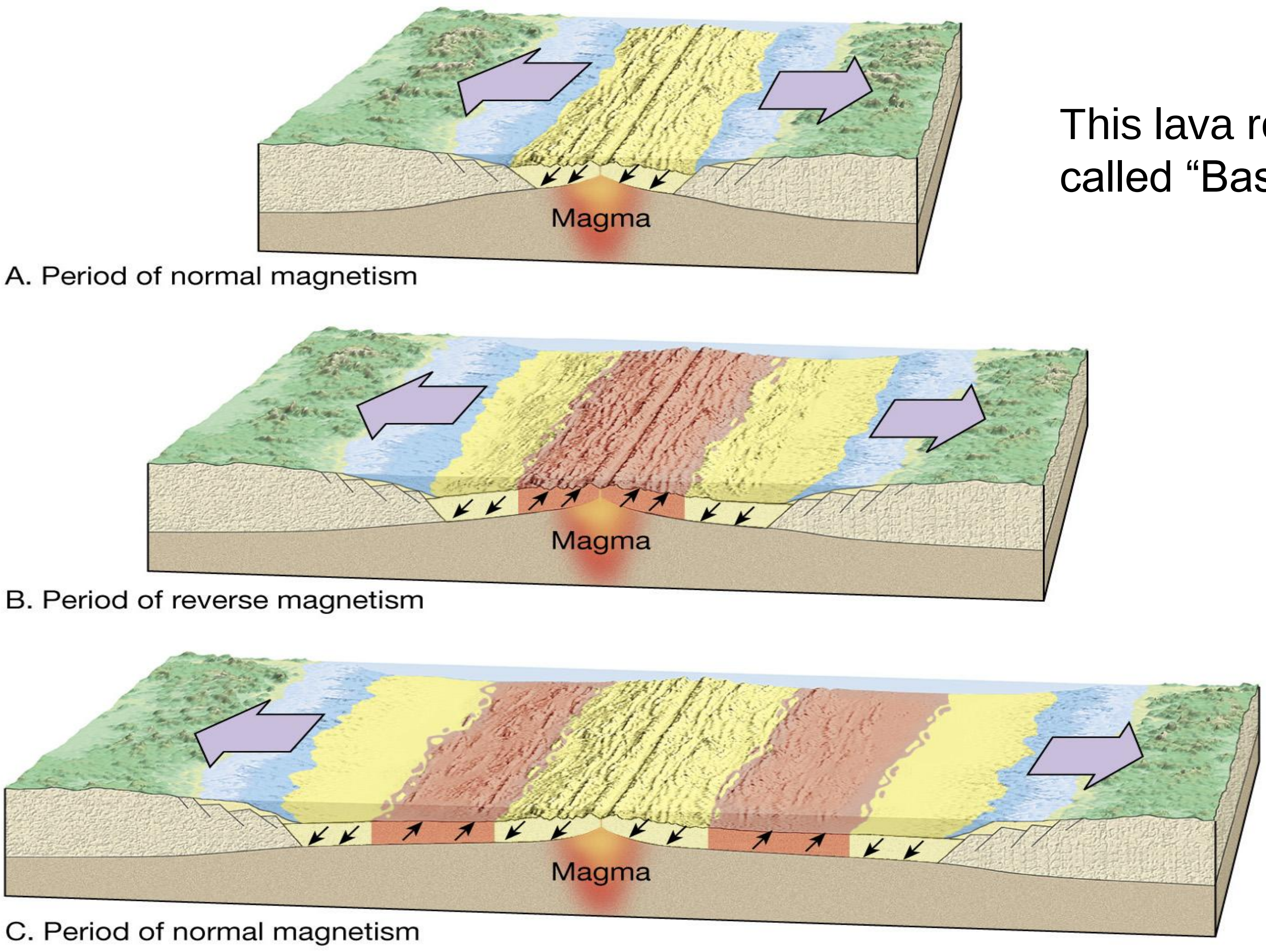


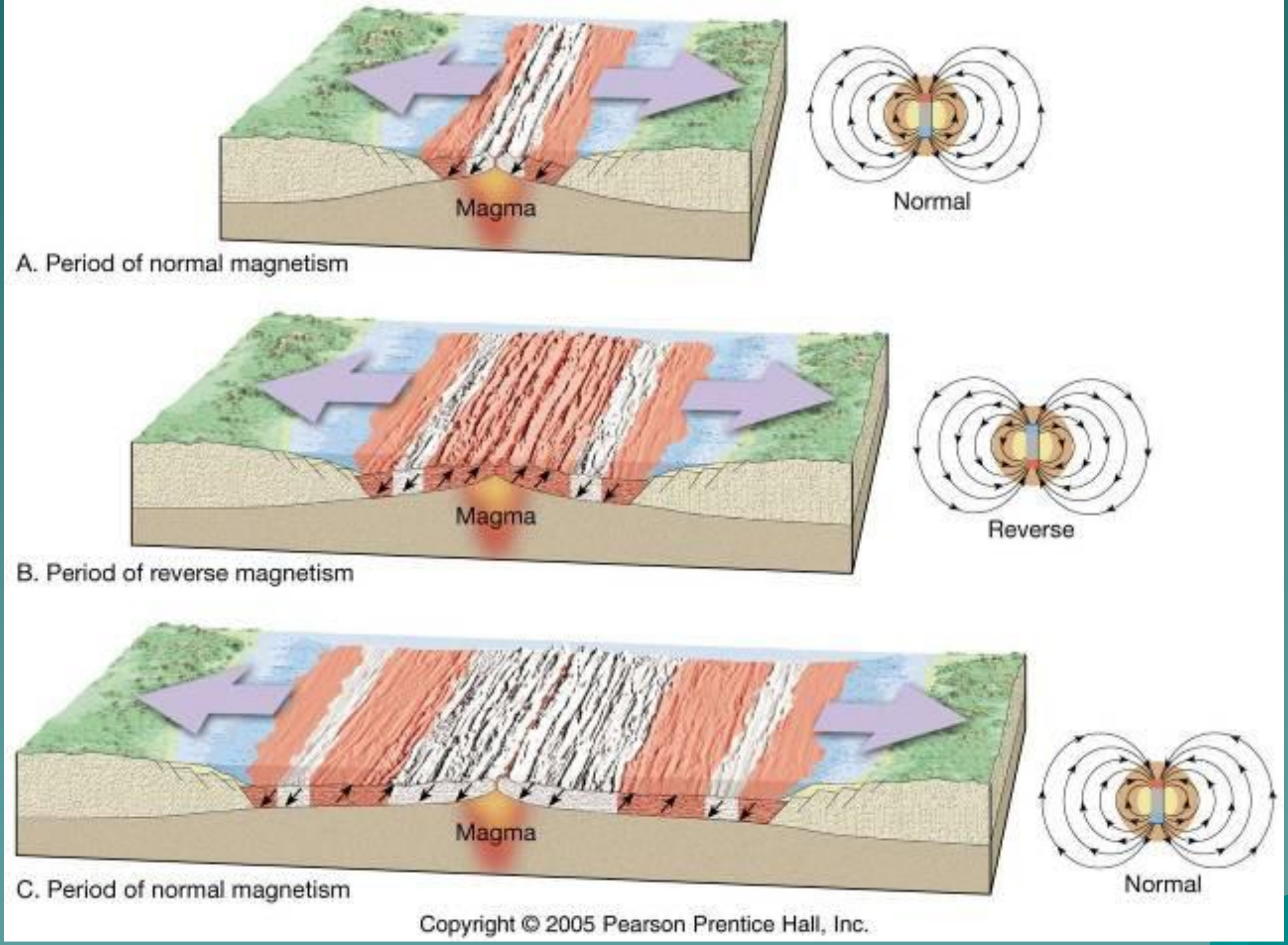
Figure A-5b Earth: Portrait of a Planet 3/e

Paleomagnetic reversals recorded by new lava rock at mid-ocean ridges



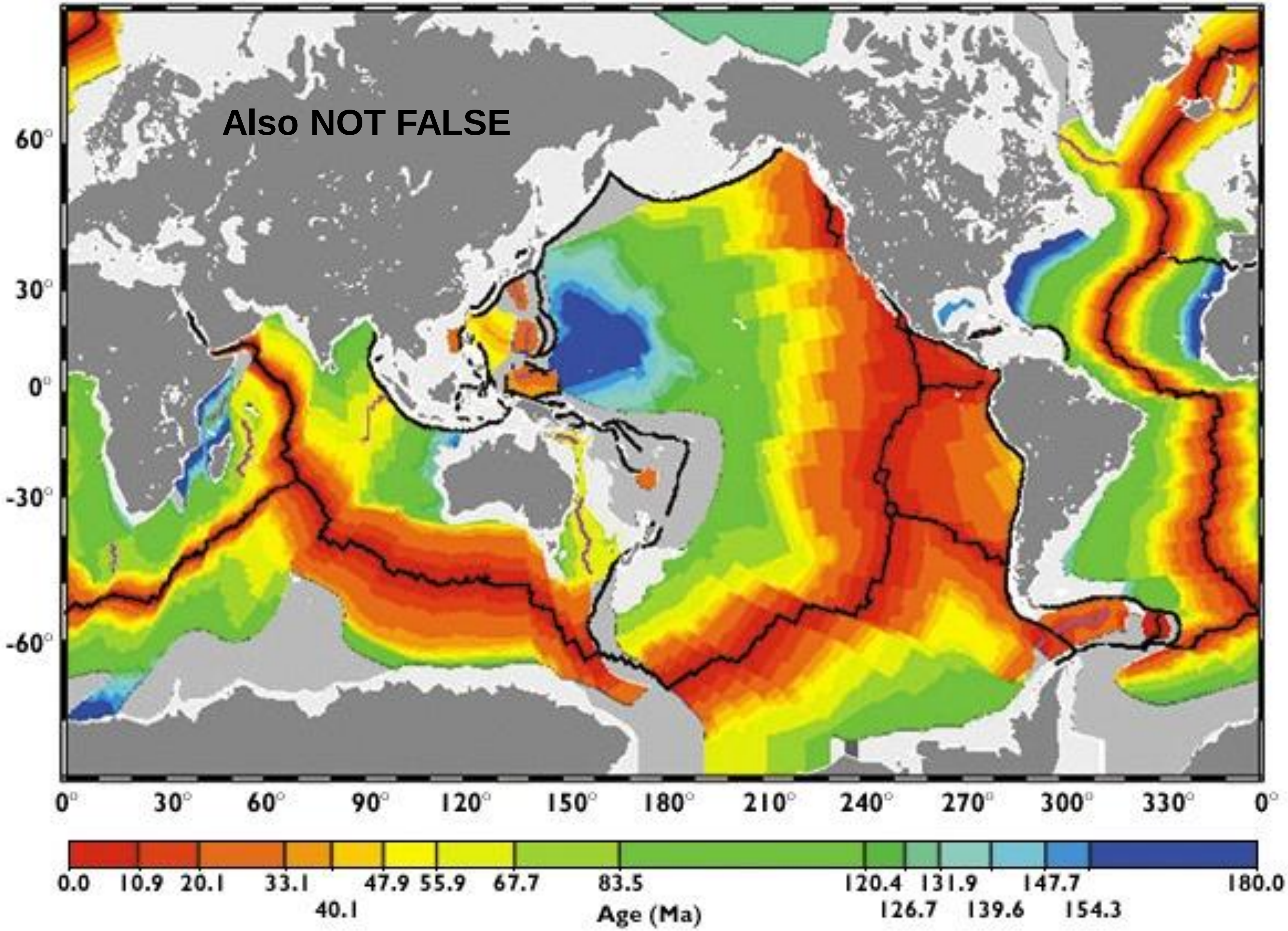
This lava rock is called “Basalt”

Seafloor spreading and paleomagnetism

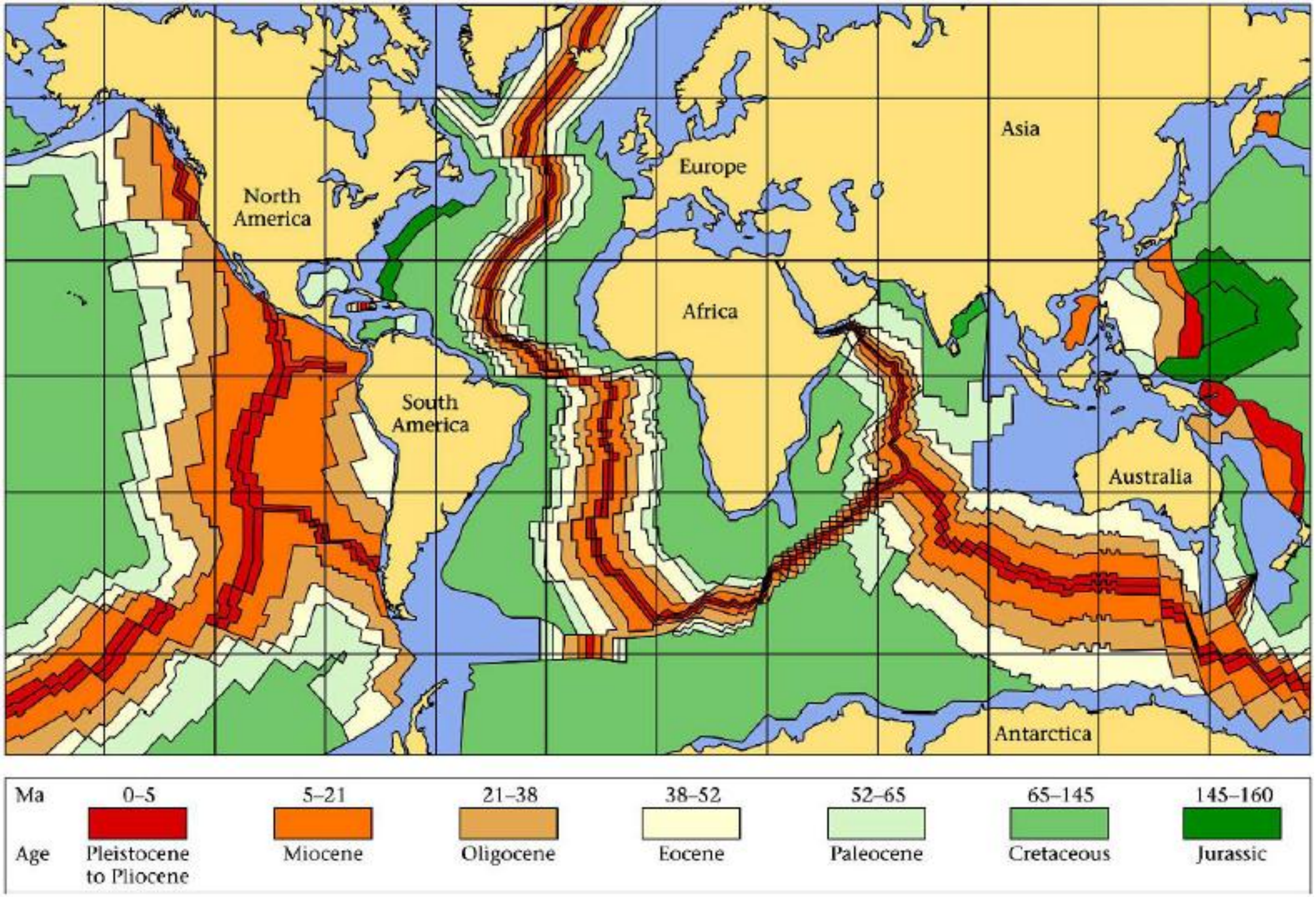


Oceanic Crust youngest at ridges

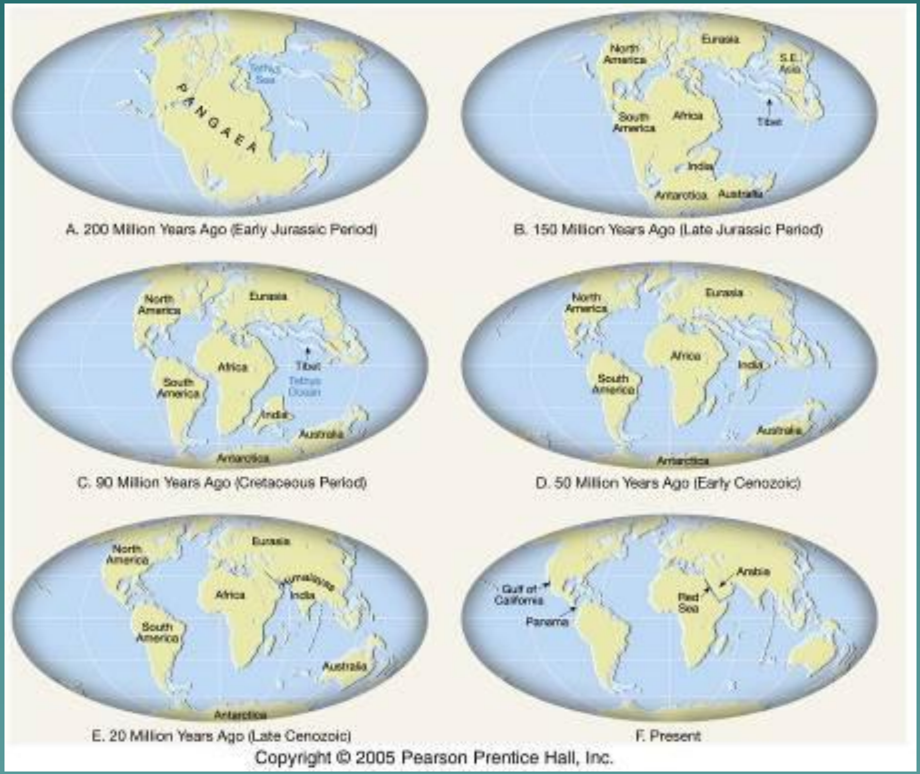
Hess model prediction: youngest at ridges, oldest at trenches



Age of the Sea Floor



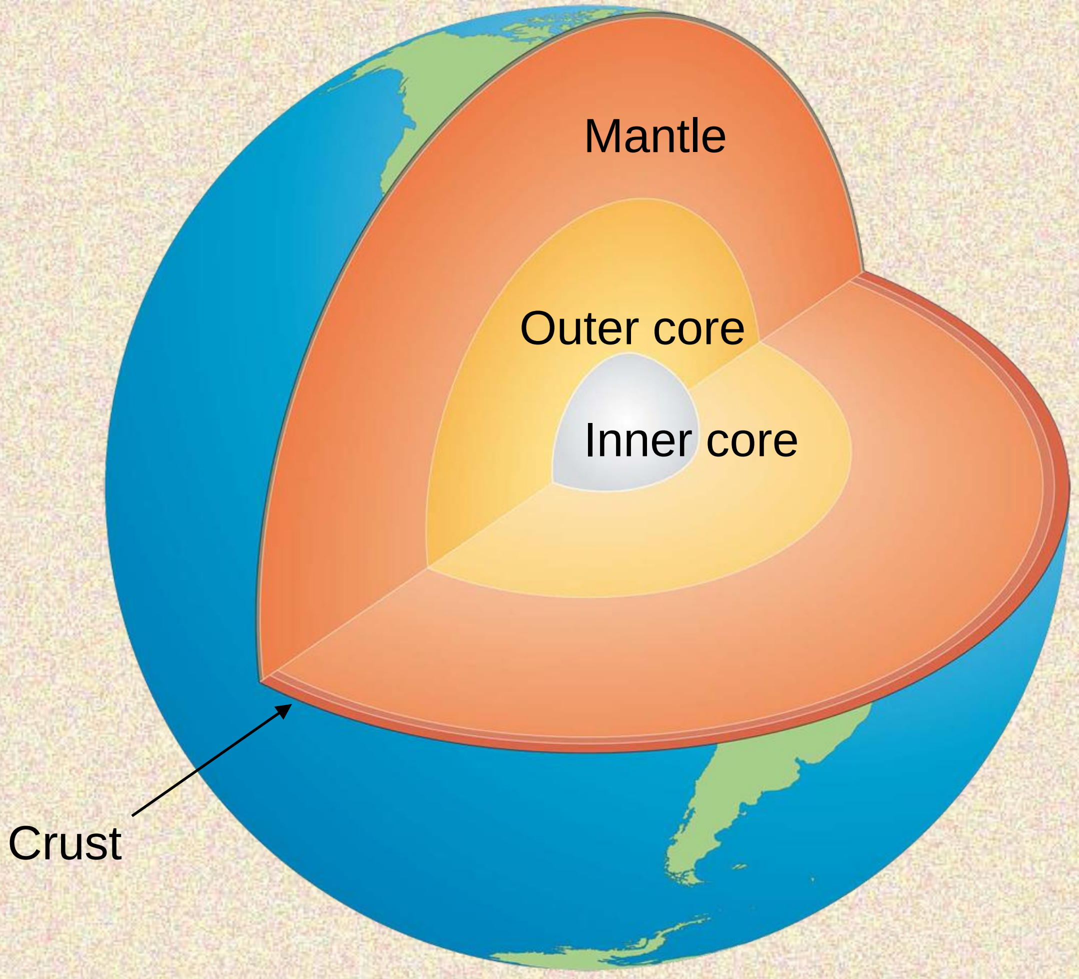
Pangaea revisited



- By piecing together this information, we can see how the continents have moved over the past 200 million years, due to seafloor spreading

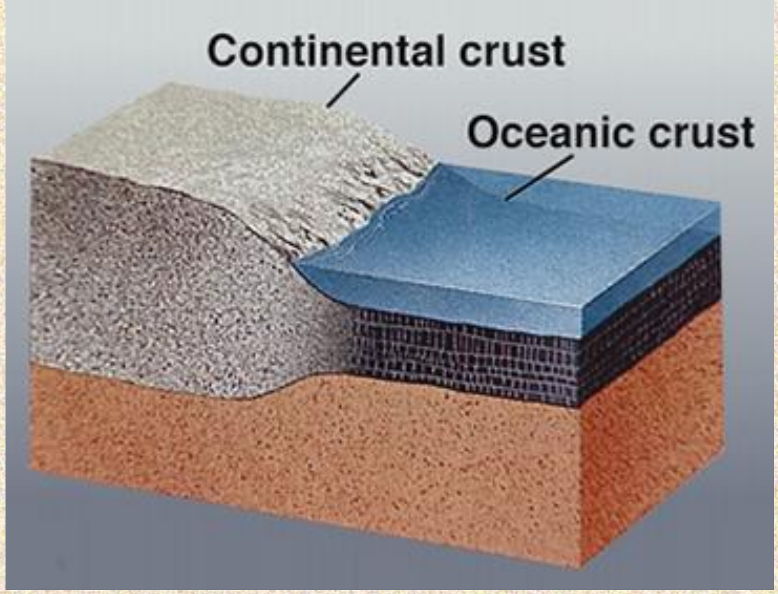
Structure of the Earth

- The Earth is made up of 3 main layers:
  - Core
  - Mantle
  - Crust



University of BRISTOL

The Crust



- The Earth's crust is made of:

Continental Crust

- thick (10-70km)
- buoyant (less dense than oceanic crust)

-mainly acidic rocks
- mostly old

Oceanic Crust

- thin (~7 km)
- dense (sinks under continental crust)
- mainly basic rocks
- young

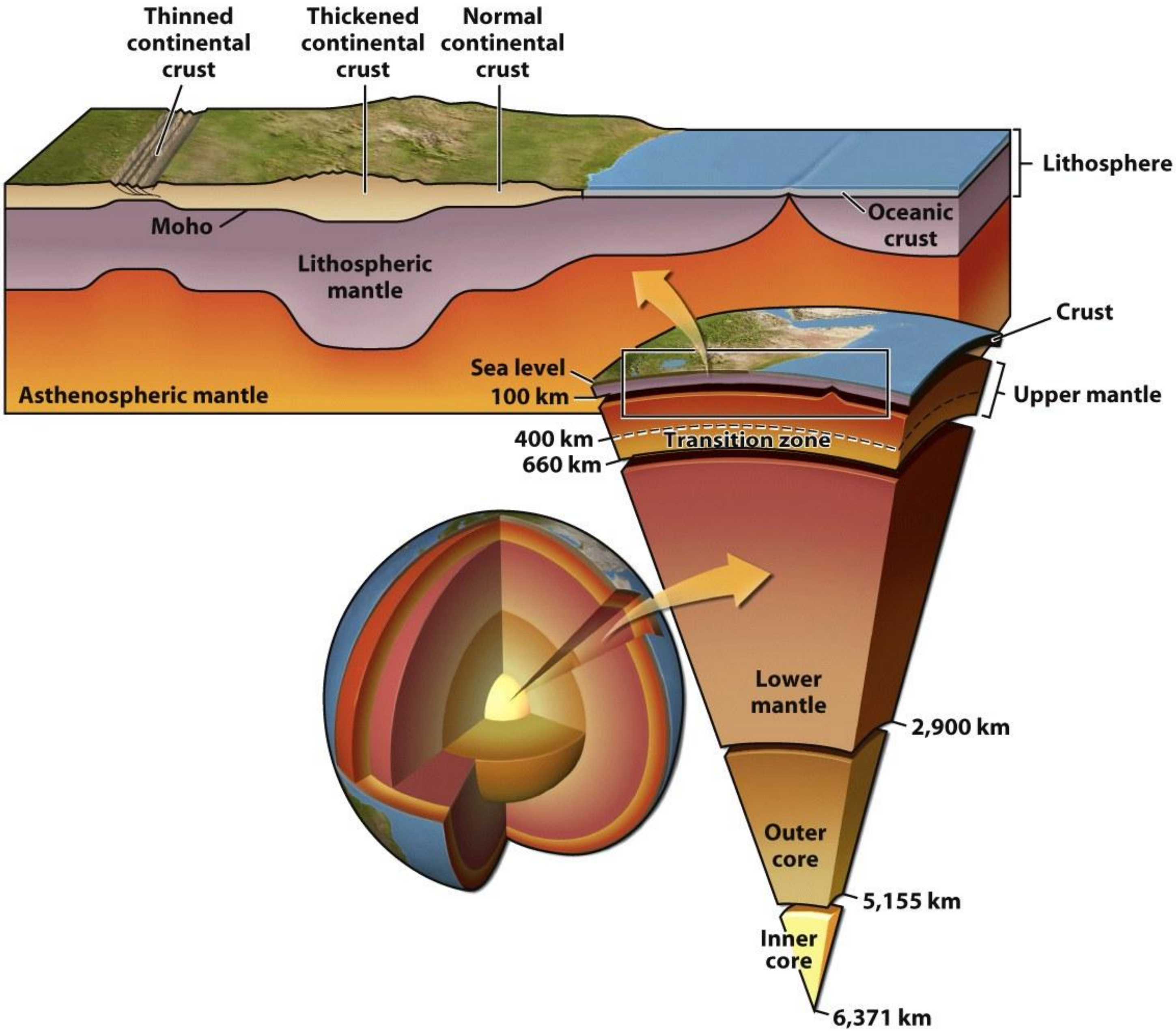


Figure 2-13a Earth: Portrait of a Planet 3/e

Compositional division of crust and mantle

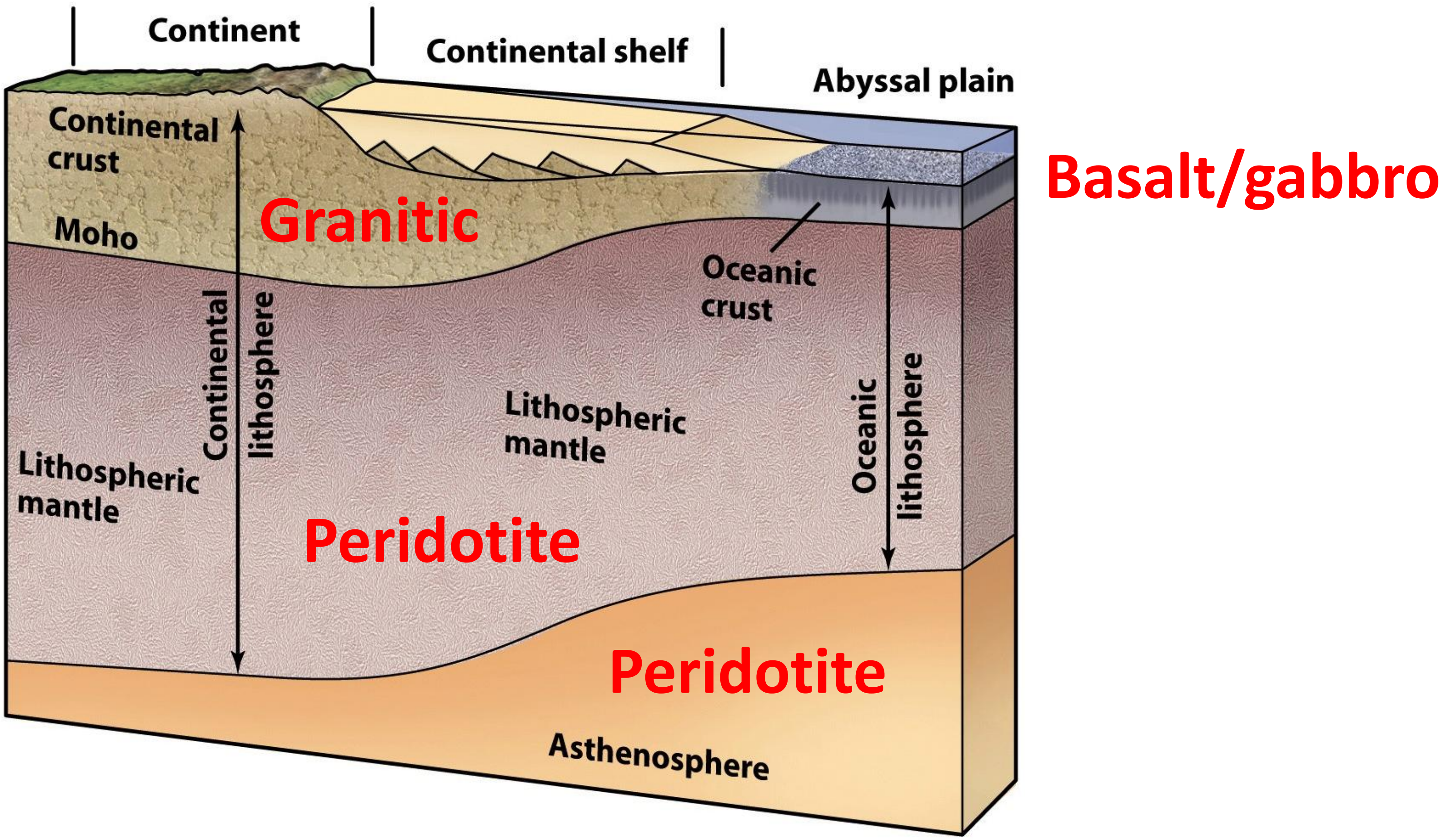


Figure 4-3 Earth: Portrait of a Planet 3/e

Lithosphere versus asthenosphere not a compositional break

Strength division of crust and mantle

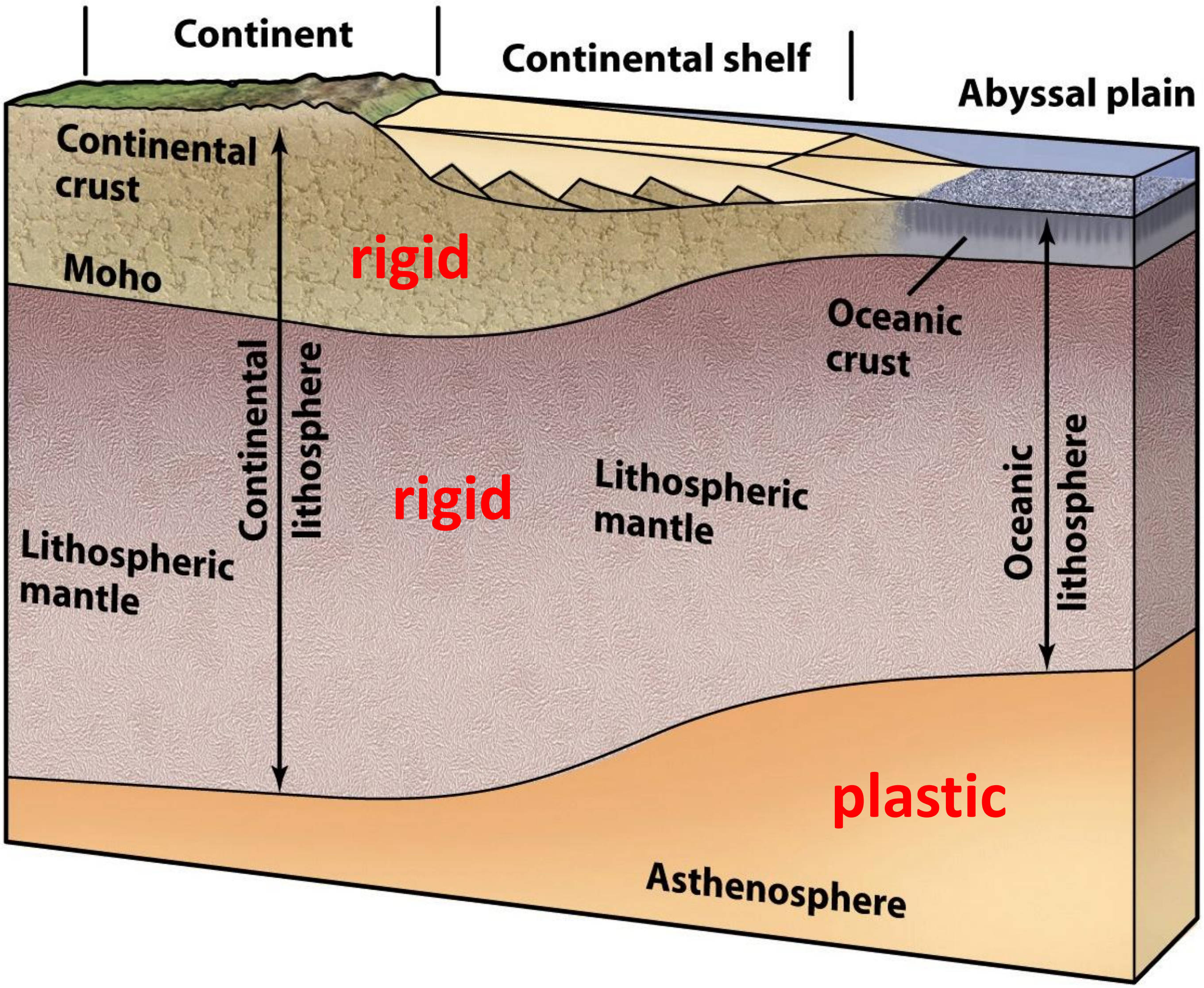


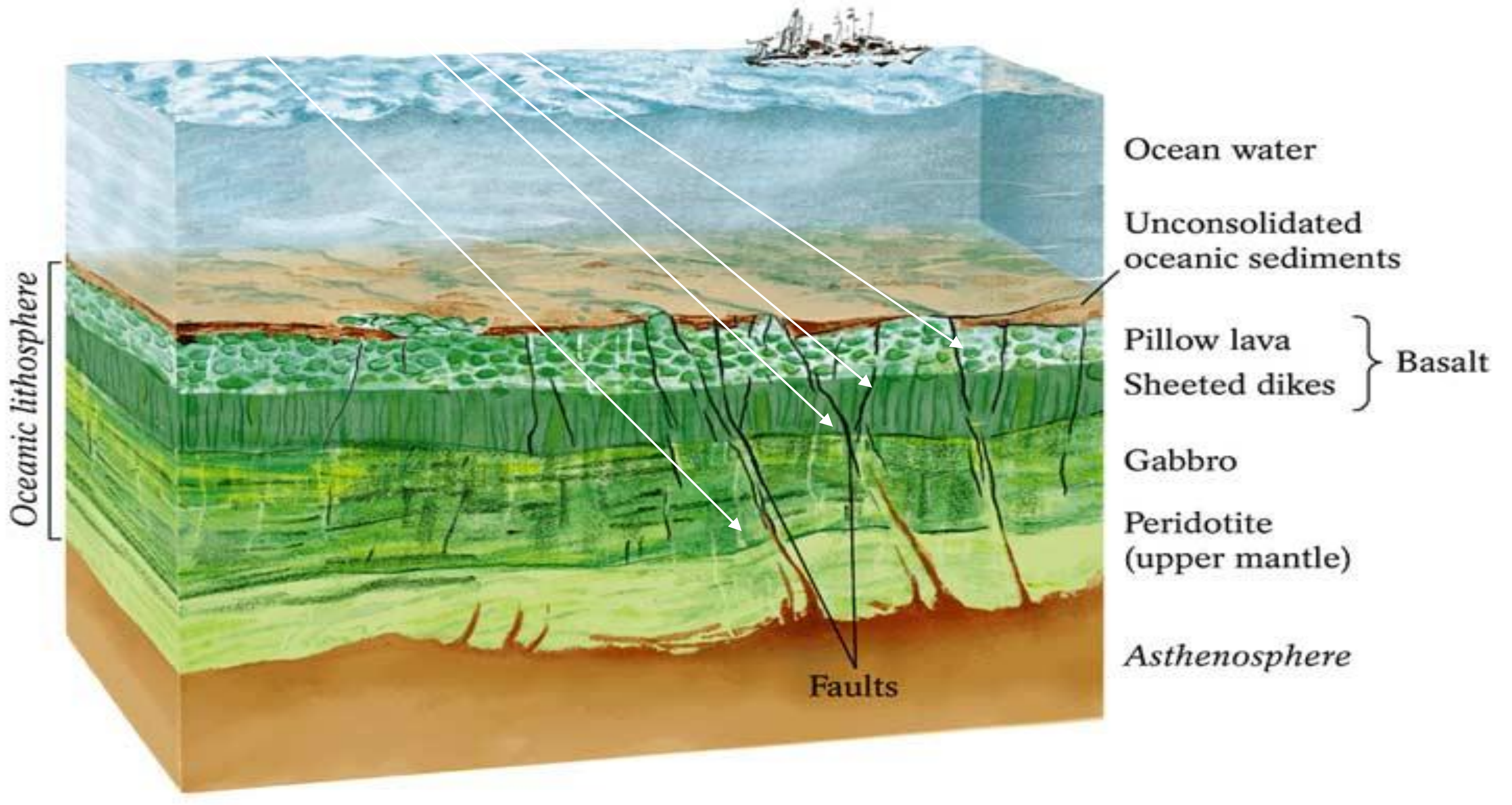
Figure 4-3 Earth: Portrait of a Planet 3/e

Two Types of Plates

1. Ocean plates - plates below the oceans
2. Continental plates - plates below the continents

Ophiolite Suite

Some **Serpentine is formed** due to hot water circulation (called Hydrothermal)

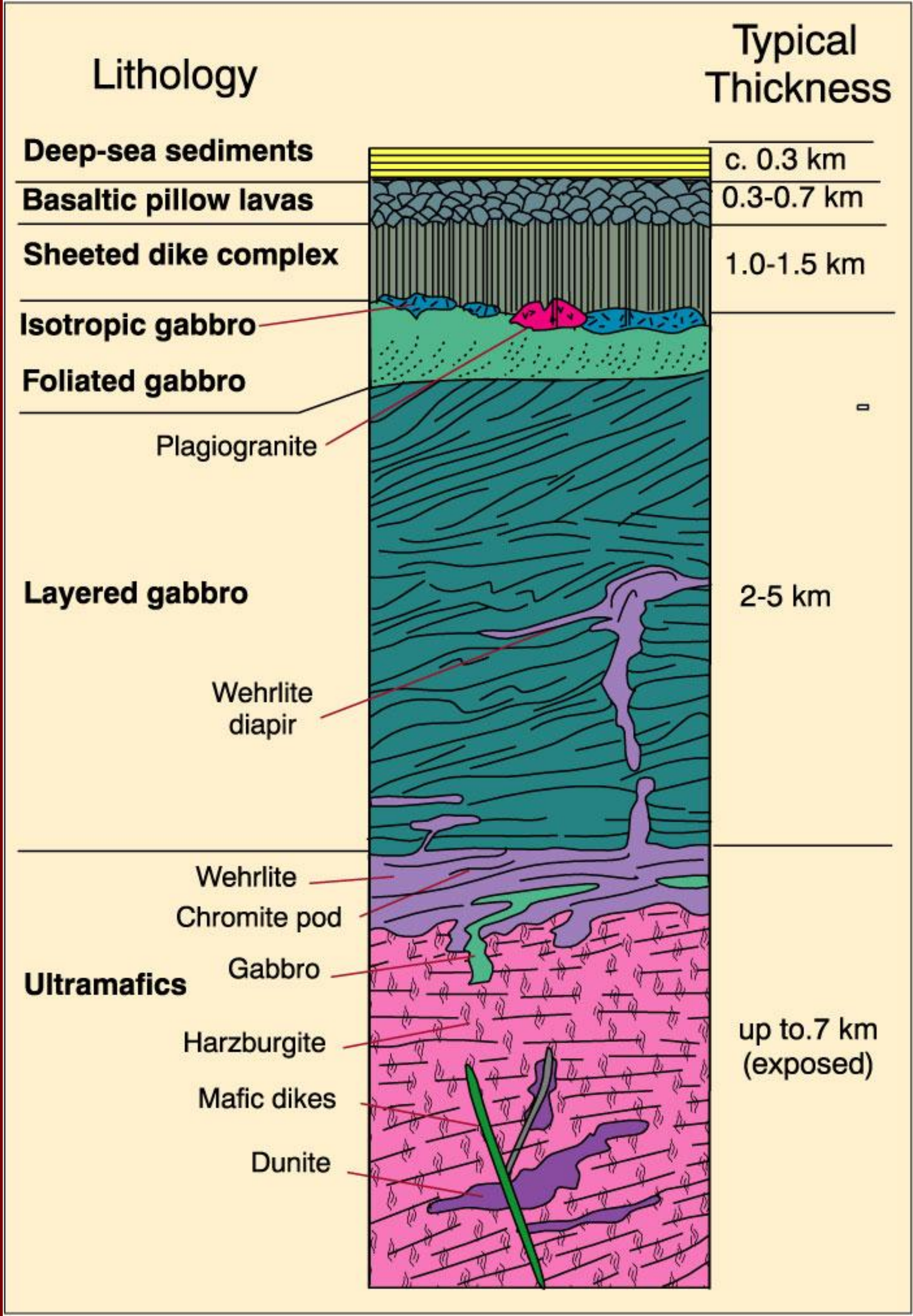


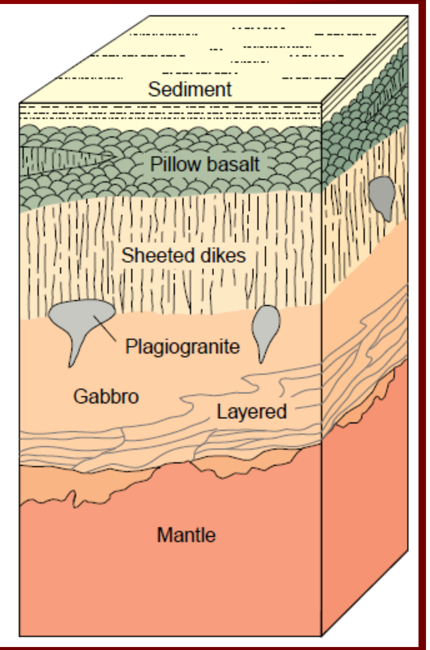
Oceanic Crust and Upper Mantle Structure

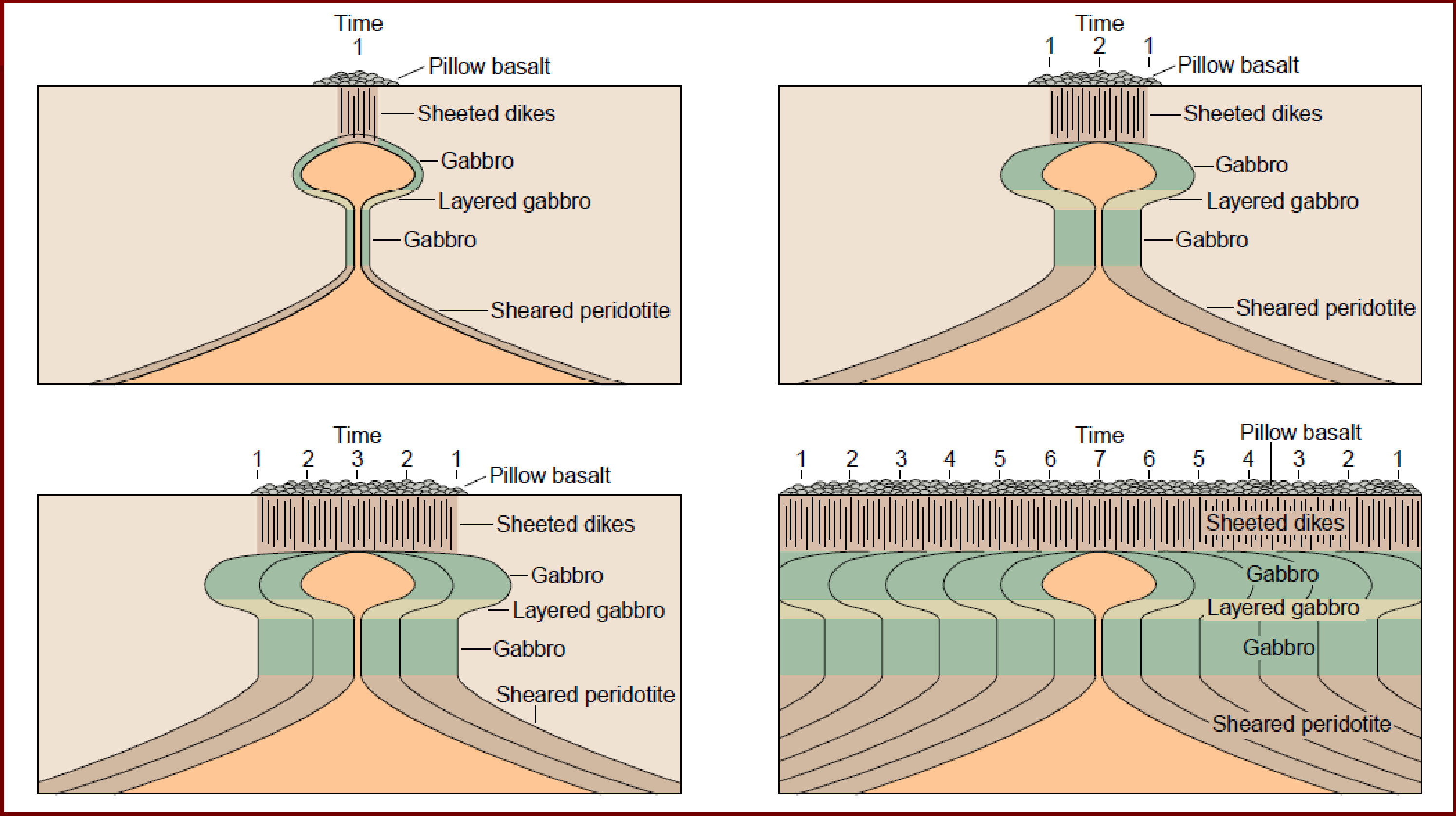
Typical Ophiolite

Wehrlite: a Peridotite mostly composed of olivine plus clinopyroxene

Figure 13-3. Lithology and thickness of a typical ophiolite sequence, based on the Samial Ophiolite in Oman. After Boudier and Nicolas (1985) Earth Planet. Sci. Lett., 76, 84-92.




