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CHAPTER: OCEAN BASIN FORMATION

SEMO4012: Marine Environment

BEng. (Naval Architecture and Offshore Engineering)

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TOPIC: OCEAN BASIN FORMATION

SEMO4012: Marine Environment

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TOPIC: OCEAN BASIN FORMATION

SEMO4012: Marine Environment

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INTRODUCTION

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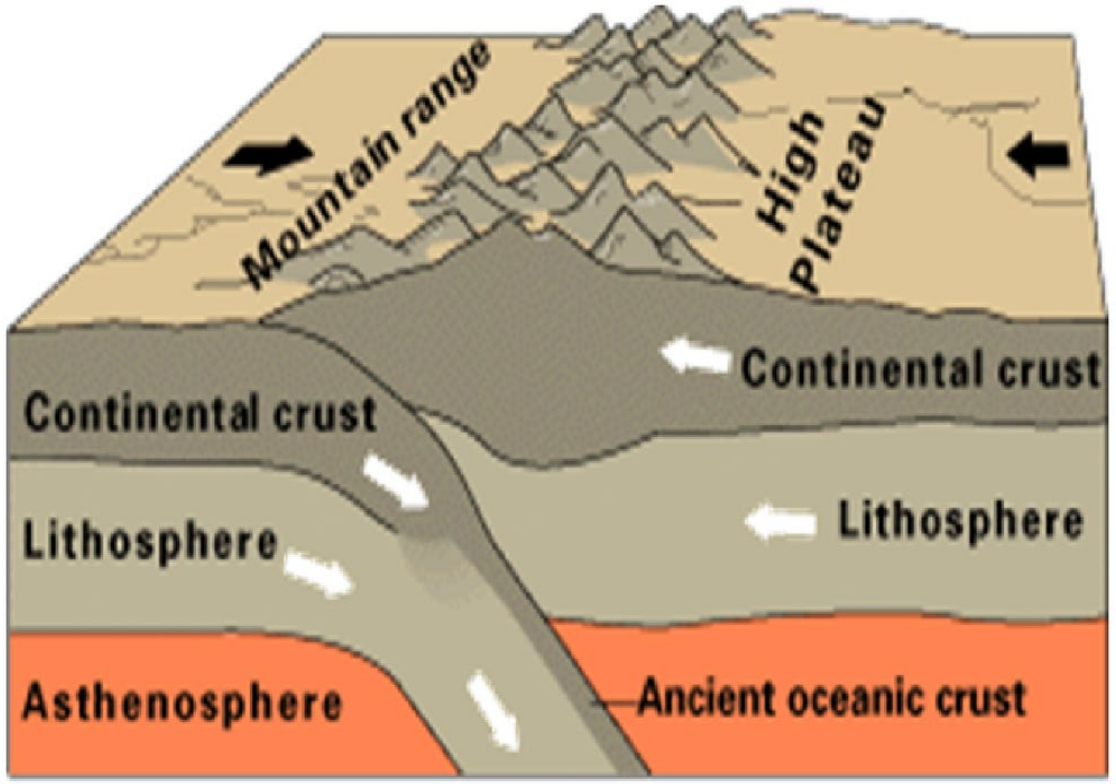
OCEAN BASIN FORMATION: THE PLATE TECTONIC REVOLUTION



