FUNDAMENTALS OF EARTH SCIENCES (ESO 213A)

DIBAKAR GHOSAL

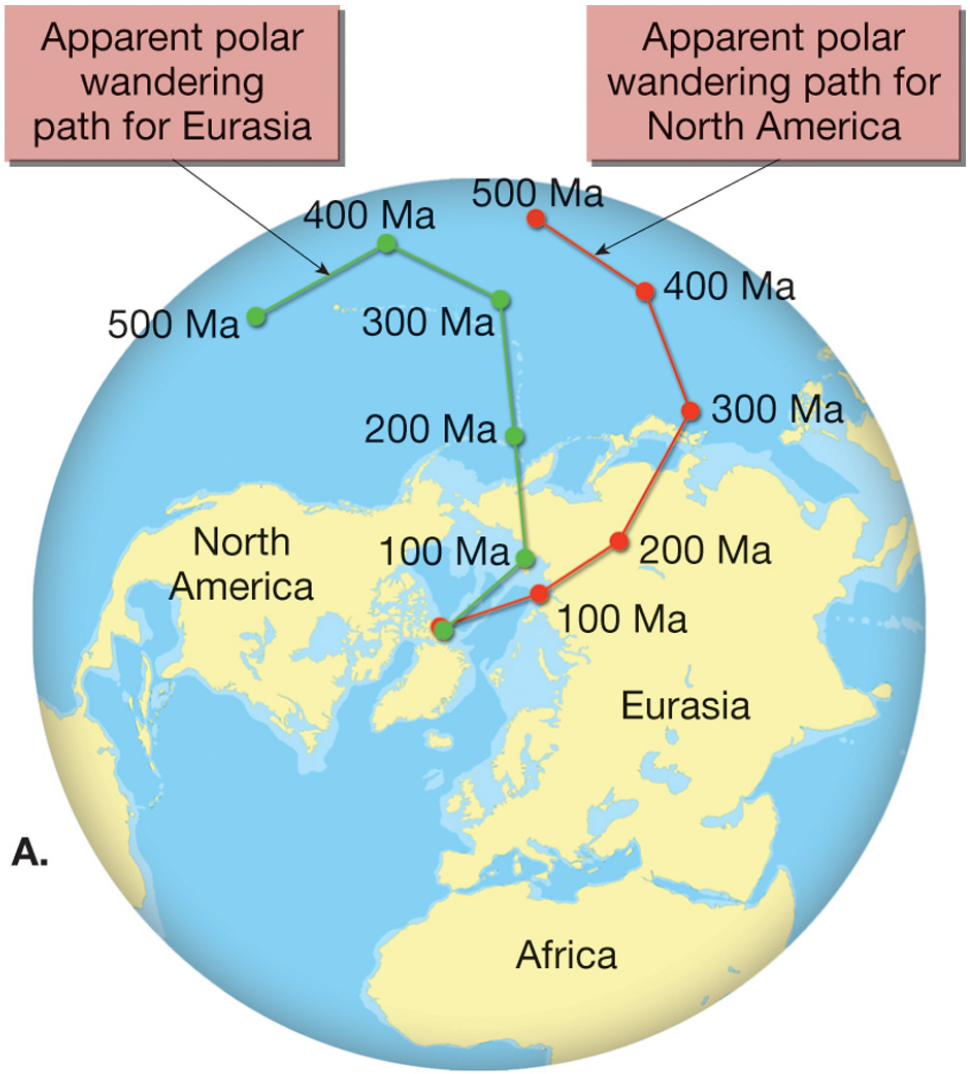
DEPARTMENT OF EARTH SCIENCES

Topic: Divergent/Convergent/Transform Plate Boundaries

Previous Class: Plate Tectonics

Last Class: Review

Polar Wandering Paths



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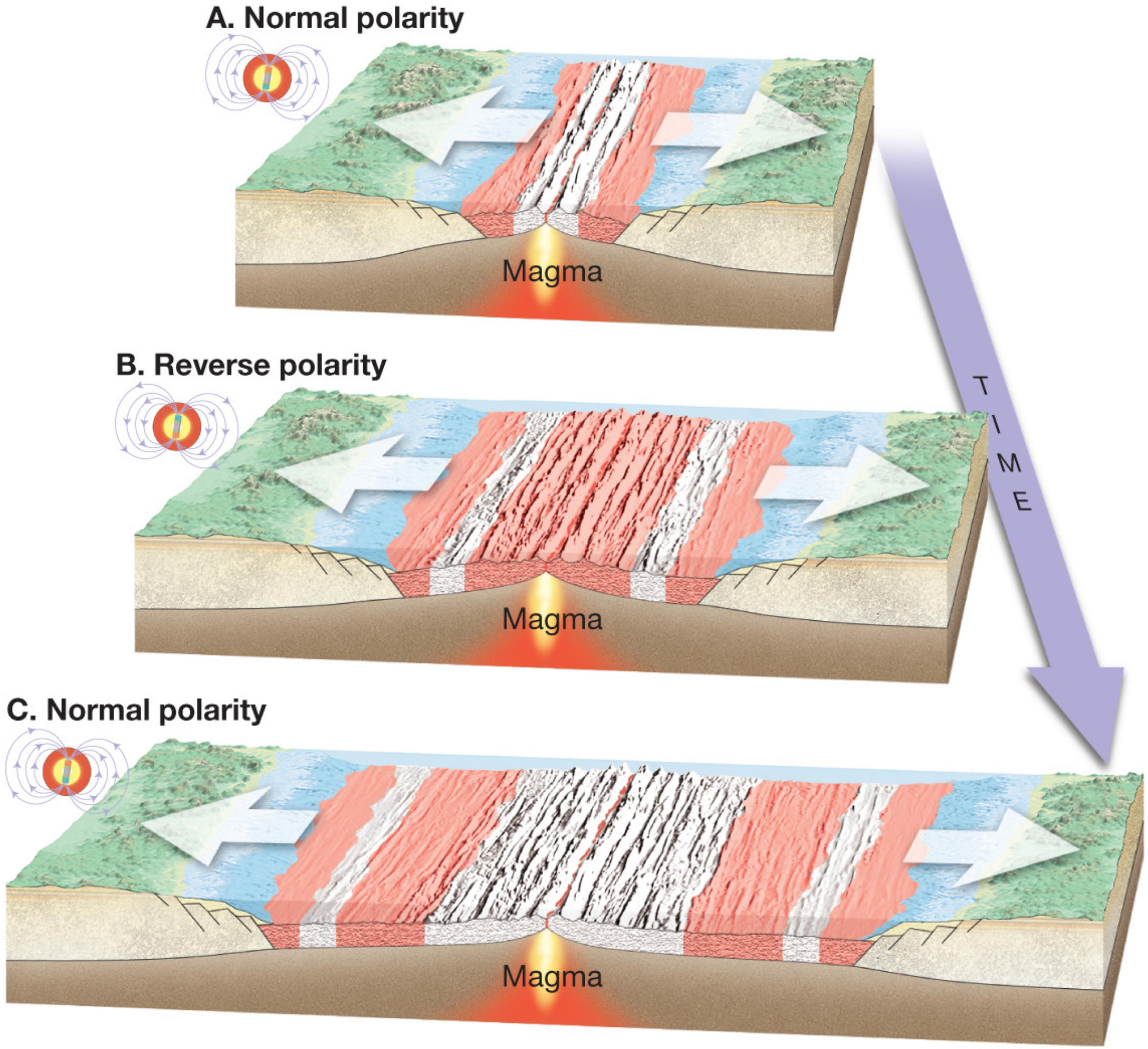
Last Class: Review

Paleomagnetic Reversals Recorded in Oceanic Crust



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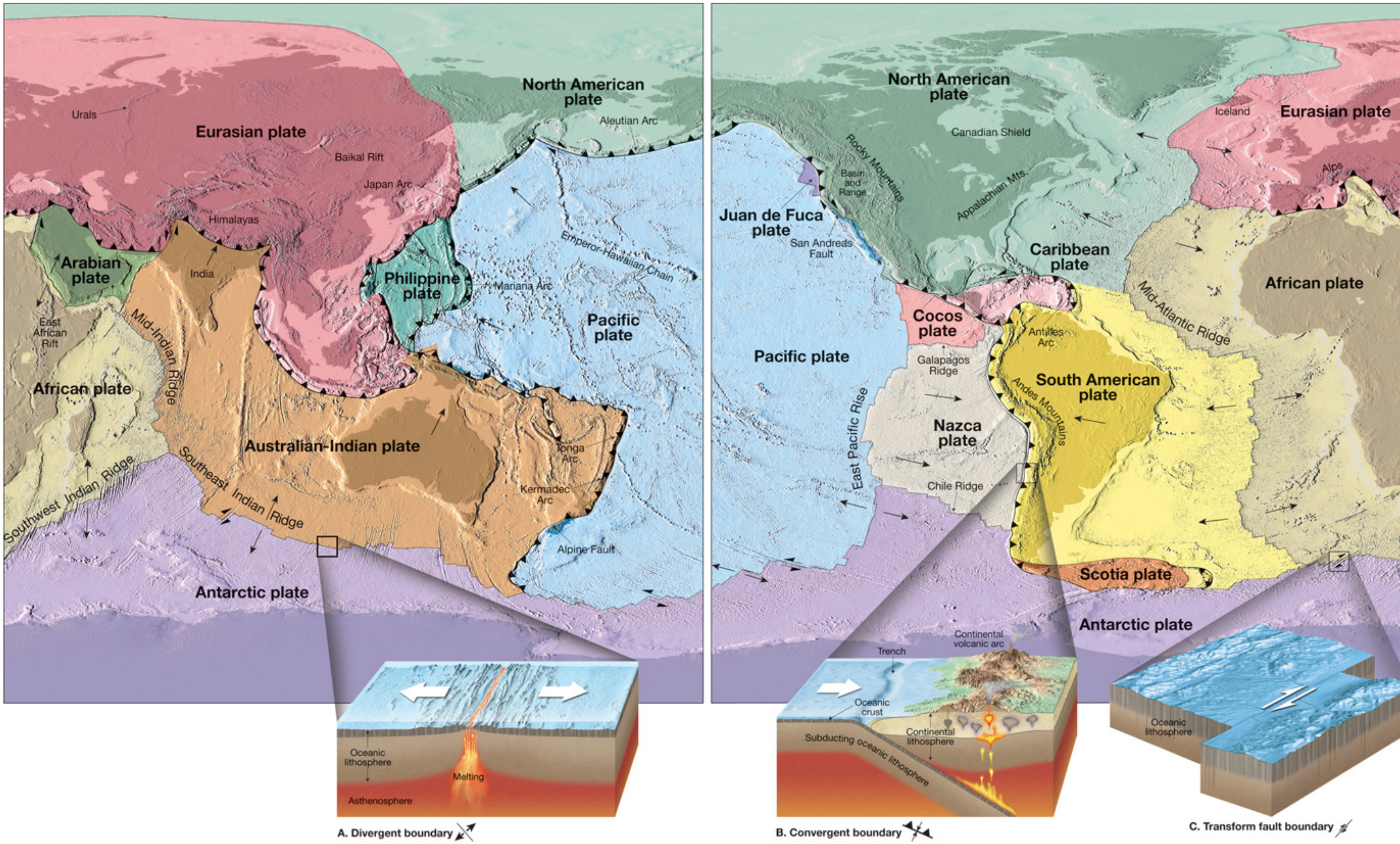
Last Class: Review



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Divergent/Convergent/Transform Plate Boundary

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Convergent Plate Boundaries

- **Older portions of oceanic plates are returned to the mantle at these destructive plate margins.**
  - **Surface expression of the descending plate is an ocean trench.**
  - **Also called subduction zones**
  - **Average angle of subduction = 45 degrees.**

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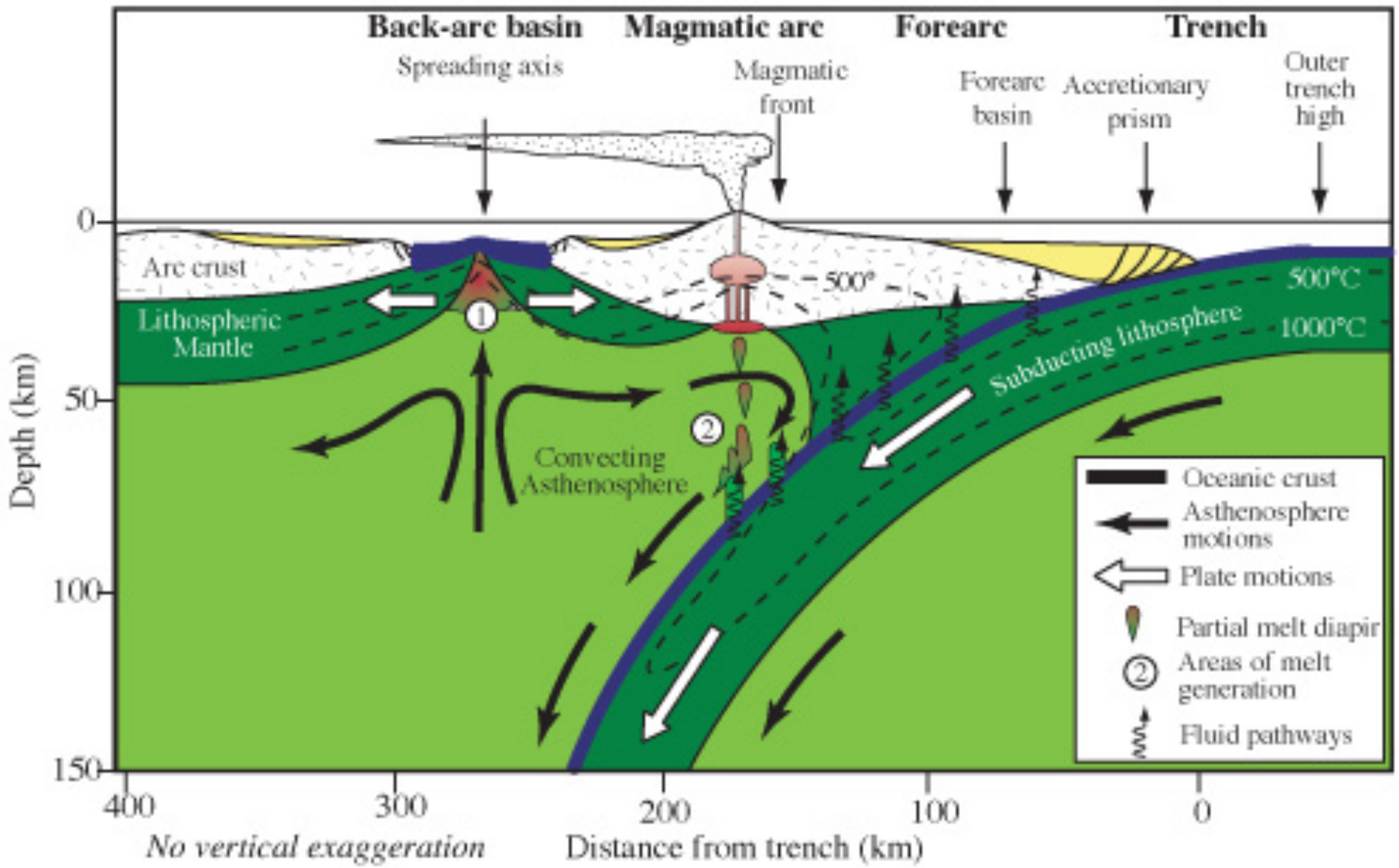
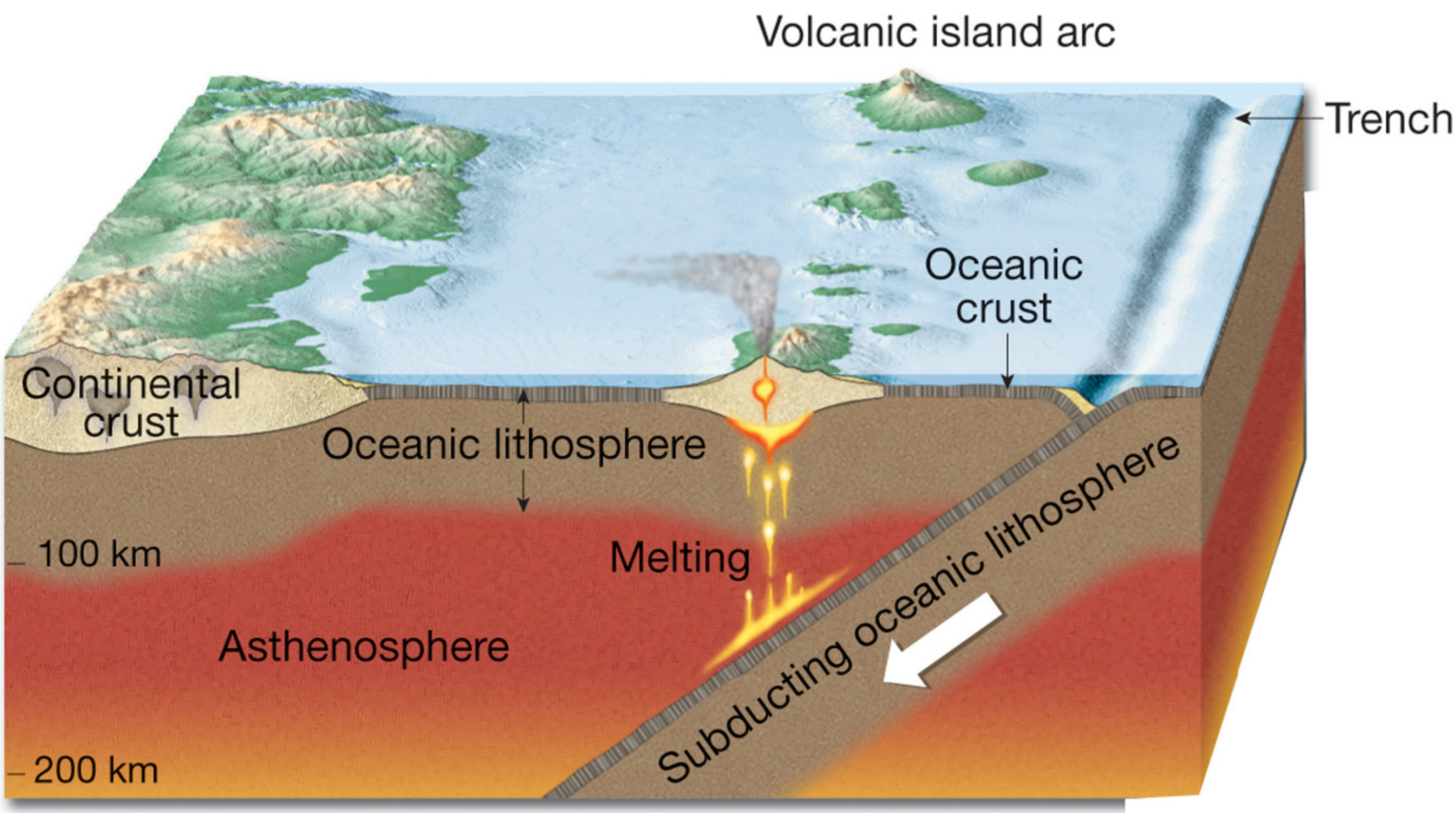
Convergent Plate Boundaries

- Types of convergent boundaries:
  - Oceanic–continental convergence
    - The denser oceanic slab sinks into the asthenosphere.
    - Along the descending plate, partial melting of mantle rock generates magma.
    - The resulting volcanic mountain chain is called a continental volcanic arc. (The Andes and the Cascades are examples.)



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, the Aleutian islands, and the Tonga islands are examples.)