Sediment
Pillow basalt
Sheeted dikes
Plagiogranite
Gabbro
Layered
Mantle


Time
1
Pillow basalt
Sheeted dikes
Gabbro
Layered gabbro
Gabbro
Sheared peridotite
Time
1 2 1
Pillow basalt
Sheeted dikes
Gabbro
Layered gabbro
Gabbro
Sheared peridotite
Time
1 2 3 2 1
Pillow basalt
Sheeted dikes
Gabbro
Layered gabbro
Gabbro
Sheared peridotite
Time
1 2 3 4 5 6 7 6 5 4 3 2 1
Pillow basalt
Sheeted dikes
Gabbro
Layered gabbro
Gabbro
Sheared peridotite

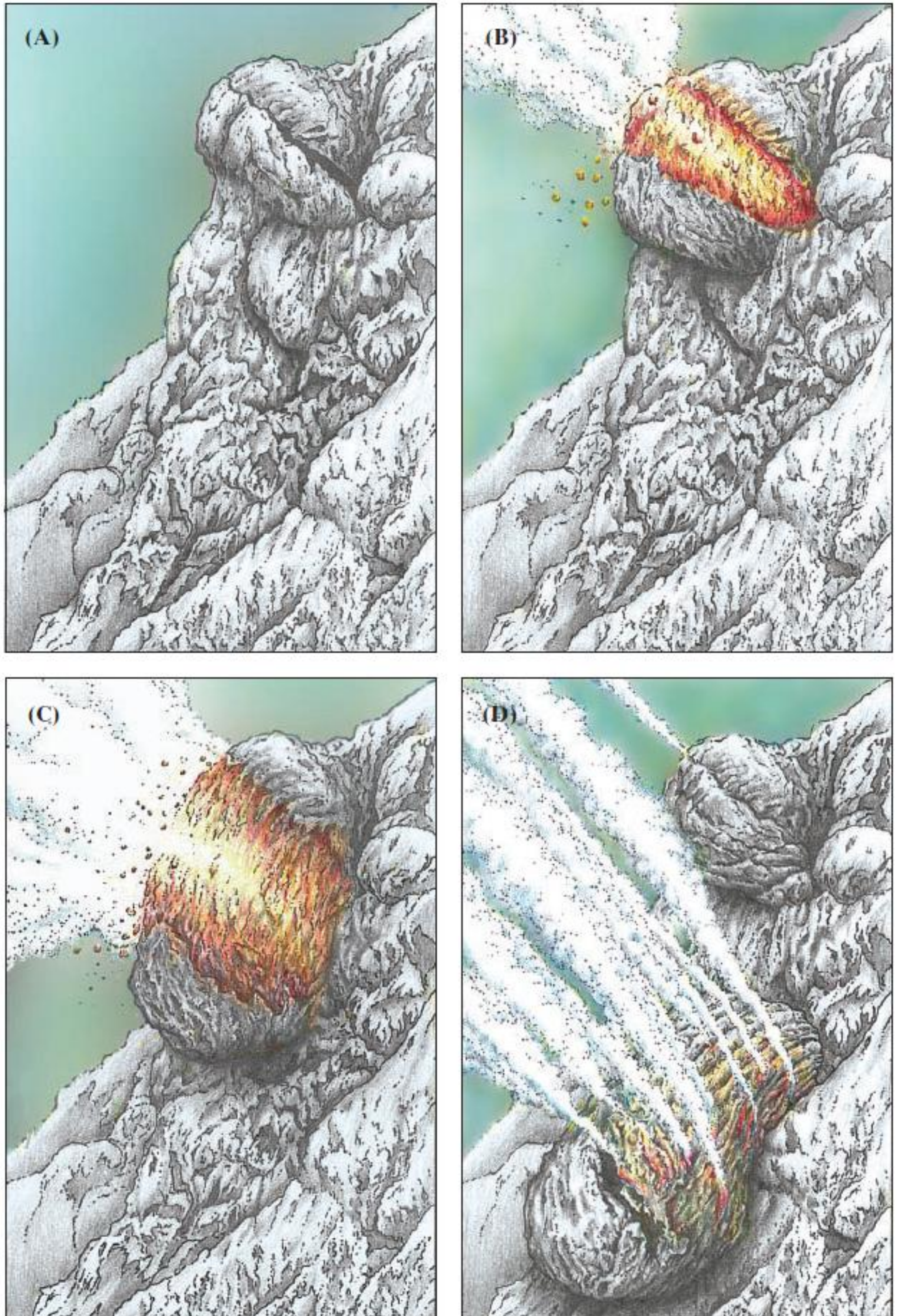
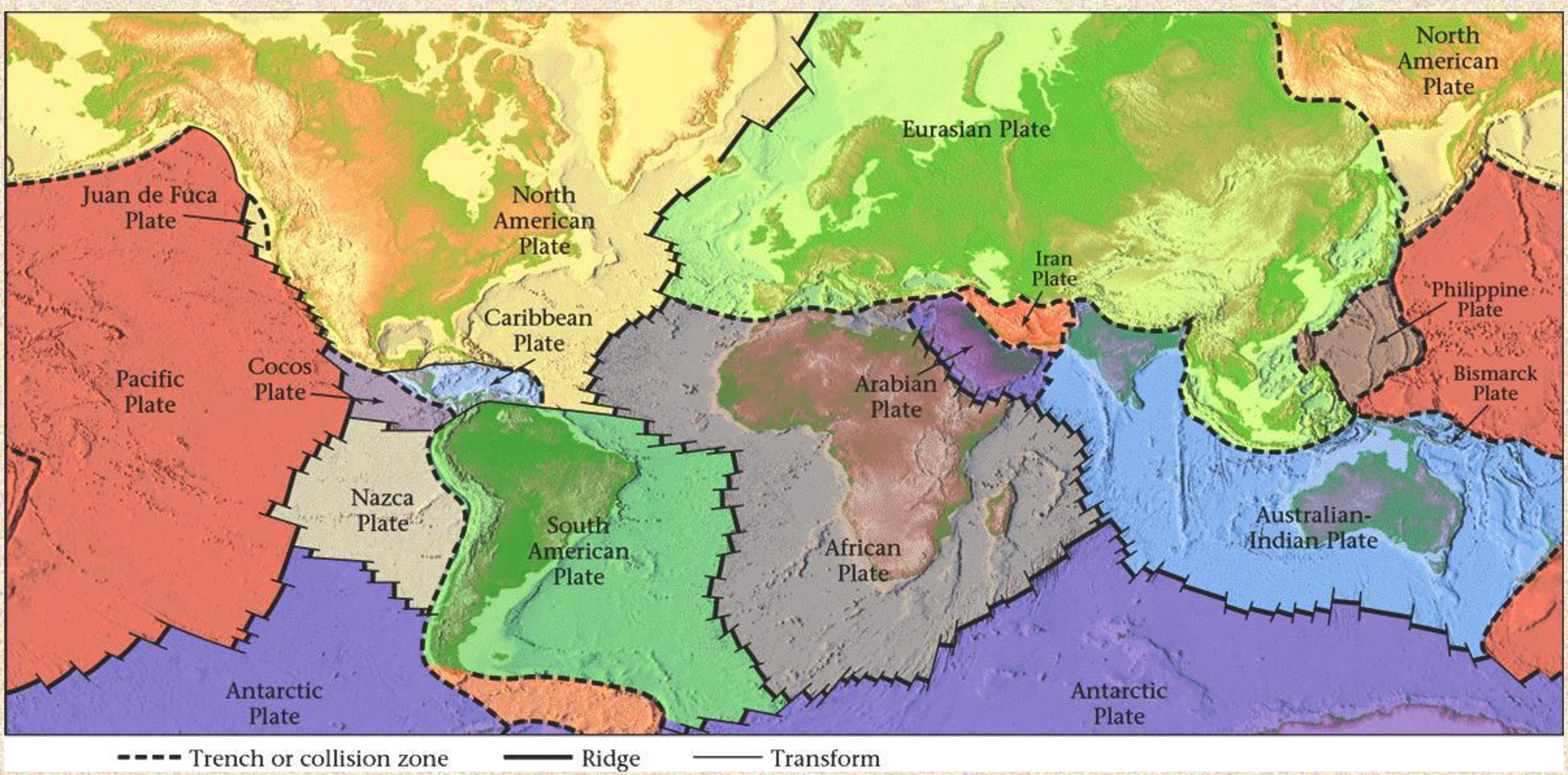


FIGURE 4.12 **Pillow basalt** is formed when lava extruded under water cools quickly, forming a series of ellipsoidal masses as shown in this sequence of sketches. (A) A new pillow buds from the front of a lava flow with a still molten interior. (B) The solid crust of the pillow splits and hot lava comes in contact with the cold water, sending a stream of water vapor bubbles toward the surface. (C) The gap widens as gravity pulls the pillow downward. (D) Eventually, the pillow breaks off and falls. Ultimately, a pile of pillows forms at the flow front and is then overridden by the rest of the flow. The photograph shows pillow lava that was originally formed on the ocean floor and is now exposed in New Zealand. Note the radial fractures and the quenched black glassy rim around each pillow.

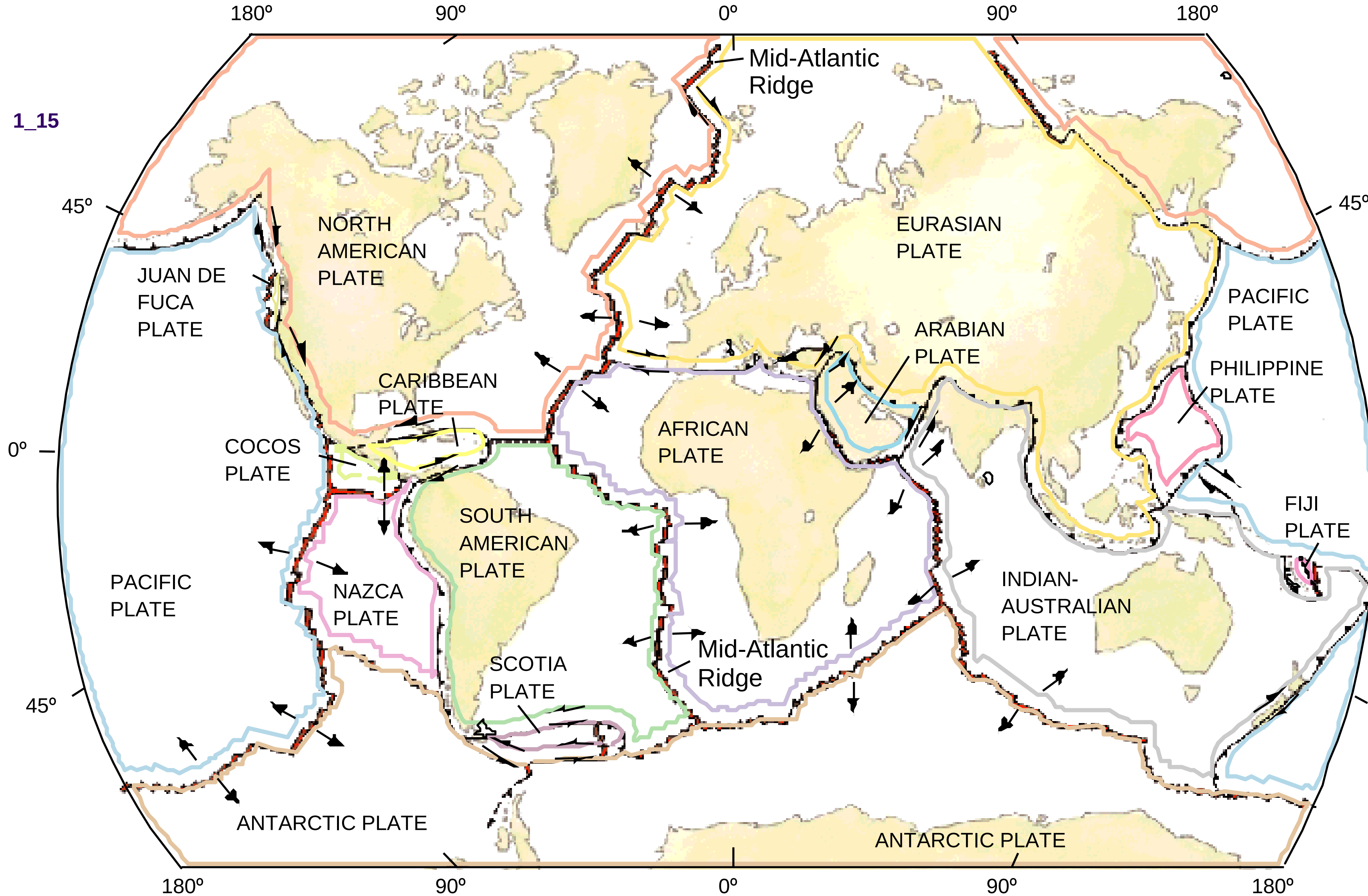
World Plates



7 Major Plates

- African Plate, covering Africa - Continental plate
- Antarctic Plate, covering Antarctica - Continental plate
- Australian Plate, covering Australia (fused with Indian Plate between 50 and 55 million years ago) - Continental plate
- Eurasian Plate covering Asia and Europe - Continental plate
- North American Plate covering North America and north-east Siberia - Continental plate
- South American Plate covering South America - Continental plate
- Pacific Plate, covering the Pacific Ocean - Oceanic plate

1_15



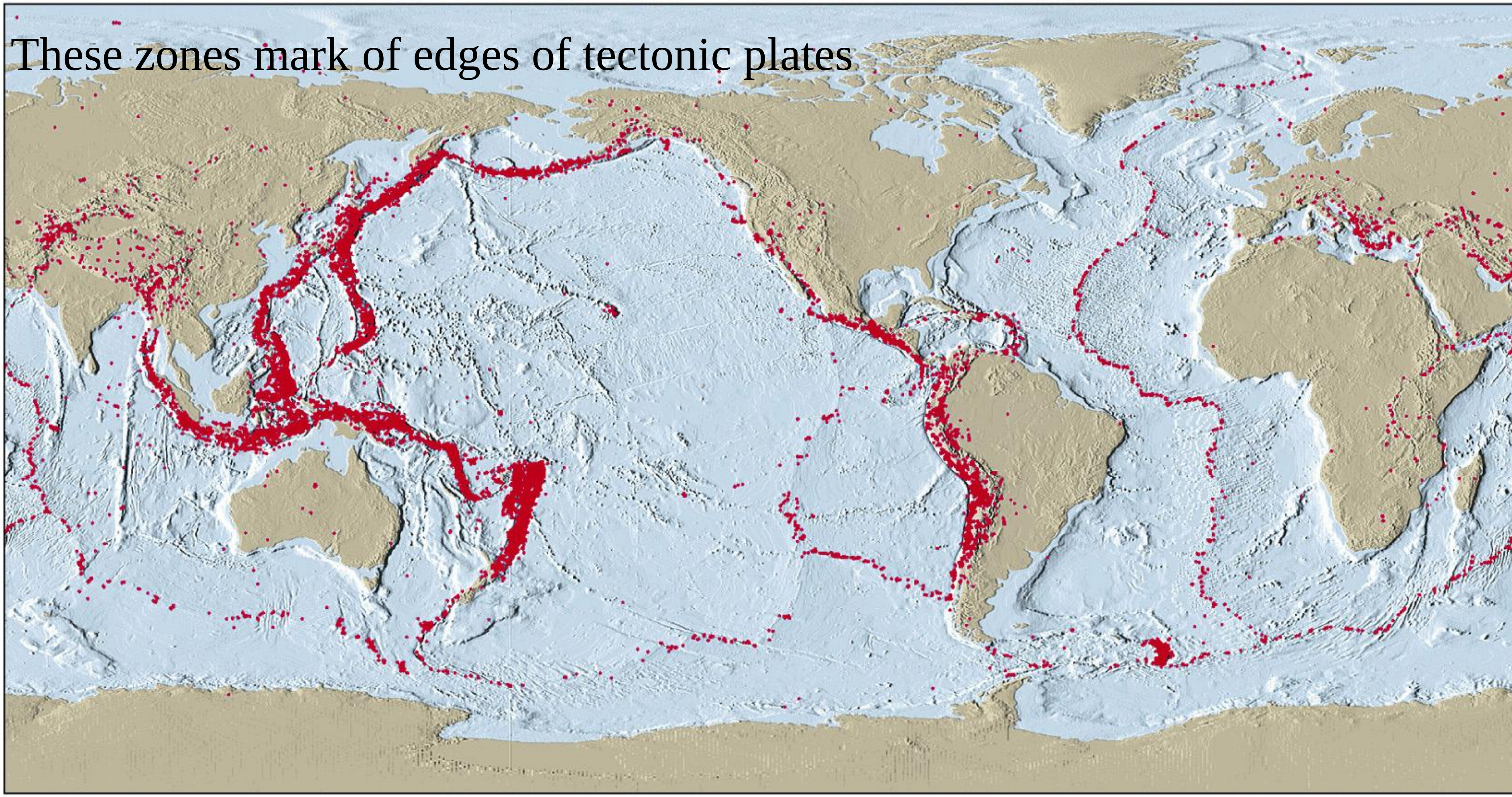
Convergent plate boundary
Divergent plate boundary
Transform plate boundary

Seven major lithospheric plates
Seven or so smaller ones.
Plates are in motion and change in shape and size
Largest plate is the Pacific plate
Several plates include an entire continent plus a large area of seafloor

Plates move relative to each other at a very slow but con
Average about 5 centimeters (2 inches) per year
Cooler, denser slabs of oceanic lithosphere desce

95% of energy released by earthquakes originates in narrow zones that wind around the Earth

These zones mark of edges of tectonic plates

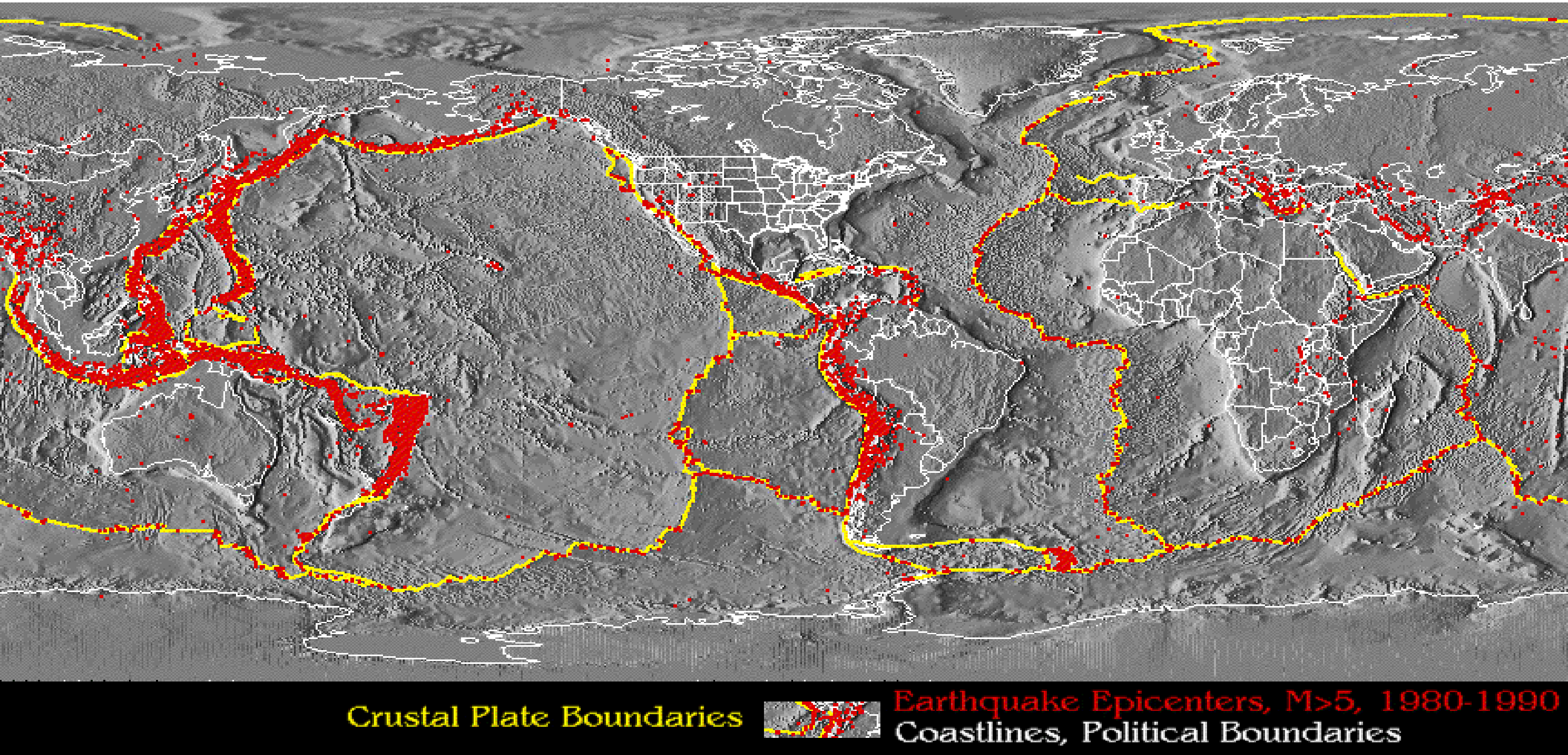


Broad are subduction zone earthquakes, narrow are MOR. Lead to recognition of plates

Plate boundaries

Each plate bounded by combination of all three boundary types: divergent, convergent, transform

Edges marked by Earthquakes



Global pattern of volcanism

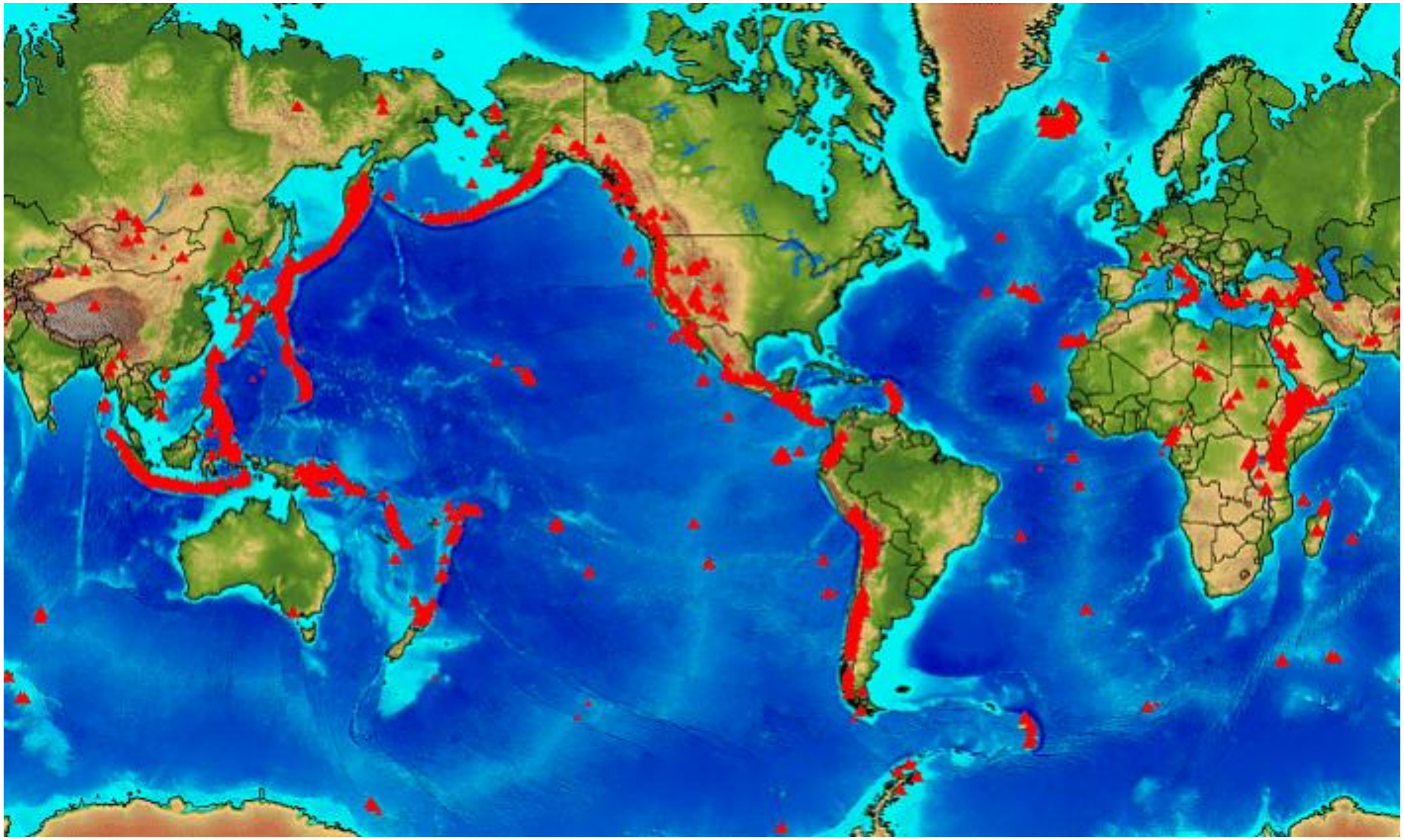


Plate Tectonics

- The Earth’s crust is divided into 12 major plates which are moved in various directions.
- This plate motion causes them to collide, pull apart, or scrape against each other.
- Each type of interaction causes a characteristic set of Earth structures or “tectonic” features.
- The word, tectonic, refers to the deformation of the crust as a consequence of plate interaction.

What are tectonic plates made of?

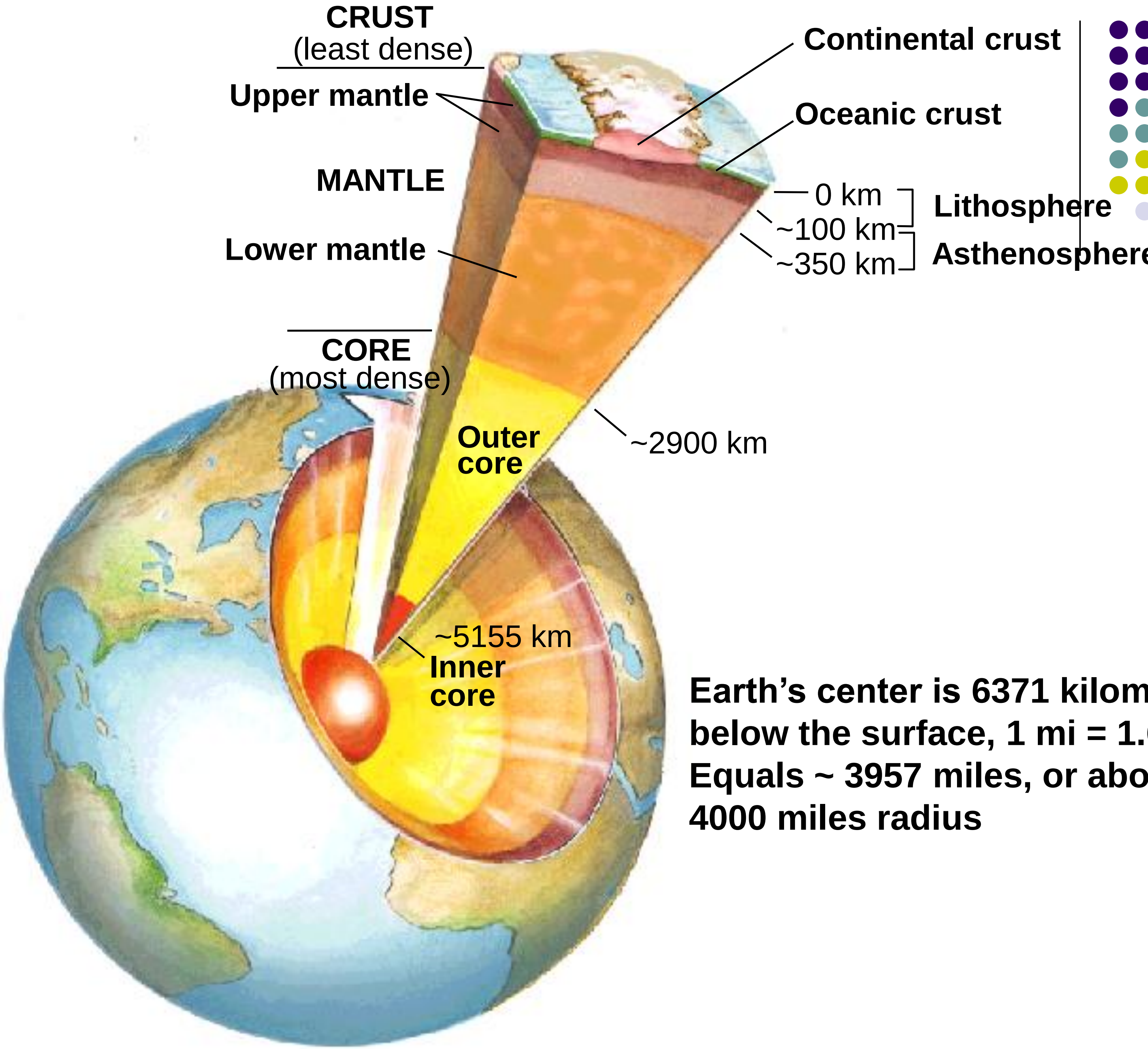
- Plates are made of rigid **lithosphere**.

The lithosphere is made up of the crust and the upper part of the mantle.

What lies beneath the tectonic plates?

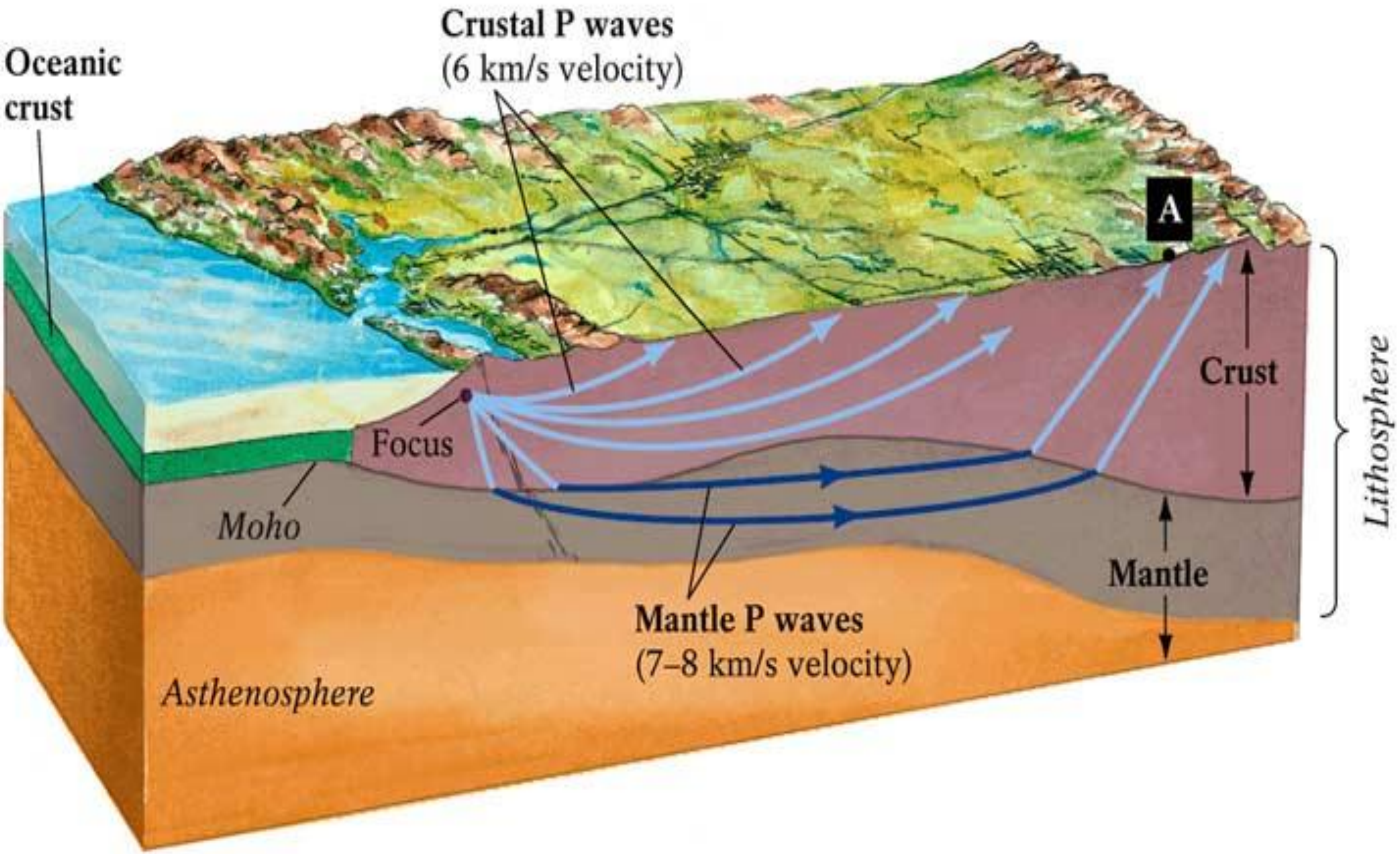
- The plates of the lithosphere float on the asthenosphere
- The Asthenosphere is hot and plastic, and sheds heat via convective currents.

1_8



Earth’s center is 6371 kilometers below the surface, 1 mi = 1.61 km. Equals ~ 3957 miles, or about 4000 miles radius

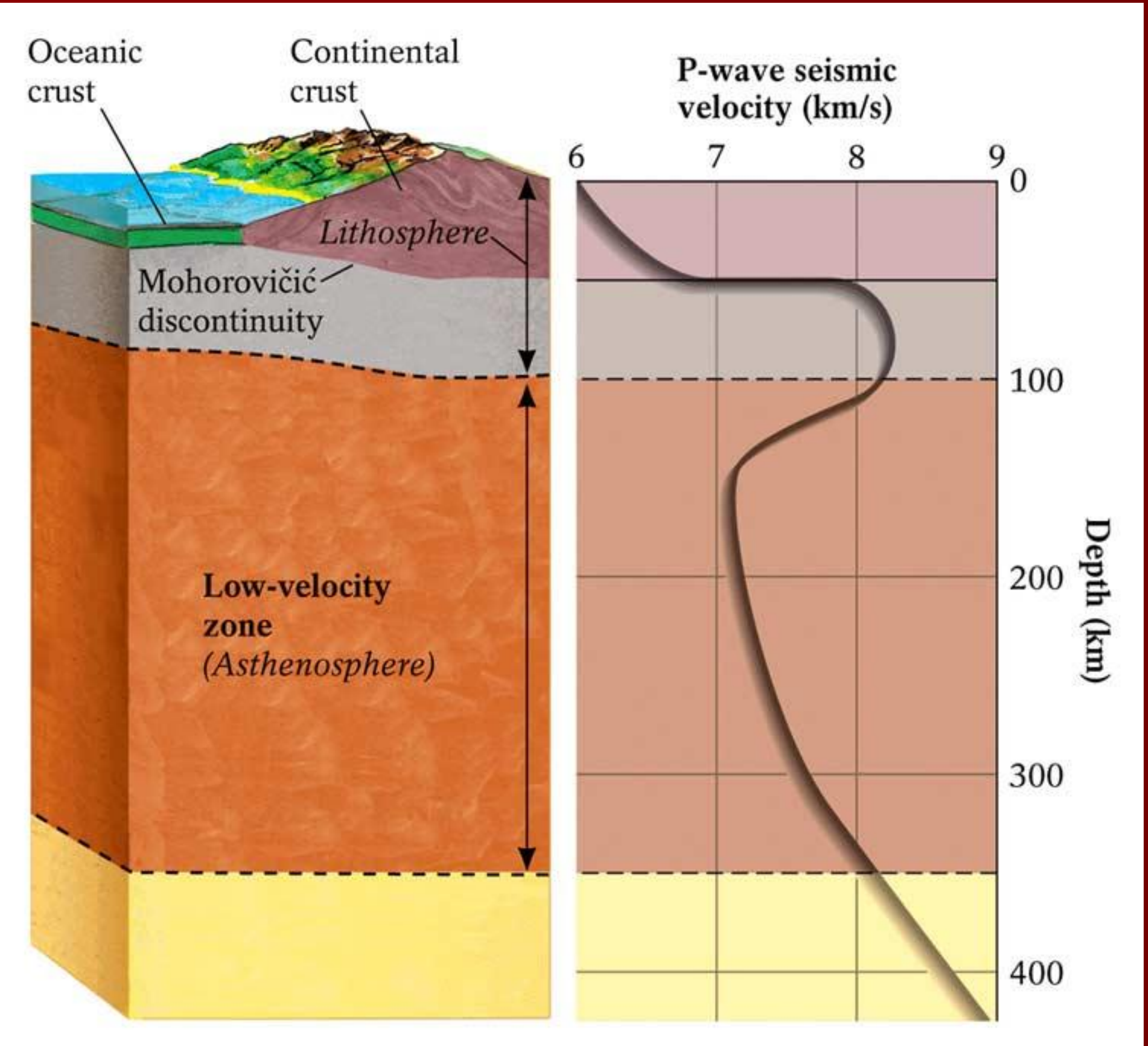
Seismic-wave velocities are faster in the upper mantle



Velocity increases w depth, waves bend back to surface.

Waves that travel via mantle arrive sooner at far destinations [Mohorovičić discontinuity]

Wave Velocities



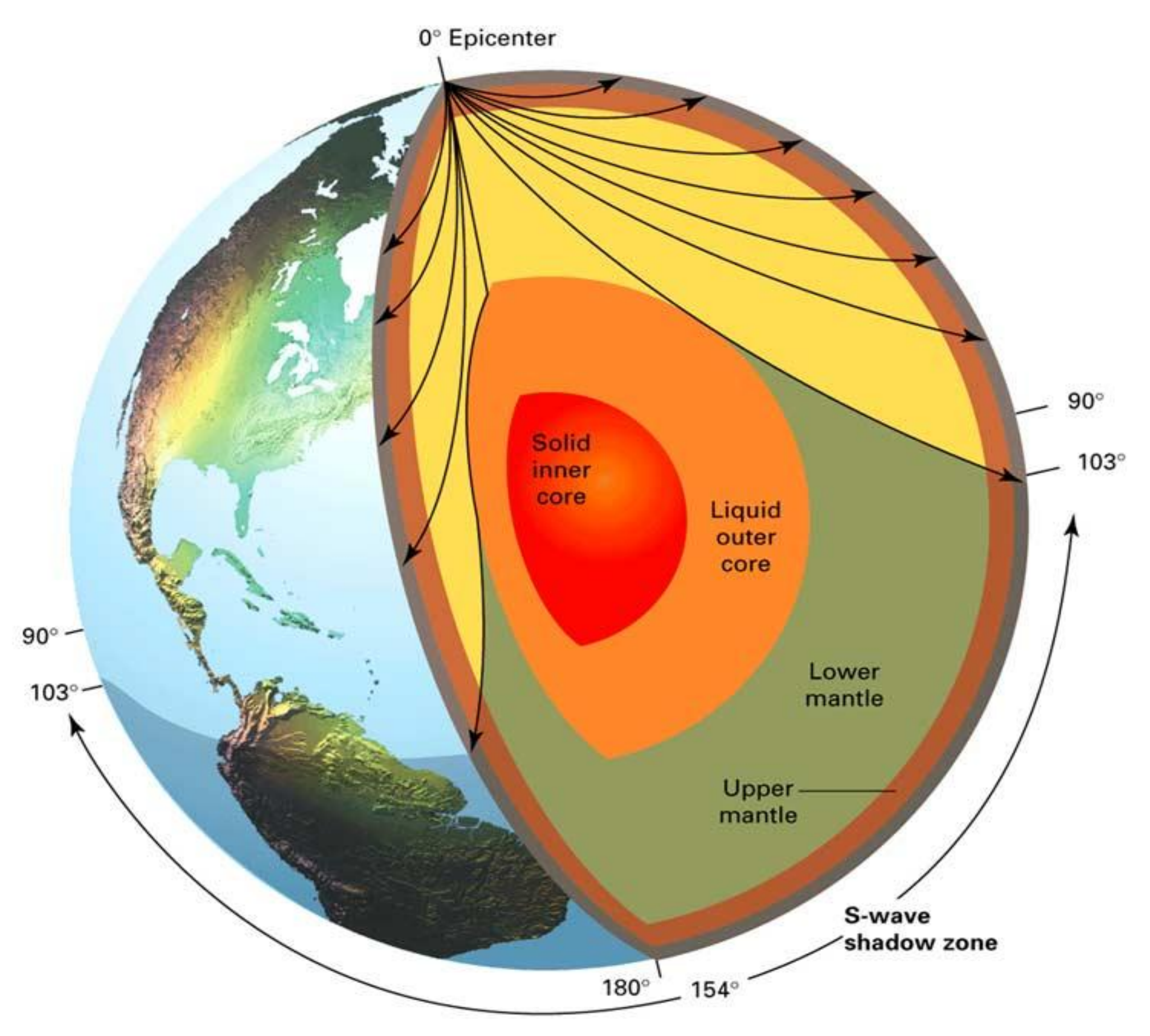
Upper Mantle Fast

Asthenosphere Slow

Lower Mantle Fast

The S-Wave Shadow Zone

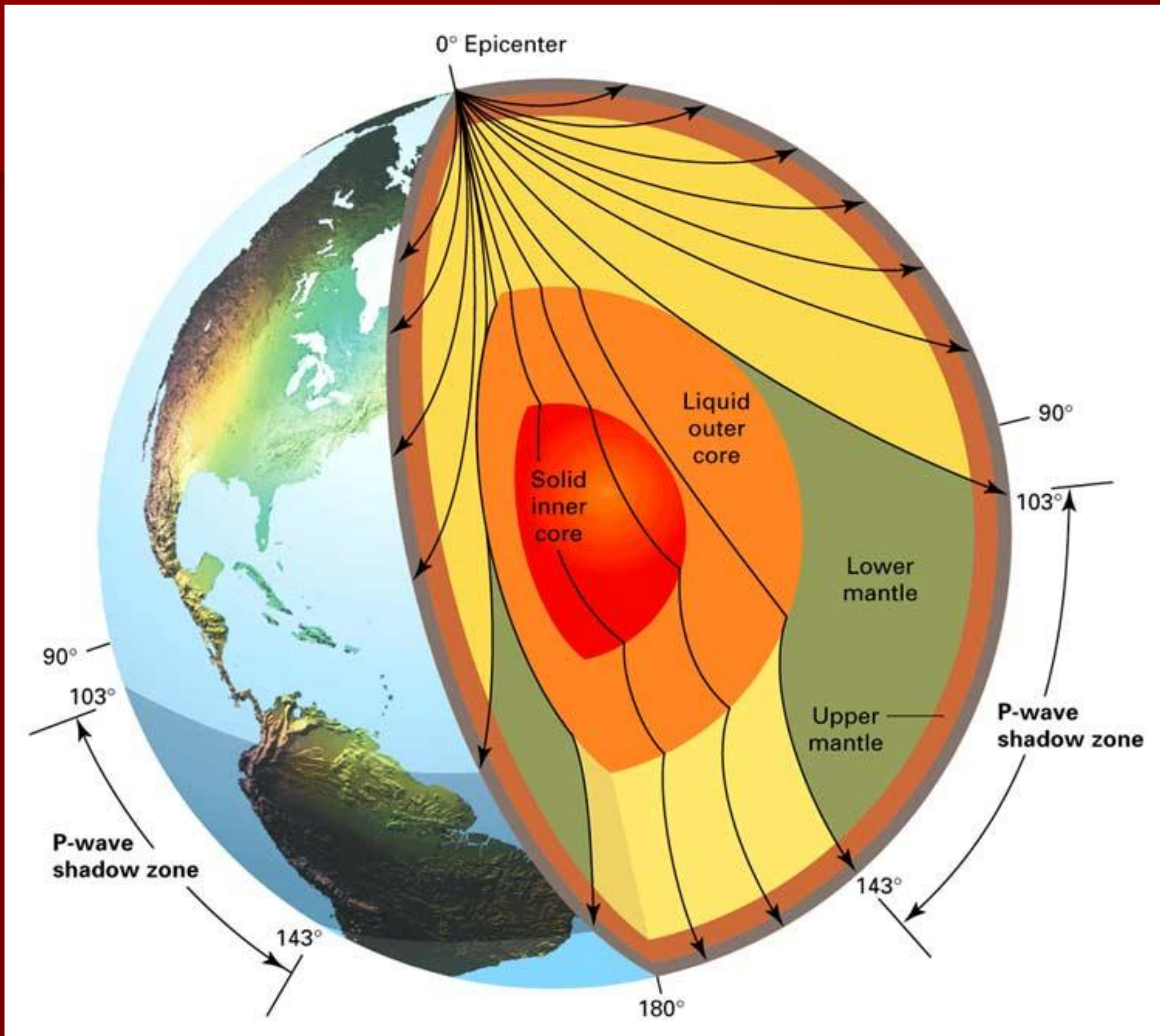
http://en.wikipedia.org/wiki/Richard_Dixon_Oldham



Since Shear (S) waves cannot travel through liquids, the liquid outer core casts a larger shadow for S waves covering everything past 103 degrees away from the source.

The P-Wave Shadow Zone

http://www.amnh.org/education/resources/rfl/web/essaybooks/earth/p_lehmann.html



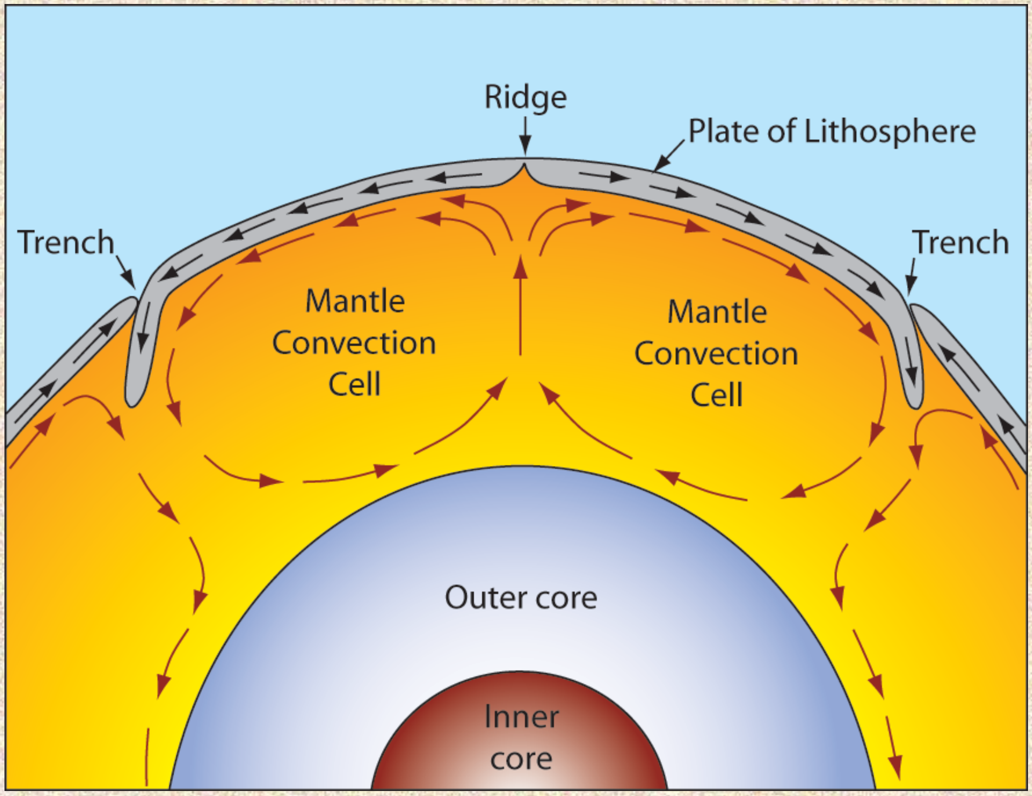
P-waves through the liquid outer core bend, leaving a low intensity shadow zone 103 to 143 degrees away from the source, here shown as the north pole

HOWEVER, P-waves traveling straight through the center continue, and because speeds in the solid inner core are faster, they arrive sooner than expected if the core was all liquid.

