Lecture Plate Boundaries

Present day movement, accretion, reformation, segregation

Three types of plate boundaries
1. Divergent
2. Convergent
3. Transform

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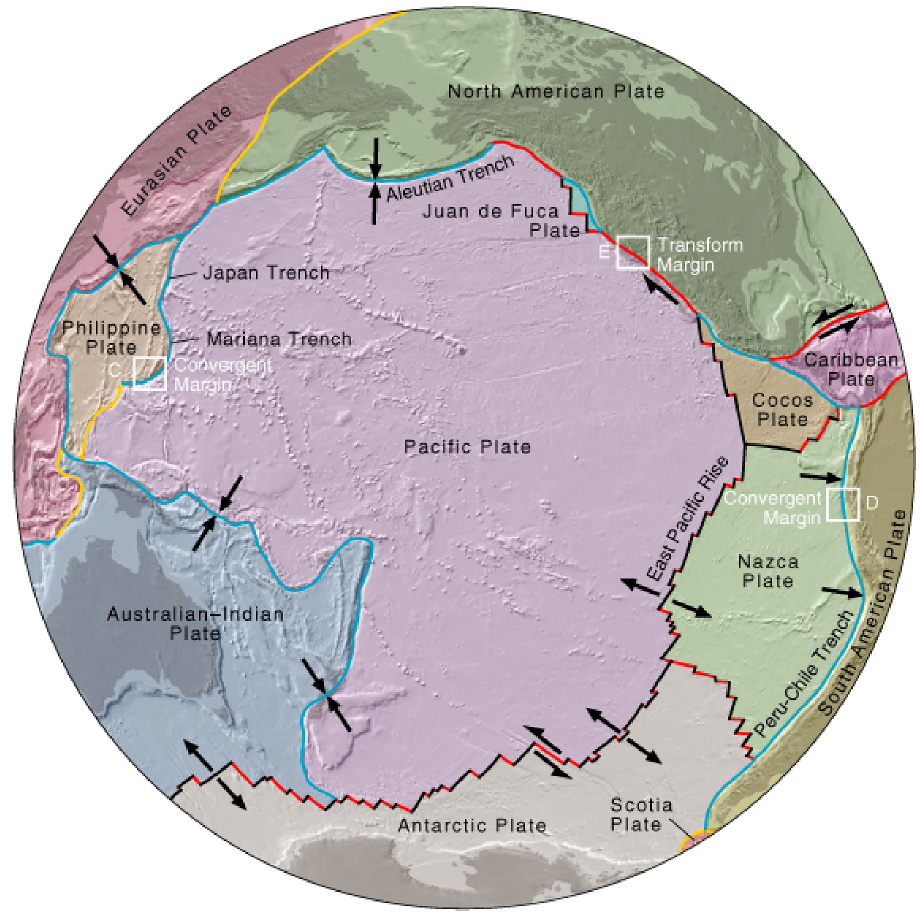
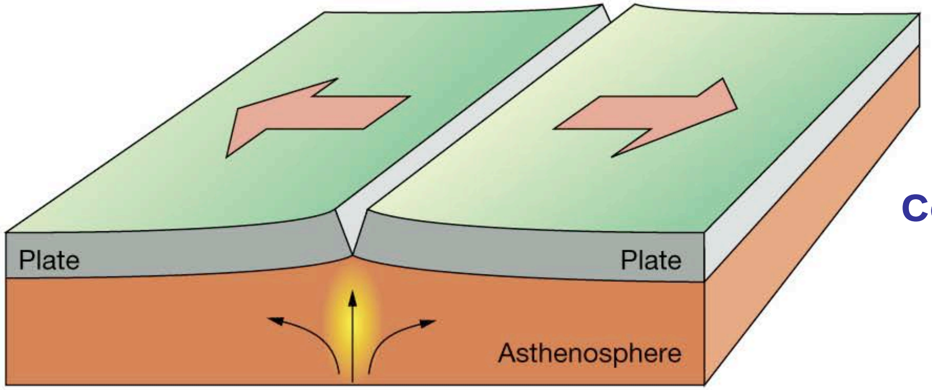


Fig. 4-4

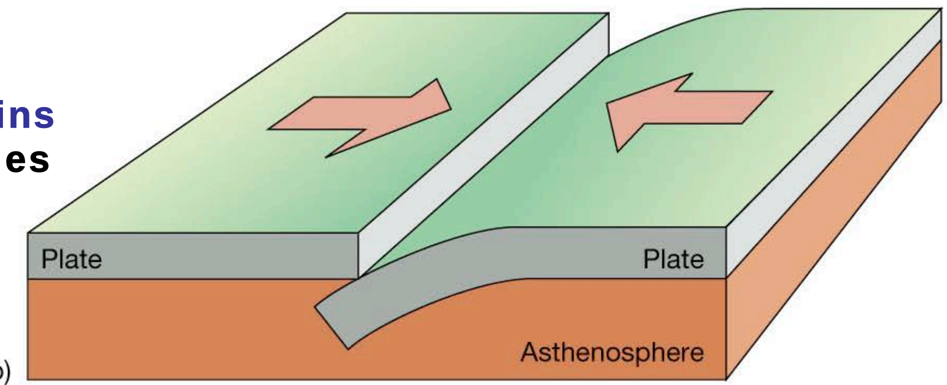
Type of boundary between plates:



(a)

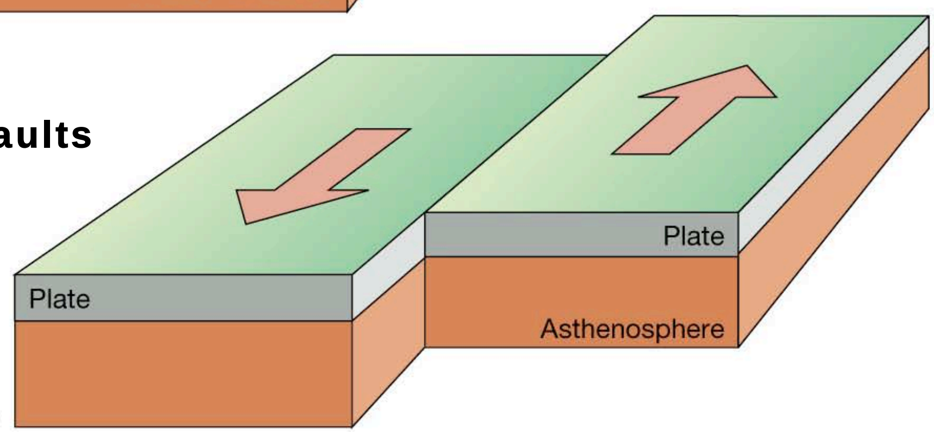
Constructive margins → Midocean ridges

Destructive margins
→ Subduction zones

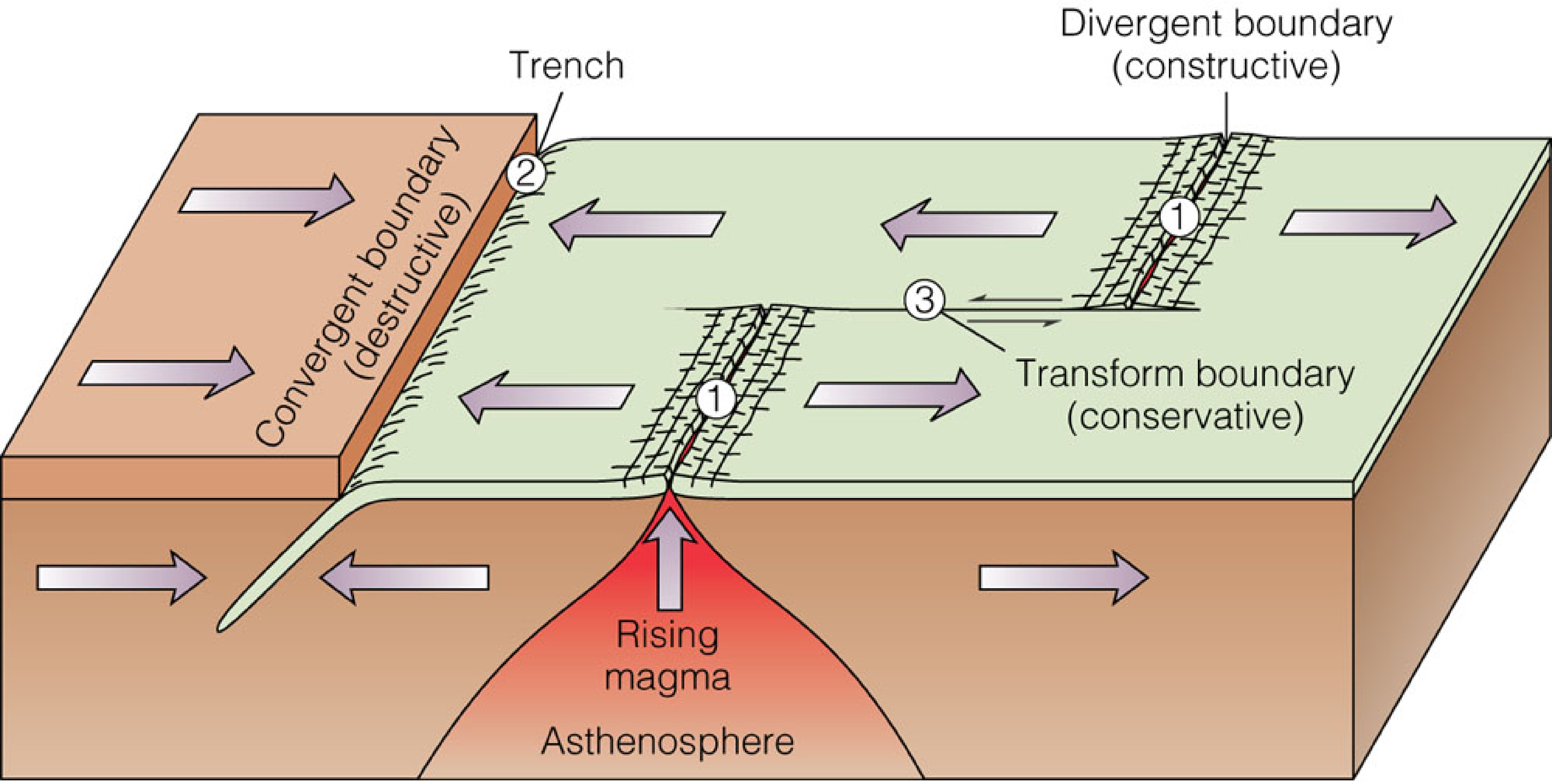


(b)

Conservative margins → Transform faults



(c)



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1. Divergent
2. Convergent
3. Transform

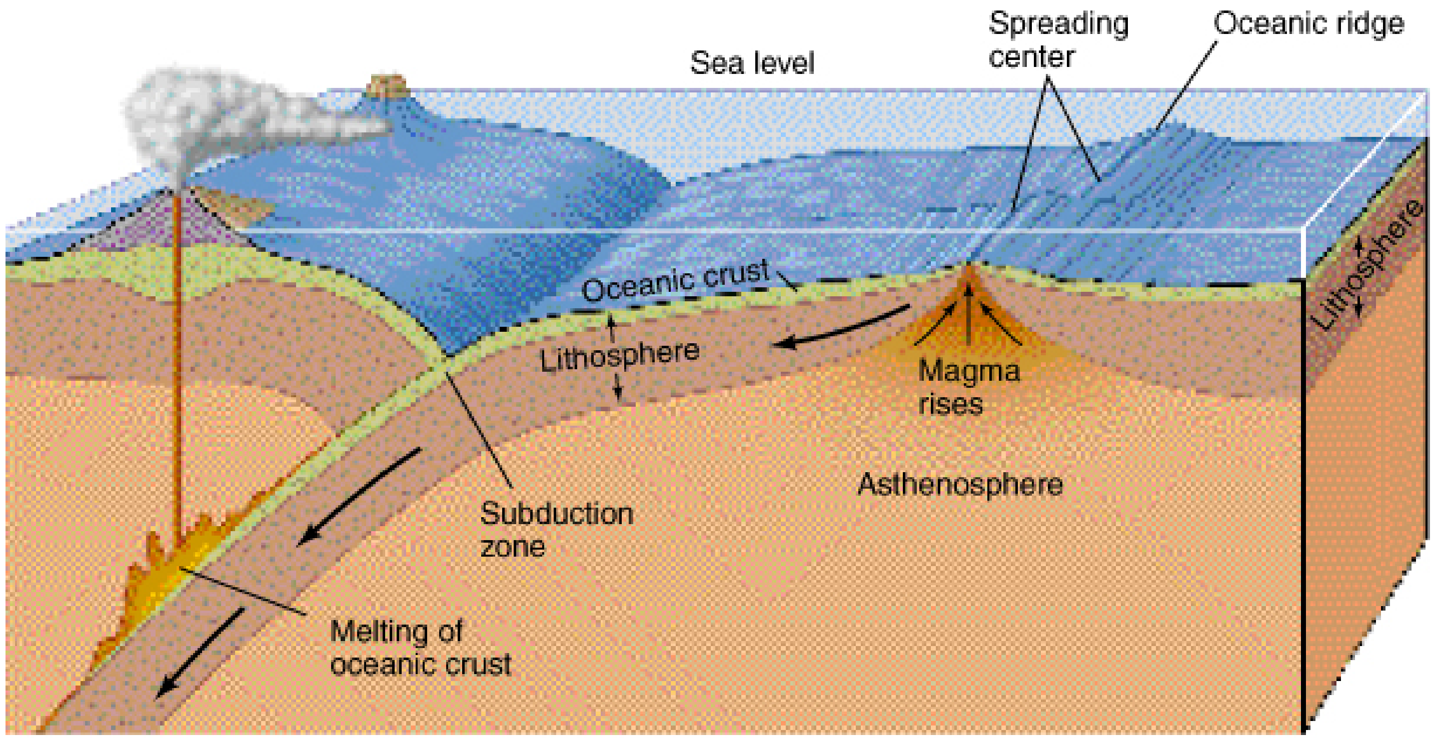

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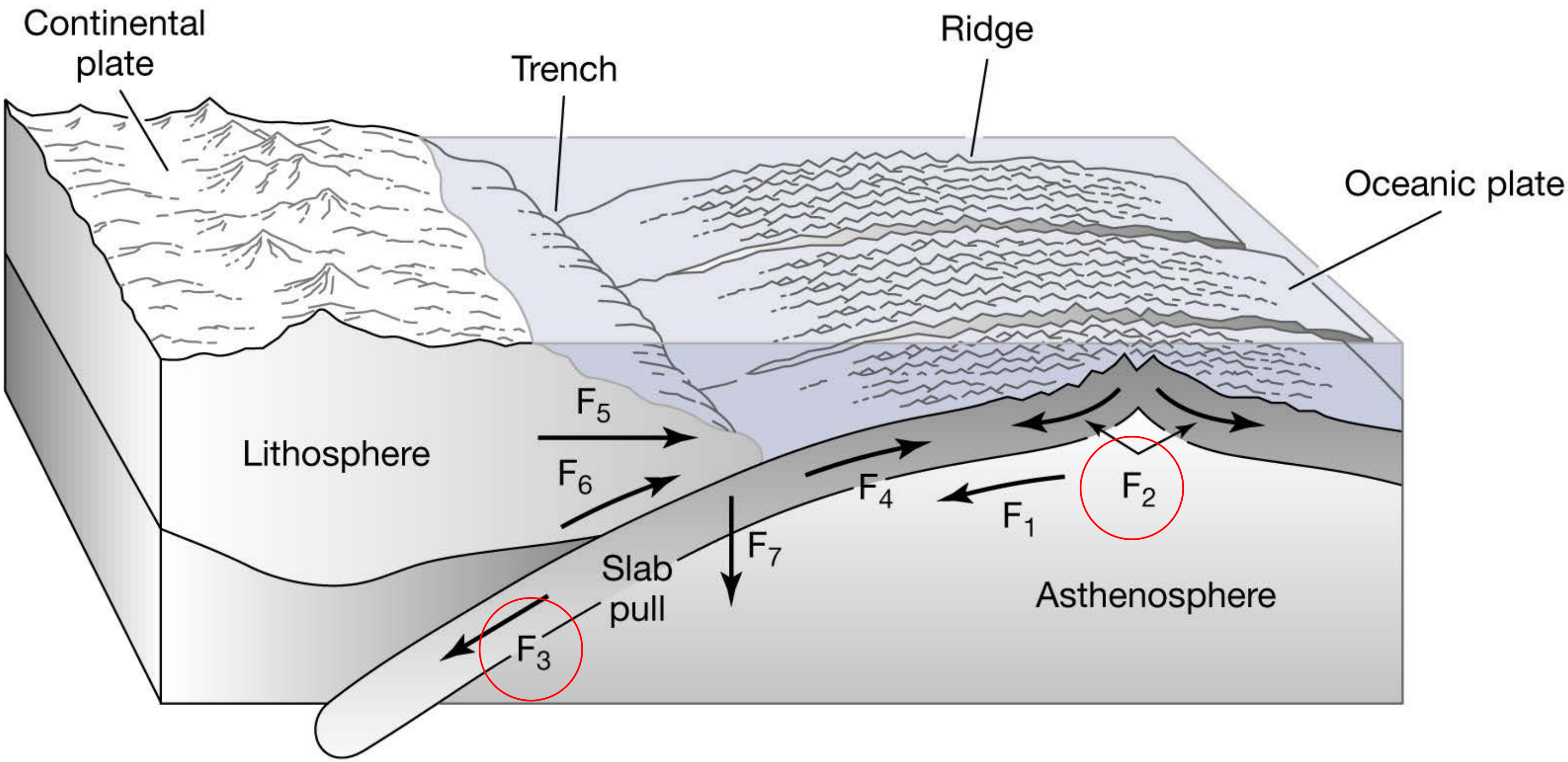
Figure 4.22 Schematic diagram showing the major features of a plate. Near the spreading center, where the temperature is high because of rising magma, the lithosphere is thin. Away from the spreading center, the lithosphere cools, becomes denser and also thicker, and so the lithosphere-asthenosphere boundary is deeper. When the lithosphere sinks into the asthenosphere at the subduction zone, it is reheated. At a depth of about 100 km, the oceanic crust starts to melt, and the magma rises and forms an arcuate belt of volcanoes parallel to the subduction zone.



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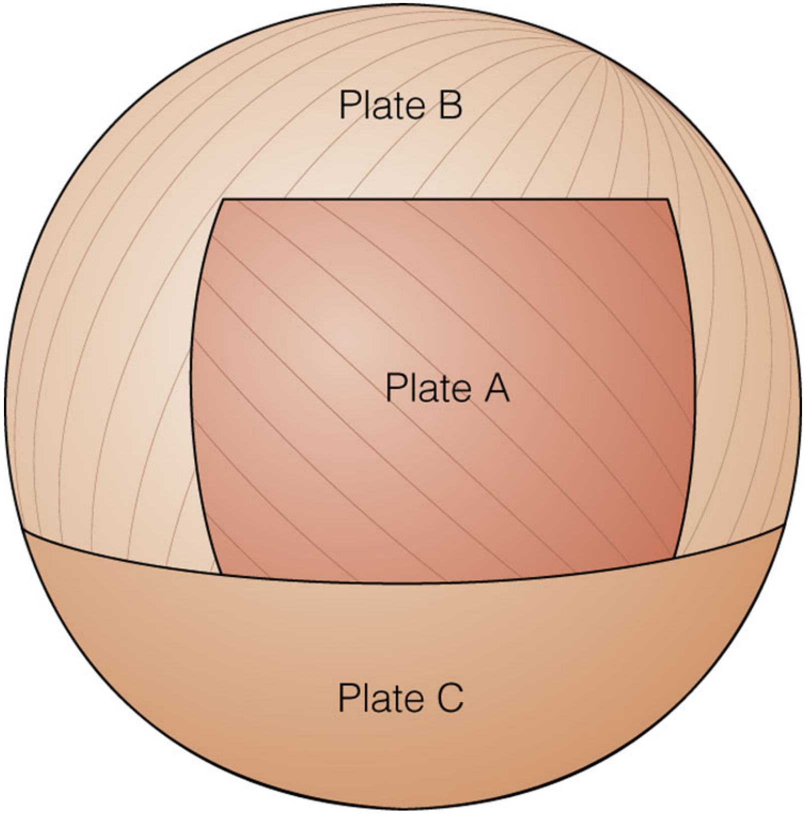
F_1 Friction between convecting asthenosphere and rigid lithosphere
F_2 Gravitational push from mid-ocean ridge (high topography)
F_3 Pull from increasing density of slab as it cools
F_4 Elastic resistance of oceanic plate being pulled into subduction zone
F_5 Pull of overriding plate toward subduction zone as subducting plate bends
F_6 Friction between subducting slab and overlying lithosphere
F_7 Sinking of oceanic slab as it cools and becomes denser

Plate boundaries

- Divergent – new oceanic crust
  - Some mantle melts – new basaltic oceanic crust
  - Symmetrical geomagnetic record and aging
  - F_2 force – pushing
  - Cools, becomes more dense and subsides away from ridge
- Convergent – plates collide
  - Subduction of oceanic crust
    - Basalt at the base of the lithosphere converted to eclogite
    - Forms at depths > 50 km in the upper mantle
  - F_3 force - pulling
- Transform – plates slide past each other

Plate boundaries



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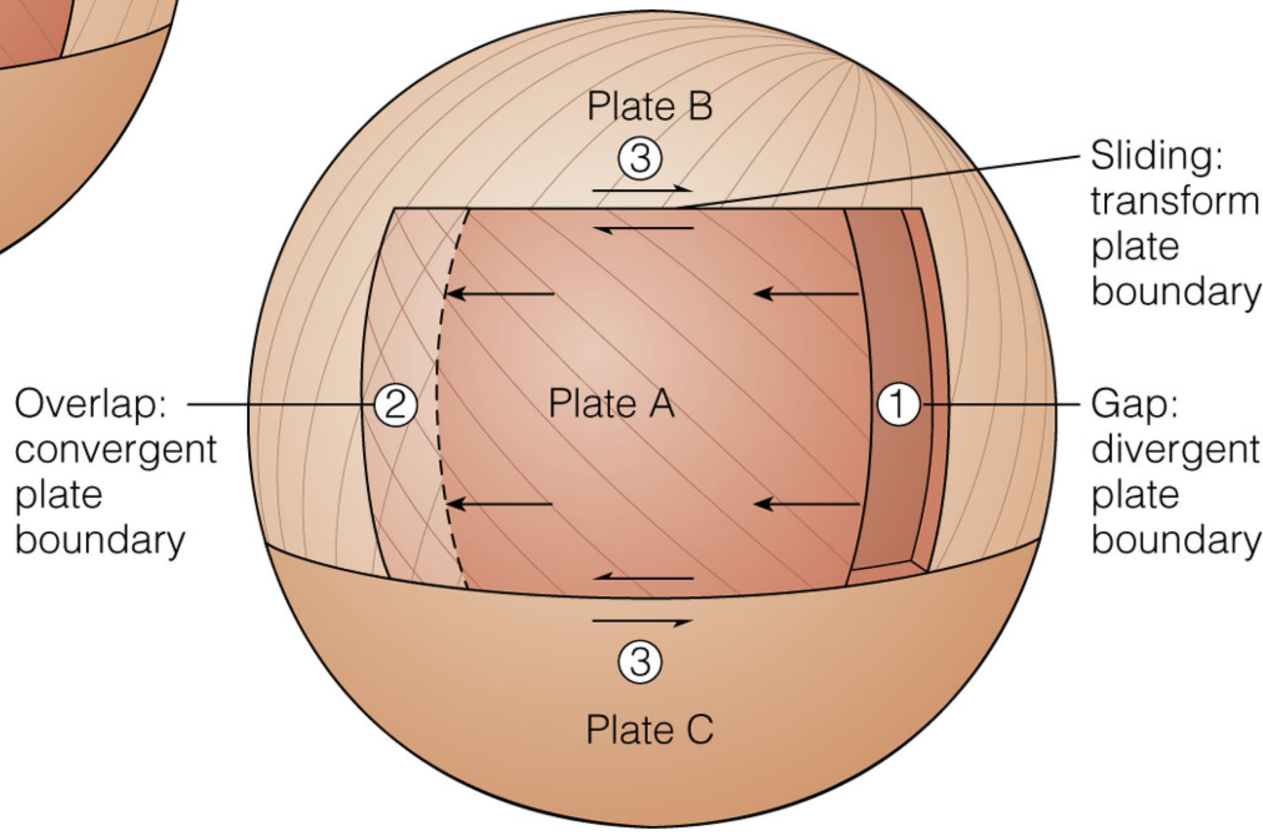