Continental-continental convergence

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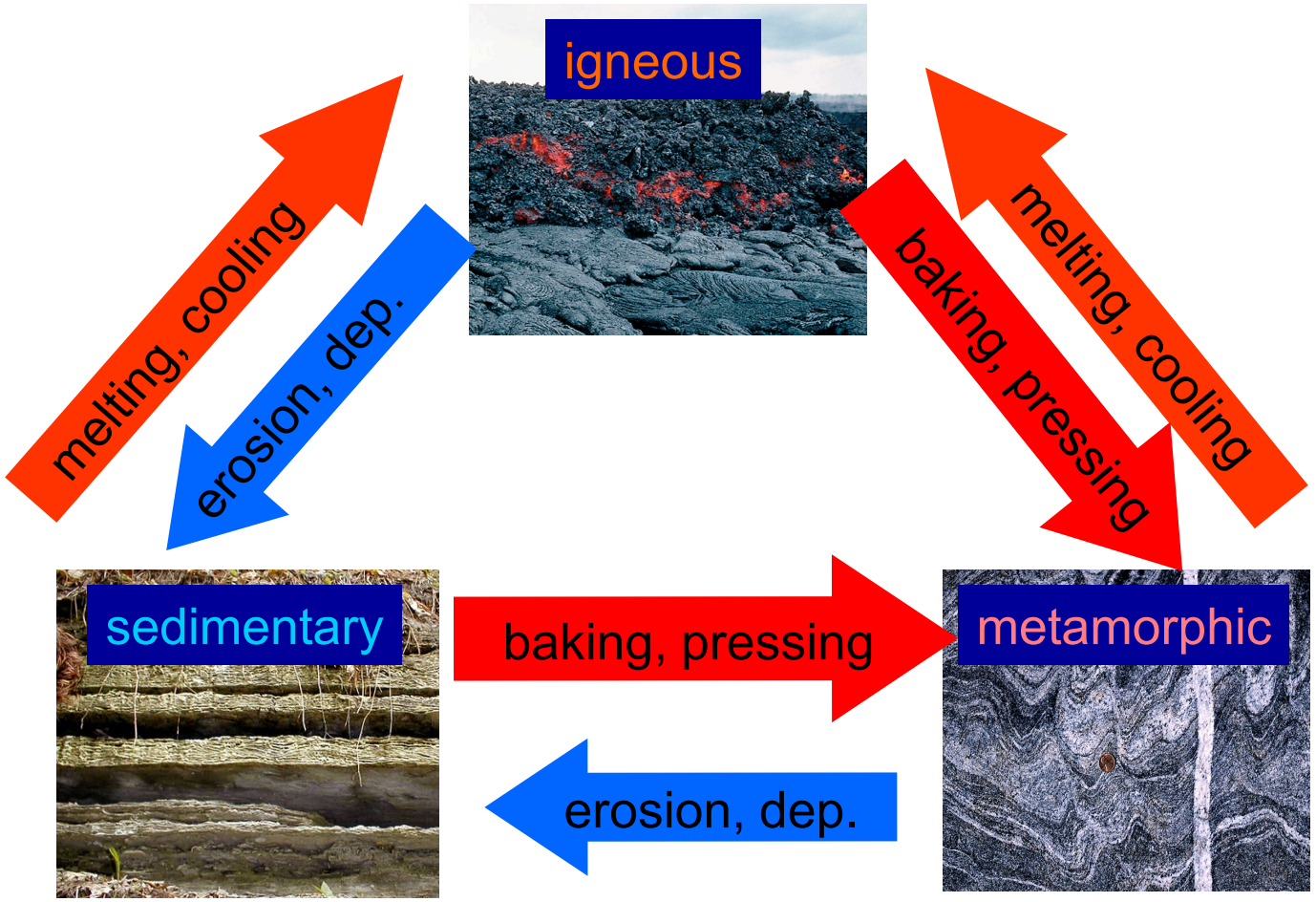
THE ROCK CYCLE



