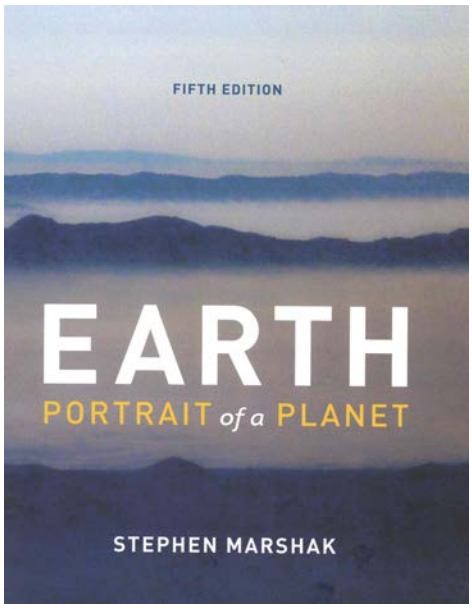
CEEES/SC 10110-20110

The Way the Earth Works: Plate Tectonics



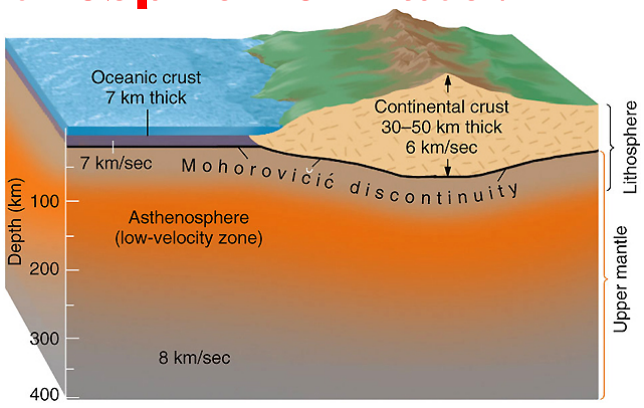
Earth

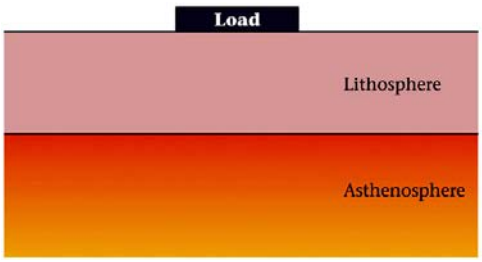
Portrait of a Planet
Fifth Edition

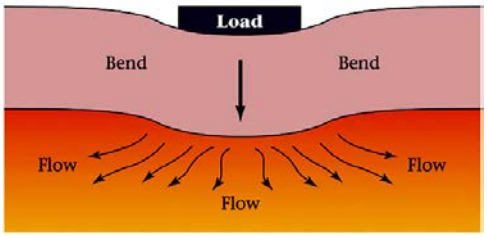
Chapter 4

What is a Lithospheric Plate?

Continental crust is thicker, less dense, and sits at a higher elevation than oceanic crust.





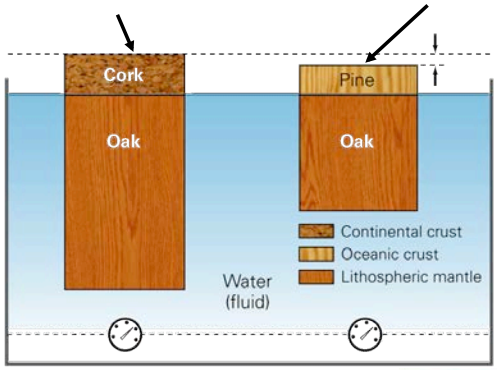


Lithosphere bends, but asthenosphere flows

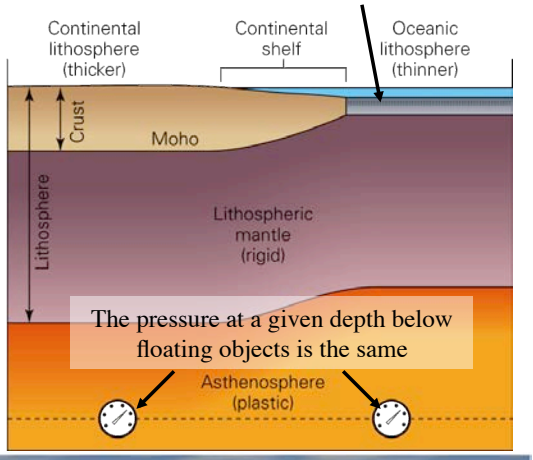
What is a Lithospheric Plate?

Continental lithosphere is like a thick oak block with a thick cork "crust."

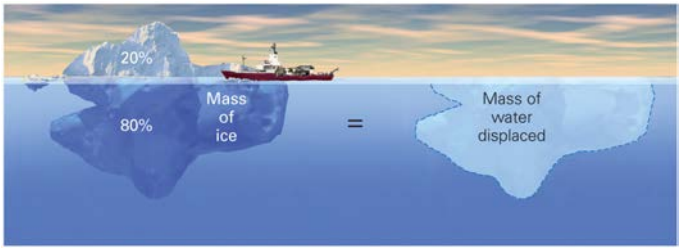
Oceanic lithosphere is like a thinner oak block with a thinner pine "crust."

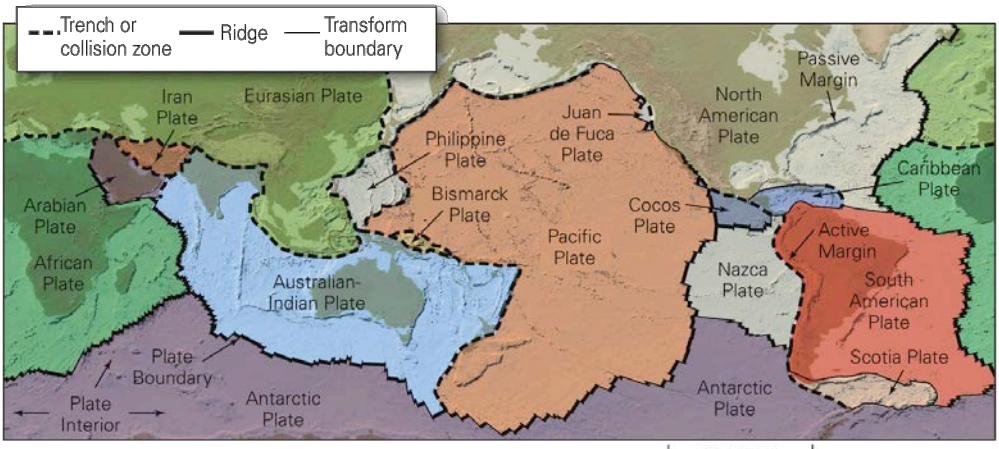


Like the pine/oak block, oceanic crust floats lower in the mantle, creating ocean basins.



Archimedes' principle: floating solids displace water equal to the mass of the solid below the water.





Junction between oceanic and continental crust = Continental Shelf.

Active Margin = Plate Boundary.

Passive Margin ≠ Plate Boundary.

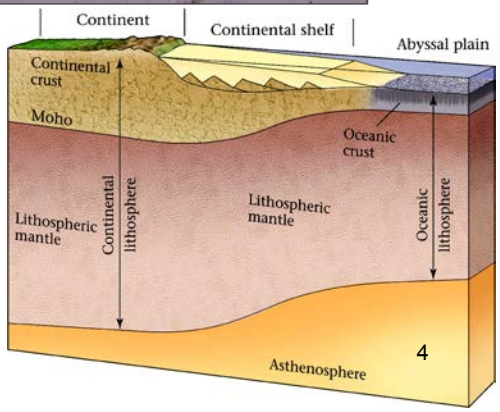
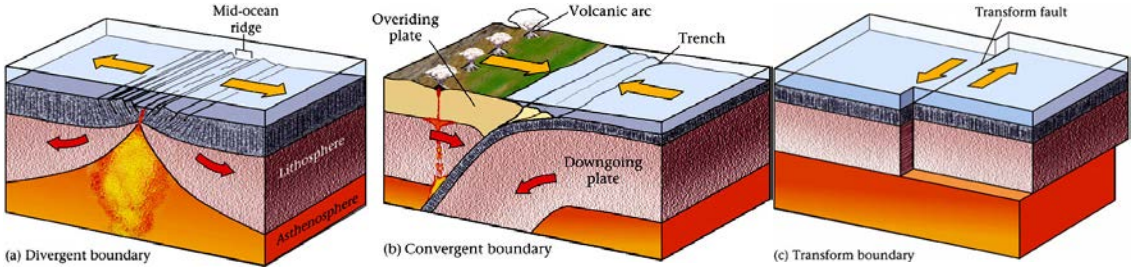


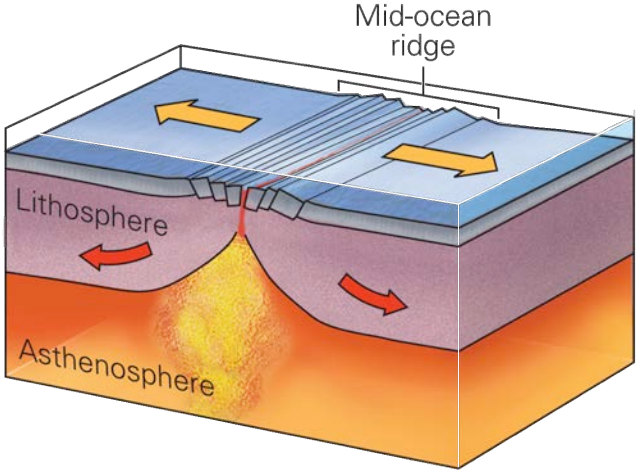
Plate Boundaries

Locations of earthquakes mark plate boundaries.

Three types of Plate Boundary:



Divergent Plate Boundary



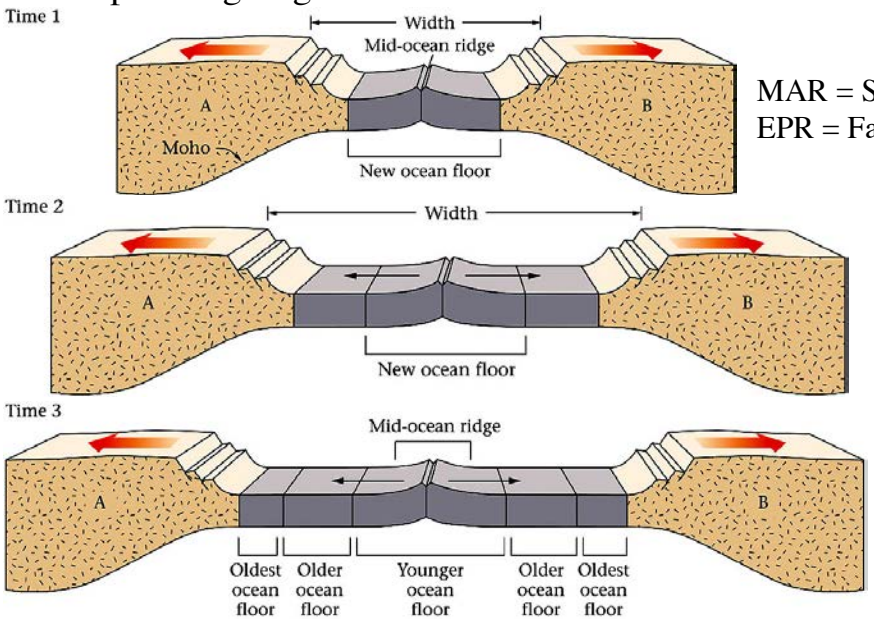
High heat flow

Active volcanism

Shallow focus earthquakes

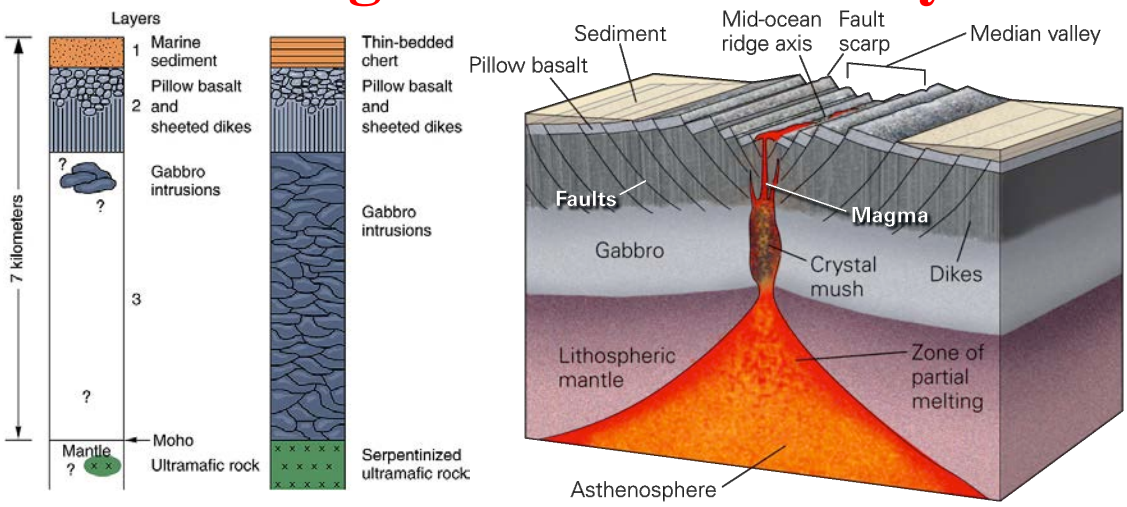
Divergent Plate Boundary

Oceanic crust is made at a mid-ocean ridge.
Slow spreading ridges: <10 km wide with steep cliffs.
Fast spreading ridges: less well defined.