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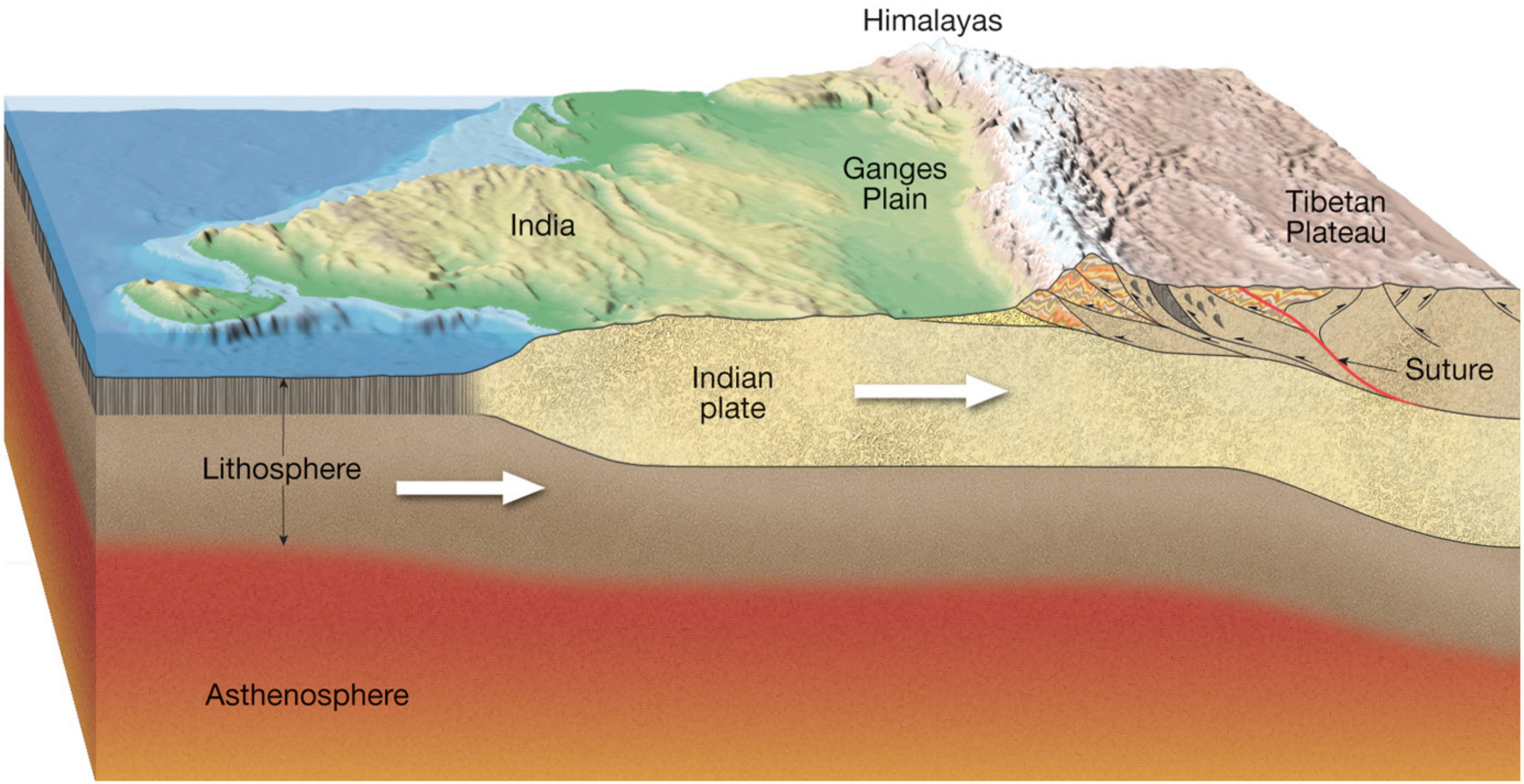
Convergent Plate Boundaries

- Types of convergent boundaries:
  - Continental–continental convergence
    - Continued subduction can bring two continents together.
    - Less dense, buoyant continental lithosphere does not subduct.
    - The resulting collision produces mountains. (The Himalayas, the Alps, and the Appalachians are examples.)



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Transform Fault Boundaries

- Plates slide past one another and no new lithosphere is created or destroyed.
- Transform faults
  - Mostly join two segments of a mid-ocean ridge (MOR) along breaks in the oceanic crust known as fracture zones.
  - A few (the San Andreas fault and Alpine Fault of New Zealand) cut through continental crust.

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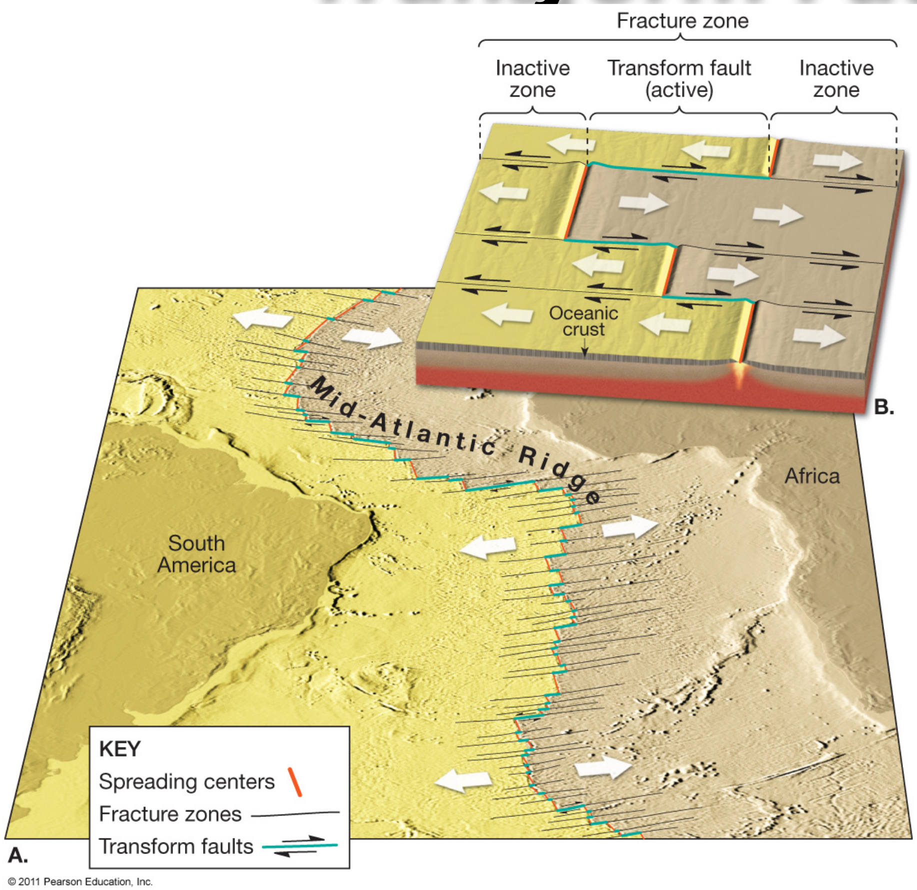
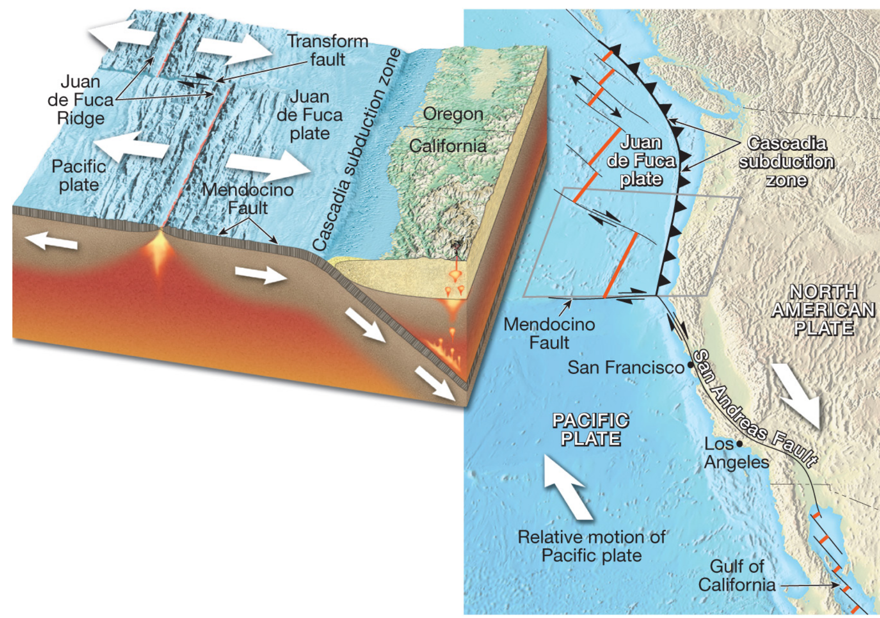
Transform Fault Boundaries





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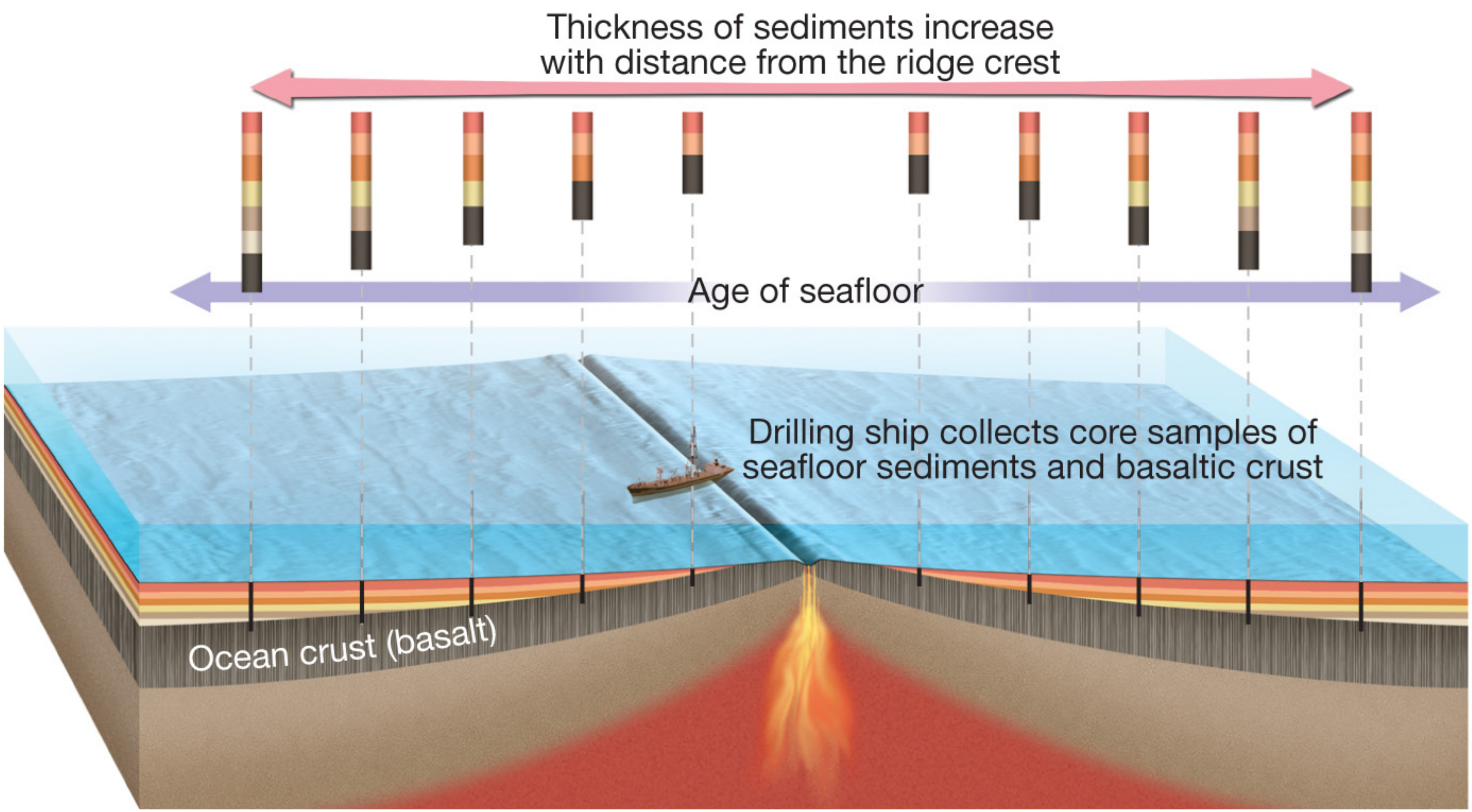
Testing the Plate Tectonics Model

- Evidence from ocean drilling
  - Some of the most convincing evidence has come from drilling directly into ocean-floor sediment.
    - Age of deepest sediments
    - The thickness of ocean-floor sediments verifies across seafloor spreading.



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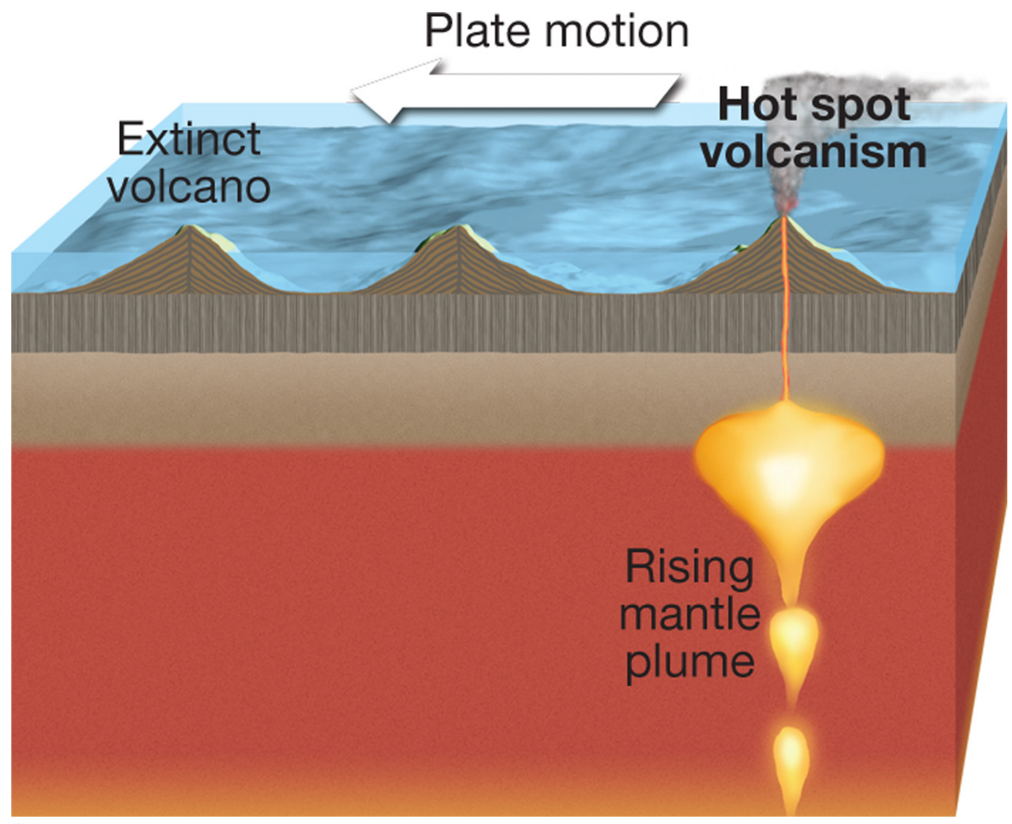
Testing the Plate Tectonics Model

- **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.**



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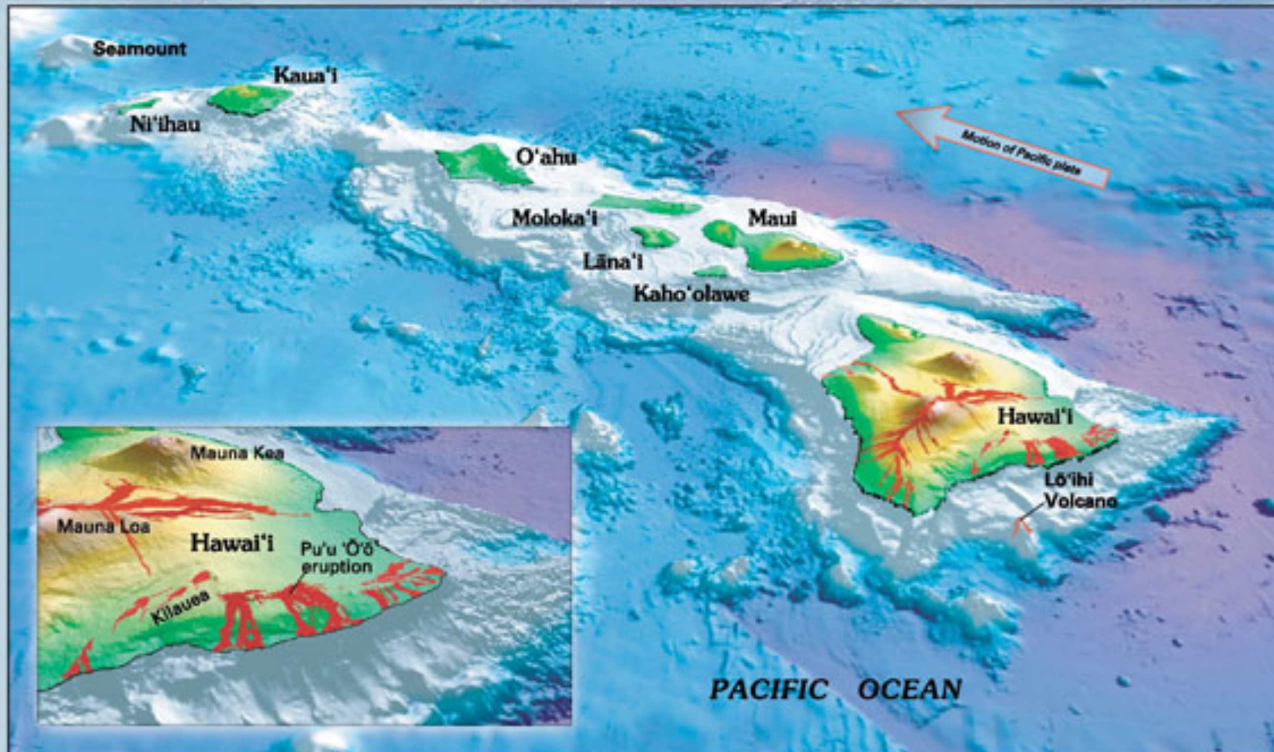


Figure 2.—Oblique view of the principal Hawaiian Islands and (the still submarine) Lō'ihi Volcano. Inset gives a closer view of three of the five volcanoes that form the Island of Hawai'i (historical lava flows are shown in red). The longest duration historical eruption on Kīlauea's east-rift zone at Pu'u 'Ō'ō (inset), which began in January 1983, continues unabated (as of spring 2006). View prepared by Joel E. Robinson (USGS).