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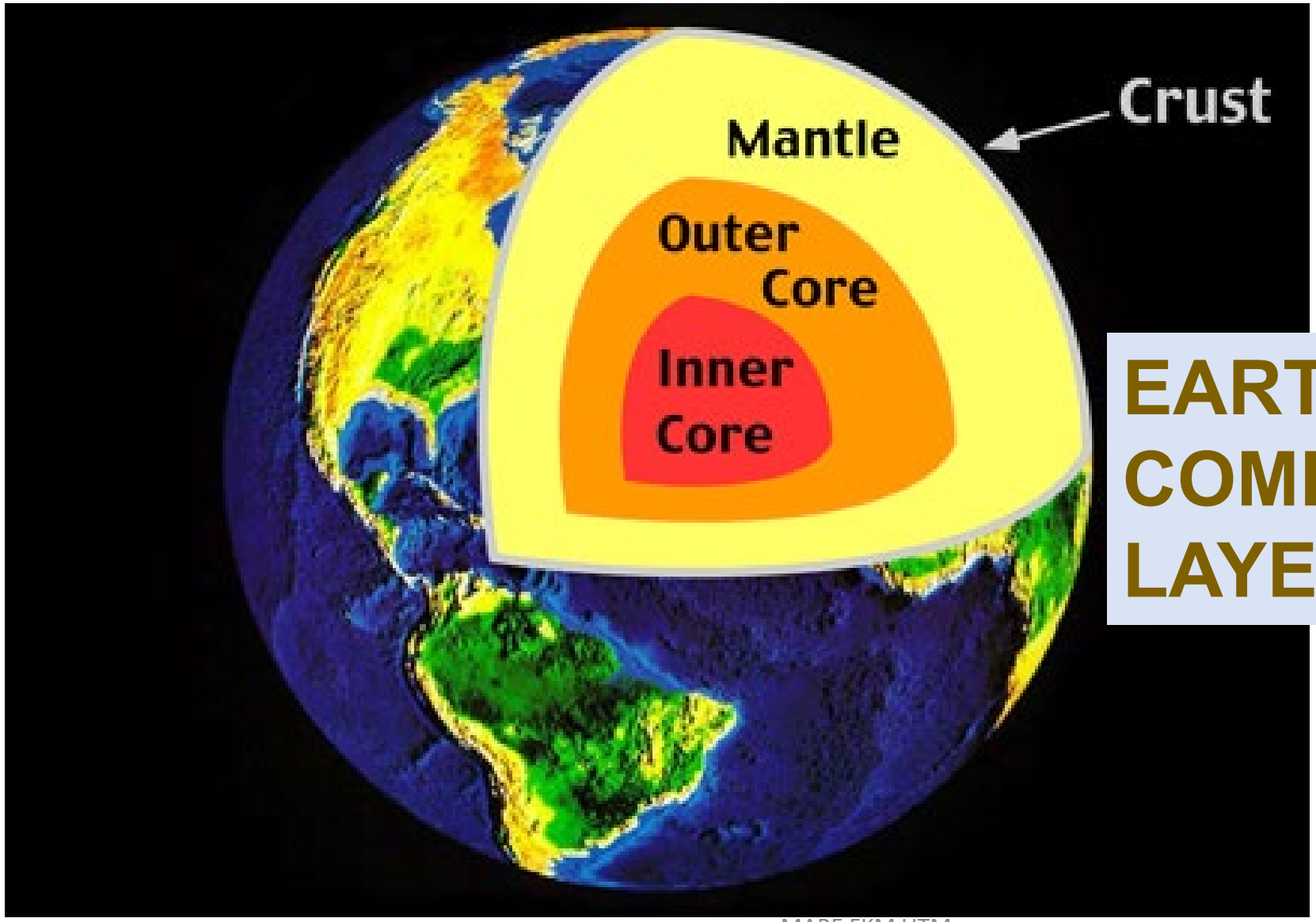
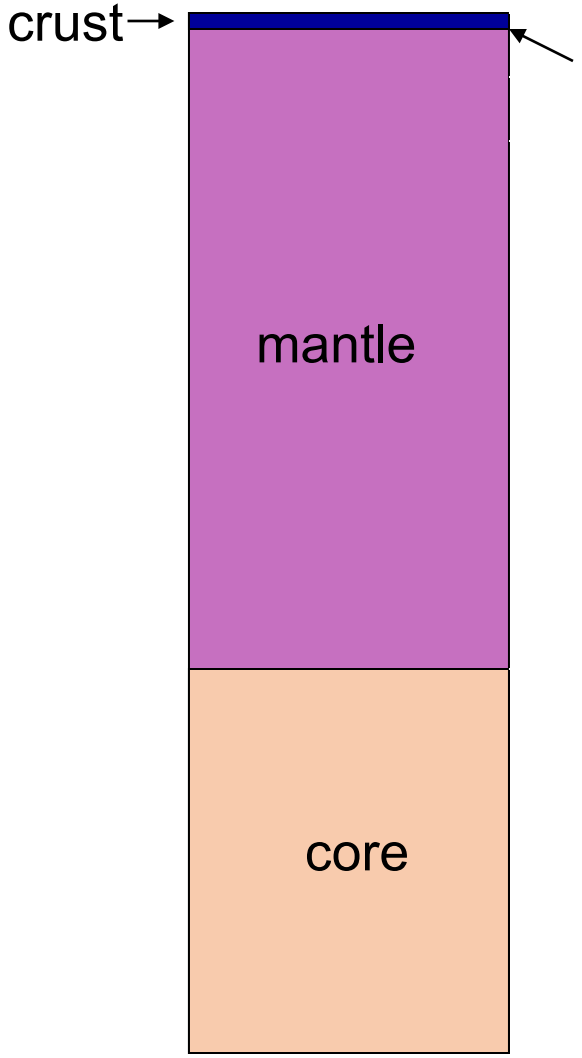