MAR = Slow (1 cm yr^{-1});
EPR = Fast (5 cm yr^{-1}).

Divergent Plate Boundary



Faults indicate tension. Dikes connect pillow basalts with the magma chamber.

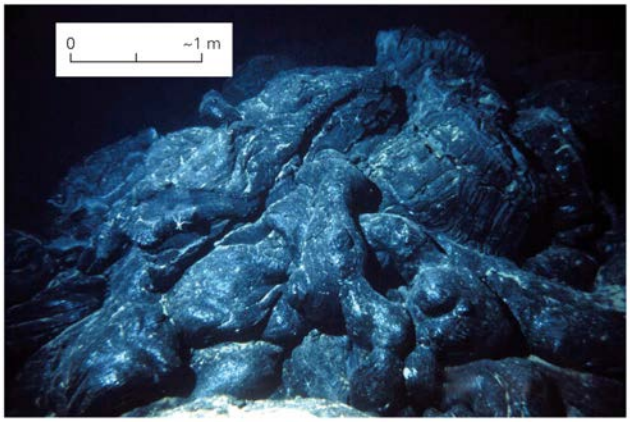
Tension thins the lithosphere and partial melting occurs.

Increased heat from buoyant magma produces the elevation of MORs.

As magma moves away from heat it becomes rock & part of the plate.

Divergent Plate Boundary

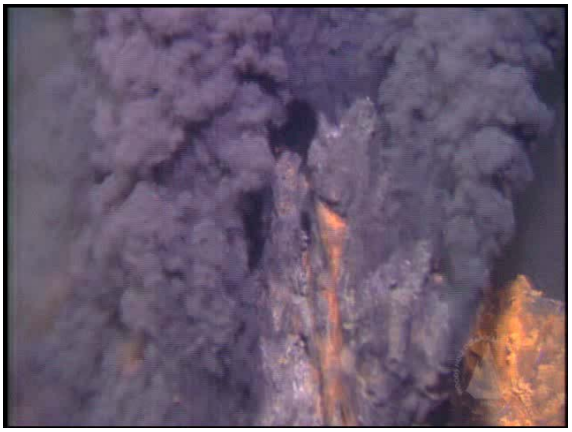
Pillow basalts.



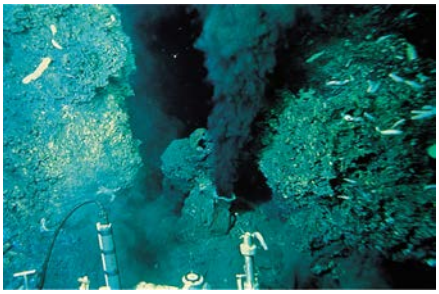
Pillow Basalts "on land".
"Obduction"

pBasalt.mov

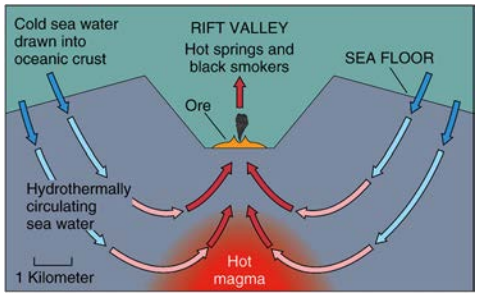
Divergent Plate Boundary



Black smokers.mov



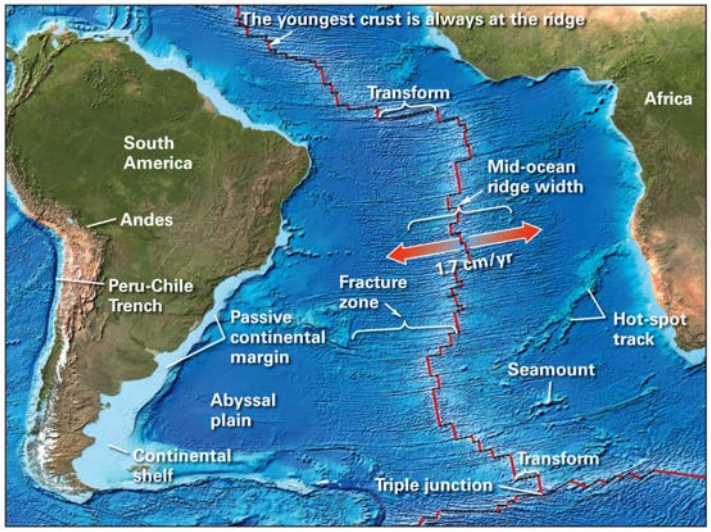
Black Smokers



SCsmoker2.mov

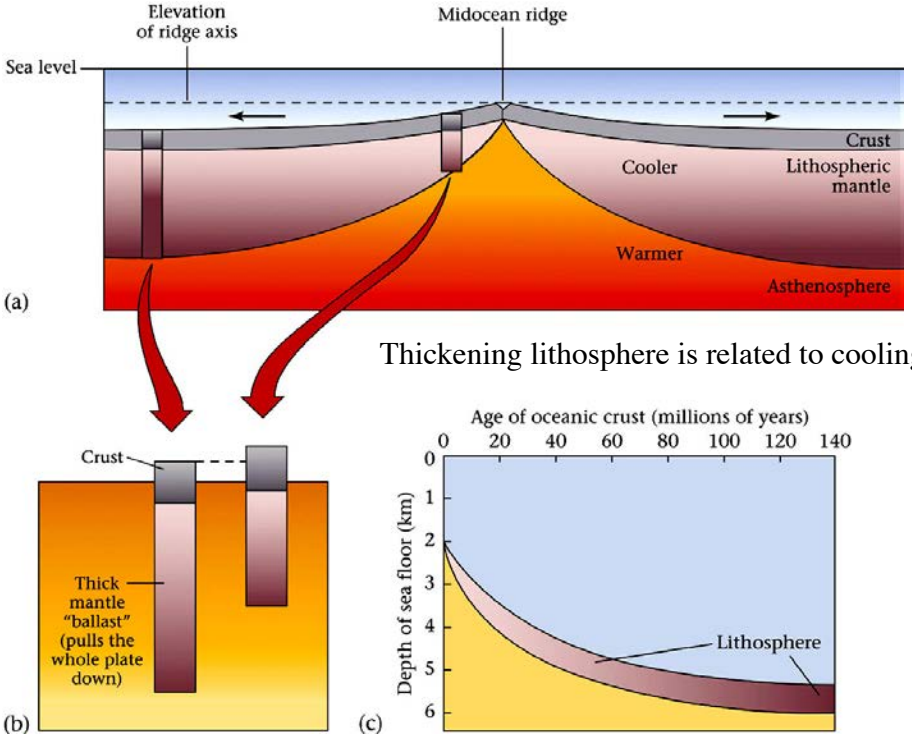
Divergent Plate Boundary

Why are Mid-Ocean Ridges Elevated?



Combination of heat beneath the MOR reducing density and the fact that as the crust moves away, it cools and becomes more dense. The older the crust, the more dense it is.

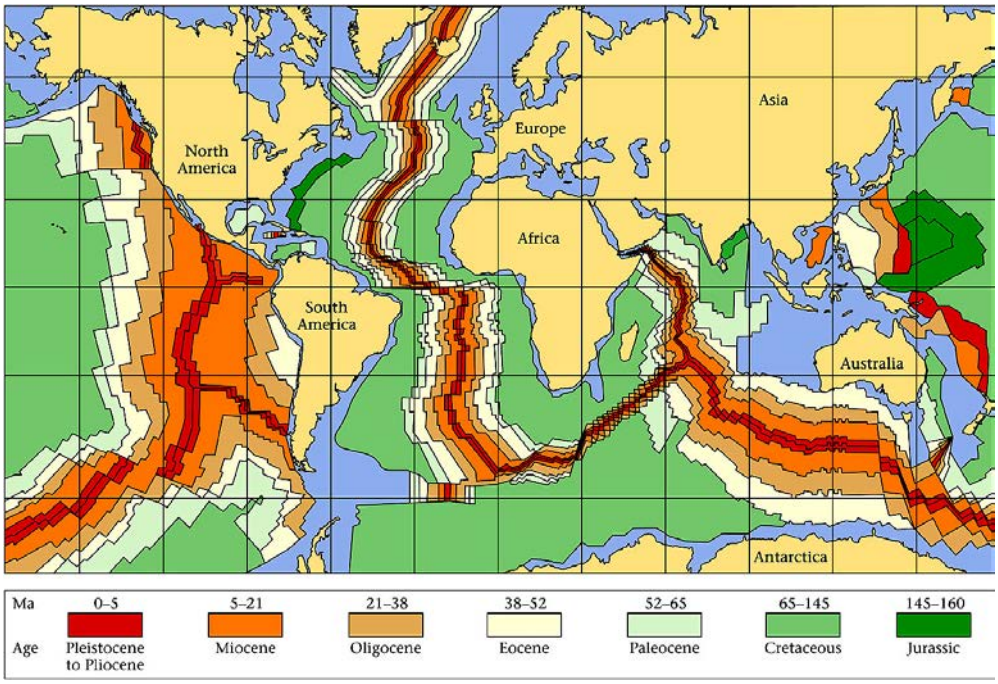
Divergent Plate Boundary



Thickening lithosphere is related to cooling.

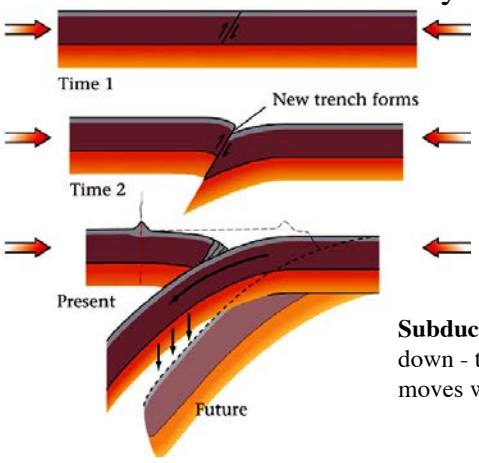
Divergent Plate Boundary

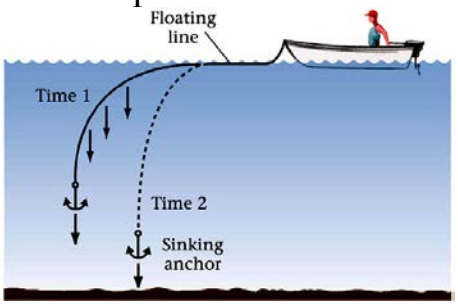
The crust furthest from the ridge is the oldest.



Convergent Plate Boundary

One plate sinks beneath another = Subduction (< 15 cm yr^{-1}).
Trenches mark the boundary between the plates.