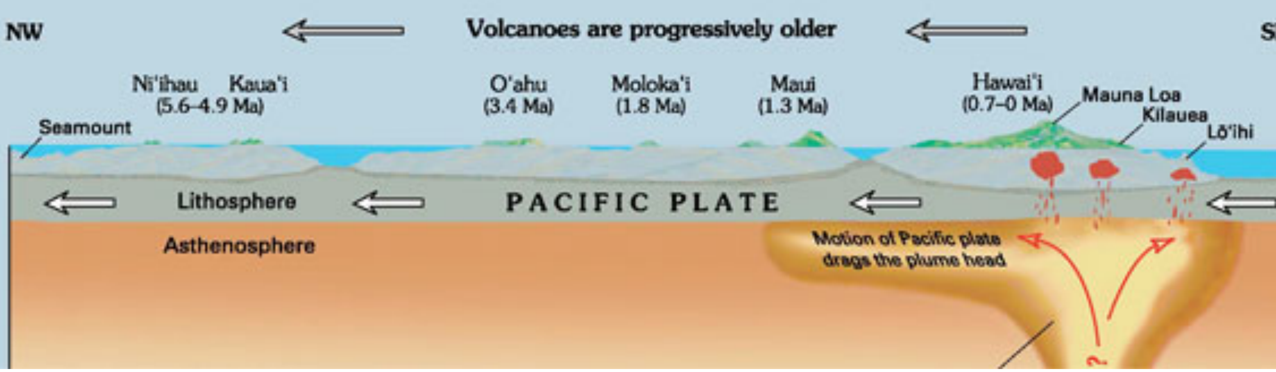
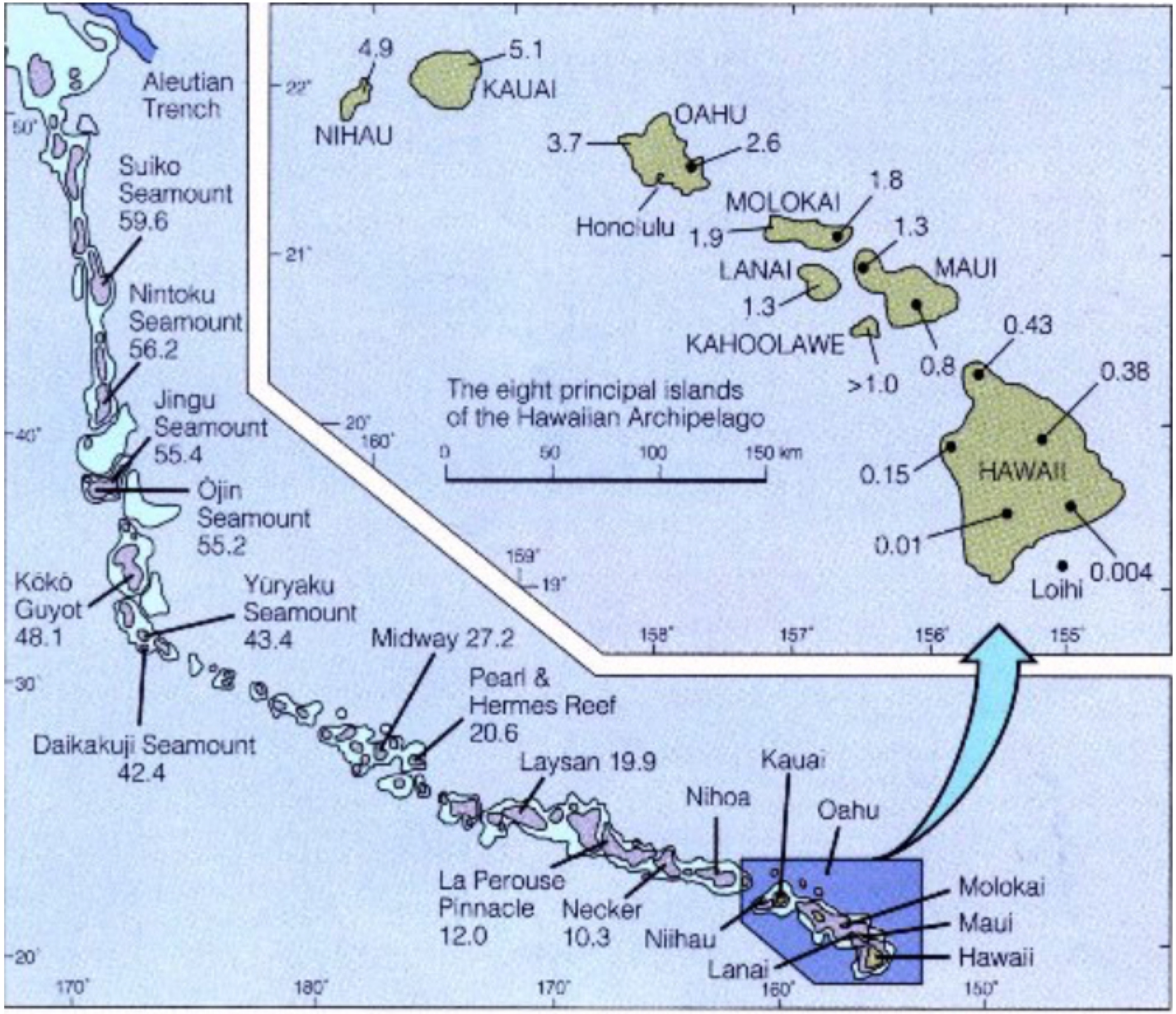


Image courtesy: USGS



In which direction the plates are moving?

Measuring Plate Motion

- **Paleomagnetism and plate motions**
  - **Paleomagnetism stored in rocks on the ocean floor provides a method for determining plate motions.**
  - **Both the direction and the rate of spreading can be established.**
- **Measuring plate velocities from space**
  - **Accomplished by establishing exact locations on opposite sides of a plate boundary and measuring relative motions**
  - **Various methods are used:**
    - **Global Positioning System (GPS)**

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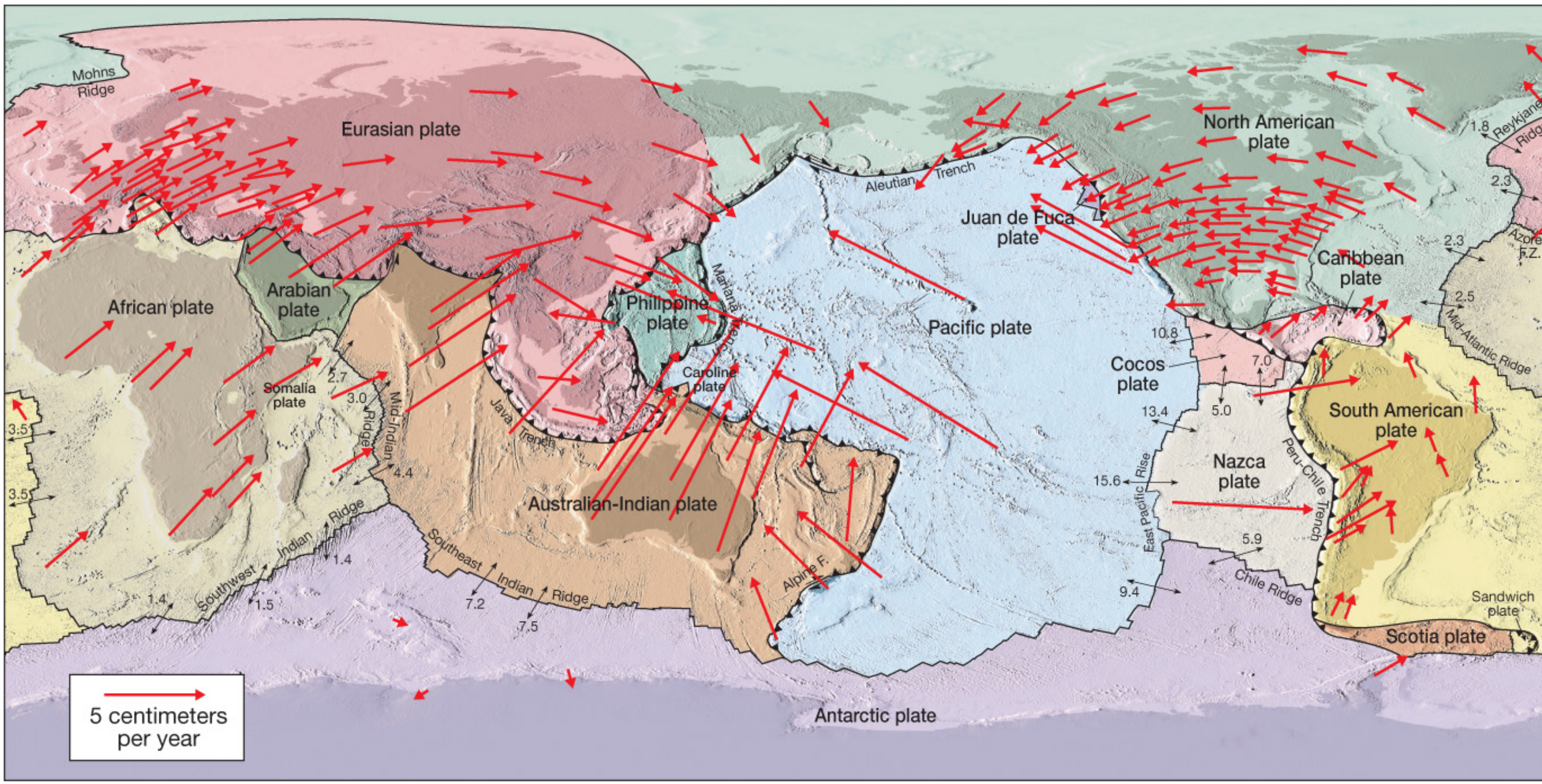
Plate Motions



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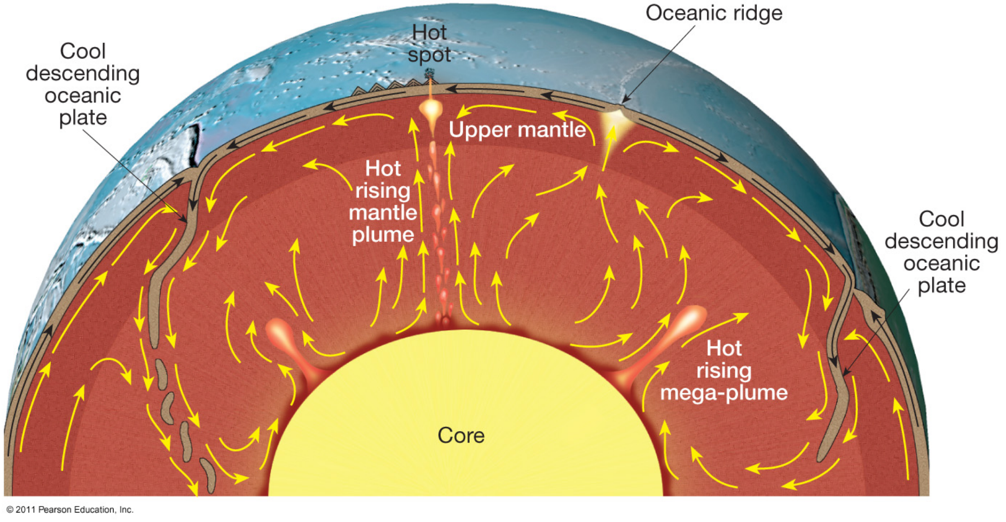
What Drives Plate Motions?

- Researchers agree that convective flow in the mantle is the basic driving force of plate tectonics.

- Driven by three thermal processes:

  - heating at the bottom by heat loss from Earth's core
  - heating from within by decay of radioactive isotopes
  - cooling from top
    (sinking of cold lithospheric slabs
    in the mantle)



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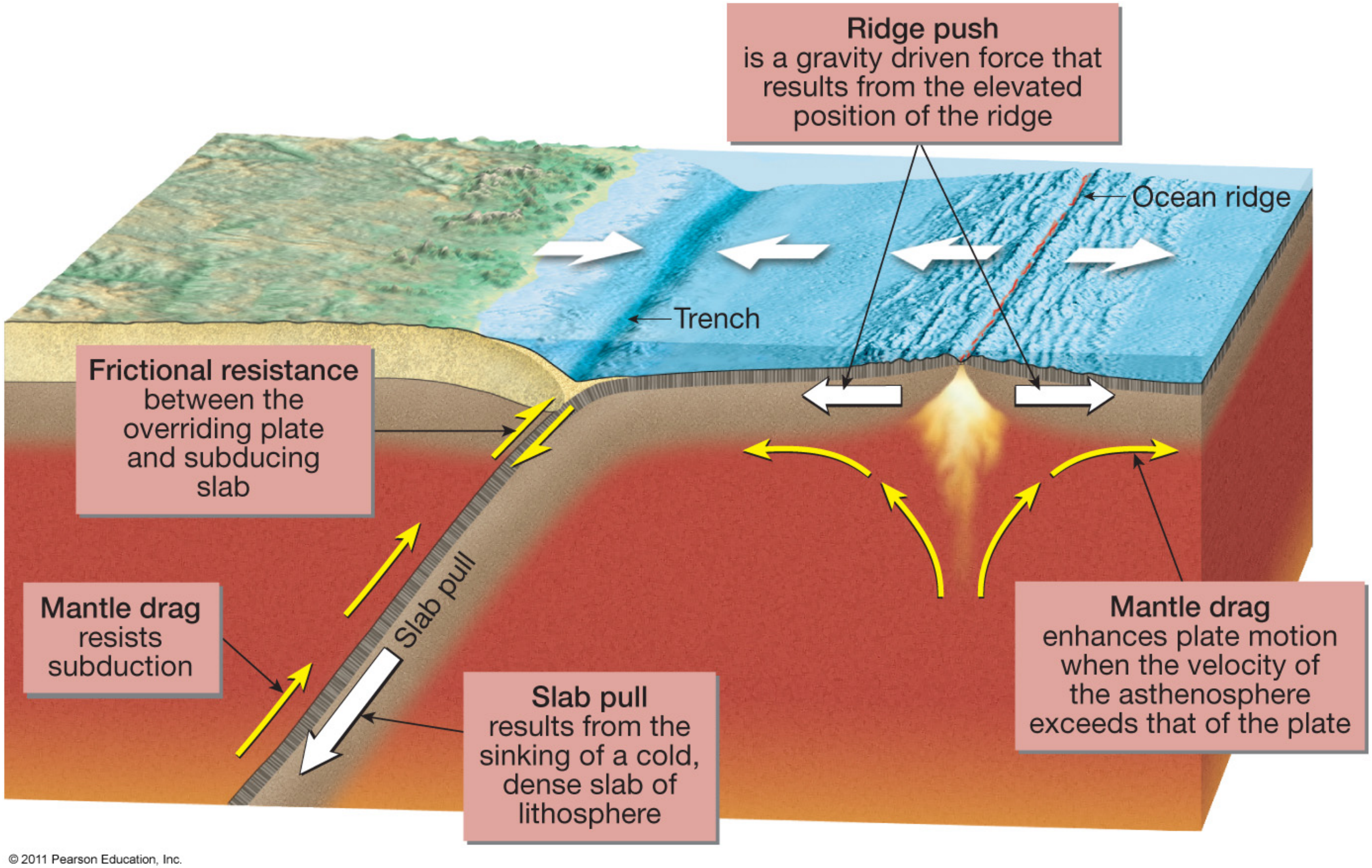
Forces Driving Plate Motions



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Importance of Plate Tectonics

- The theory provides explanations for:
  - Earth's major surface processes
  - Distribution of earthquakes, volcanoes, and mountains
  - Distribution of ancient organisms and mineral deposits

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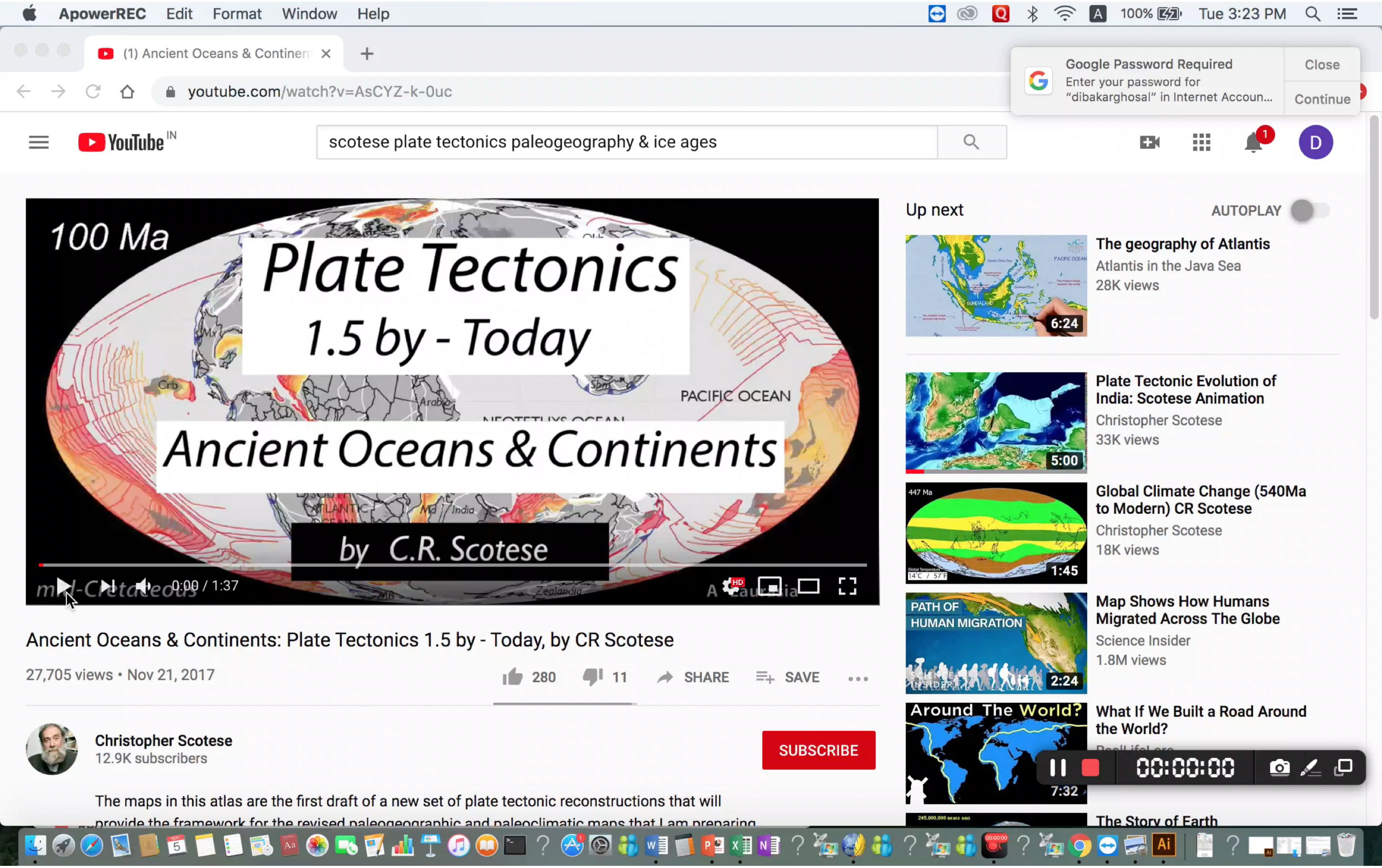
Reconstructed Plate tectonics in geologic past



Questions

1. The volcanoes of Hawaii are localized above a deep mantle hot spot; they are not part of the East Pacific oceanic ridge.
Answer: TRUE / FALSE

2. New oceanic crust and lithosphere are formed at ________.
A) transform boundaries by submarine eruptions
B) convergent boundaries by submarine eruptions
C) divergent boundaries by submarine eruptions

3. The Himalayan Mountains and Tibetan Plateau are still rising today as Eurasia slides beneath the Indian subcontinent.
Answer: TRUE / FALSE

4. Deep ocean trenches are surficial evidence for ________.
A) rifting beneath a continental plate and the beginning of continental drift
B) sinking of oceanic lithosphere into the mantle at a subduction zone
C) rising of hot asthenosphere from deep in the mantle
D) transform faulting between an oceanic plate and a continental plate

5. Hotspot can be used to measure ________ plate motion.

Continental Margins

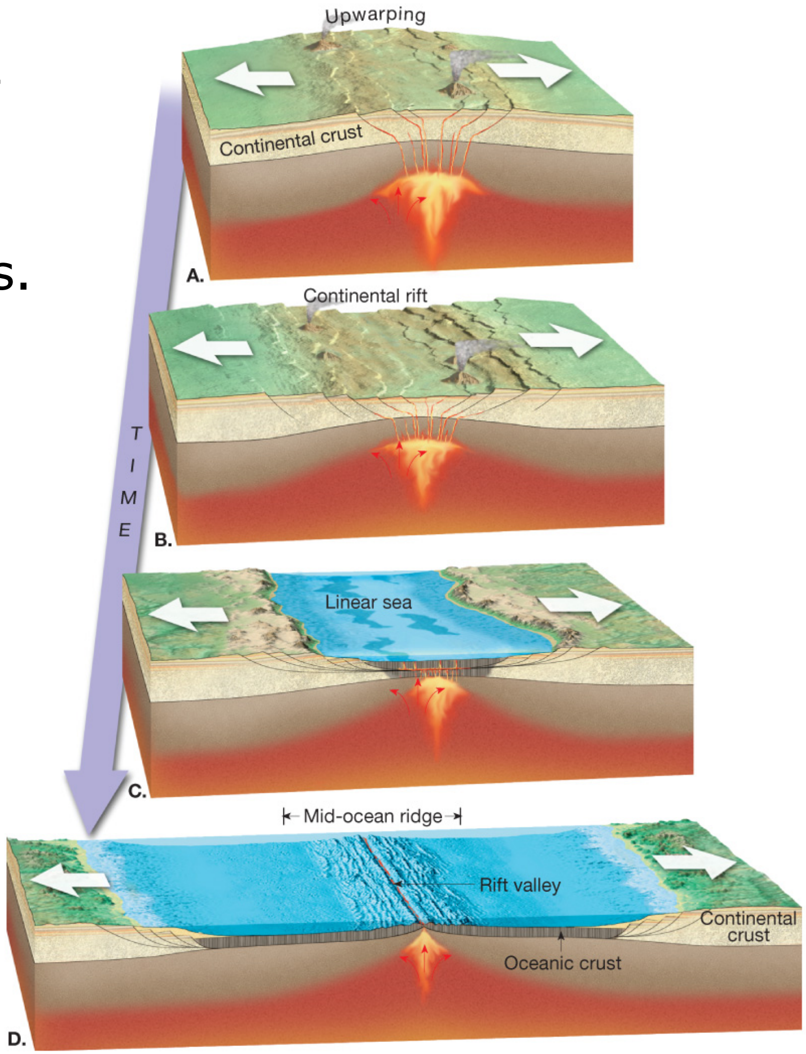
Continental margins are underwater edge of continents. These include continental shelf, slope, rise and abyssal plain. These margins are of two types: passive and active margins.