EARTH: COMPOSITIONAL LAYERS

COMPOSITION

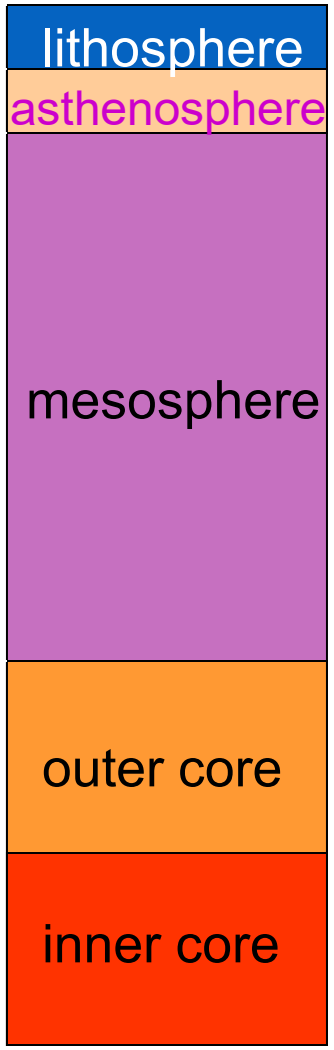


Similar to mantle but with lighter metals

Mostly silica, magnesium, iron, with some other stuff

Mainly iron and nickel

PHYSICAL CHARACTERISTICS



Brittle, solid

Solid, but behaves plastically

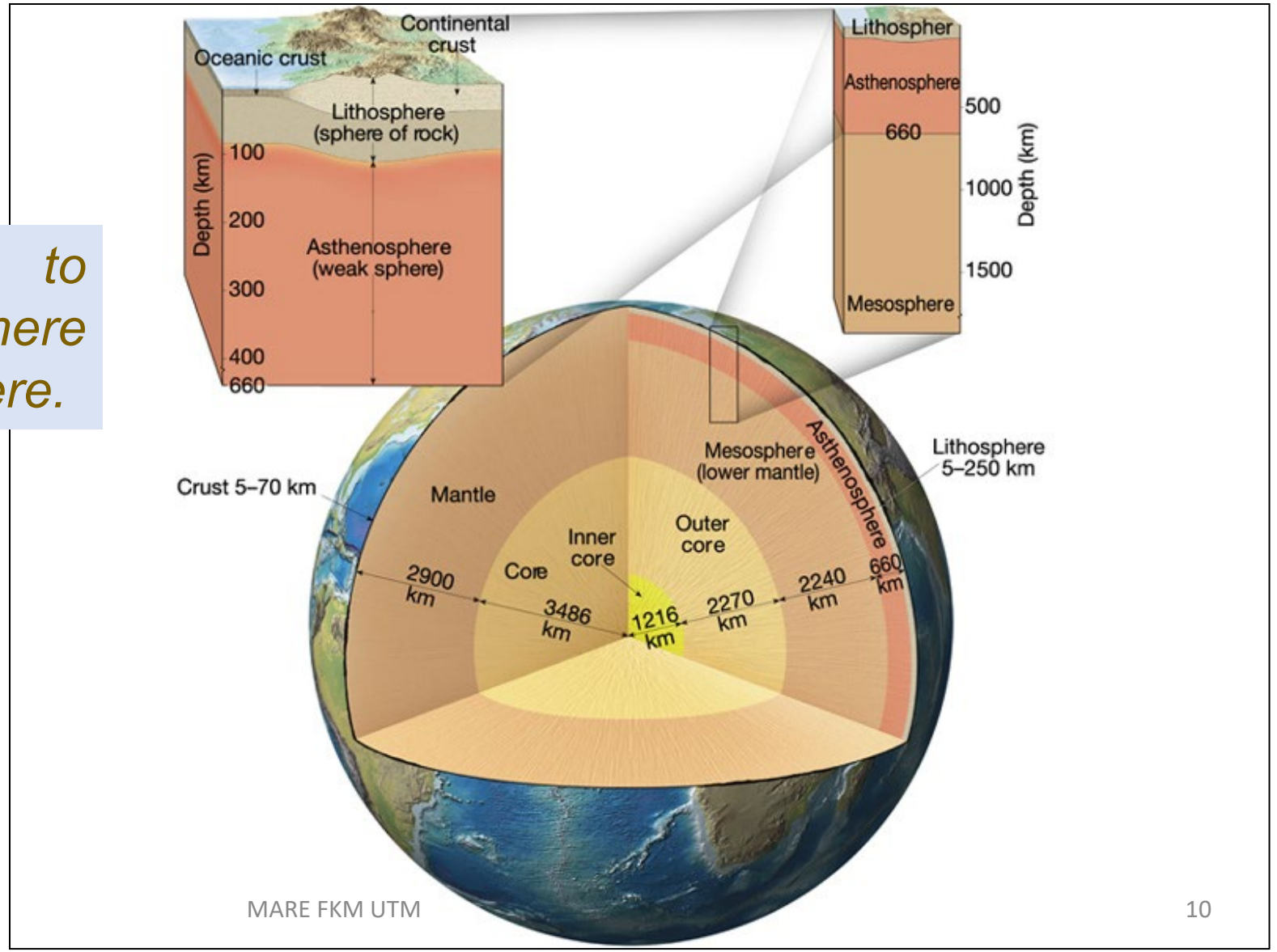
Solid but flows slowly over long periods of time

Liquid

Solid

Note: Lithosphere contains both crust and uppermost (brittle) layer of mantle

Focus your attention to interaction of brittle lithosphere and near-liquid asthenosphere.



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ISOSTACY

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ISOSTACY

Isostasy is the rising or settling of a portion of the Earth's lithosphere that occurs when weight is removed or added in order to maintain equilibrium between buoyancy forces that push the lithosphere upward and gravity forces that pull the lithosphere downward.

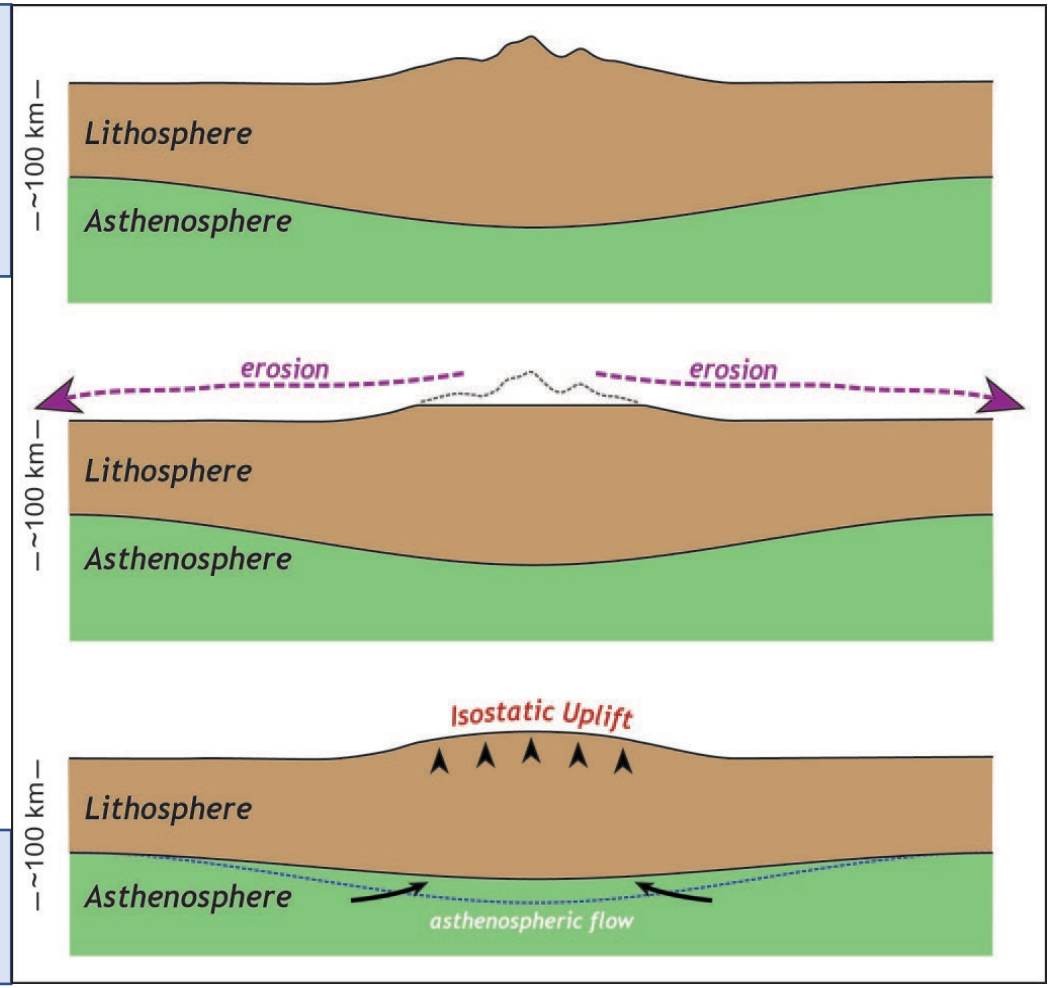
Oceanic Crust
- Average Density: 3.0 g/cm^3
- Average Thickness: 7 km
- Maximum Age: 180 million years