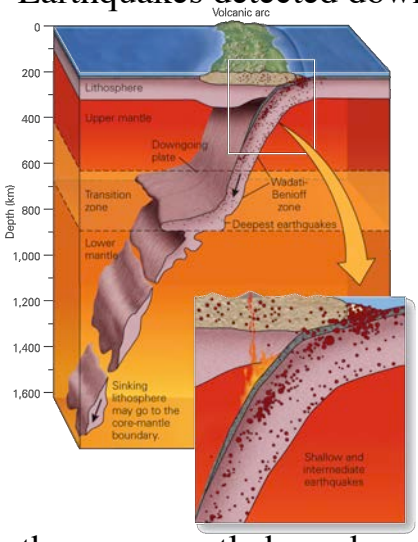
Subduction illustration: anchor pulling a floating anchor line down - the bend in the anchor line (or plate) progressively moves with time.

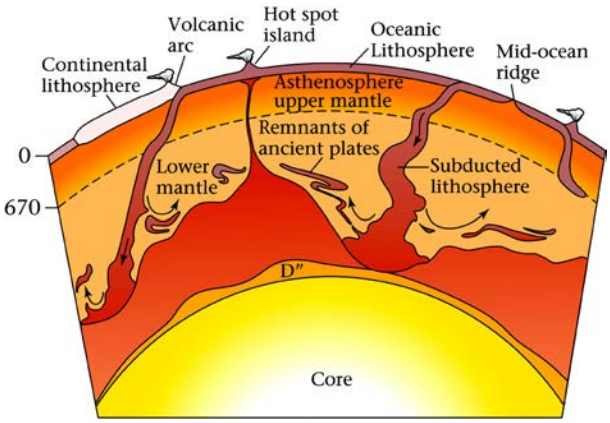
The less dense (continental) plate rides over the denser (oceanic) plate. Occasionally, an oceanic plate overrides an oceanic plate, but oceanic plates are always consumed.

Oceanic crust < 200 m.y. old; Continental crust ≤ 3.8 b.y. old.

Convergent Plate Boundary

Downgoing plate triggers earthquakes - foci (hypocenters) define the Wadati-Benioff Zone (or Benioff Zone).
Earthquakes detected down to 660 km (U-L Mantle boundary).



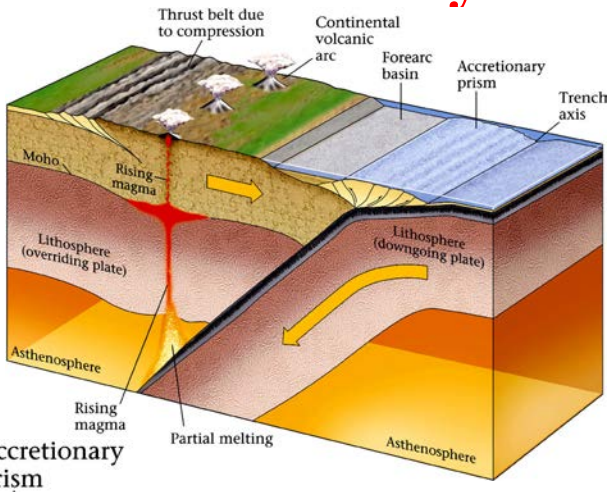


Seismic imaging shows slabs can extend to the core-mantle boundary - conditions for earthquakes don't exist in the lower mantle (i.e., friction greatly reduced).

Convergent Plate Boundary

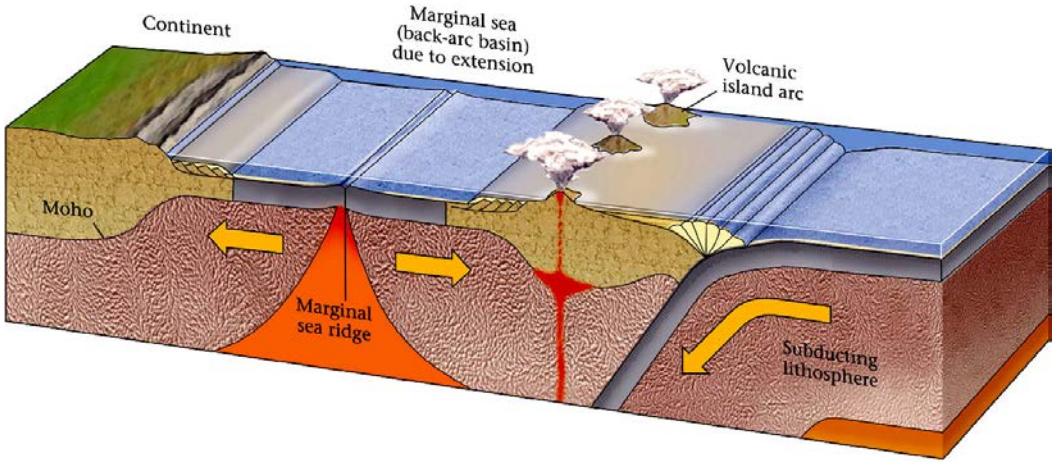
Anatomy

Volcanic Arc: Arcuate chain of volcanoes. Can be built on either oceanic or continental crust.



Accretionary Prism: piling up of sediment scraped off the downgoing plate.

Convergent Plate Boundary

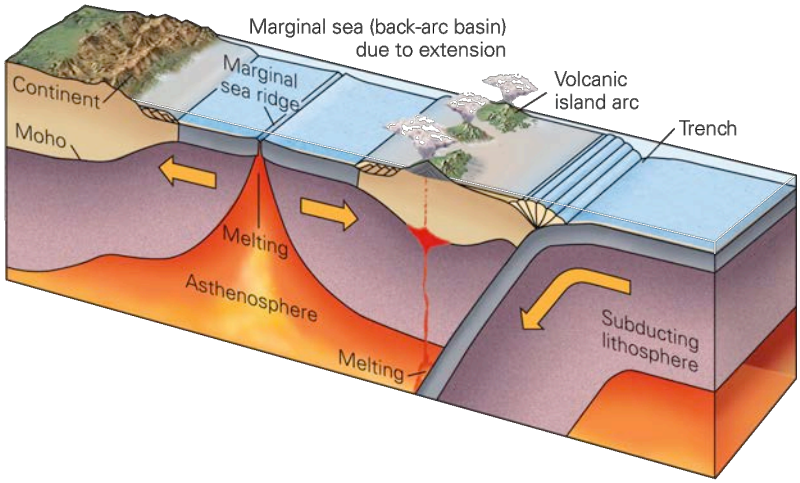


If arc is built on oceanic crust a Back-Arc Basin can develop - depends on the angle of subduction. This is an area of extension behind an area of intense compression.

Convergent Plate Boundaries

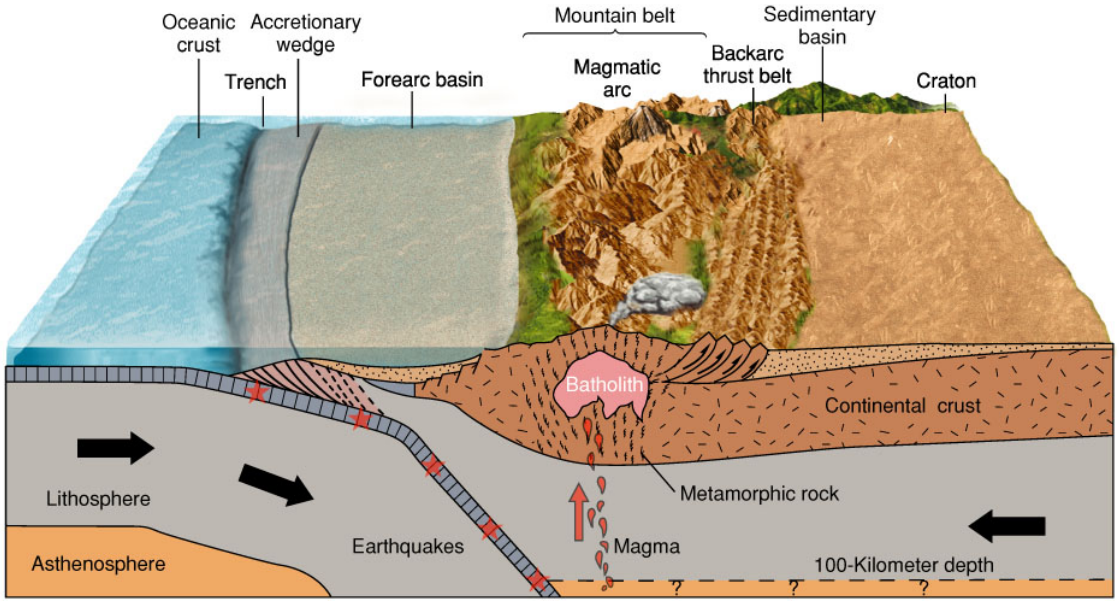
3 types –

oceanic crust subducted beneath continental;
oceanic crust subducted beneath oceanic crust;
continent-continent collision.



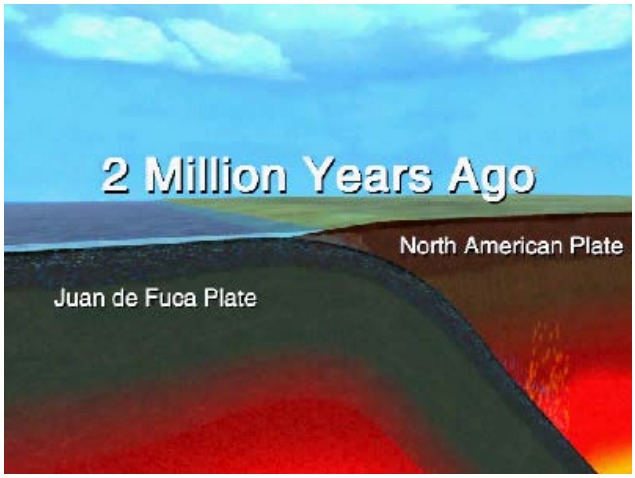
Convergent Plate Boundaries

Oceanic crust subducted beneath Continental crust.



Convergent Plate Boundaries

Oceanic crust subducted beneath Continental crust.

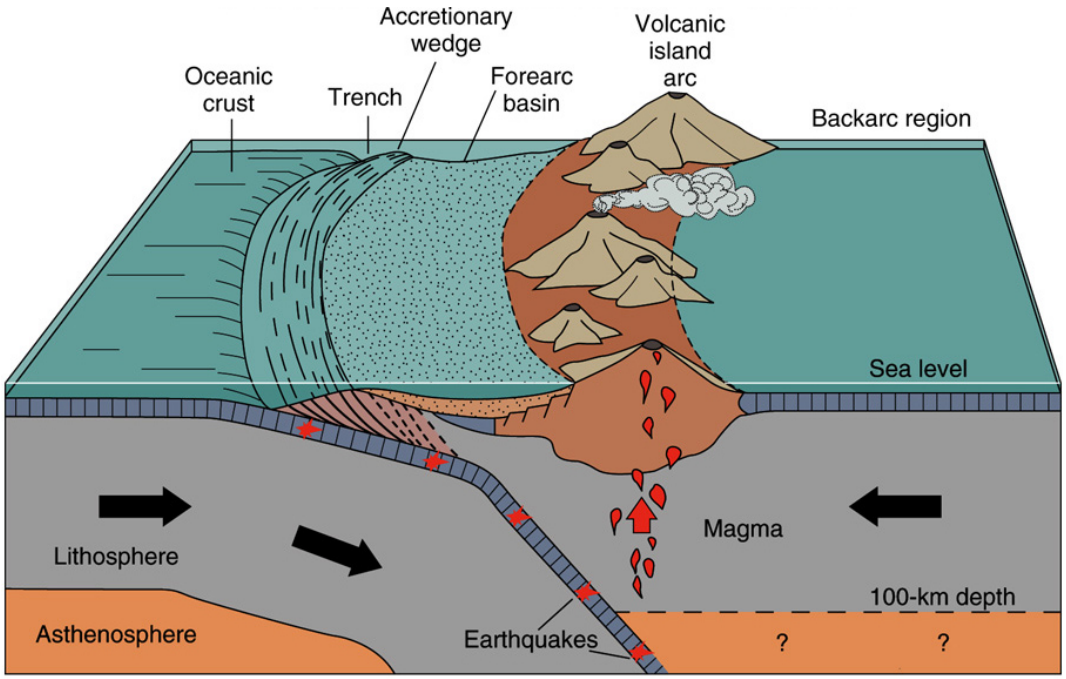


Addition of volatiles (e.g., water) to hot mantle lowers the melting point and induces melting.

o-c.mov

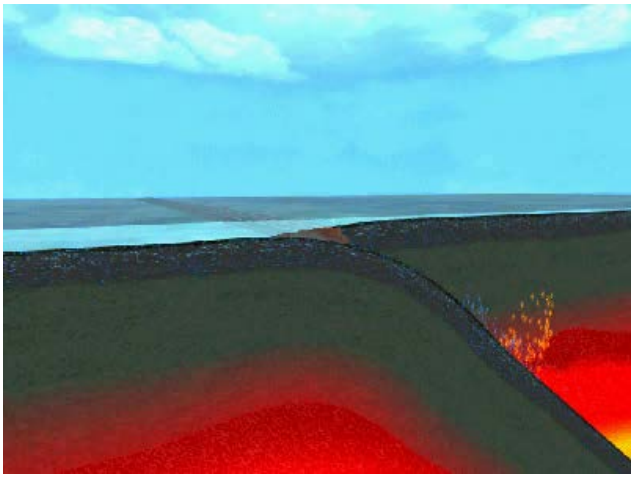
Convergent Plate Boundaries

Oceanic crust subducted beneath Oceanic crust.