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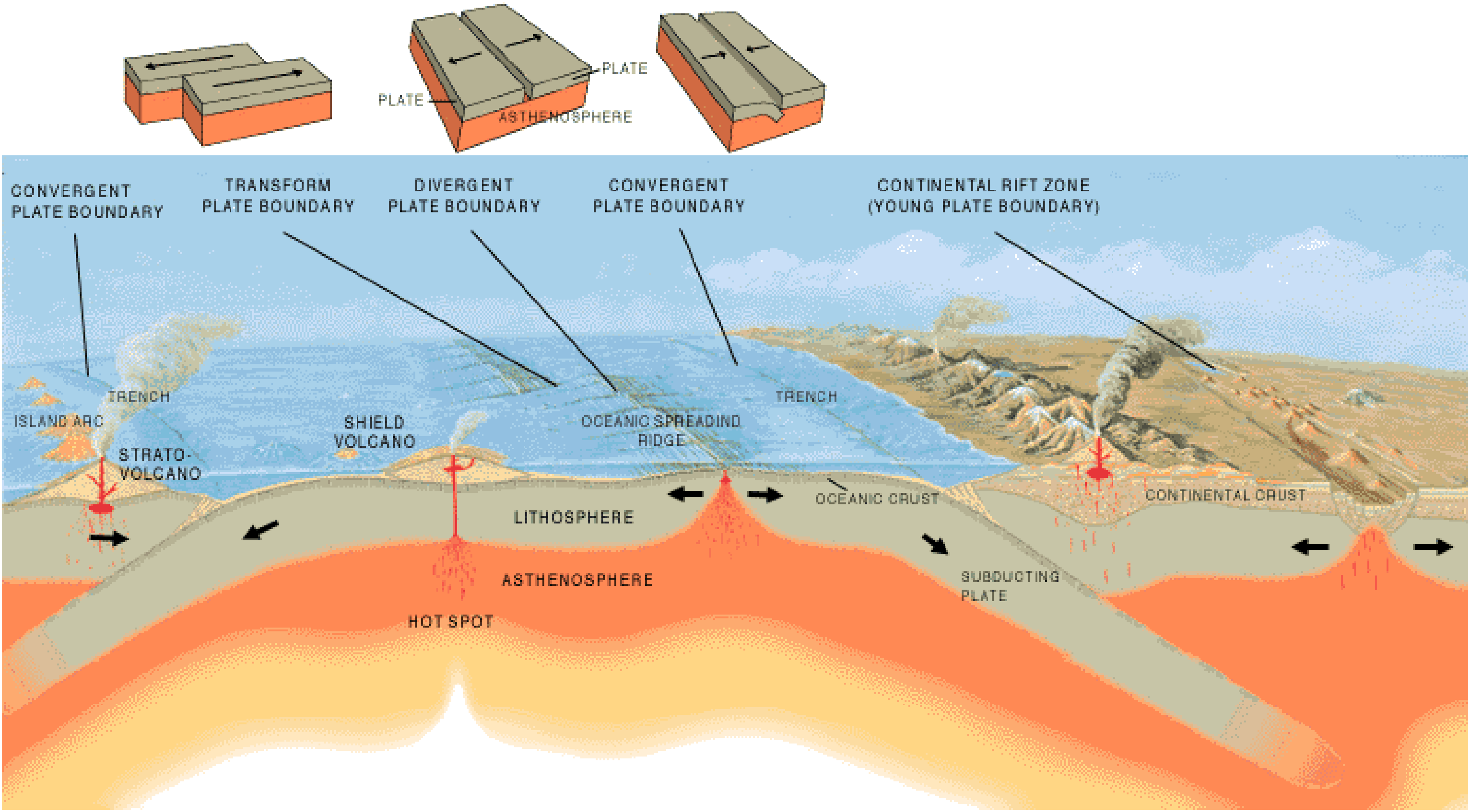
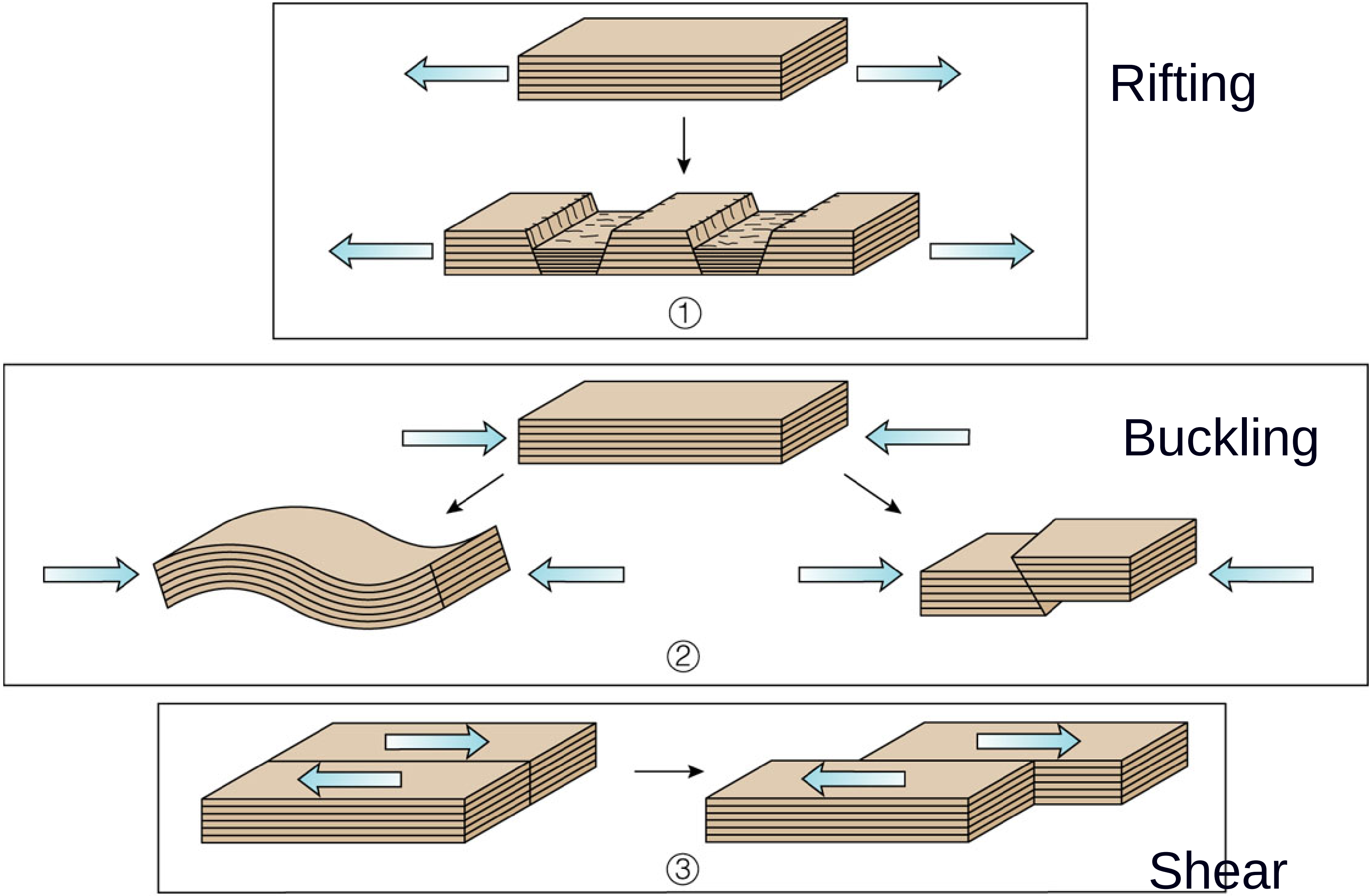


PLATE
PLATE
ASTHENOSPHERE
CONVERGENT
PLATE BOUNDARY
TRANSFORM
PLATE BOUNDARY
DIVERGENT
PLATE BOUNDARY
CONVERGENT
PLATE BOUNDARY
CONTINENTAL RIFT ZONE
(YOUNG PLATE BOUNDARY)
TRENCH
ISLAND ARC
STRATO-
VOLCANO
SHIELD
VOLCANO
OCEANIC SPREADING
RIDGE
TRENCH
OCEANIC CRUST
CONTINENTAL CRUST
LITHOSPHERE
ASTHENOSPHERE
HOT SPOT
SUBDUCTING
PLATE



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1. Divergent
2. Convergent
3. Transform

Table 3.1 Characteristics of Plate Boundaries

Plate Boundary		Plate Movement	Seafloor	Events Observed	Example Locations
Divergent plate boundaries	Ocean-ocean	Apart	Forms by seafloor spreading.	Ridge forms at spreading center. Ocean basin expands, plate area increases. Many small volcanoes and/or shallow earthquakes.	Mid-Atlantic Ridge, East Pacific Rise
	Continent-continent		New ocean basin may form as continent splits.	Continent spreads, central rift collapses, ocean fills basin.	East African Rift Valley, Red Sea
Convergent plate boundaries	Ocean-continent	Together	Destroyed at subduction zones.	Dense oceanic lithosphere plunges beneath less dense continental. Earthquakes trace path of down-moving plate as it descends into asthenosphere. A trench forms. Subducted plate partially melts. Magma rises to form continental volcanoes.	Western South America, Cascade Mountains in western United States
	Ocean-ocean			Older, cooler, denser crust slips beneath less dense crust. Strong quakes. Deep trench forms in arc shape. Subducted plate heats in upper mantle, magma rises to form curving chains of volcanic islands.	Aleutians, Marianas
	Continent-continent		Closure of Ocean Basins.	Collision between masses of granitic continental lithosphere. Neither mass is subducted. Plate edges are compressed, folded, uplifted; one may move beneath the other.	Himalayas, Alps
Transform plate boundaries		Past each other	Neither created nor destroyed.	A line (fault) along which lithospheric plates move past each other. Strong earthquakes along fault.	San Andreas Fault; South Island, New Zealand
				Transform faults across spreading center.	Mid-ocean ridges

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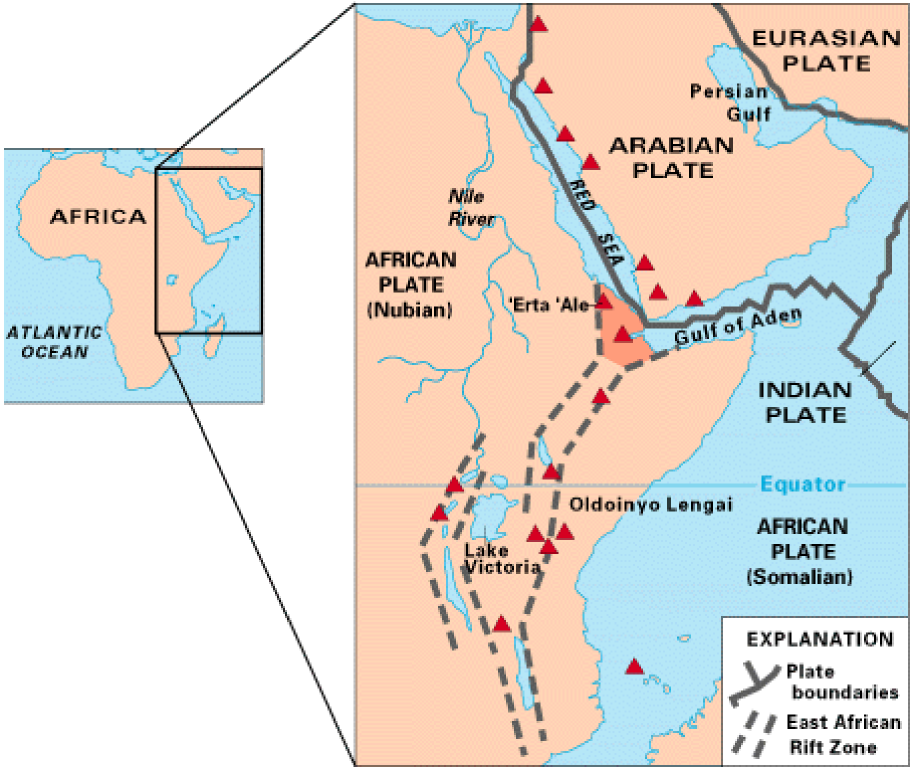
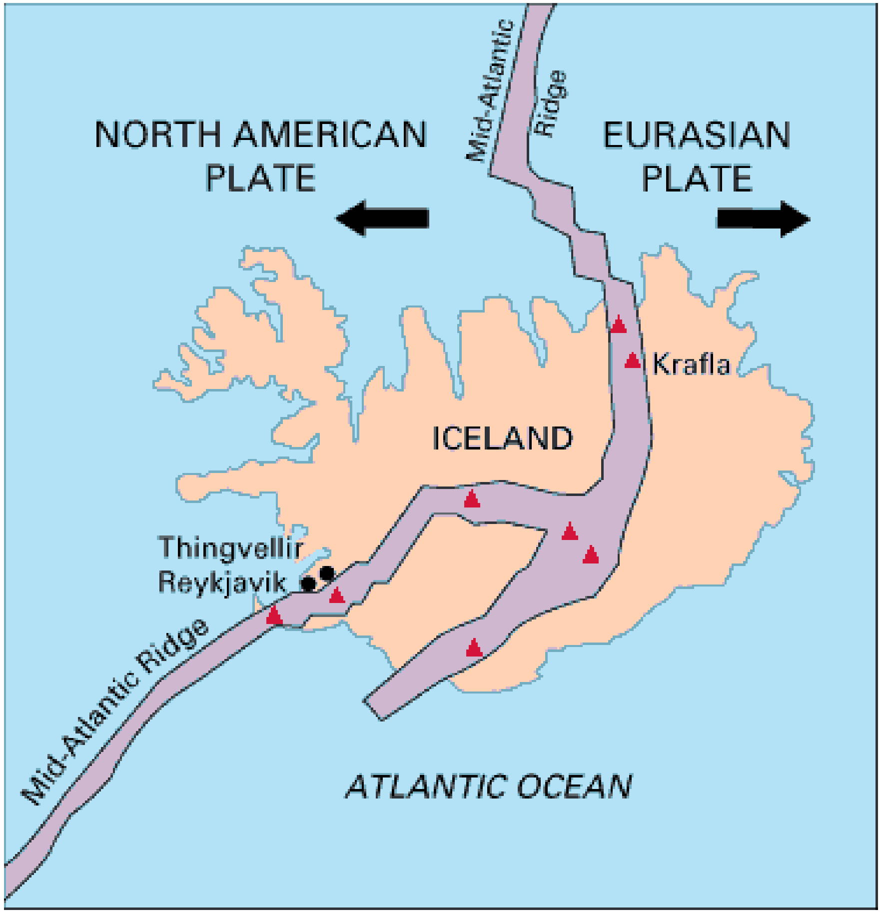
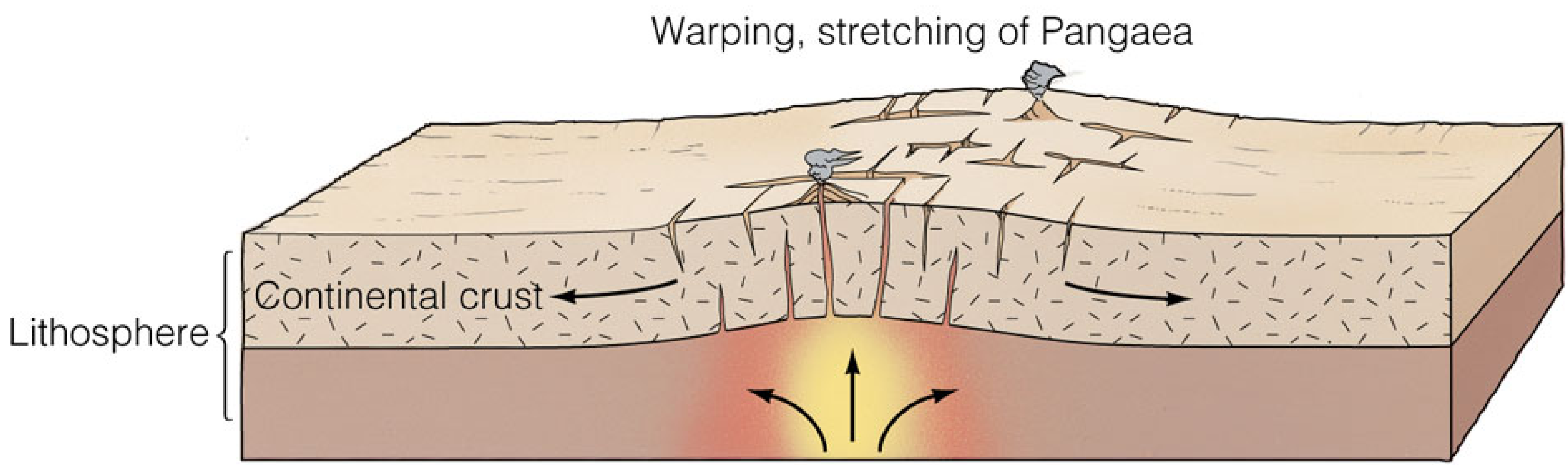
Diverging Boundaries





Formation of ocean basin



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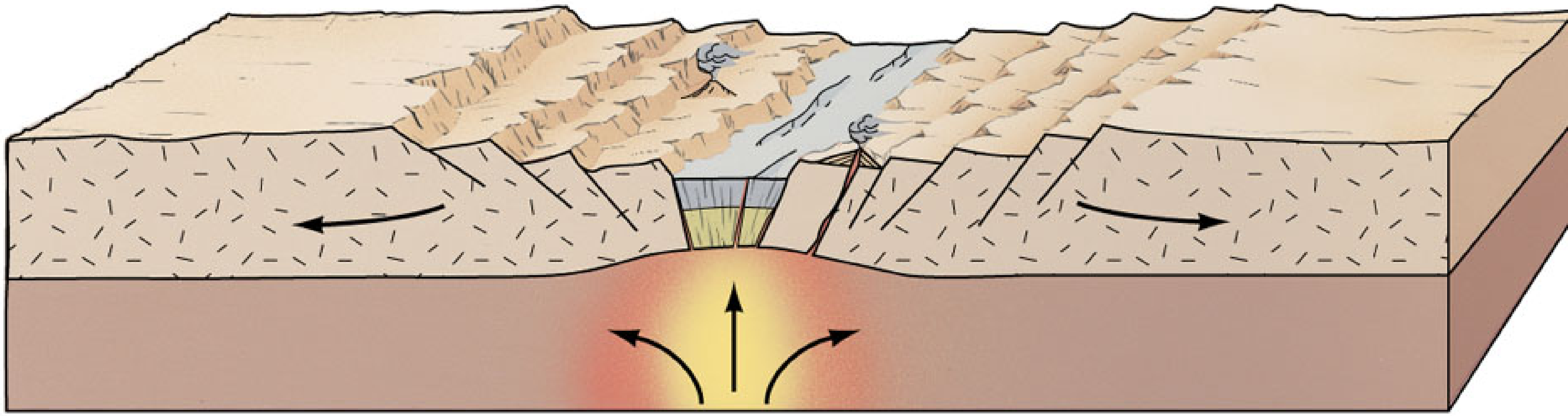
Formation of rift valley



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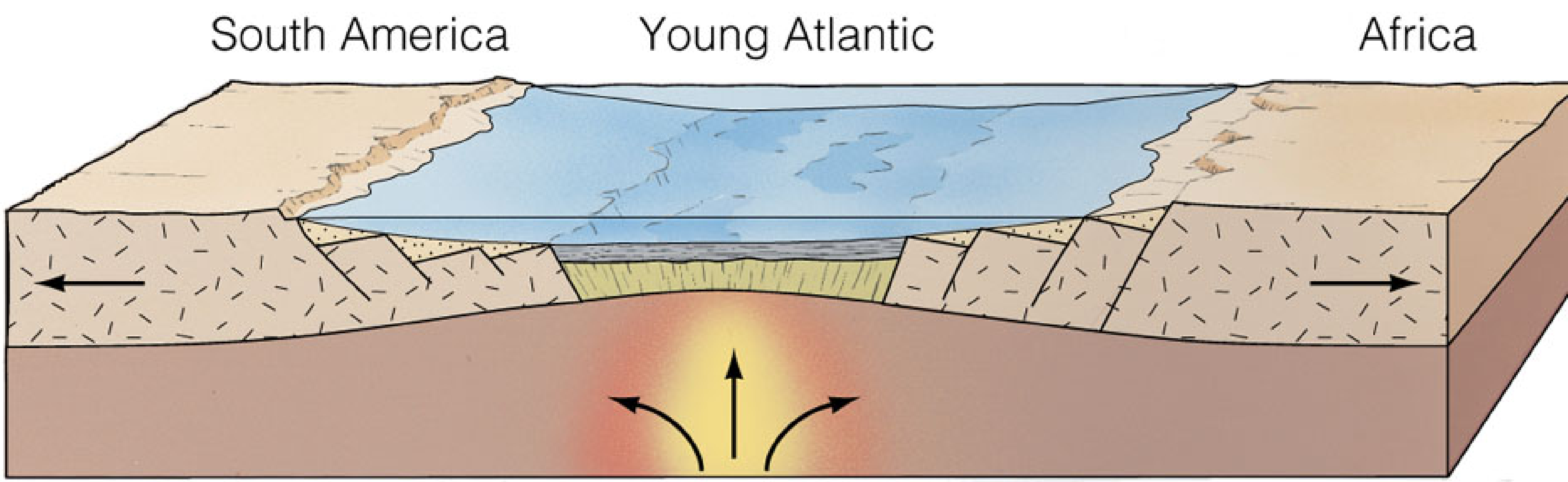

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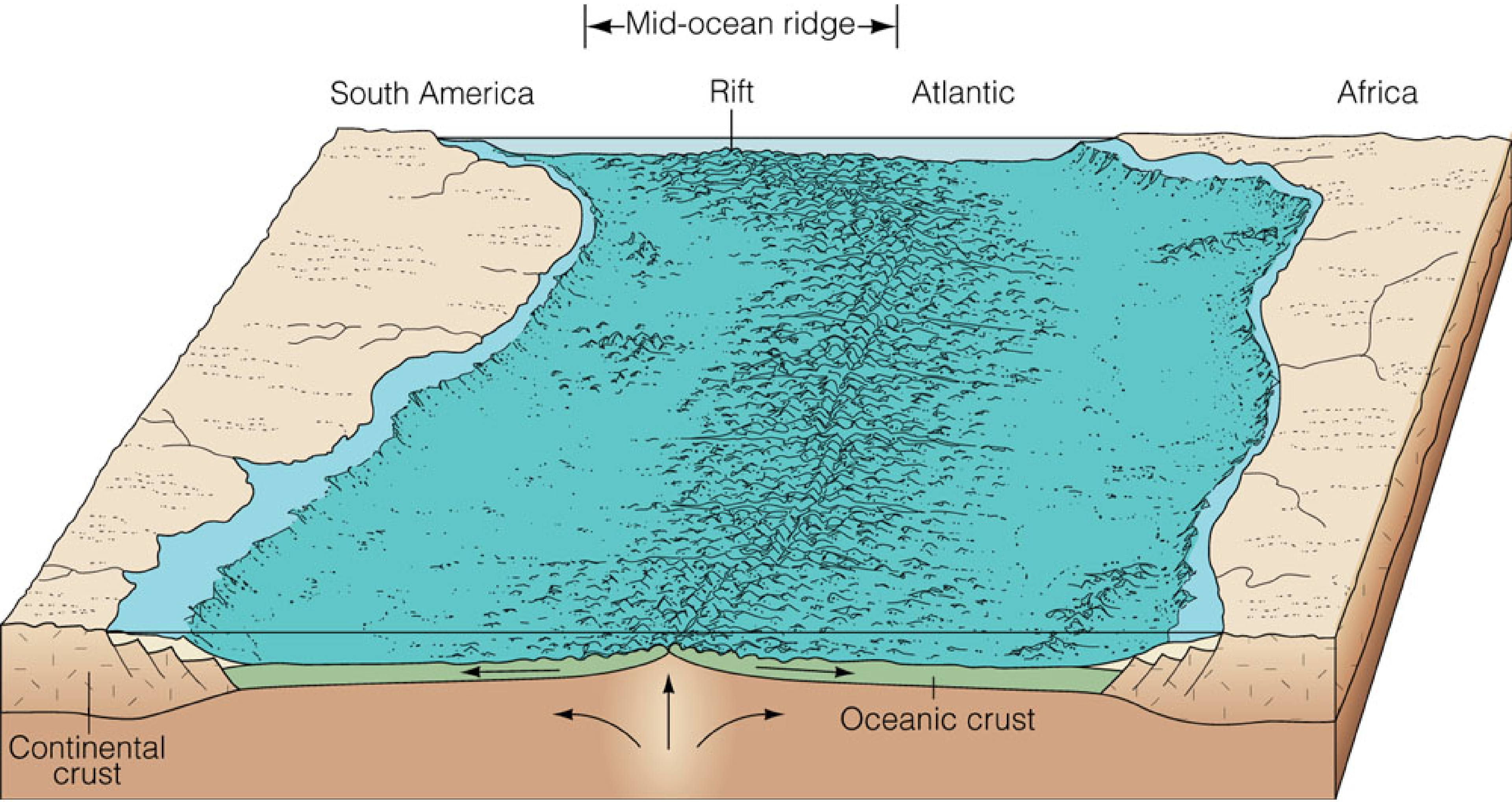