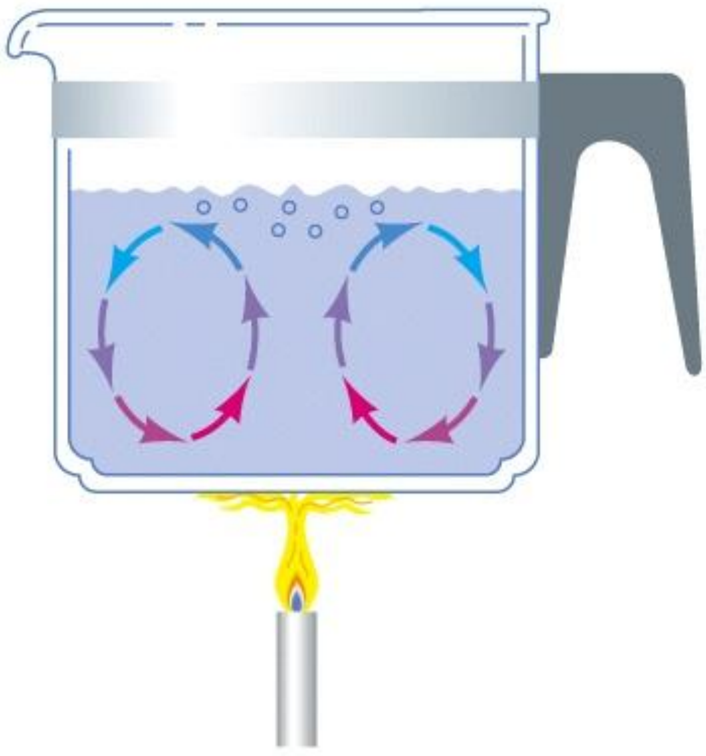
Behavior of waves through center reveal Earth's Interior

Plate Movement

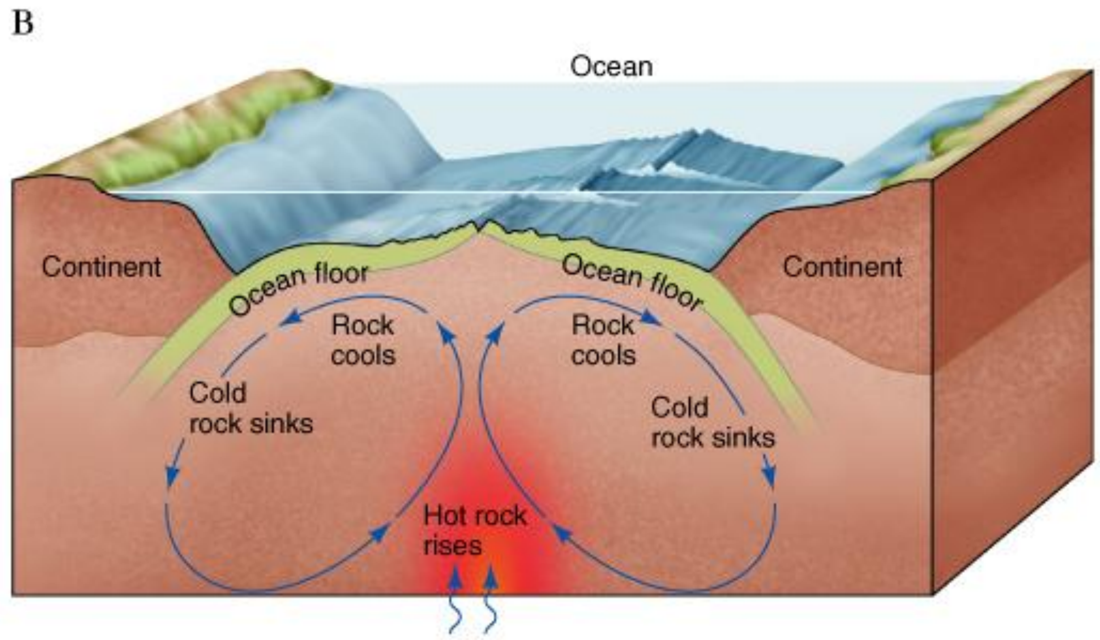
- “Plates” of lithosphere are moved around by the underlying hot mantle convection cells



Mantle Convection Drives Plate Motion



(a)



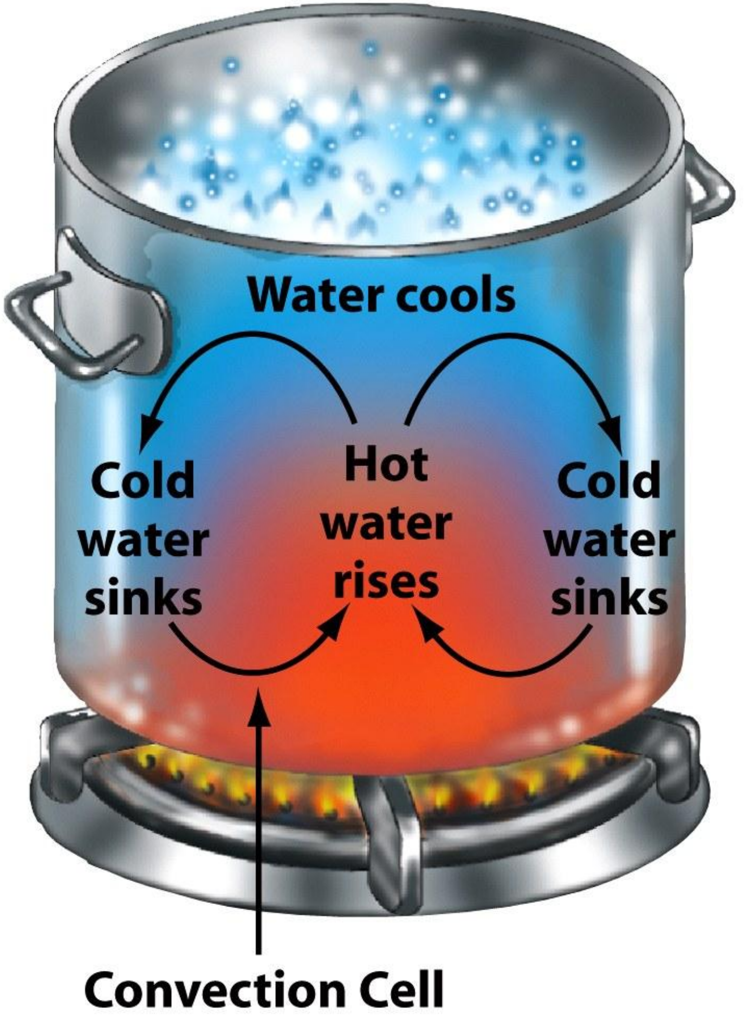
internal heat engine

Heat Sources

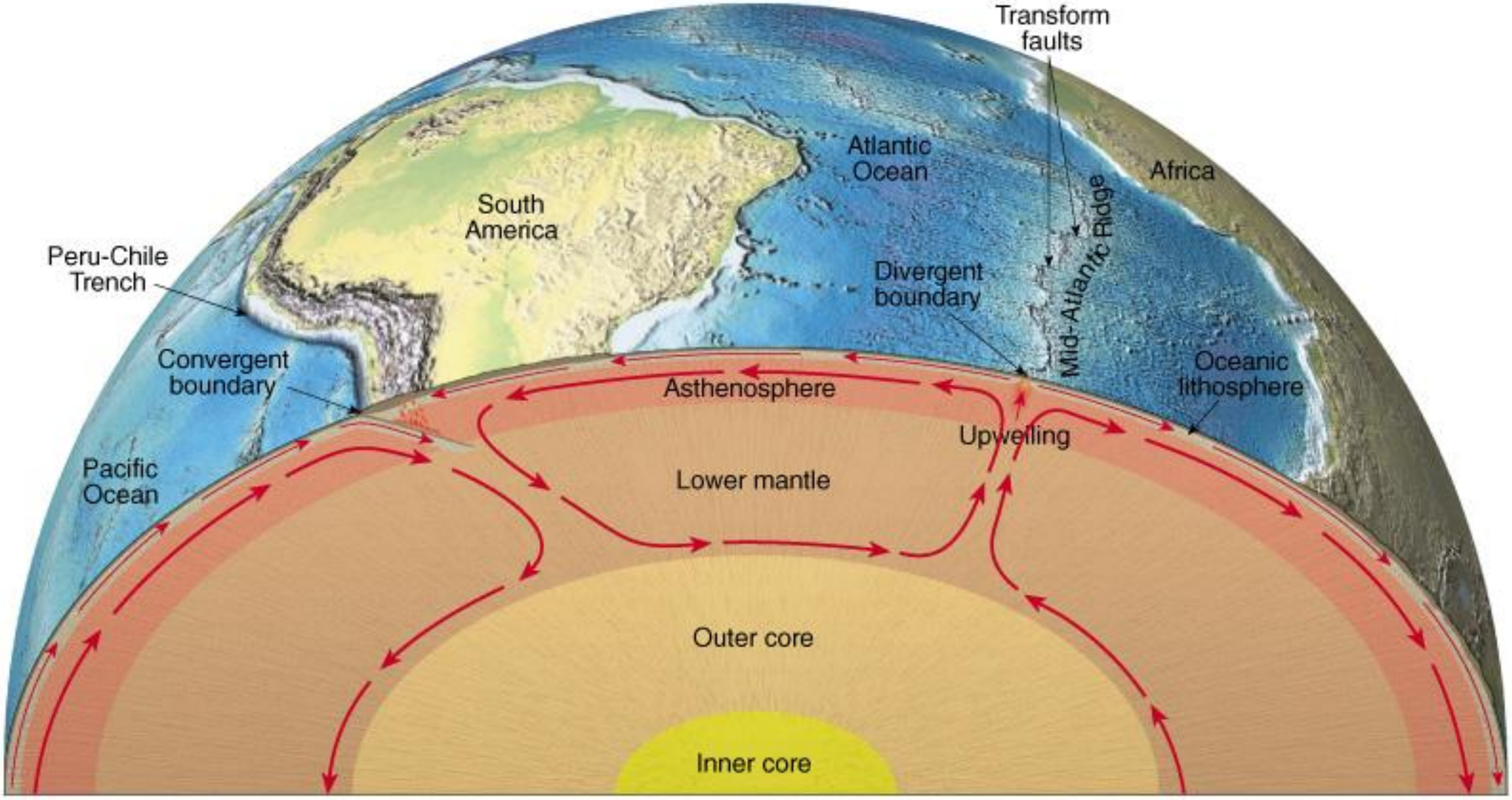
- Primordial from formation of the Earth
- Radioactive decay of U, Th, and K in the core and mantle

The search for a mechanism

- Earth's internal heat
  - Conduction
    - Slow release of heat
  - Convection
    - A form of heat transfer in which hot material circulates from hotter to colder regions, looses its heat, and then repeats the cycle

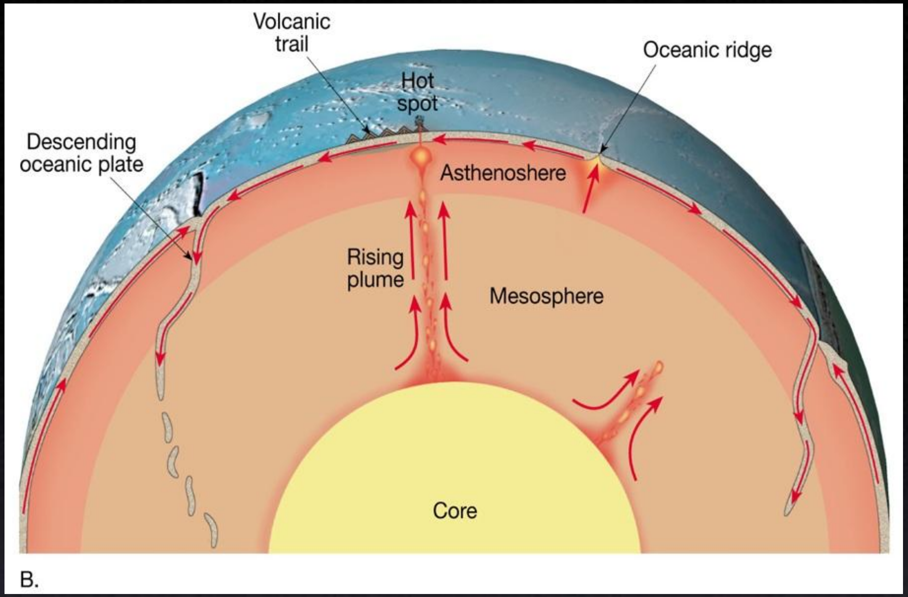


Mantle circulations are an example of convection, heat transfer by moving fluids

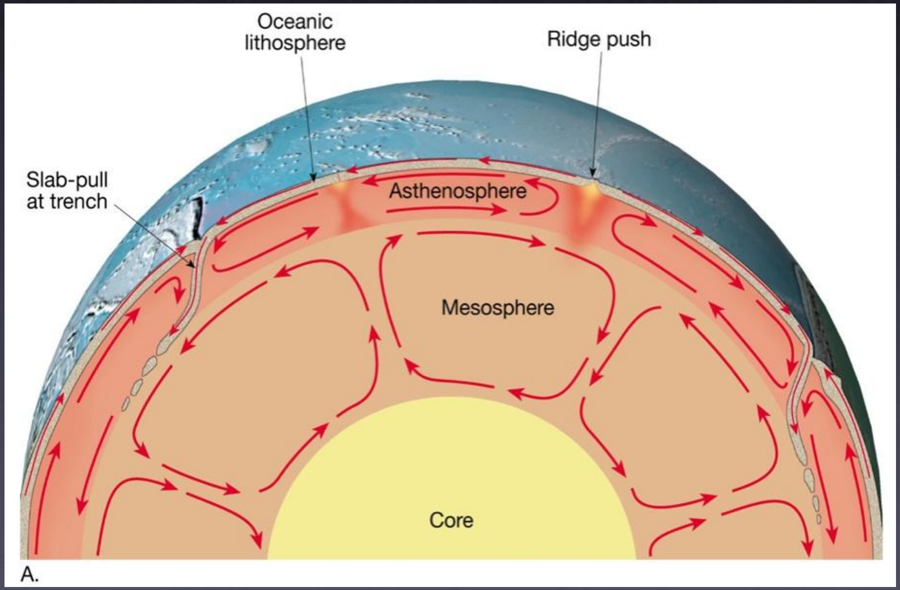


This example shows transfer of core heat to the upper mantle and crust

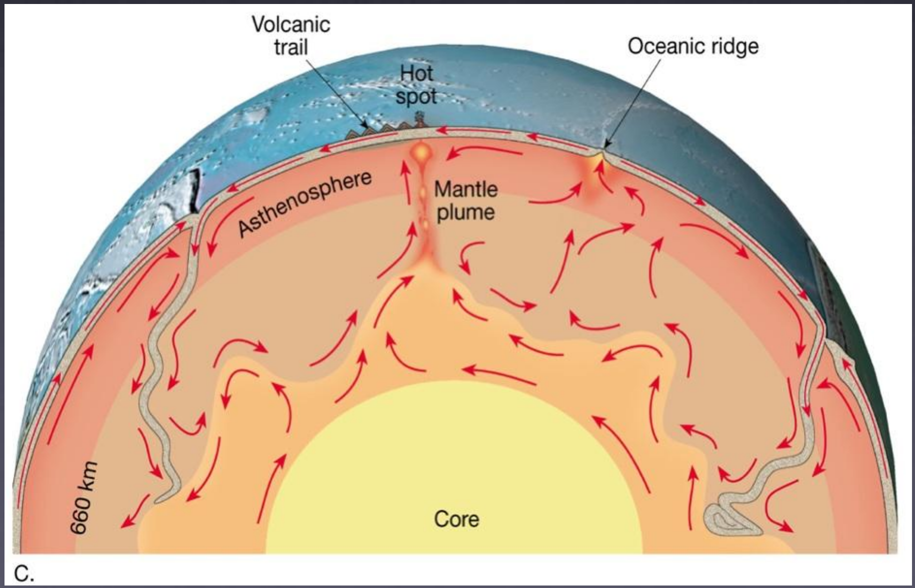
How does convection work? No one knows—but they aren't afraid to propose models!



Whole-mantle convection



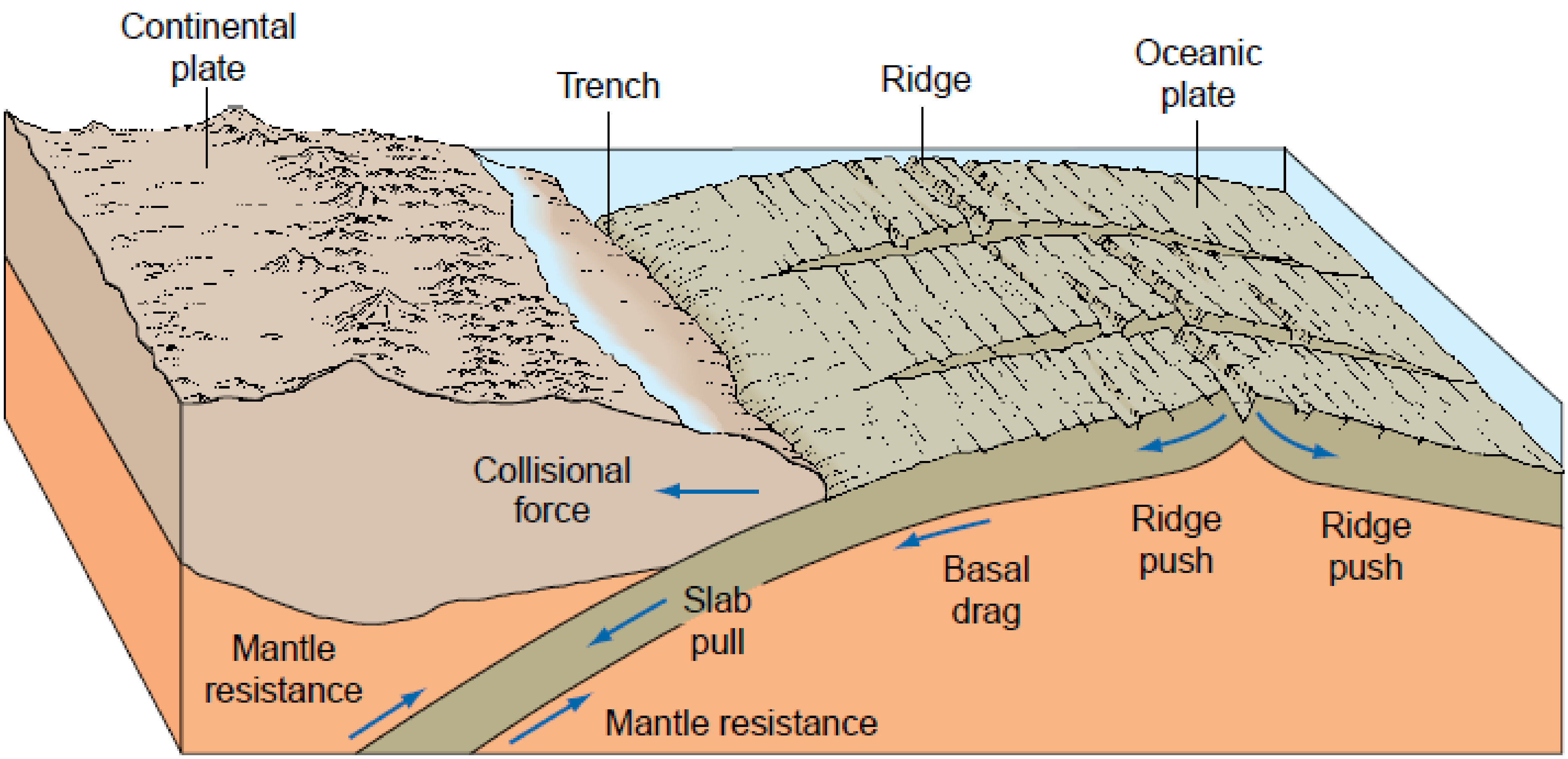
Two mantle convection cells



Complex convection

Driving Forces of Plate Tectonics

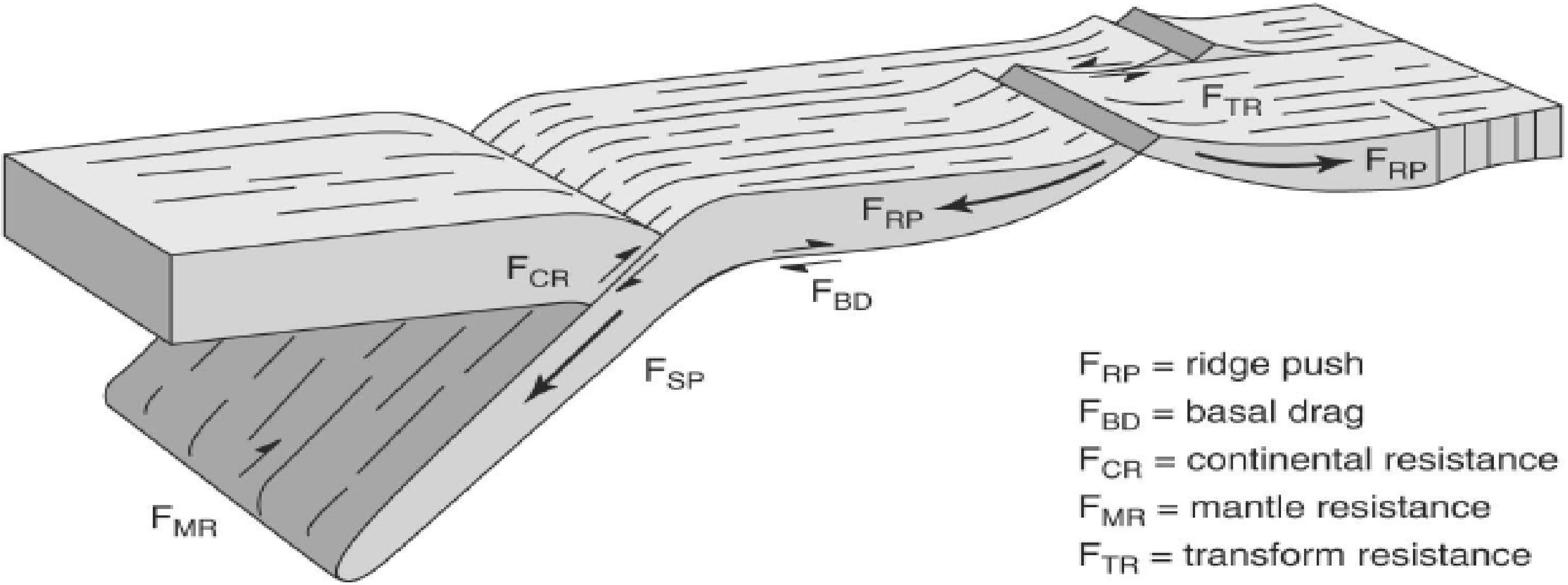
Force-balance Model



Driving Forces of Plate Tectonics

Force-balance Model

Plate Forces

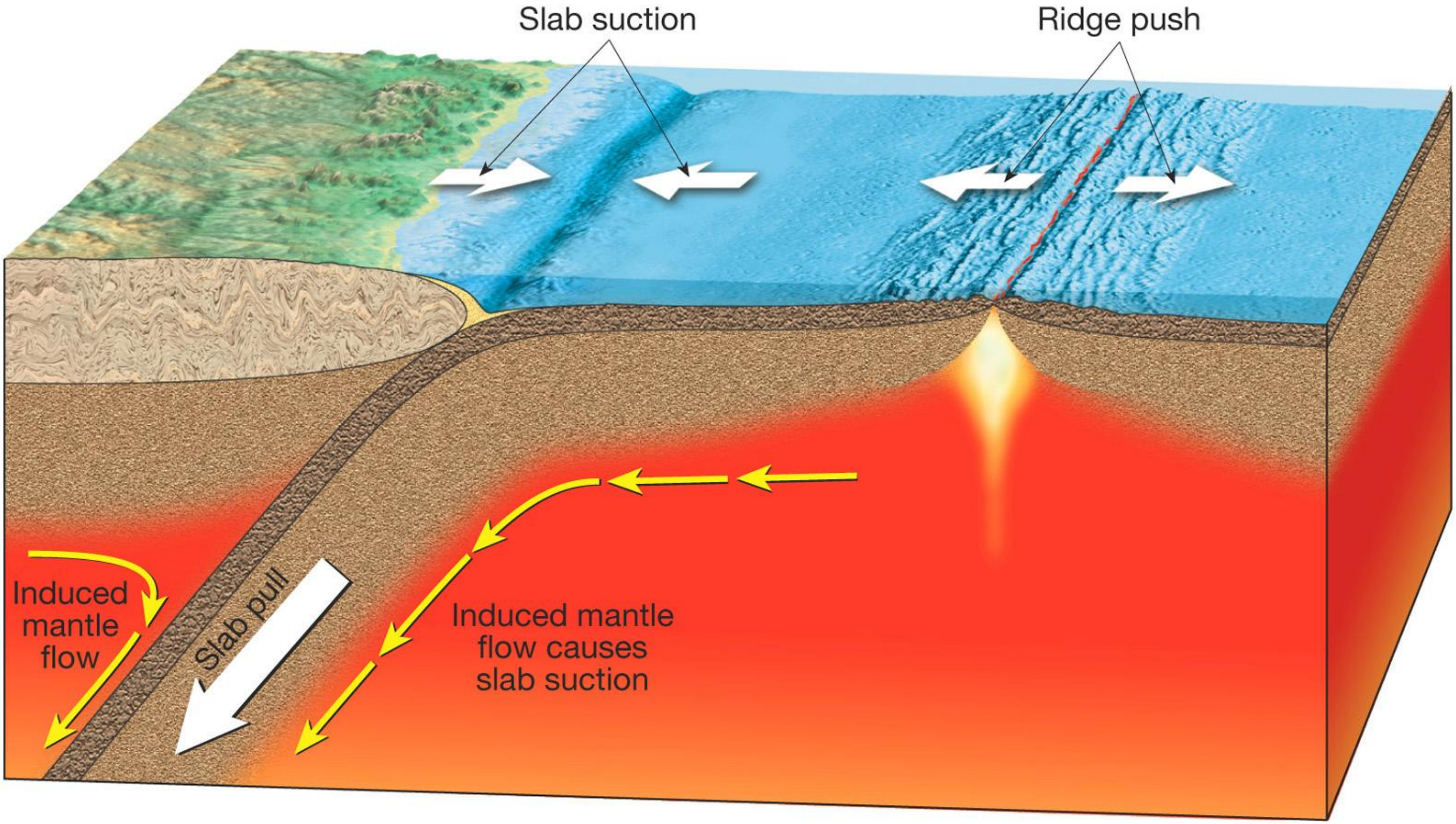


F_{RP} = ridge push
F_{BD} = basal drag
F_{CR} = continental resistance
F_{MR} = mantle resistance
F_{TR} = transform resistance
F_{SP} = slab pull

Gravitational forces:

- Ridge push: topographic spreading
- Slab pull: negative buoyancy of slab

Other (resistive) forces are relatively small


Slab suction
Ridge push
Induced mantle flow
Slab pull
Induced mantle flow causes slab suction

Ridge push

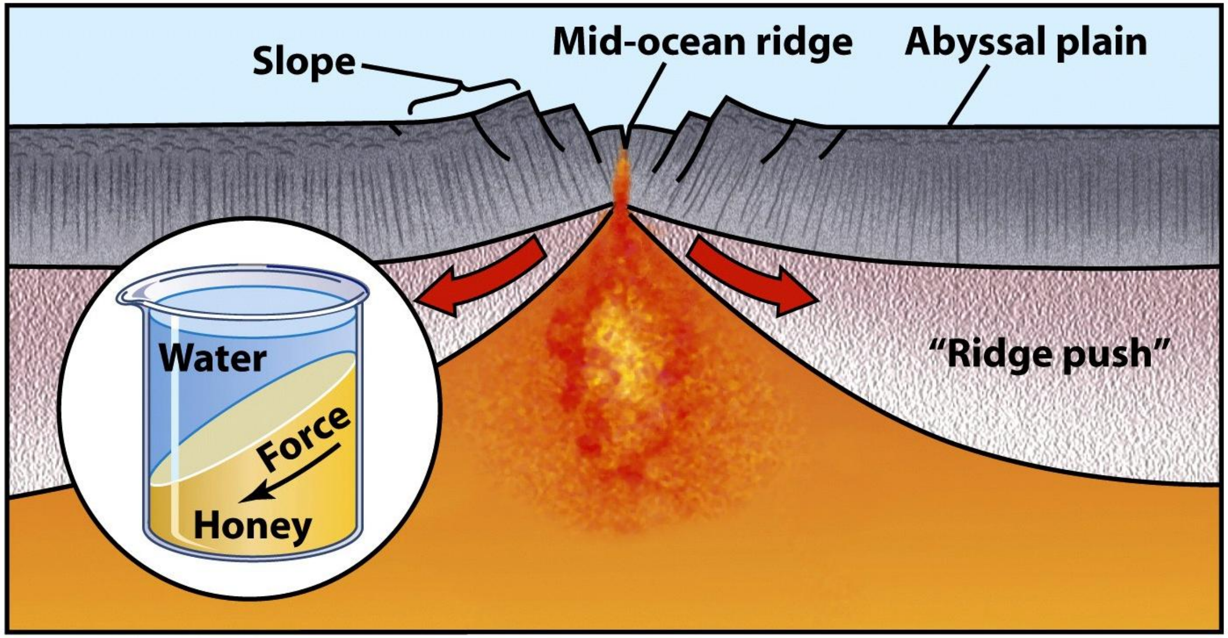


Figure 4-28a Earth: Portrait of a Planet 3/e

Slab pull

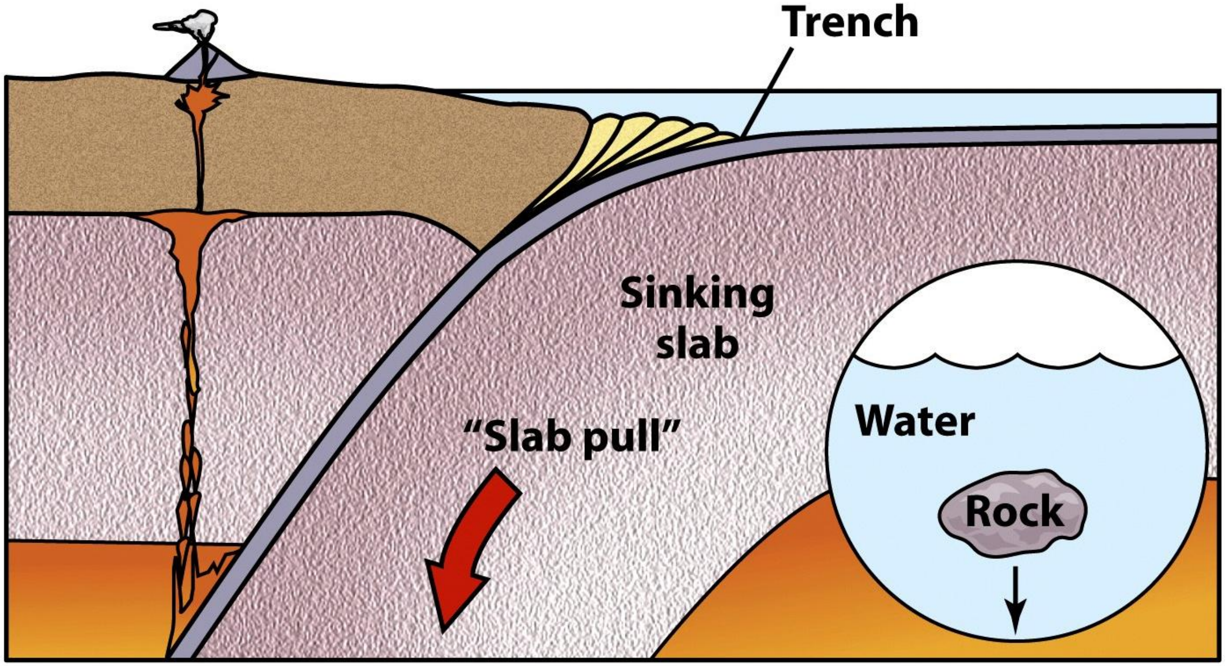


Figure 4-28b Earth: Portrait of a Planet 3/e

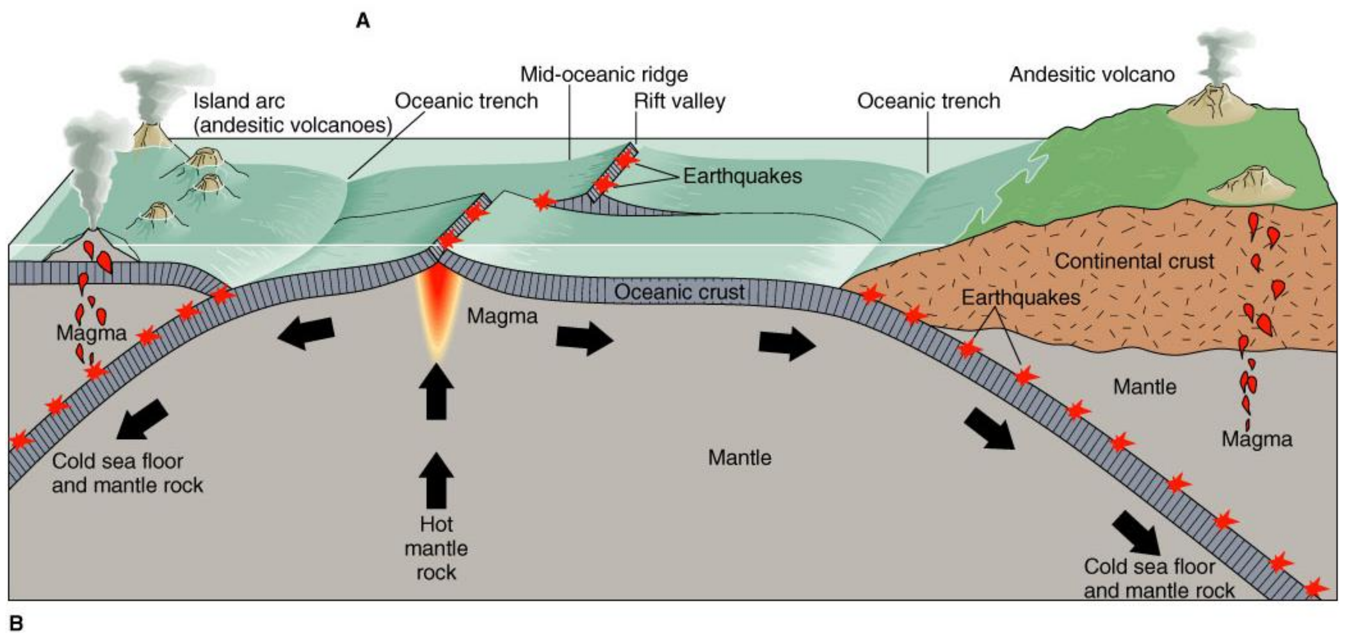
Plate Tectonics

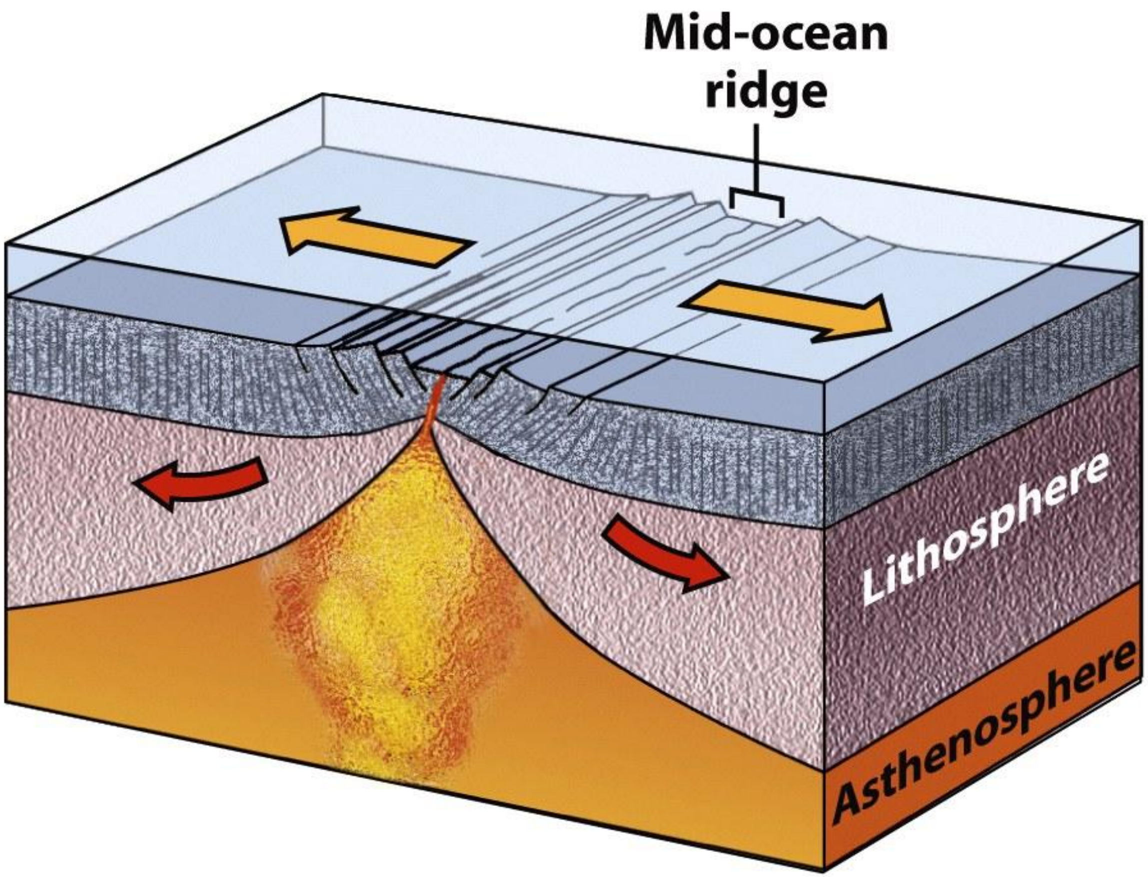
Types of Plate Boundaries:

- Divergent (Constructive)
- Convergent (Destructive)
- Transform (Conservative)

Plate boundaries

- **Divergent**
  - Plates moving apart
  - Extensional features (normal faults)
  - Results in ocean basin
- **Convergent**
  - Plates moving towards each other
  - Compressive features (folding, thrust faults)
  - Oceanic crust can be subducted, continental crust can't
    - If both plates at convergence line are continental, Collision (folding, thrust faults, granites)
    - If one is oceanic, Subduction (volcanic chain, may be thrusts and folds)
- **Transform**
  - Plates moving past each other
  - Strike-slip features
  - Small areas of divergence or convergence due to irregularities in boundary

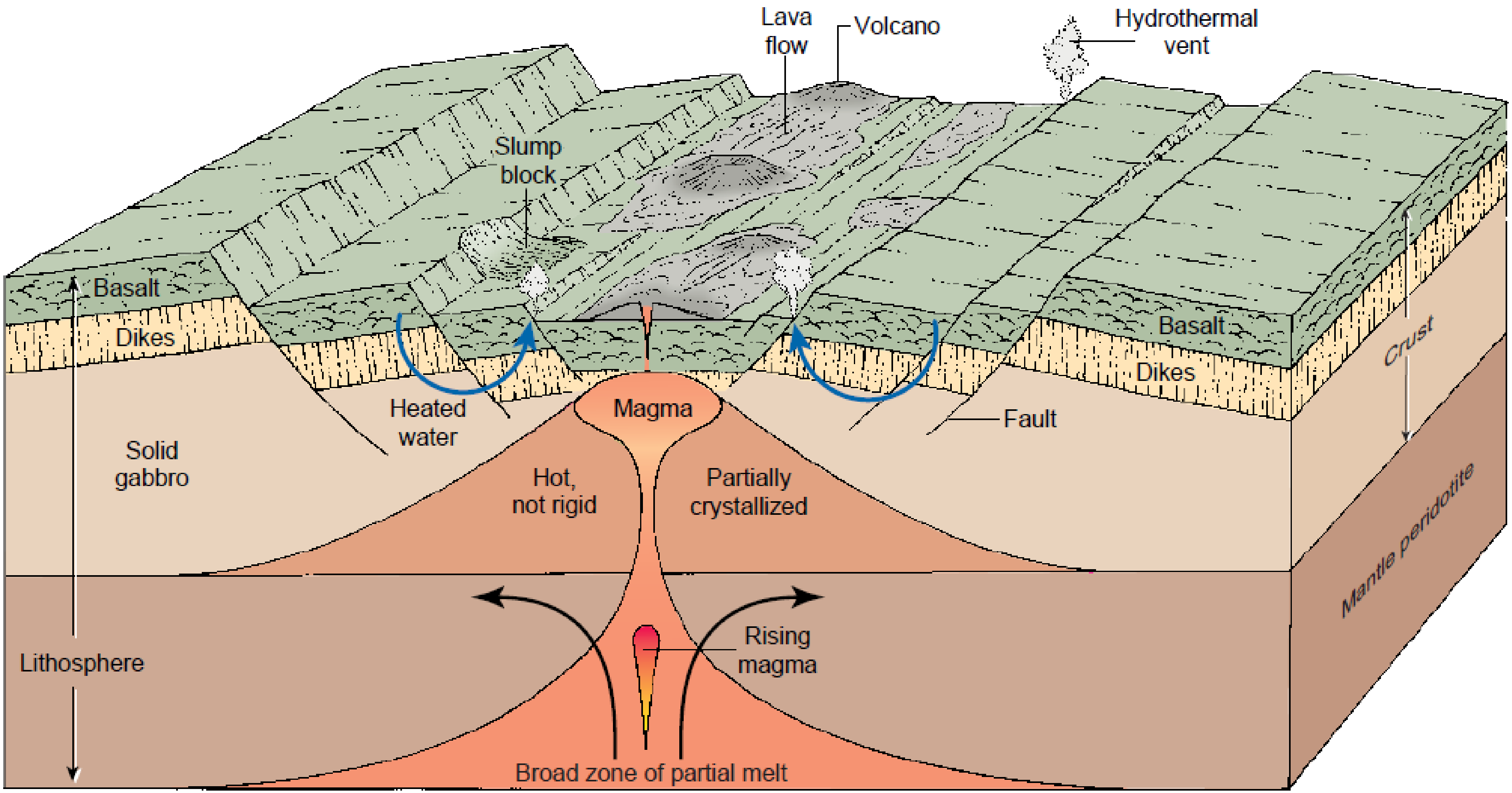




Divergent boundary
also called
Spreading boundary
Mid-ocean ridge
Ridge

Figure 4-6a Earth: Portrait of a Planet 3/e

Idealized cross section of a Mid oceanic Ridge



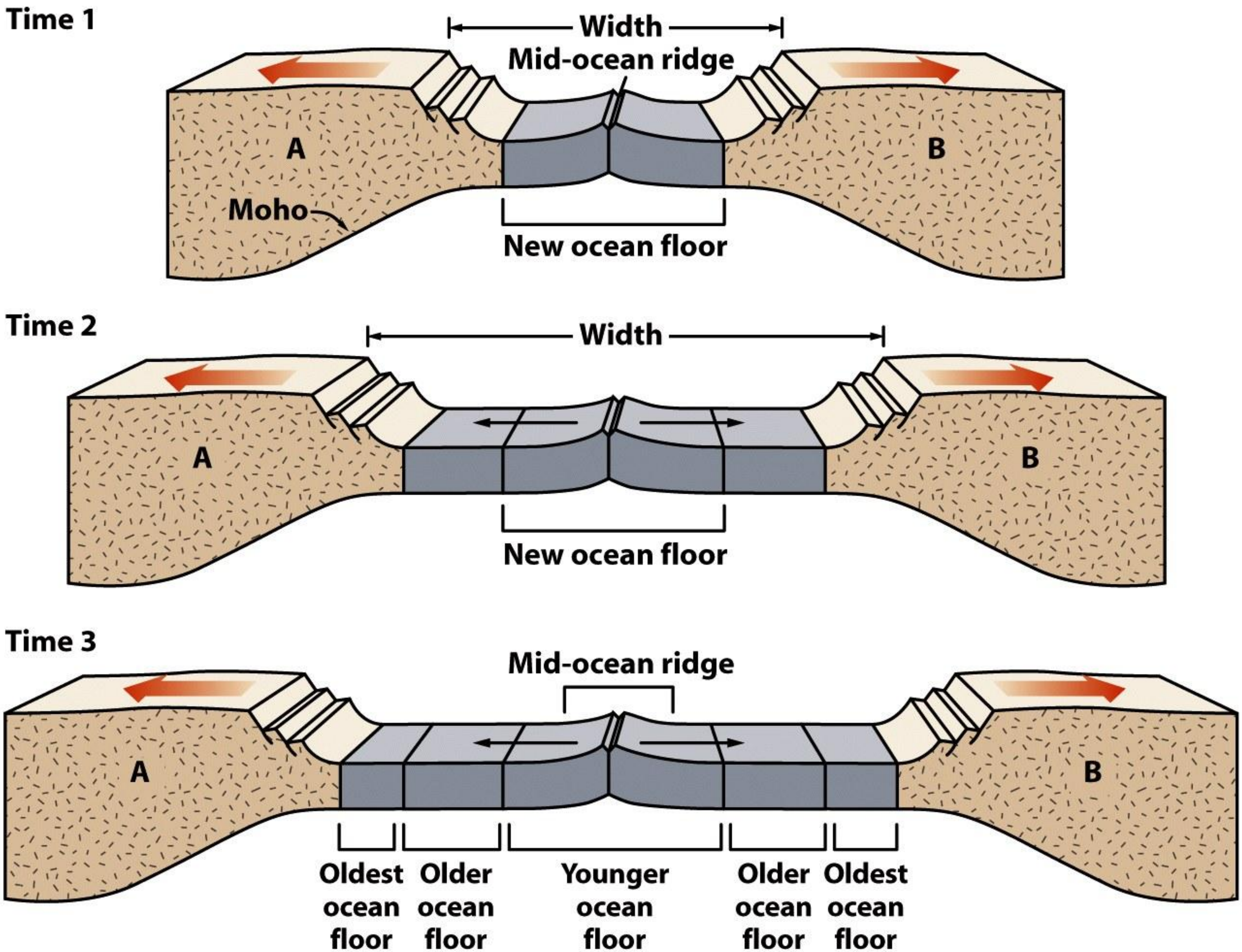
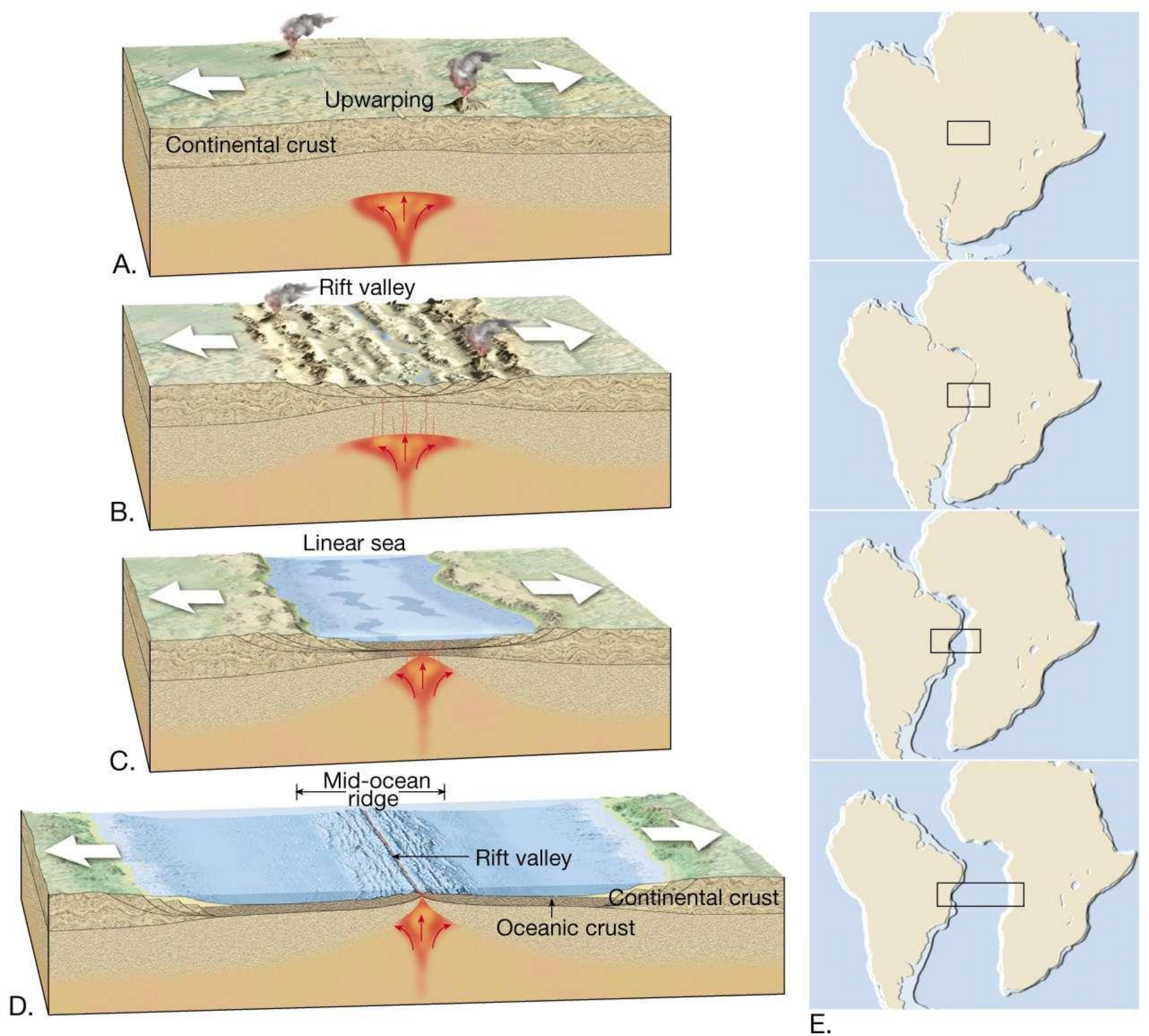