Convergent Plate Boundaries

Oceanic crust subducted beneath Oceanic crust.

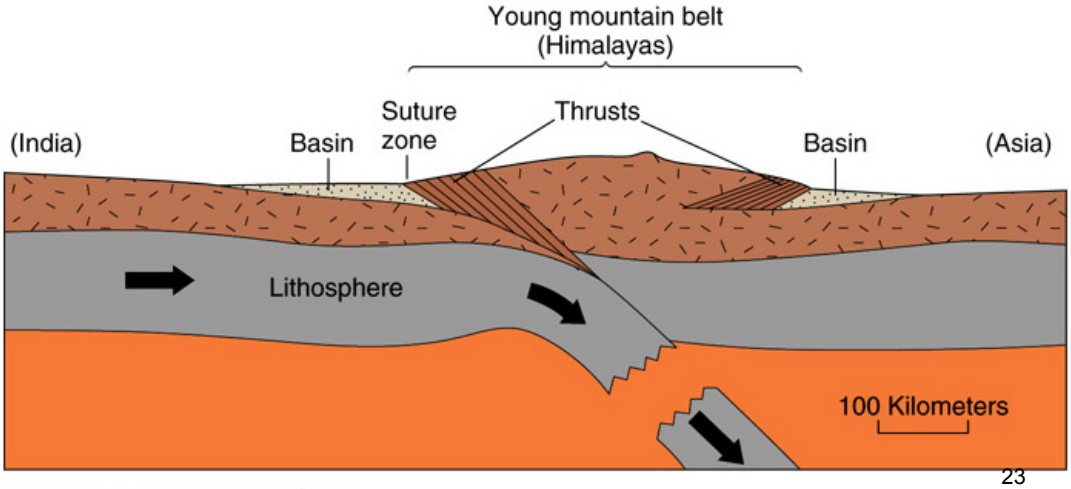


o-o.mov

Convergent Plate Boundaries

Continent-Continent collision.

India has collided with Asia and continues to move north at 20 cm/year – the result = Himalayas.



Continent-continent collision

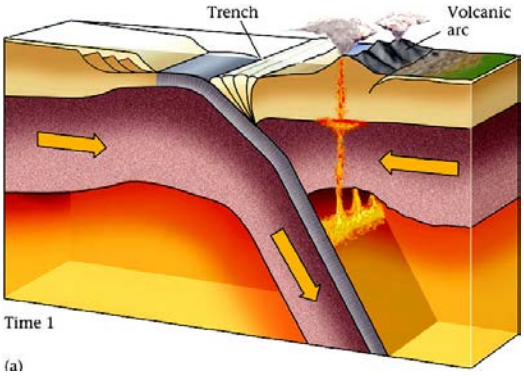
Convergent Plate Boundaries

Continent-Continent collision.

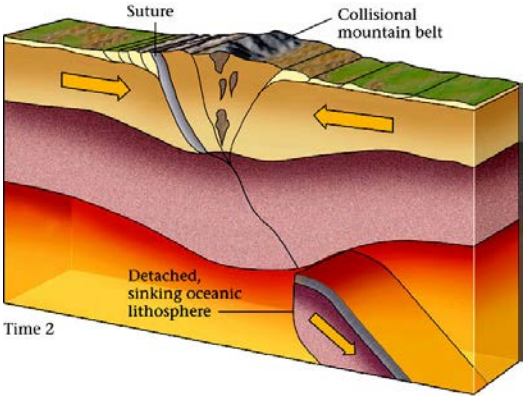
himalaya.mov

Convergent Plate Boundaries

Continent-Continent collision.

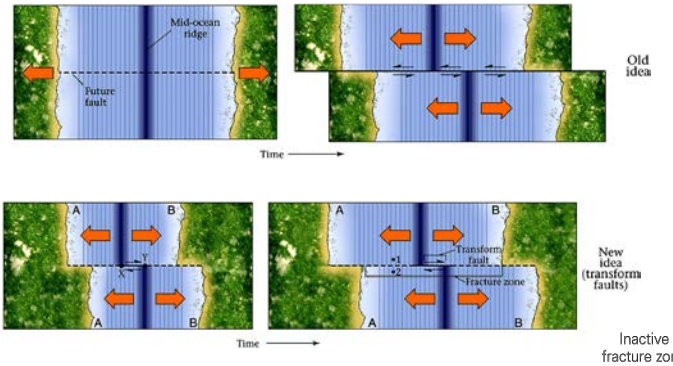


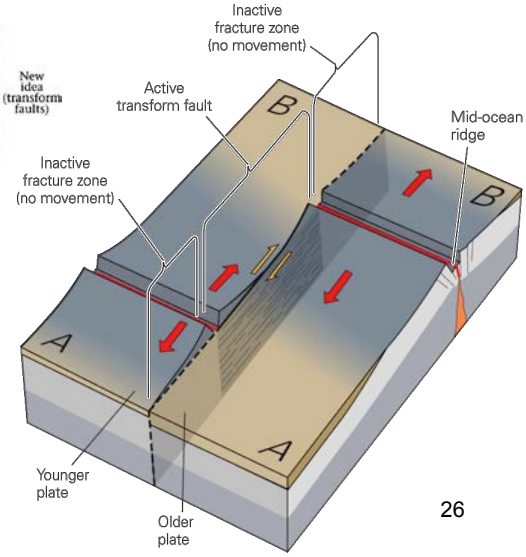
Subduction consumes an oceanic plate before continent-continent collision.



After collision, the oceanic plate detaches and sinks into the mantle. Continental material is pushed up (too light to be subducted) and mountains form.

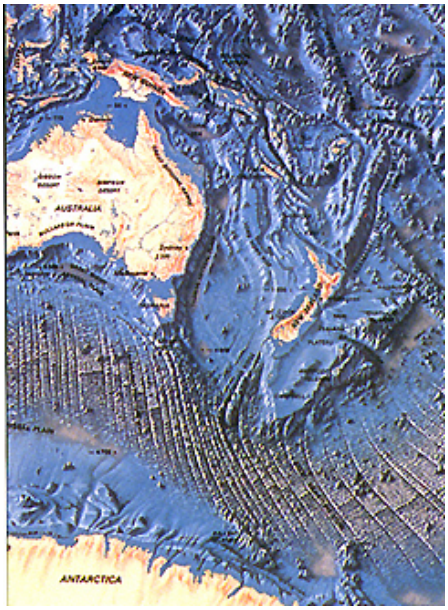
Transform Plate Boundary





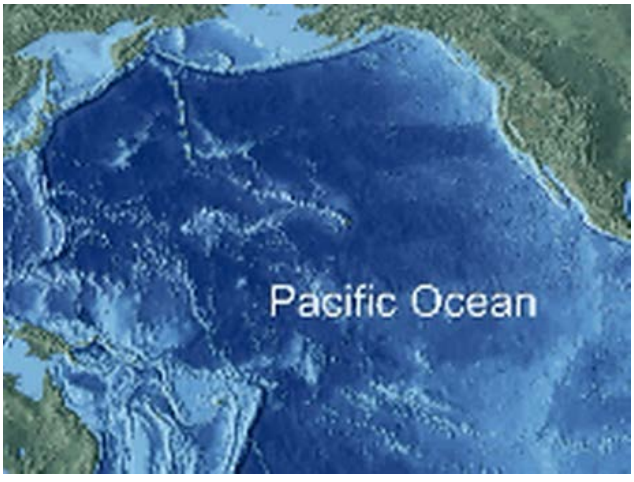
Transform fault only between ridge segments. Beyond the ridge = **Fracture Zone**.

Transform Plate Boundary

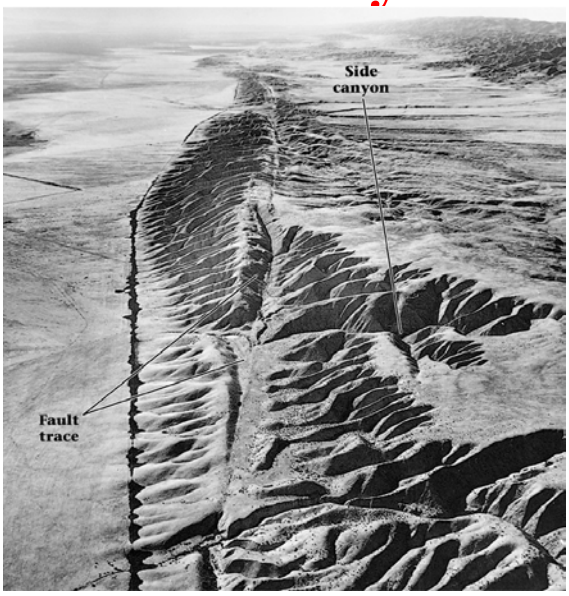


New Zealand

Transform Plate Boundary



Transform Plate Boundary



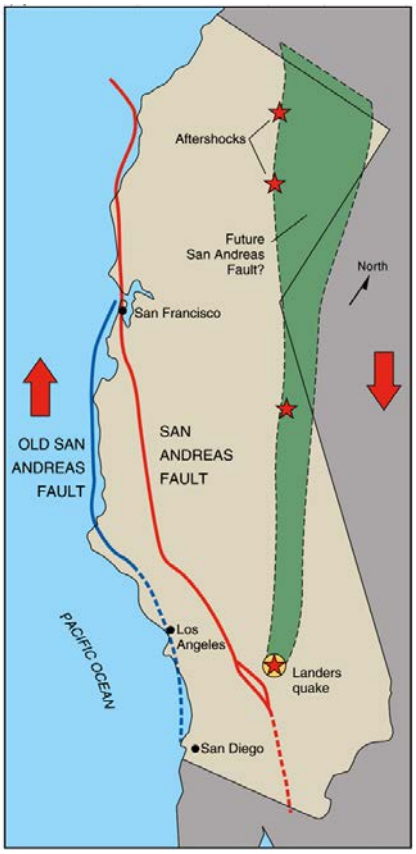
San Andreas: Right lateral or Left lateral?

Transform Plate Boundary

Massive faults.

Plates slide against each other.

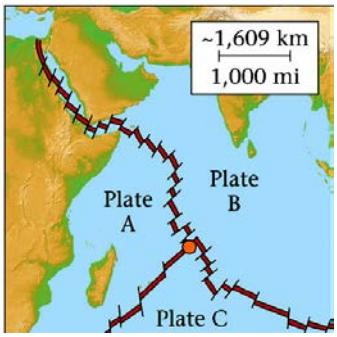
Occasionally boundaries can changes position – new faults can form and material is moved from one plate to another.