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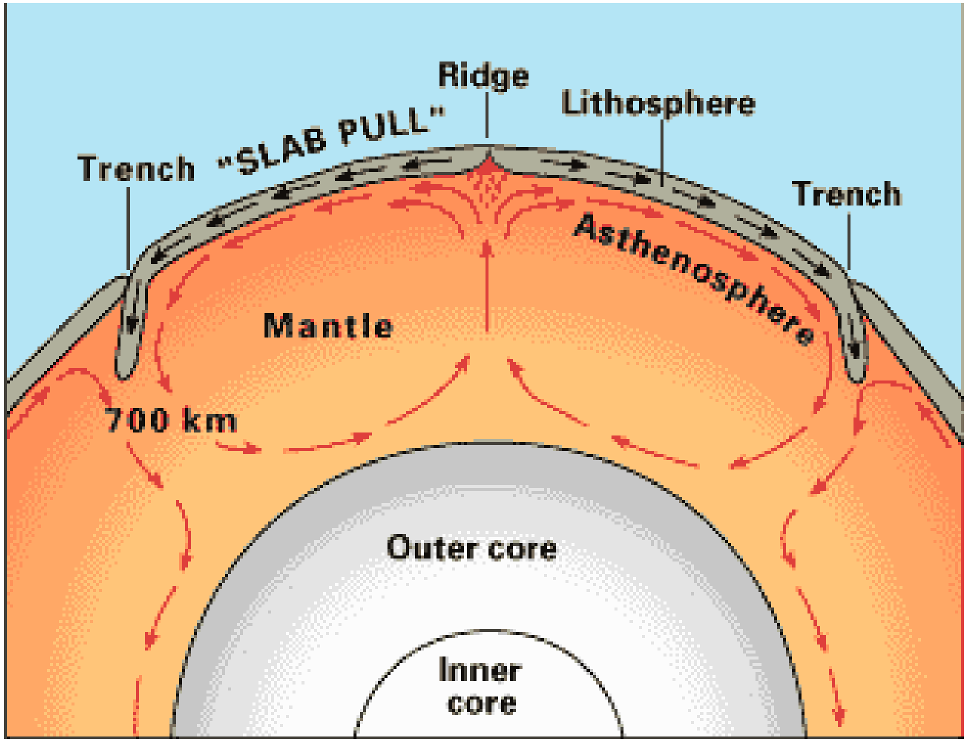
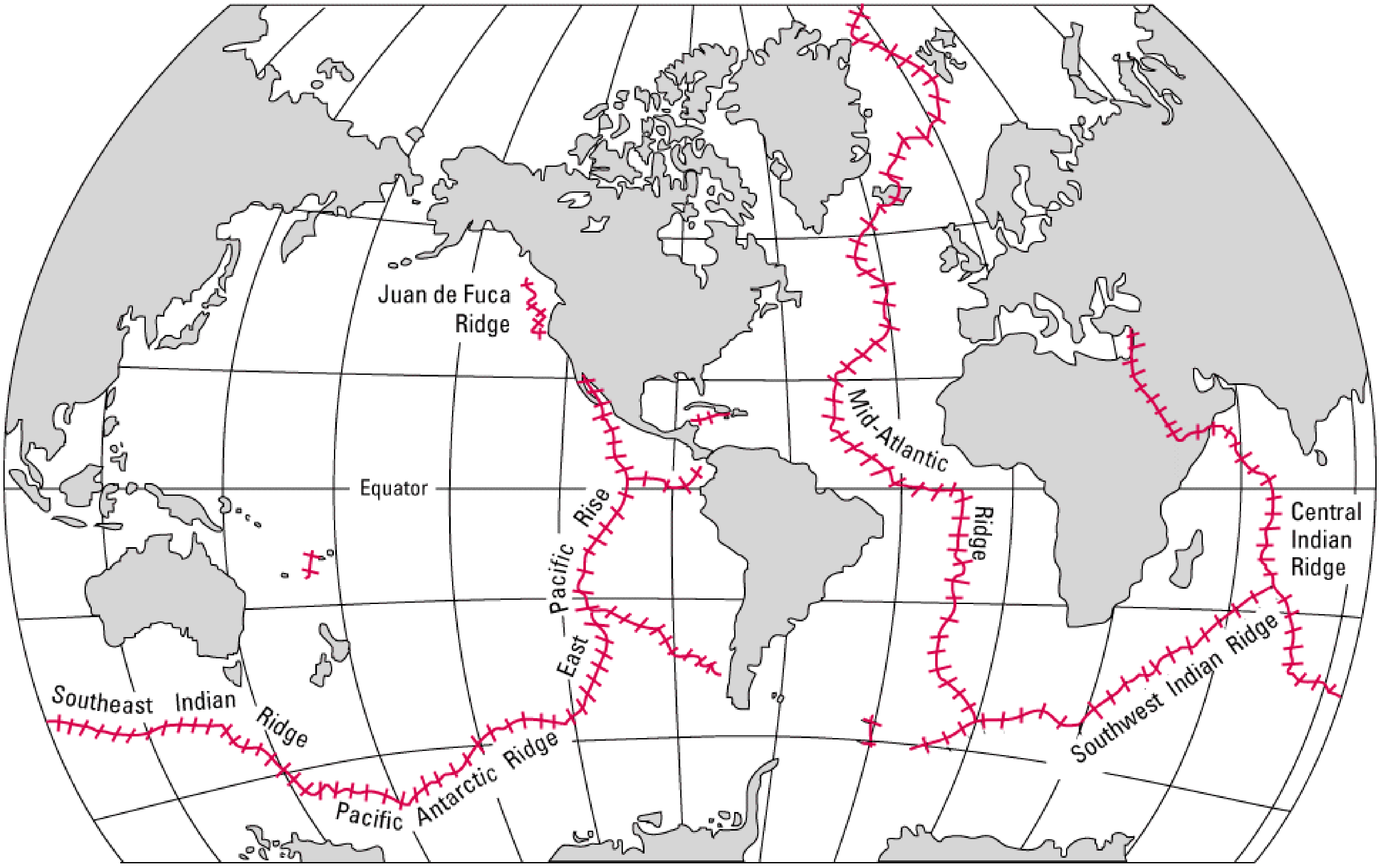
Other evidence

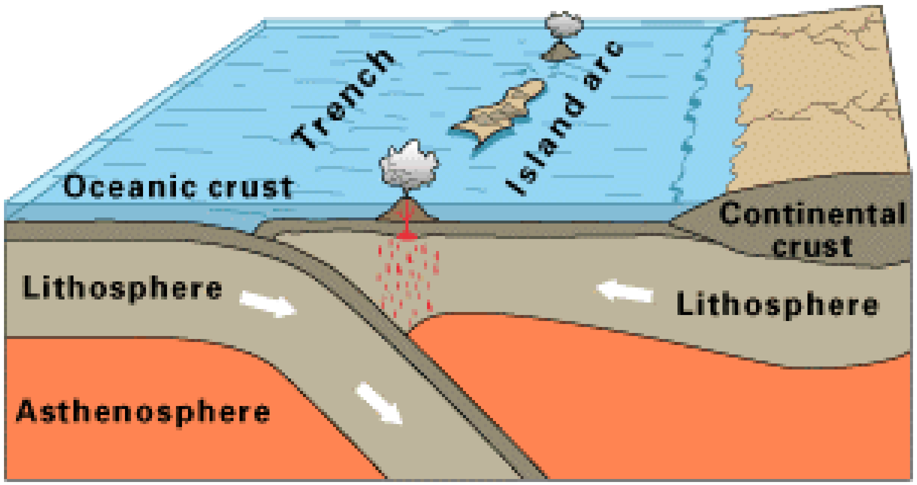
- Hydrothermal vents (discovered in 1977)
  - Thermal anomalies (unusually warm water) found in 1972 over a ridge near Galapagos Islands
  - Sent Alvin down in 1977
- Unusual organisms
- Pillow lavas from recently extruded ocean crust
- Hot water comes from seawater ventilating through the rocks
- Energy for life comes from geothermal energy and chemical energy comes from sea water – chemosynthetic bacteria are base of food chain


Ridge
Lithosphere
Trench
"SLAB PULL"
Trench
Asthenosphere
Mantle
700 km
Outer core
Inner
core

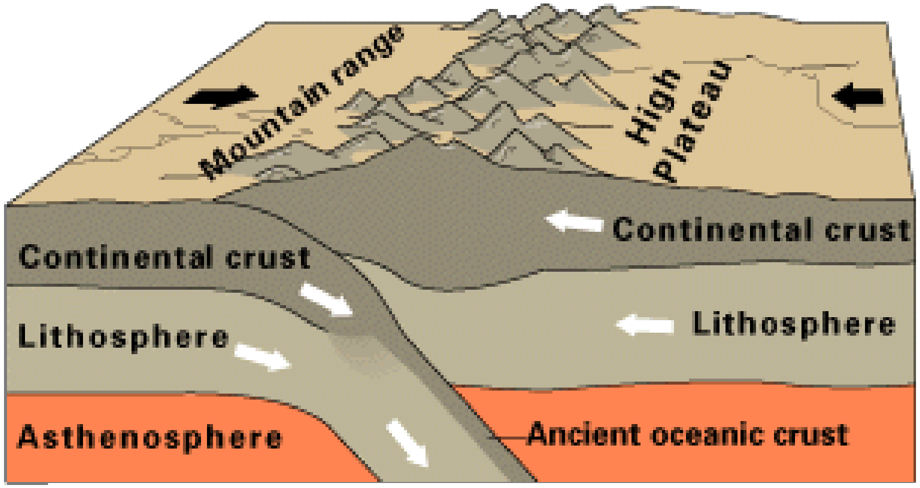
Global Ridge System



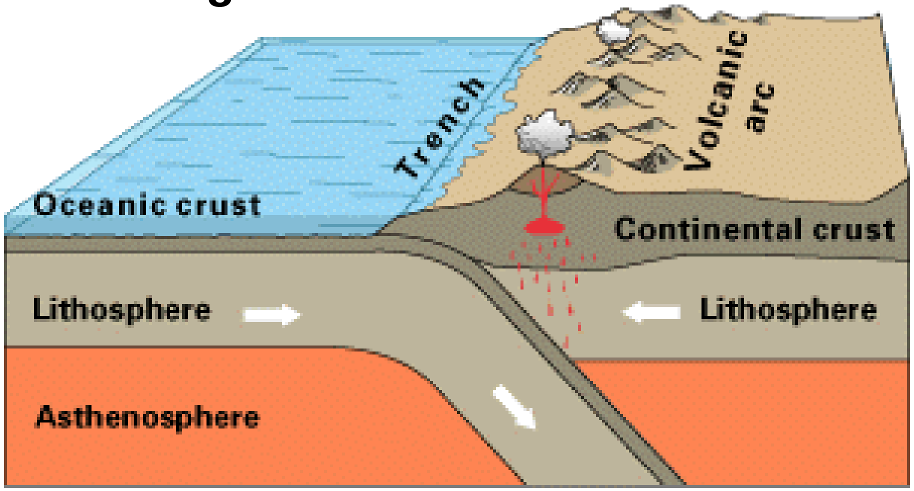
Converging Boundaries



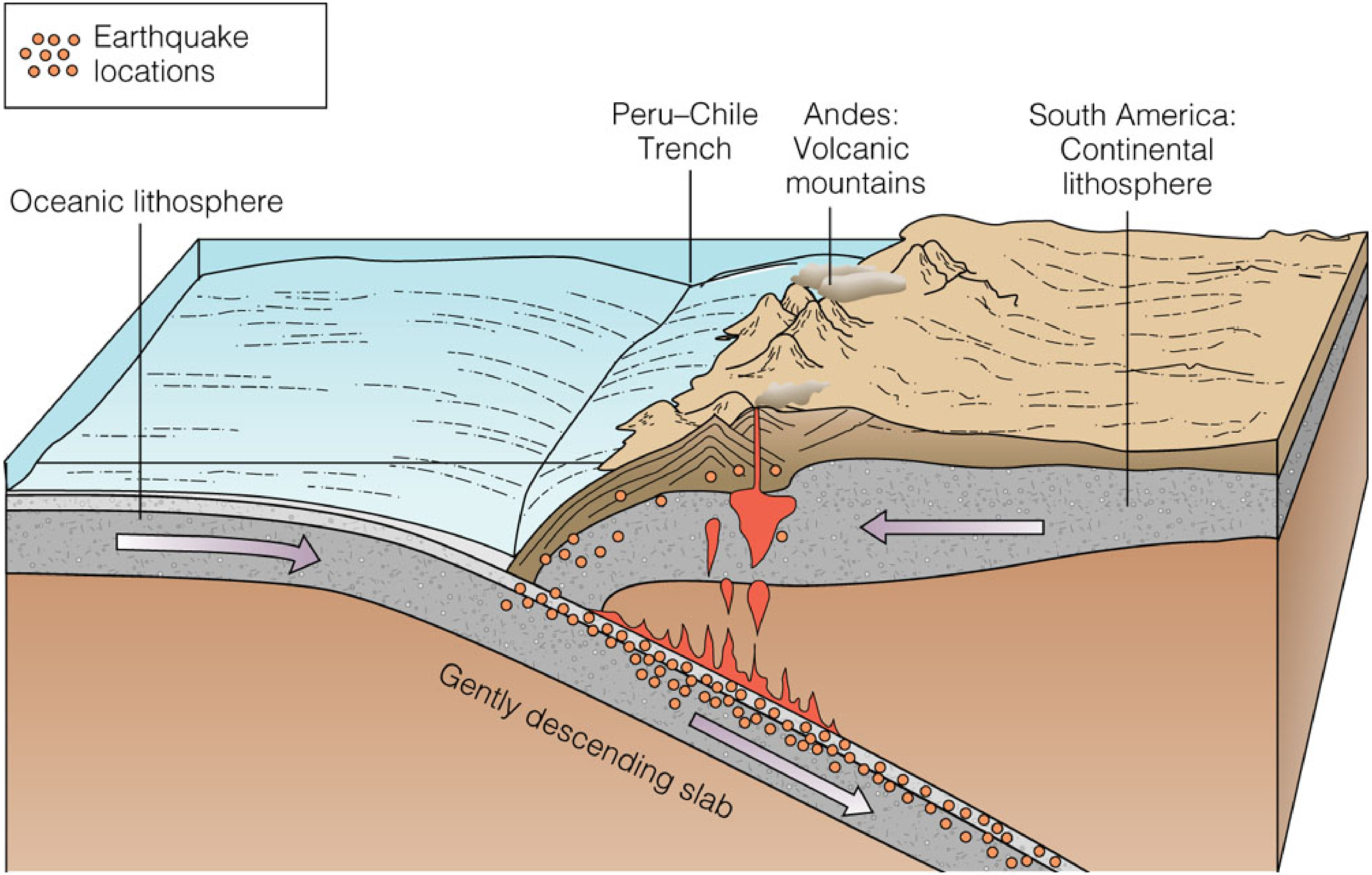
Oceanic-oceanic convergence



Continental-continental convergence



Oceanic-continental convergence



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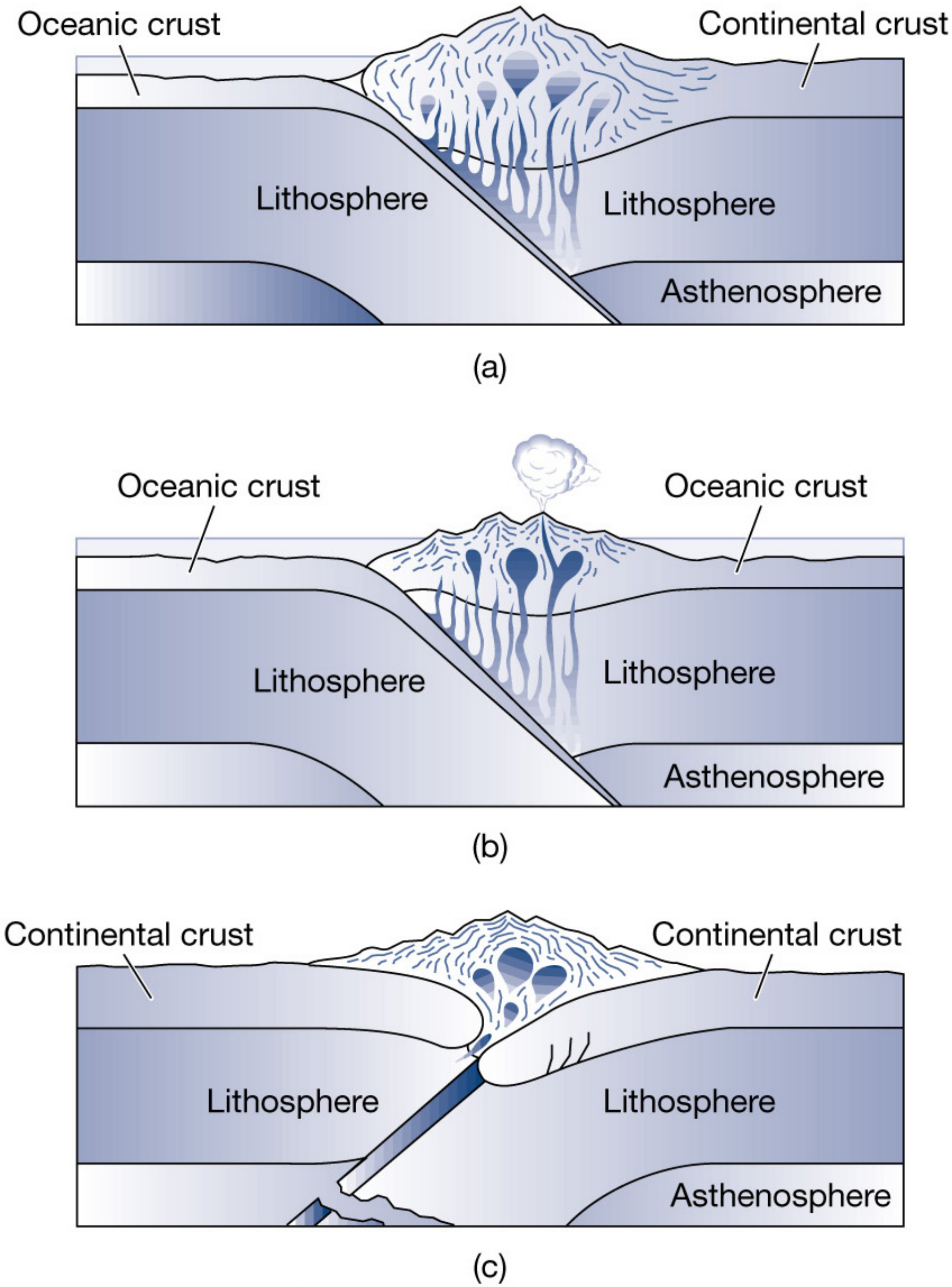
Cooler, more dense slab sinks
Melting of subducting slab + water and CO_2 + some mantle + some continental lithosphere

Converging plates

- 2 continental plates – e.g., Himalayas and Alps
  – Can get marine fossils in mountains (remember continental shelf is part of the continental lithosphere)
- Continental and oceanic plates – e.g., S America & N America
  – Mountains and island arcs
- 2 oceanic plates – Aleutian and Marianas trenches
  – Older slab (denser and cooler) sinks

Three types of collisions



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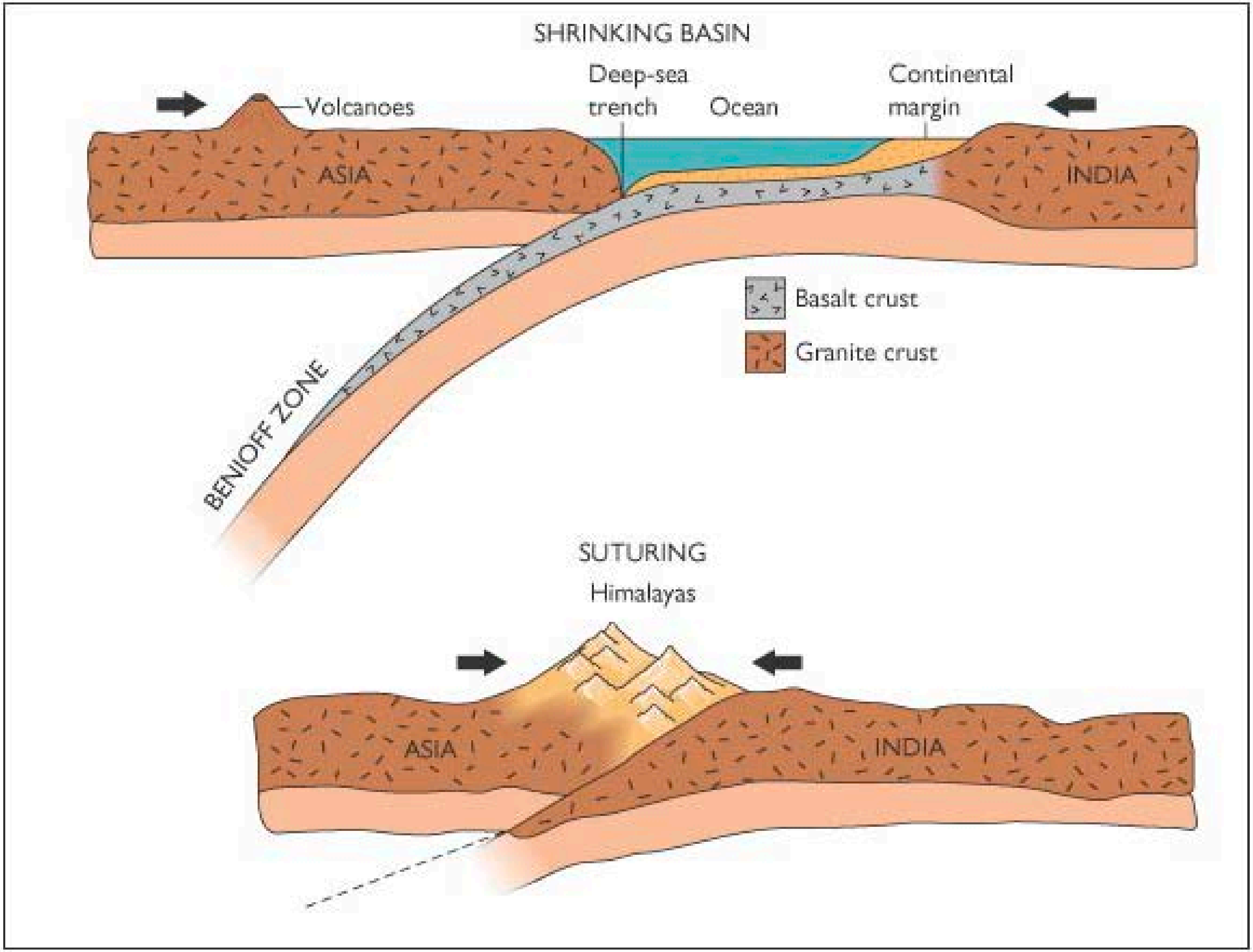
Continental arc (oceanic plate- continental plate collision)

Island arc (oceanic plate- oceanic plate collision)

continental plate- continental plate collision

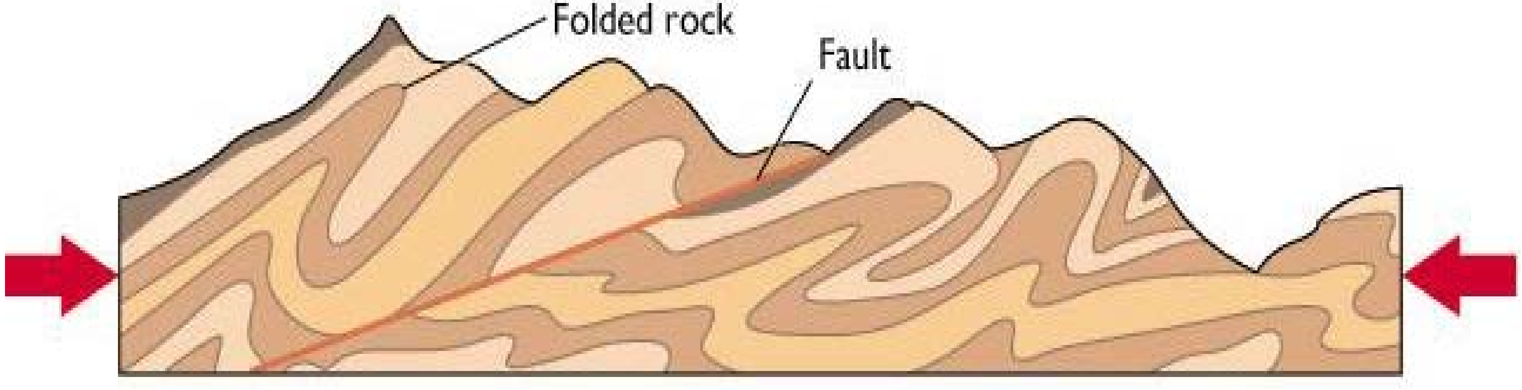
Fig. 7-19

Collision of continental crust



COLLISION of Continental plates

- Whereas oceanic ridges indicate tension, continental mountains indicate compressional forces are squeezing the land together.