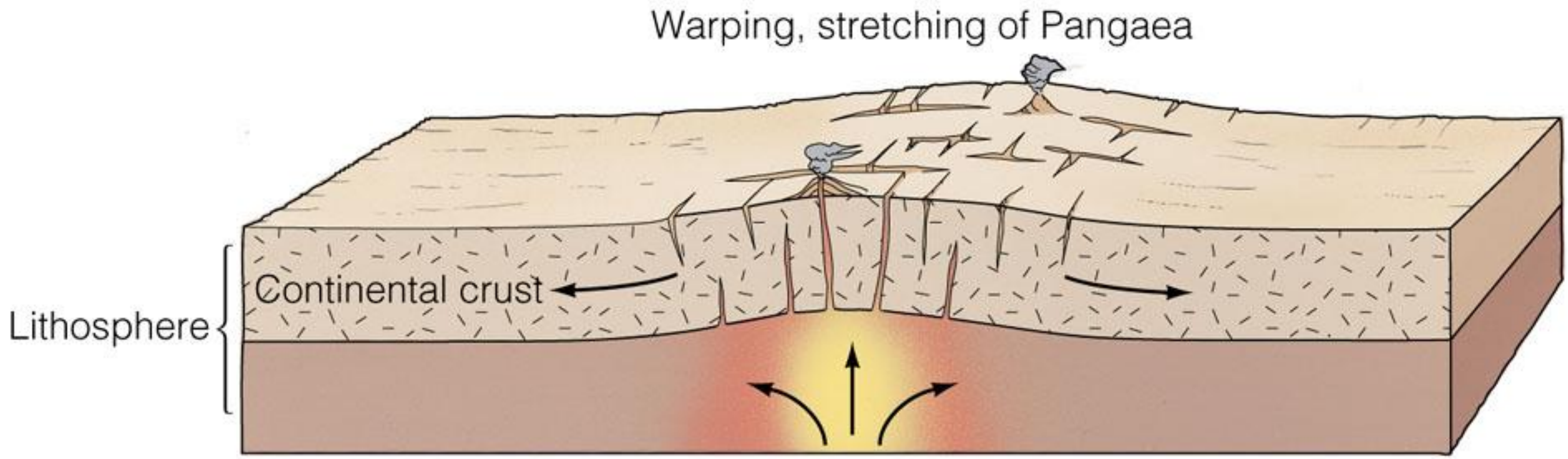
Figure 4-7 Earth: Portrait of a Planet 3/e

Plate Tectonics

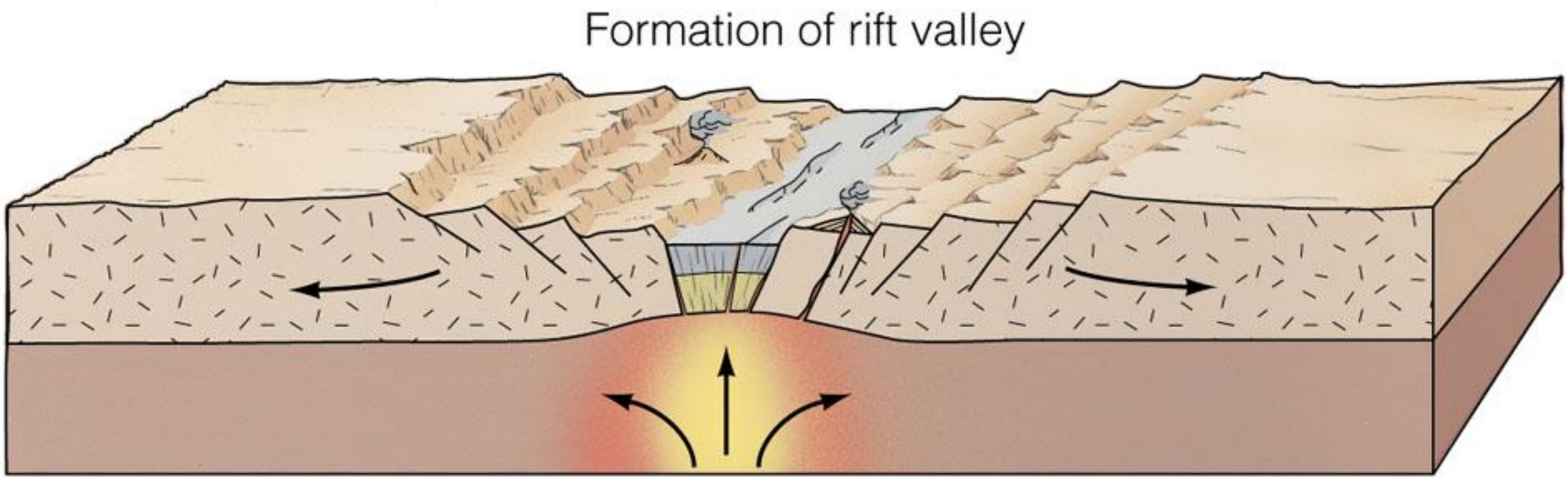
Divergent Boundaries



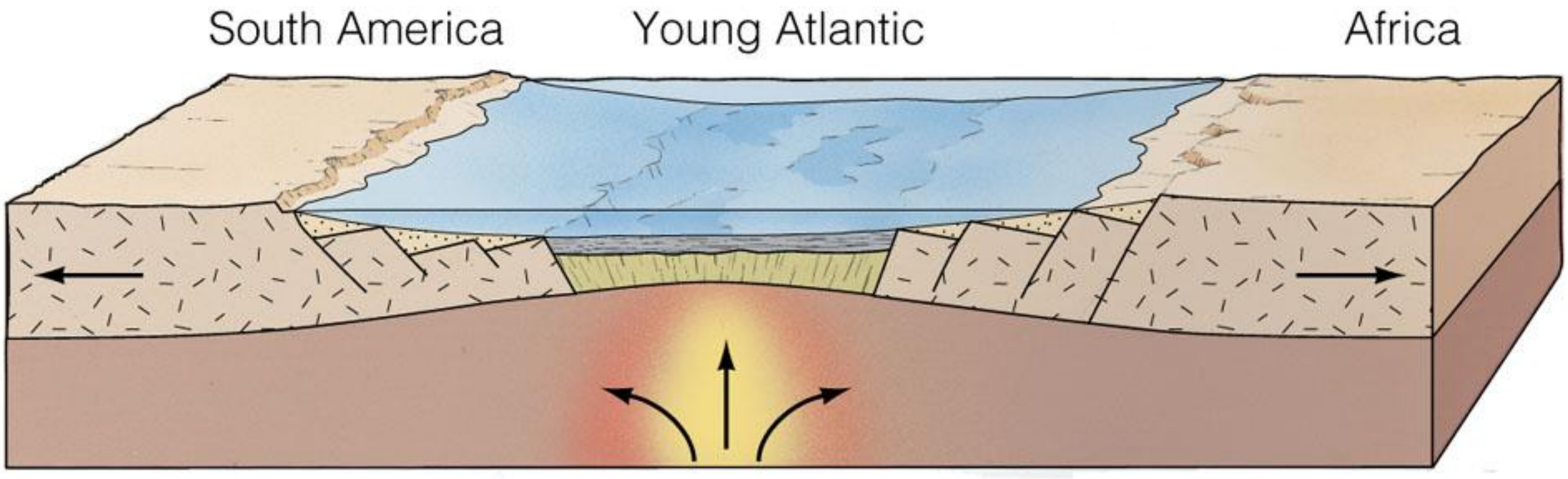
Divergent Boundaries



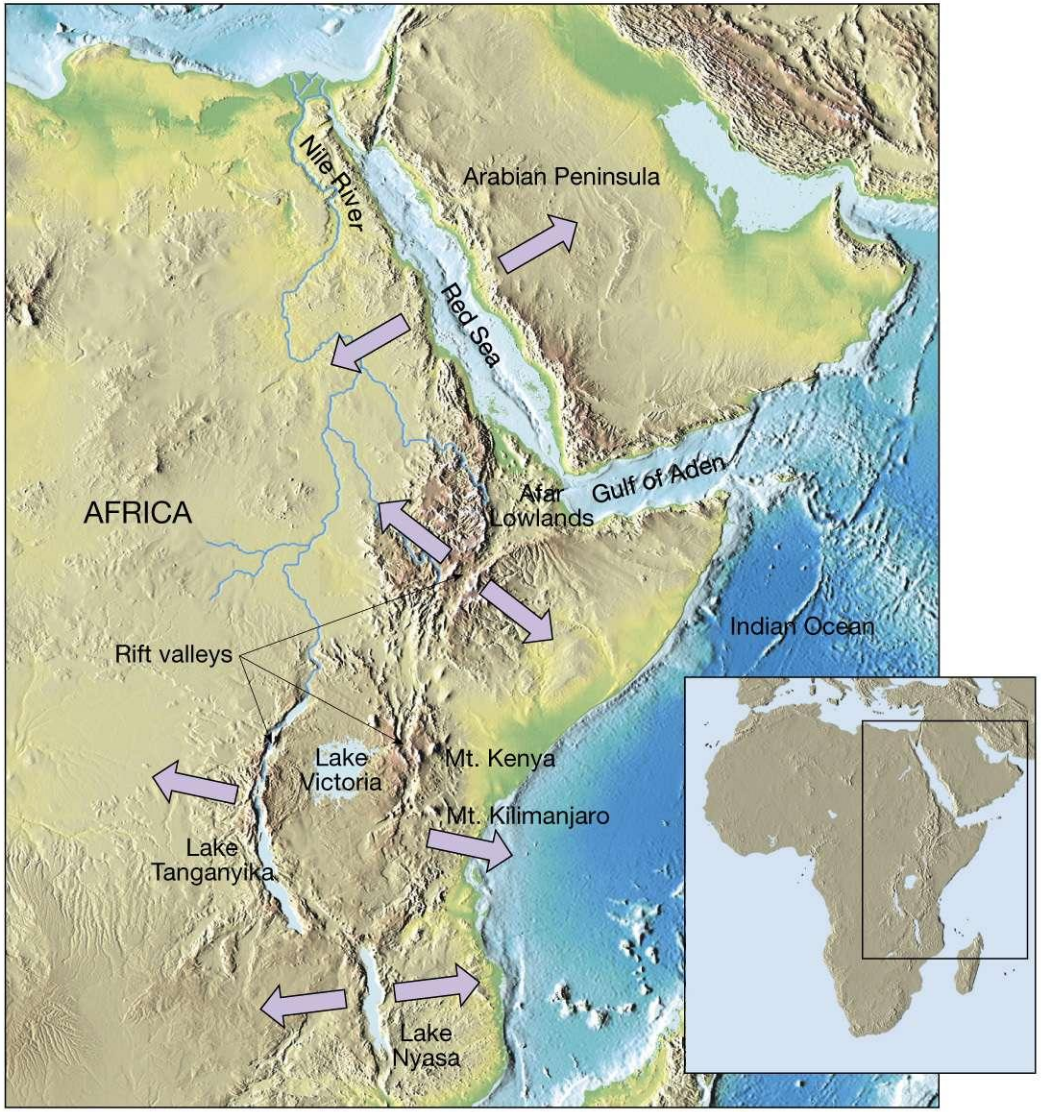
Divergent Boundaries

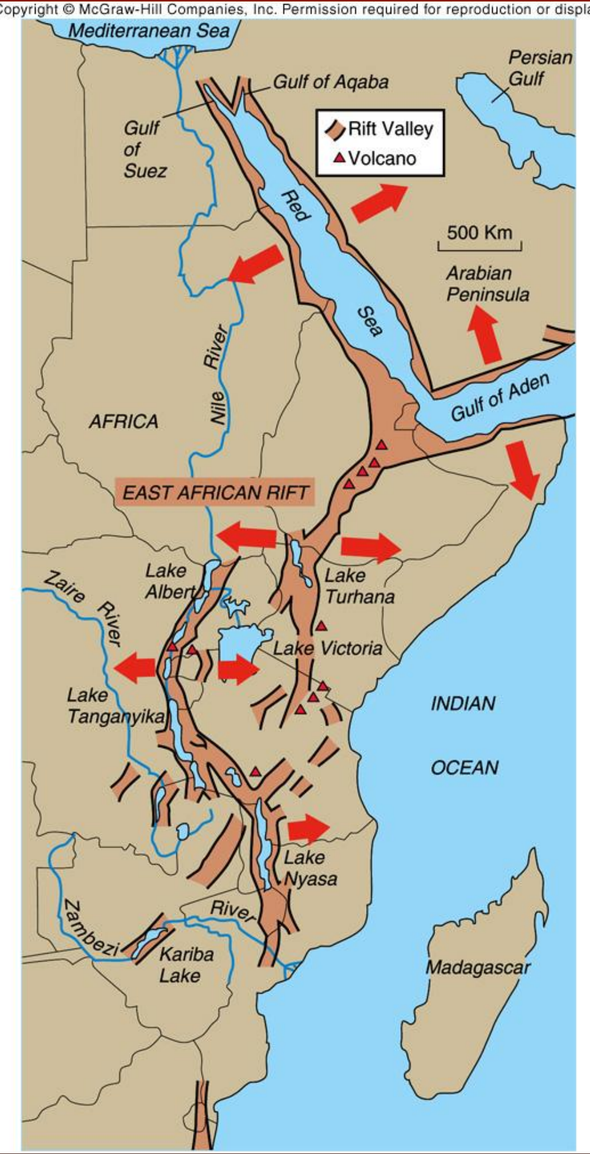


Divergent Boundaries

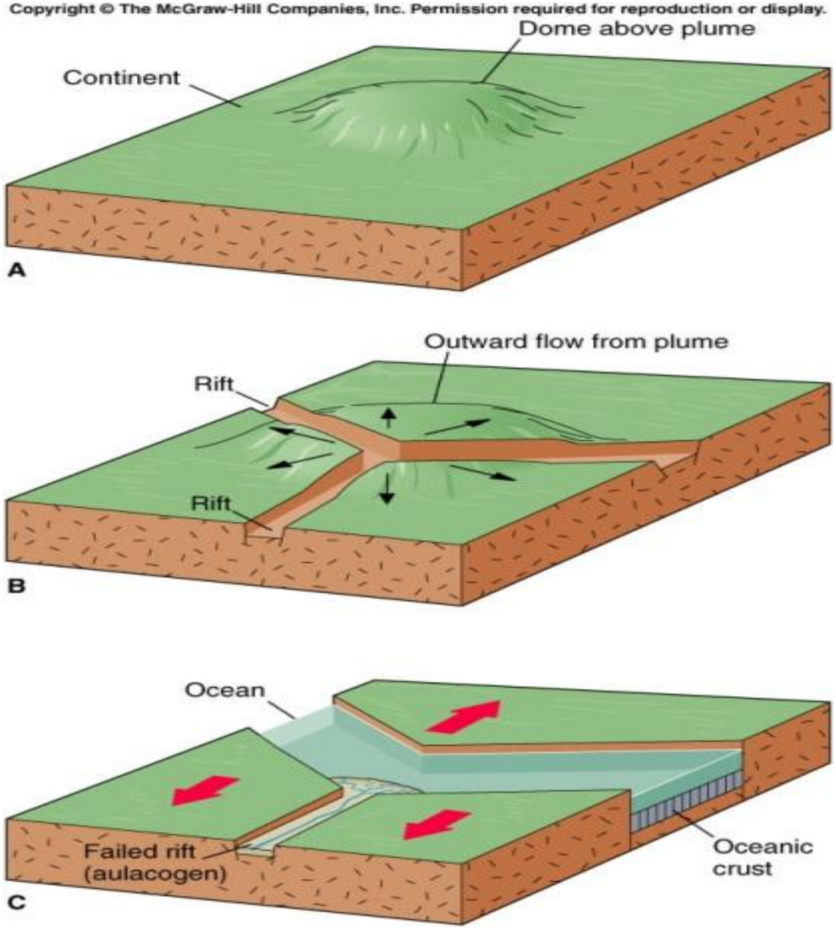


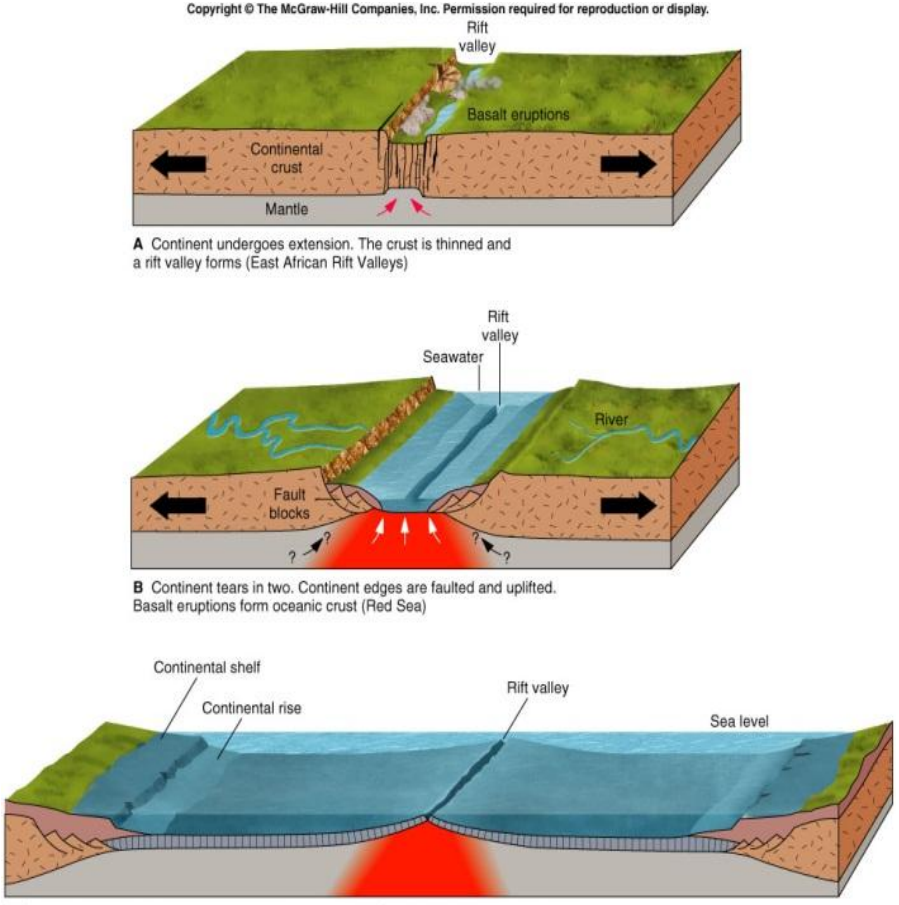
East African-Red Sea Rift





Continental Rift





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)

Plate Tectonics

Characteristics of Divergent Plate Boundaries

1) **Extensional Forces**:
   - Normal faults.
   - Long mountain ranges separated by deep valleys.
2) **Elevated Topography**:
   - Due to shallow, hot asthenosphere.
   - Continental rifts; mid-ocean ridges.
3) **Volcanism**:
   - Decompression melting of hot asthenosphere.
   - Primarily basalt.
   - Some rhyolite at continental rifts.
4) **Subsidence with age**:
   - Asthenosphere contracts as it cools.
   - Failed continental rifts; passive continental margins.

Three Stages of Plate Divergence

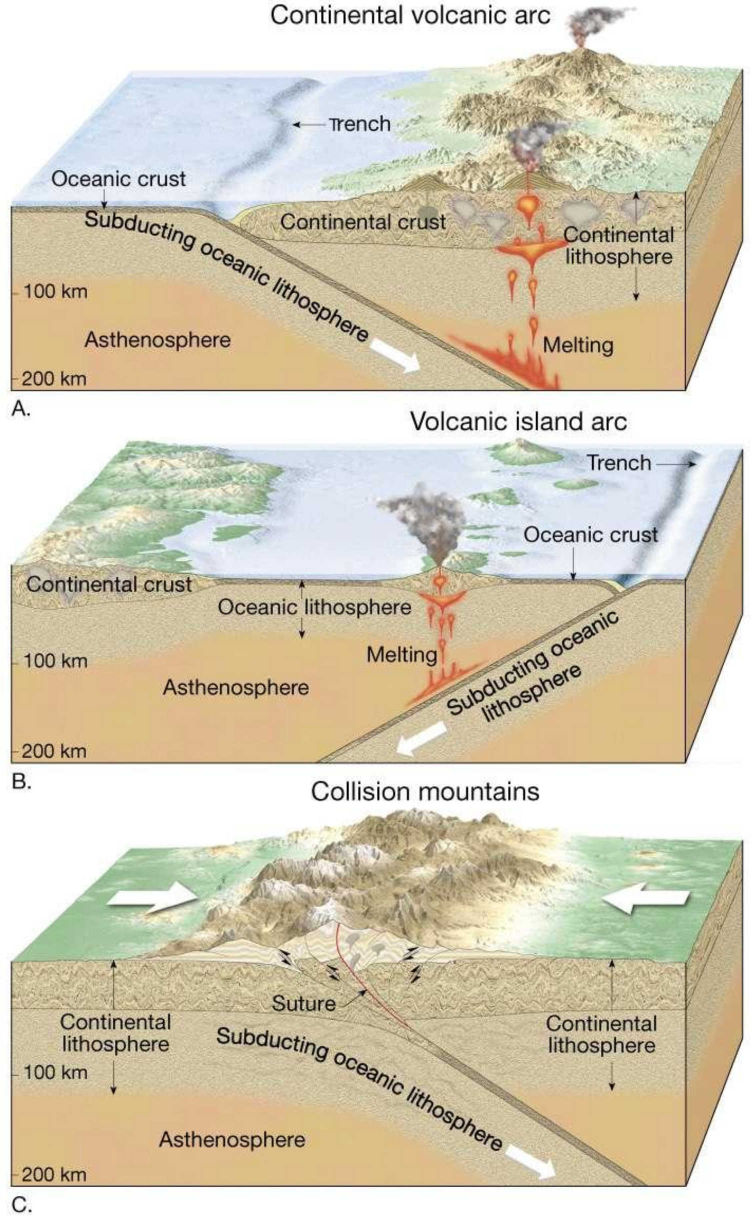
1) **Continental Rift**:
   - Elevated topography on continental crust.
   - Long mountain ranges; deep valleys.
   - Basalt with some rhyolite volcanism.
   - East African Rift; Basin and Range Province.

2) **New Ocean**:
   - Subsidence as thin oceanic crust develops.
   - Basalt volcanism.
   - Red Sea; Gulf of California.

3) **Mature Ocean**:
   - Active plate boundary at mid-ocean ridge.
     - Mid-Atlantic Ridge; East Pacific Rise.
   - Passive margins developed as continental edges subside.
     - East Coast of United States.

Plate Tectonics

Convergent boundaries

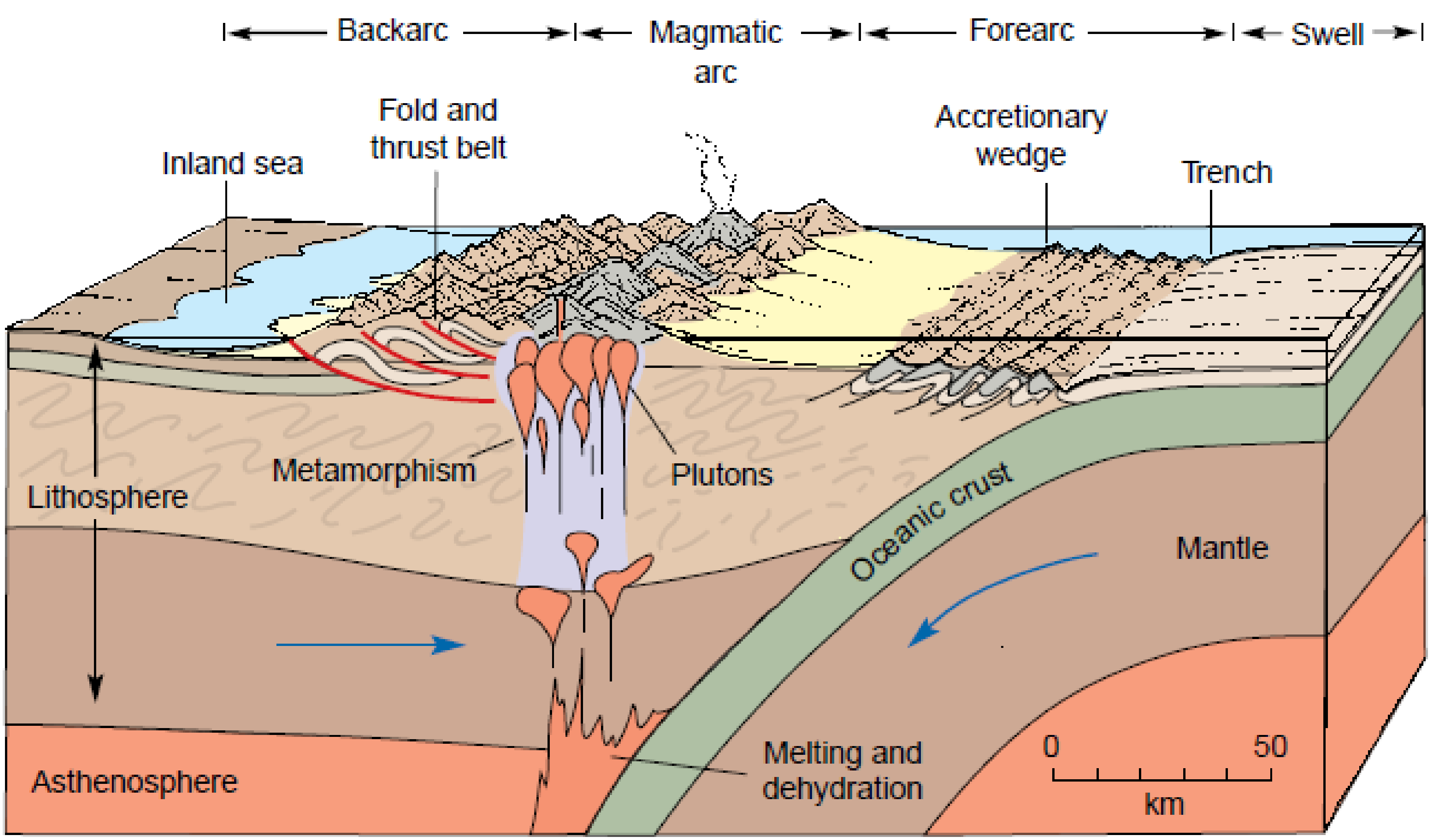


Ocean-Continent (Andean)

Ocean-Ocean (Japan)

Continent-Continent (Himalaya)

Features of ocean-continent convergence



Earthquake depth from Trench to Arc

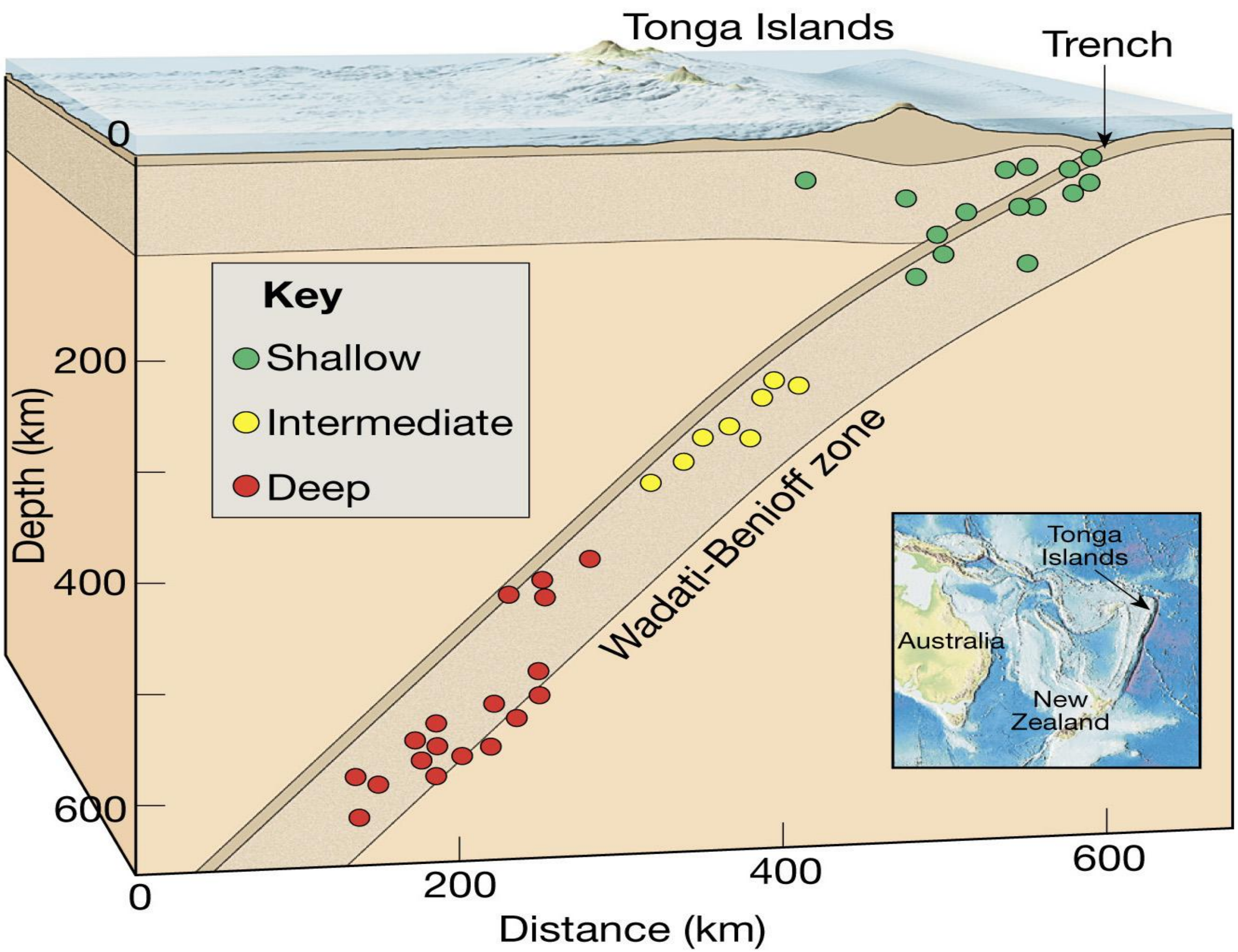
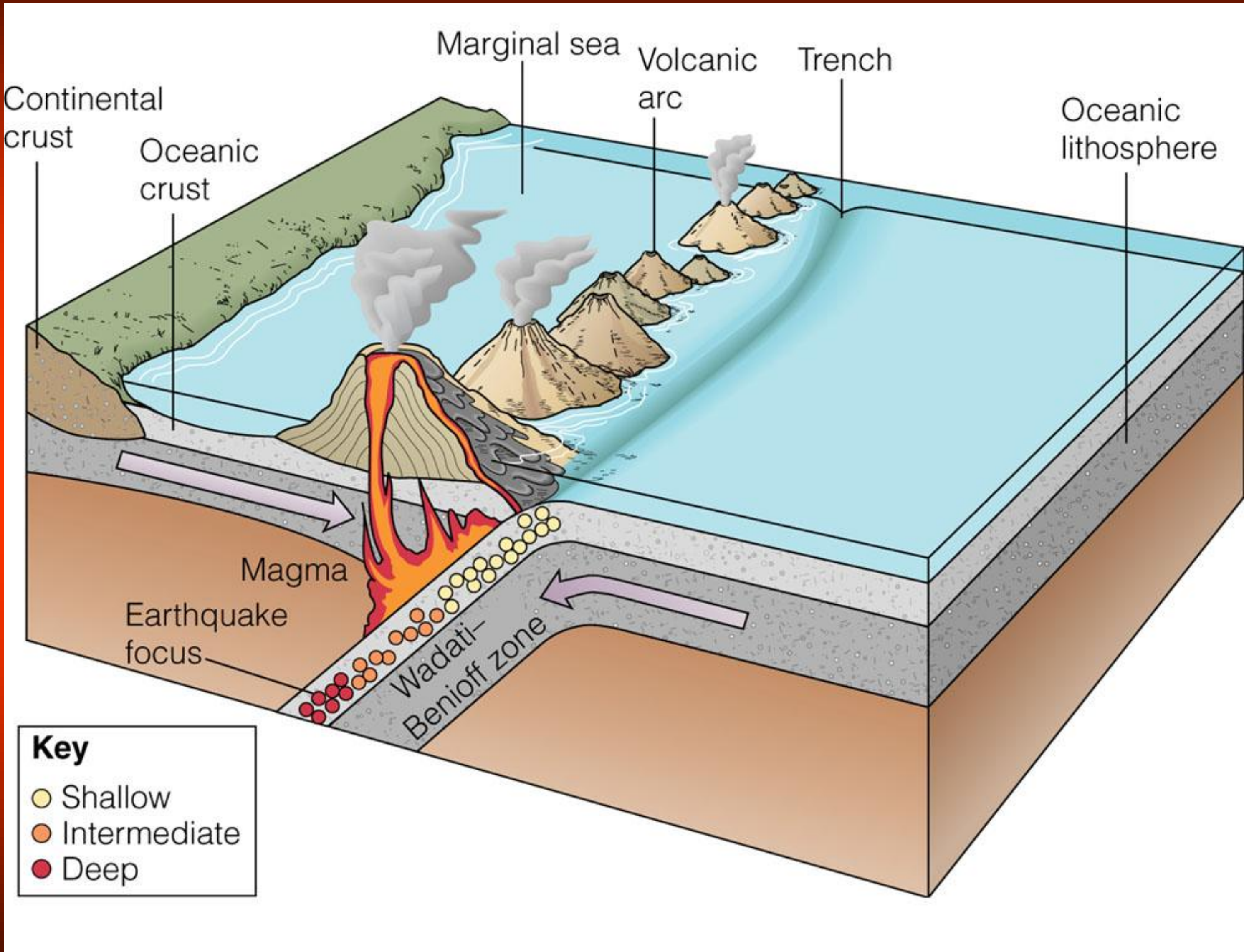


Plate Tectonics

Ocean-Ocean (Japan)



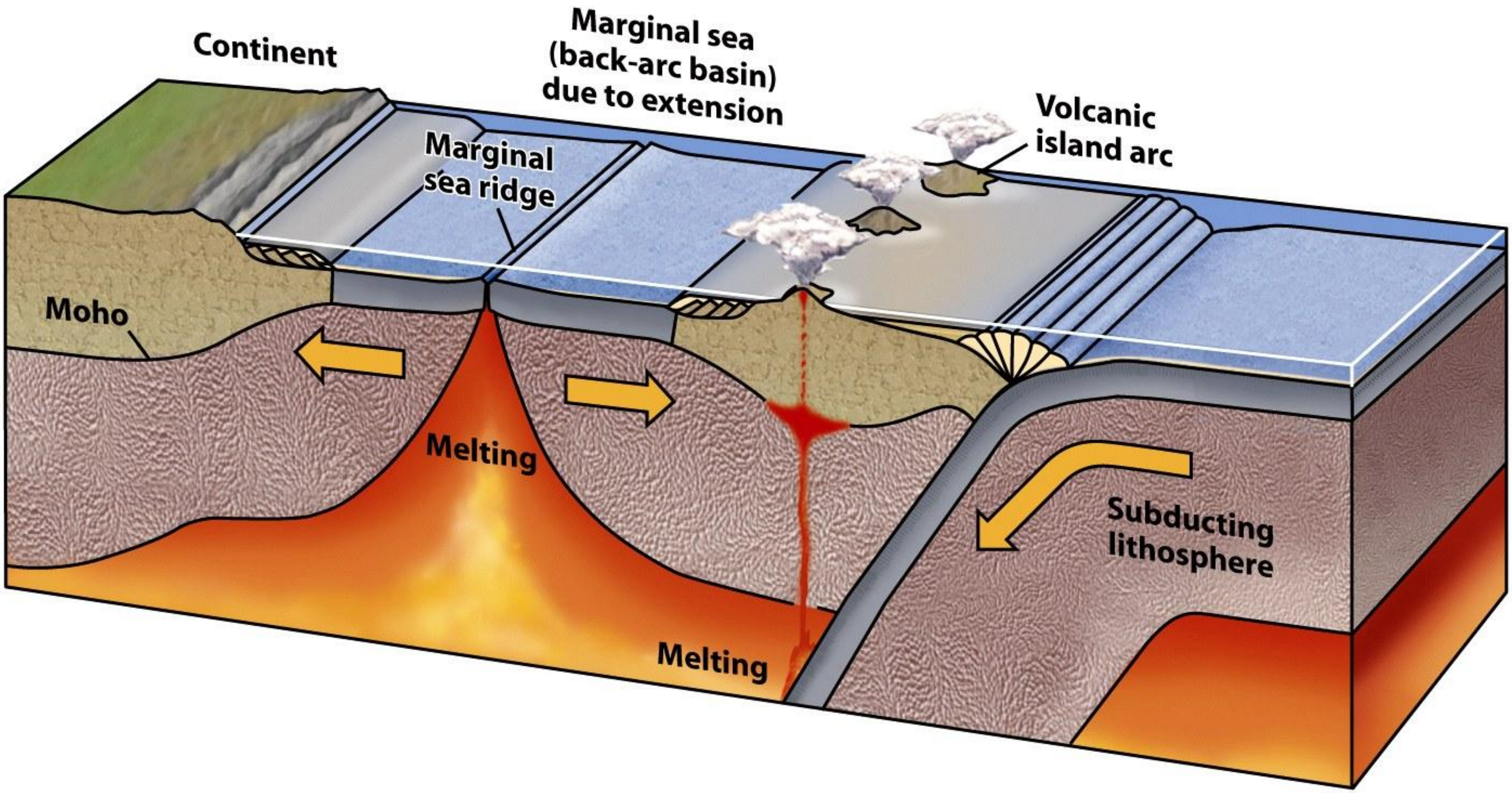


Figure 4-16 Earth: Portrait of a Planet 3/e

Features of ocean-ocean convergence

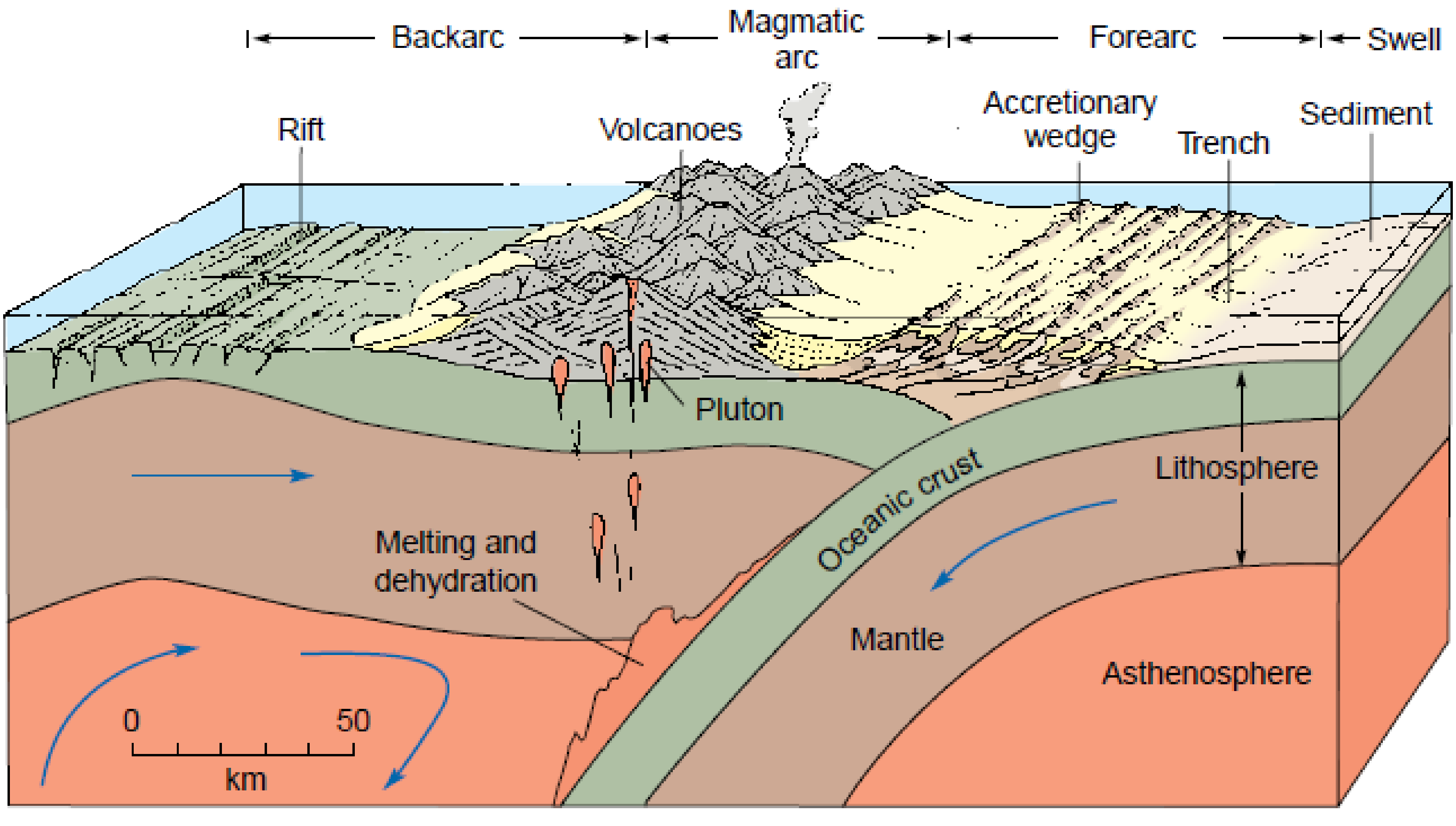


Plate Tectonics

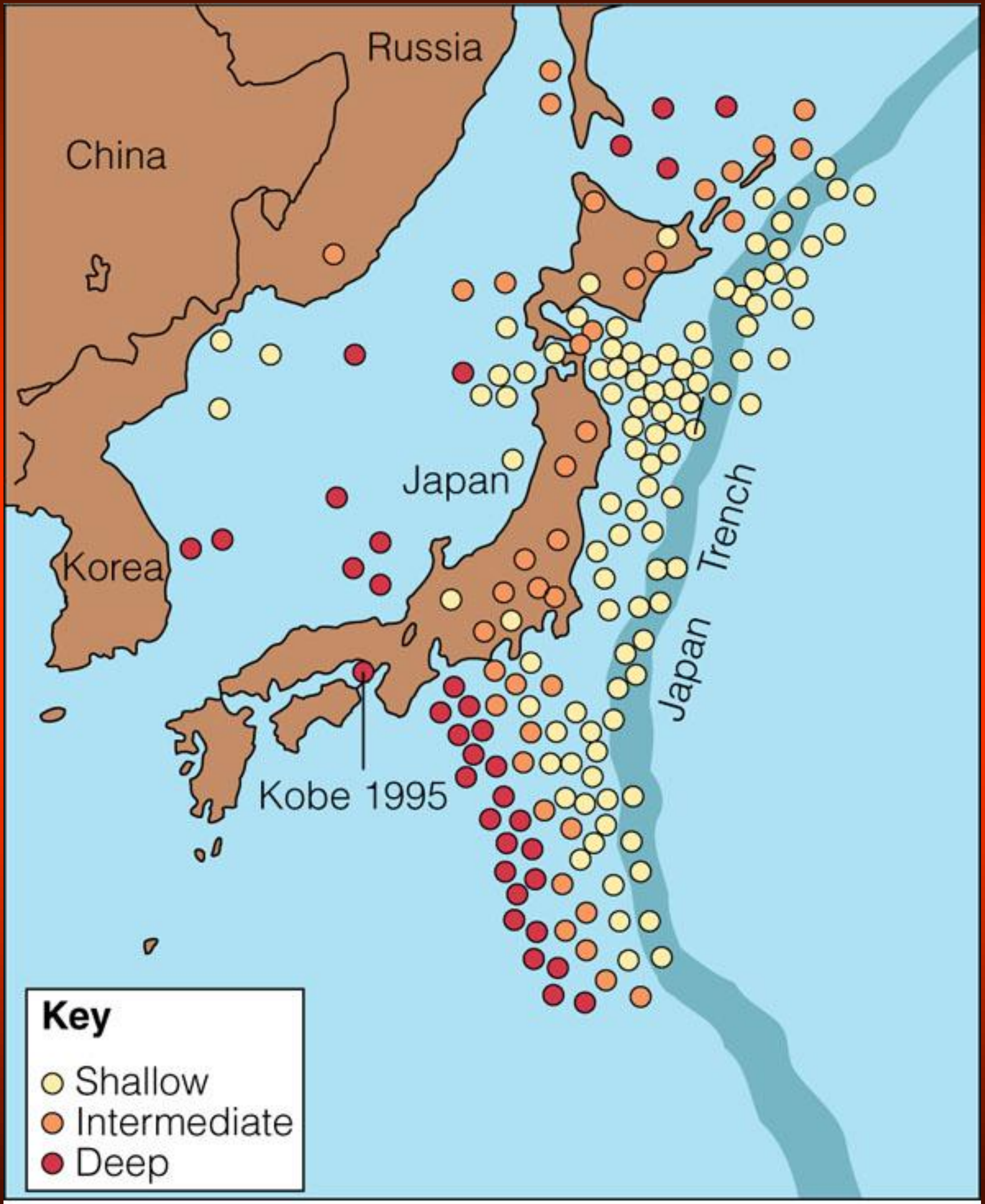
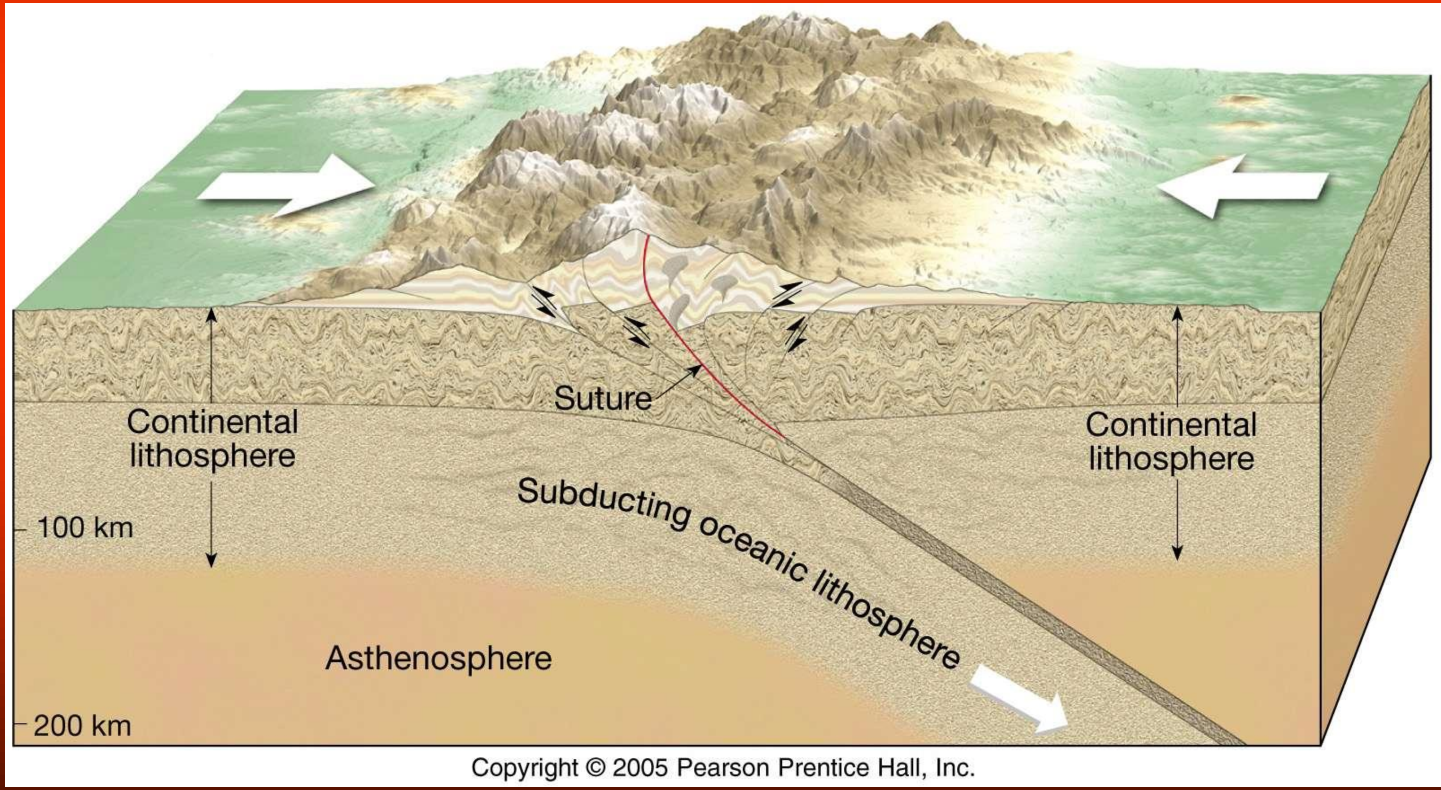
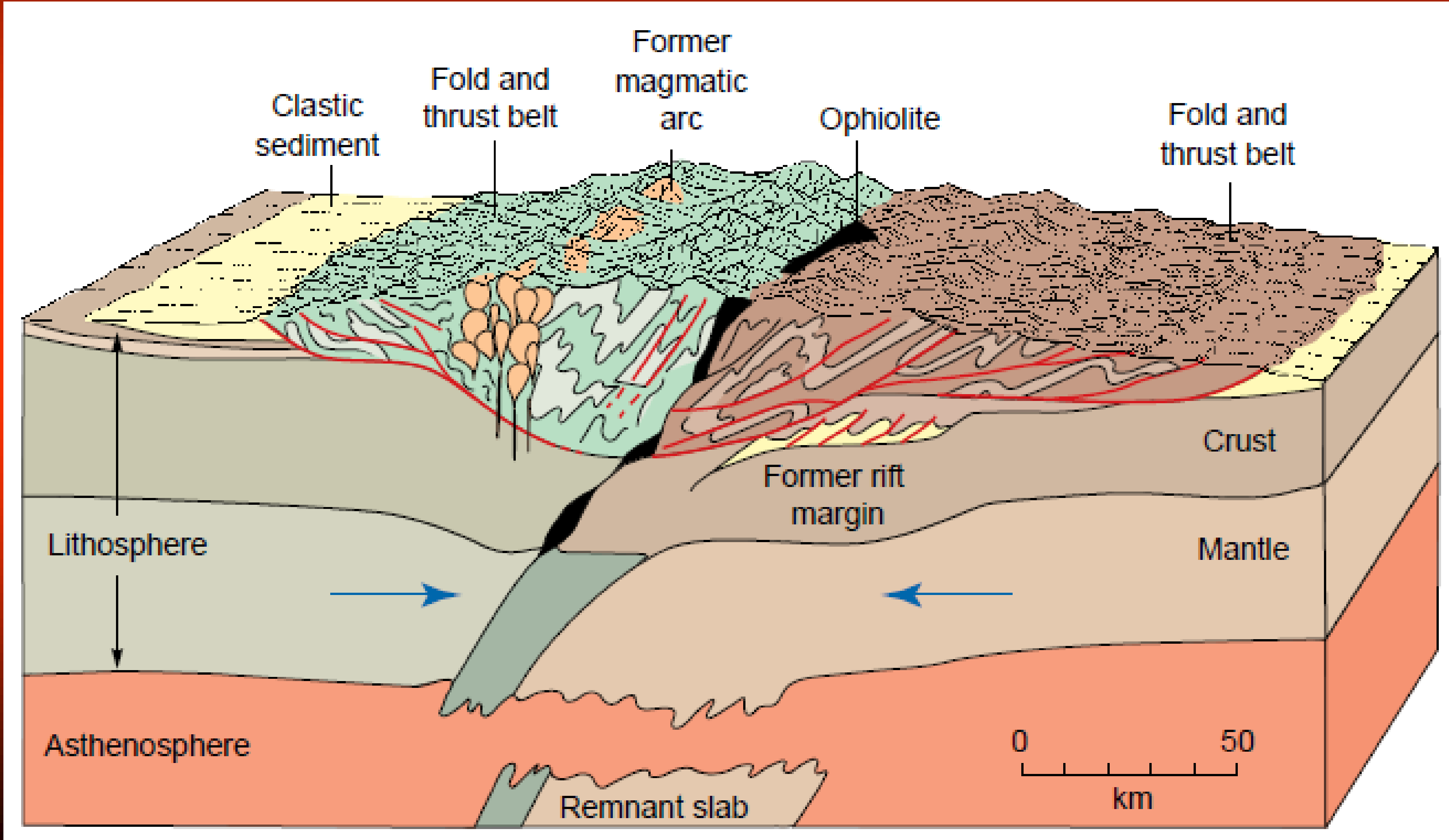