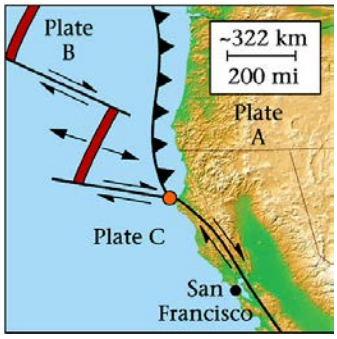


Triple Junctions

Junction between three plates.

Indian Ocean = ridge-ridge-ridge triple junction

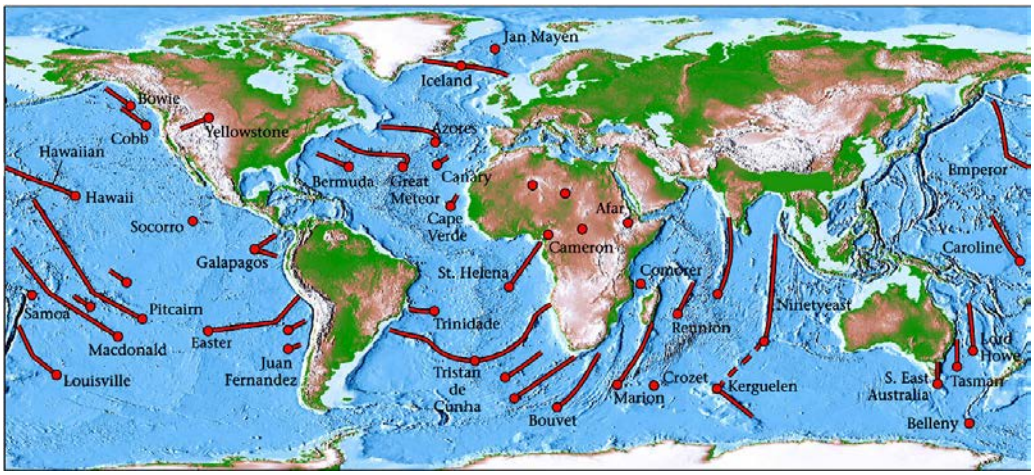




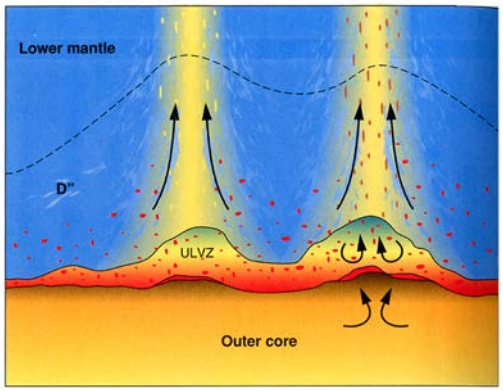
Pacific Ocean = transform-transform-trench triple junction.

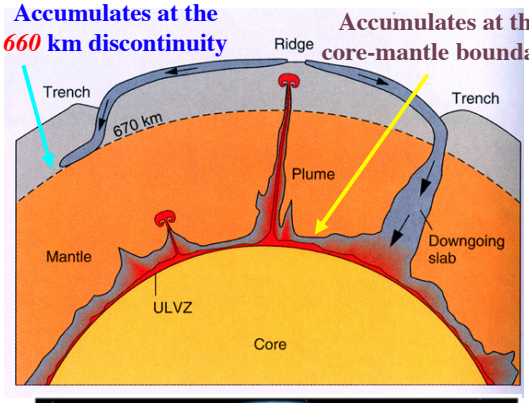
Hot Spots

These at first don't seem to fit into Plate tectonic Theory.
Marked by "intra-plate" volcanoes (e.g., Hawaii, Yellowstone).
A few lie on plate boundaries (e.g., Iceland).
Considered to form through mantle plumes.



Origin of Plumes



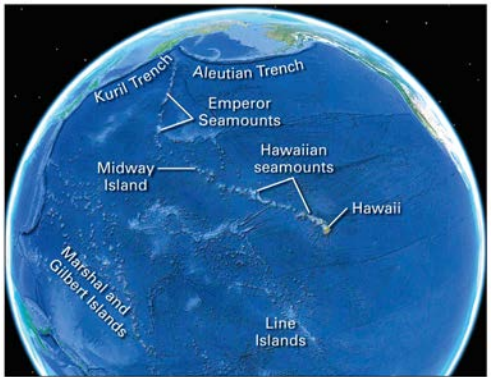


THEORY.

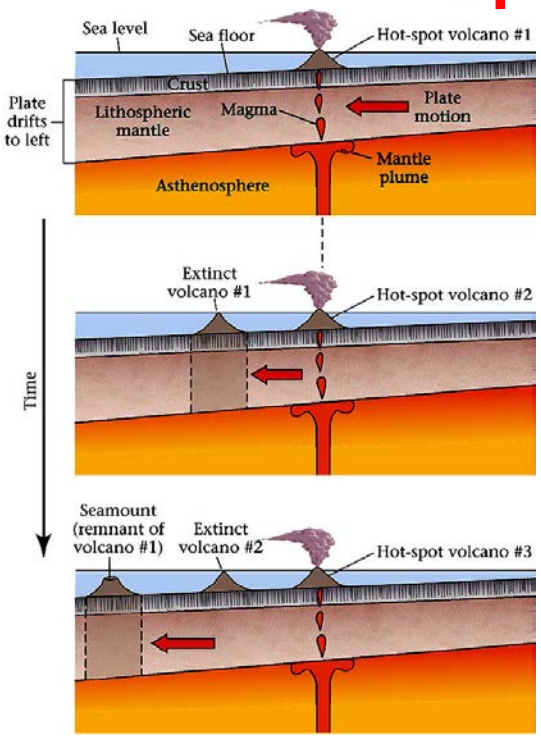
Transfer of heat across a boundary promotes hotspots.

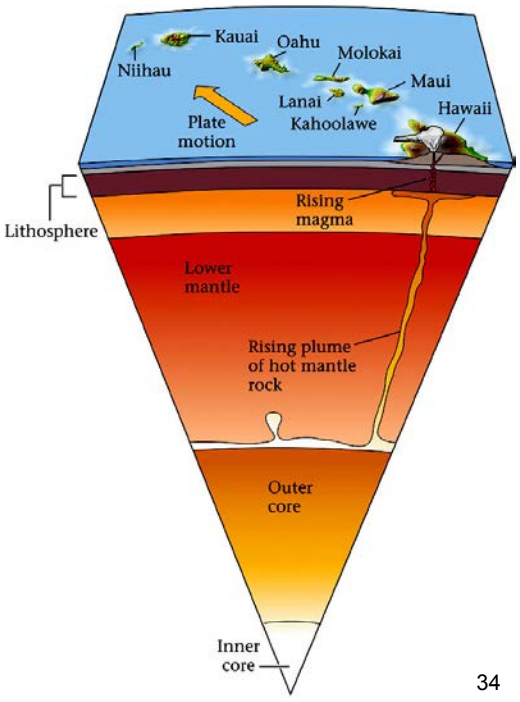
Seismic data suggest plumes may be linked to return of crust via subduction.

THEORY: Accumulation of subducted material promotes hotspots.

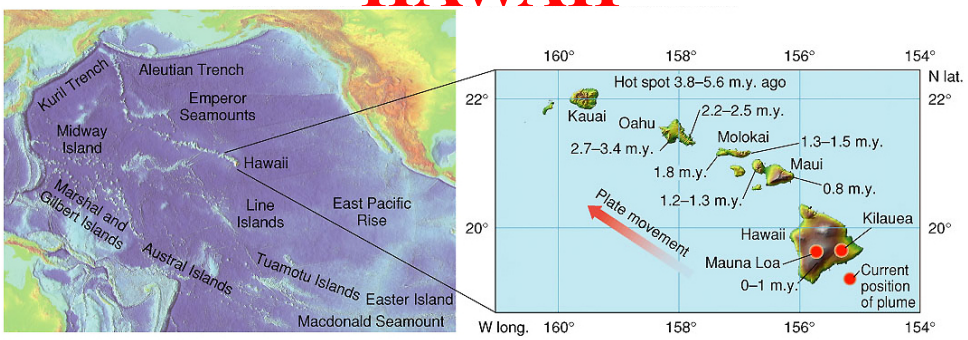


Hot Spot Chains

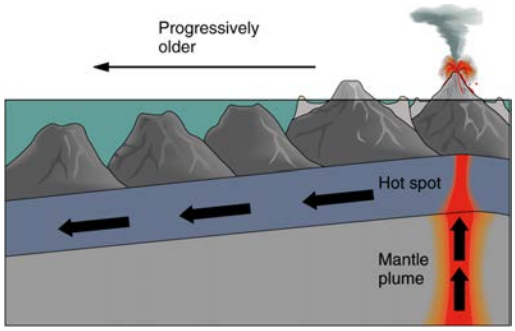




HAWAII



Bend = 43 Ma.

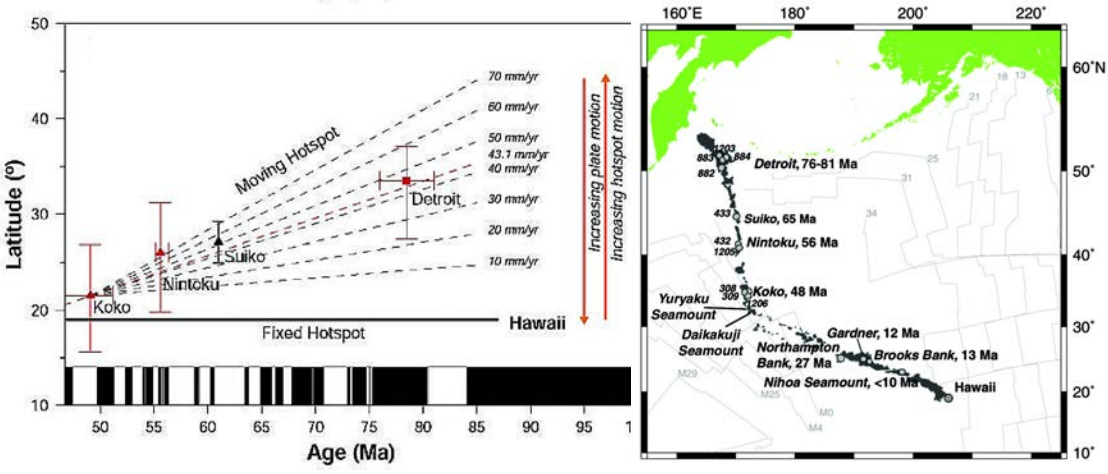


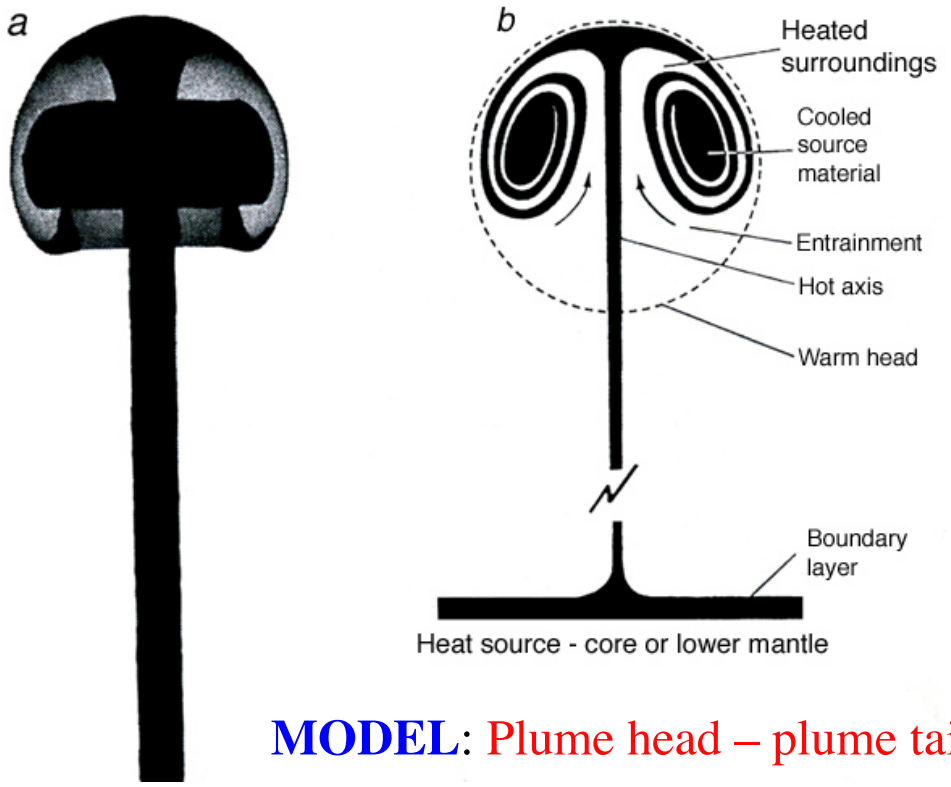
Active volcano at the end of the chain.