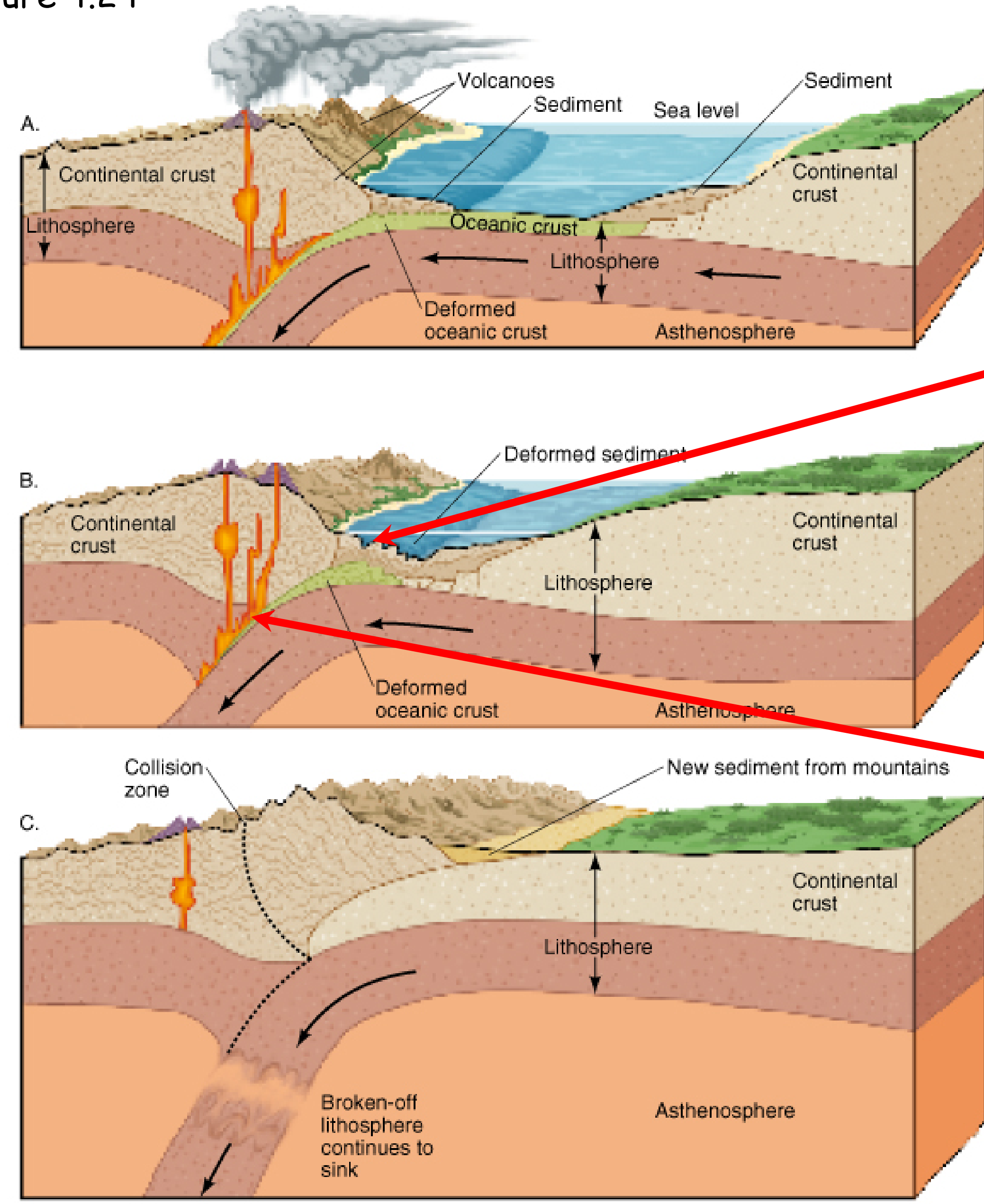


Sedimentary Rocks Squeezed by Compression

Continent-continent collision

The convergence of the Nazca and South American Plates has deformed and pushed up limestone strata to form towering peaks of the Andes, as seen here in the Pachapaqui mining area in Peru.

Figure 4.24



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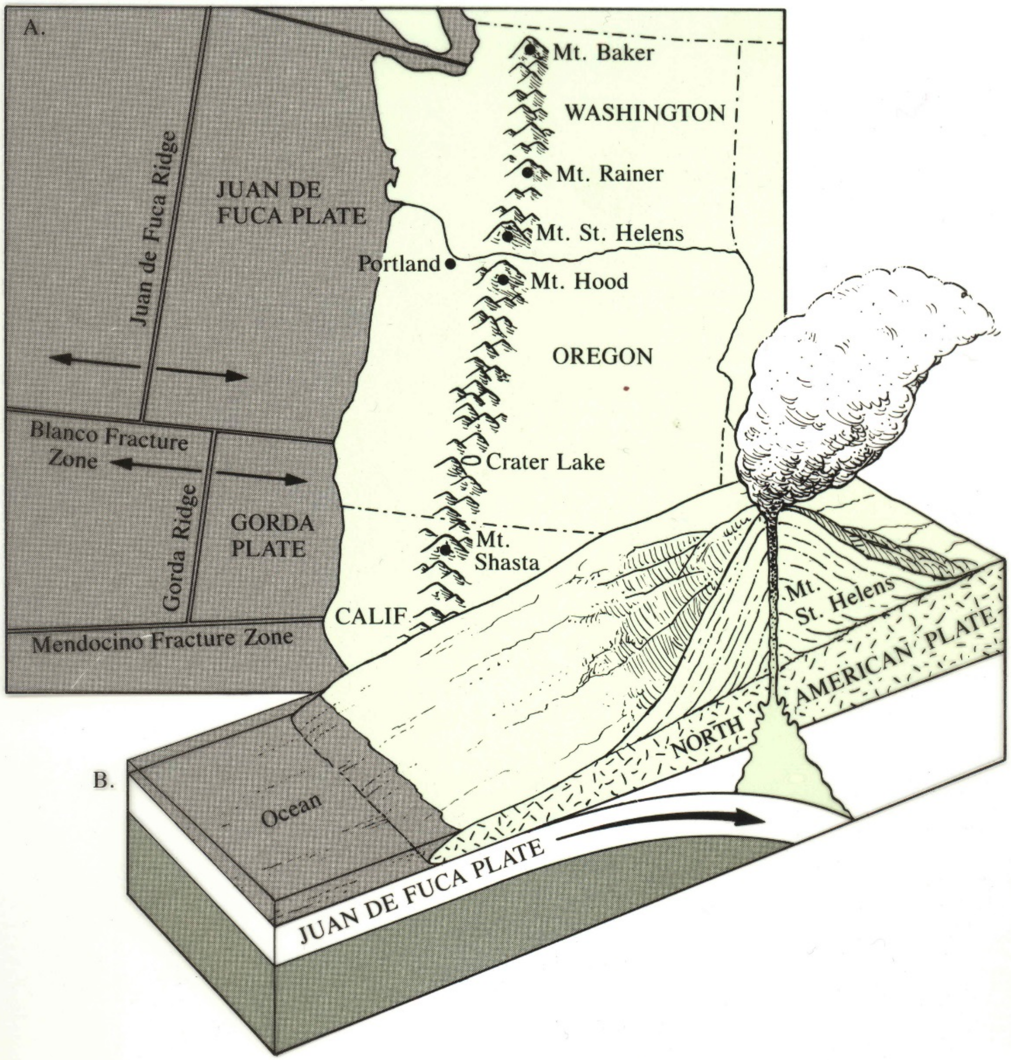
Continental arc system
Continent-oceanic collision

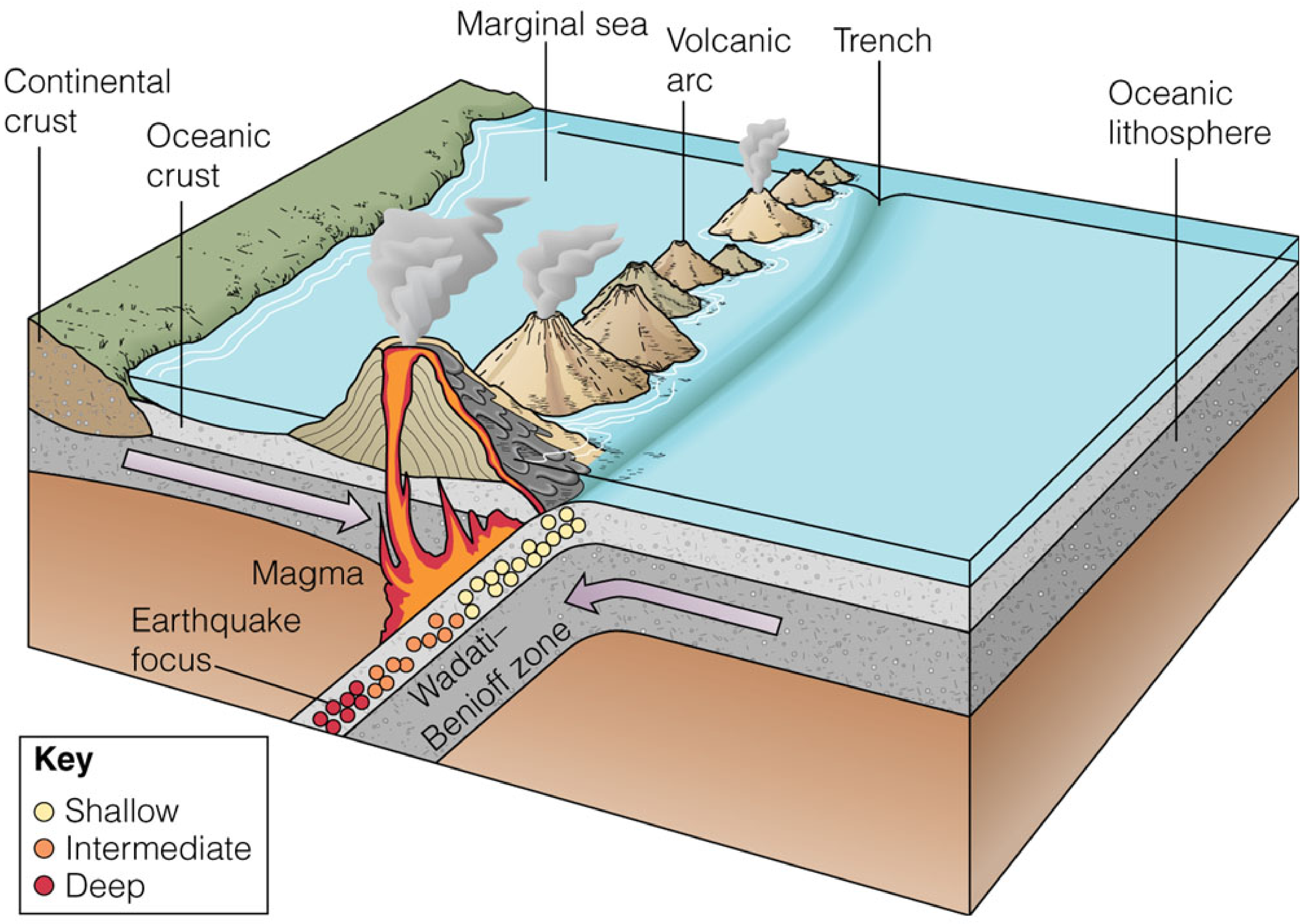
Sediment at the edge of continental crust on the subducting plate is deformed and welded onto already deformed continental crust on overriding plate.

Partial melting of slab (sinking plate), sediment cover and continental crust

Collision near continental edge : Ocean crust sinks because its denser



Island arc systems (2 oceanic plates far from continental crust)



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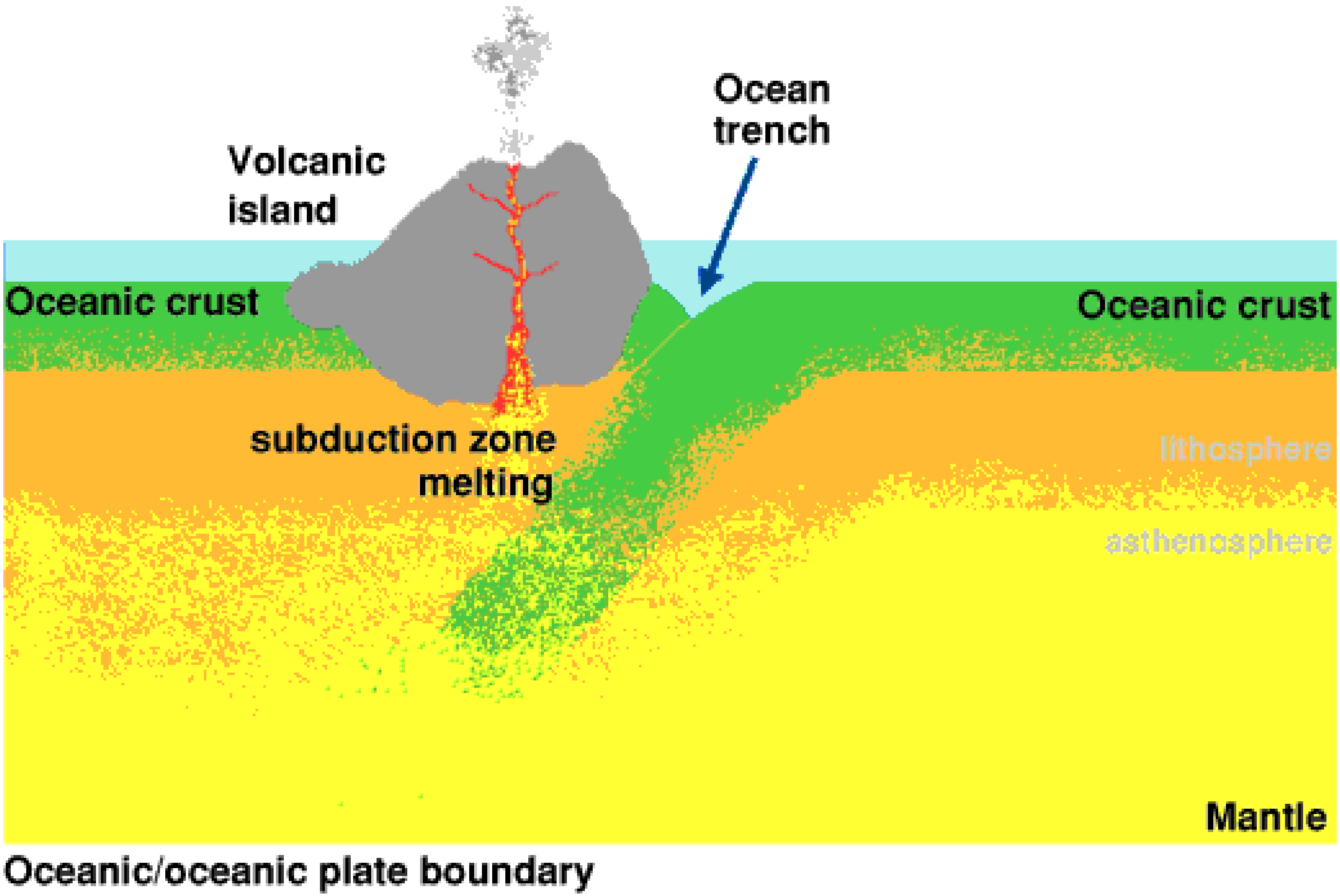
Island Arc Formation



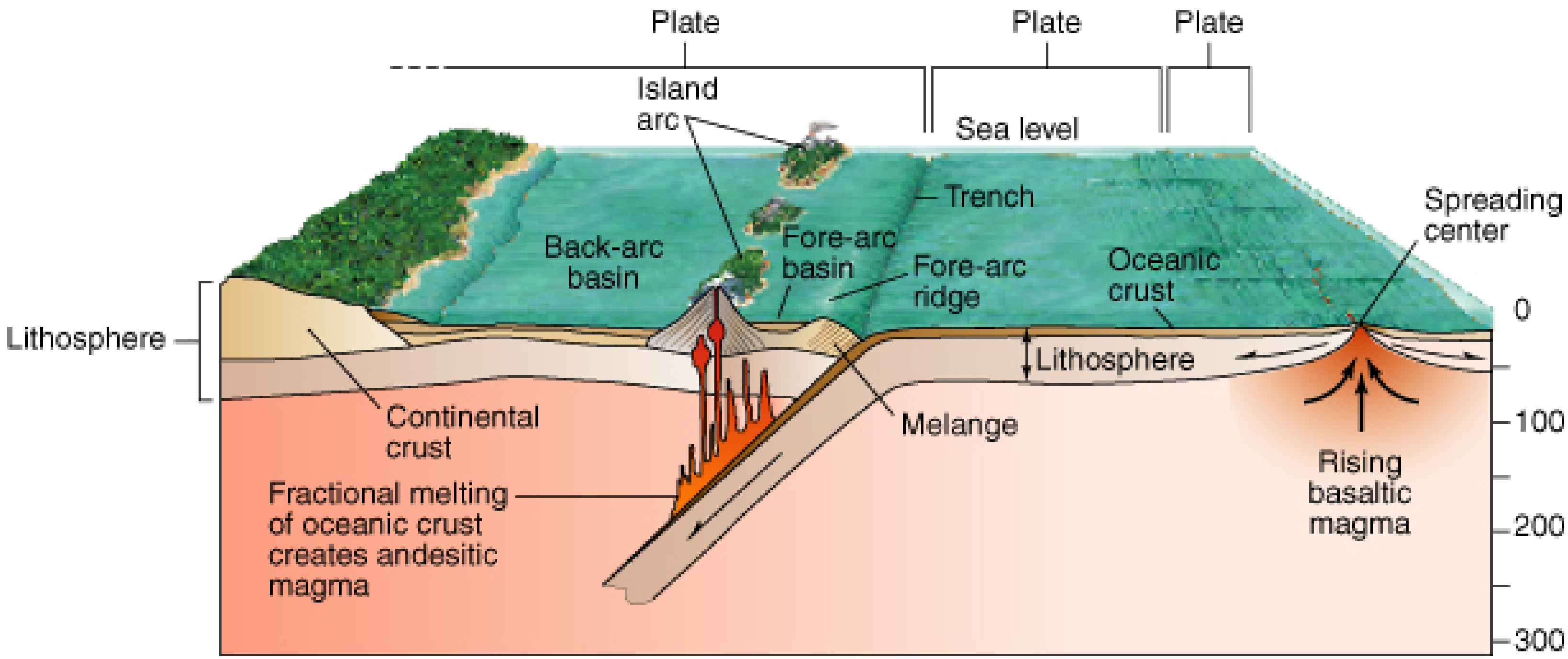


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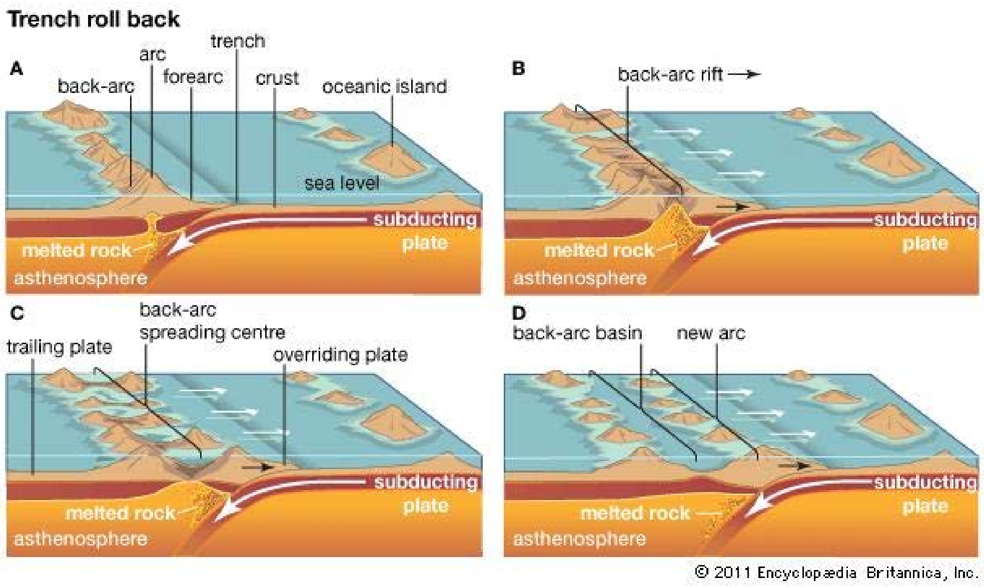
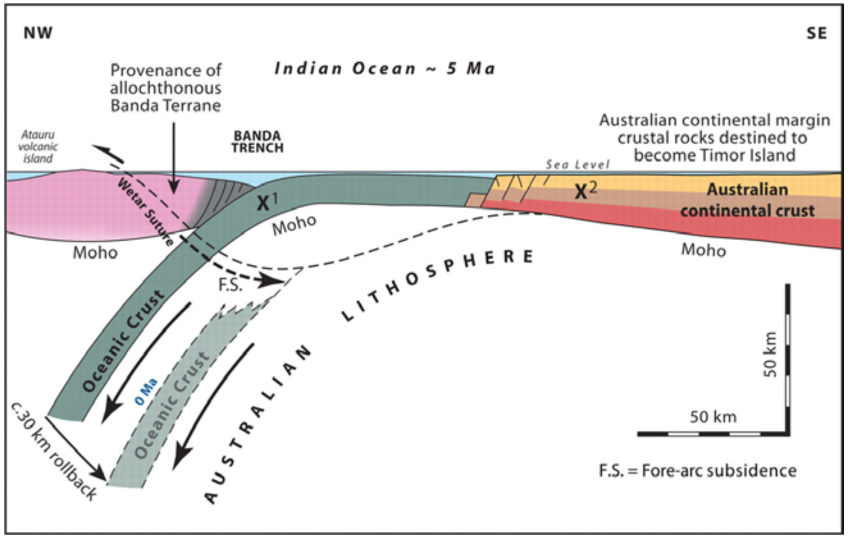
Figure 4.20 Structure of tectonic plates at a convergent margin. Along the line of subduction, an oceanic trench is formed, and sediment deposited in the trench, as well as sediment from the sinking plate, is compressed and deformed to create a mélange of shattered and crushed rock shaped as a fore-arc ridge. The sinking oceanic crust eventually r eaches the temperature where melting commences and forms andesitic magma, which then rises to form an arc of volcanoes on the overriding plate. On the side of the island arc away from the trench, tensional forces lead to the development of a back-arc basin.