Plate Tectonics

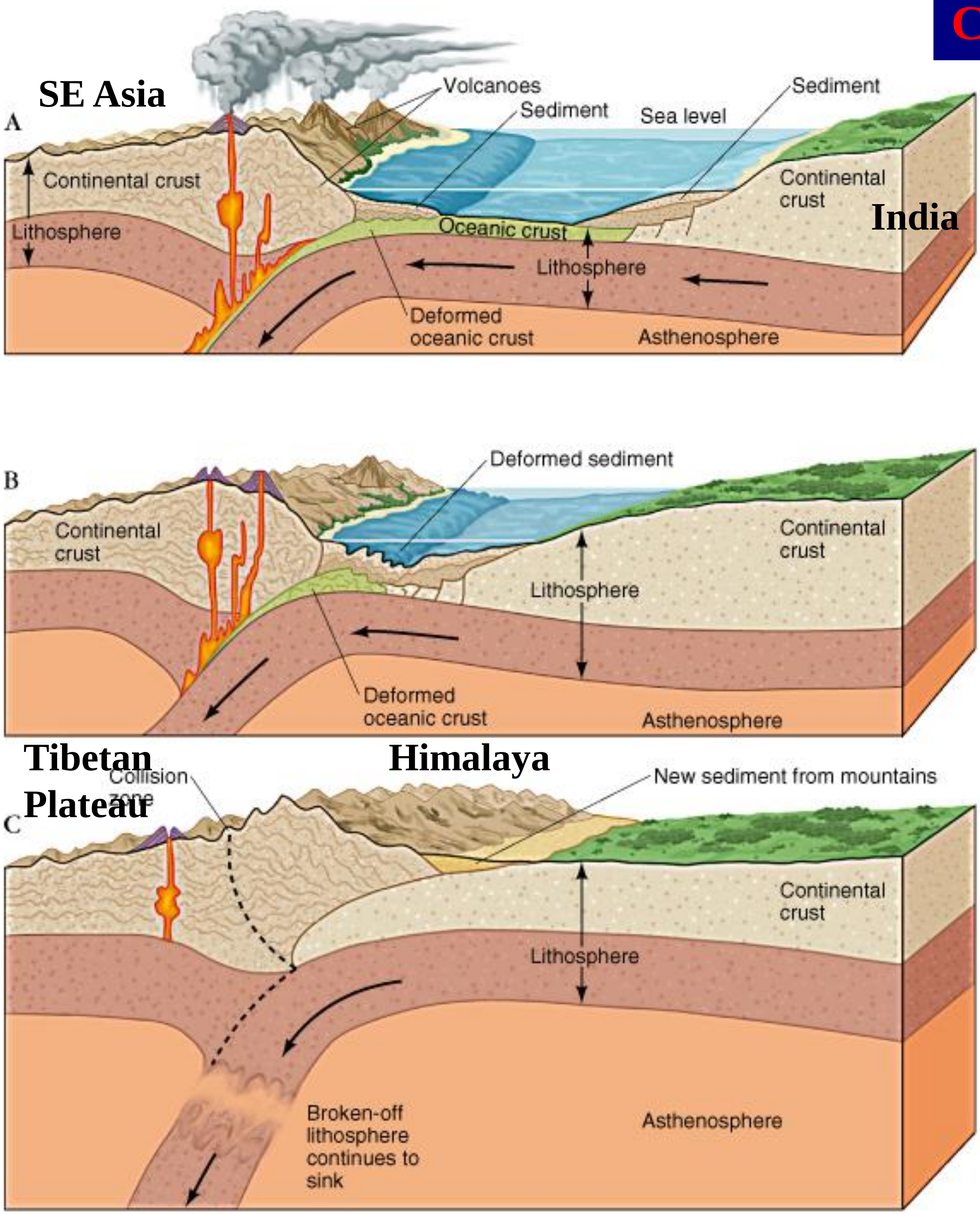
Continent-Continent (Himalaya)



Features of continent-continent collision



Continent-Continent Convergence

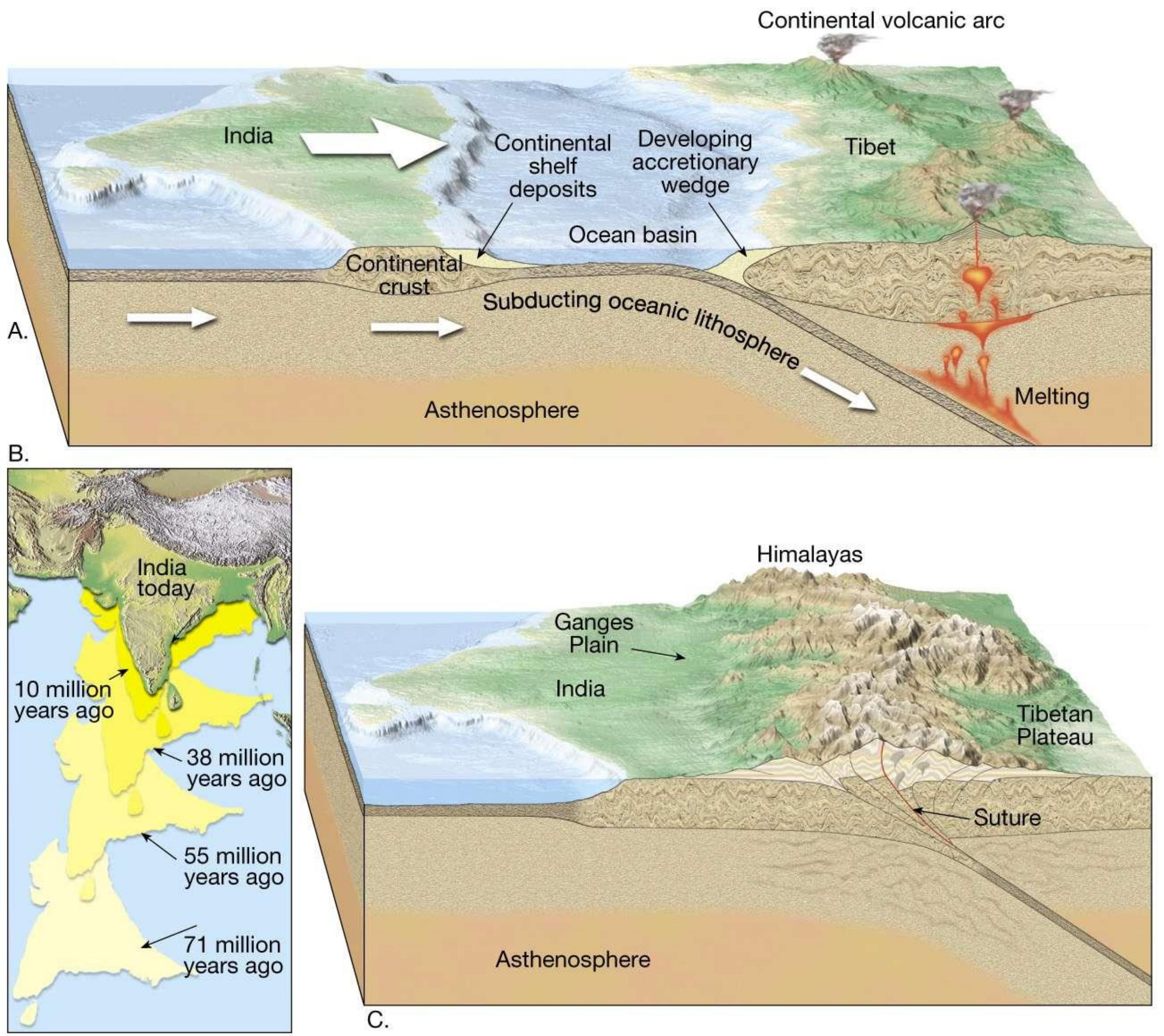


60 million years ago

30 million years ago

Today

Plate Tectonics



The collision of India and Asia produced the Himalayas

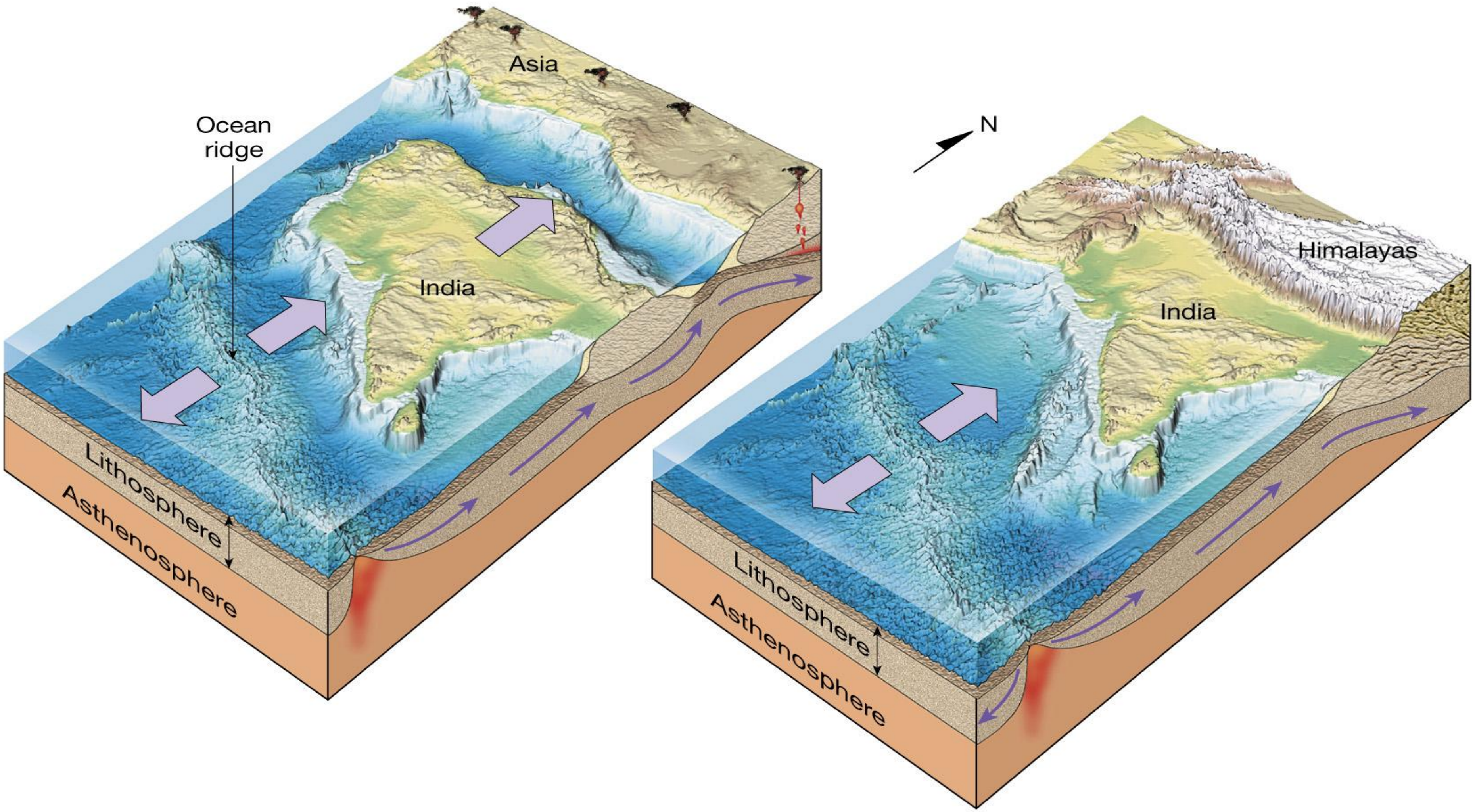
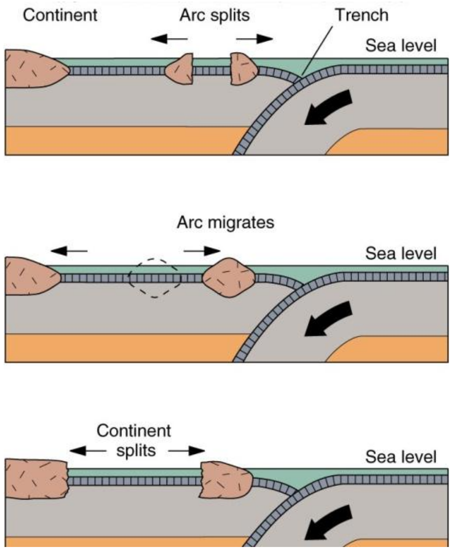
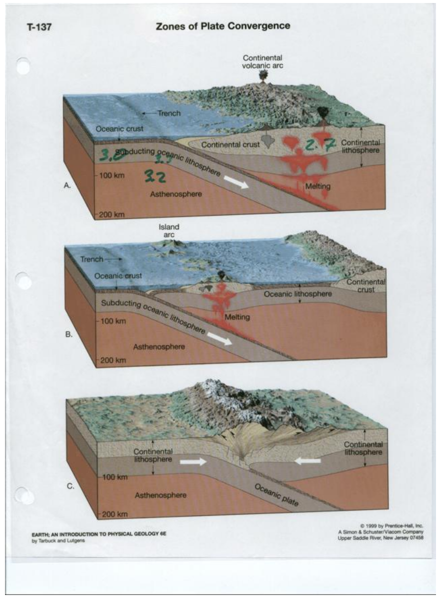
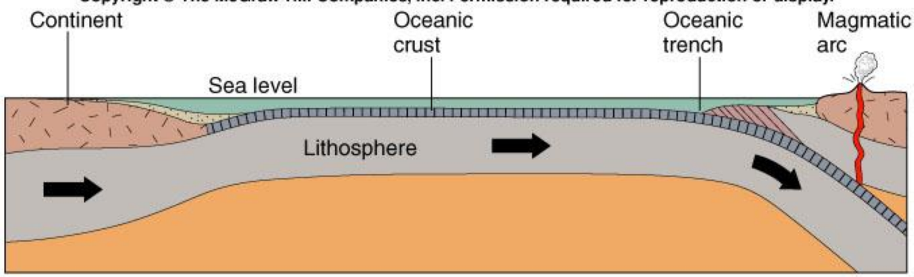


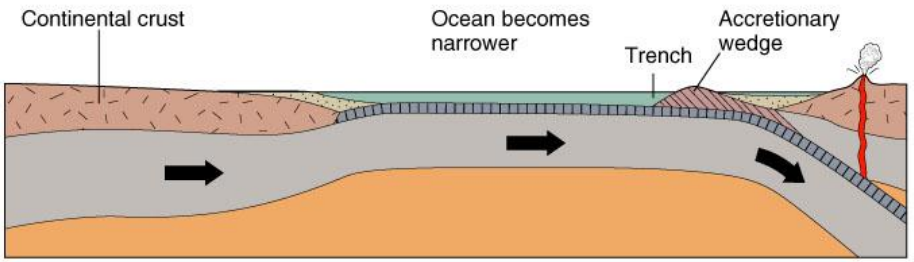
Plate boundaries > Convergent



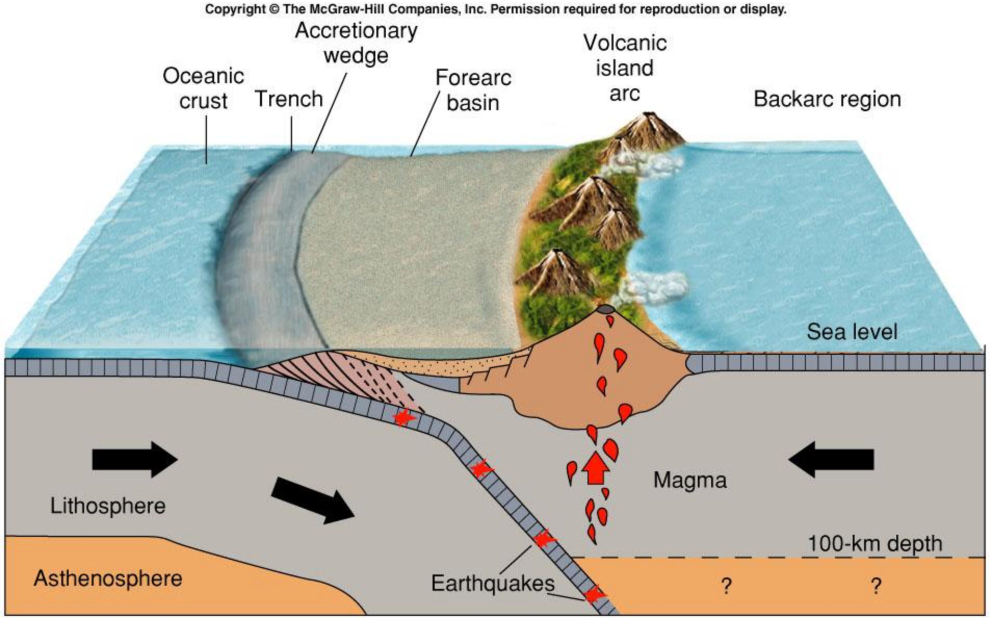


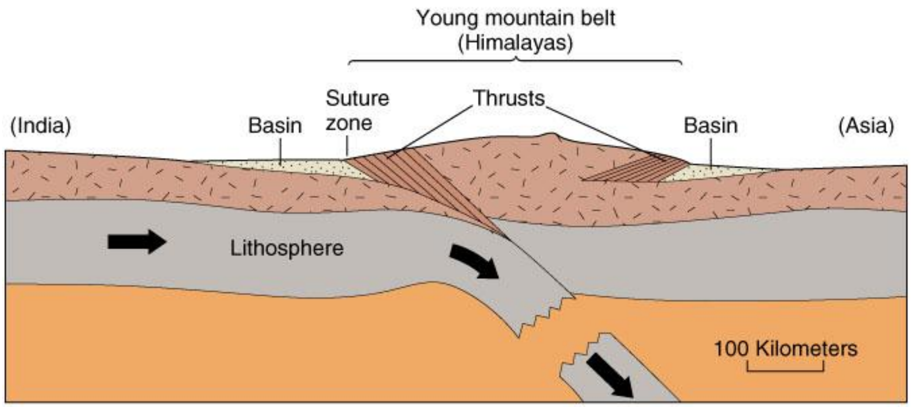


A Ocean-continent convergence



B Ocean-continent convergence





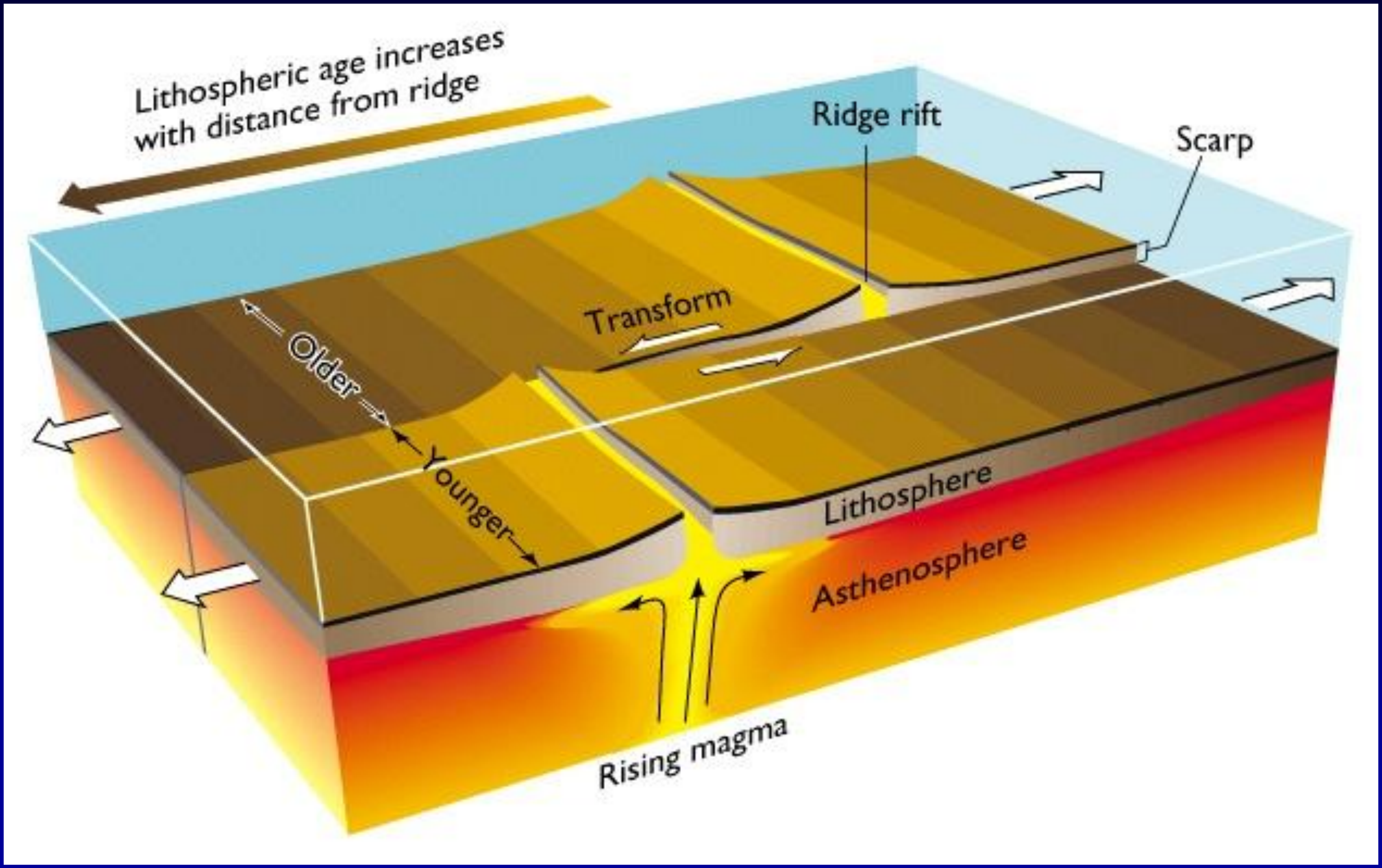
C Continent-continent collision

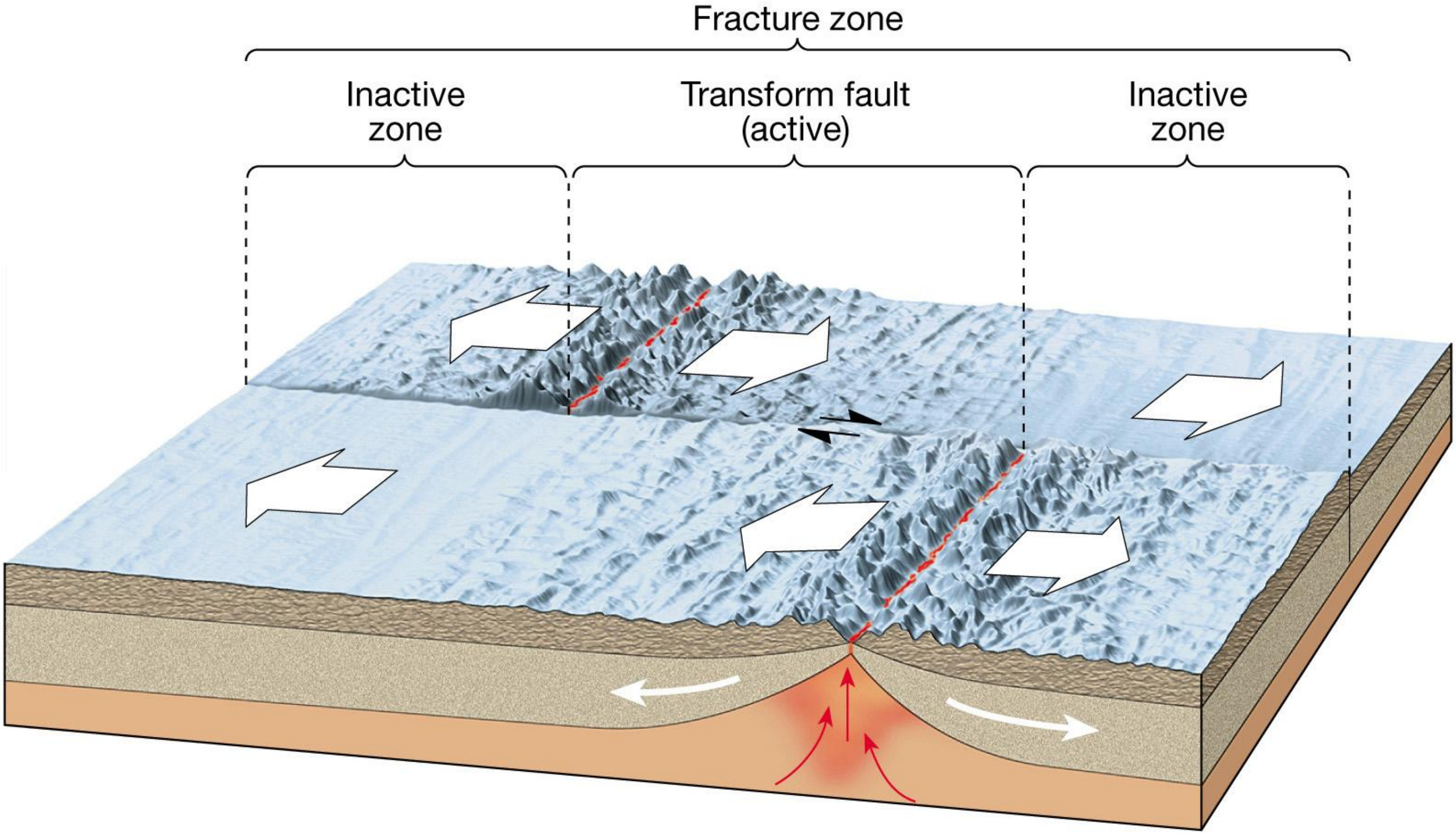
Magma generation

- Magma, molten rock in the earth's crust, has an important relationship with volcanic explosivity and hazard level
- Andesitic magmas, formed by wet partial melting at subduction zones produce highly explosive and destructive composite volcanoes

Magma type	Generation	Tectonic setting	Hazards
Basaltic Low silica, low gas, low viscosity.	Dry partial melting of upper mantle	Oceanic Hot spot (Hawaii) Constructive (Iceland)	Lava flow
Andesitic Intermediate	Wet partial melting of subducting plates	Destructive plate margin (Andes) Island arc margin (Montserrat)	Lava flow, ash and tephra, pyroclastic flow, lahar, gas emission
Rhyolitic High silica, high gas, high viscosity.	In situ melting of lower continental crust *(very rare eruptions)*	Continental Hot spot (Yellowstone) Continent collision zone (Himalayas)	Cataclysmic explosion, pyroclastic flow

Transform Boundary




Fracture zone
Inactive
zone
Transform fault
(active)
Inactive
zone

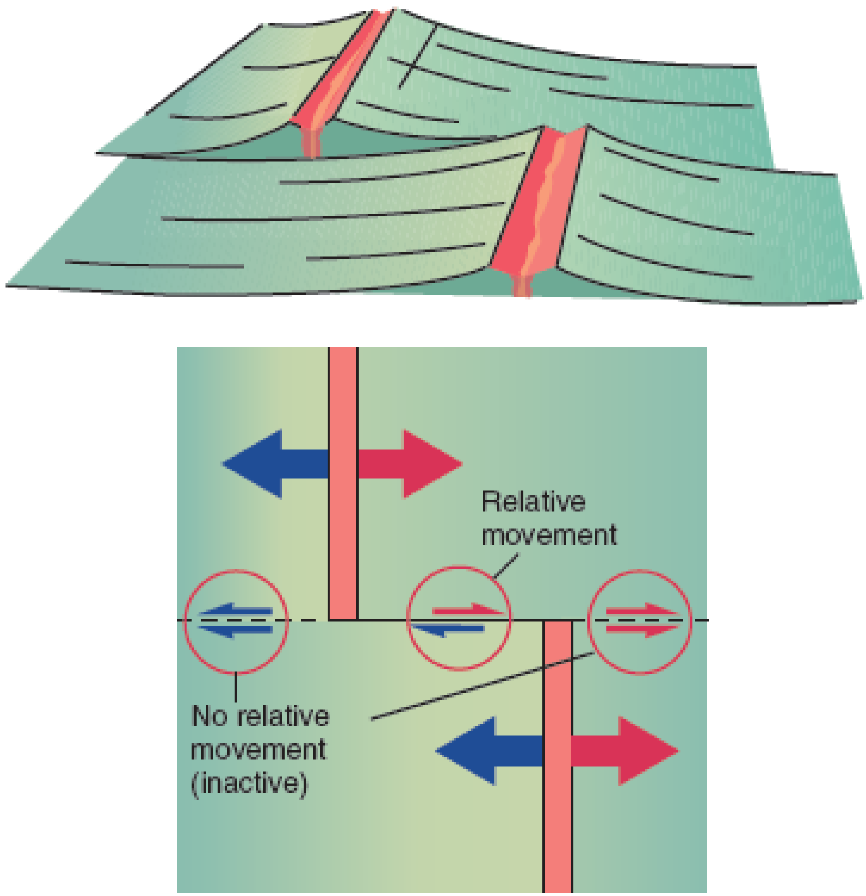


Figure 18.5 Transform fault at a mid-ocean ridge (perspective and map view). The fault is only active between the ridge segments (except for minor vertical adjustments). The offset is constant along the active part of the fault, and its length grows at a rate that is directly proportional to the spreading rate.

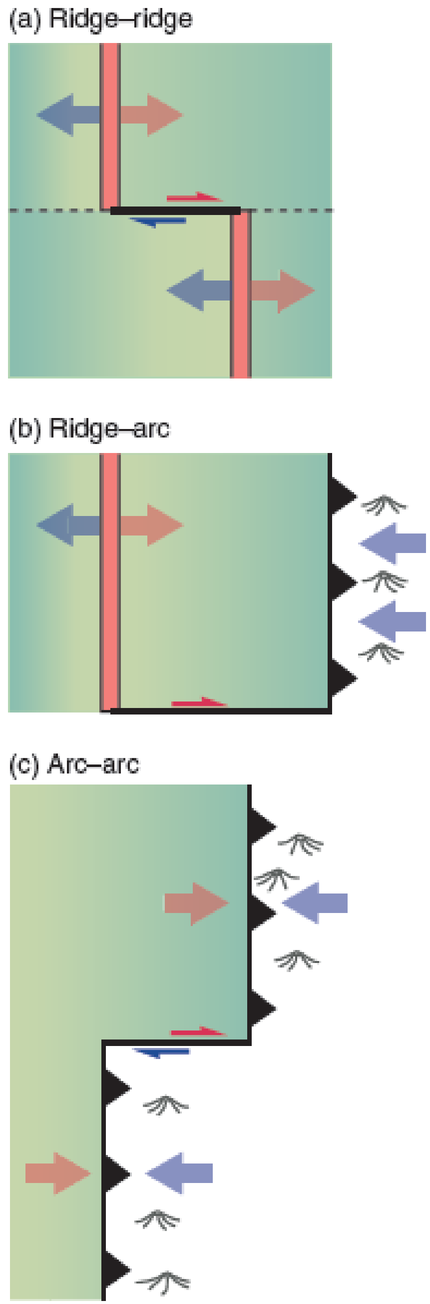
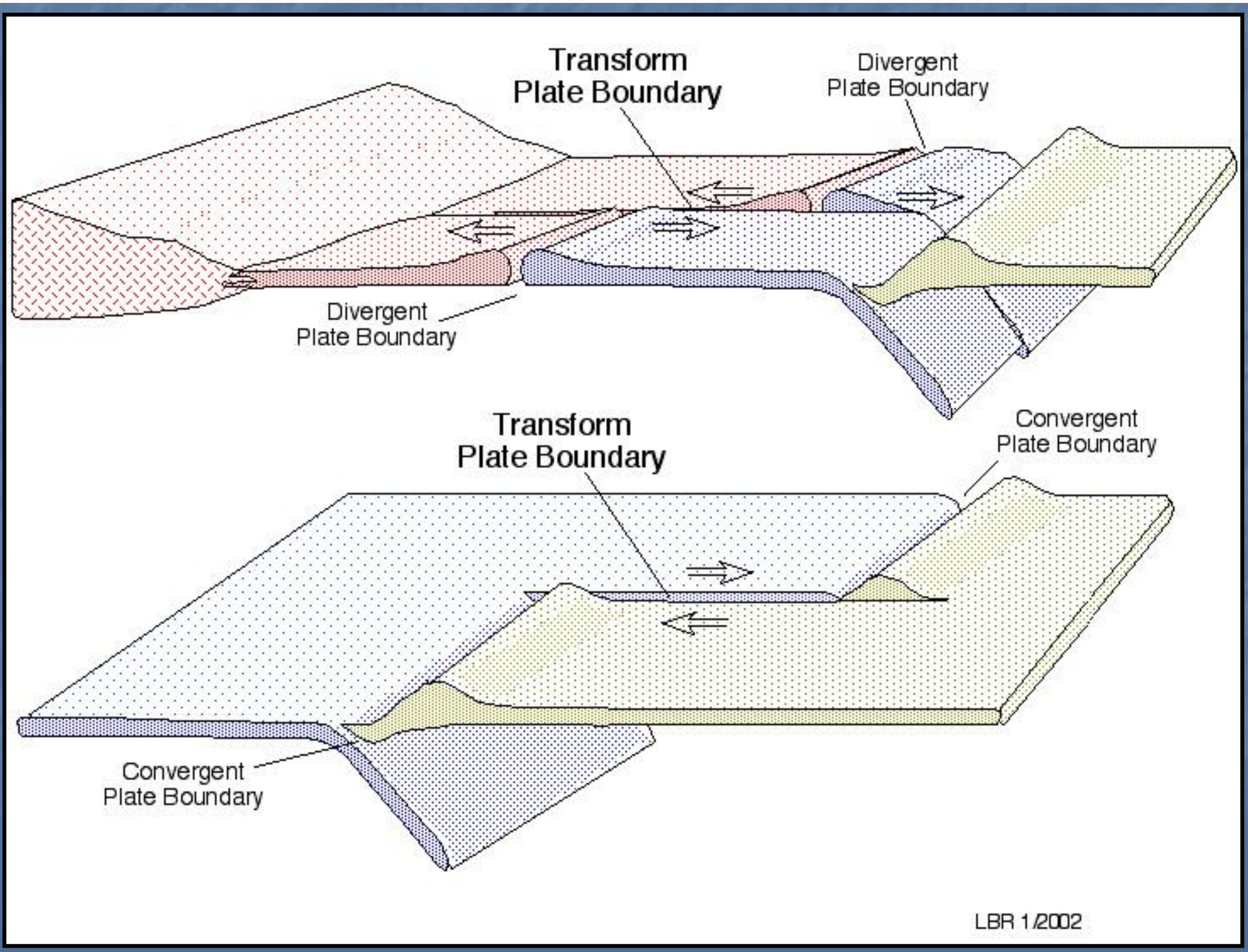
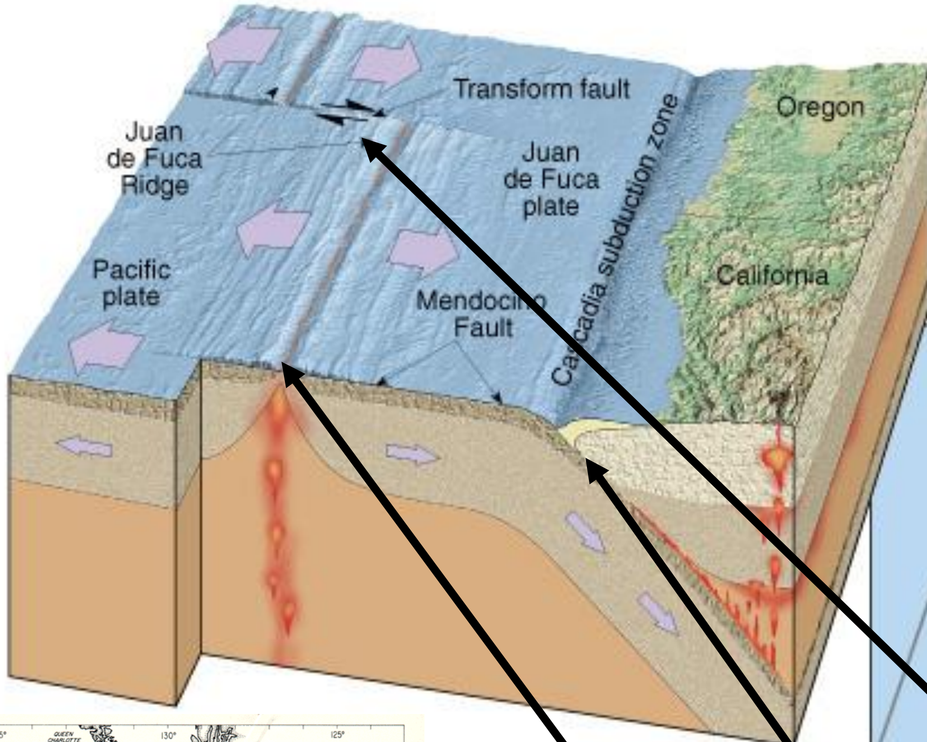


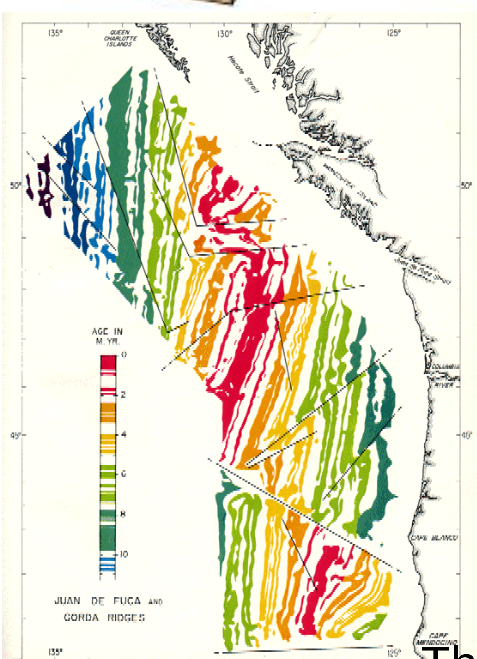
Figure 18.6 Transform faults are strike-slip faults connected by plate boundaries. (a) Fault between two mid-ocean spreading ridge segments. (b) Transform fault connecting a rift segment and an island arc/ subduction zone. (c) Fault displacing a destructive plate boundary.

Transform Plate Boundary



Structure of three Plates





Youngest at ridges, oldest at trenches
NOT FALSE

Three boundary types, **divergent, convergent, and transform**

Plate boundaries > Transform

- **Transform** (plates moving past each other) (strike-slip features)
  - These are secondary features that mainly take up the slack from convergent and divergent boundaries.
  - Unless the boundary is a perfect great circle (straight line-equivalent), there will be tiny areas of convergence and of divergence, resulting in small compressive and tensional regions.