Continental Crust
- Average Density:2.7 g/cm^3
- Average Thickness: 35-40
- Maximum Age: 4.0 billion years

Note: Average Density of Mantle Material is 3.3 g/cm^3

Both oceanic and continental crust are welded to lithospheric mantle (the hard, brittle, uppermost part of mantle to form lithospheric plates)

Oceanic plates are heavier than continental plates !



Isostasy - The William & Mary Blogs

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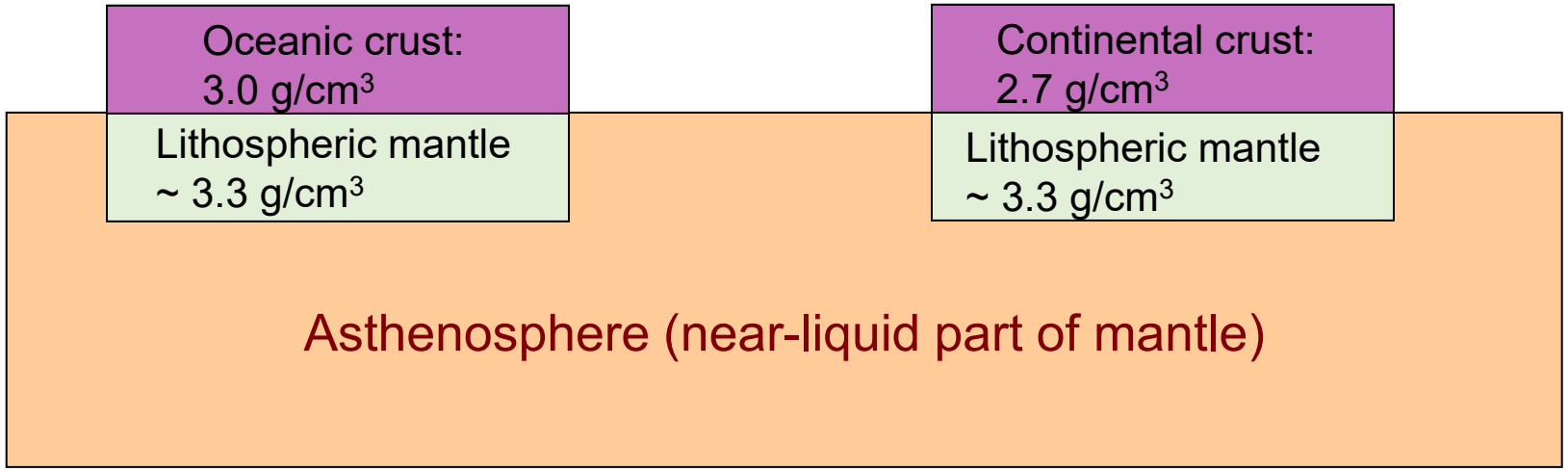
EFFECTS OF DENSITY

A block of continental lithosphere (containing continental crust plus uppermost) stands higher than a block of oceanic lithosphere (containing oceanic crust) of the same dimensions.