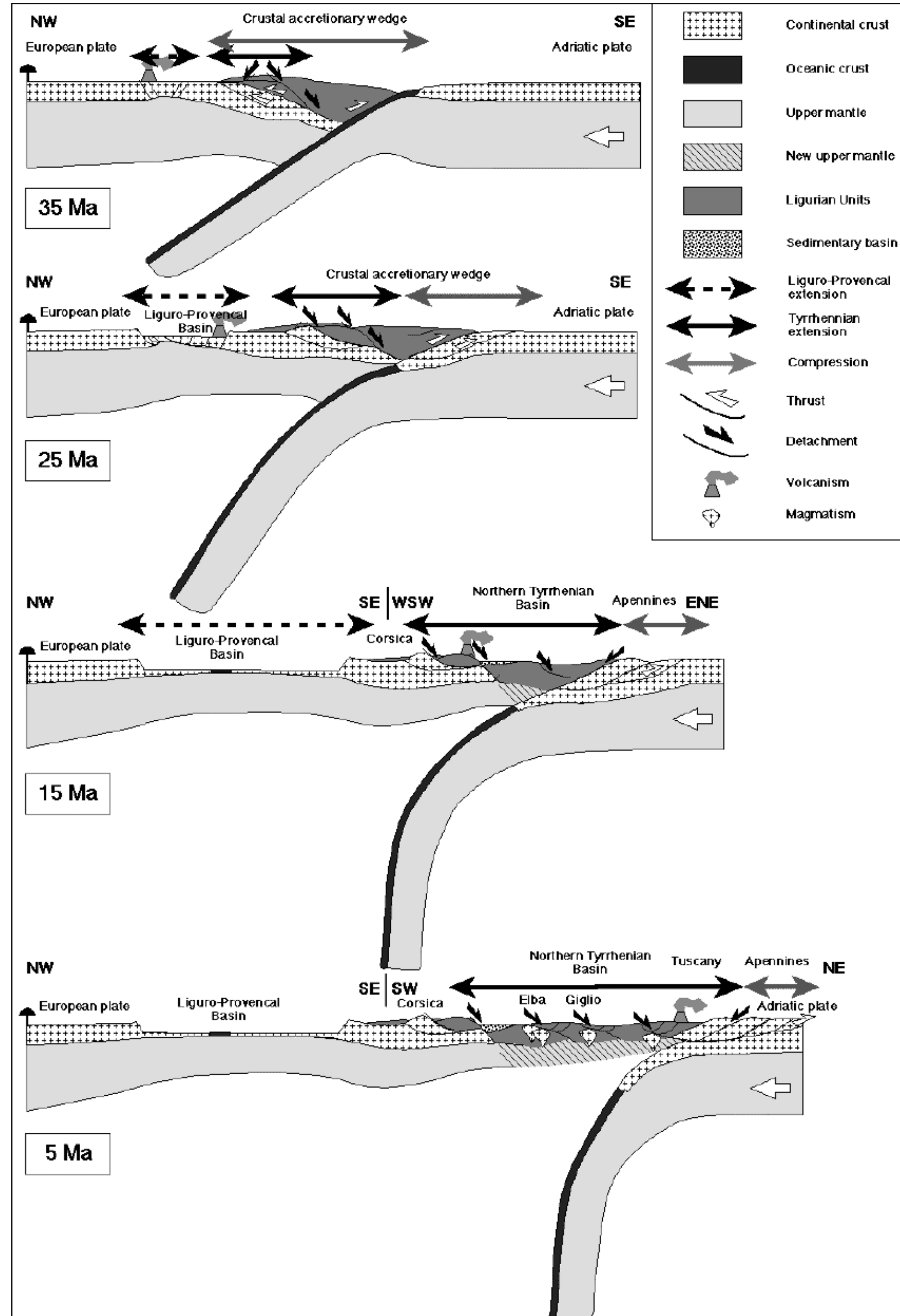


Although trenches would seem to be positionally stable over time, it is hypothesized that some trenches, particularly those associated with subduction zones where two oceanic plates converge, retrograde, that is, they move backward into the plate which is subducting, akin to a backward-moving wave.

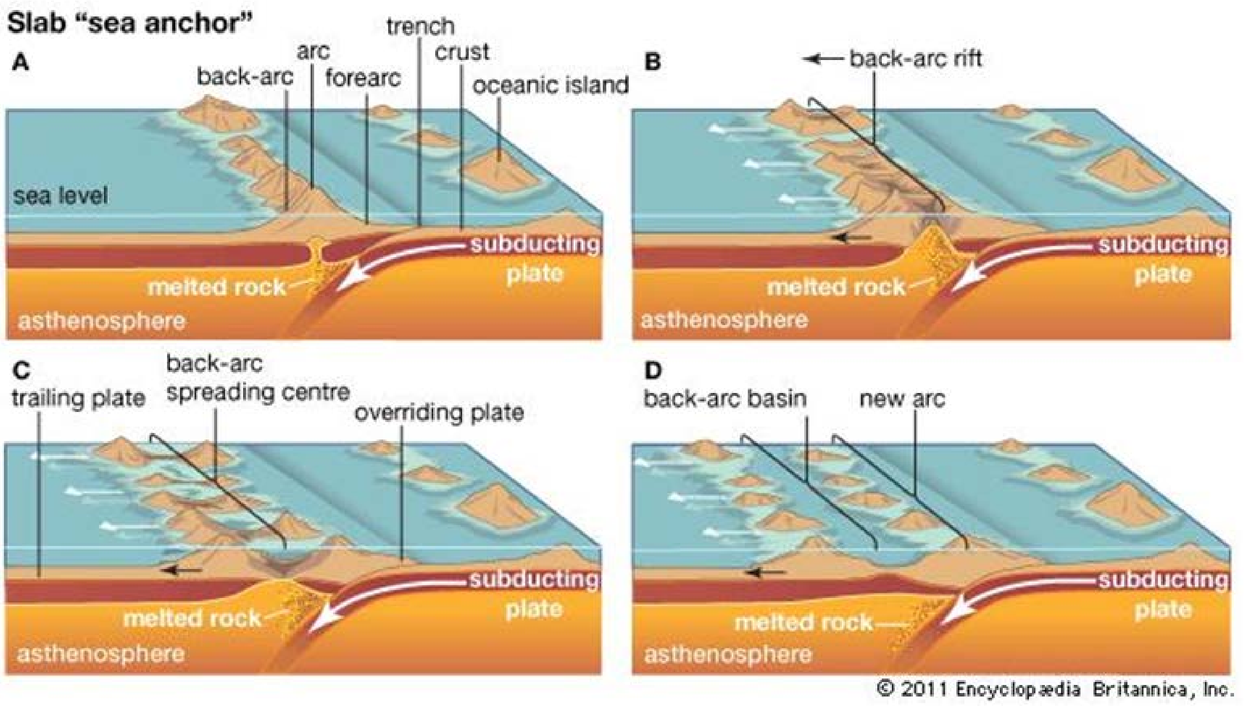
This has been termed trench rollback or hinge retreat (also hinge rollback). This is one explanation for the existence of back-arc basins.

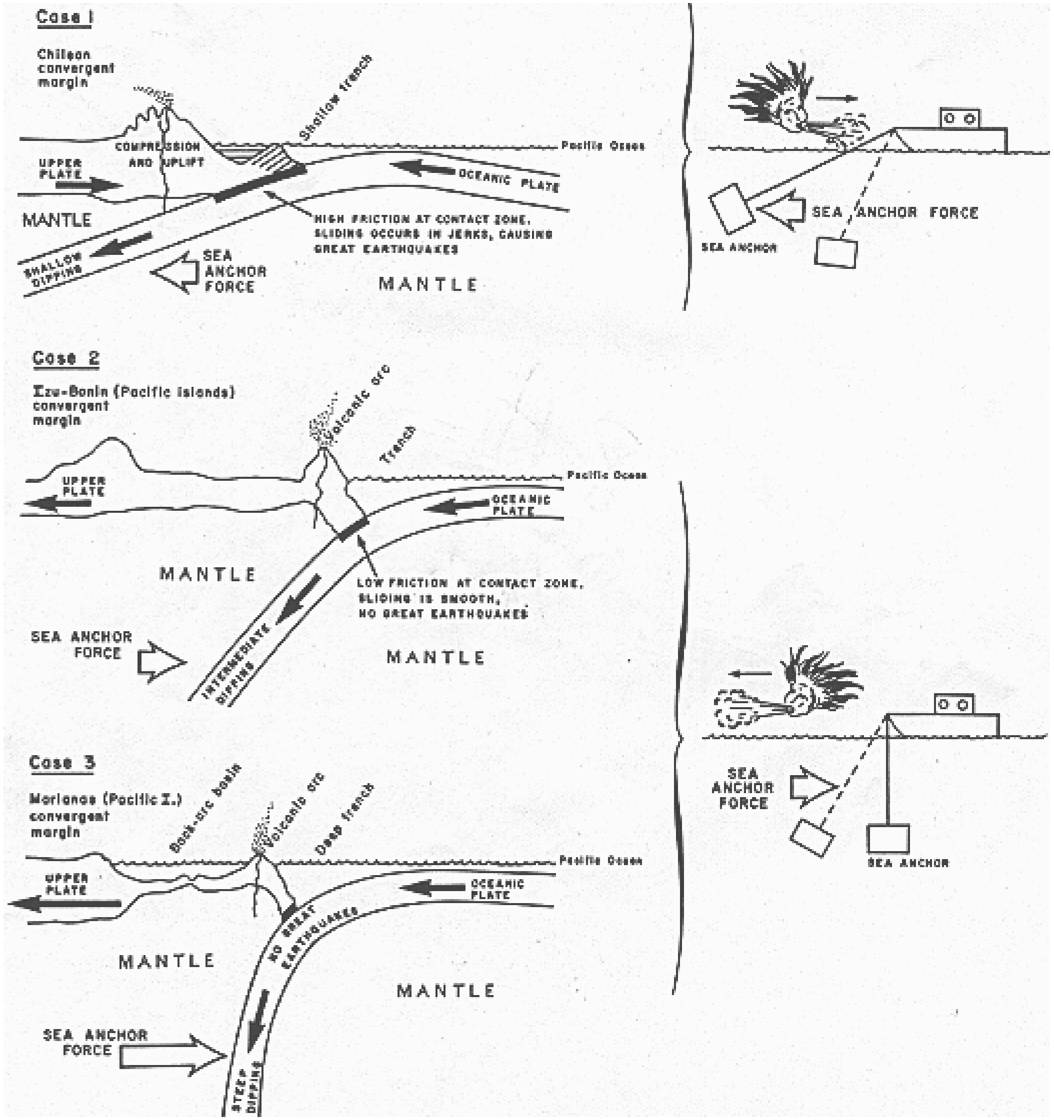
TRENCH roll back





Photograph: Scientists at Lamont-Doherty Earth Observatory and the University of Chile have discovered that most of earth's great crustal plates behave like sea anchors that mariners use to aim their ships in stormy seas. When an upper plate is moving over the earth's mantle toward a descending plate, a "sea anchor force" draws the descending slab up through the mantle to a shallow angle, like a sea anchor of a ship against the wind, and great earthquakes occur (Case 1). When the upper plate is moving away from the descending plate, the sea anchor force pushes against the slab and bends it down--like the anchor of a ship going with the wind. That relieves friction at the contact zone where the two plates slide past one another until a certain point, sliding becomes smooth and no earthquakes occur (Case 2). When the upper plate is moving away rapidly enough, it rifts apart to create a new ocean basin behind an arc of volcanic islands, called a back-arc basin (Case 3). Photograph: Christopher Scholz. Photo Credit: Sally Savage.

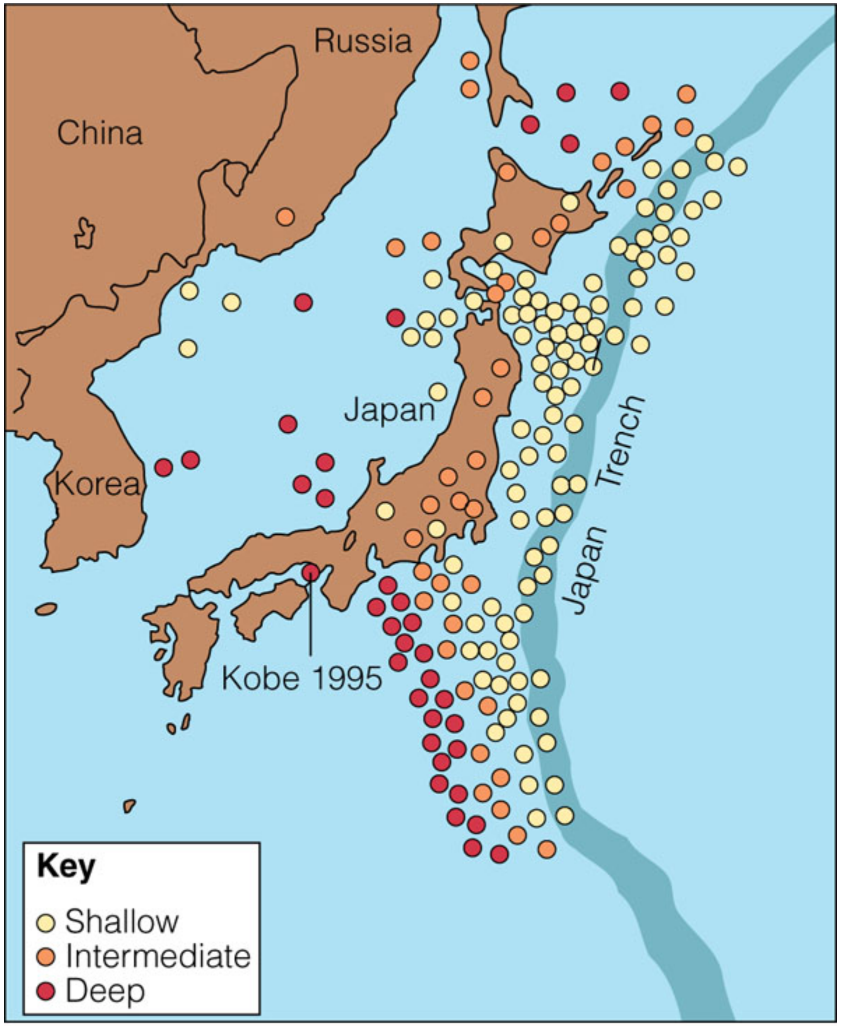



Case 1
Chilean convergent margin
Shallow trench
Pacific Ocean
COMPRESSION AND UPLIFT
UPPER PLATE
OCEANIC PLATE
MANTLE
HIGH FRICTION AT CONTACT ZONE, SLIDING OCCURS IN JERKS, CAUSING GREAT EARTHQUAKES
SHALLOW DIPPING
SEA ANCHOR FORCE
MANTLE
SEA ANCHOR FORCE
SEA ANCHOR
Case 2
Izu-Bonin (Pacific Islands) convergent margin
Volcanic arc
Trench
Pacific Ocean
UPPER PLATE
OCEANIC PLATE
MANTLE
LOW FRICTION AT CONTACT ZONE, SLIDING IS SMOOTH, NO GREAT EARTHQUAKES
SEA ANCHOR FORCE
INTERMEDIATE DIPPING
MANTLE
SEA ANCHOR FORCE
SEA ANCHOR
Case 3
Marianas (Pacific I.) convergent margin
Back-arc basin
Volcanic arc
Deep trench
Pacific Ocean
UPPER PLATE
OCEANIC PLATE
NO GREAT EARTHQUAKES
MANTLE
MANTLE
SEA ANCHOR FORCE
STEEP DIPPING

Bac-arc basin

- Back-arc basin, submarine basin that forms behind an island arc. Such basins are typically found along the western margin of the Pacific Ocean near the convergence of two tectonic plates. Back-arc basins are sites of significant hydrothermal activity, and the deep-sea vents that occur in these regions often harbour diverse biological communities. Examples of back-arc basins include the Sea of Japan, the Kuril Basin in the Sea of Okhotsk, the Mariana Trough in the Philippine Sea, and the South Fiji Basin.

- A back-arc basin is formed by the process of back-arc spreading



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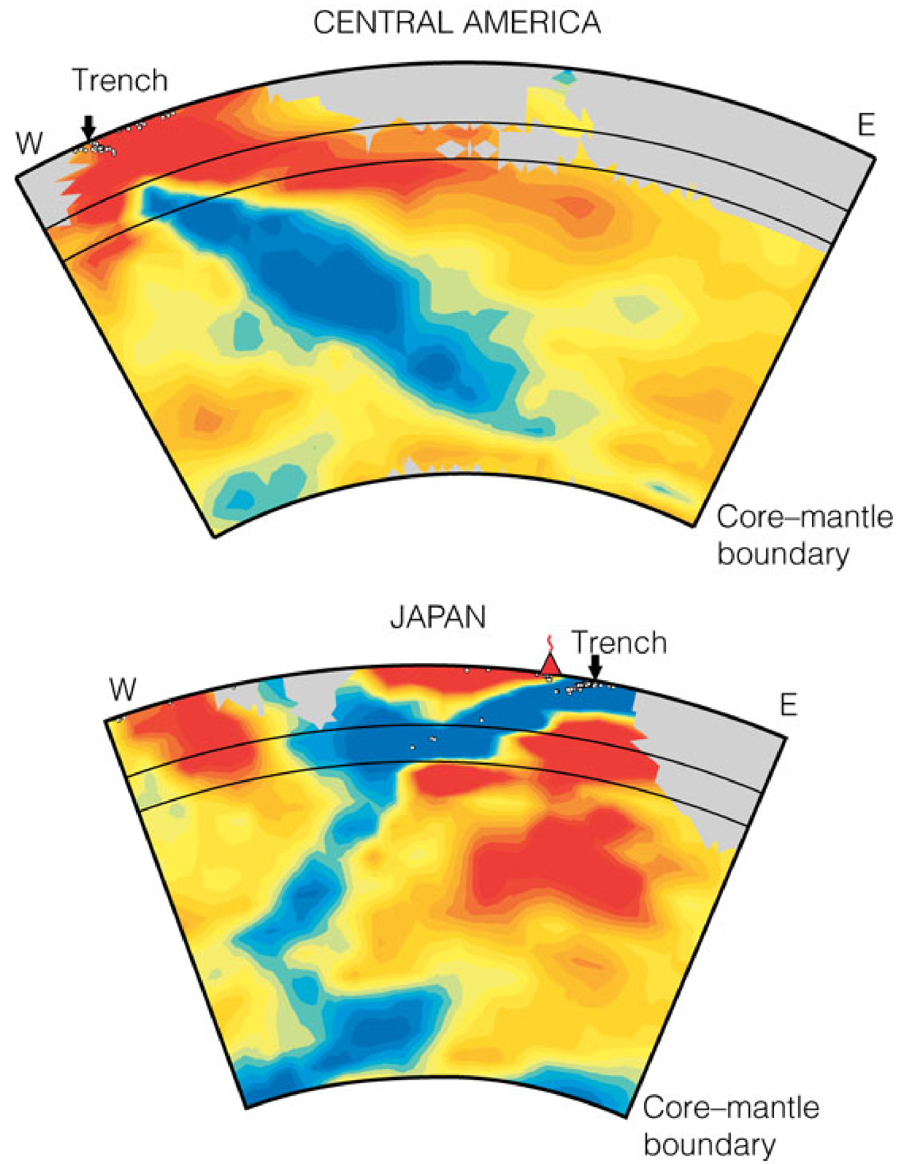