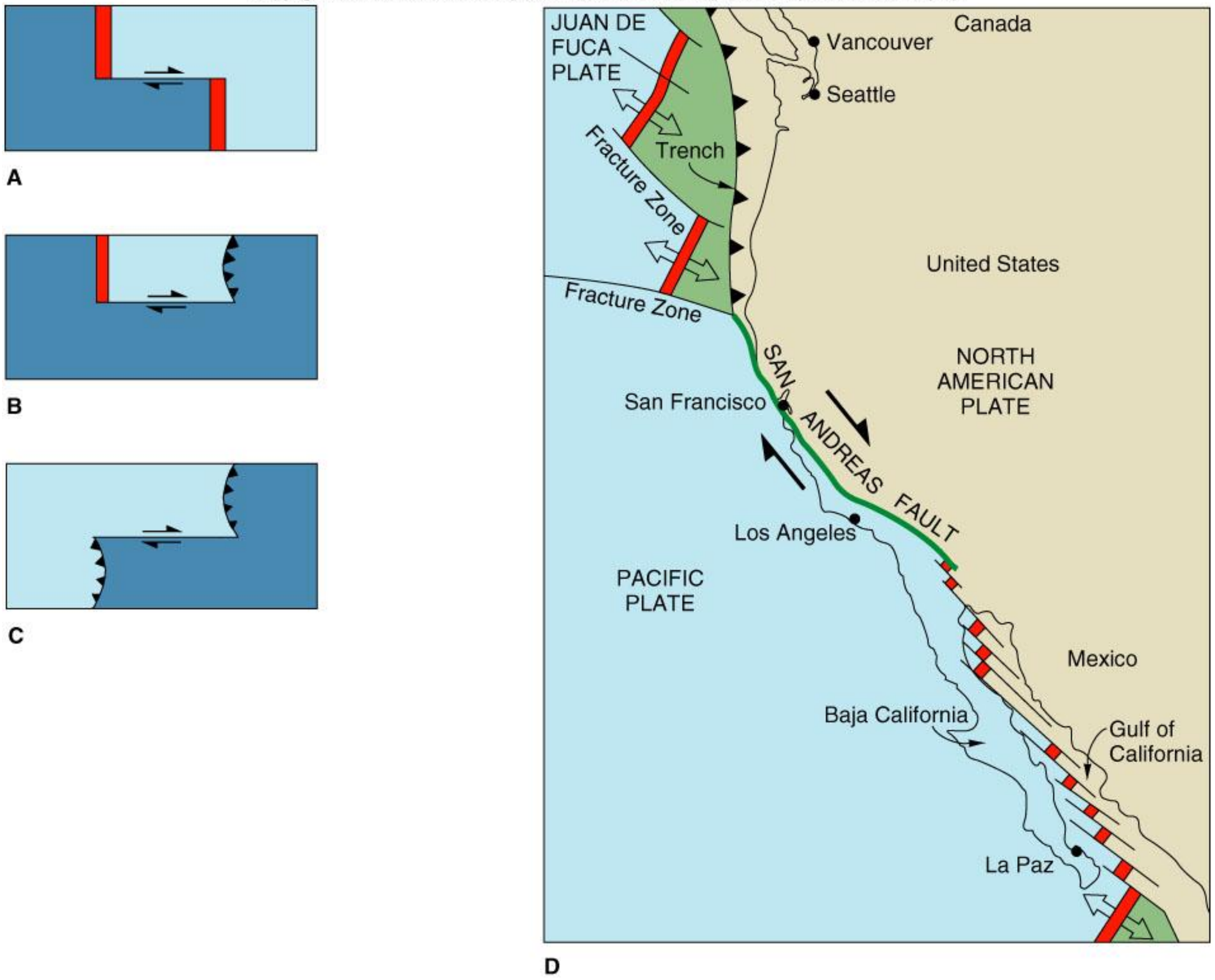
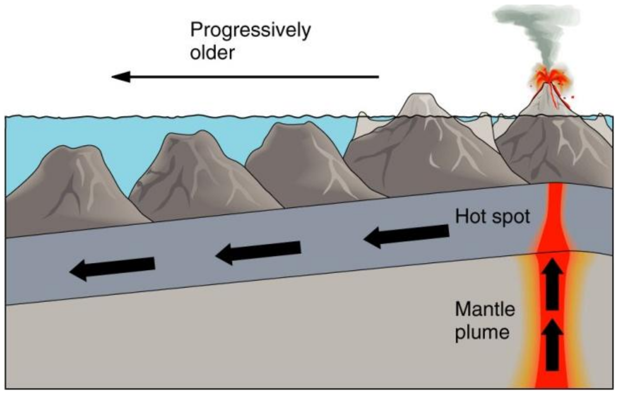
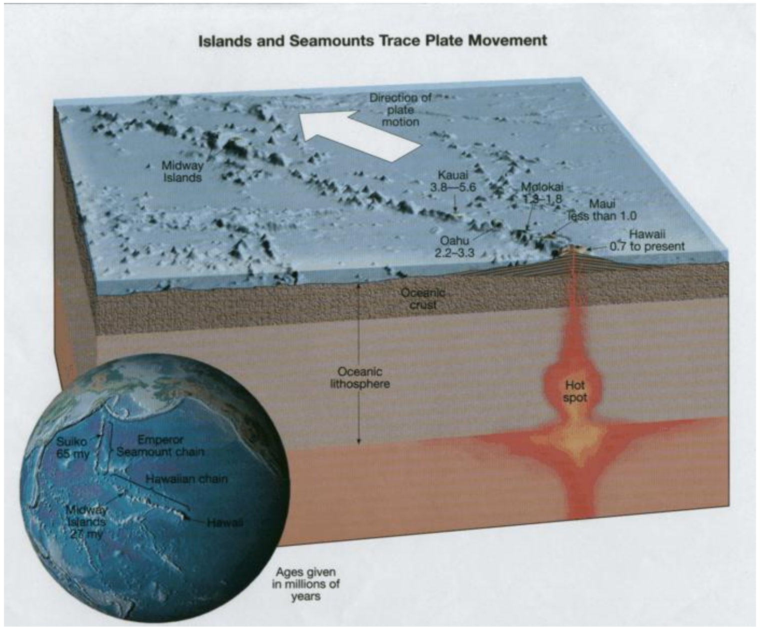


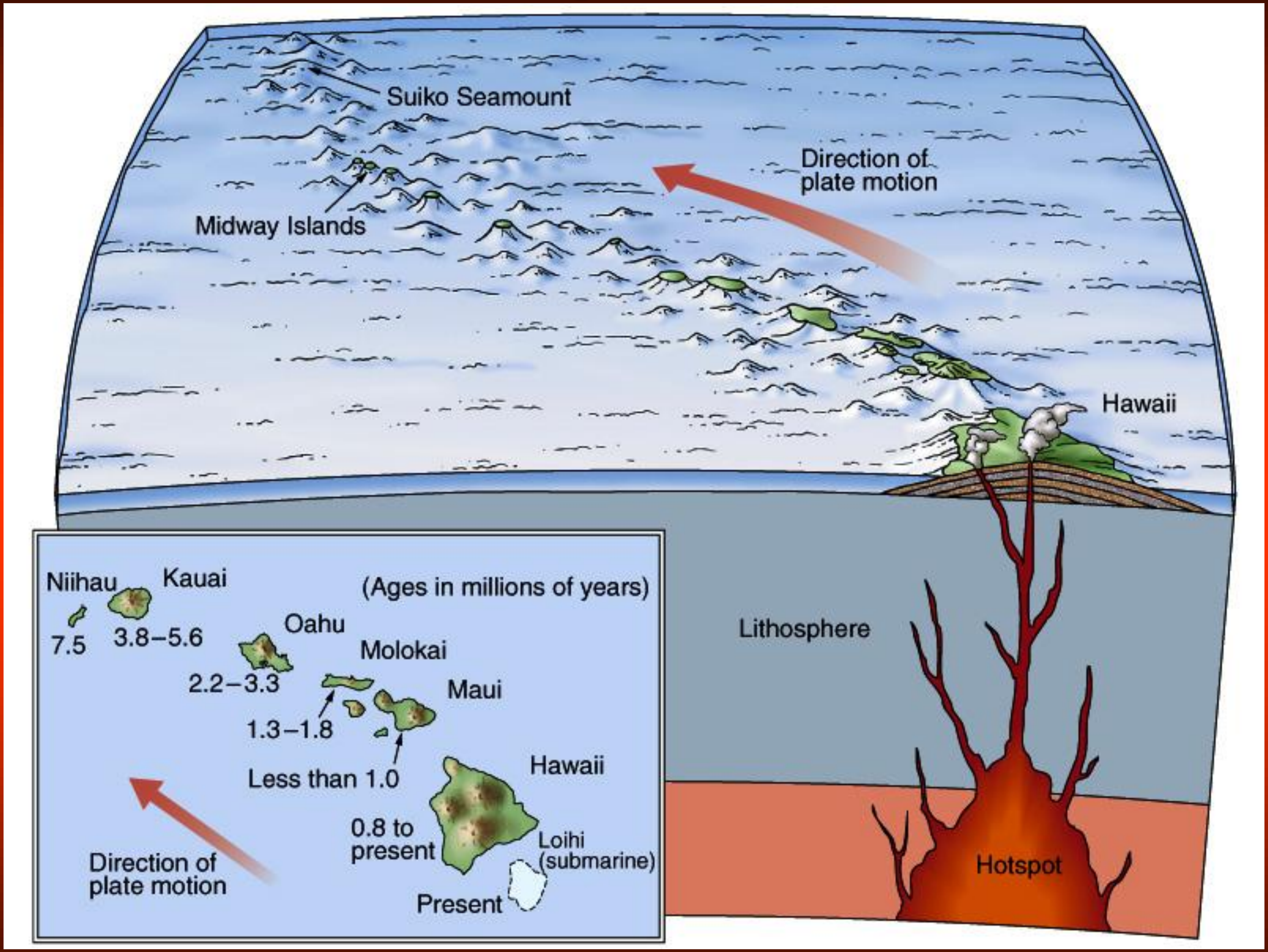
Plate interiors

- In plate tectonics theory, most deformation occurs at the boundaries. Plate interiors are more passive and only respond to loading and unloading, as thin, elastic plates (a civil engineering theory of how to handle sheets and the origin of the name **plate** tectonics)
- **Hot spots** are trails of volcanic activity that appear unrelated to plate boundaries, but do trace plate motion. These seem to be fixed with the mantle, and the tracks record plate motion. Typically, there is a chain of volcanic features of progressive age. The youngest feature marks the current position of the hotspot.





Hotspot


Suiko Seamount
Direction of plate motion
Midway Islands
Hawaii
Lithosphere
Hotspot
Niihau
Kauai
(Ages in millions of years)
7.5
3.8–5.6
Oahu
Molokai
2.2–3.3
Maui
1.3–1.8
Less than 1.0
Hawaii
0.8 to present
Loihi (submarine)
Present
Direction of plate motion

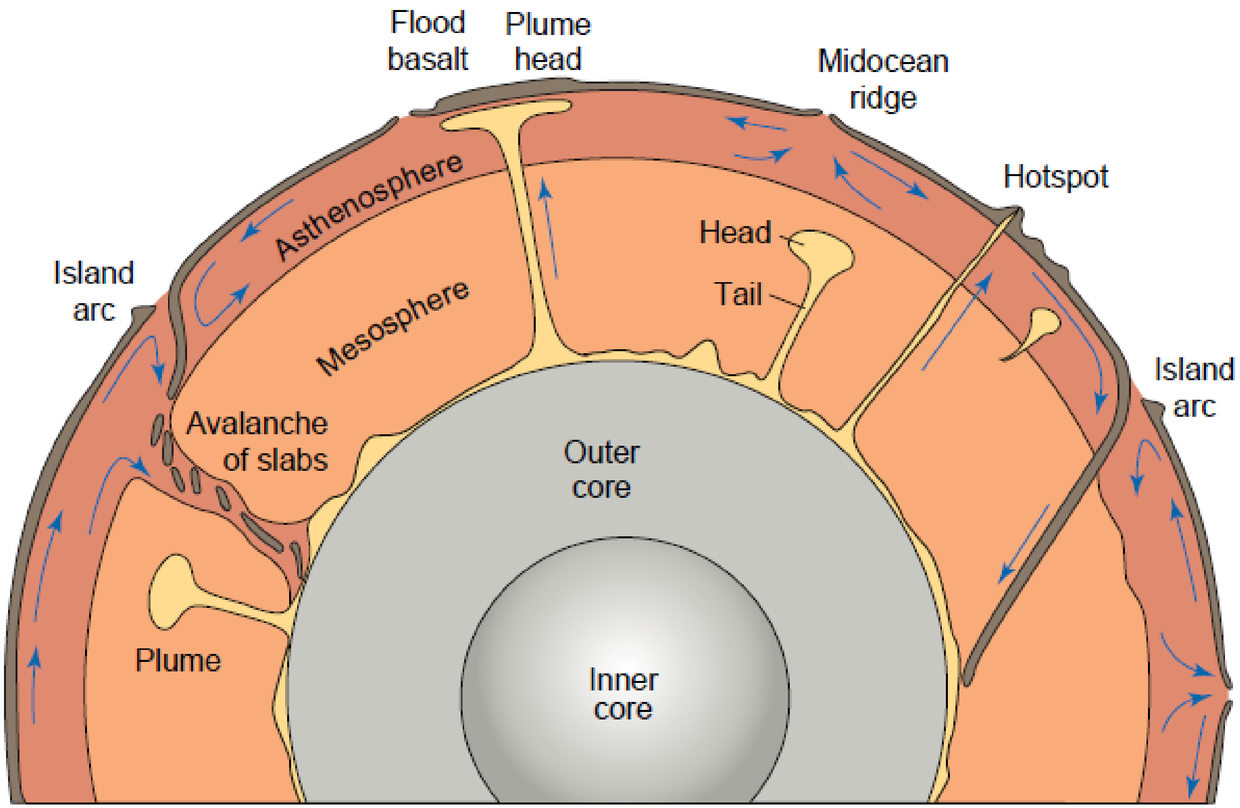


FIGURE 22.6 Plumes rise from the core-mantle boundary, according to current theory, and are an important type of mantle convection. Some mantle material in the hot boundary layer between the mantle and core becomes hot, and therefore more buoyant, and rises upward in a cylindrical plume. A new plume starts with a large head, behind which is a slender tail. When the plume reaches the cold, rigid lithosphere, it flattens and spreads outward. Flood basalts may erupt from the plume head. Hotspot islands may form from the narrower, long-lived tail. Oceanic crust subducted deep into the mantle at some ancient subduction zone (right) may be part of the source material of mantle plume.

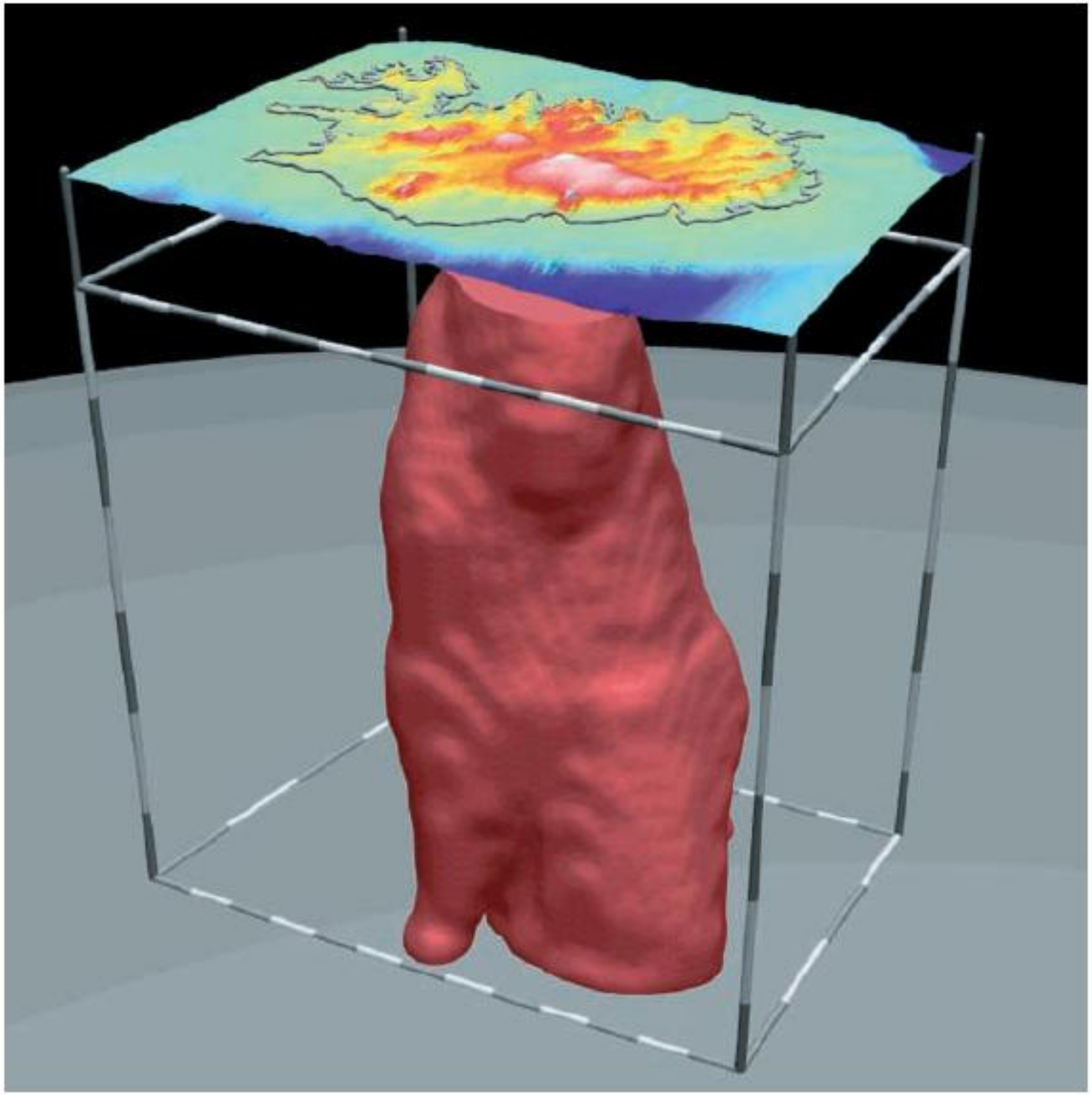
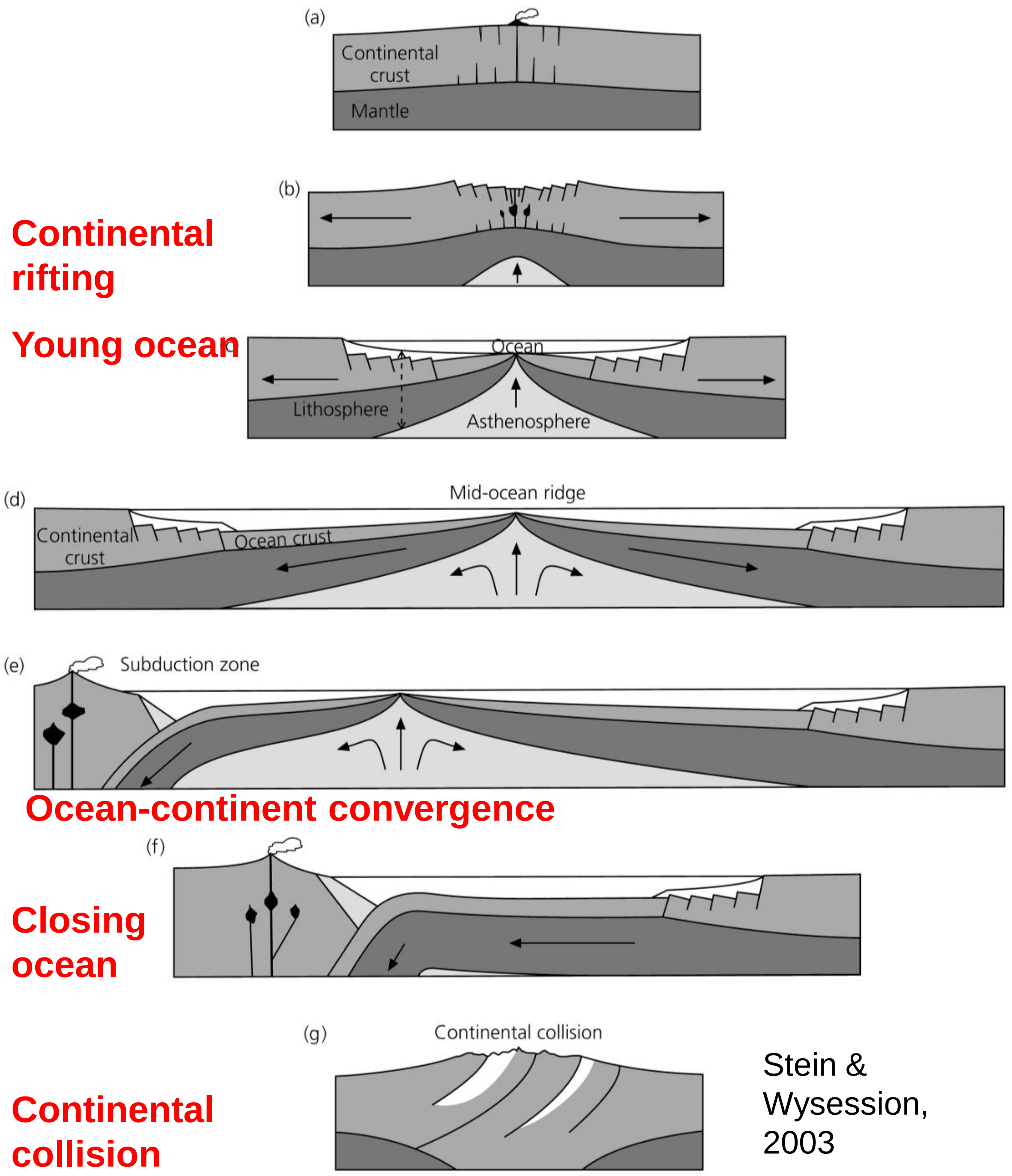


FIGURE 22.3 A mantle plume beneath Iceland is revealed by anomalously low seismic wave velocities in a cylindrical mass below the island. The low seismic wave velocities show that the plume has a higher temperature than the surrounding mantle. The plume extends to at least 400 km depth and has a diameter of about 300 km. *(Courtesy of C. Wolfe and S. Solomon)*

WILSON CYCLE

Oceanic lithosphere is formed at midocean ridges & destroyed at subduction zones

Continental plates are rifted apart and then collide, but survive



Continental rifting — East African Rift

Young ocean — Gulf of Aden, Gulf of California

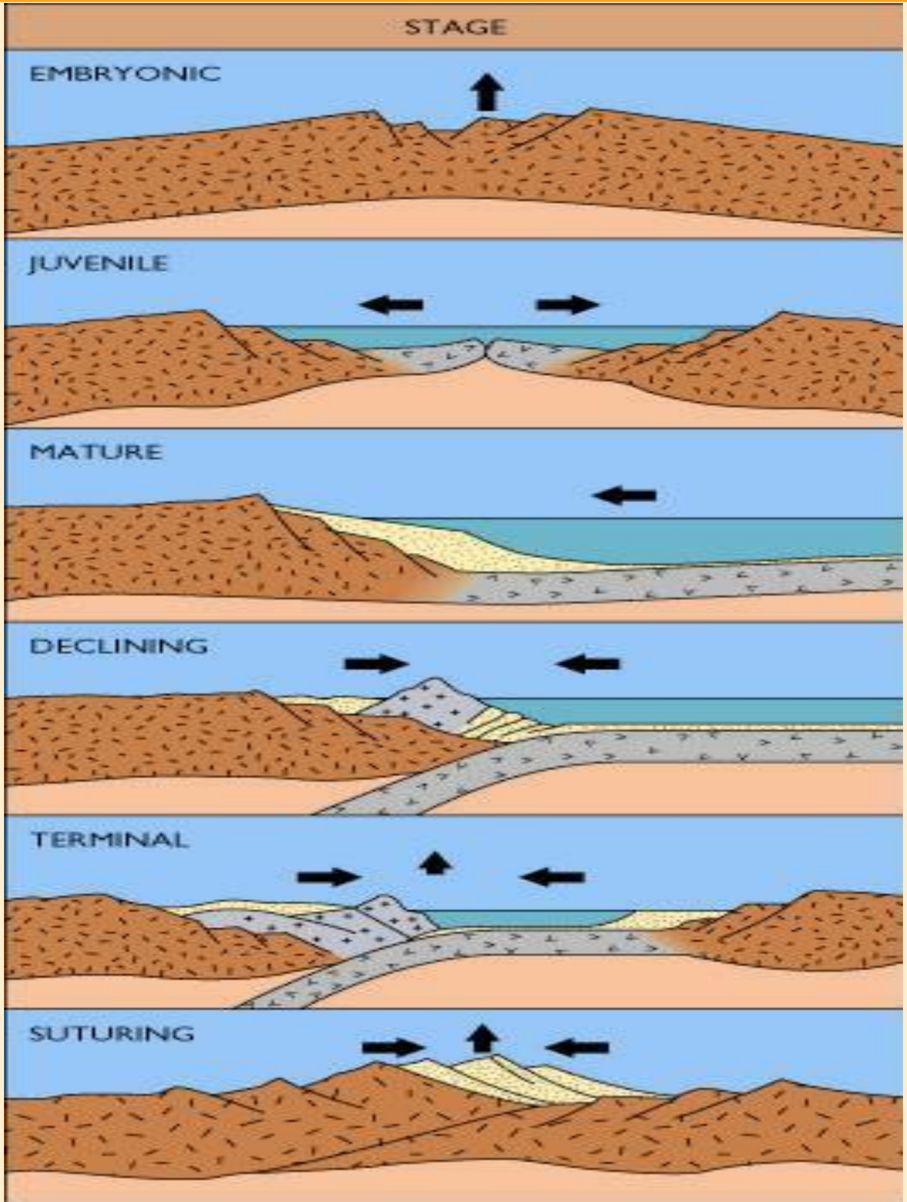
Ocean-continent convergence — Andes

Closing ocean — Southern Europe

Continental collision — Himalaya, Zagros

Stein & Wysession, 2003

The Wilson Cycle



Evidence in favor of plate tectonics

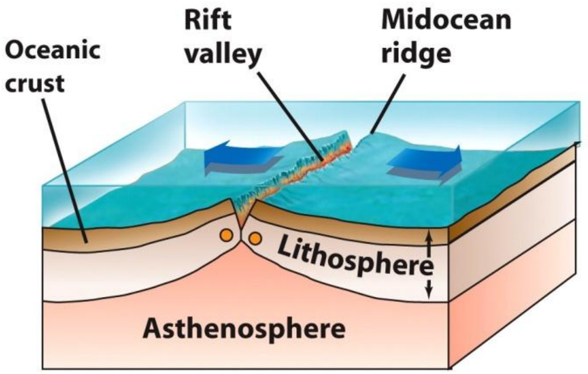
1. Distribution of earthquakes and volcanoes
2. Fit of continents, geologic features (including ice ages) across ocean basins
3. Distribution of organisms and fossils.
4. Age distribution of sea floor
5. Magnetic stripes on ocean floor
6. Polar wandering from sediments
7. Odd lack of old sediments in the oceans
8. Over-abundance of basalts at sea and granites on land.
9. Velocity distribution of crustal material

- ****Surveying****

- Why was it rejected initially? (Mainly lack of believable driving mechanism, and the claim that continents moved over or through oceanic crust, which they clearly don't) Was widely accepted in Gondwanaland.
- We still don't have a good driving mechanism.

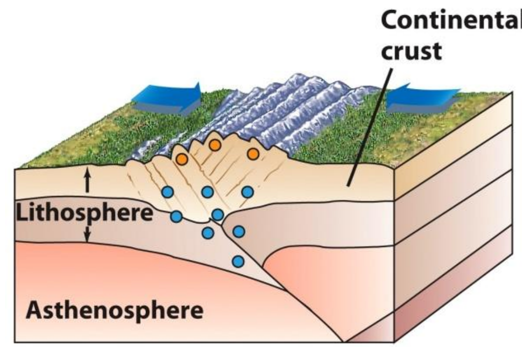
Earthquake and plate margins

- Earthquake
  - Tectonic movement produce pressure and friction.
  - Friction is overcome, the block slips and pent up energy releases with a huge “snap”
  - Focus
    - Where earthquake begins
  - Epicenter
    - Point on earth’s center directly over the focus



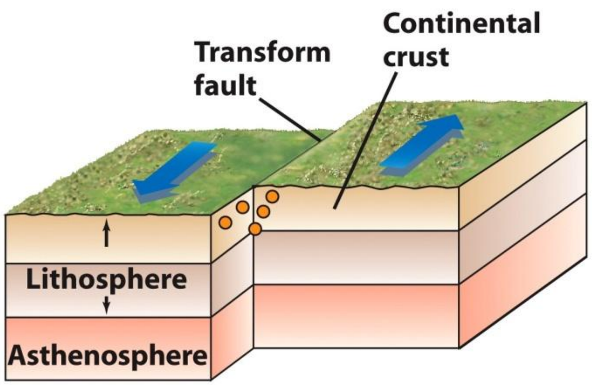
DIVERGENT BOUNDARY

At divergent margins, earthquakes tend to be fairly weak and shallow. Earthquakes can only occur in rock that is cold and brittle enough to break; at a midocean ridge, this means they cannot be very deep.



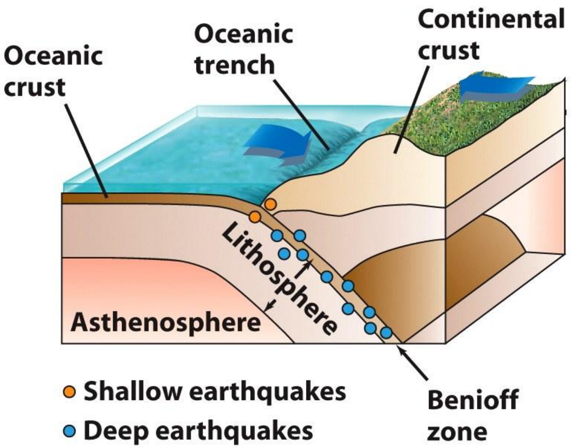
CONTINENTAL COLLISION BOUNDARY

In collision zones the earthquakes can be deep and also very powerful.



TRANSFORM FAULT BOUNDARY

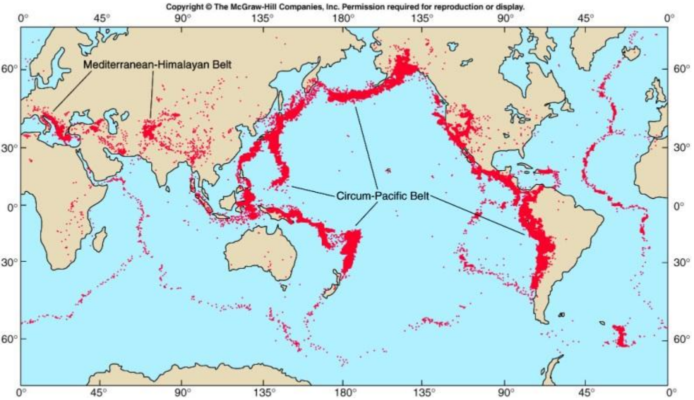
Transform fault margins have shallow earthquakes, but they can be very powerful.

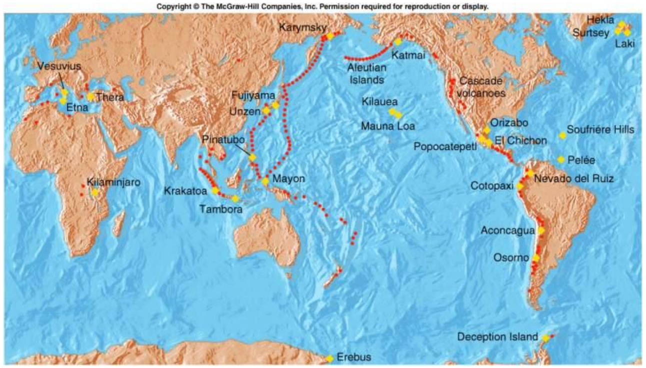


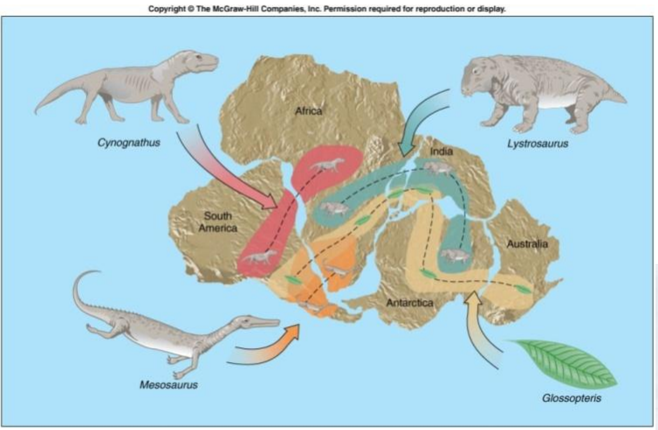
SUBDUCTION ZONE BOUNDARY

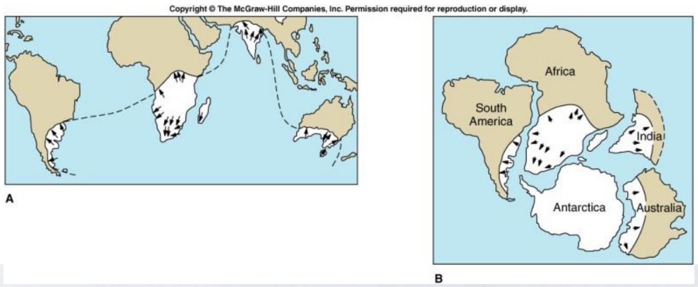
The deepest and most powerful quakes occur in subduction zones. Here, an oceanic plate moves downward relative to a continental plate. The earthquake foci are shallow near the oceanic trench, but become deeper along the descending edge of the subducting plate. These zones of shallow- and deep-focus earthquakes, called *Benioff zones*, first alerted scientists to the phenomenon of *subduction*.

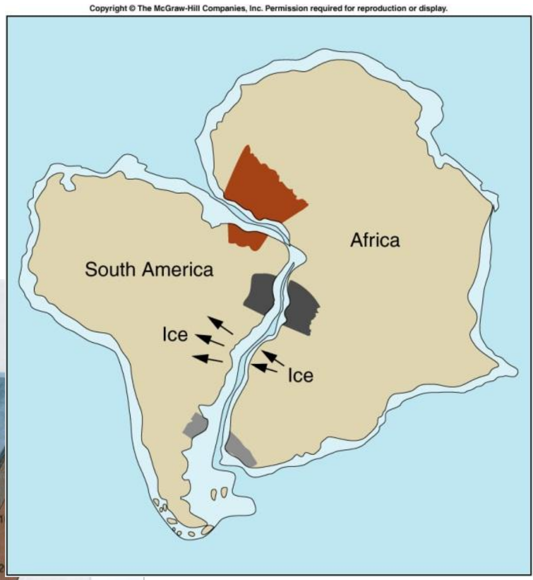
Evidence>Earthquakes, Volcanoes, and Geologic Features

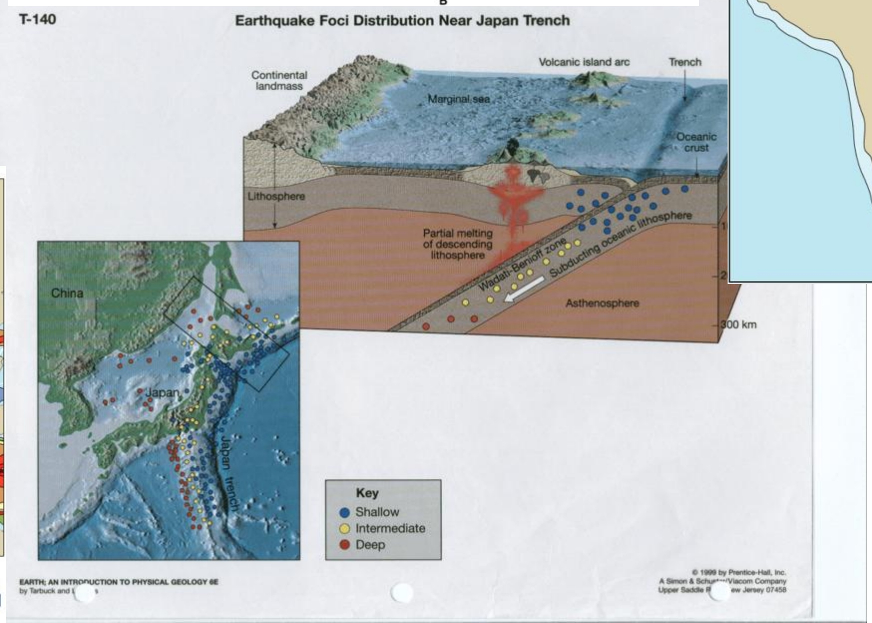












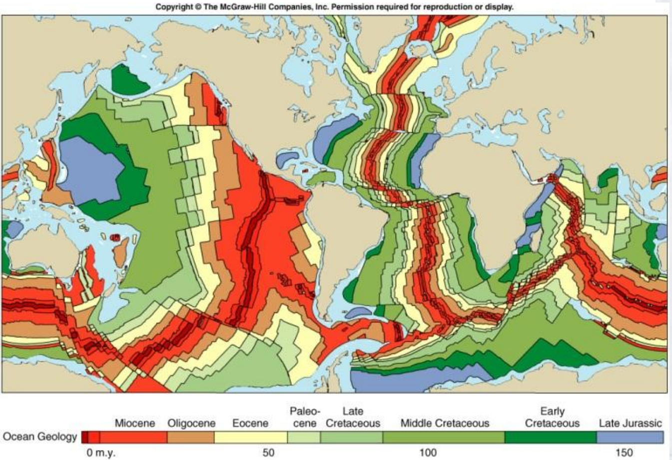


Plate Tectonic - Igneous Genesis

1. Mid-ocean Ridges
2. Intracontinental Rifts
3. Island Arcs
4. Active Continental Margins
5. Back-arc Basins
6. Ocean Island Basalts
7. Miscellaneous Intra-Continental Activity
   - kimberlites, carbonatites, anorthosites...

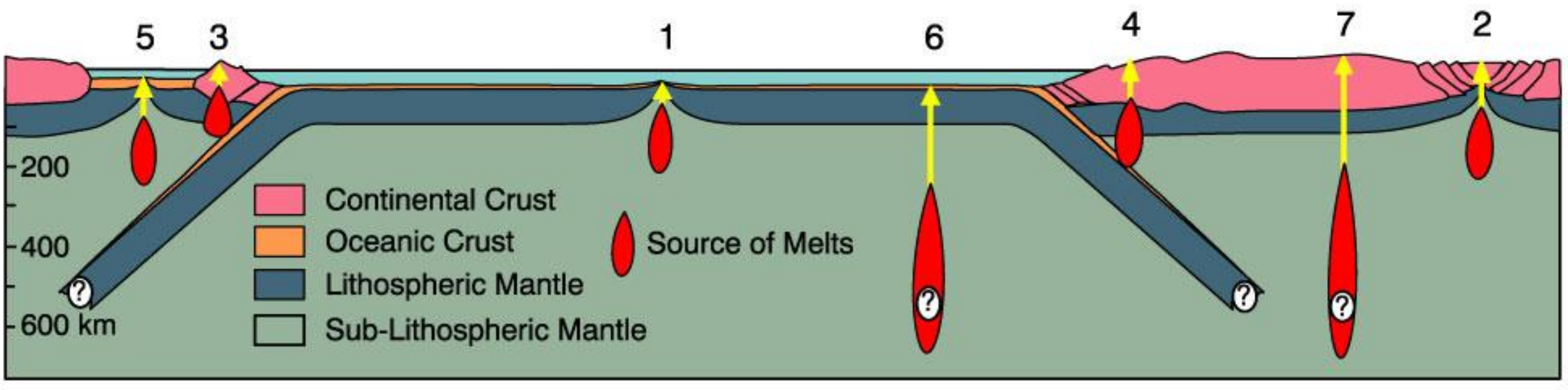
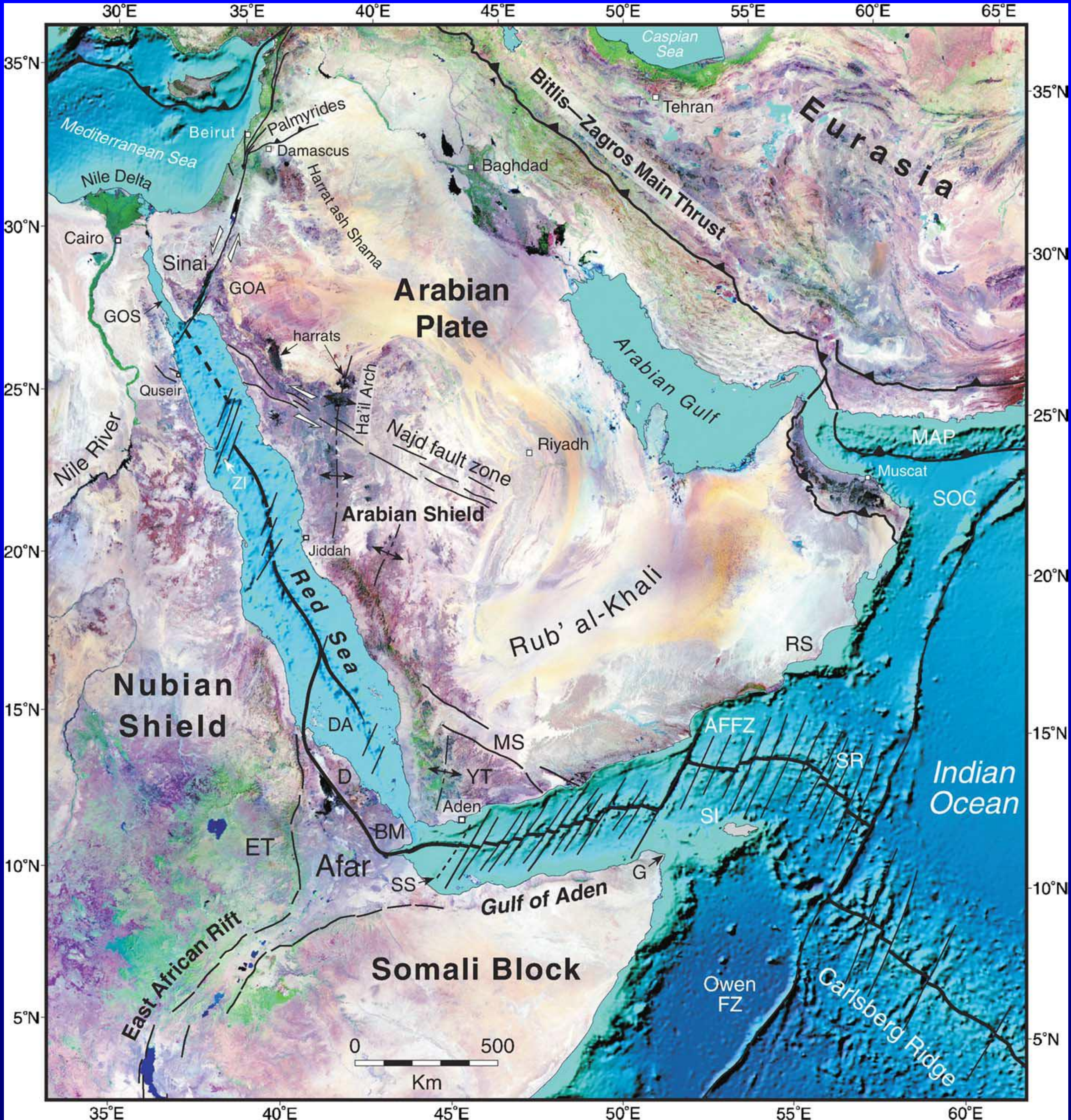


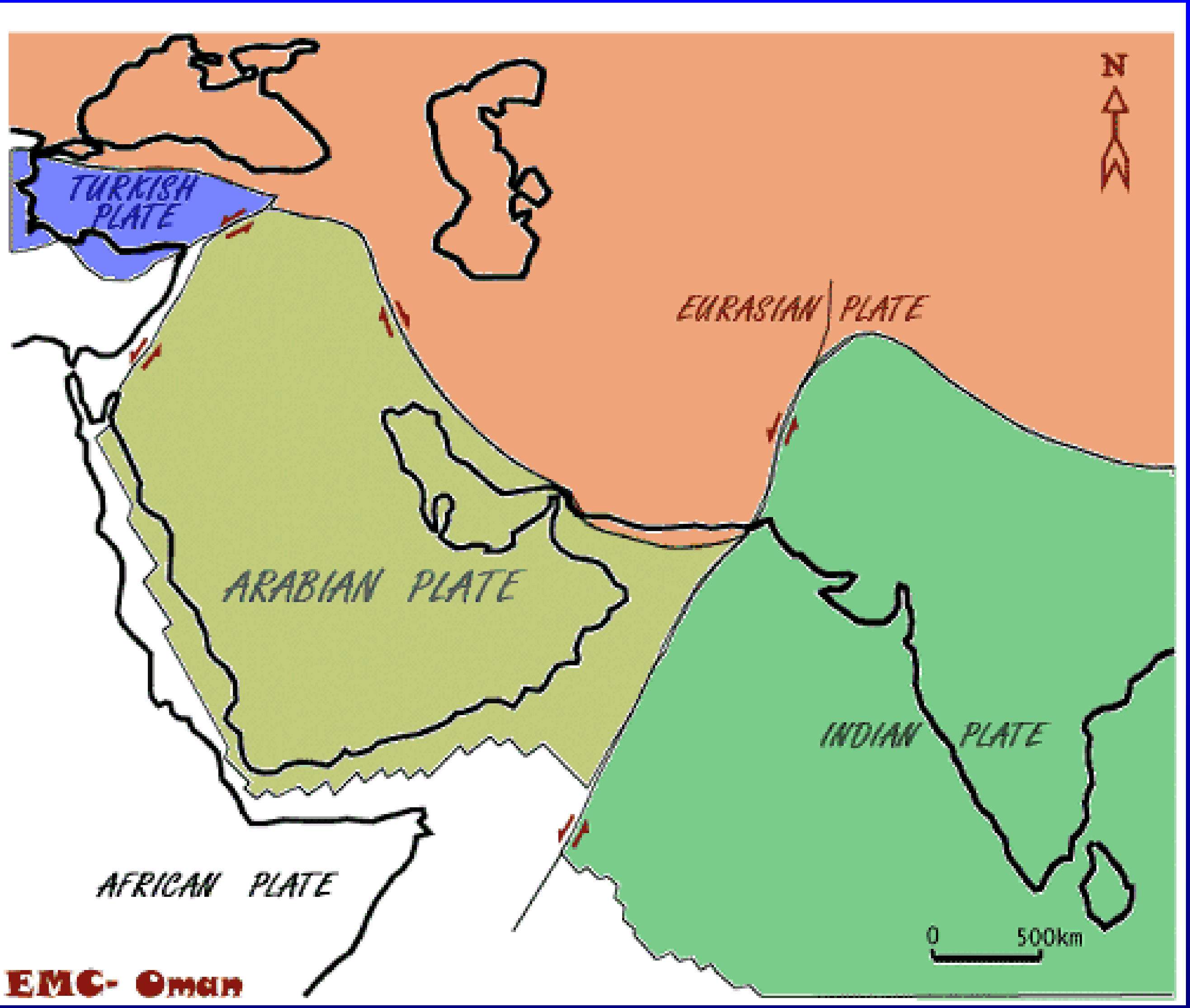
Plate Tectonics Explains It All

- We now understand mountains, volcanoes, and big earthquakes associated with, for example, the San Andres fault.
- We understand rift valleys and how oceans form, deep ocean trenches, mid ocean ridges, why fossils and mountain ranges look alike across vast oceans.