I. **Passive continental margins**

Found along most coastal areas that surround the Atlantic Ocean

Not associated with plate boundaries

Experience little volcanism and few earthquakes



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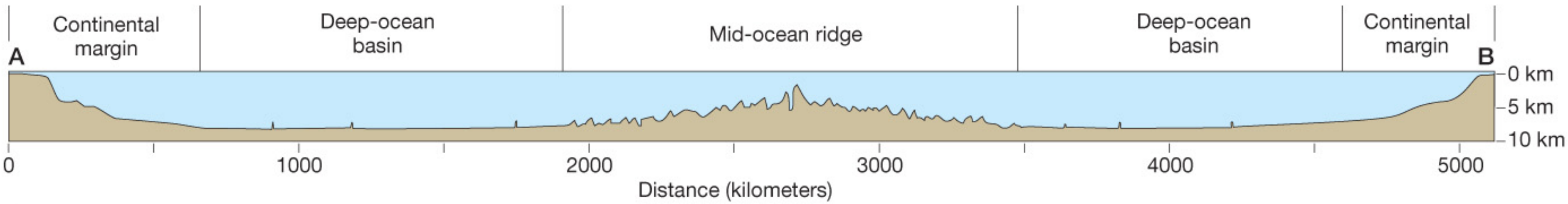

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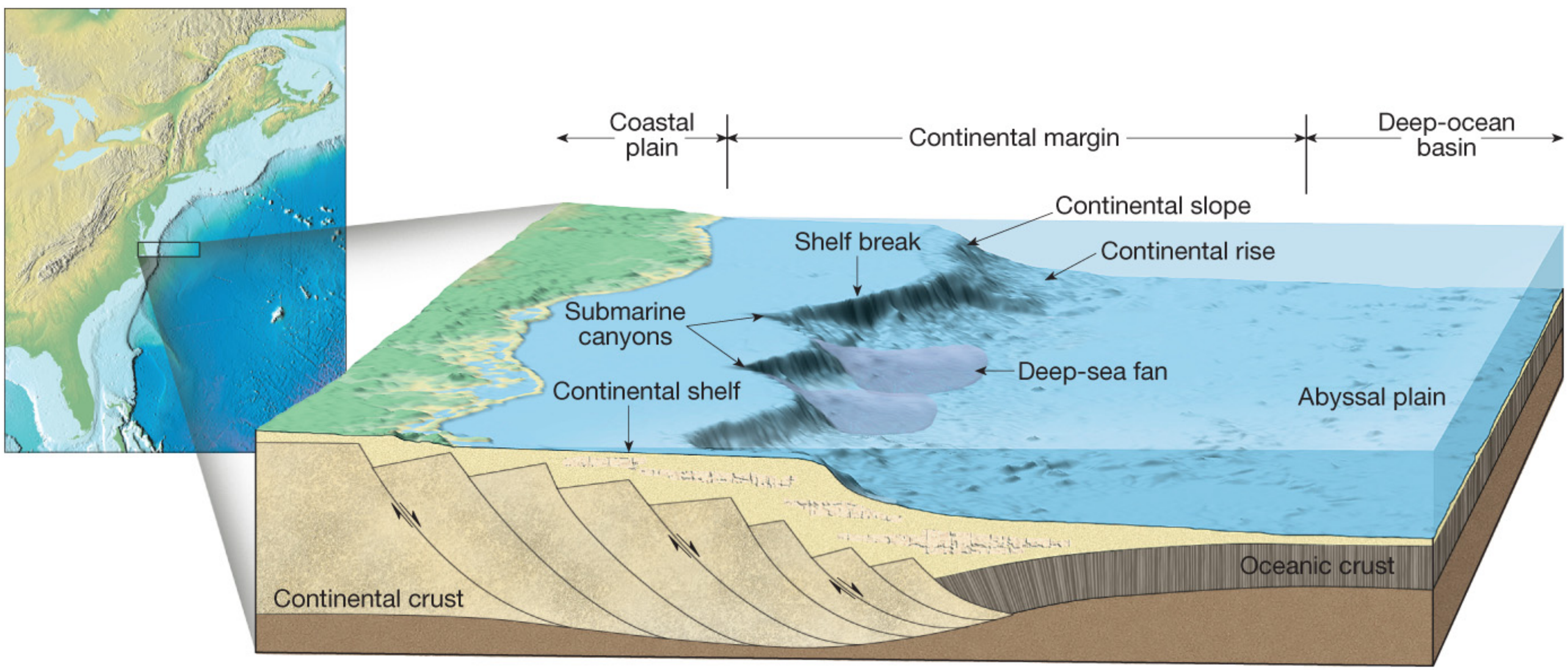
Continental Margins

- Features comprising a passive continental margin
  - Continental shelf
    - Flooded extension of the continent upto shelf
    - Varies greatly in width (average = 80 km)
    - Gently sloping
    - Contains important mineral deposits
    - Some areas are mantled by extensive glacial deposits.



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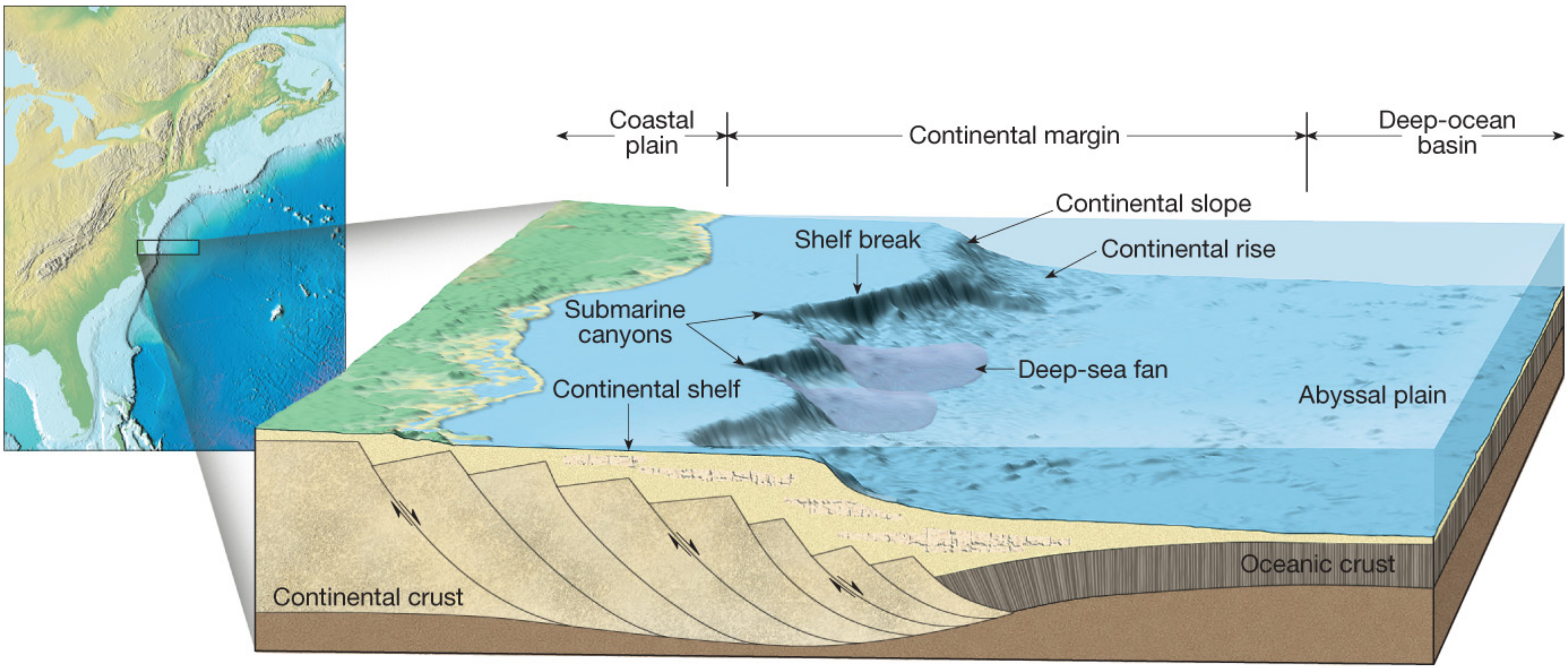
Continental Margins

- Features comprising a passive continental margin
  - Continental slope
    - Marks the seaward edge of the continental shelf
    - Water depth increases rapidly
    - Relatively steep structure (5^{O} – 25^{O})
    - Boundary between continental crust and oceanic crust



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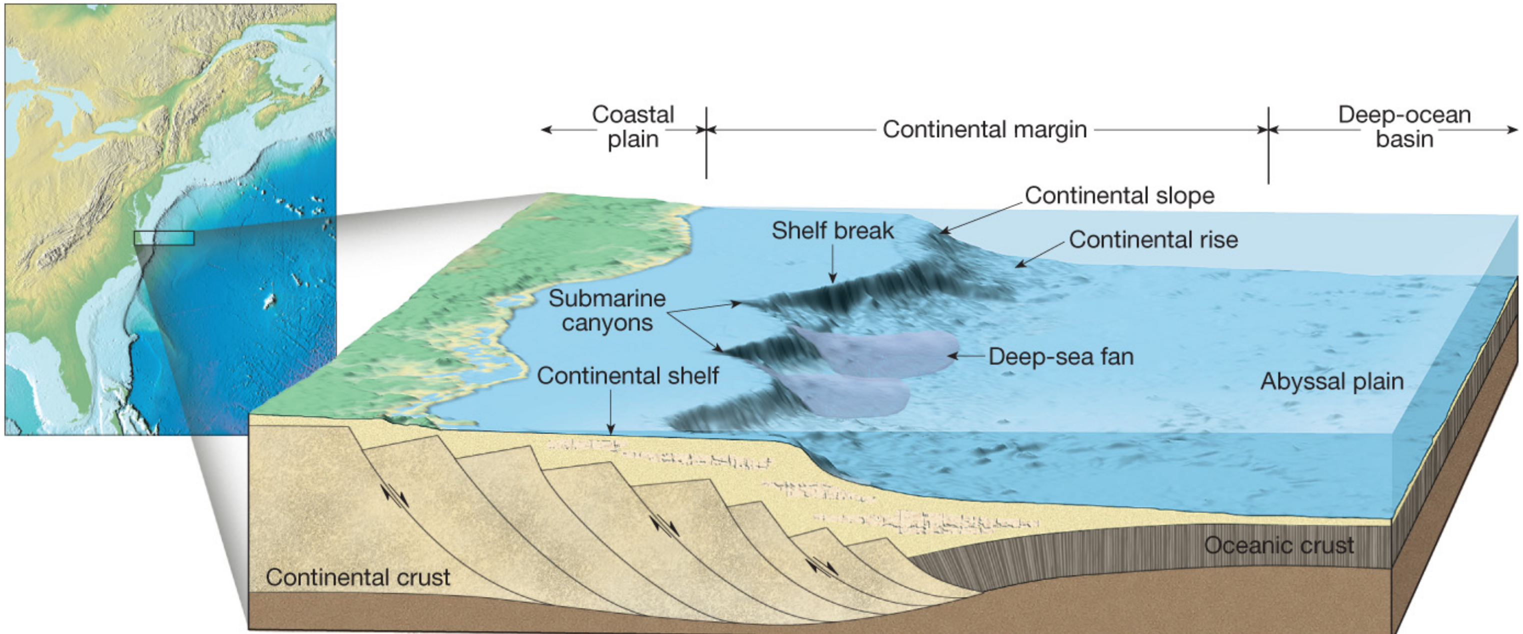
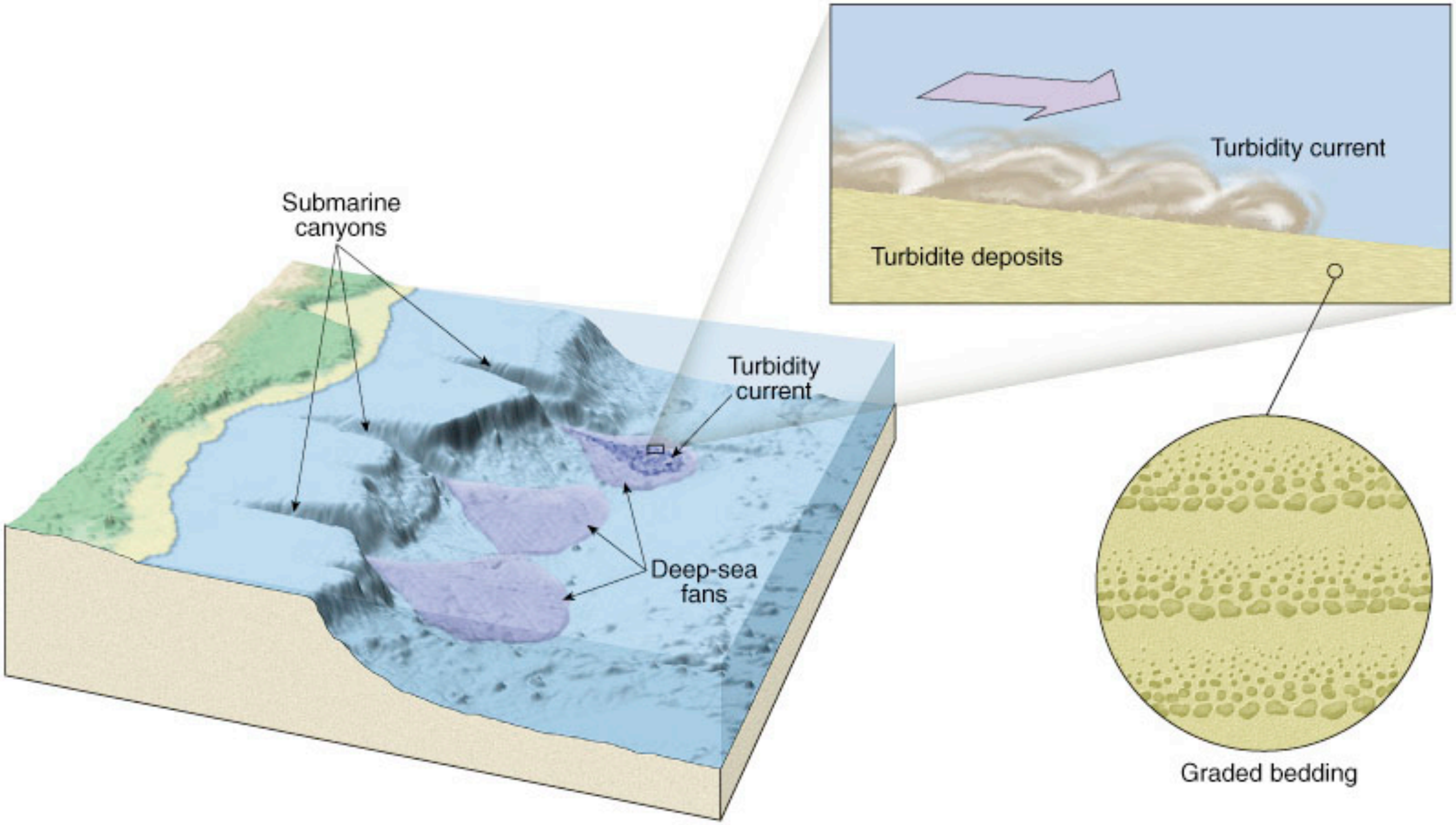
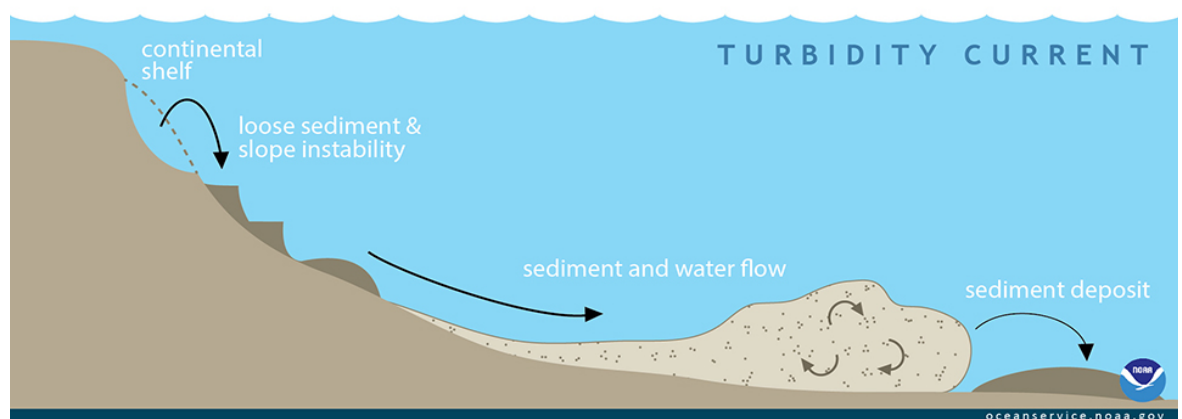
Continental Margins

- Features comprising a passive continental margin
  - Continental rise
    - Sediments become unstable on slope and tumble downward and form continental rise.
    - Found in regions where trenches are absent
    - A continental slope merges into a more gradual incline—the continental rise.
    - Thick accumulation of sediment
    - At the base of the continental slope, turbidity currents deposit sediment that forms deep-sea fans.