Oceanic lithosphere floats low on asthenosphere (forms basins)
Continental lithosphere floats high on asthenosphere (forms continents)

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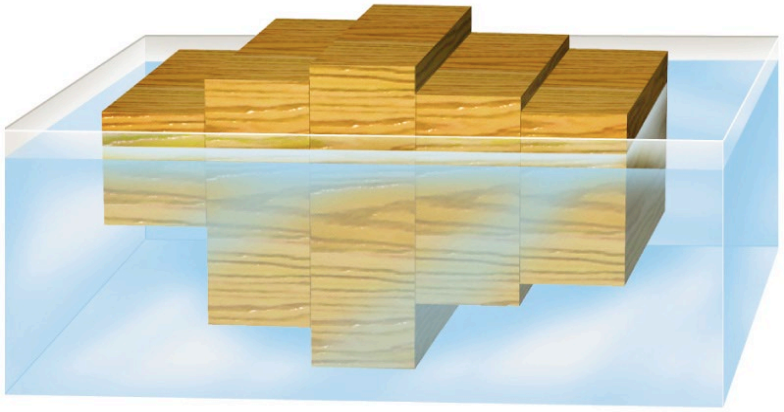
EFFECT OF LITHOSPHERIC THICKNESS

For a buoyant material, a thick block stands higher than a thin block

Example: top surface of thick block of wood stands higher above water level than that of thin block of wood.
However, the proportion of material standing above and below water mark is the same for all blocks.



So, low density of continents combined with great crustal thickness make continents stand higher than ocean floors.

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PLATE BOUNDARIES OF EARTH'S SURFACE

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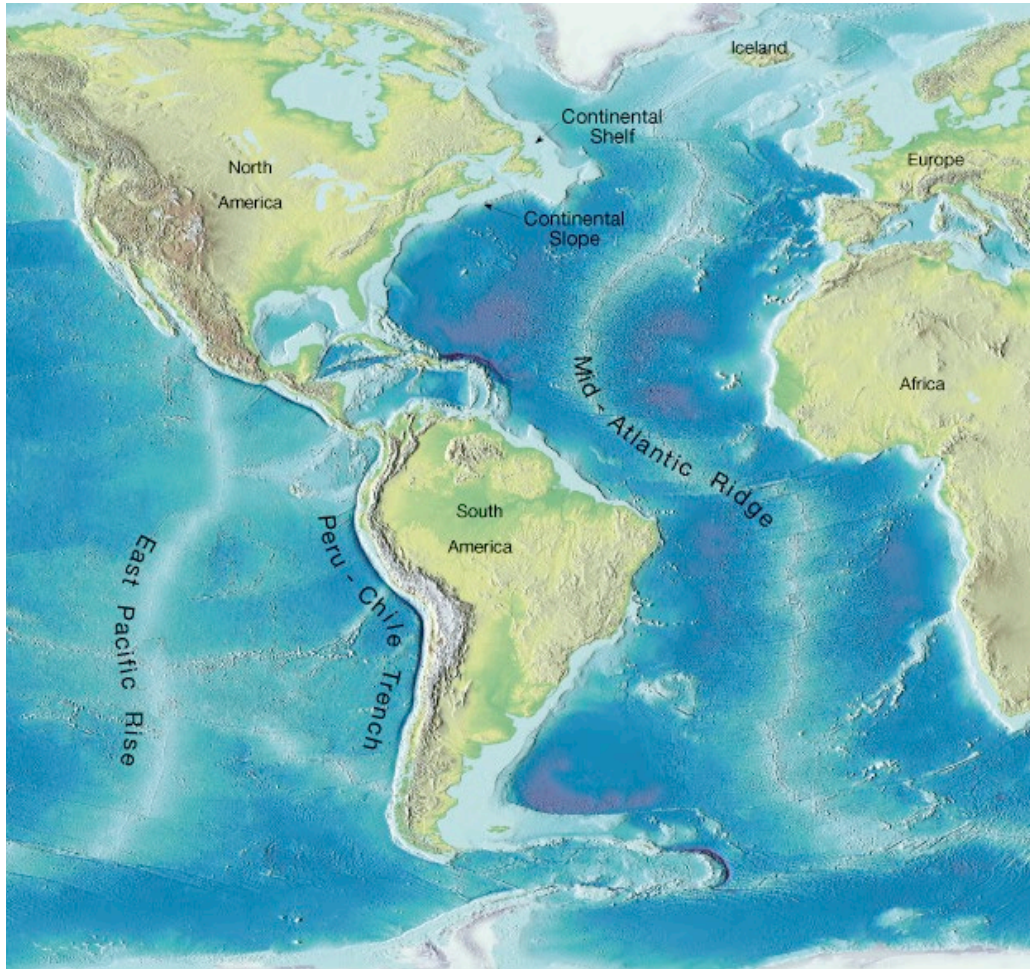
PHYSIOGRAPHY OF THE EARTH'S SURFACE