Plate Tectonics Summary

- The Earth is made up of 3 main layers (core, mantle, crust)
- On the surface of the Earth are tectonic plates that slowly move around the globe
- Plates are made of crust and upper mantle (lithosphere)
- There are 2 types of plate
- There are 3 types of plate boundaries
- Volcanoes and Earthquakes are closely linked to the margins of the tectonic plates


30°E
35°E
40°E
45°E
50°E
55°E
60°E
65°E
35°N
30°N
25°N
20°N
15°N
10°N
5°N
Caspian Sea
Tehran
Bitlis—Zagros Main Thrust
Eurasia
Beirut
Palmyrides
Damascus
Mediterranean Sea
Baghdad
Nile Delta
Harrat ash Shama
Cairo
Sinai
GOA
Arabian Plate
GOS
harrats
Arabian Gulf
Quseir
Ha'il Arch
Najd fault zone
Riyadh
MAP
Nile River
ZI
Muscat
SOC
Arabian Shield
Jiddah
Red Sea
Rub' al-Khali
RS
Nubian Shield
DA
MS
AFFZ
SR
D
YT
Indian Ocean
Aden
SI
BM
ET
Afar
SS
G
Gulf of Aden
East African Rift
Somali Block
Owen FZ
Carlsberg Ridge
0
500
Km


N
TURKISH PLATE
EURASIAN PLATE
ARABIAN PLATE
INDIAN PLATE
AFRICAN PLATE
0
500km
EMC- Oman

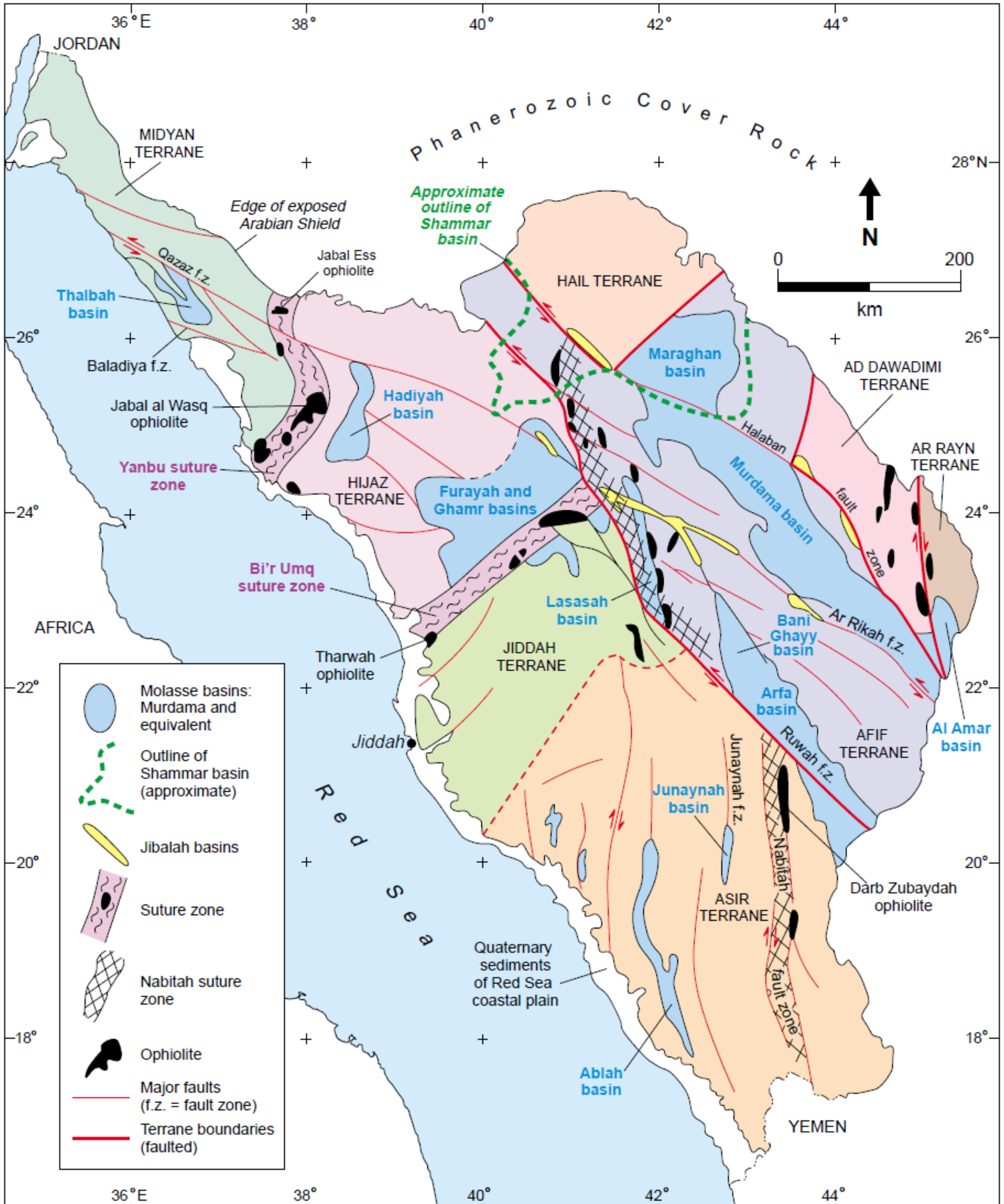
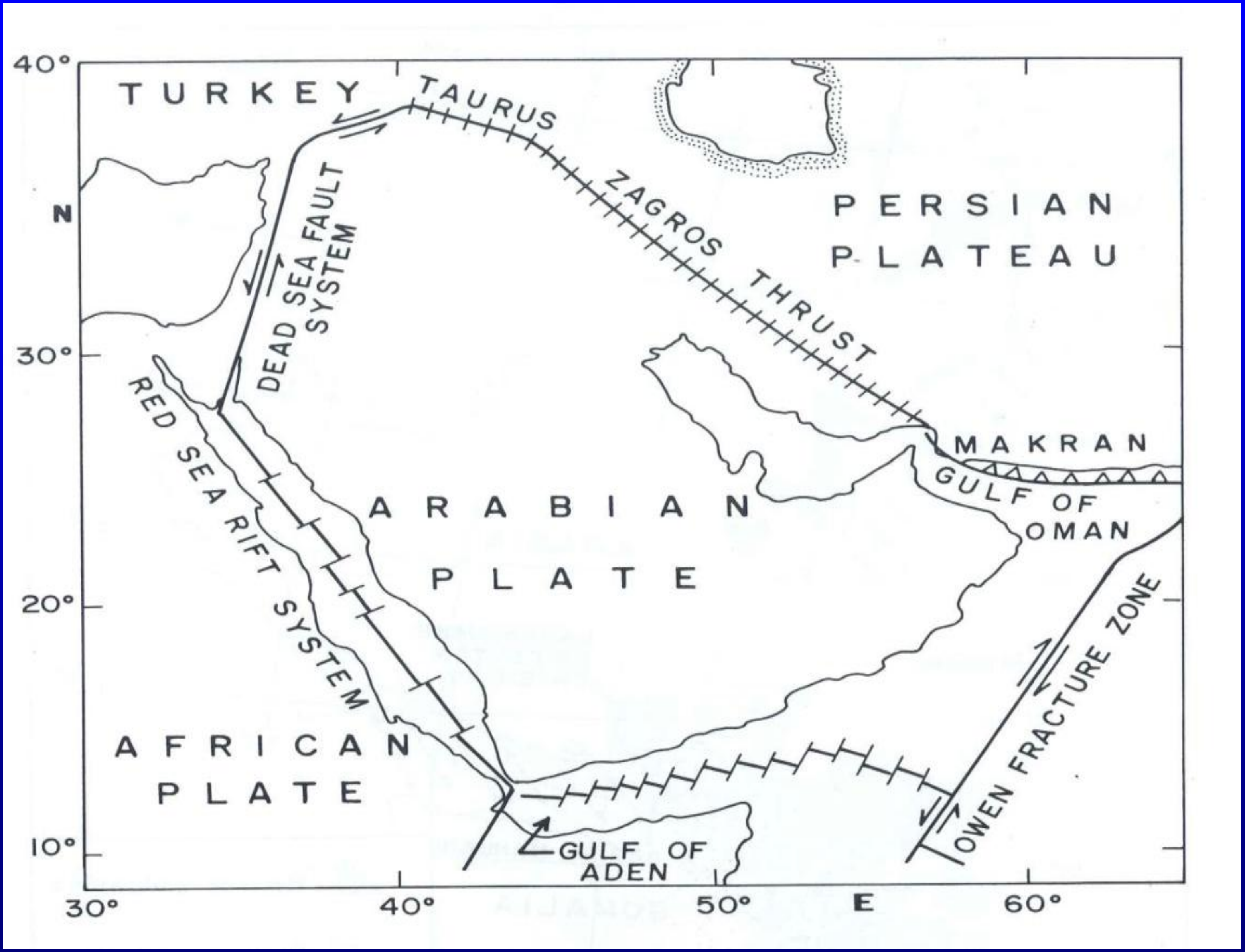
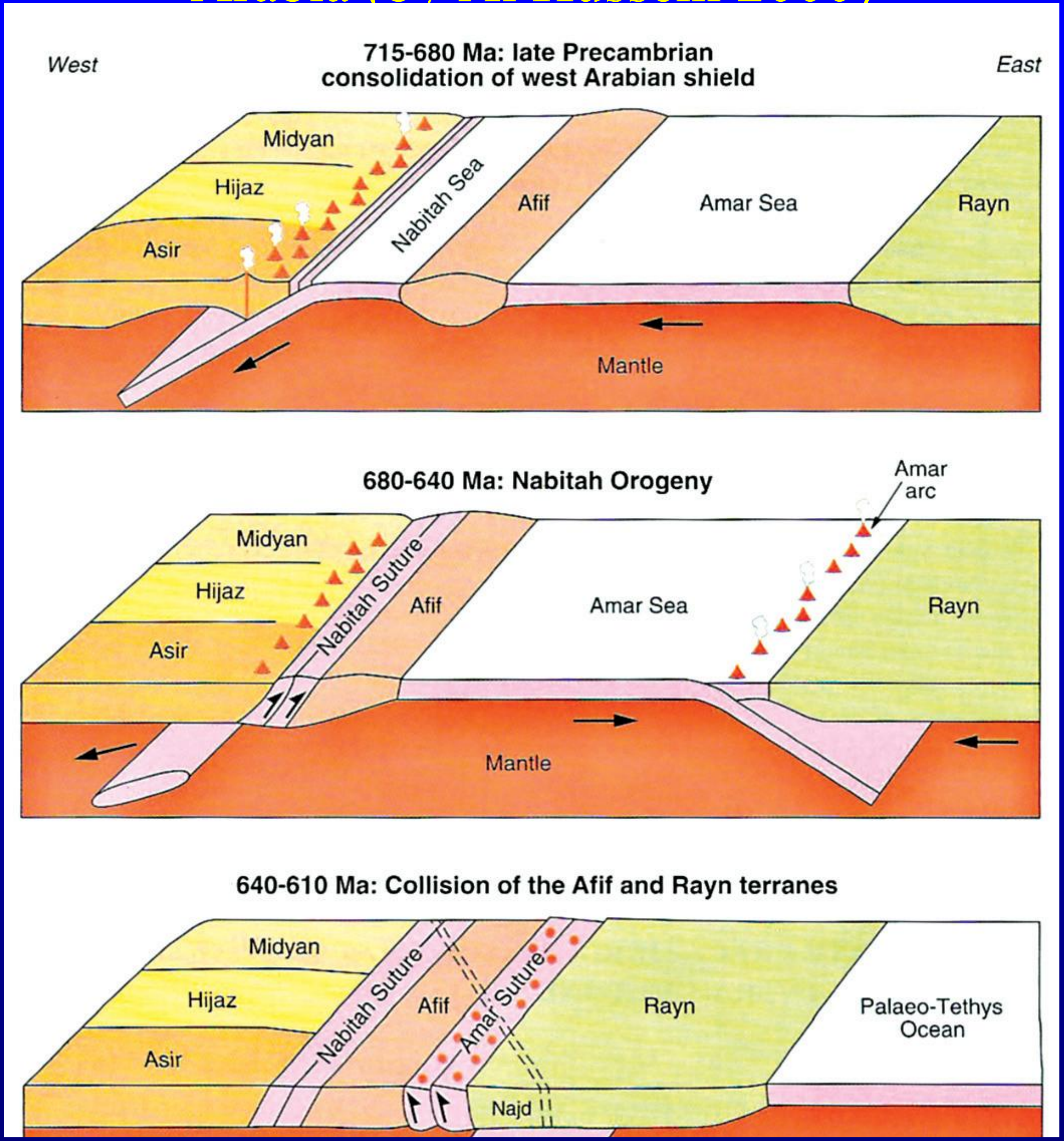


Figure 3: Simplified geologic sketch map of the Arabian Shield showing the terranes and their boundaries, and the main Pan-African structural features and sedimentary basins. Major fault zones, such as Ruwah, Ar Rikah, Halaban, and Qazaz, belong to the Najd fault system.

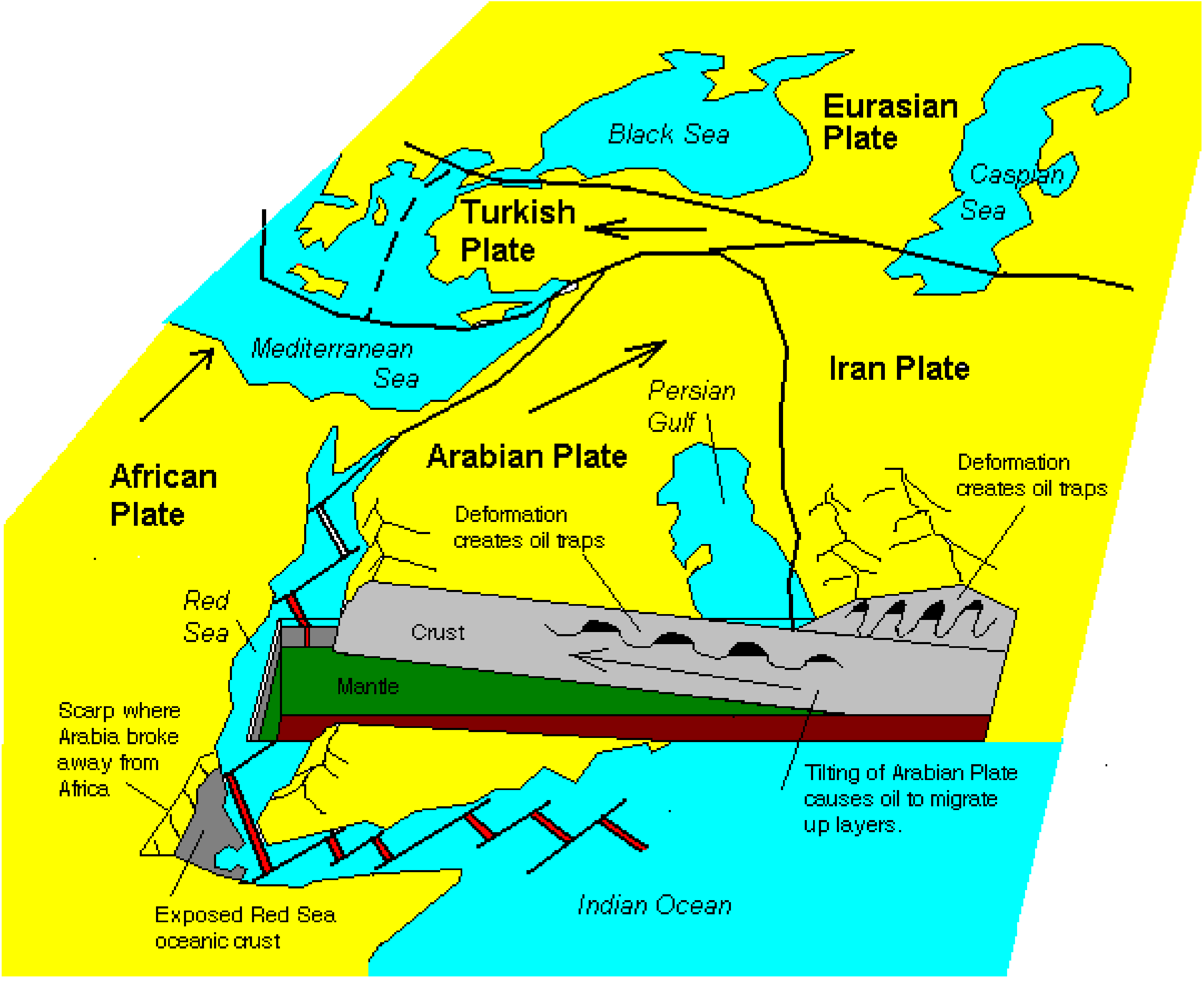
Boundaries of Arabian Plate

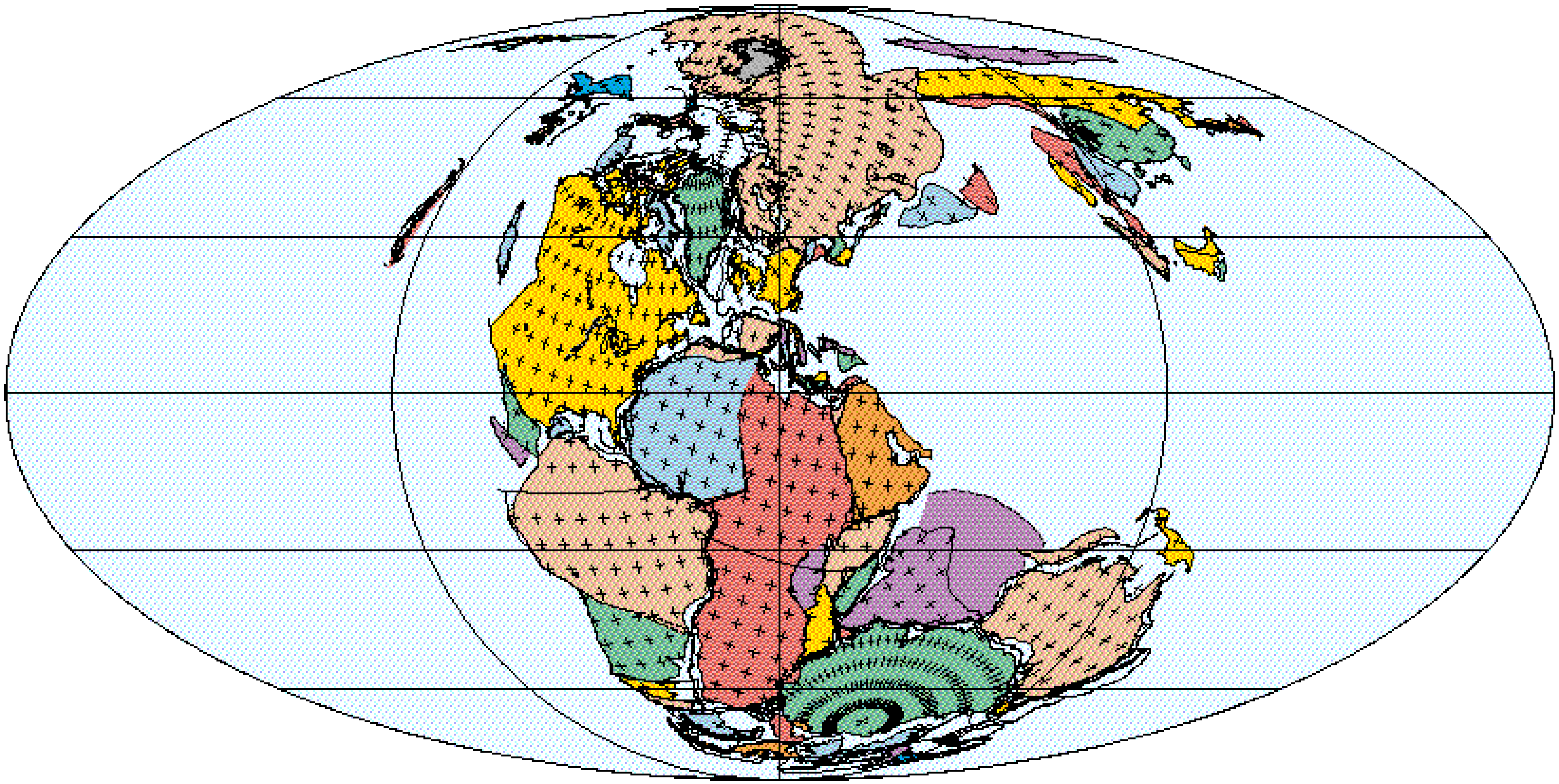


Complex terrane fabric of the Arabian shield and Eastern Arabia (by Al Husseni 2000)



Why Does the Middle East Have so Much Oil?



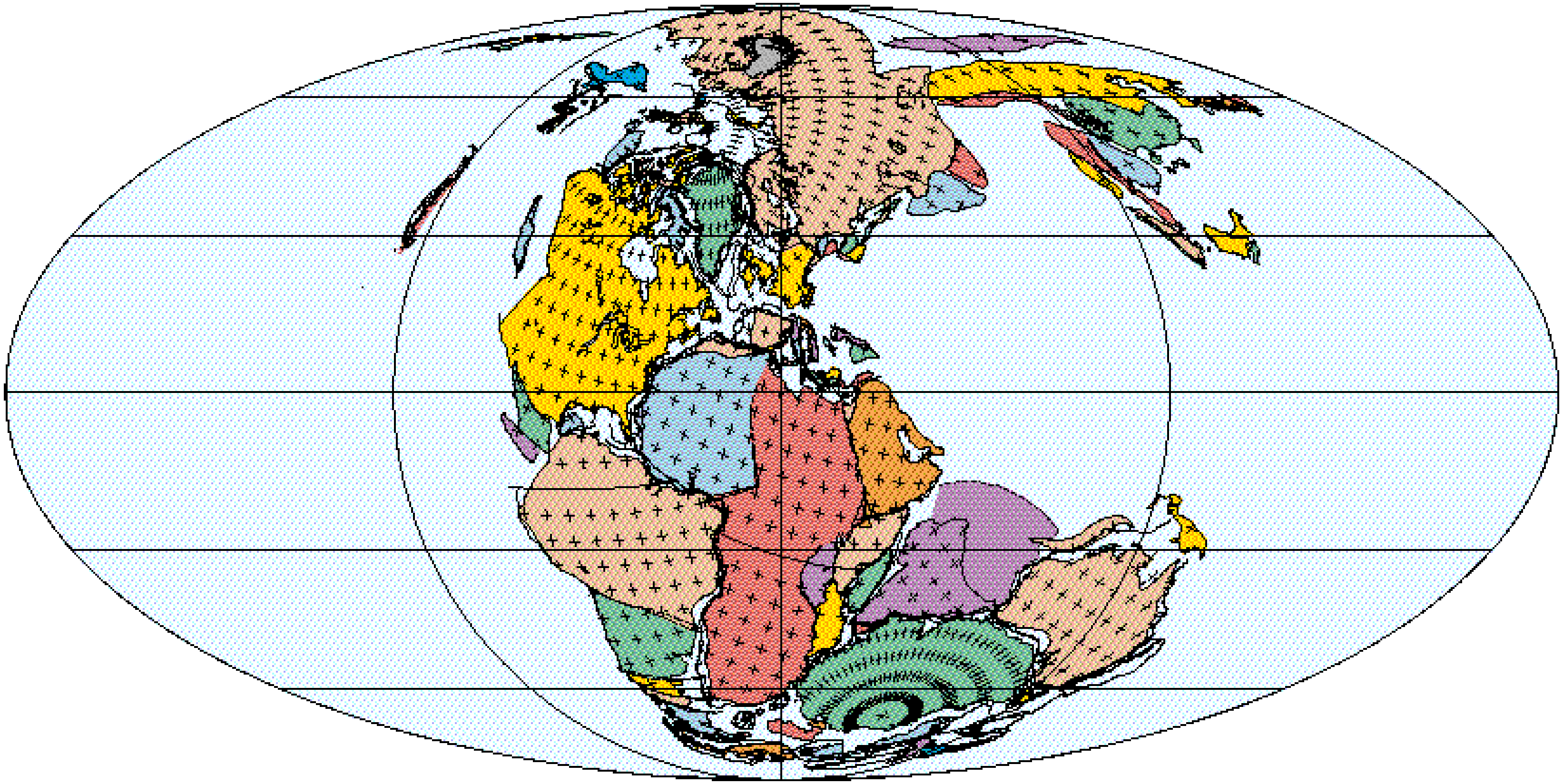


200 Ma

Sinemurian (Early Jurassic)

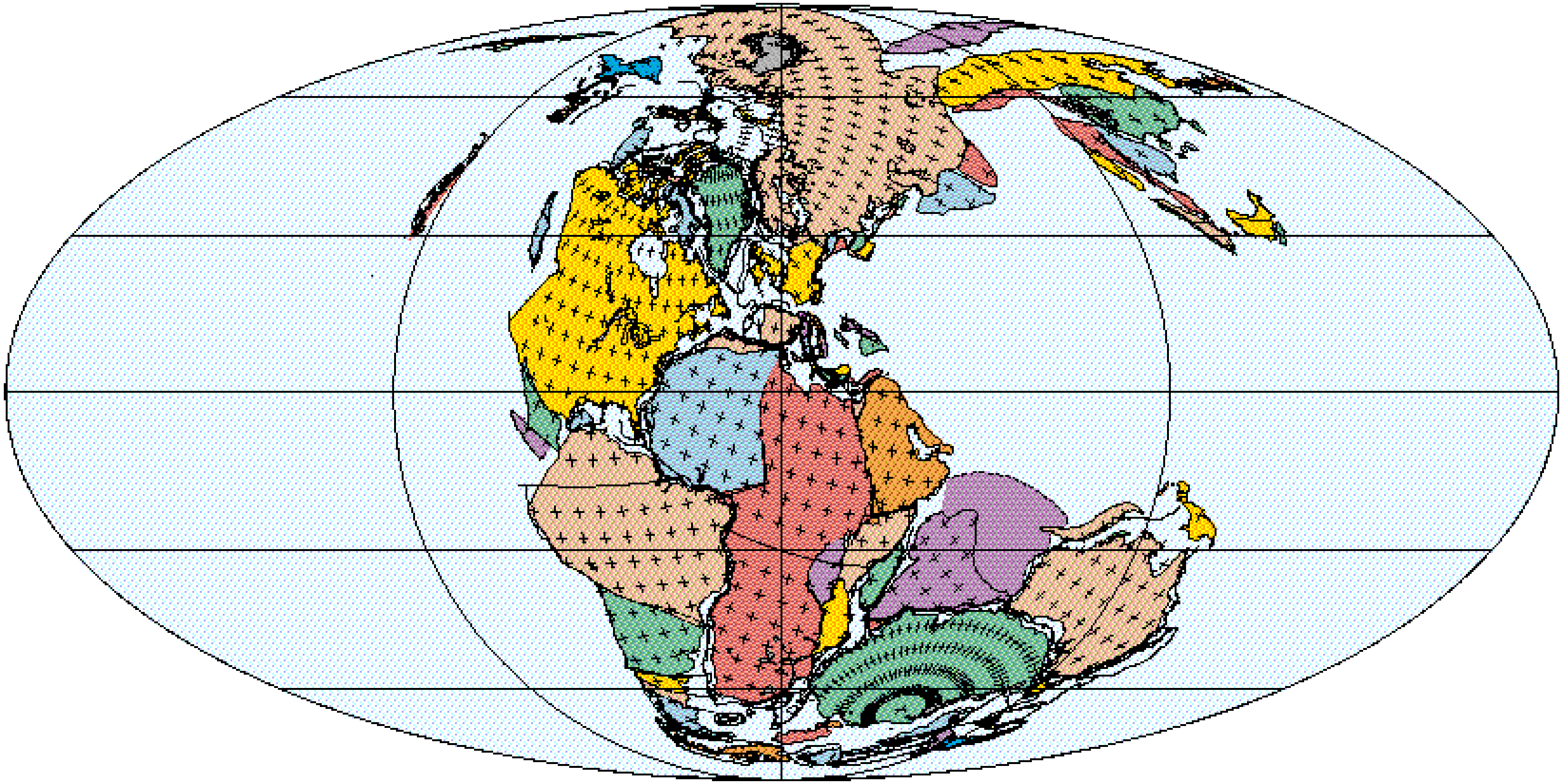
PLATES/UTIG

July 1999



190 Ma
Pliensbachian (Early Jurassic)

PLATES/UTIG
July 1999

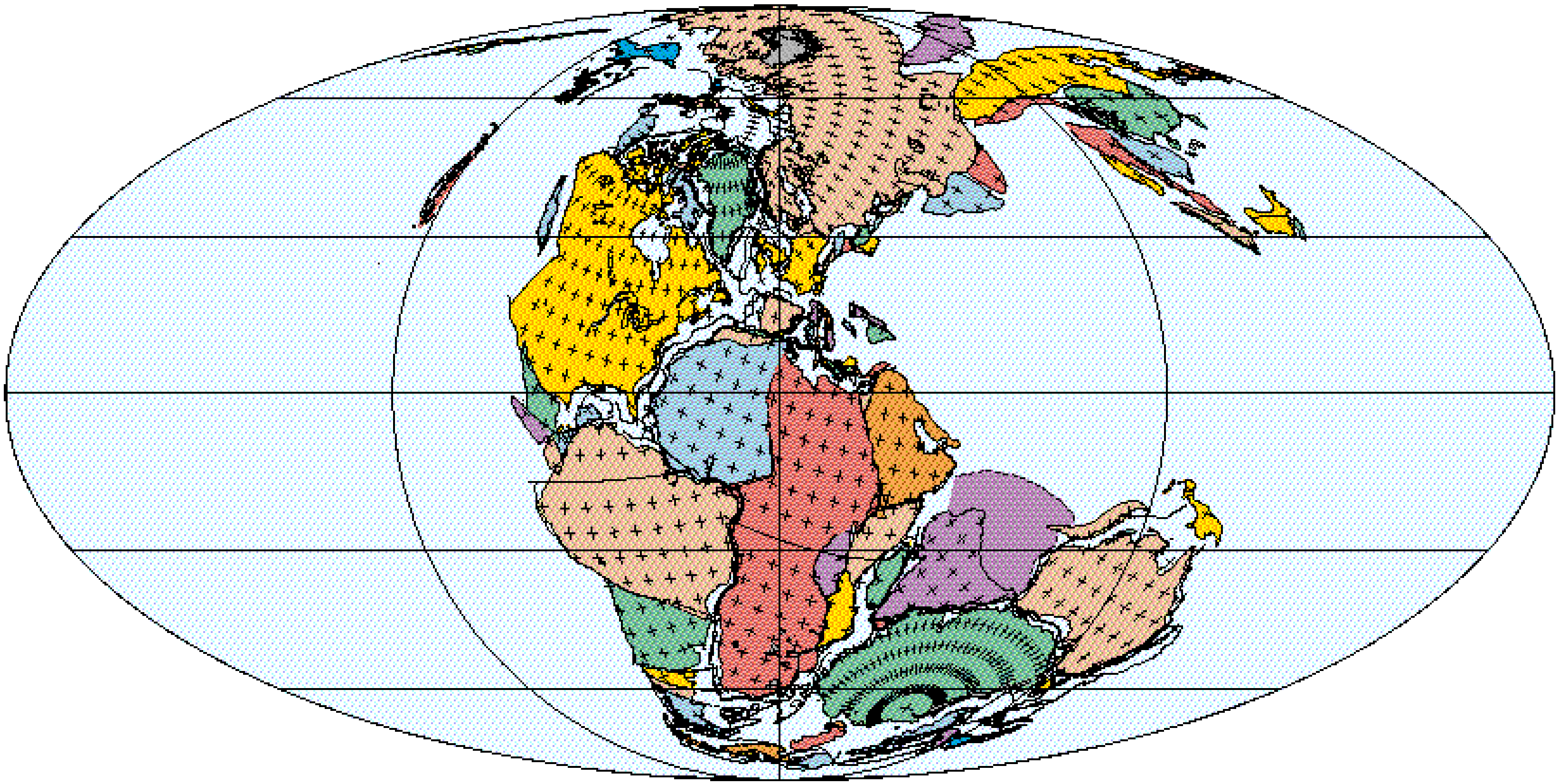


180 Ma

Aalenian (Middle Jurassic)

PLATES/UTIG

July 1999

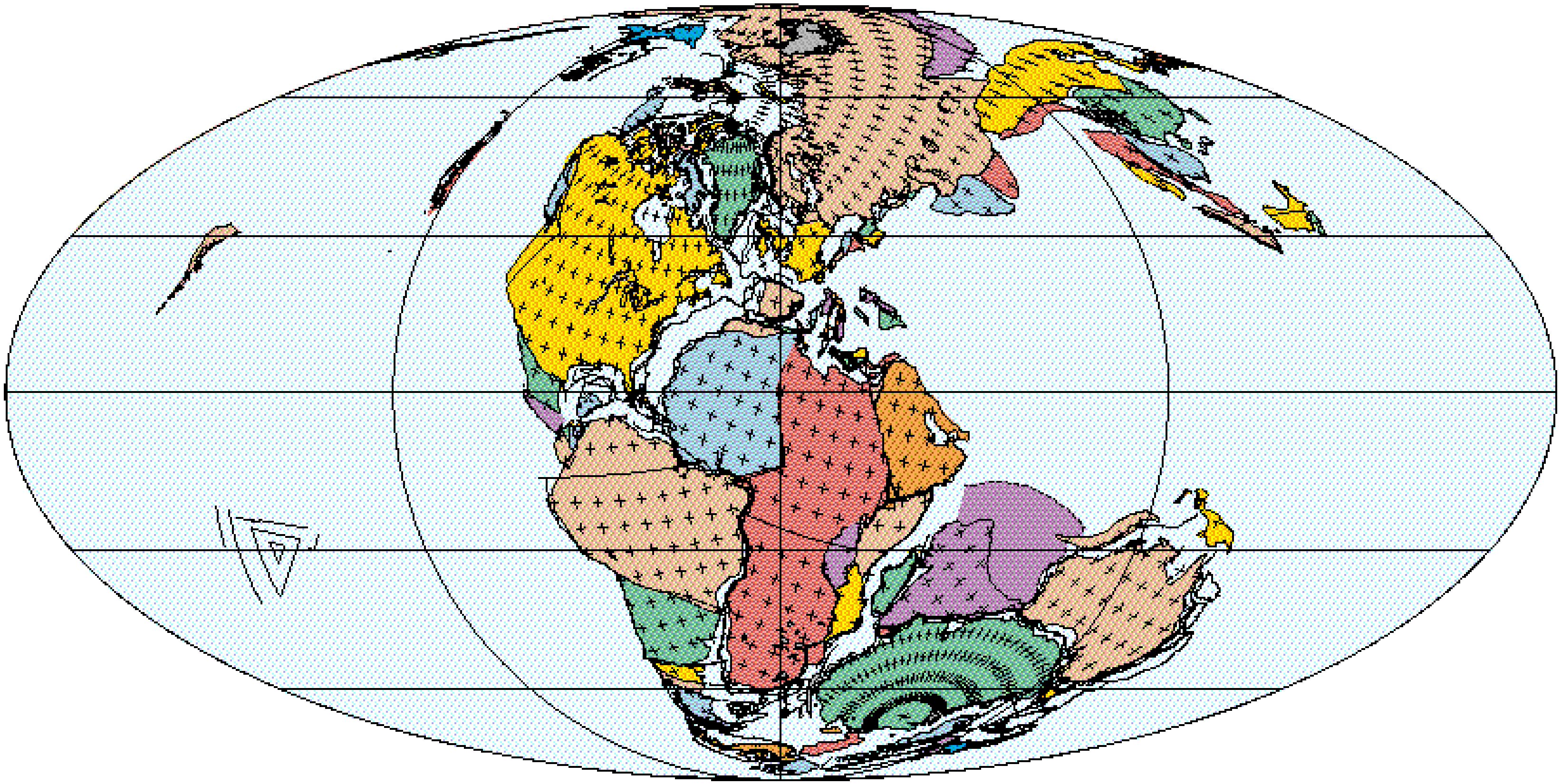


170 Ma

Bajocian (Middle Jurassic)

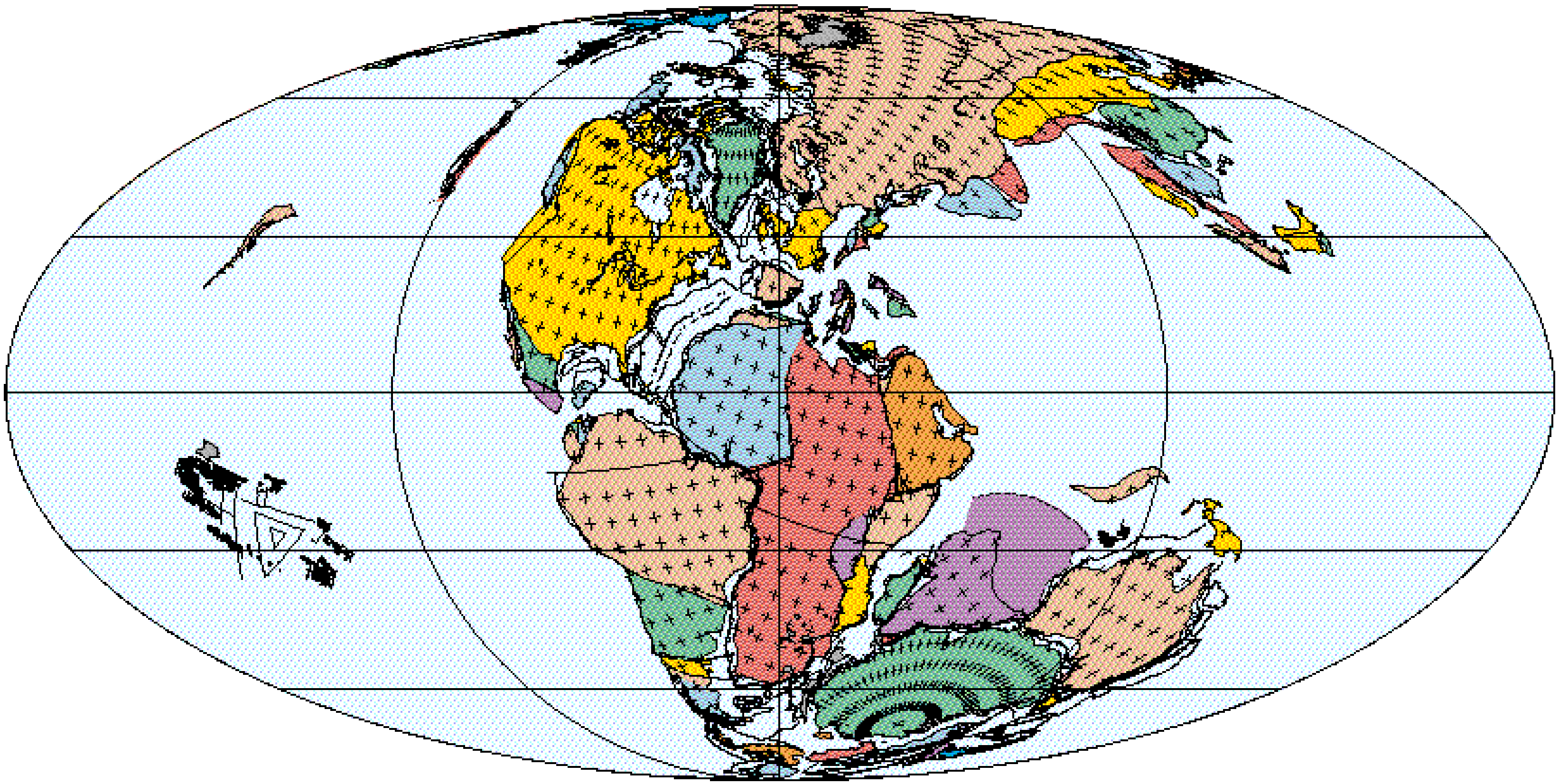
PLATES/UTIG

July 1999



160 Ma
Callovian (Middle Jurassic)

PLATES/UTIG
July 1999

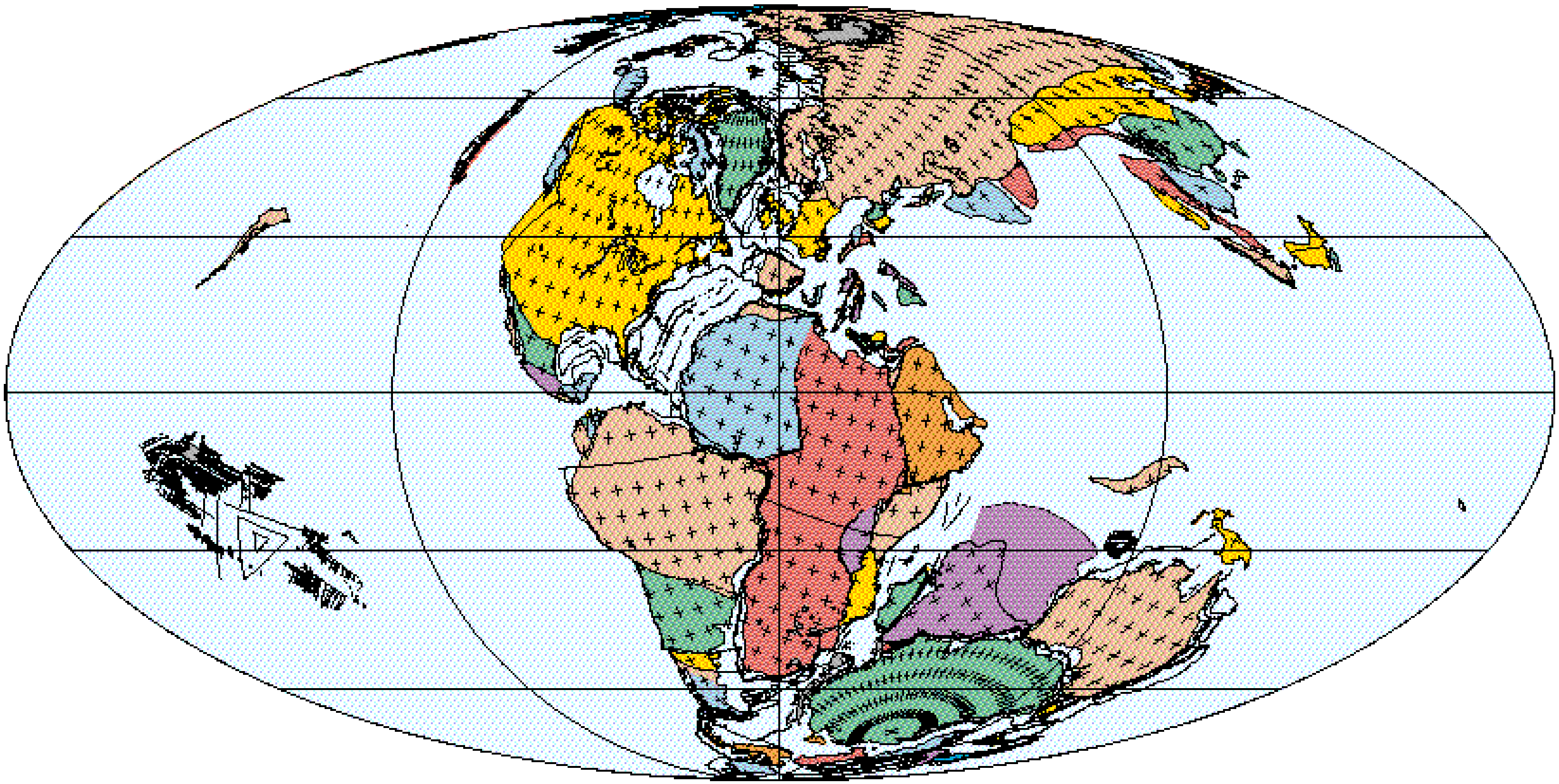


150 Ma

Volgian (Late Jurassic)

PLATES/UTIG

July 1999

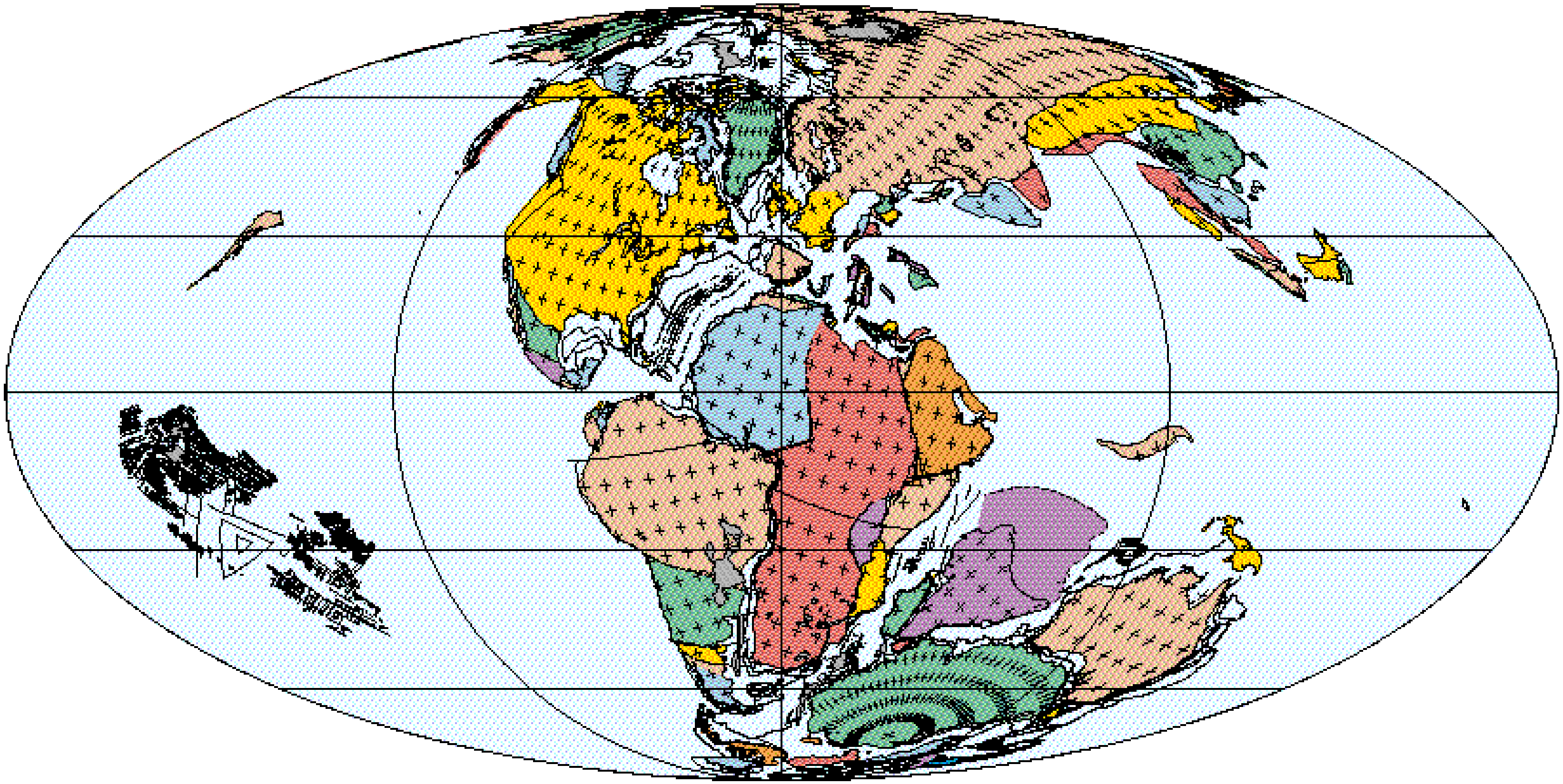


140 Ma

Ryazanian (Early Cretaceous)

PLATES/UTIG

July 1999

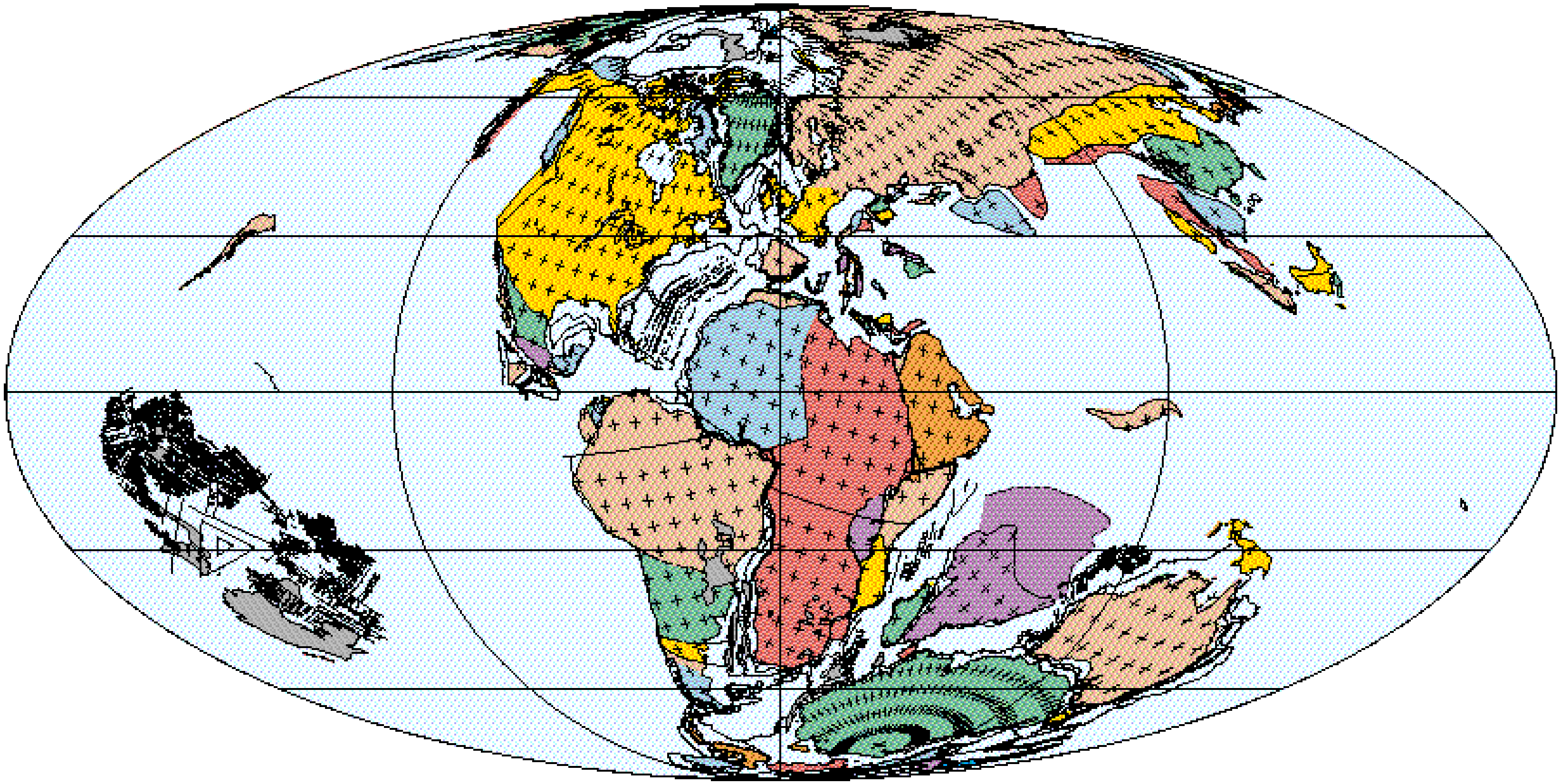


130 Ma

Hauterivian (Early Cretaceous)