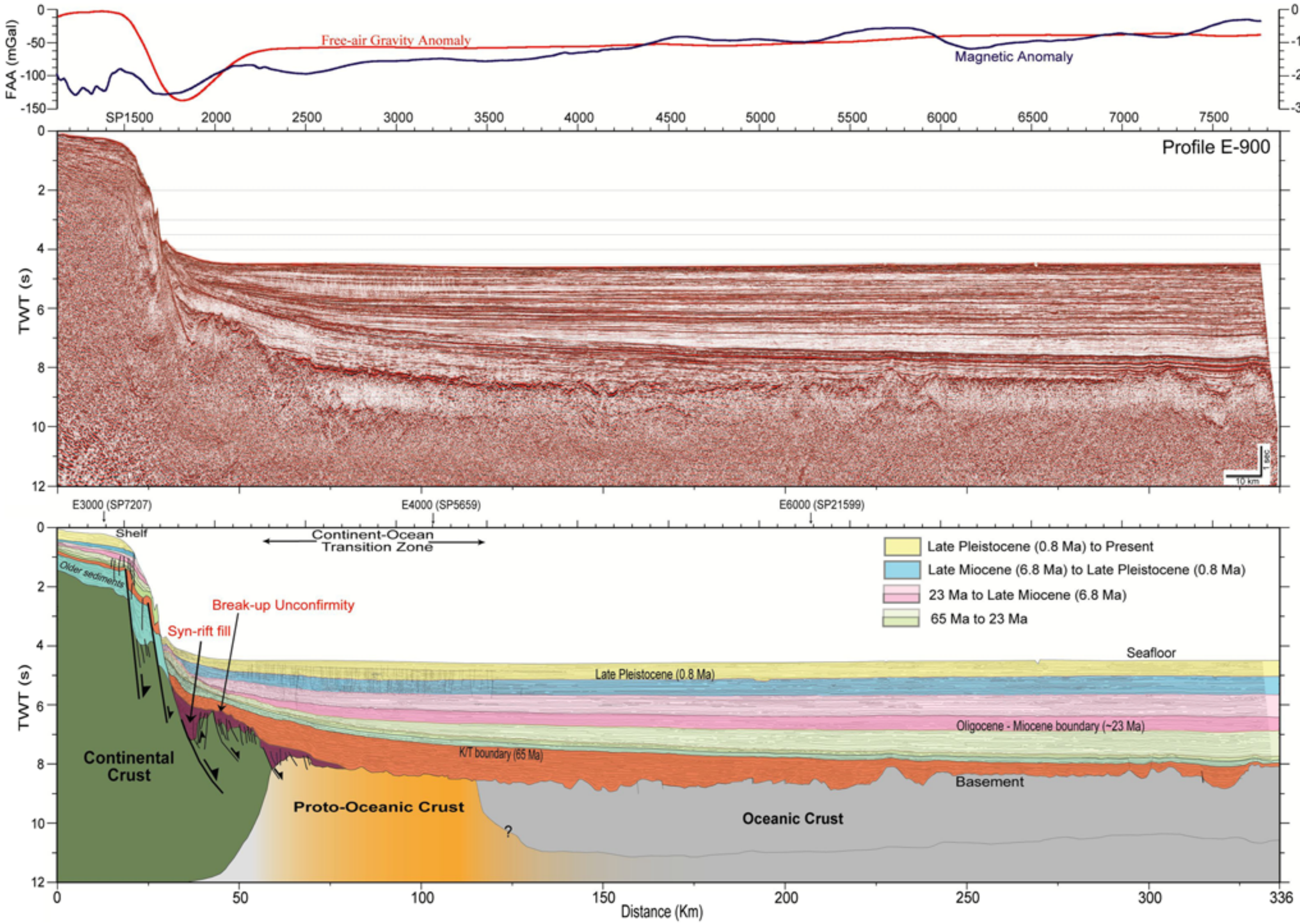


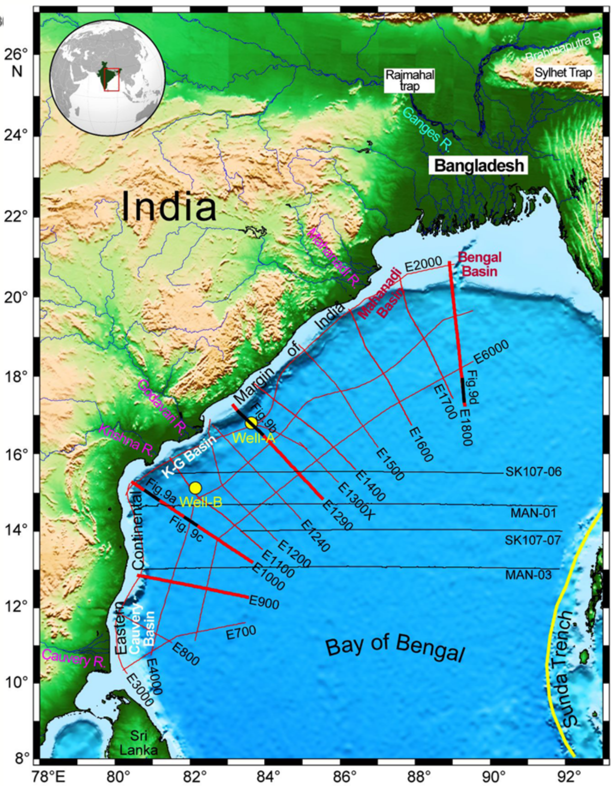
Turbidity current





Passive margin: Krishna-Godavari basin



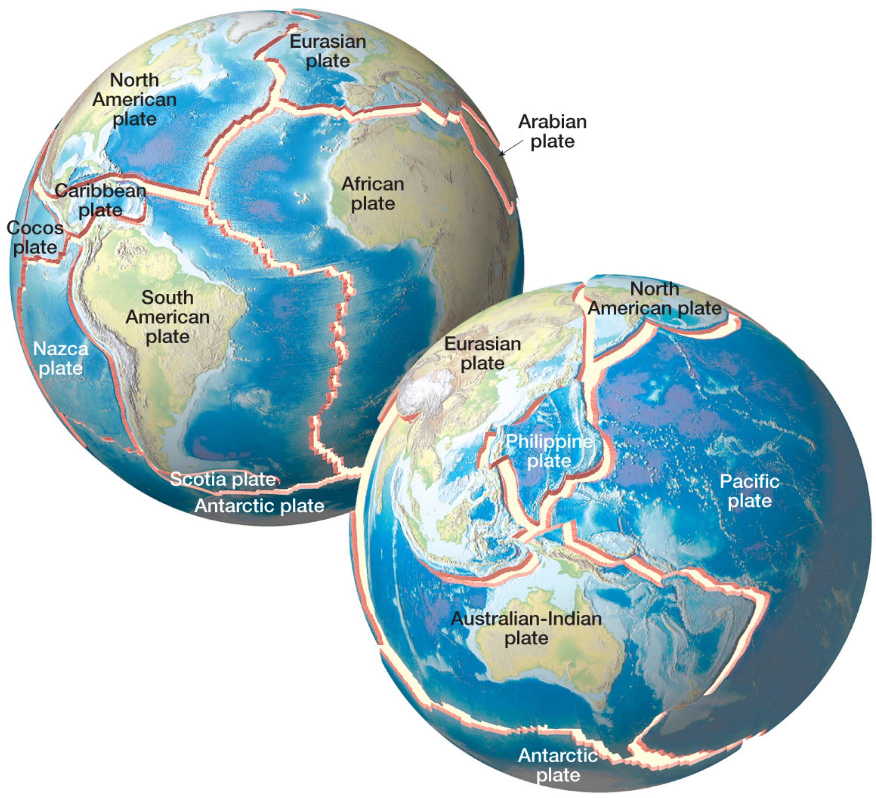


Seismic profile E900 across the offshore Cauvery Basin and adjacent deep-water region. Line drawing of interpreted seismic data together with free-air gravity and magnetic anomaly data are also shown (Ismaiel et al., 2020).

Continental Margins

II. Active continental margins

- The continental slope descends abruptly into a **deep-ocean trench**.
- Located primarily around the Pacific Ocean



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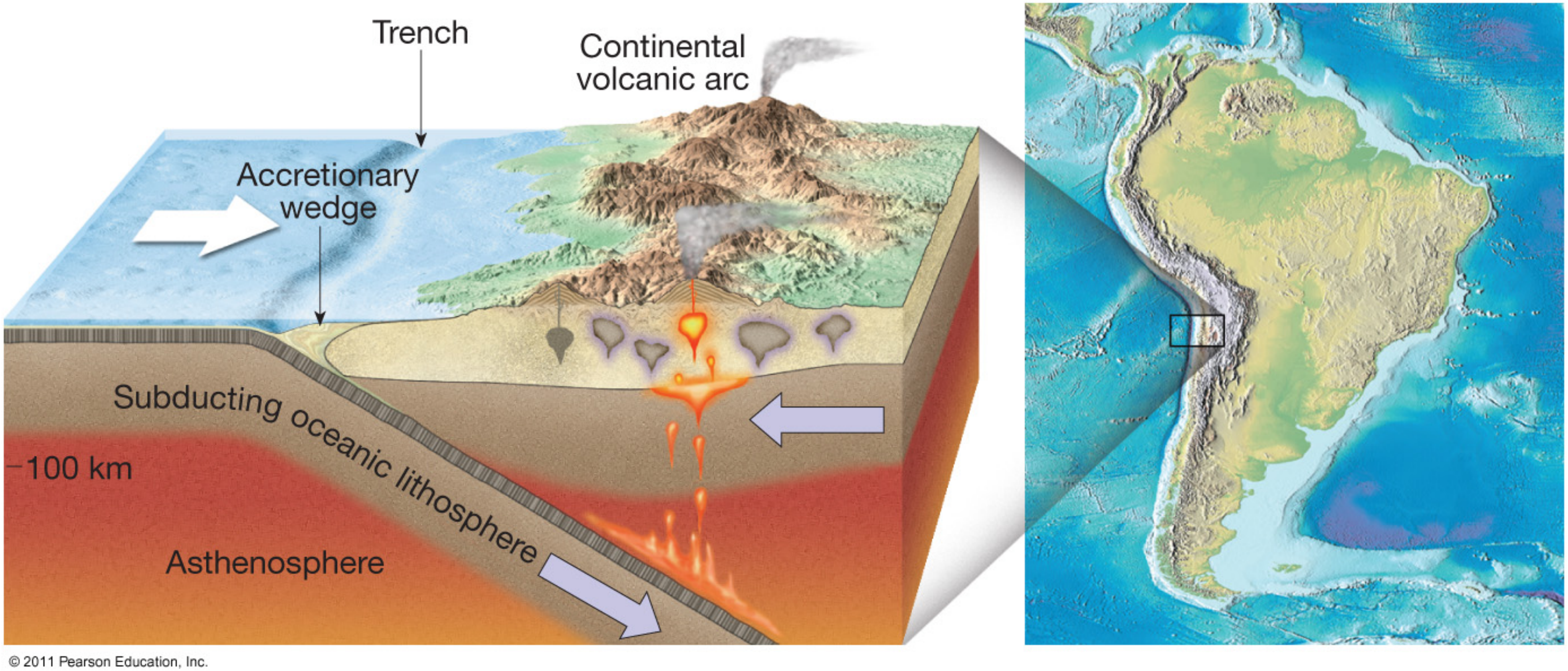
An Active Continental Margin



Accumulations of deformed sediment and scraps of ocean crust form accretionary wedges.

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Detailed plate boundaries and continental margins

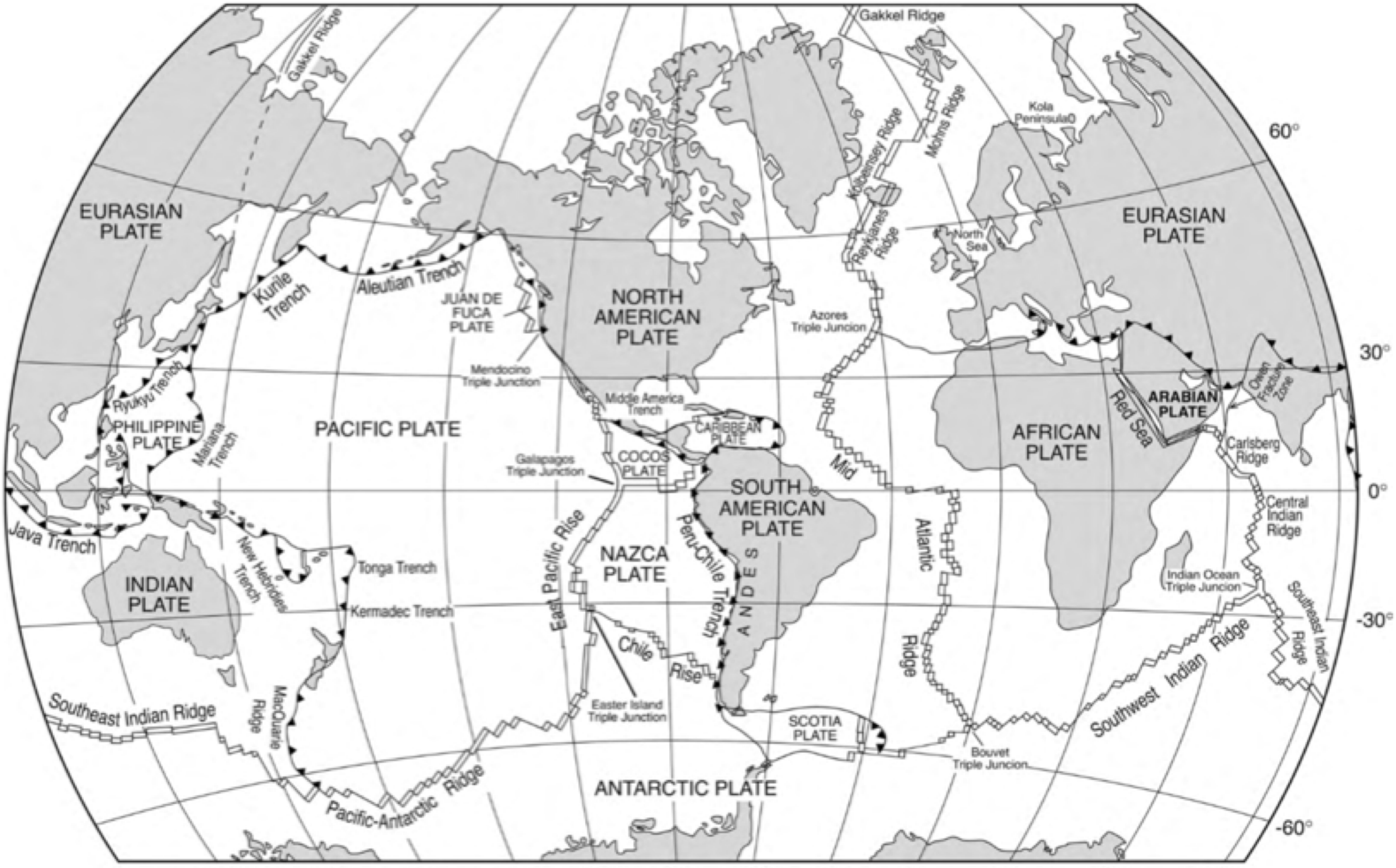


Plate margin seismicity

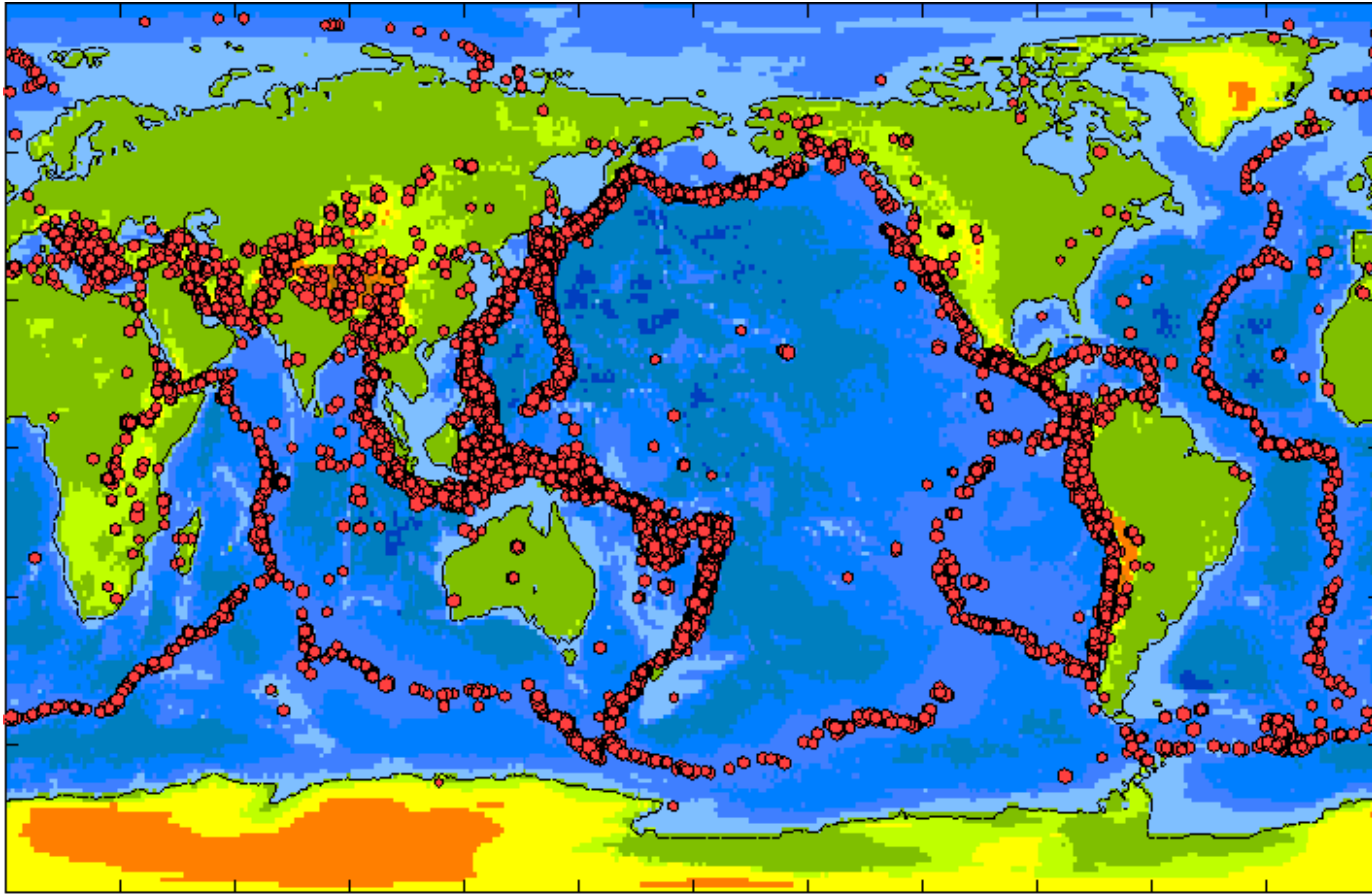
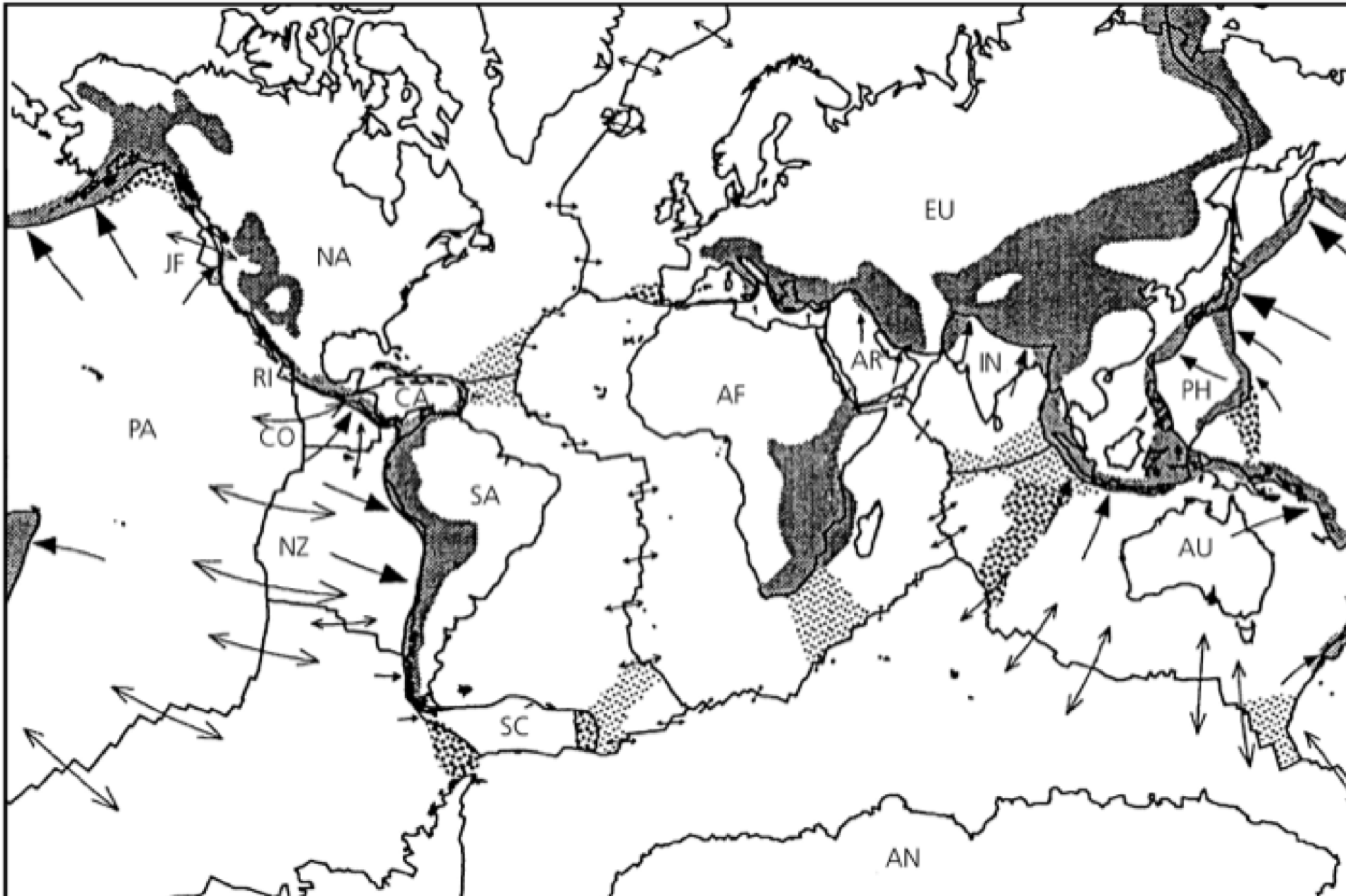
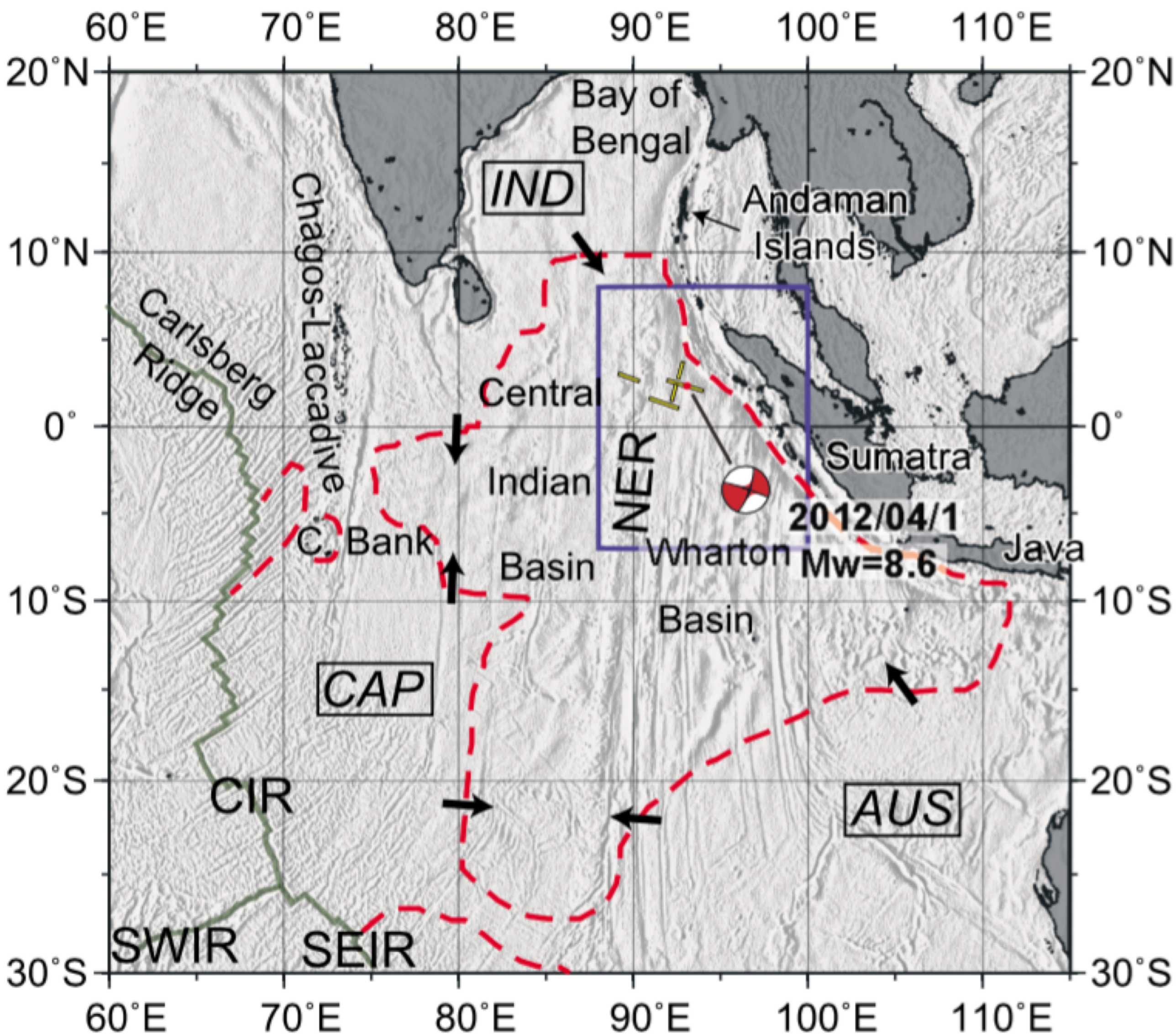