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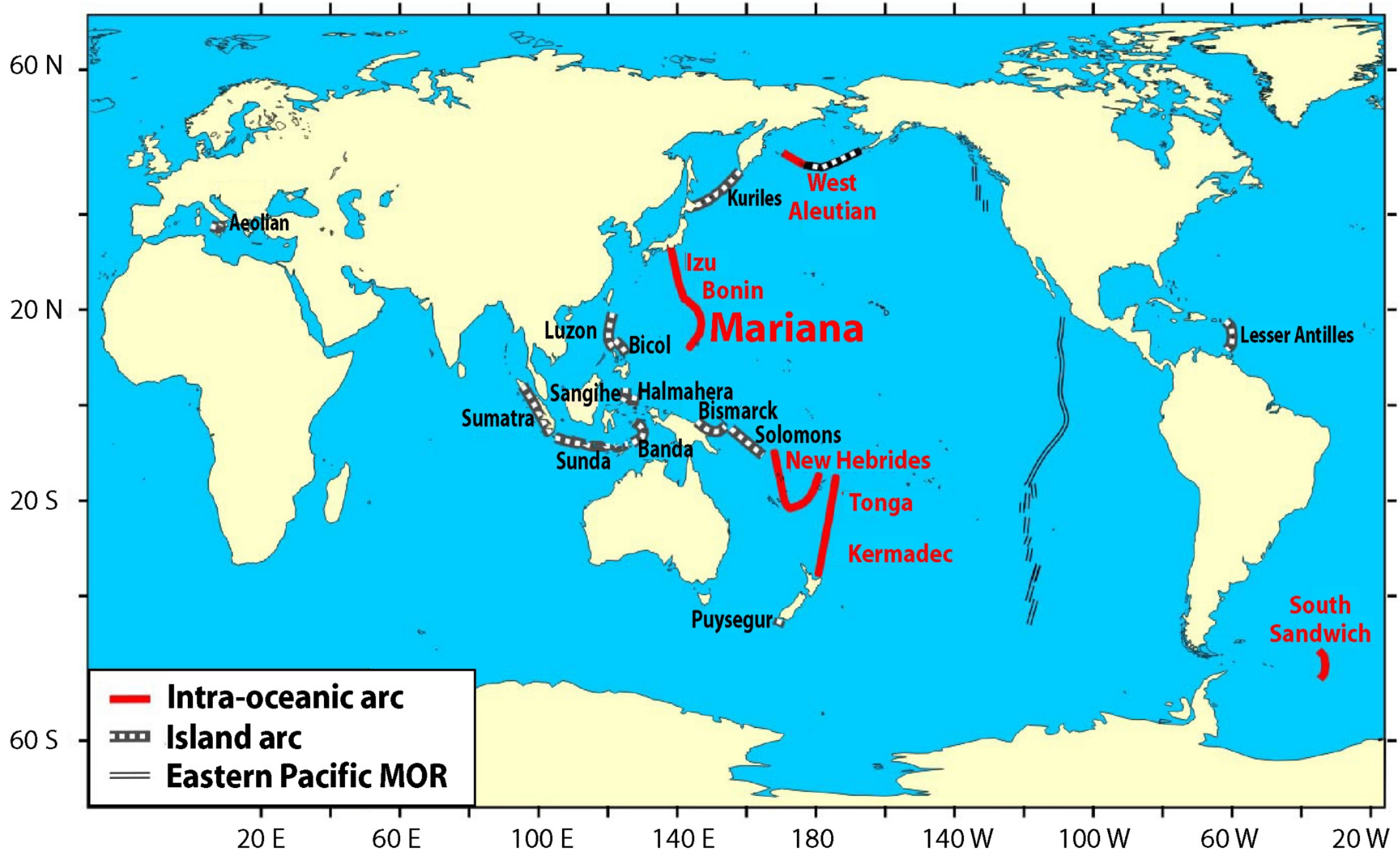
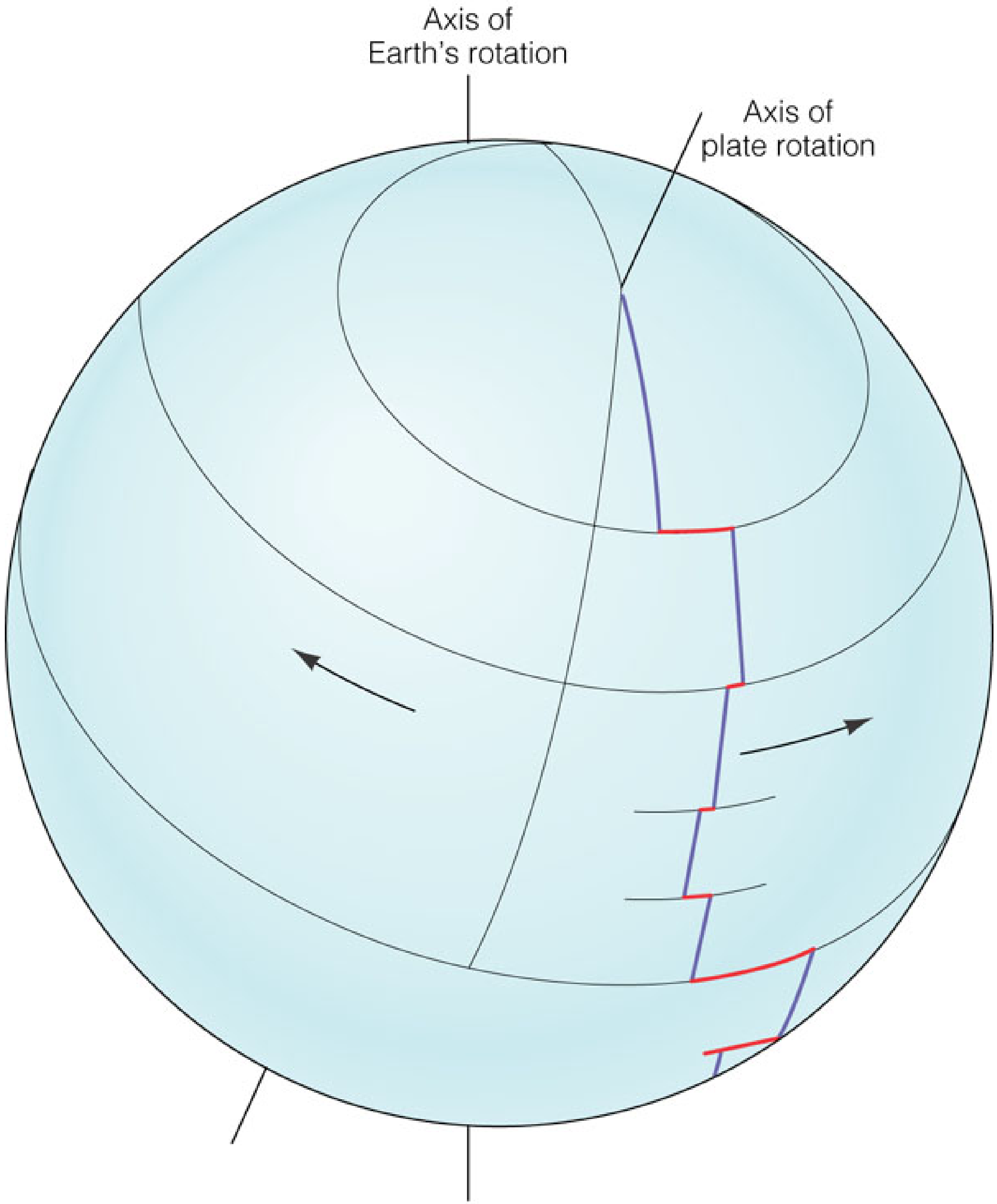
Global Distrubution of Active Marine Volcanic Arcs



Transform faults

- Transform faults
  - Plates moving past each other
  - Relieve pressure due to earth’s curvature, relative rates of spreading, etc



Axis of spreading is broken up by curvature of earth or unequal spreading, etc

Spreading cannot proceed evenly on the surface of a sphere (this would necessarily require faster spreading at the equator and slower spreading at the poles

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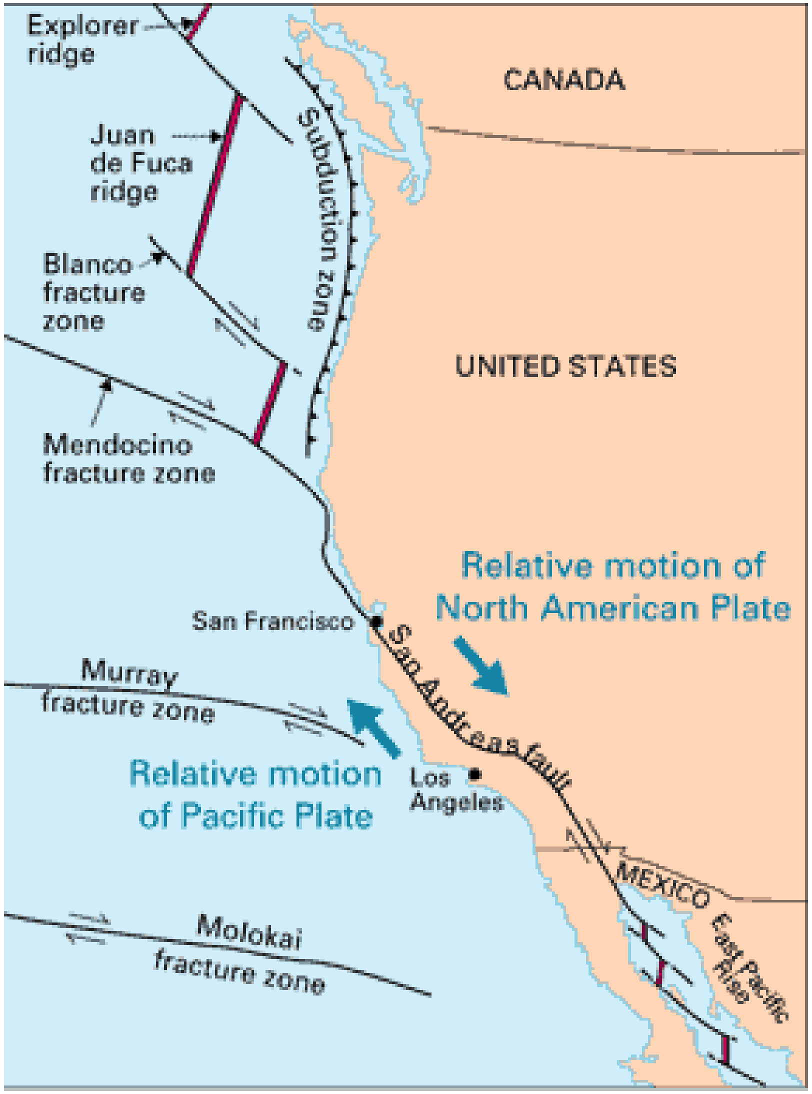
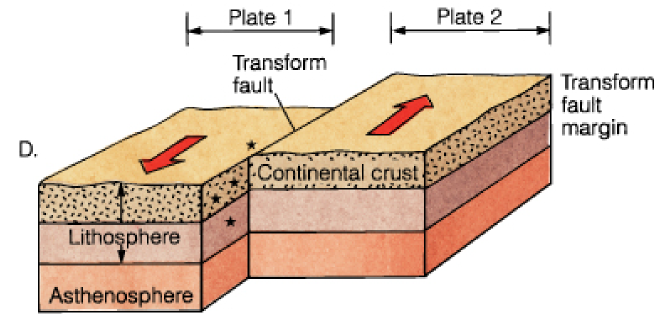
Transform Boundaries



Transform fault. No characteristic topographic expression, but margin is often marked by a long, thin valley. Earthquakes down to 100 km and often strong.



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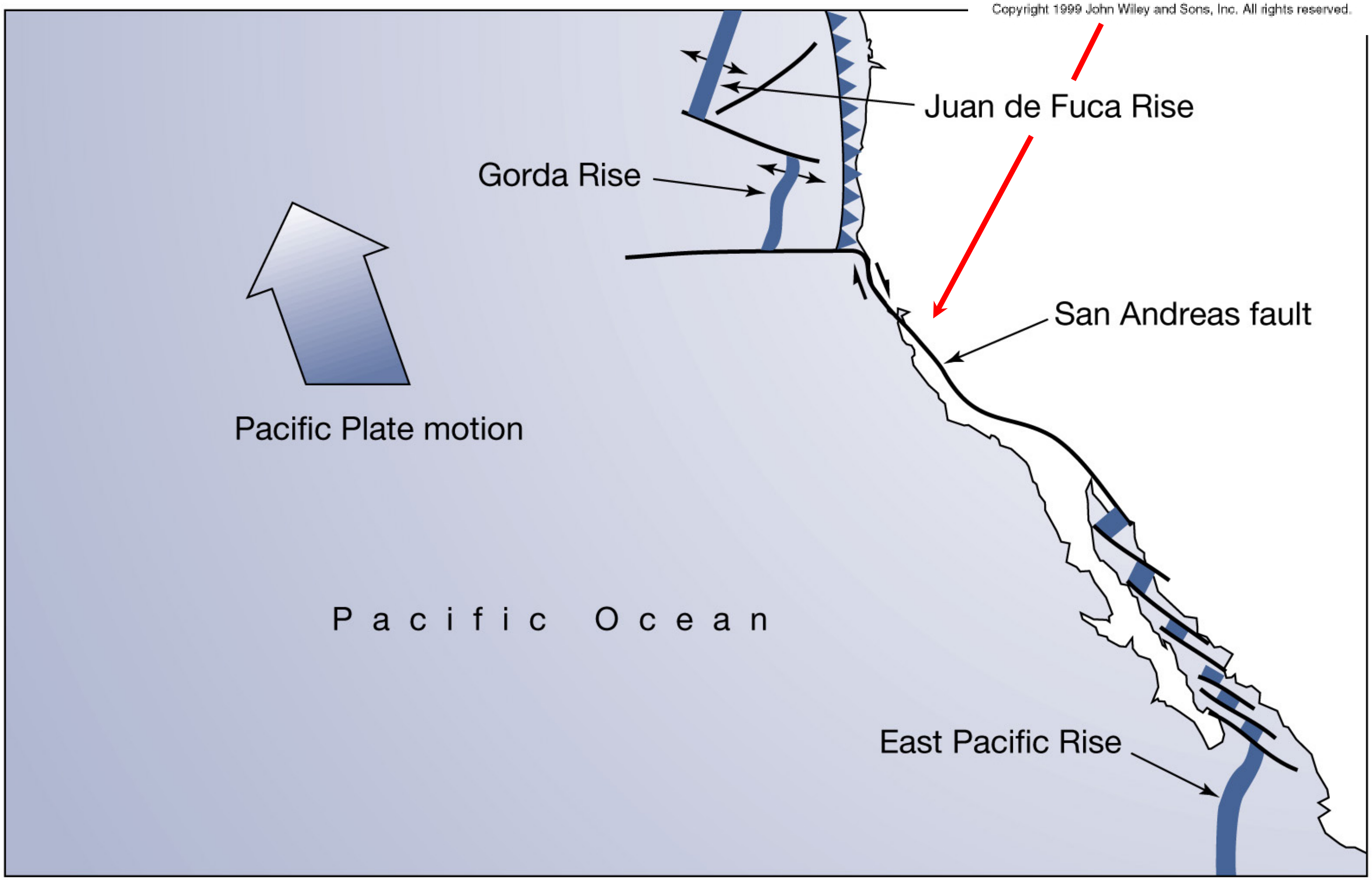

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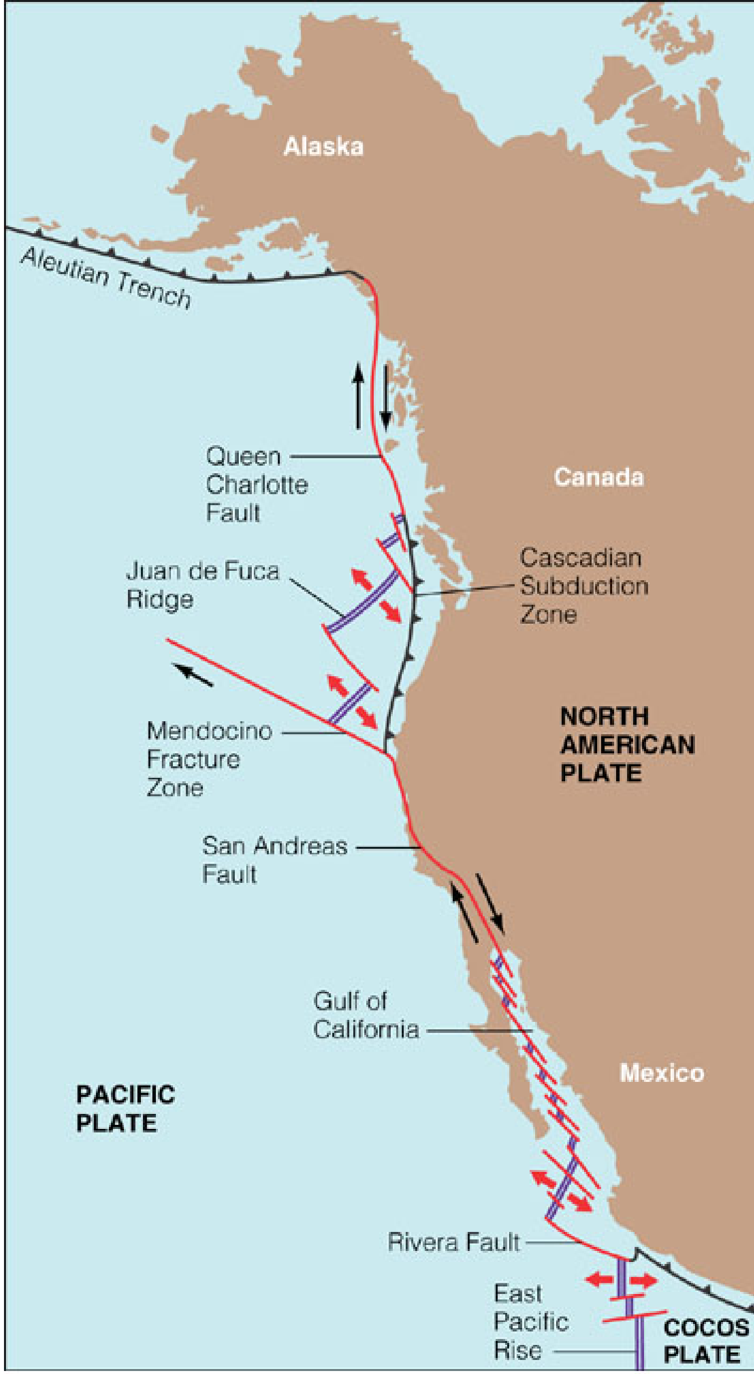

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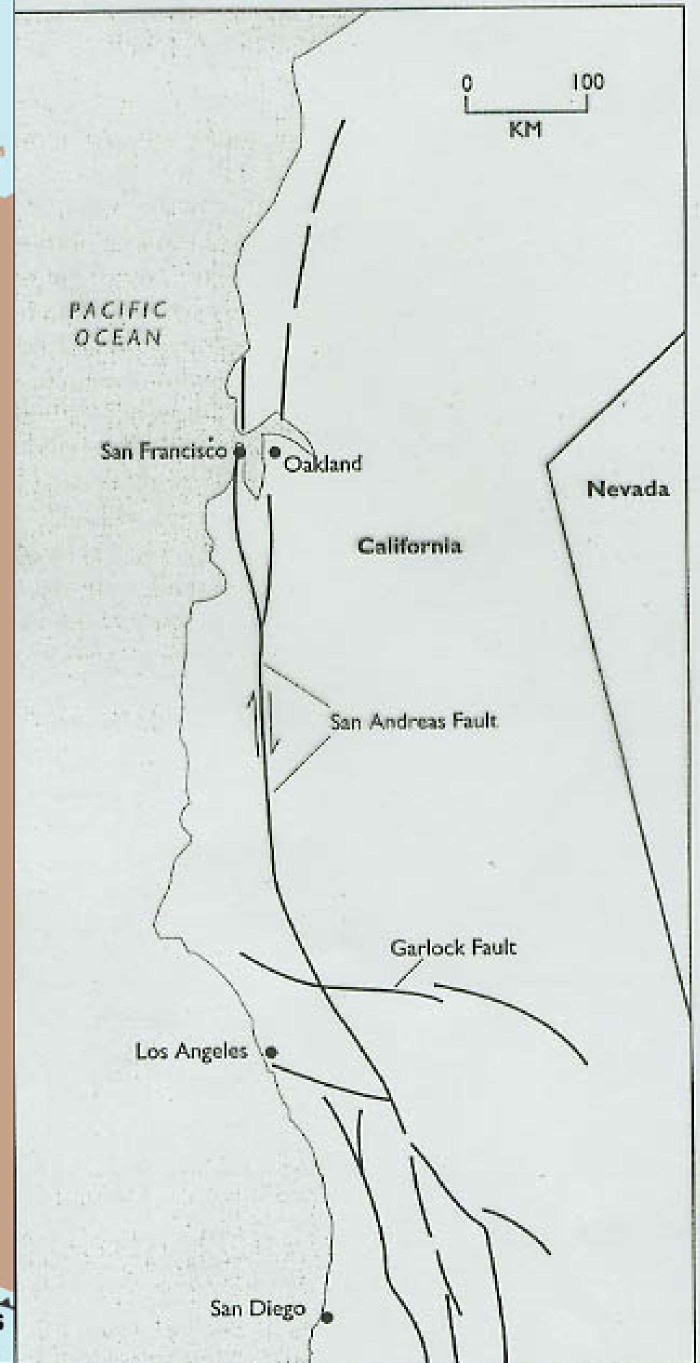
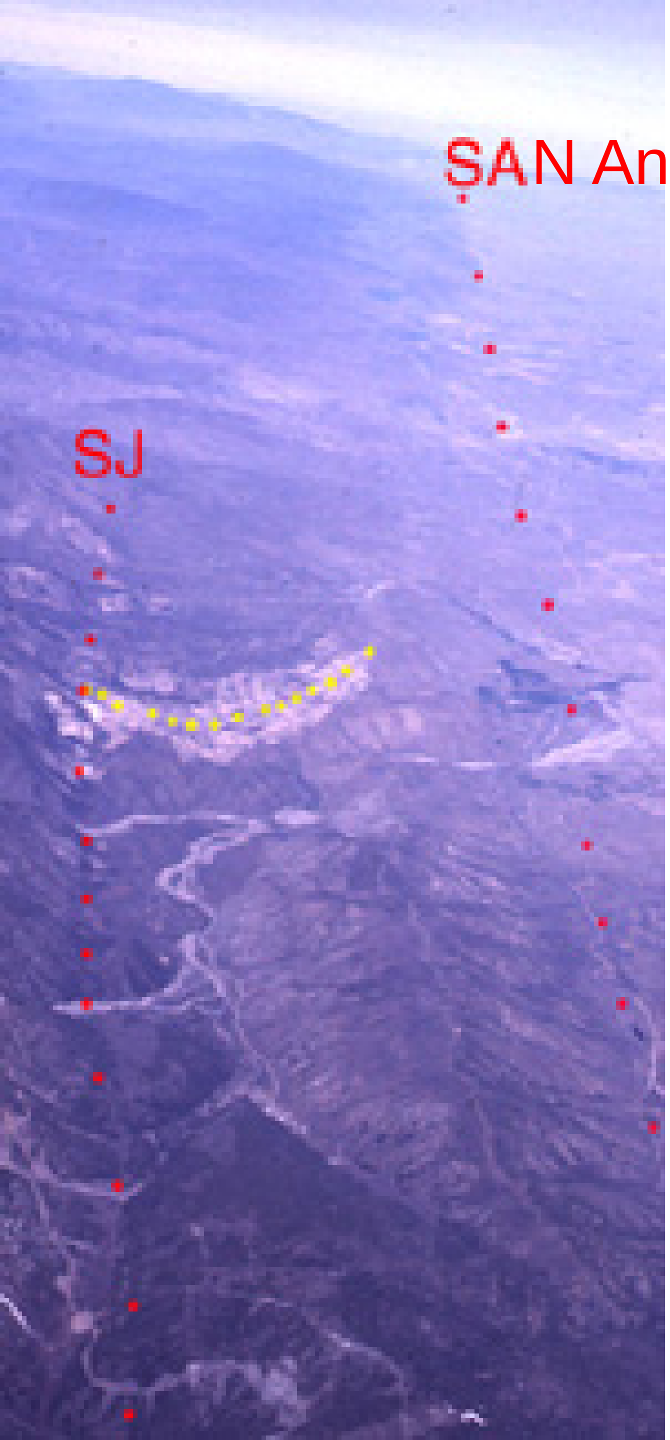
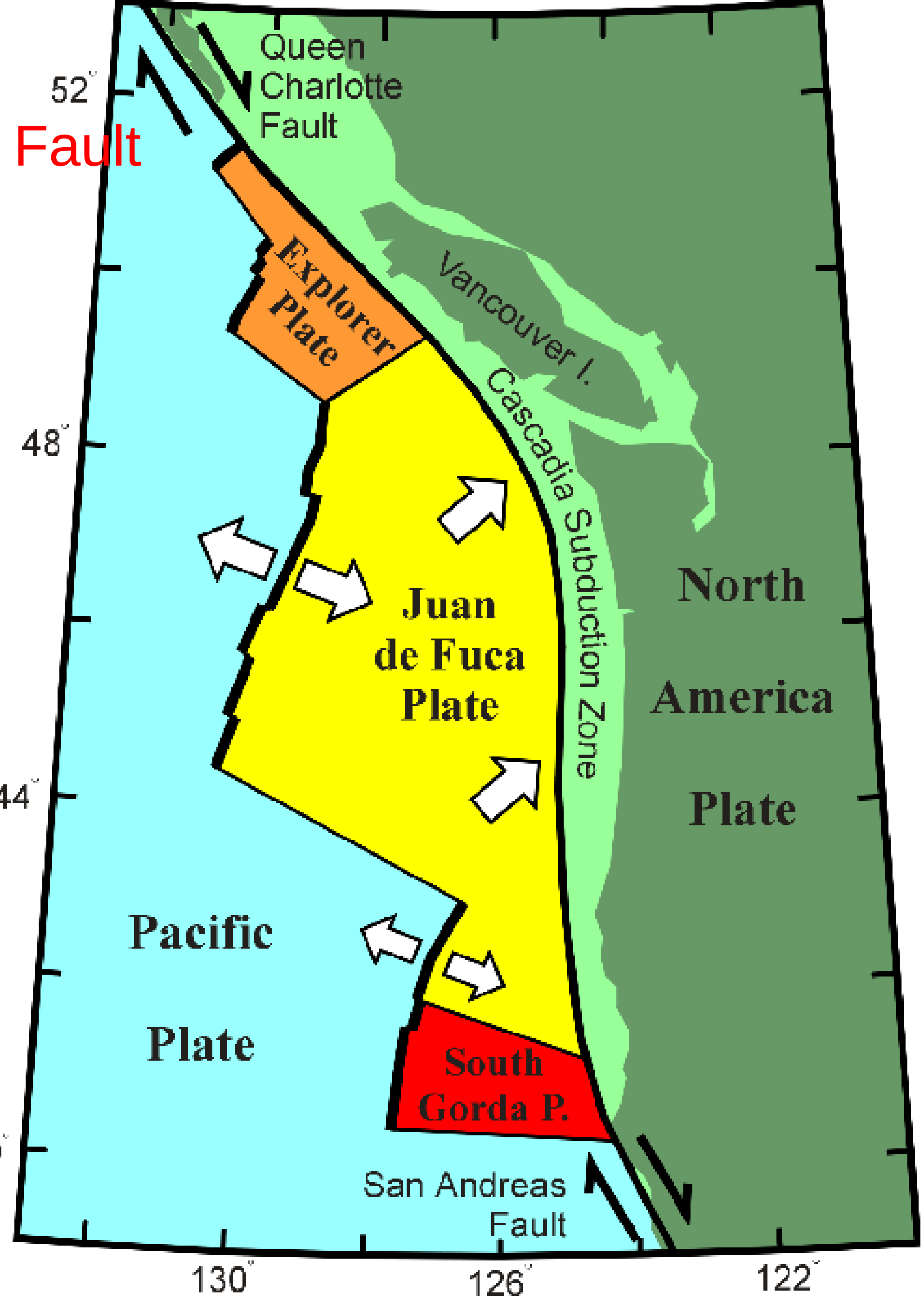