As plate moves over the hot spot, volcano forms. As the volcano moves away, volcanic activity dies down and lithosphere cools. Volcano sinks beneath the sea - becomes a seamount.

Hawaii

It was assumed that hot spots were fixed - can then calculate absolute plate motion, but…..





MODEL: Plume head – plume tail.

PLUMES

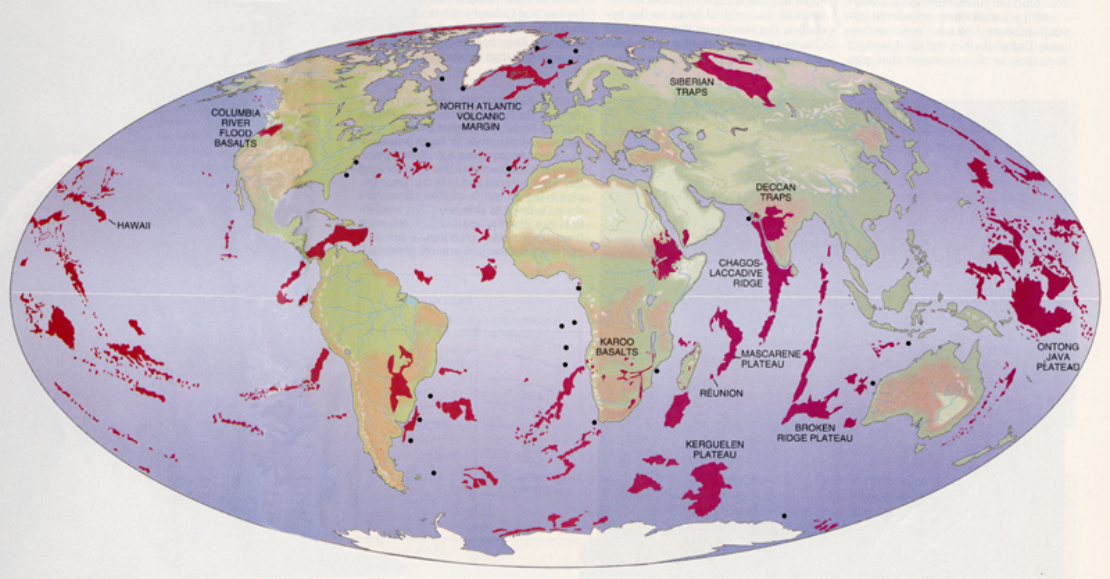
Short-lived surfacing plume head – large igneous province (LIP) formation:

- **Continental flood basalts (e.g., Columbia River basalts)**
- **Oceanic plateaus (e.g., Ontong Java Plateau)**
- **Passive continental margins**
- **Massive volcansim on an unprecedented scale!**

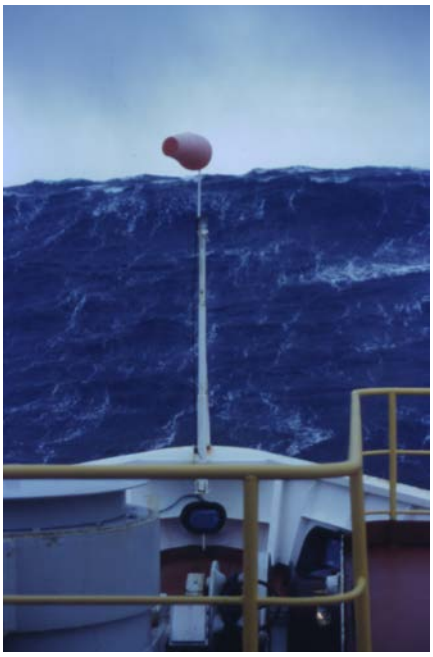
Longer-lived plume tail:

- **Linear volcanic chains**
- **Aseismic ridges**

Worldwide Distribution of Large Igneous Provinces (LIPs)



JOIDES Resolution



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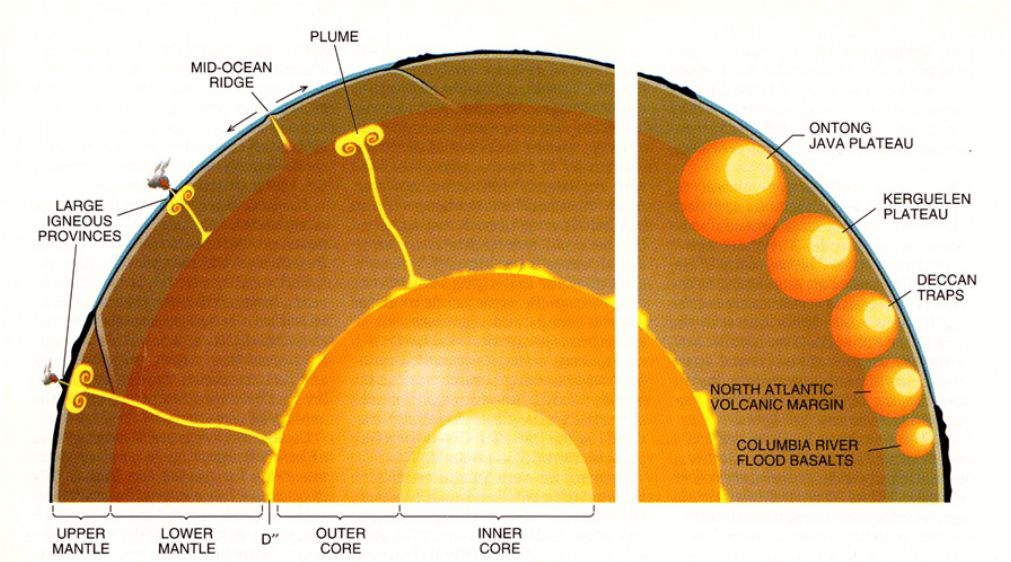
Sizes of "Plume Heads"



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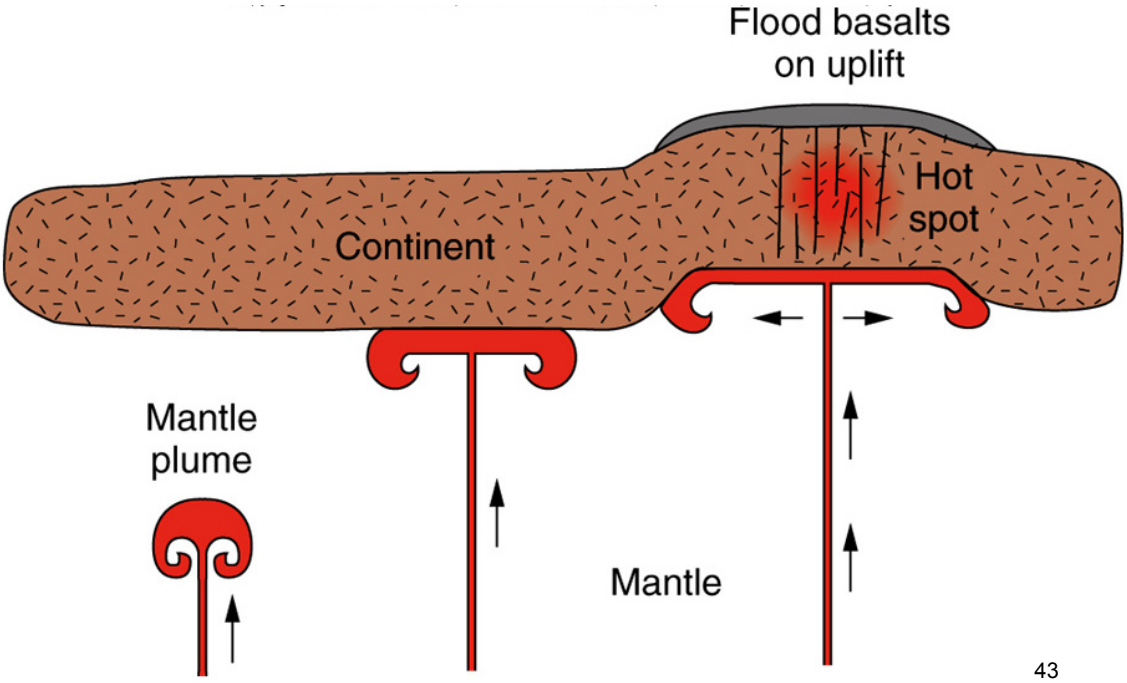
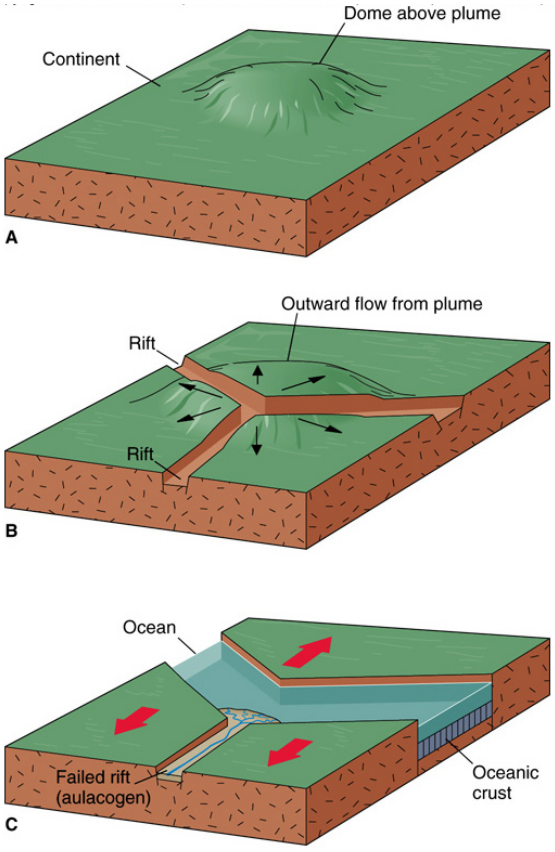
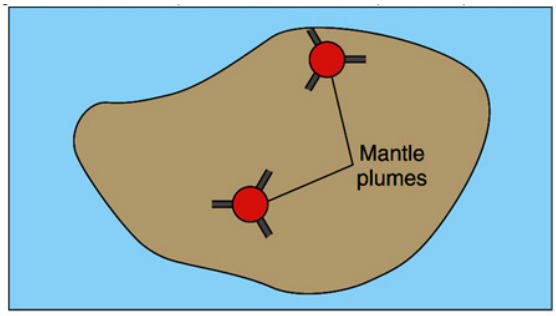
Large Igneous Province Formation





Surfacing plume heads can promote formation of new oceans – Atlantic.

Surfacing Plume Head can Promote Formation of New Oceans.