Figure 5.2-4: Relative plate motions and diffuse plate boundary zones.



Diussed plate boundary example

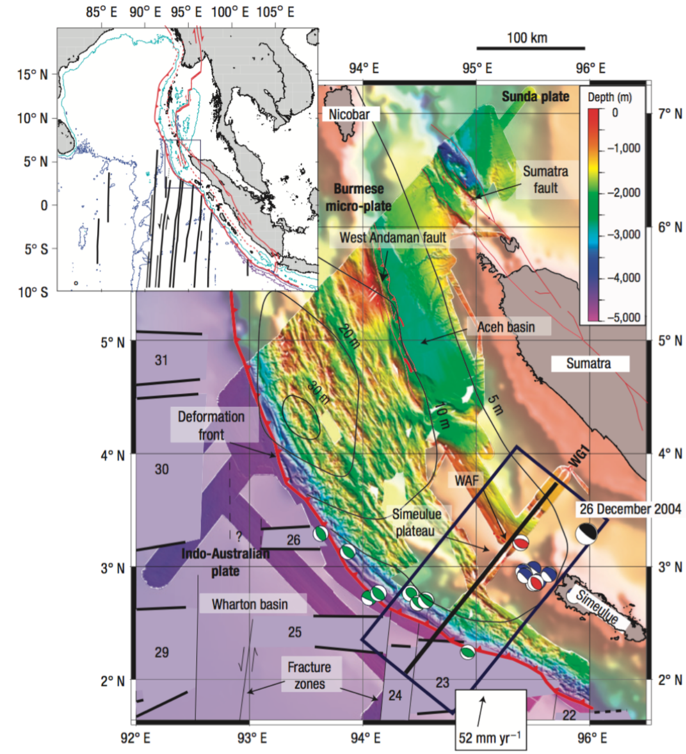


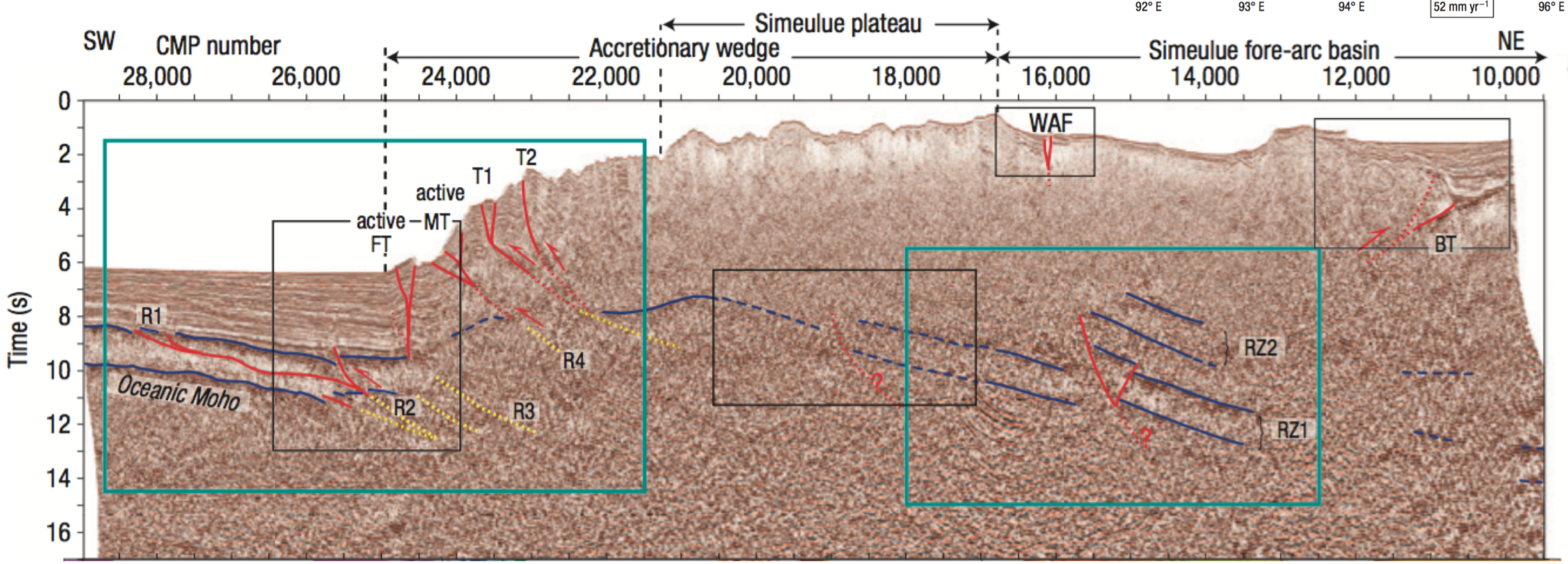
Carton et al., (2014)

Component plates of the Indo-Australian plate (IND: India; AUS: Australia; CAP: Capricorn) and diffuse deformation zones according to Royer and Gordon [1997]. Deformation zones are marked as red dashed contours; active spreading centers (Carlsberg Ridge; SEIR: Southeast Indian Ridge; SWIR: Southwest Indian Ridge; CIR: Central Indian Ridge) are marked as semitransparent green-gray lines. Arrows indicate motion between component plates. Red dot is epicenter location of the 11 April 2012 M_w8.6 great strike-slip earthquake, and bars indicate proposed rupture zone of Yue et al. [2012]. Location of Figure 2 is shown with a blue box. C. Bank: Chagos Bank; NER: Ninety East Ridge.

Examples of Active margins: Sumatra

Seafloor is irregular
Subducting oceanic crust is buckled
Subducting oceanic crust is broken
Thick pile of deposits

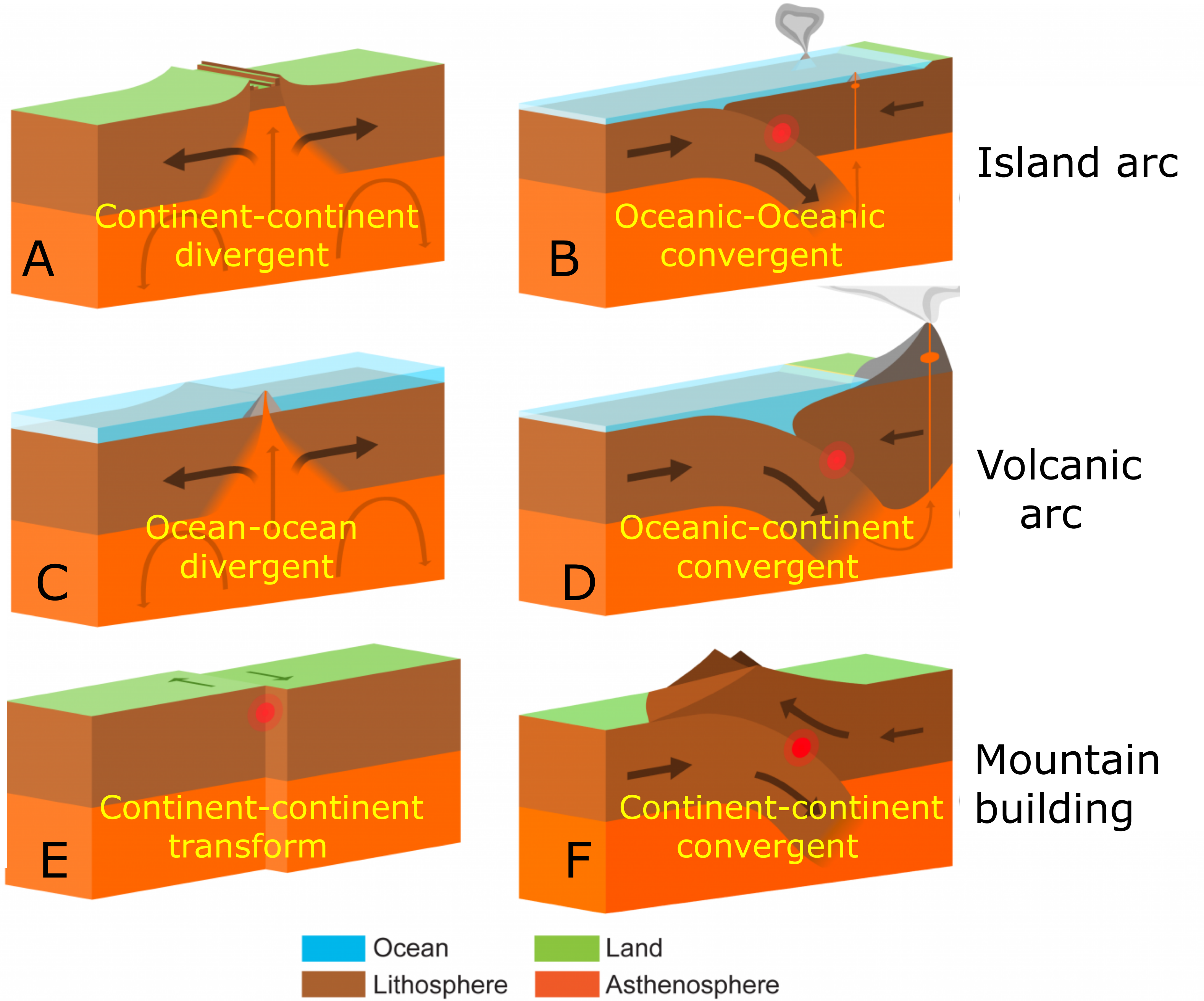




Singh et al., (2008), Nature

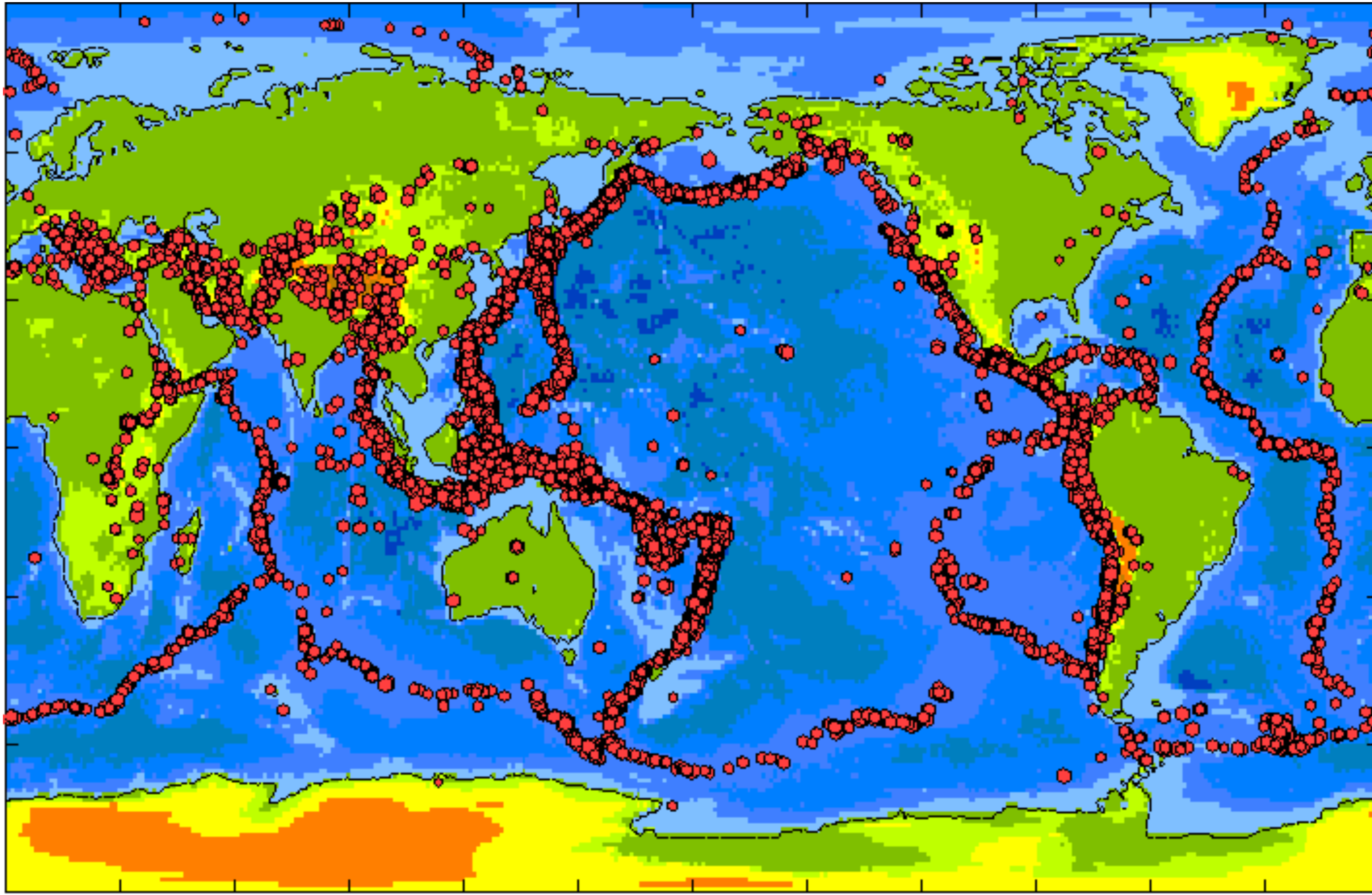
Q1: Identify the tectonic setup and different landforms

Q2: Which setup will form the active and passive continental margins?



Plates and plate boundaries do not stay the same for all time !