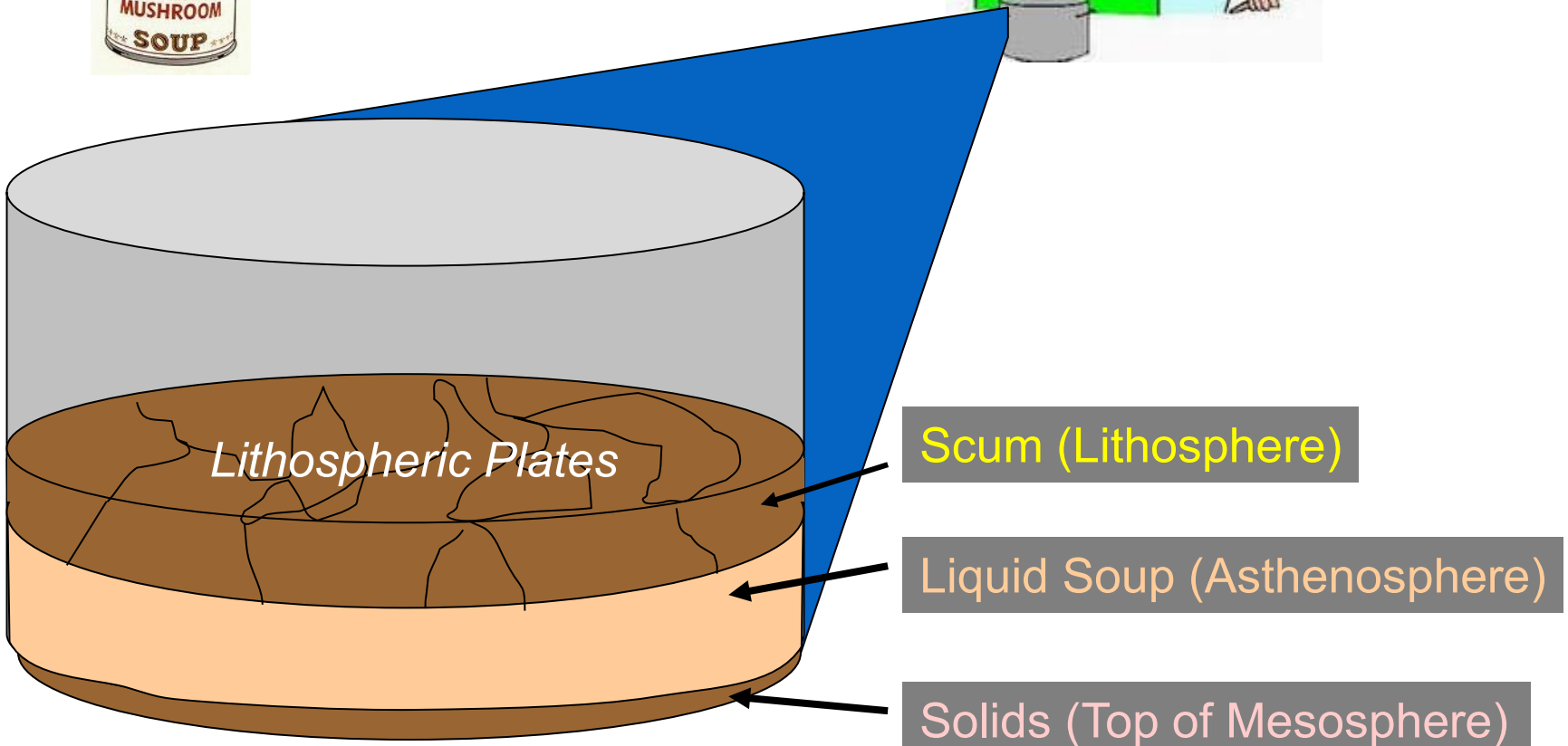


We have explained why continents stand high and ocean basins stand low, but what about features within ocean basins ?

Mid-Ocean Ridges Trenches

These features are significant in understanding how oceans open and close

Plates in a can



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Several lithospheric plates are recognized on Earth's surface