(b) SAN ANDREAS FAULT

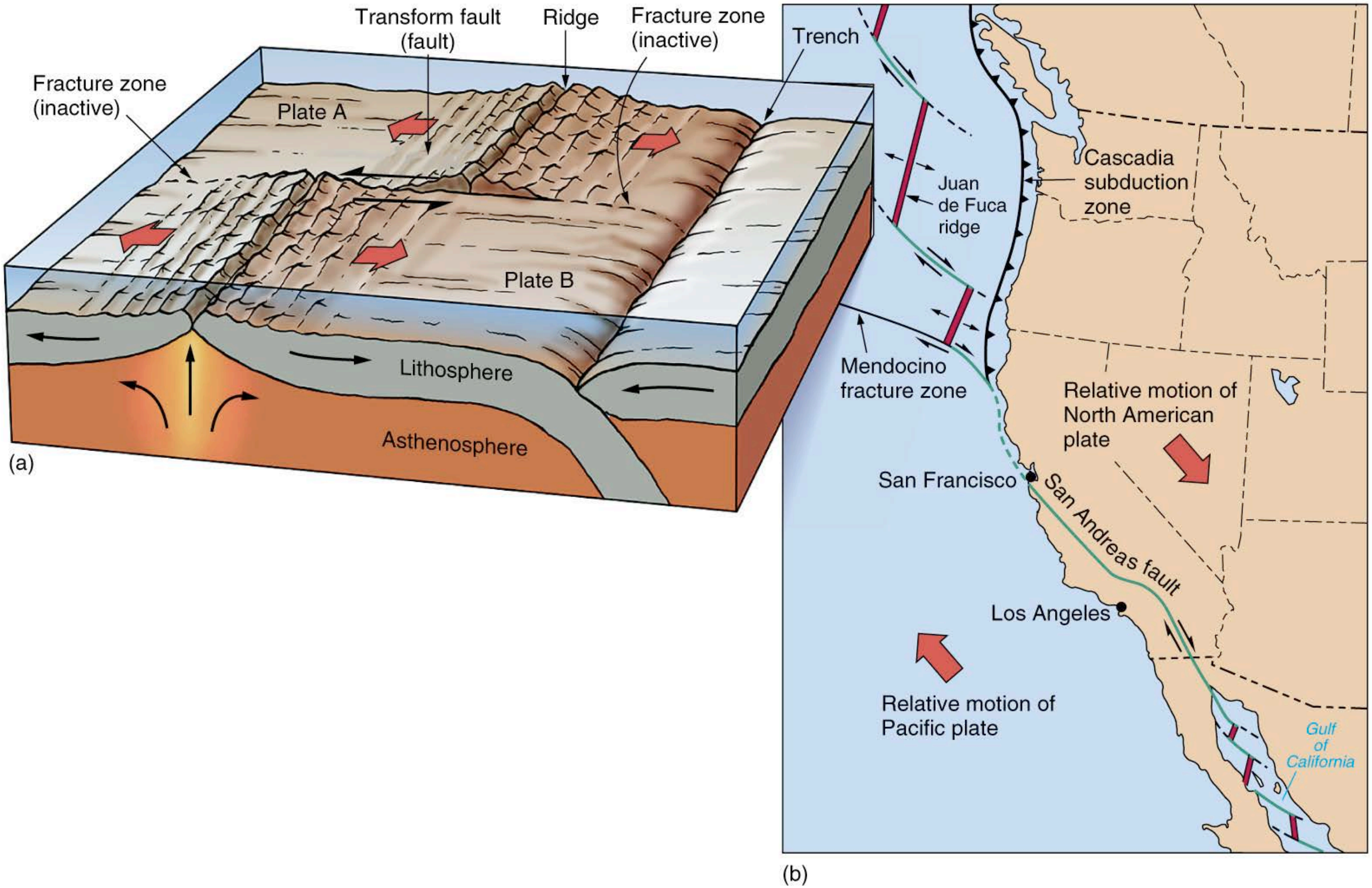
SAN Andreas Fault





Conservative margins

Transform faults



Conservative margins
Transform faults

(a) PLATE BOUNDARY

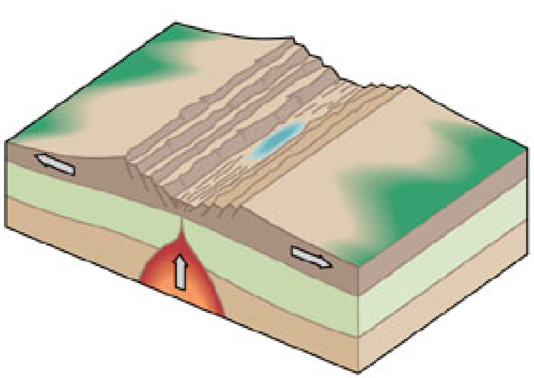
The San Andreas fault in southern California

Transform faults and accretion

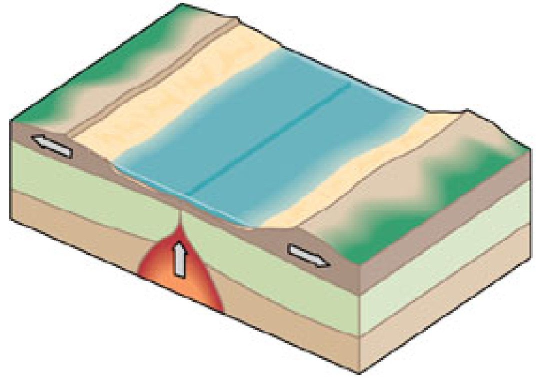
- Can cleave off bits of continental crust that are plastered onto other continental land masses

Net result

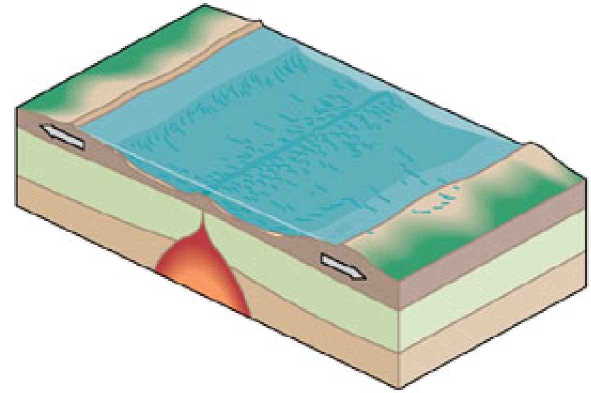
- Spreading rates at transform faults
  - Pacific plate moves NW at 8 cm/yr
  - N American plate moves W at 2 cm/yr
  - Indian plate moves NE at 12 cm/yr
- Pacific Ocean is shrinking and Atlantic is growing
  - Atlantic opened about 200 MY ago so there should be no rocks older than this in the Atlantic



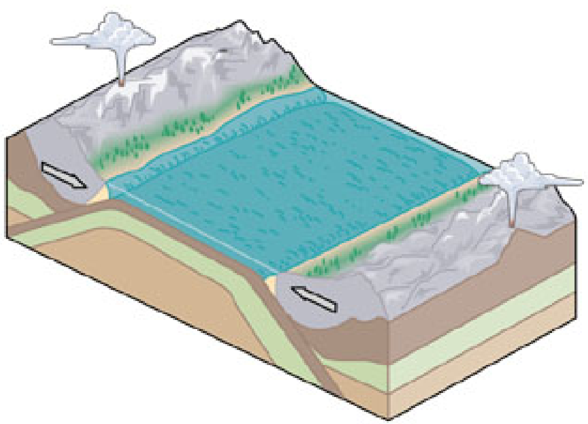
Stage 1: **Embryonic**
Motion: Rift flank uplift, rift valley subsidence
Features: Complex system of rift valleys and lakes on continent
Example: East African Rift Valleys



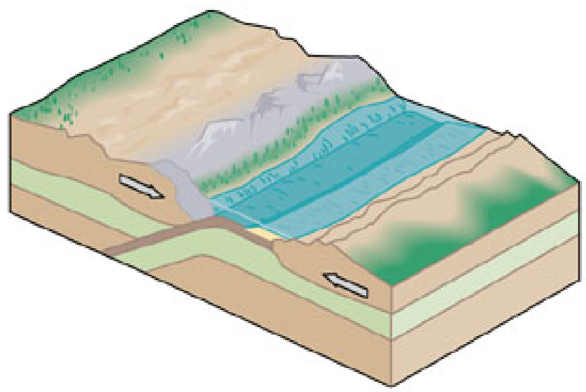
Stage 2: **Juvenile**
Motion: Divergence (spreading)
Features: Narrow sea with matching coasts. Oceanic ridge formed.
Example: Red Sea



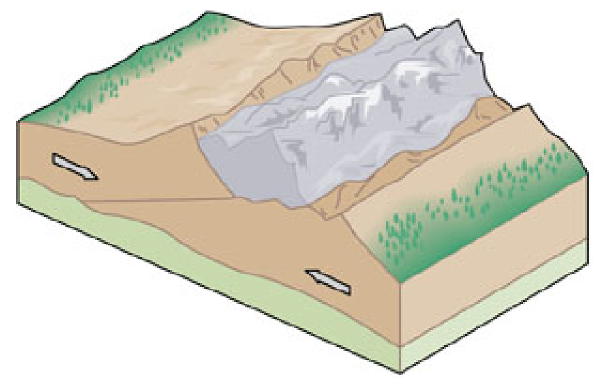
Stage 3: **Mature**
Motion: Divergence (spreading)
Features: Ocean basin with continental margins. Ocean continues to widen at oceanic ridge.
Example: Atlantic Ocean, Arctic Ocean



Stage 4: **Declining**
Motion: Convergence (subduction)
Features: Subduction begins. Island arcs and trenches form around basin edge.
Example: Pacific Ocean



Stage 5: **Terminal**
Motion: Convergence, collision, and uplift
Features: Oceanic ridge subducted. Narrow, irregular seas with young mountains.
Example: Mediterranean Sea



Stage 6: **Suturing**
Motion: Convergence and uplift
Features: Mountains form as two continental crust masses collide, are compressed, and override.
Example: India–Eurasia collision, Himalaya Mountains

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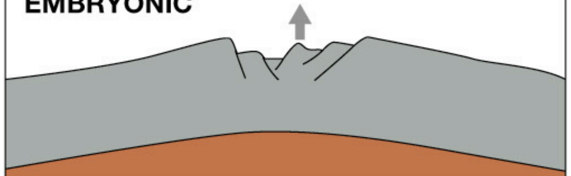
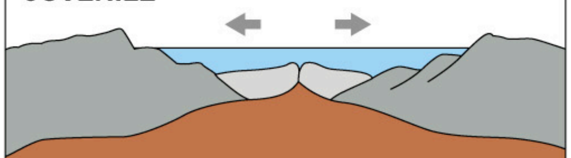
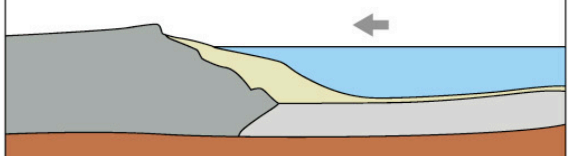
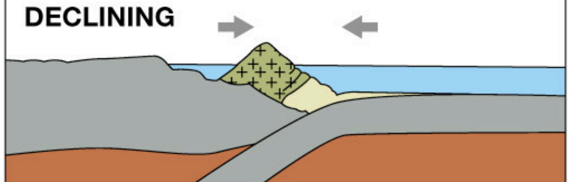
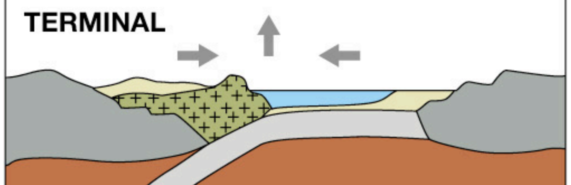
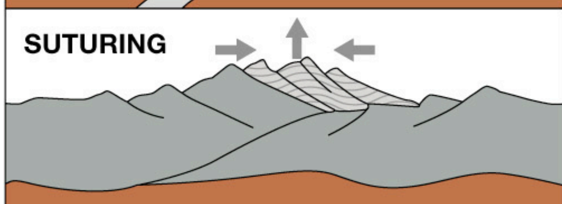
STAGE	MOTION	PHYSIOGRAPHY	EXAMPLE
EMBRYONIC 	Uplift	Complex system of linear rift valleys on continent	East African rift valleys
JUVENILE 	Divergence (spreading)	Narrow seas with matching coasts	Red Sea
MATURE 	Divergence (spreading)	Ocean basin with continental margins	Atlantic and Arctic Oceans
DECLINING 	Convergence (subduction)	Island arcs and trenches around basin edge	Pacific Ocean
TERMINAL 	Convergence (collision) and uplift	Narrow, irregular seas with young mountains	Mediterranean Sea
SUTURING 	Convergence and uplift	Young to mature mountain belts	Himalaya Mountains

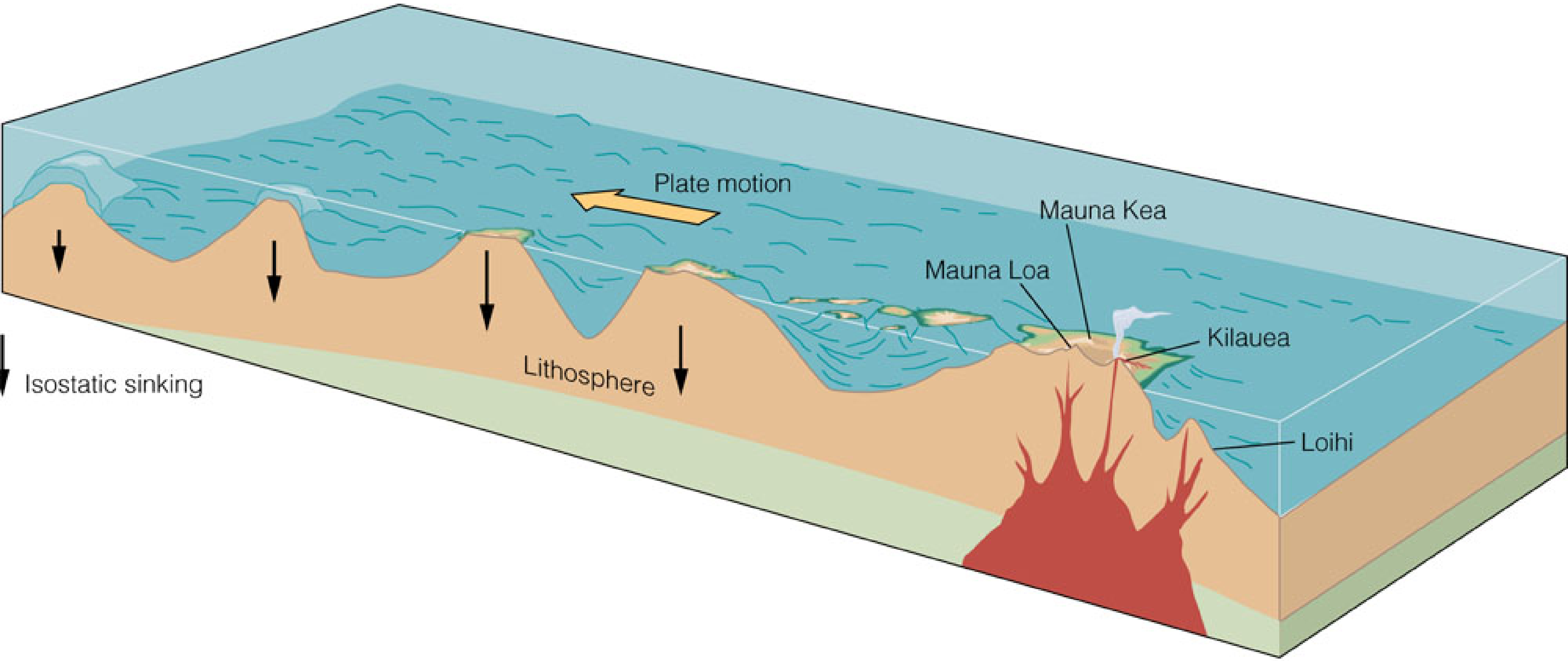
Life cycle of Plates

"The Wilson Cycle"

Hotspots

- Mantle plume
- Direction of plate motion

Hot spots – surface expressions of plumes
Stationary spot and plate moving over it.



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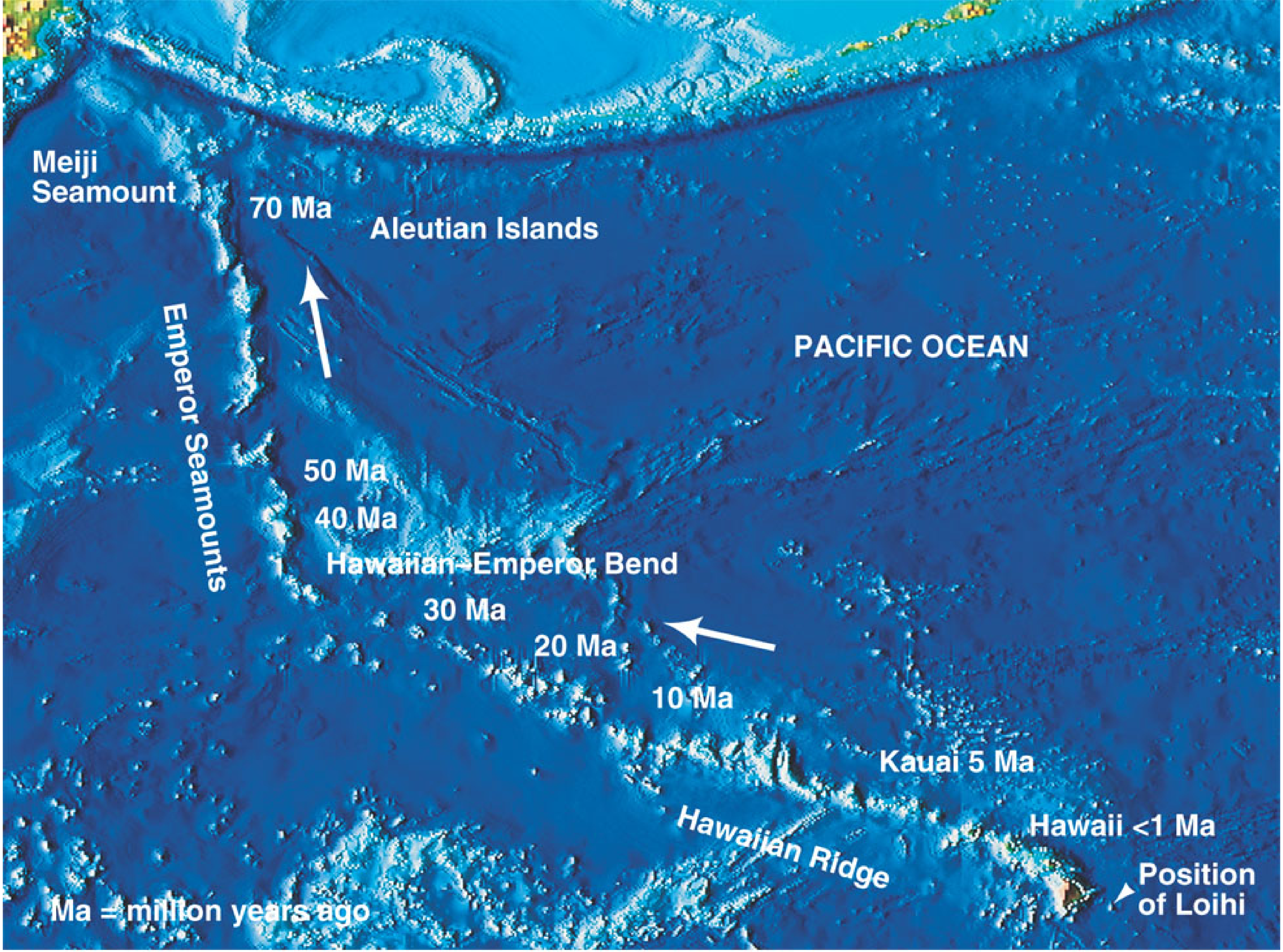

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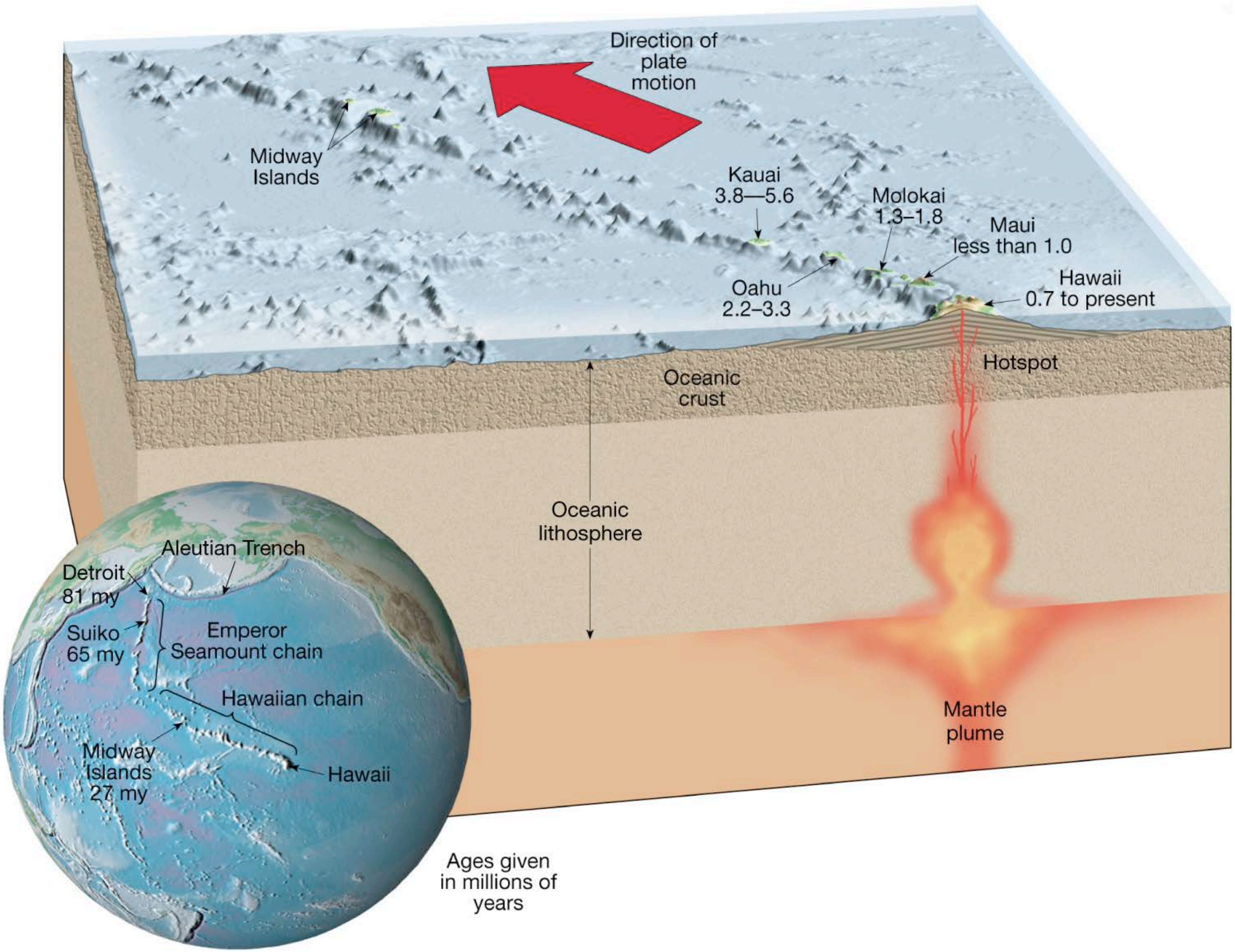
Hot Spots ?