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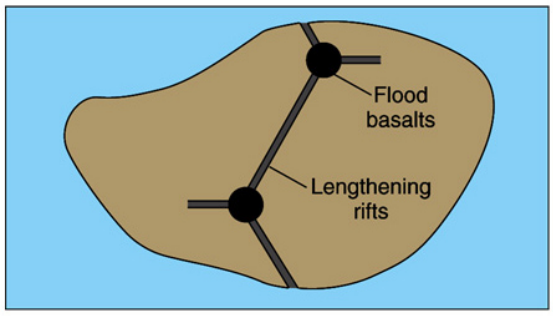
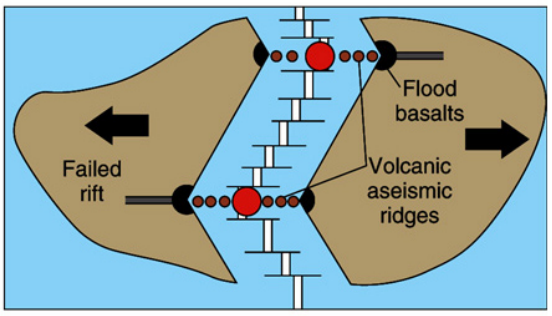
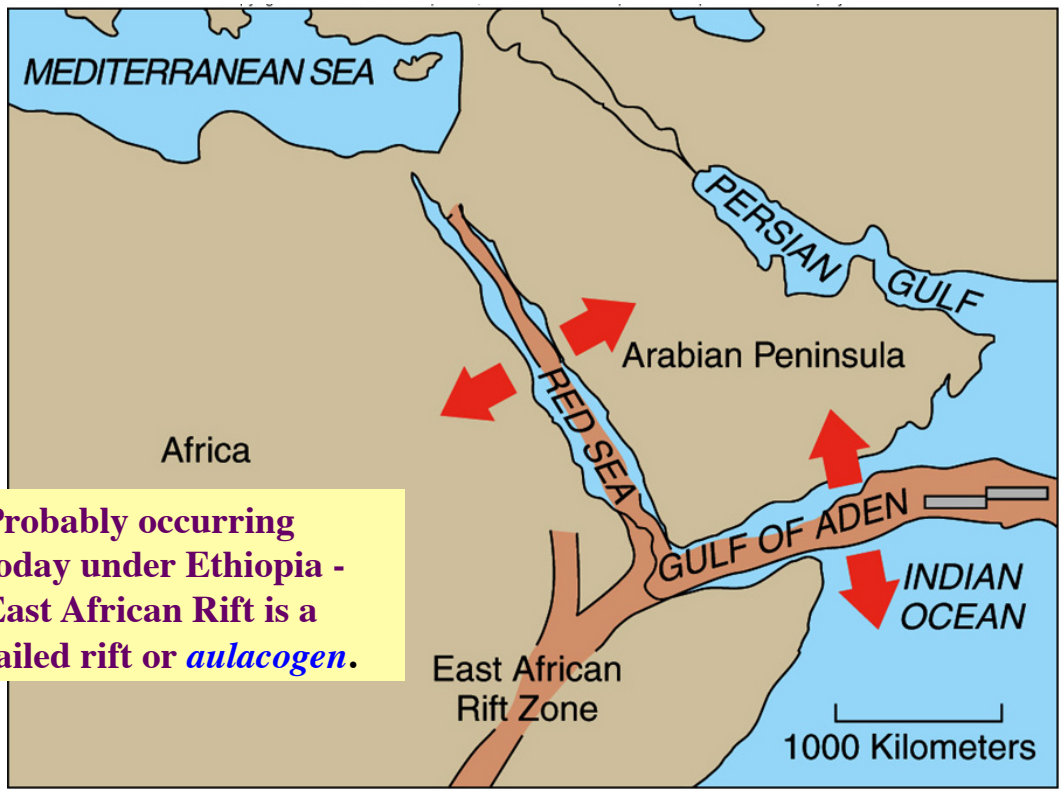




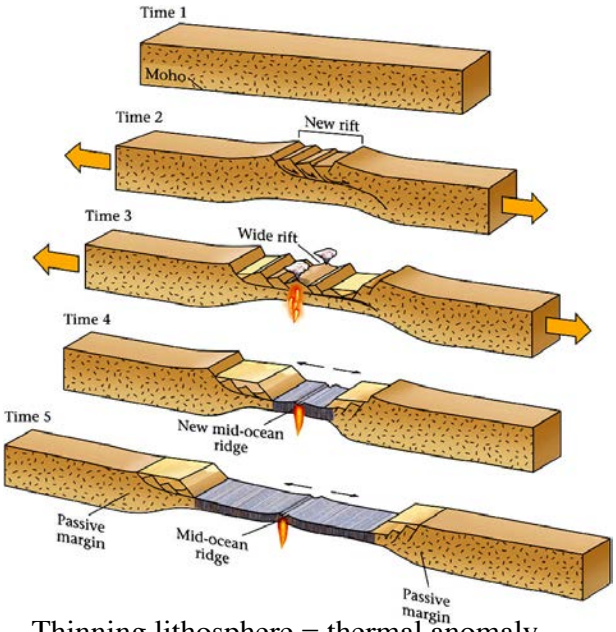


Probably occurring today under Ethiopia - East African Rift is a failed rift or *aulacogen*.

Rifting

Extension within a continent (continental rifting) is the beginning of the formation of a new plate boundary.

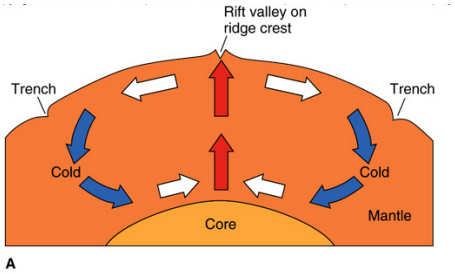
Failed rifts: The Rhine; East African Rift - **Aulacogens**.

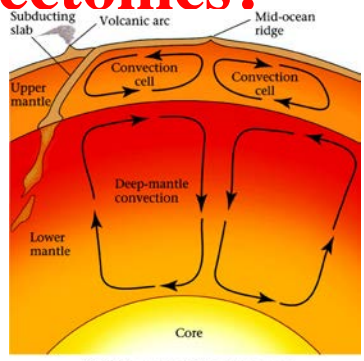


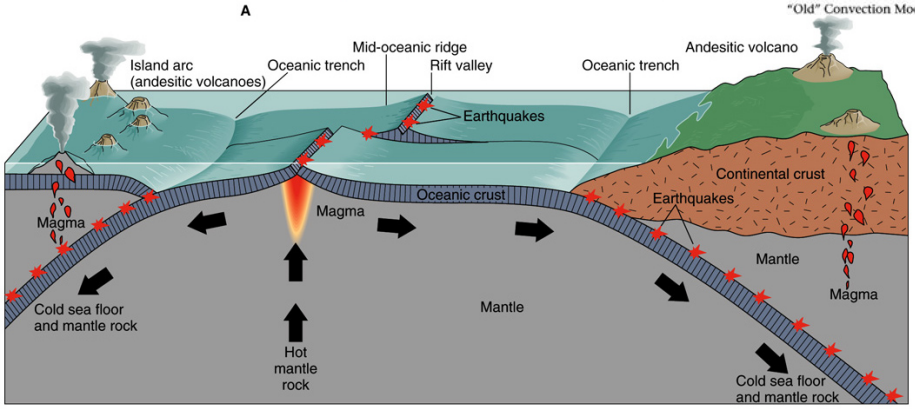
Thinning lithosphere = thermal anomaly.

What Drives Plate Tectonics?

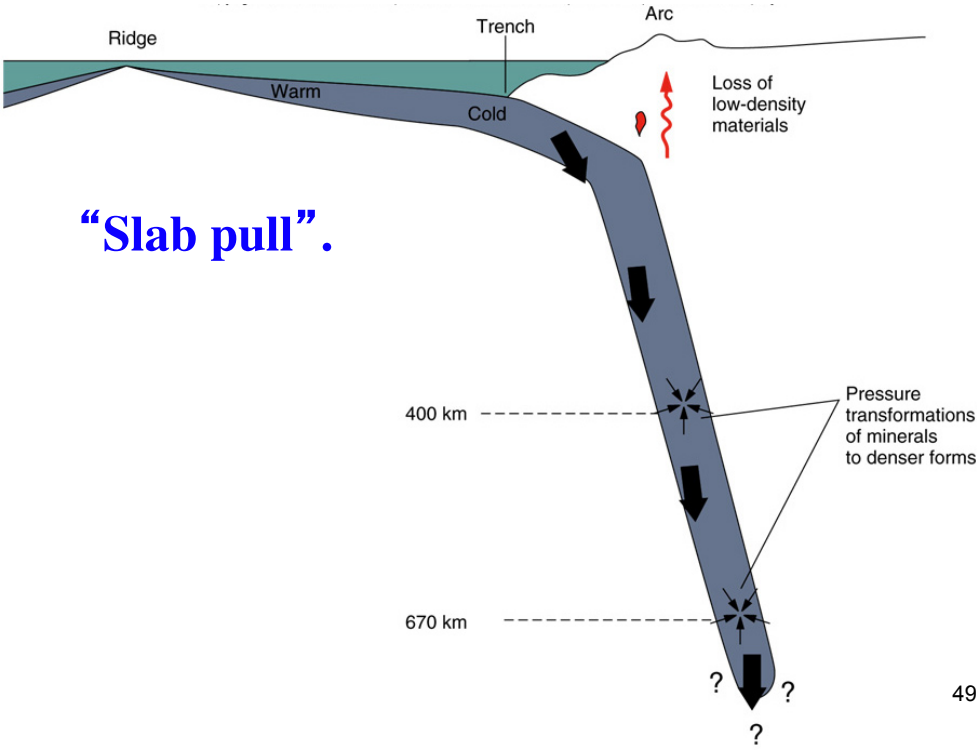
Convection





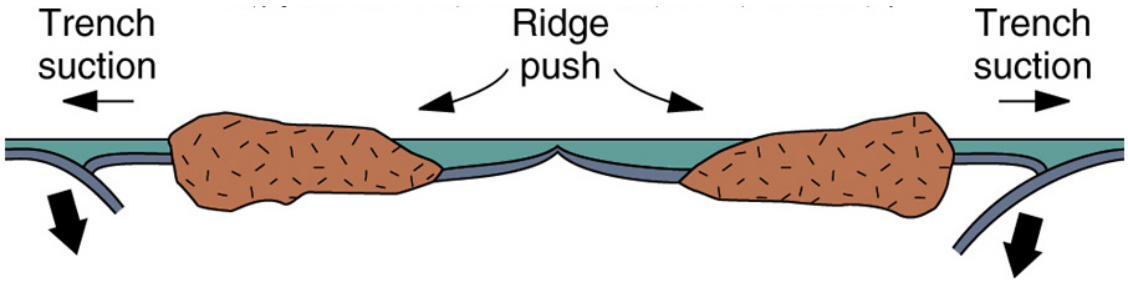


What Drives Plate Tectonics?



"Slab pull".

What Drives Plate Tectonics?



"Ridge push".

What Drives Plate Tectonics?