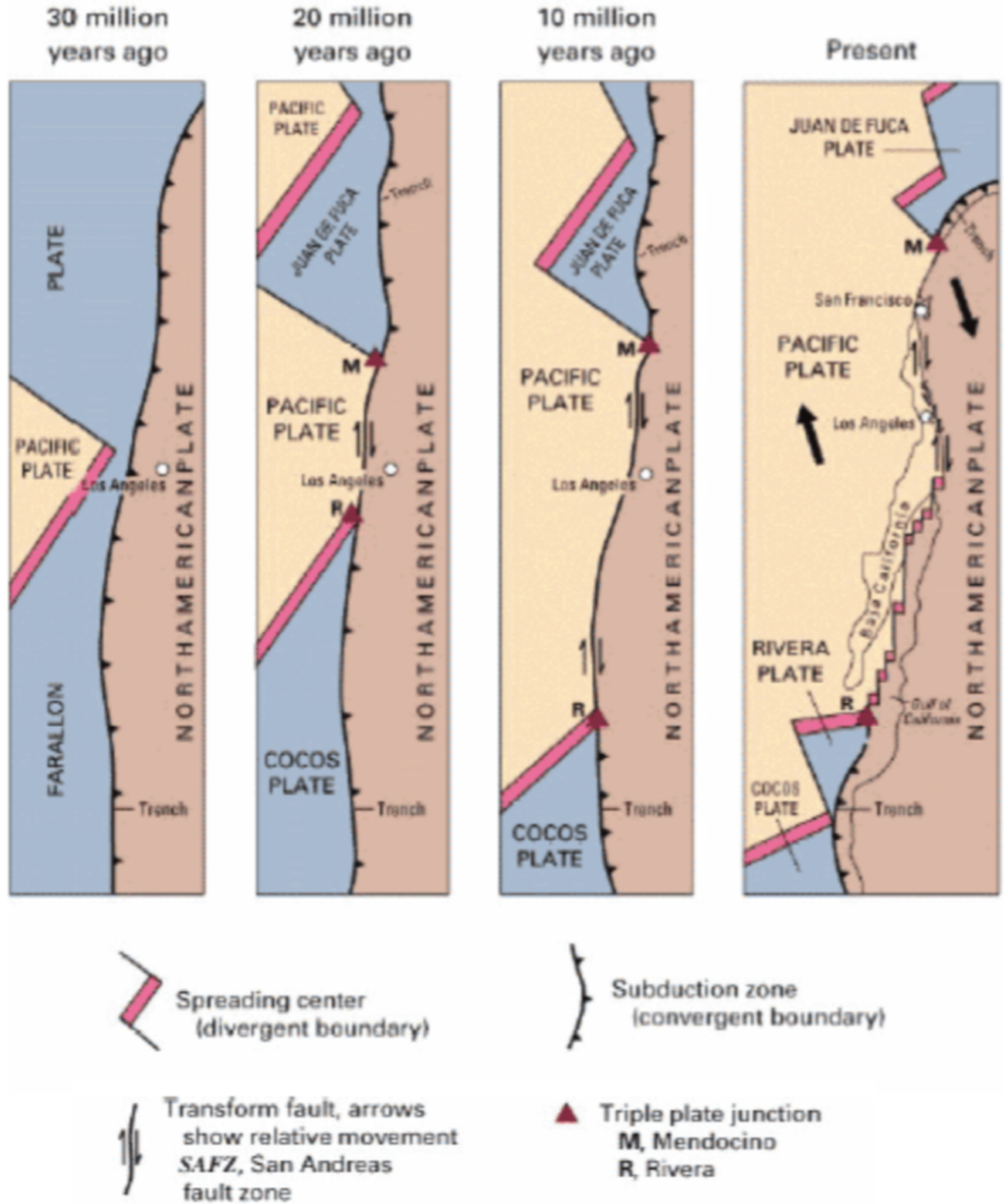
The formation of new plates and destruction of existing plates are the most obvious global reasons why plate boundaries and relative motions change.



Tripple junction:

A *triple junction* is a point at which three plates meet.

They are important as they provide a tool to calculate kinematic evolution of plate boundaries; and their motion cause significant reworking of lithospheric material.



Features of the Deep-Ocean Basin

I. Deep-ocean trench

- Long, relatively narrow features
- Deepest parts of ocean
- Most are located in the Pacific Ocean.
- Sites where moving lithospheric plates plunge into the mantle
- Associated with volcanic activity
- Often paralleled by arc-shaped row of active volcanoes (volcanic island arc; continental volcanic arc)

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Earth's Deep-Ocean Trenches

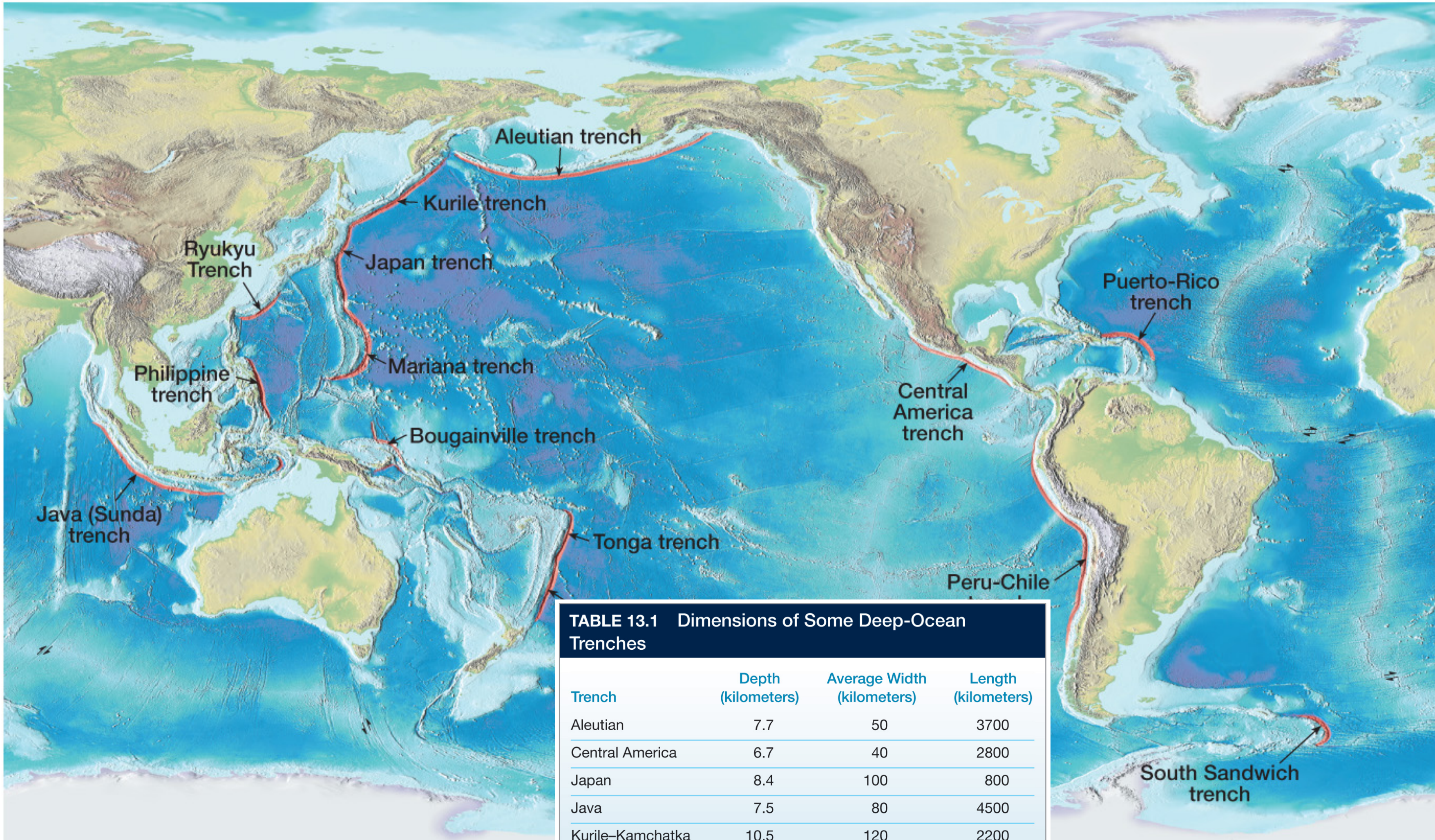

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TABLE 13.1 Dimensions of Some Deep-Ocean Trenches

Trench	Depth (kilometers)	Average Width (kilometers)	Length (kilometers)
Aleutian	7.7	50	3700
Central America	6.7	40	2800
Japan	8.4	100	800
Java	7.5	80	4500
Kurile–Kamchatka	10.5	120	2200
Mariana	11.0	70	2550
Peru–Chile	8.1	100	5900
Philippine	10.5	60	1400
Puerto Rico	8.4	120	1550
South Sandwich	8.4	90	1450
Tonga	10.8	55	1400

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Features of the Deep-Ocean Basin

II. Abyssal plains

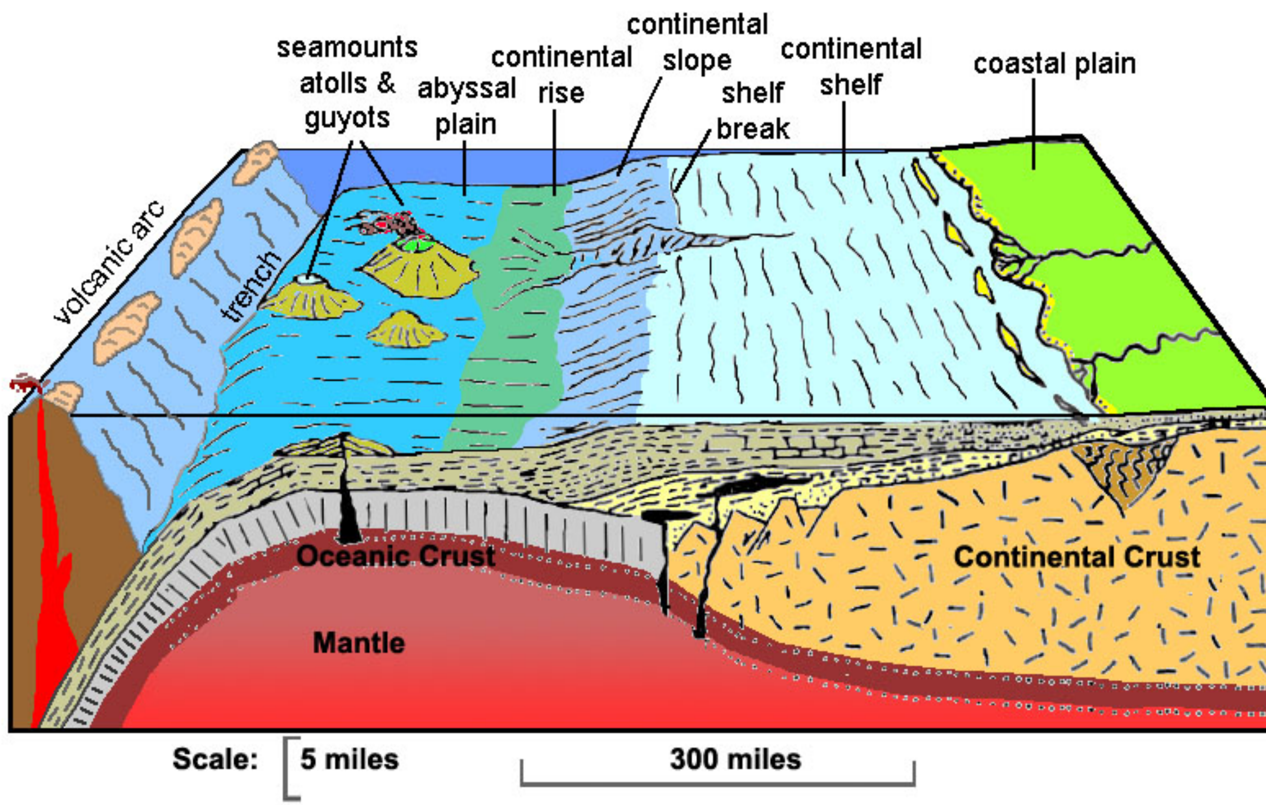
- Likely the most level places on Earth
- Sites of thick accumulations of sediment
- Found in all oceans

•**Seamount:** It is a mountain with pointed summits, rising from the seafloor that **does not reach the surface** of the ocean. Seamounts are volcanic in origin. These can be 3,000-4,500 m tall.

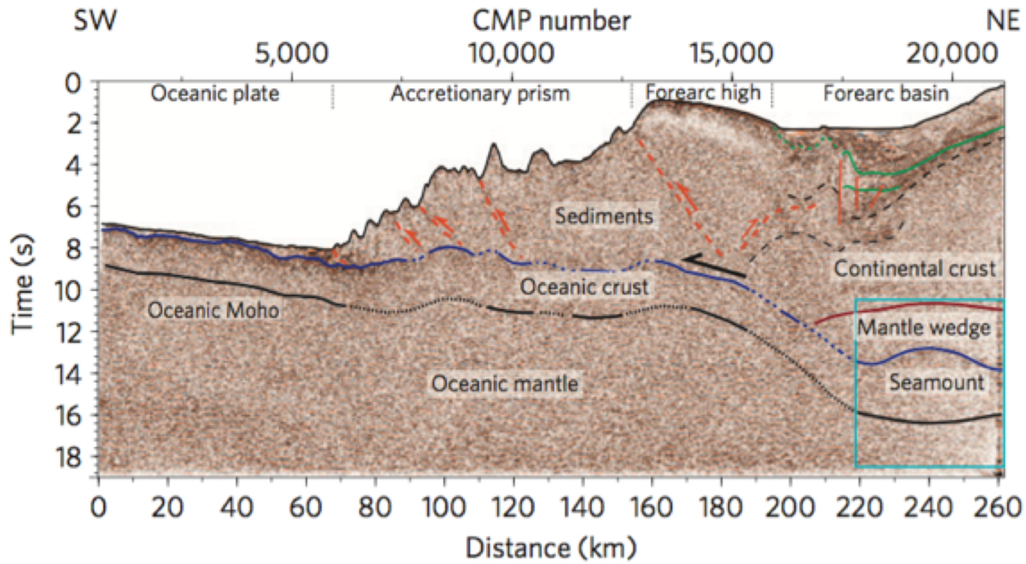
•**Guyots:** The flat topped mountains (seamounts) are known as guyots.

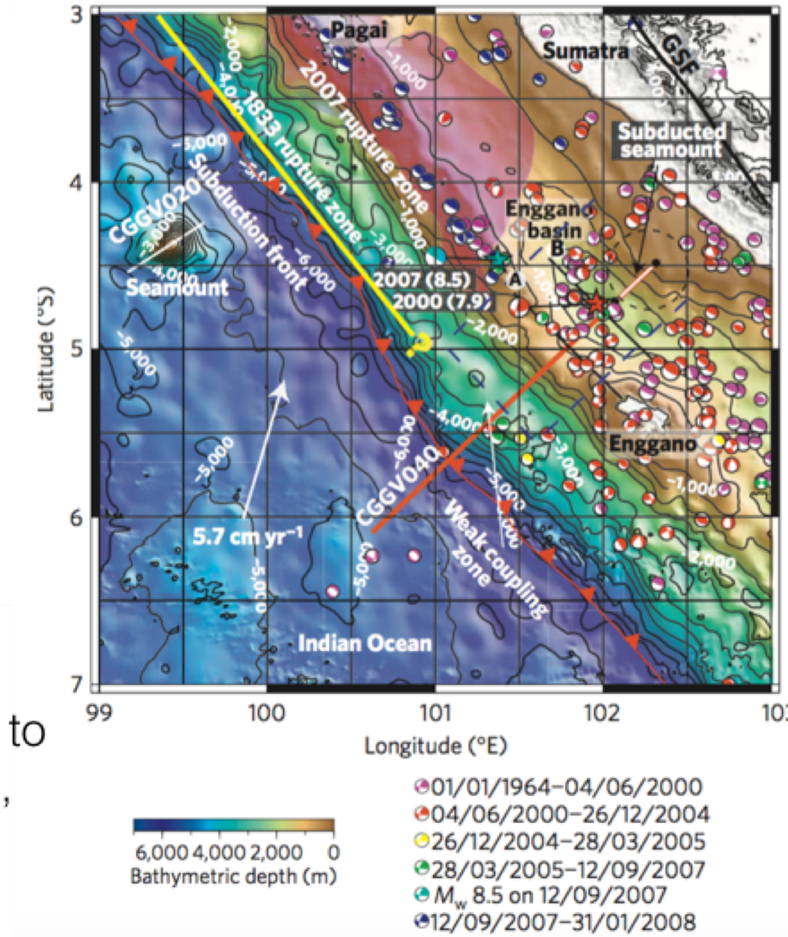
Atoll: These are low islands found in the tropical oceans consisting of coral reefs surrounding a central depression.

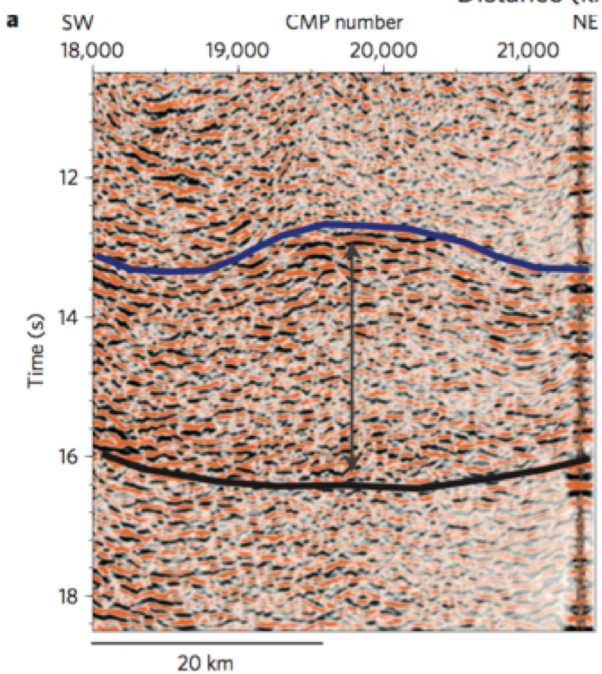
It may be a part of the sea (lagoon), or sometimes form enclosing a body of fresh, brackish, or highly saline water.