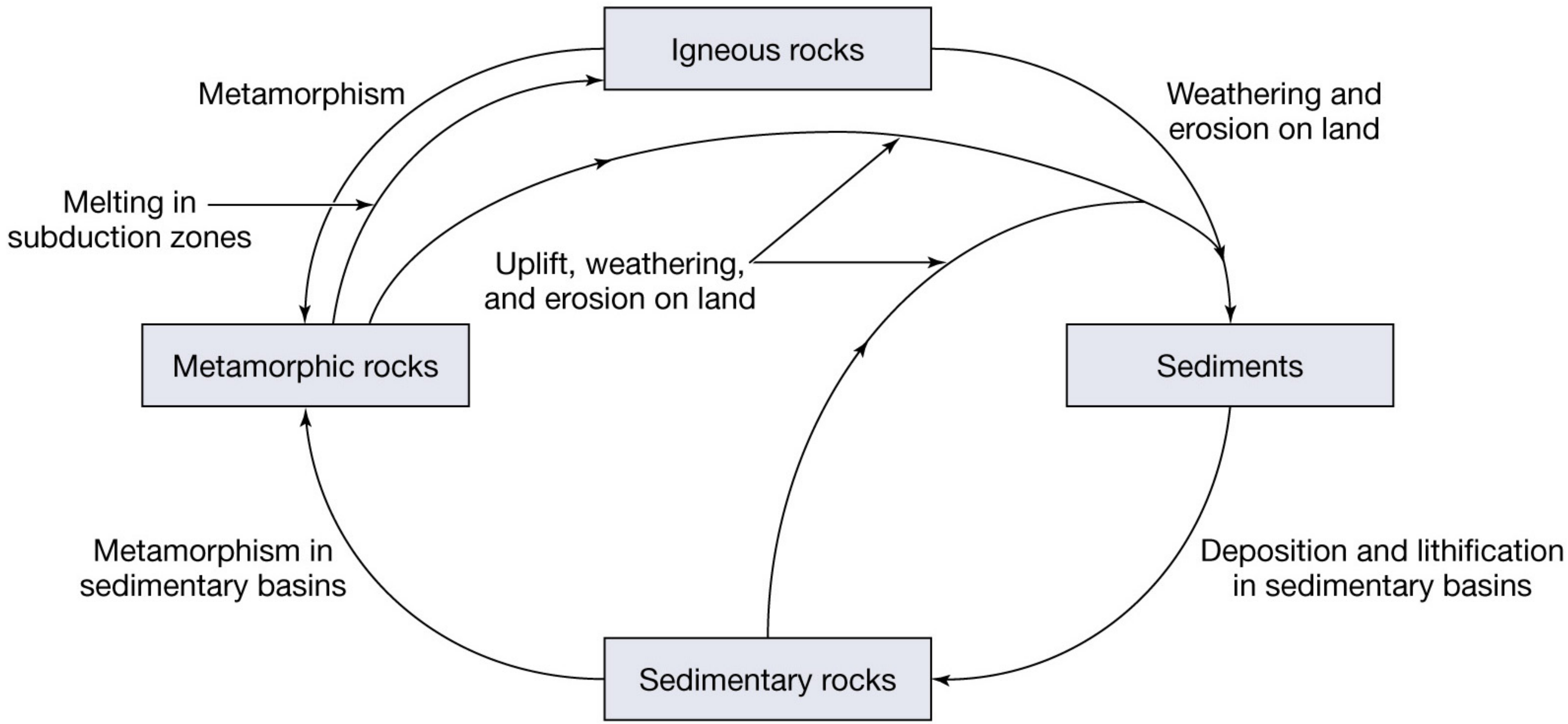
Direction of plate motion
Midway Islands
Kauai 3.8—5.6
Molokai 1.3–1.8
Maui less than 1.0
Oahu 2.2–3.3
Hawaii 0.7 to present
Hotspot
Oceanic crust
Oceanic lithosphere
Mantle plume
Aleutian Trench
Detroit 81 my
Suiko 65 my
Emperor Seamount chain
Hawaiian chain
Midway Islands 27 my
Hawaii
Ages given in millions of years

The Earth's Early Crust

	Oceanic crust	Continental crust
First appearance	~4.5 bybp	~4.3 bybp
Where formed	ocean ridge High temperature	submarine plateaus Lower temperature
Composition	basalt	TTG*
Lateral extent	widespread, rapidly recycled	local, rapidly recycled (?)
How generated	partial melting of ultramafic rock in upper mantle	partial melting of wet mafic rocks

*tonalite-trondhjemite-granodiorite
Low K, high Si granitoids dominated by quartz and plagioclase feldspar

The Rock cycle



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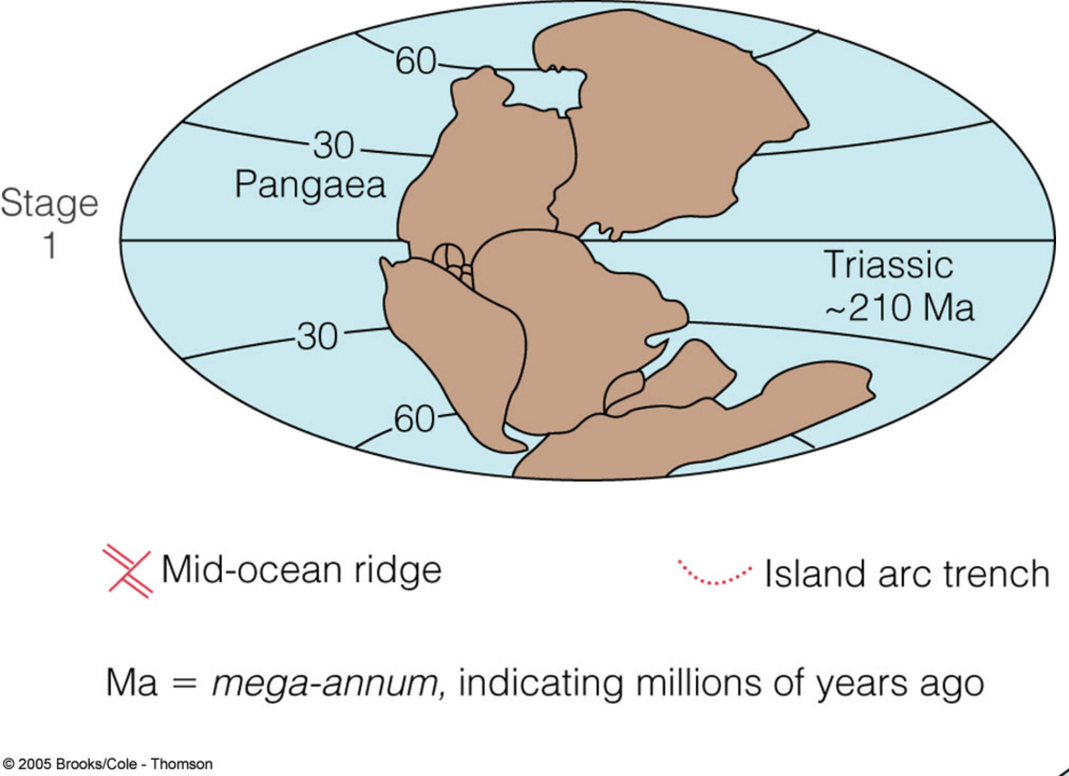
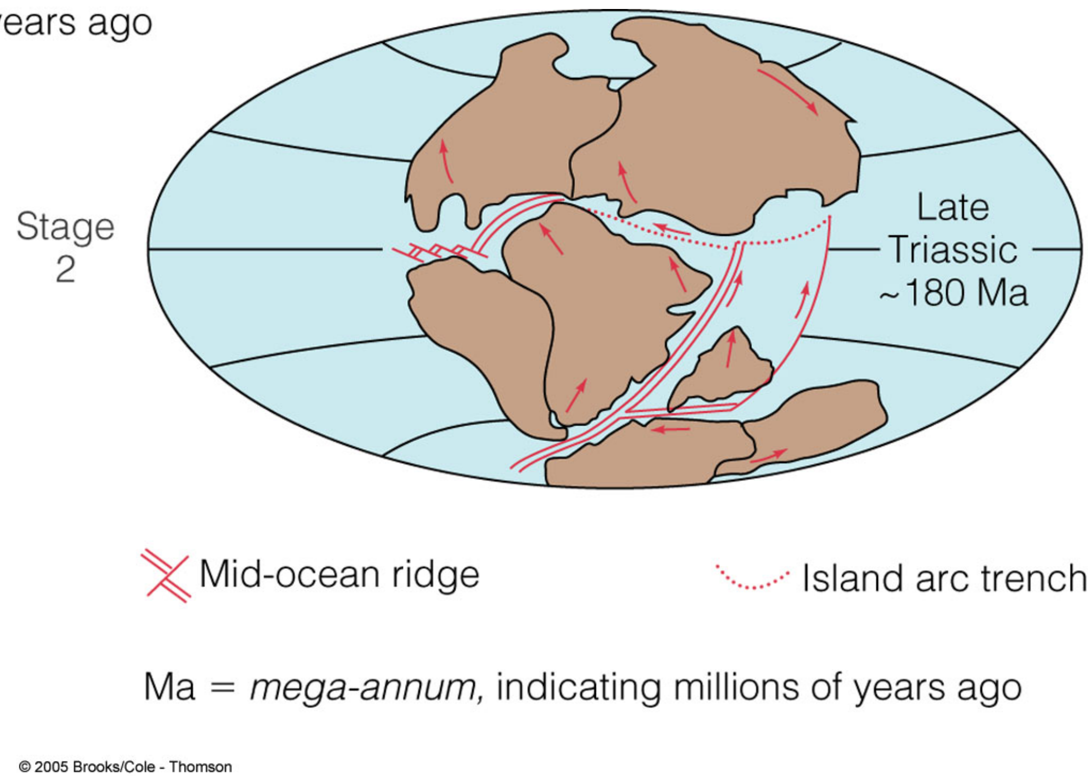


Most recent episode of Seafloor spreading:

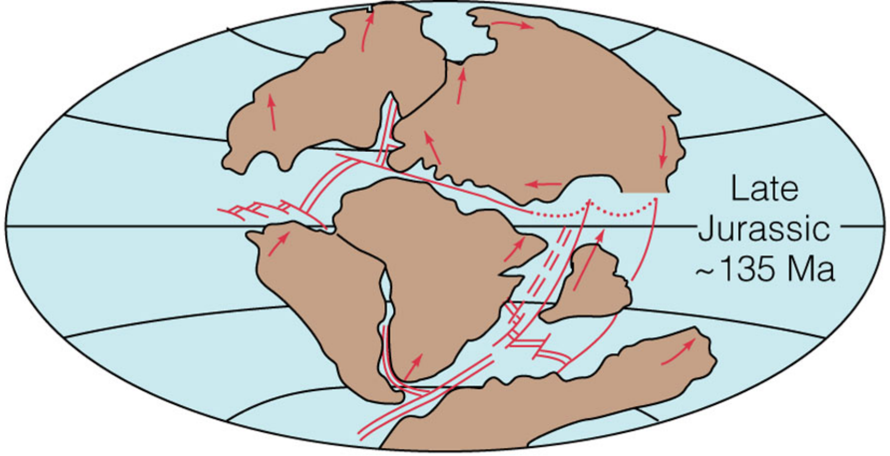
Pangaea first broke into 2 pieces

Sea opens between N and S continents and Between Africa and Antarctica

India moves North



Stage 3



Mid-ocean ridge   Island arc trench

Ma = *mega-annum,* indicating millions of years ago

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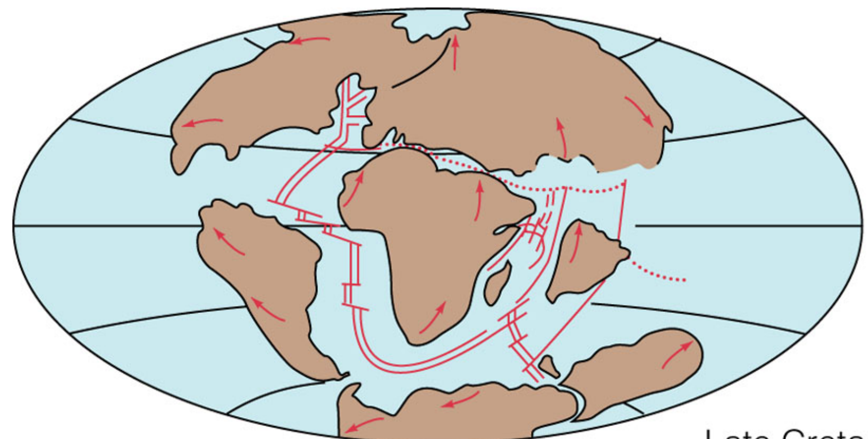
S Atlantic opens
Antarctica moving S
India moving N
Australia separates
and moves N

Stage 4



Late Cretaceous
~65 Ma

Mid-ocean ridge   Island arc trench

Ma = *mega-annum,* indicating millions of years ago

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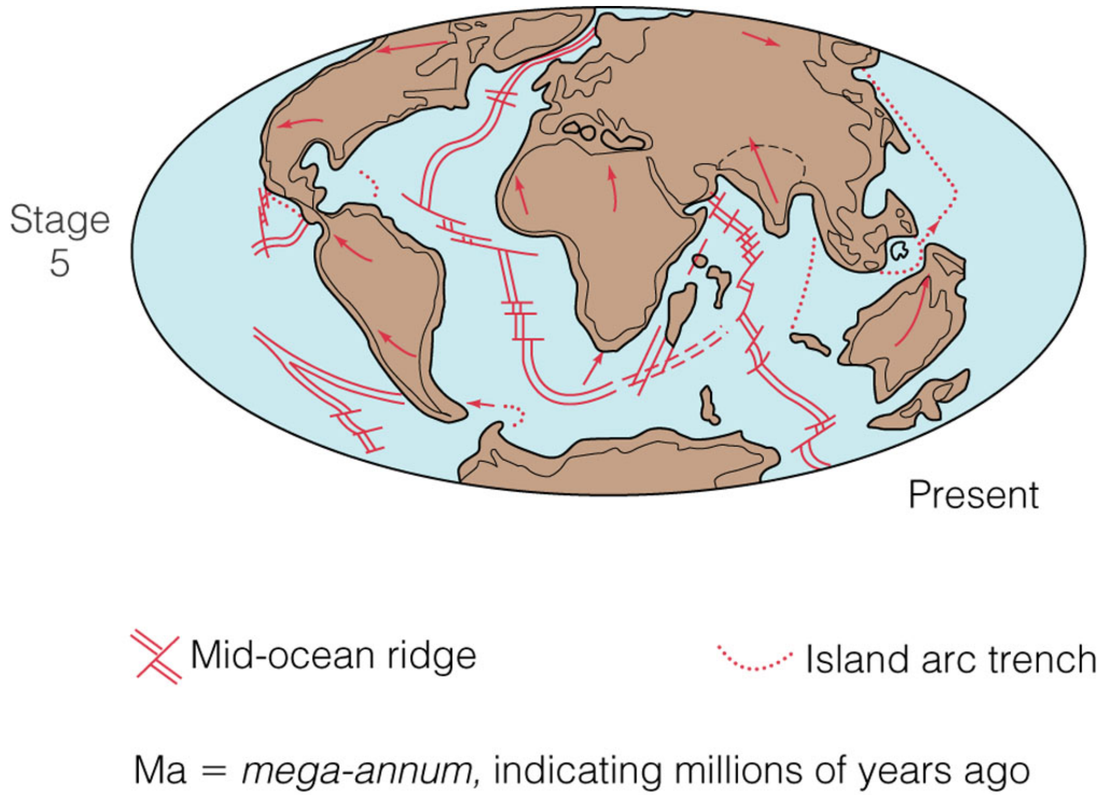

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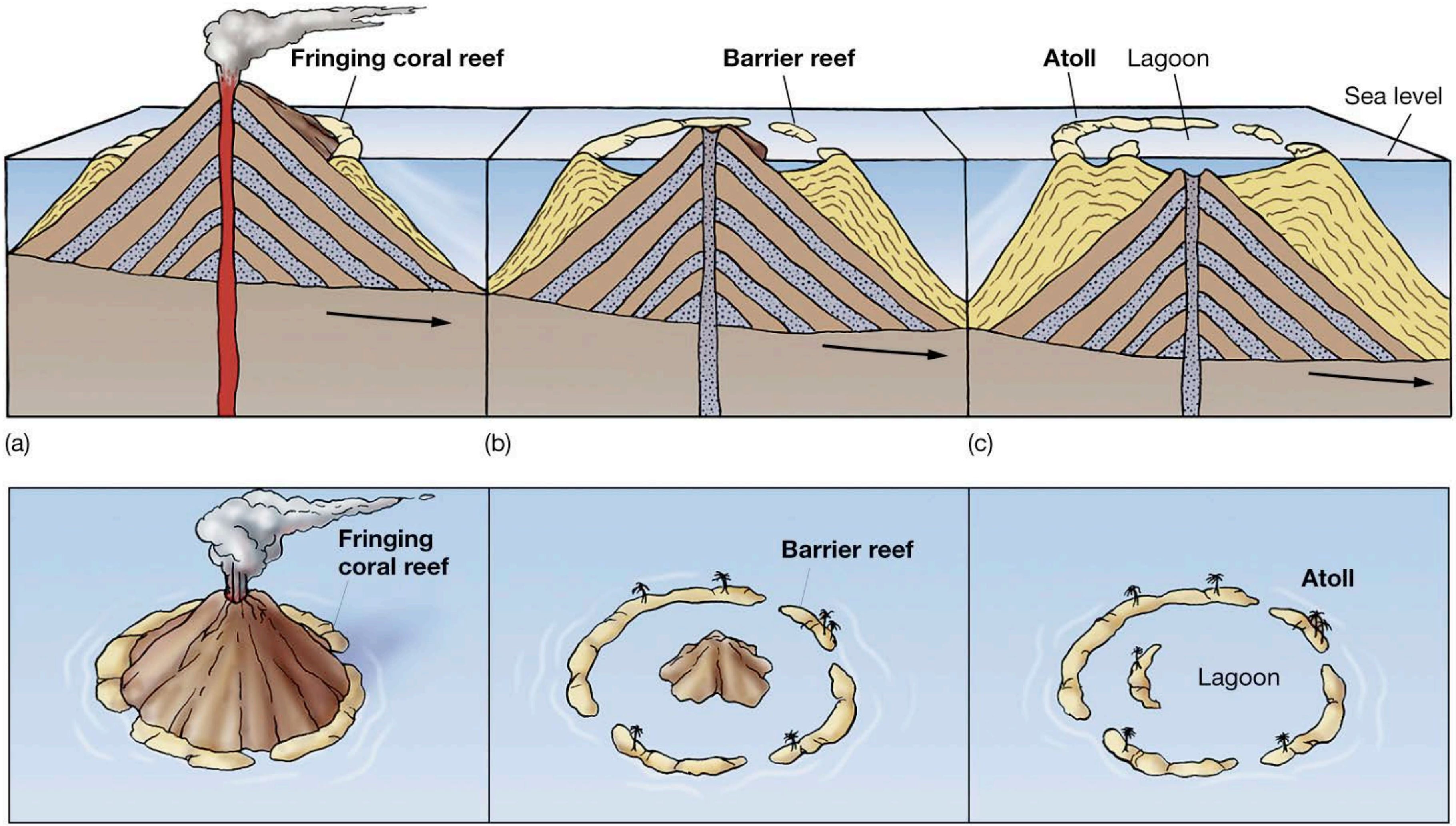
50 MY in the future:

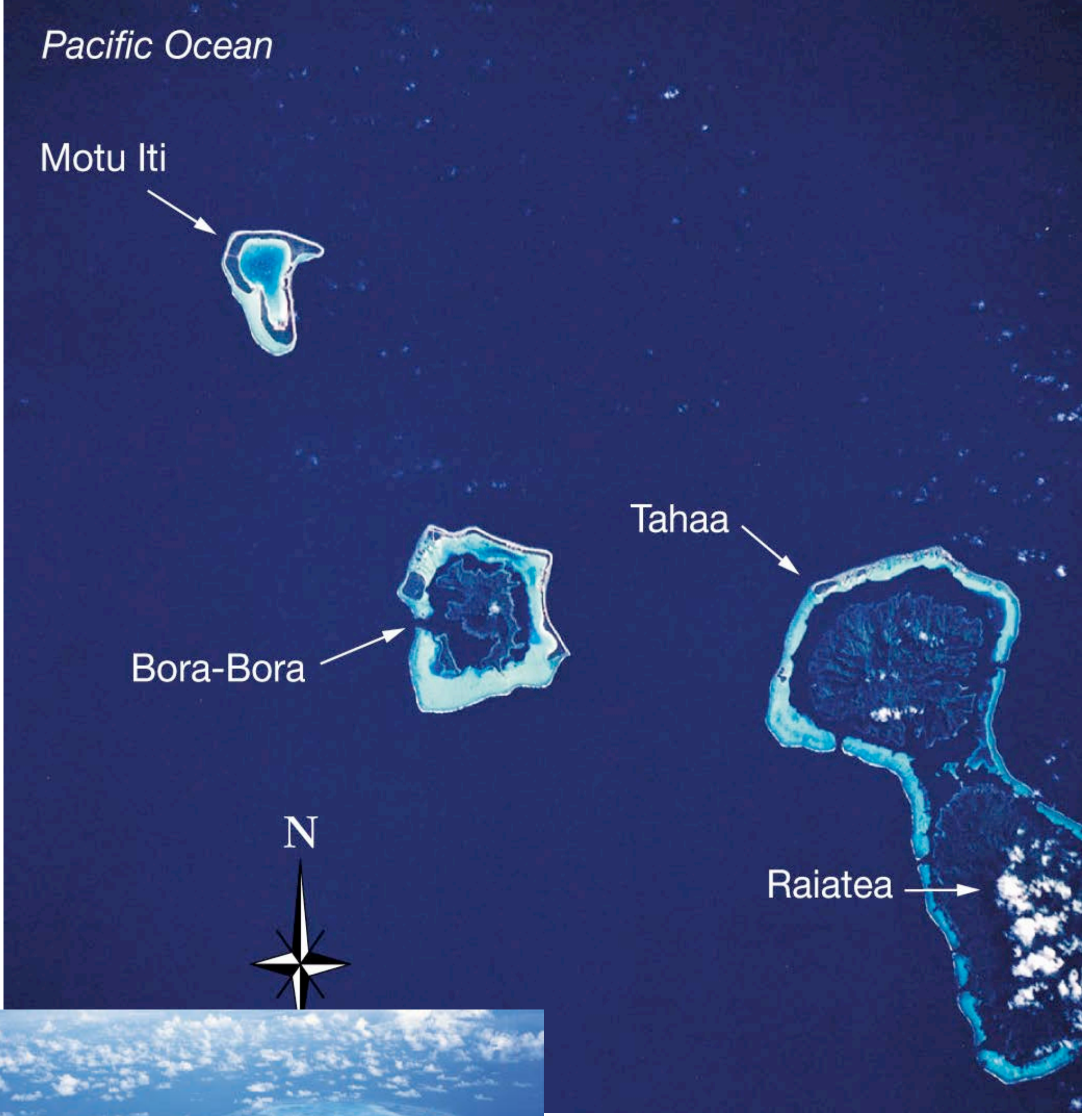
1. Africa will move N and close Mediterranean Sea
2. E Africa will detach (Red Sea rift zone) and move to India
3. Atlantic Ocean will grow and Pacific will shrink as it is swallowed into Aleutian trench.
4. W California will travel NW with the Pacific Plate (LA will be swallowed into the Aleutian trench in 60 MY).

Coreal Reefs



Atolls →

Palmyra Island



Fanning Island

Homework #2

- Prepare a short report (<5 pages with figures) for how the East Sea and Dokdo and Uleung Islands have been formed

  - due in two weeks