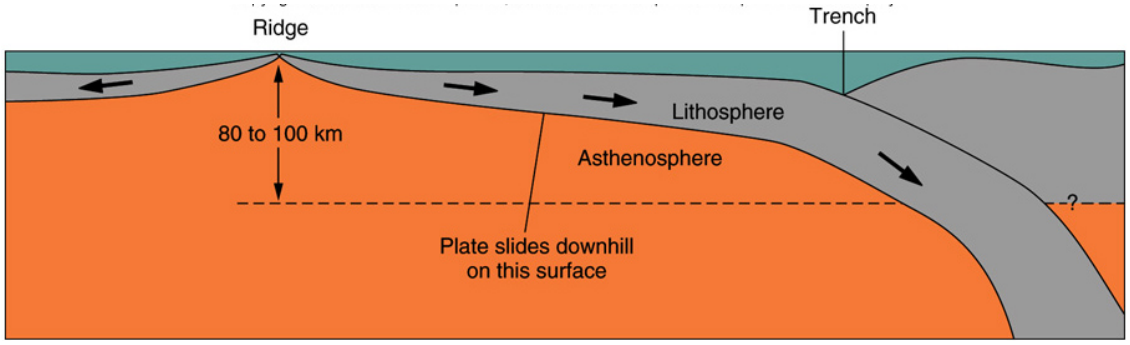
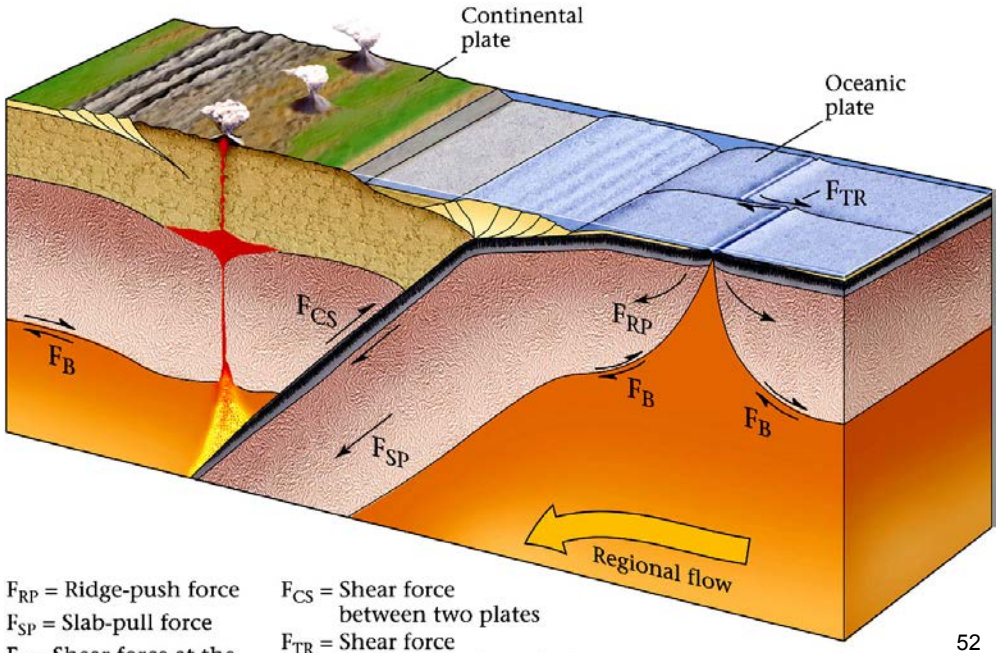


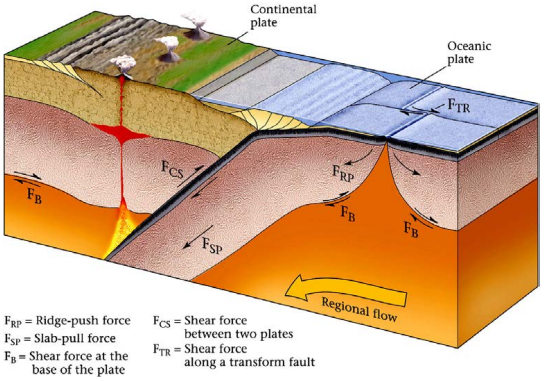
Plate "slides downhill" (gravity).

What Drives Plate Tectonics?

Probably a combination of all those forces.



What Drives Plate Tectonics?



Now let's summarize our discussion of forces that drive plate motions. Plates move away from ridges—in other words, sea-floor spreading occurs—in response to the ridge-push force, and as this happens, new asthenosphere rises to fill the space that opens between the plates. Old, cool oceanic lithosphere sinks down into the asthenosphere, creating a slab-pull force that tows the rest of the plate along with it. But ridge push and slab pull are not the only forces acting on the plate. The asthenosphere does convect and the flow of the asthenosphere probably exerts a force on the base of the plate, just as flowing water exerts a force on the base of a boat tied to a dock. If this force, or shear, happens to be in the same direction the plate is already moving, it can speed up the plate motion, but if the shear is in the opposite direction, it might slow the plate down. Also, where one plate grinds against another, as occurs along a transform fault or at the base of an overriding plate at a convergent margin, friction (the force that resists sliding on a surface) may slow the plate down (▶Fig. 4.29c).

Textbook:

Today, geoscientists favor the hypothesis that individual plate motion can best be thought of as a response to two forces, ridge-push force and slab-pull force.

What initiates "slab pull" and "ridge push"?

Plate Motion

Relative Plate Motion: Motion of one plate relative to another or a "fixed" hot spot.

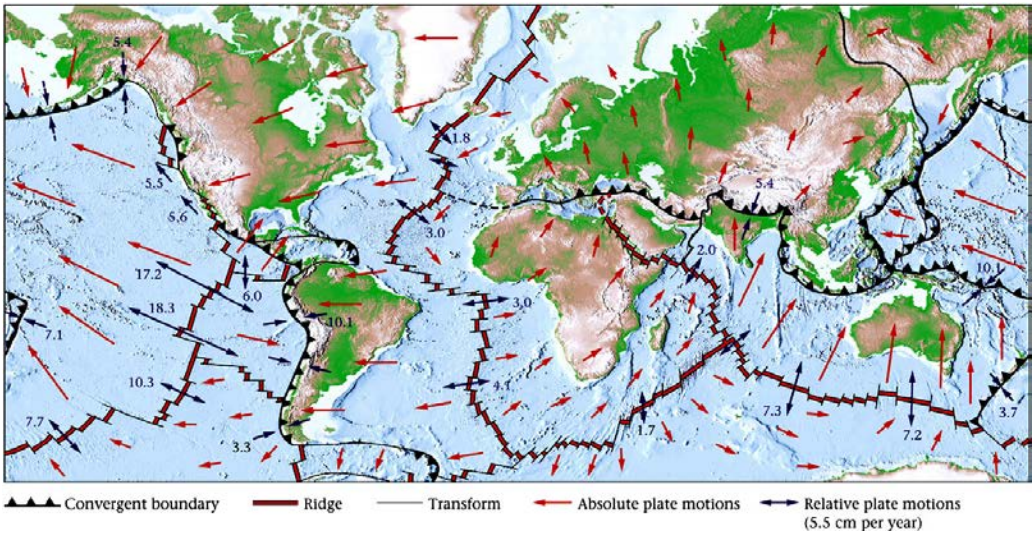


Plate Motion

Absolute Plate Motion: Use GPS.

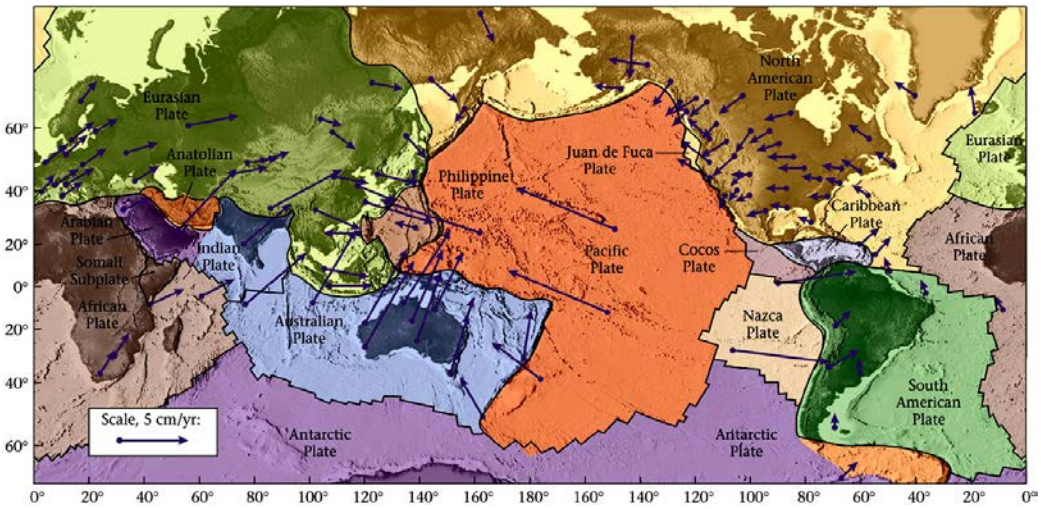
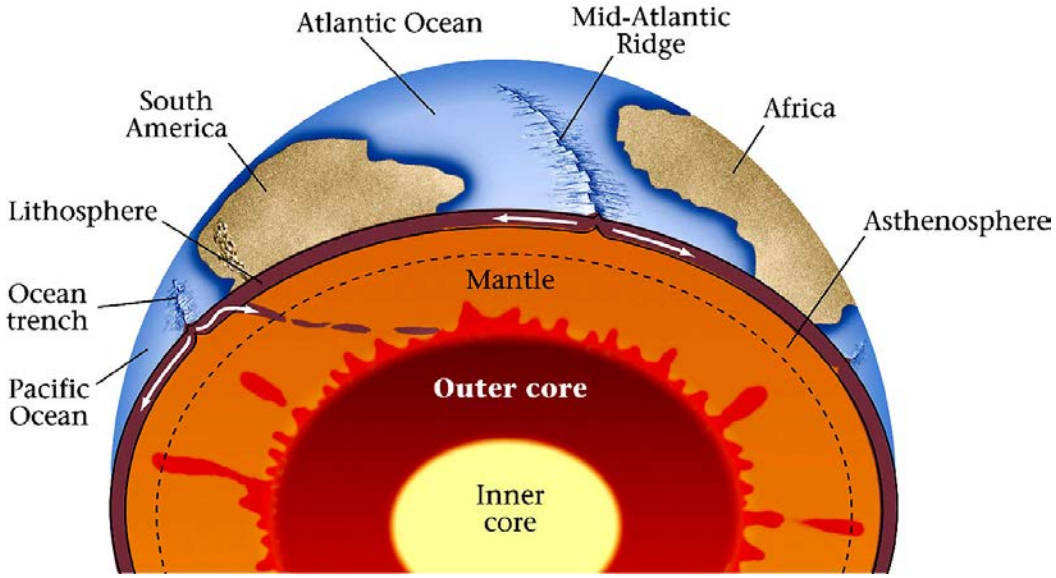


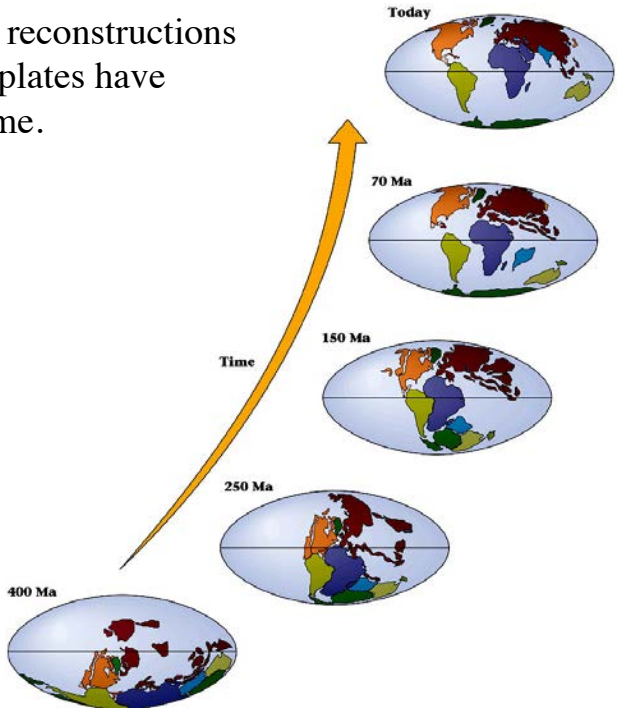
Plate Tectonic Summary



Involves the transfer of material from the mantle to the surface and back again. Subducted material ponding at the U-L mantle boundary or the Core-Mantle boundary can promote plumes.

The Dynamic Planet

Plate tectonics reconstructions show how the plates have moved over time.



Summary

What is a Lithospheric Plate? Continental & Oceanic Crust; Active & Passive Margins.

Plate Boundaries: Divergent; Convergent, Transform.

Divergent:High heat flow; Active volcanism; Shallow earthquakes; Fast & Slow spreading ridges; Structure of oceanic crust; Pillow basalts; Black smokers.

Convergent: Angle of subduction; Trench; Benioff Zone; Fate of subducted plate; Volcanic arc; Accretionary prism; Back-arc basins. 3 types of convergent plate boundaries.

Transform: segments along MORs; Fracture Zones vs. Transform Faults; San Andreas Fault.

Triple Junctions: boundary of 3 plates.

Hot Spots: Origin of Plumes; Hot spot chains; Hawaii; Moving hot spots;.

Plume Head/Plume Tail: Large Igneous Provinces; Sizes of plume heads; LIP formation; Sea-floor spreading initiation; Rifting.

What Drives Plate Tectonics? Convection; Slab Pull; Ridge Push; Gravity.

Plate Motion: Relative and Absolute.

Dynamic Planet: Plate reconstructions.