Case Study 1: Sumatra-Andaman Subduction system





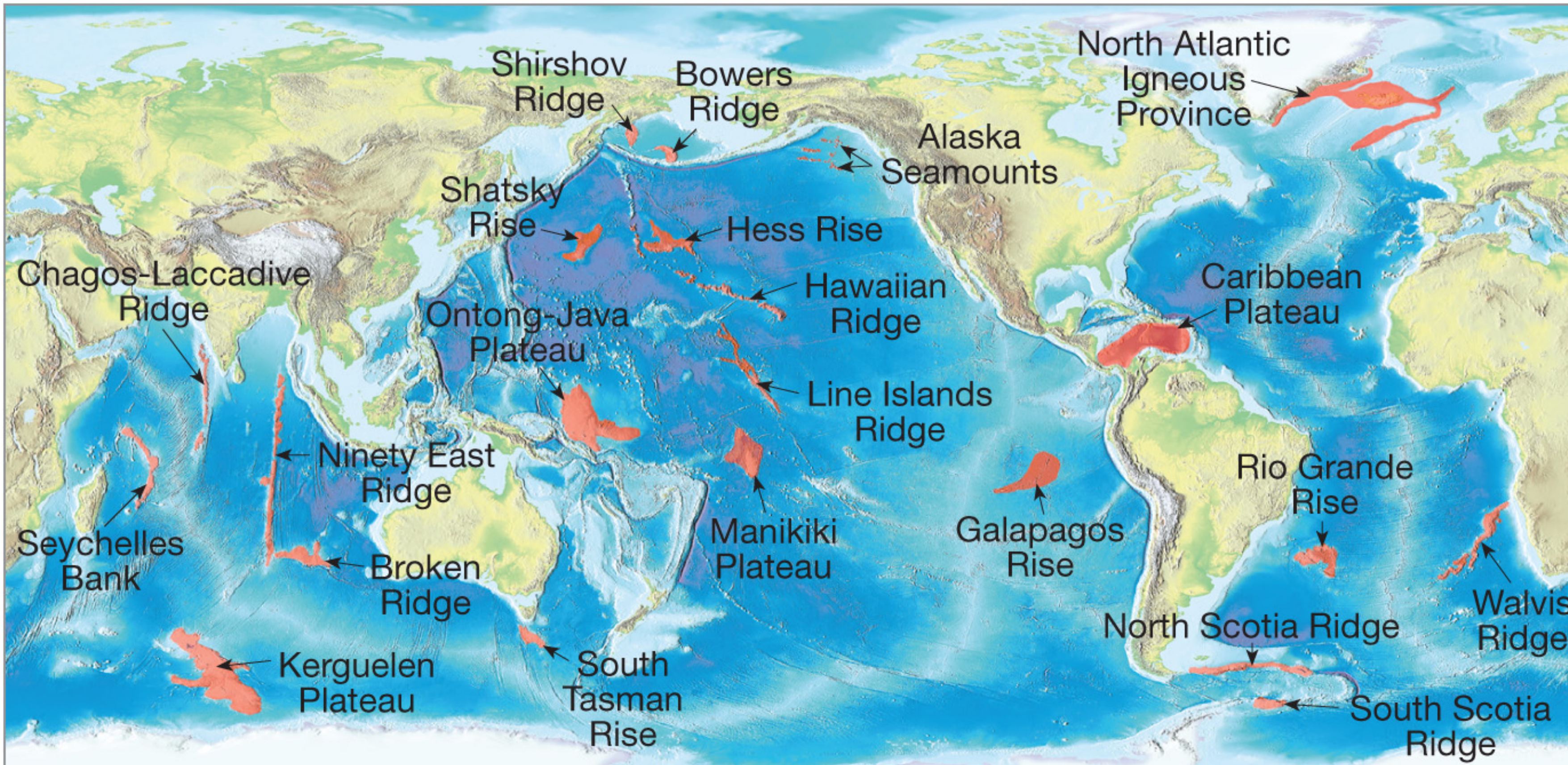


- Seamount subduction links to the plate locking, seismogenesis, crustal erosion

- Evidence of subjected seamount is reported in Sumatra from high-resolution seismic images at 30-40 km depth below forearm mantle, reducing maximum size of the megathrust

Singh et al., (2011)

Distribution of Ocean Plateaus, Hot Spots, and Submerged Crustal Fragments



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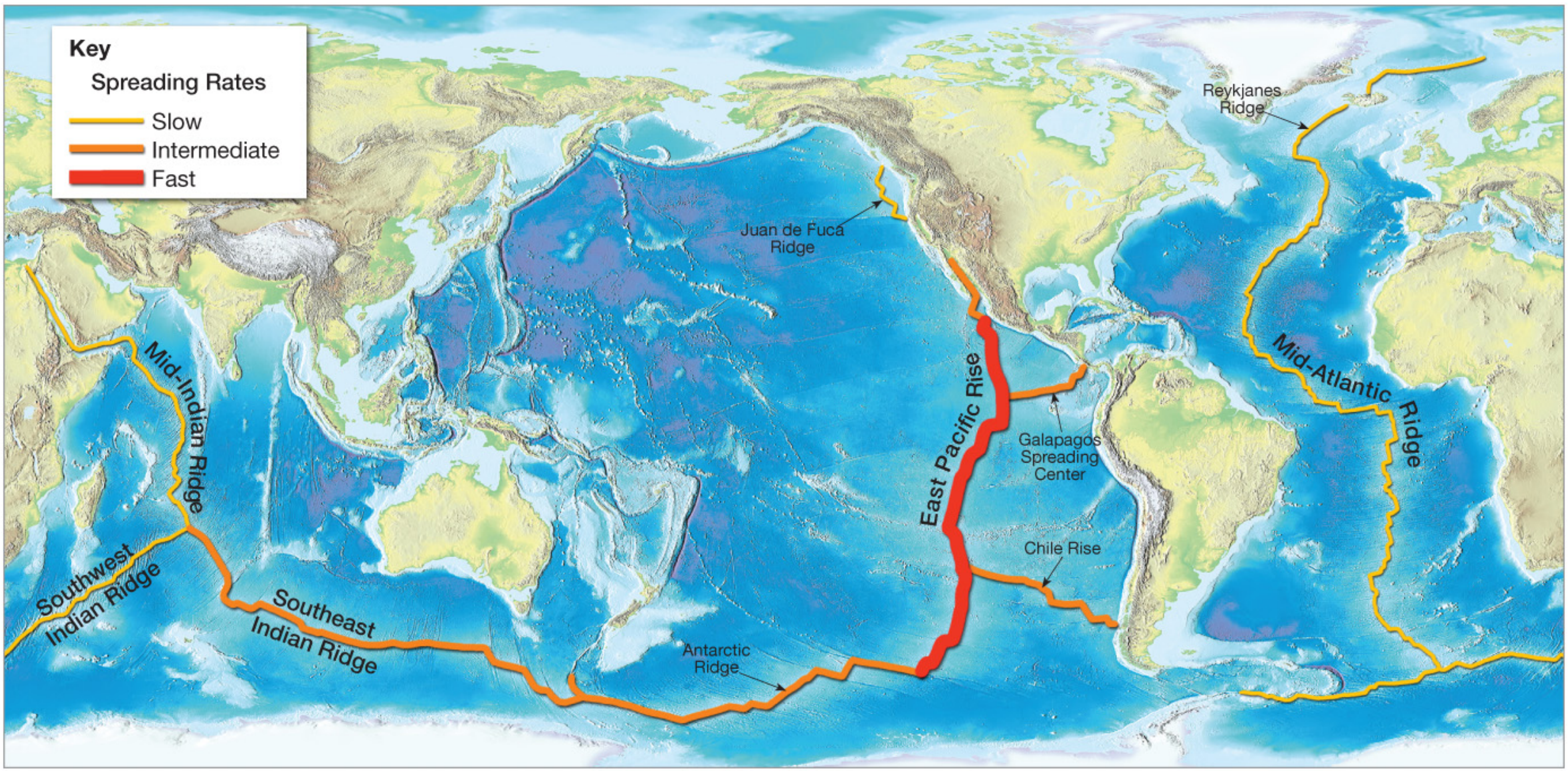
Distribution of the Oceanic Ridge System



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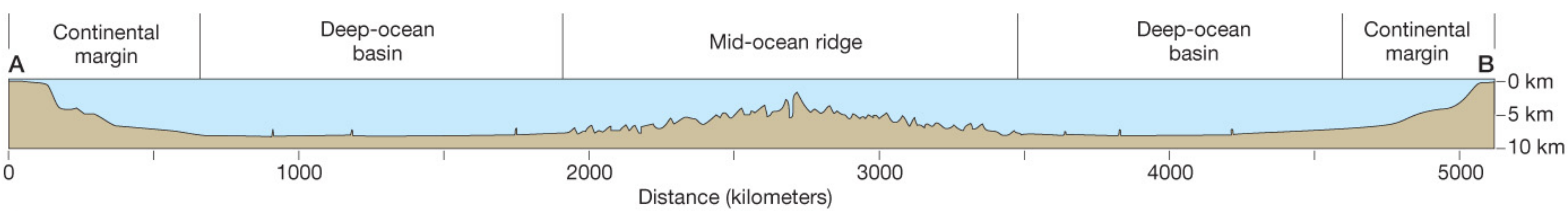
Oceanic Ridges and Seafloor Spreading

- **Why are oceanic ridges elevated?**
  - **The primary reason is because newly created oceanic lithosphere is hot and occupies more volume than cooler rocks.**
  - **As the basaltic crust travels away from the ridge crest, it is cooled by seawater.**
  - **As the lithosphere moves away, it thermally contracts and becomes more dense.**



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Anatomy of the Oceanic Ridge
Oceanic Ridges and Seafloor Spreading

- **Spreading rates and ridge topography**
  - **Ridge systems exhibit topographic differences.**
  - **Topographic differences are controlled by spreading rates.**
    - **At *slow spreading rates* (1 to 5 centimeters per year), a prominent rift valley develops along the ridge crest that is usually 30 to 50 kilometers across and 1500 to 3000 meters deep.**
    - **Mid-Atlantic; Mid-Indian**

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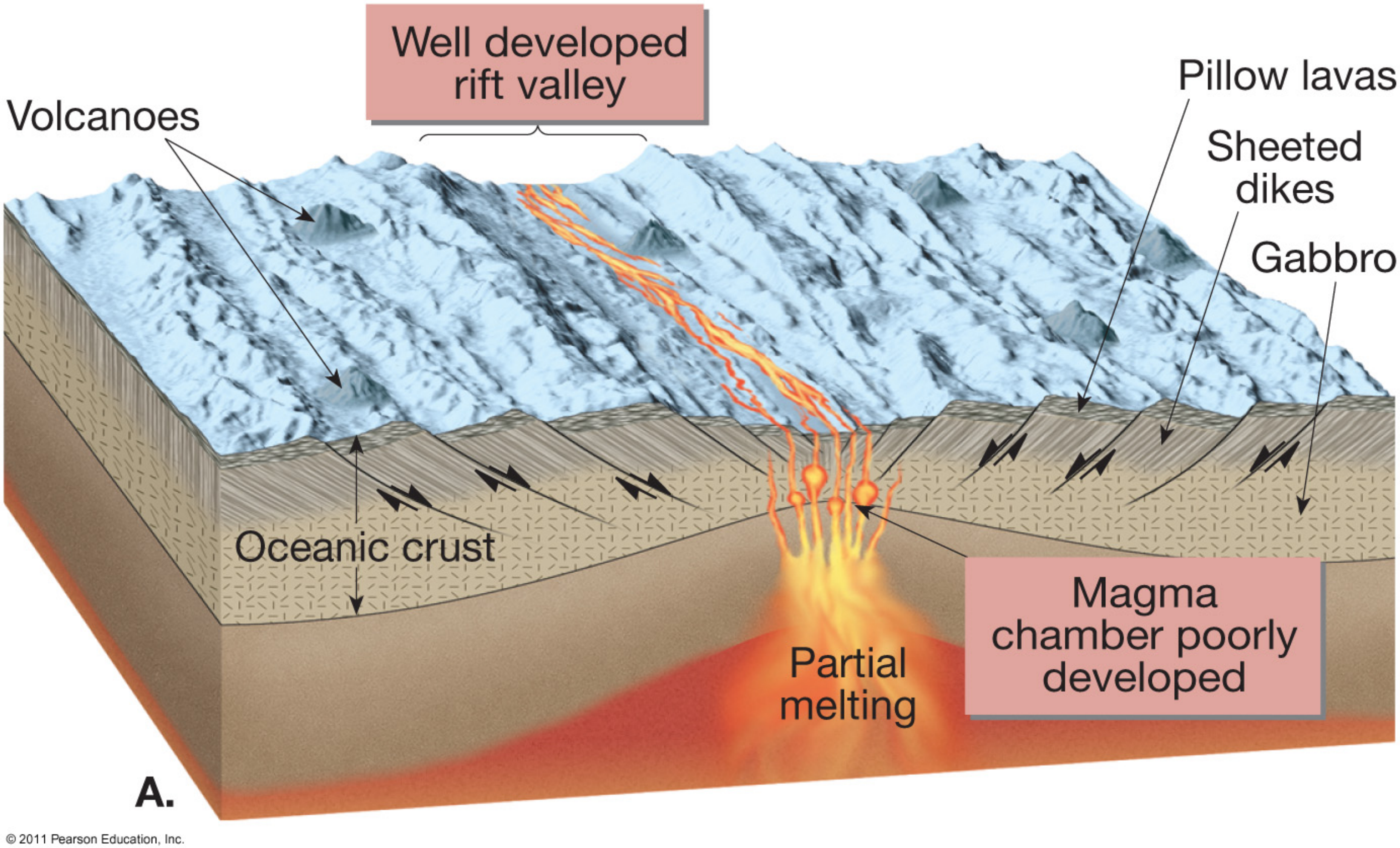
Slow Spreading Oceanic Ridge



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Oceanic Ridges and Seafloor Spreading

- Spreading rates and ridge topography
  - Topographic differences are controlled by spreading rates.
    - At *intermediate spreading rates* (5 to 9 centimeters per year), rift valleys that develop are shallow and less than 200 meters deep (e.g., Galapagos Ridge)
    - At *spreading rates greater than 9 cm / year*, no median rift valley develops and these areas are usually narrow and extensively faulted (e.g., East Pacific Rise)

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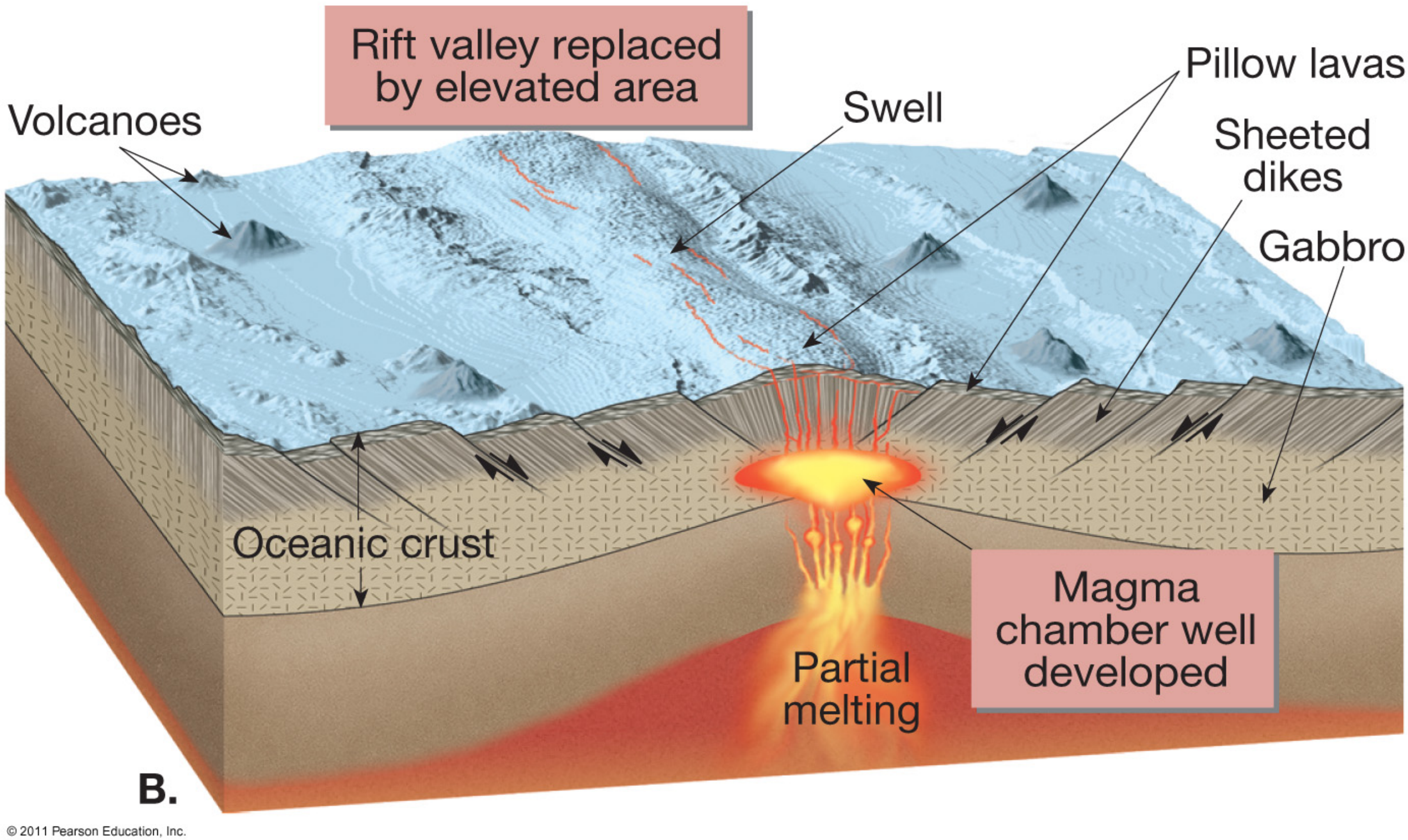
Fast Spreading Oceanic Ridge



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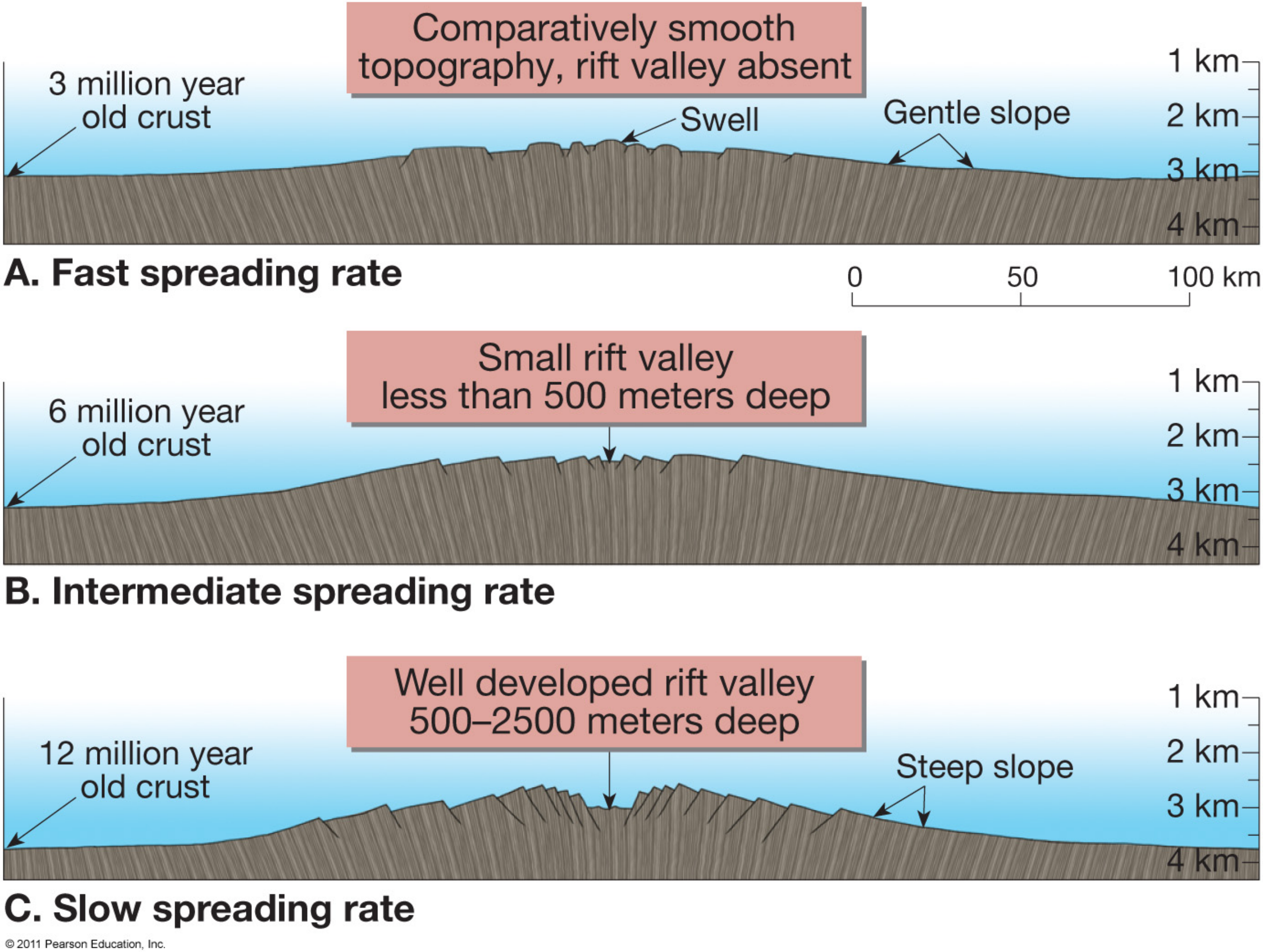

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Questions

1. The oldest rocks of the oceanic crust are found in deep ocean trenches far away from active, mid-ocean ridges.
Answer: TRUE/ FALSE

2. The boundaries of the Earth's tectonic plates are shown as zones of high seismic activity.
Answer: TRUE / FALSE

3. The ________ lies at the base of the continental slope.
A) offshore shelf
B) off-slope reef
C) continental rift
D) continental rise

4. Spreading rates along the East Pacific Rise are relatively fast with many areas spreading more than 9 centimeters per year.
Answer: TRUE / FALSE

5. Island arc forms in ________ setup
A) Ocean-continent transform
B) Ocean-ocean convergent
C) Continent-continent divergent
D) Ocean-continent subduction