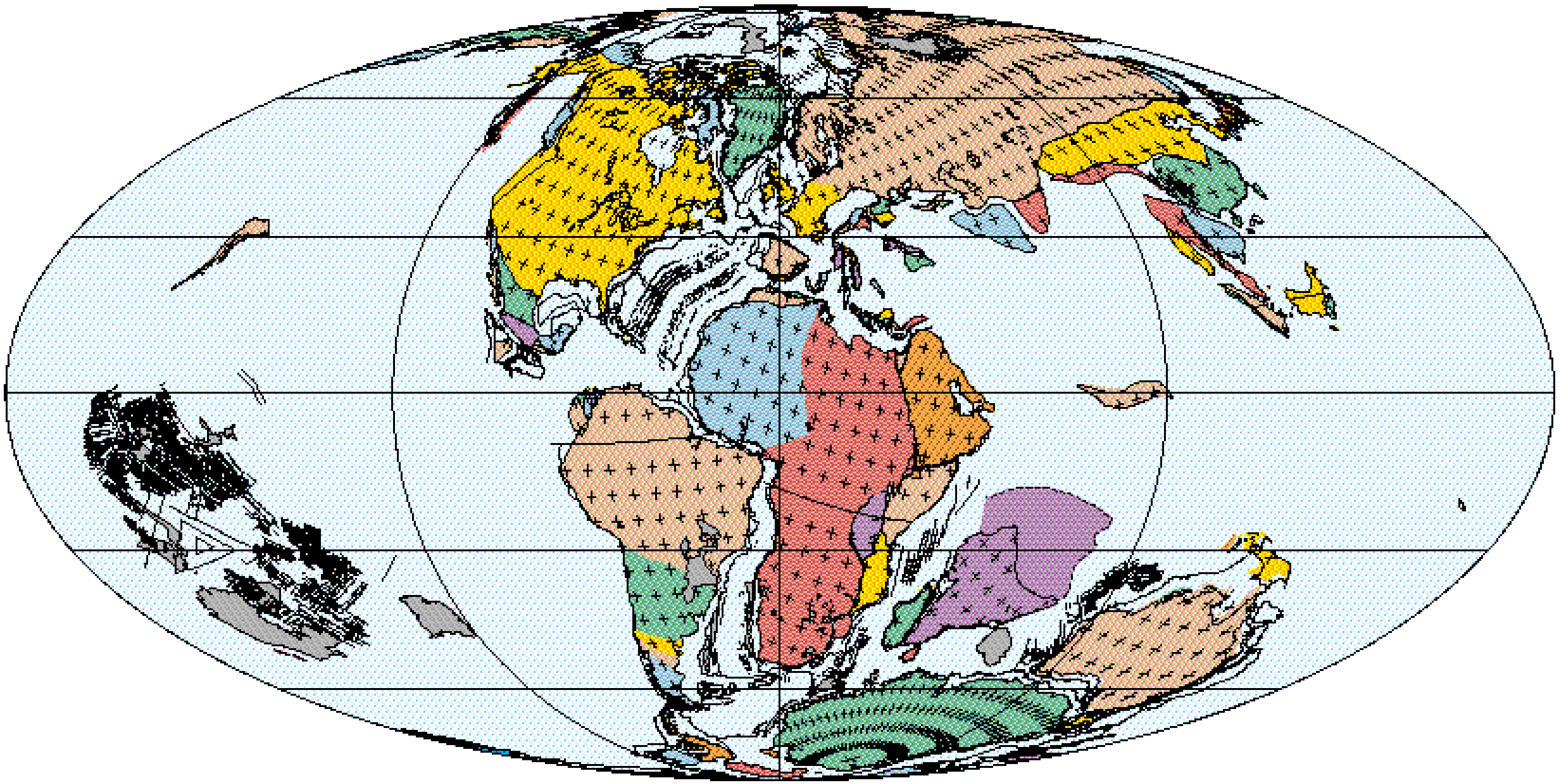
PLATES/UTIG

July 1999



120 Ma
Aptian (Early Cretaceous)

PLATES/UTIG
July 1999

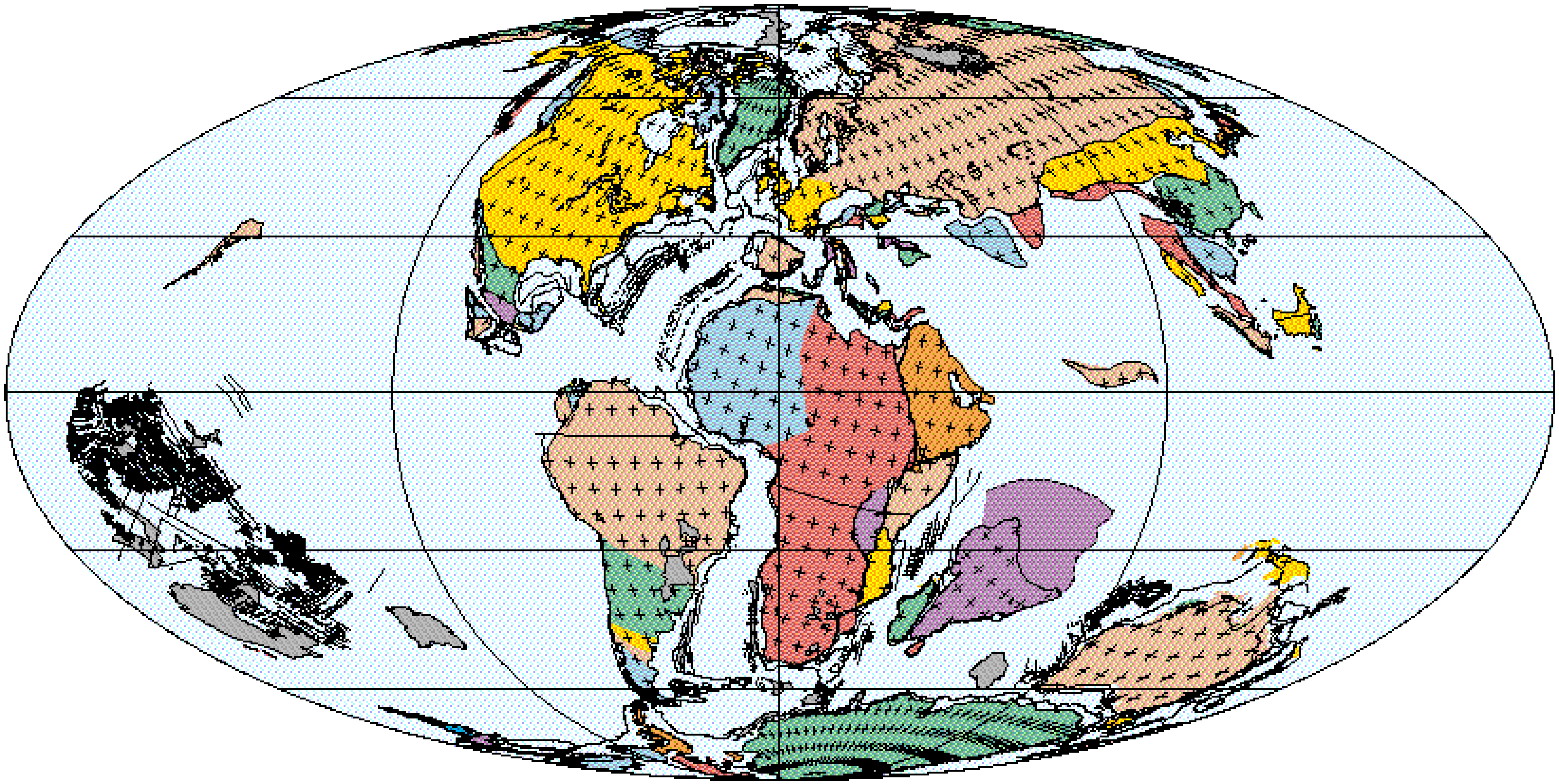


110 Ma

Early Albian (Early Cretaceous)

PLATES/UTIG

July 1999

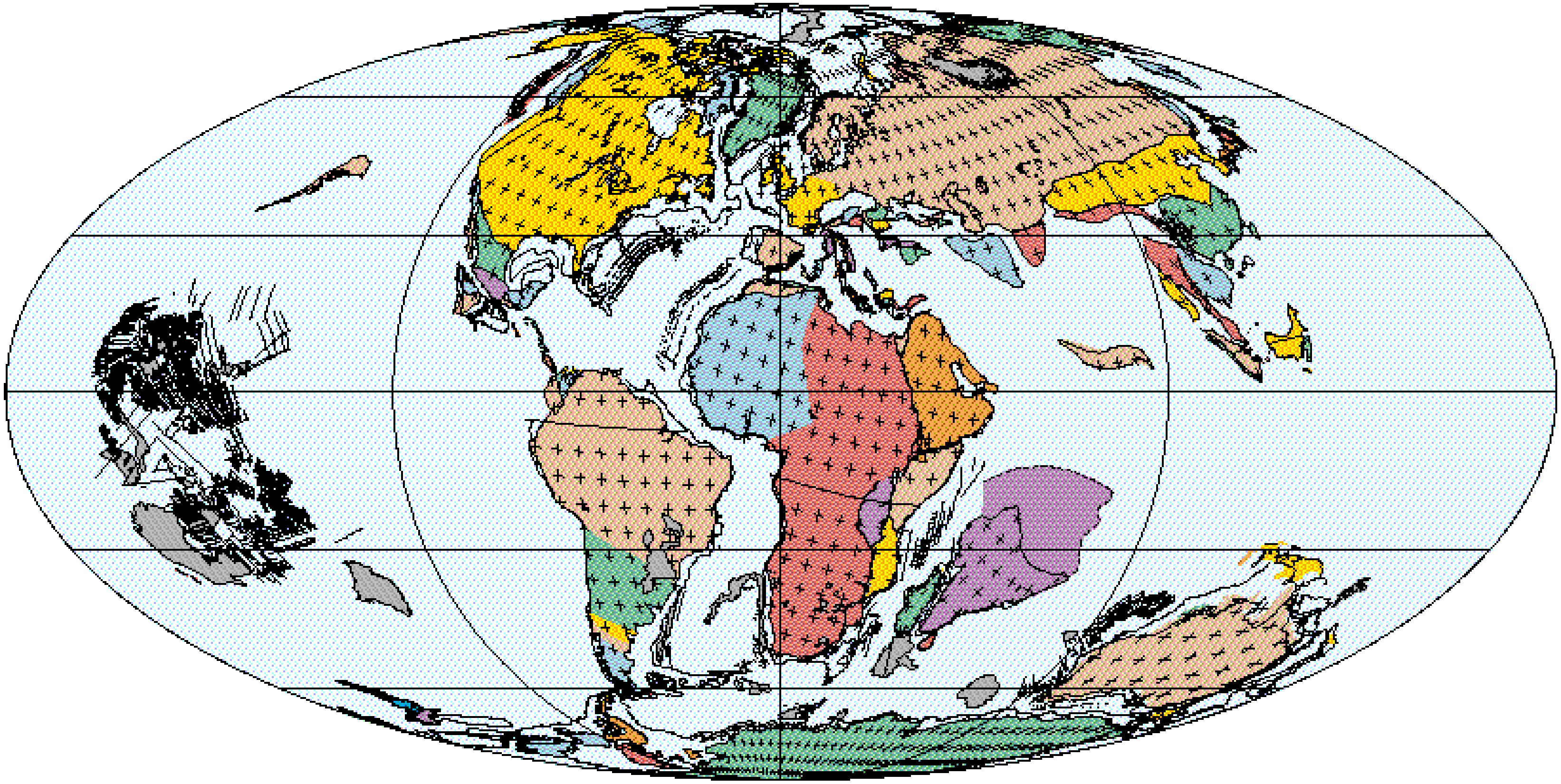


100 Ma

Late Albian (Early Cretaceous)

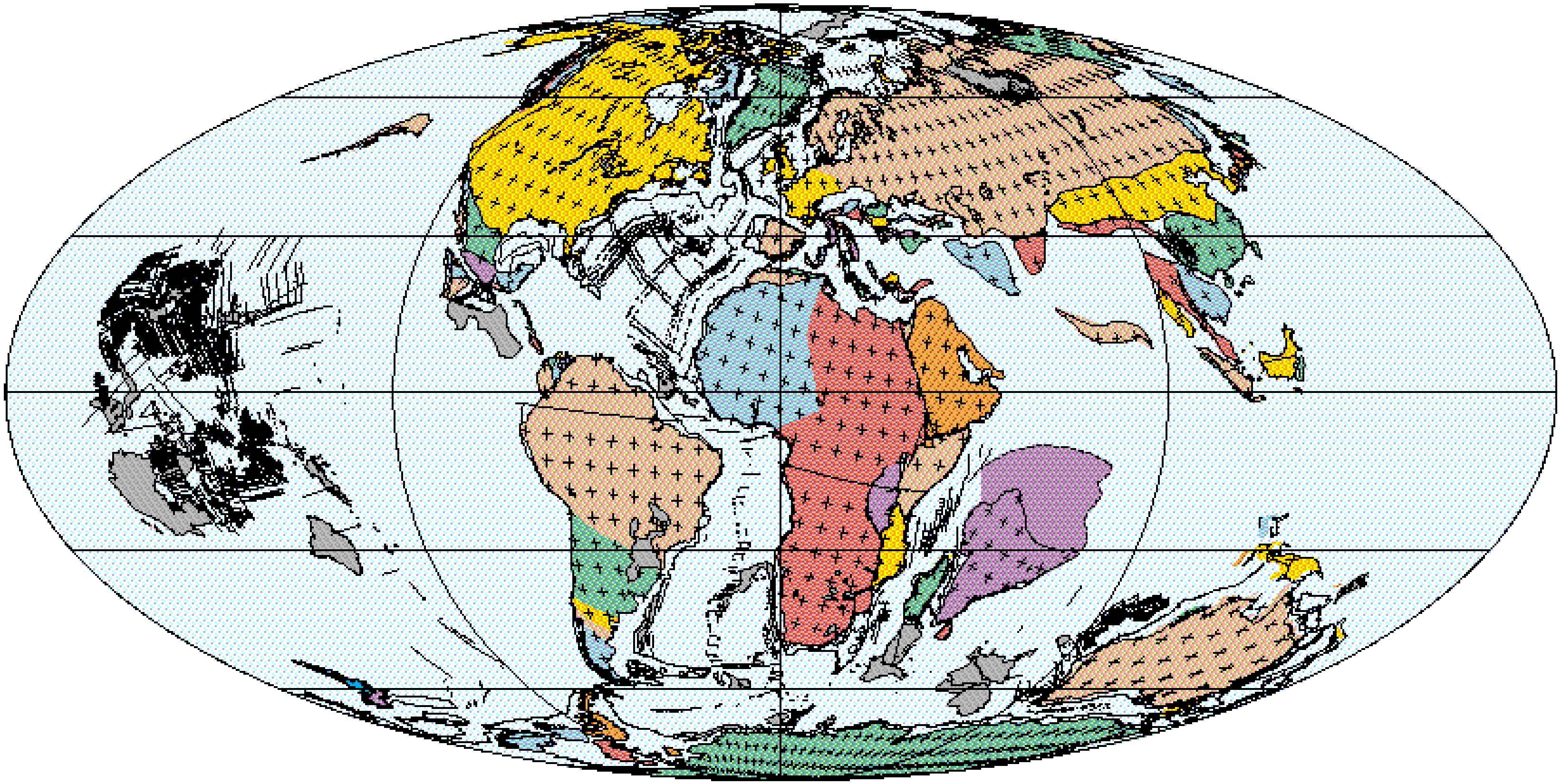
PLATES/UTIG

July 1999



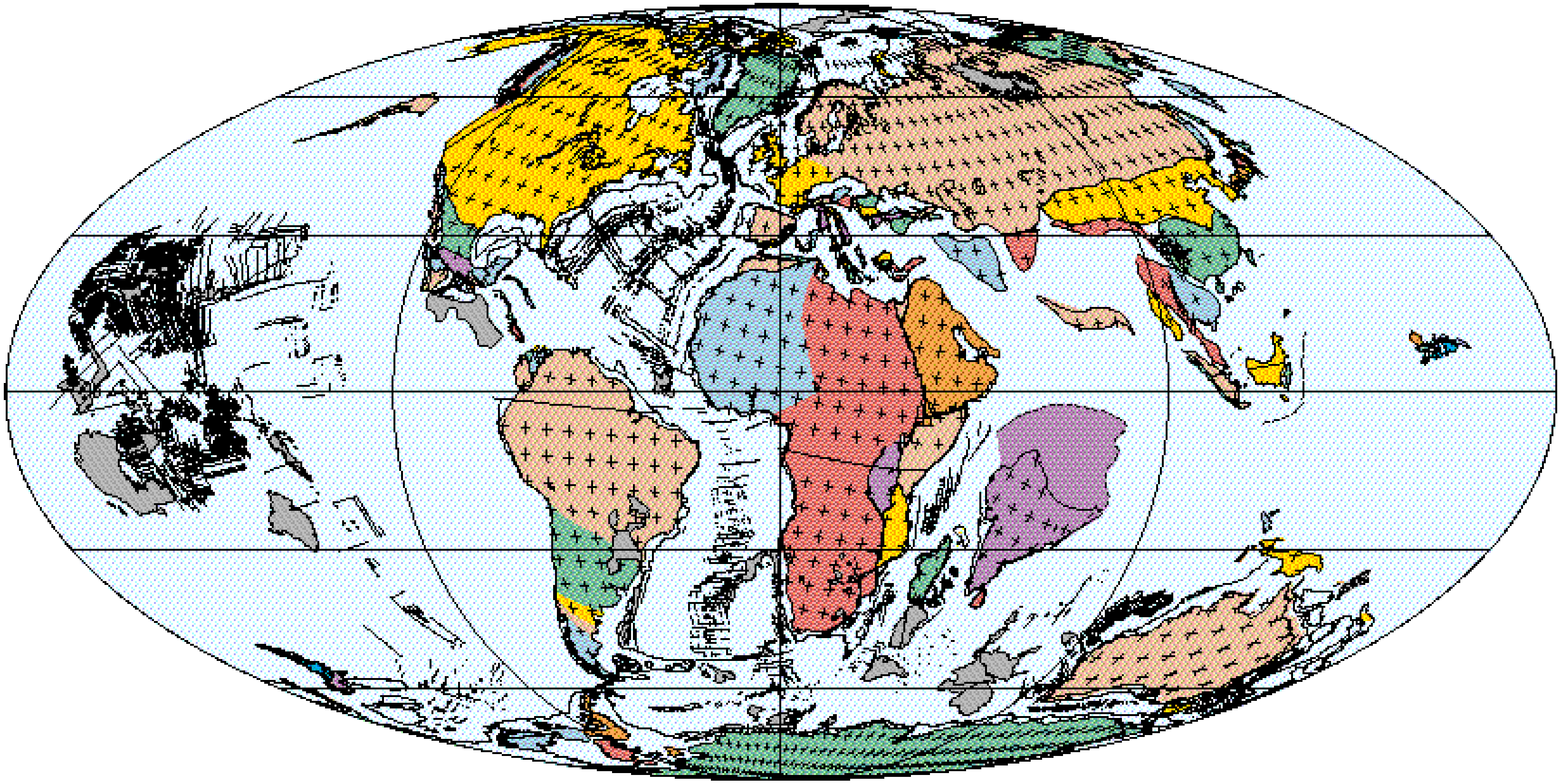
90 Ma
Turonian (Late Cretaceous)

PLATES/UTIG
July 1999



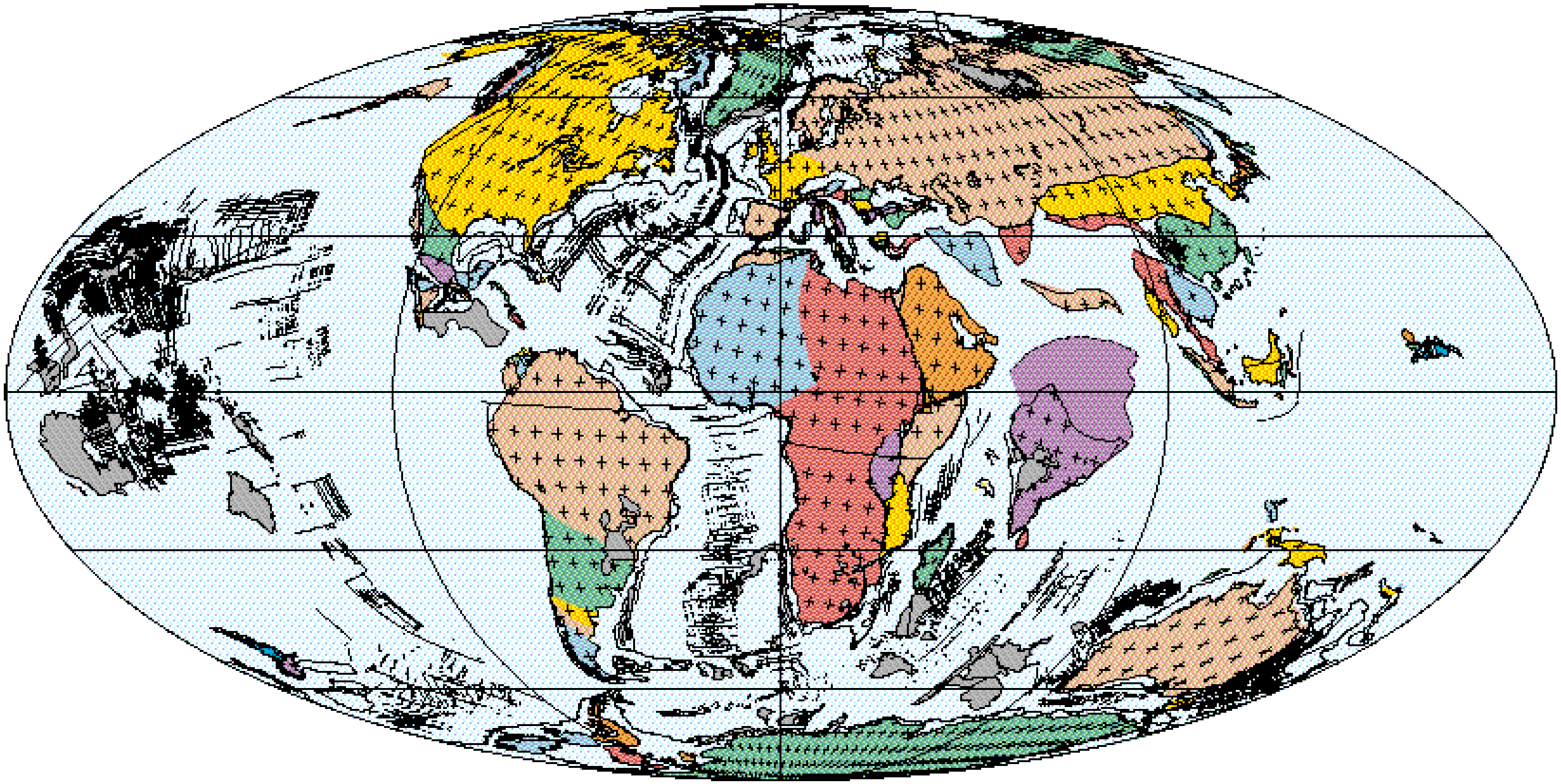
80 Ma
Campanian (Late Cretaceous)

PLATES/UTIG
July 1999



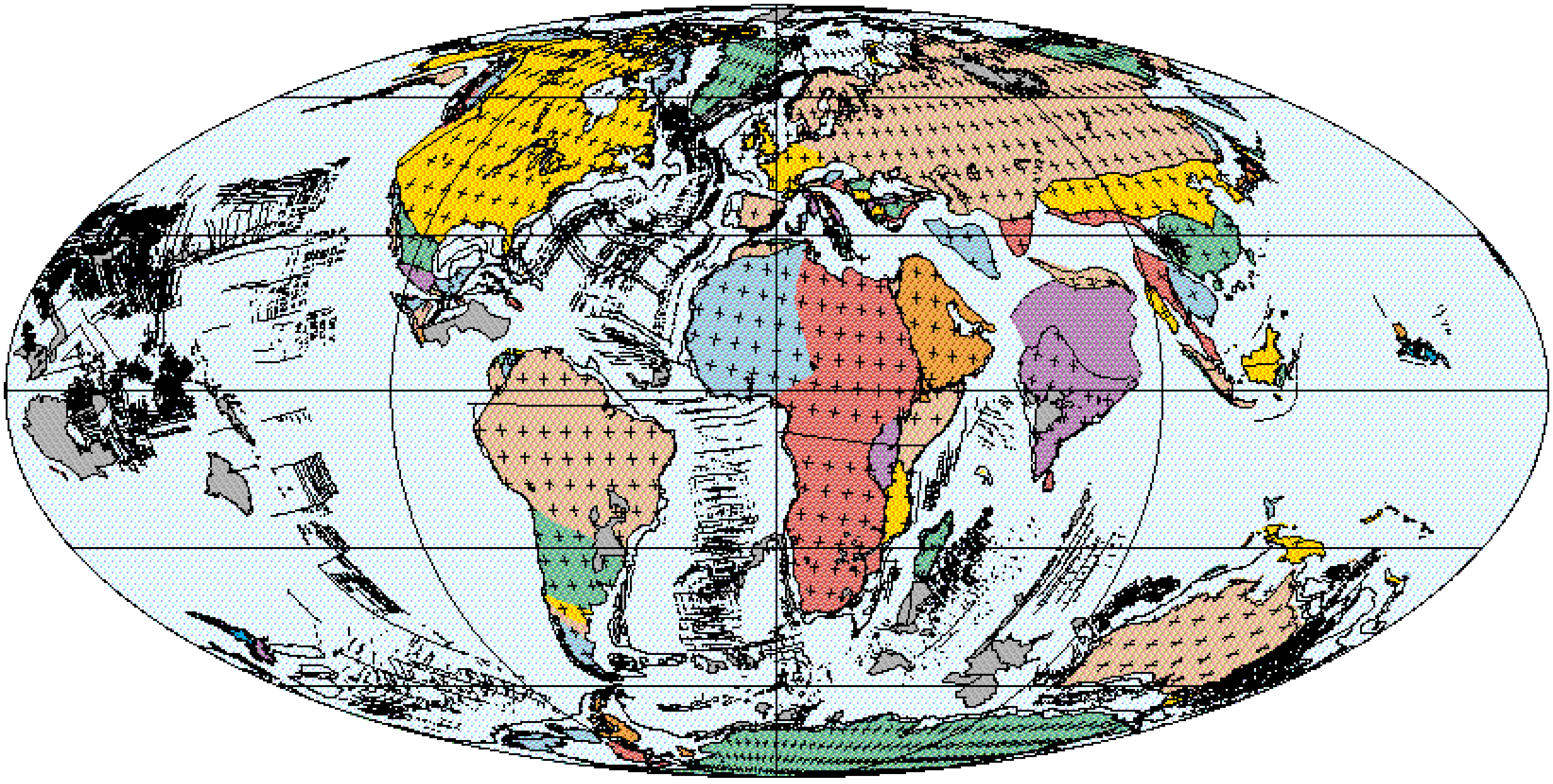
70 Ma
Maastrichtian (Late Cretaceous)

PLATES/UTIG
July 1999



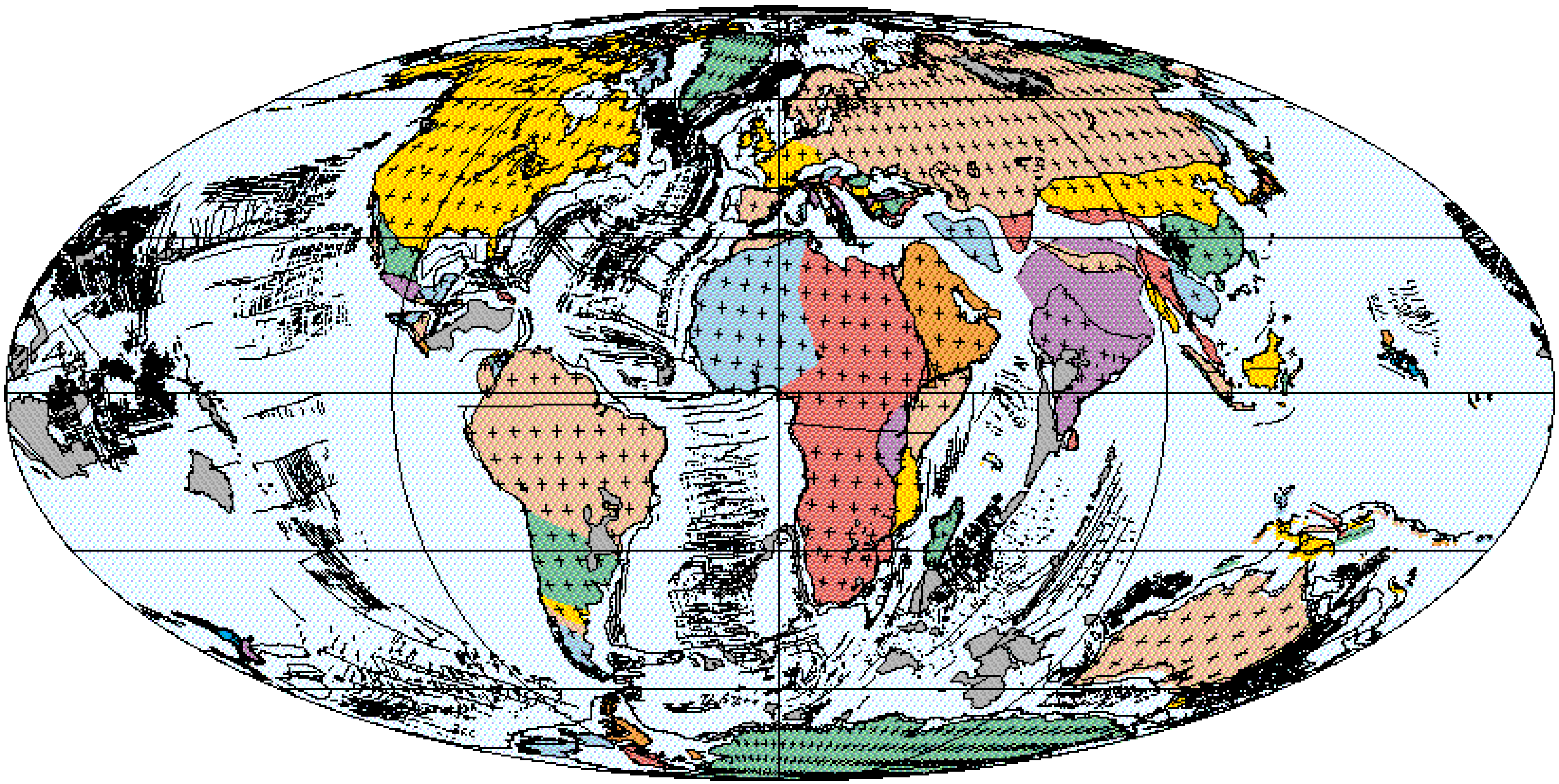
60 Ma
Late Paleocene

PLATES/UTIG
July 1999



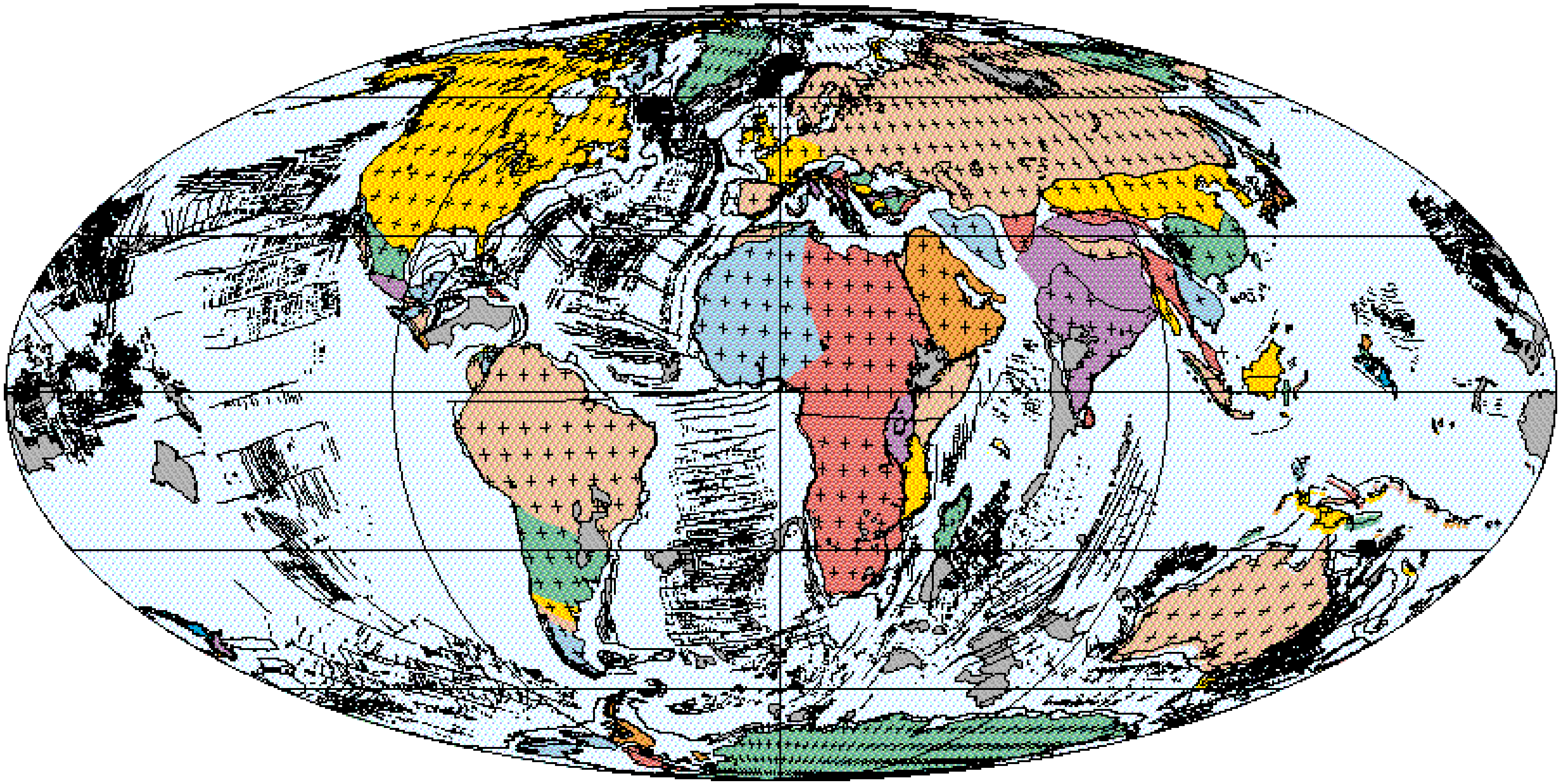
50 Ma
Early Eocene

PLATES/UTIG
July 1999



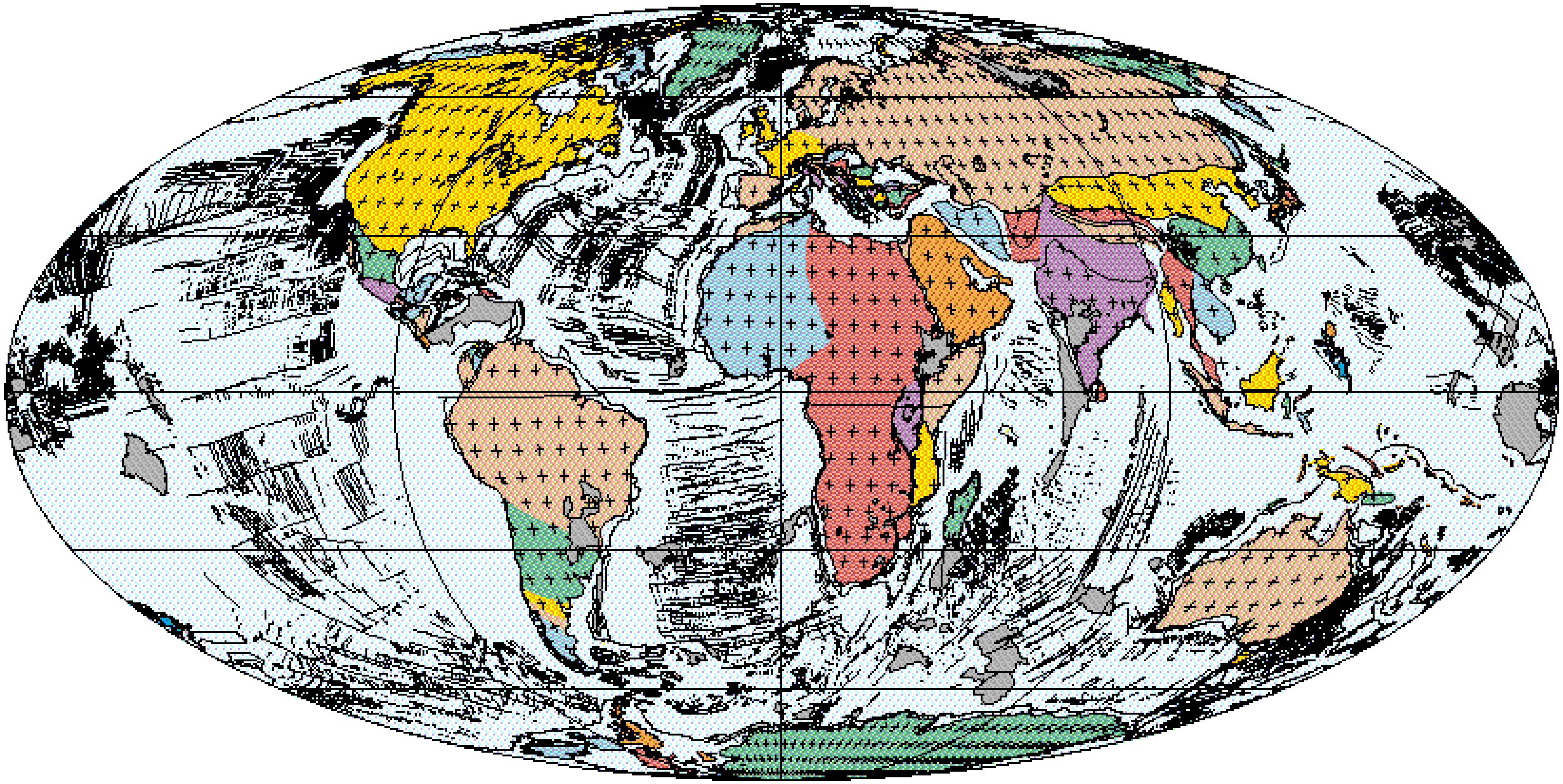
40 Ma
Middle Eocene

PLATES/UTIG
July 1999



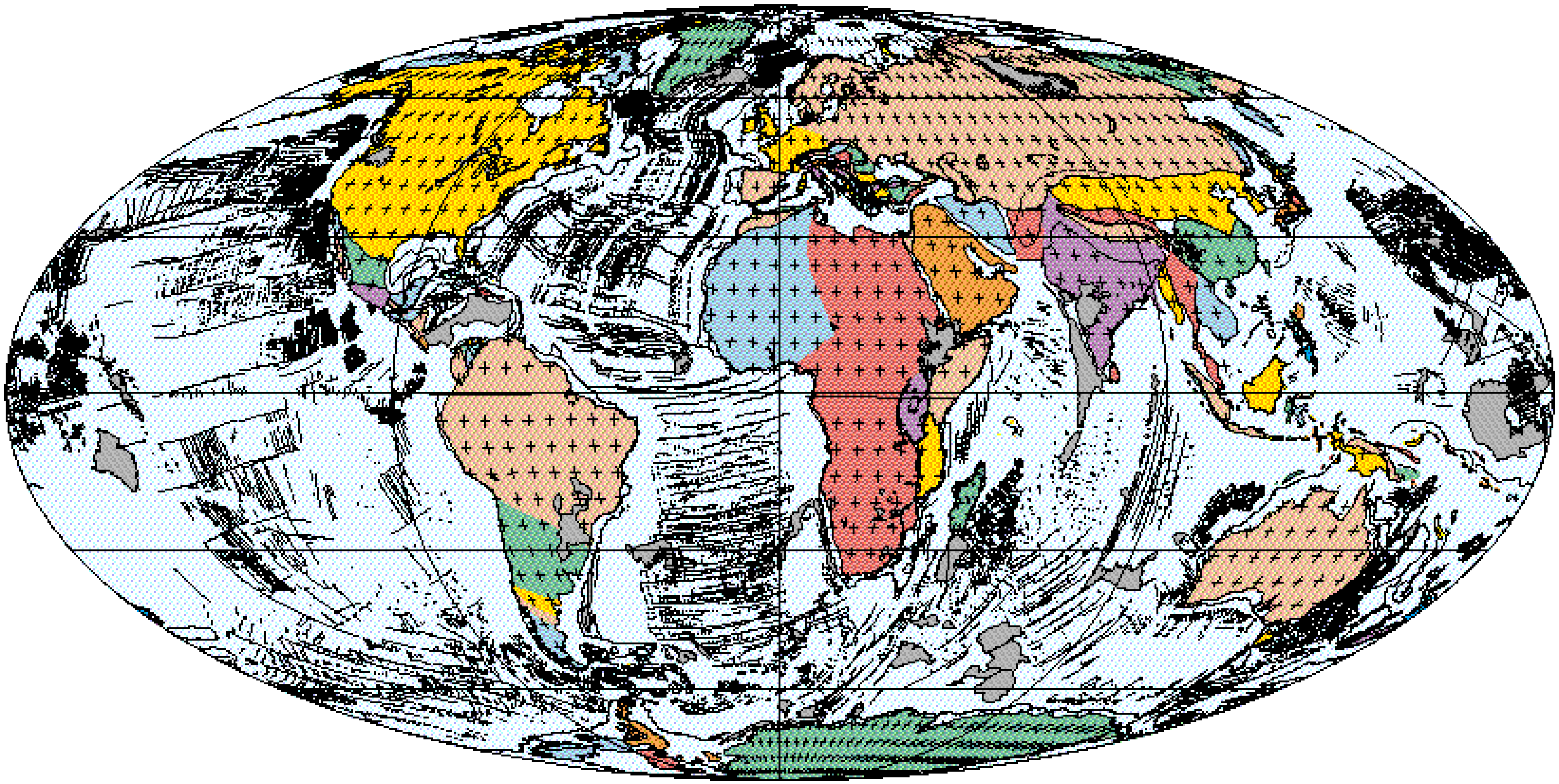
30 Ma
Early Oligocene

PLATES/UTIG
July 1999



20 Ma
Early Miocene

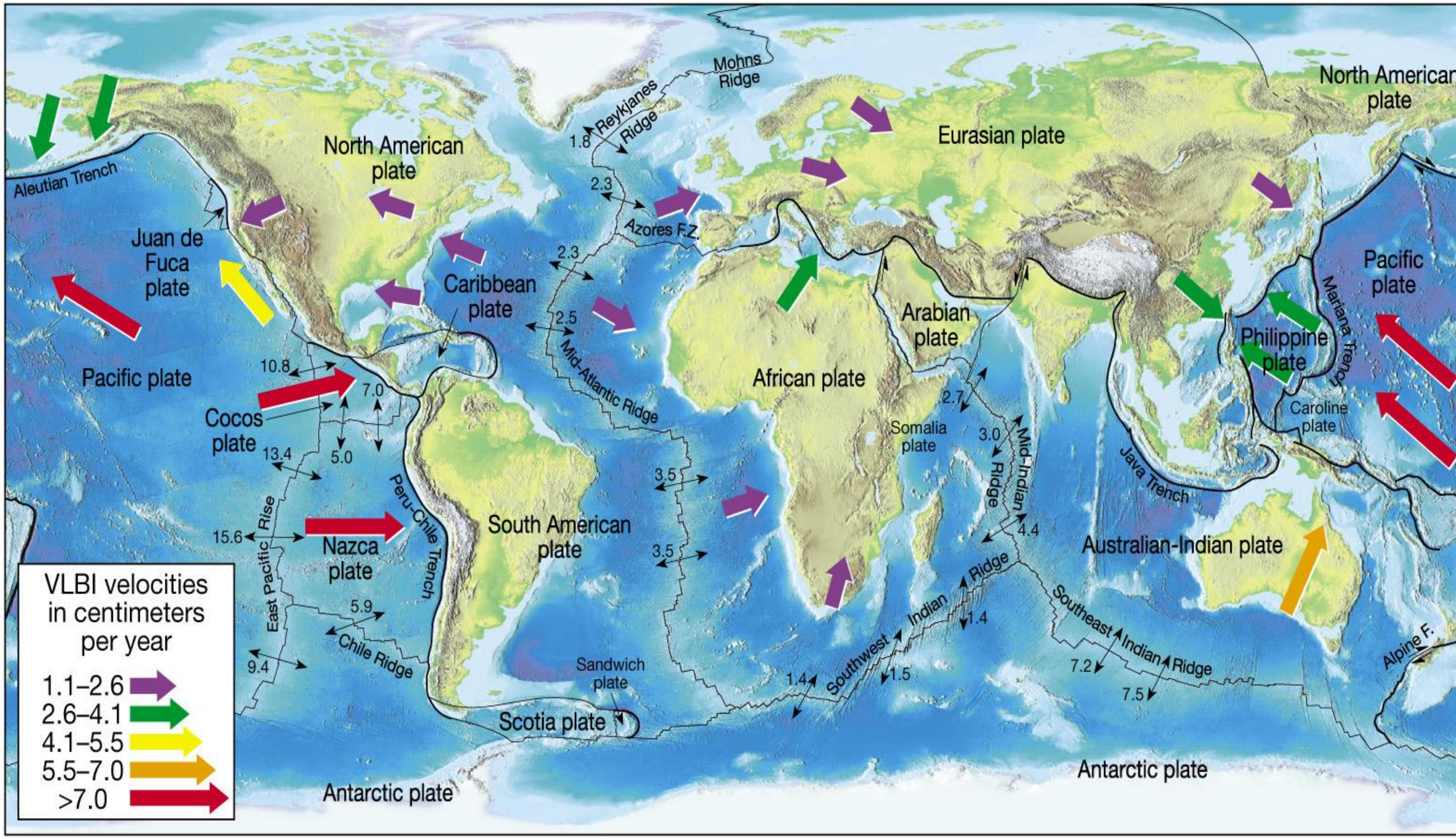
PLATES/UTIG
July 1999

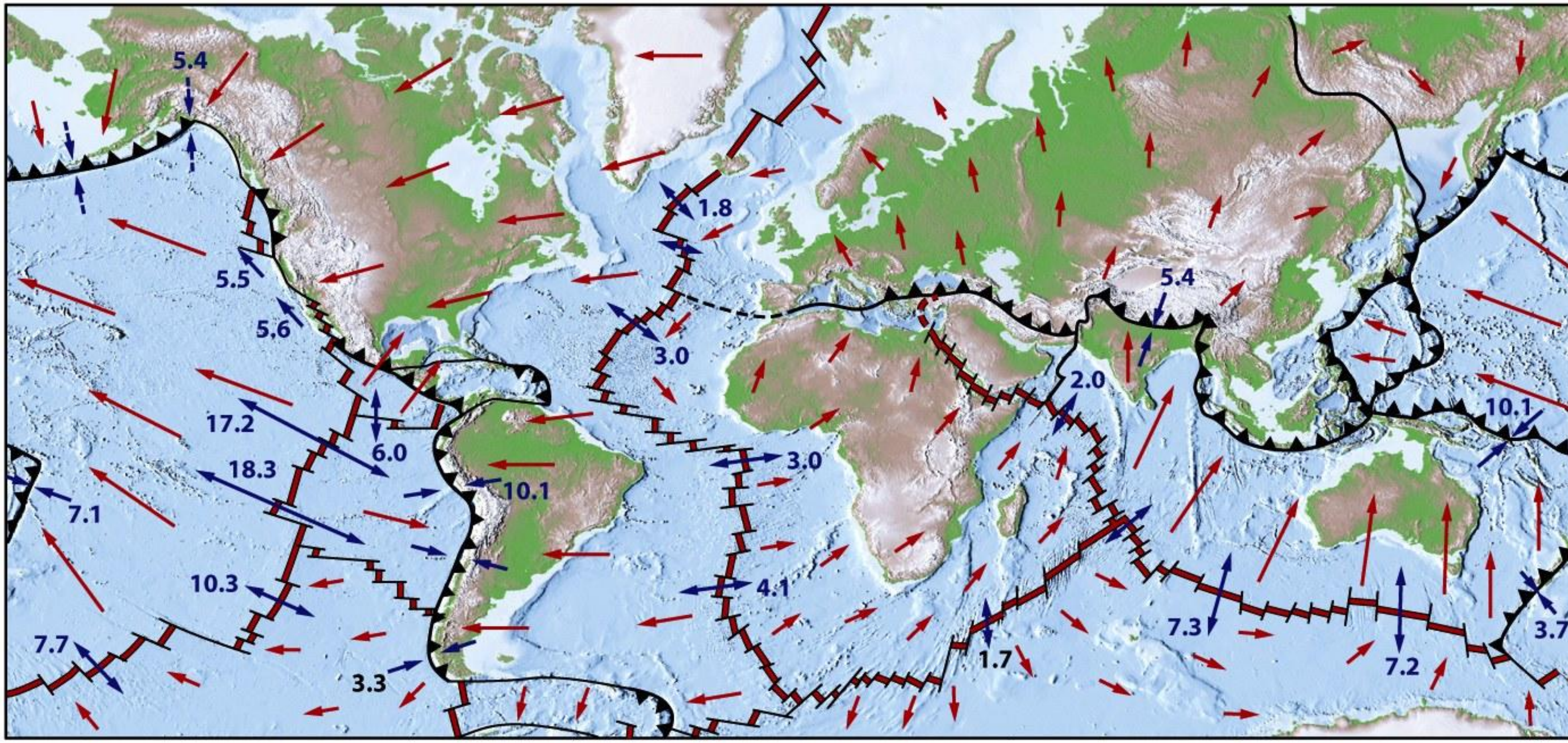


10 Ma
Late Miocene

PLATES/UTIG
July 1999

Plate velocity





Convergent boundary — Ridge — Transform

Absolute plate motions — Relative plate motions (5.5 cm per year)

Figure 4-29 Earth: Portrait of a Planet 3/e
Modified from Cox and Hardt, 1986