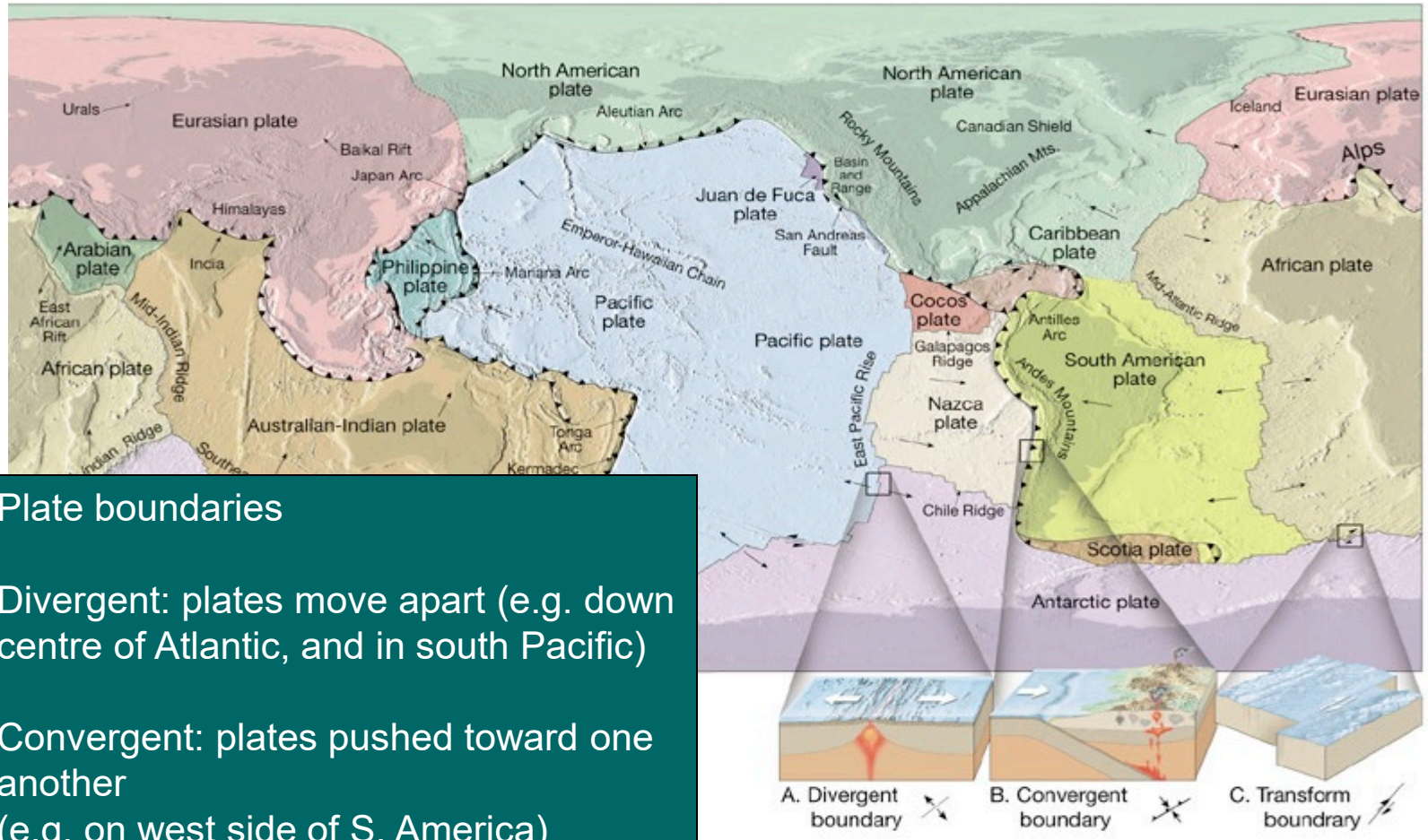

Plate boundaries

Divergent: plates move apart (e.g. down centre of Atlantic, and in south Pacific)

Convergent: plates pushed toward one another
(e.g. on west side of S. America)

Transform: plates slide alongside one another (e.g. San Andreas fault)

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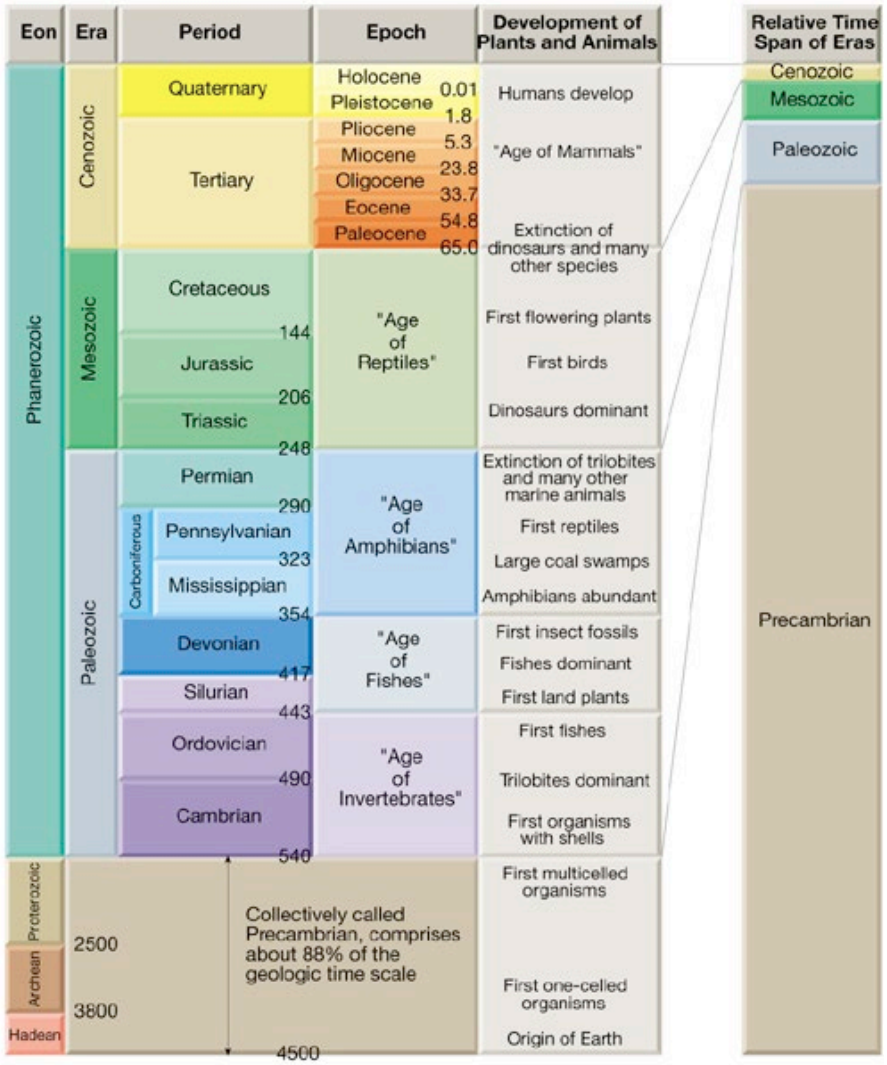


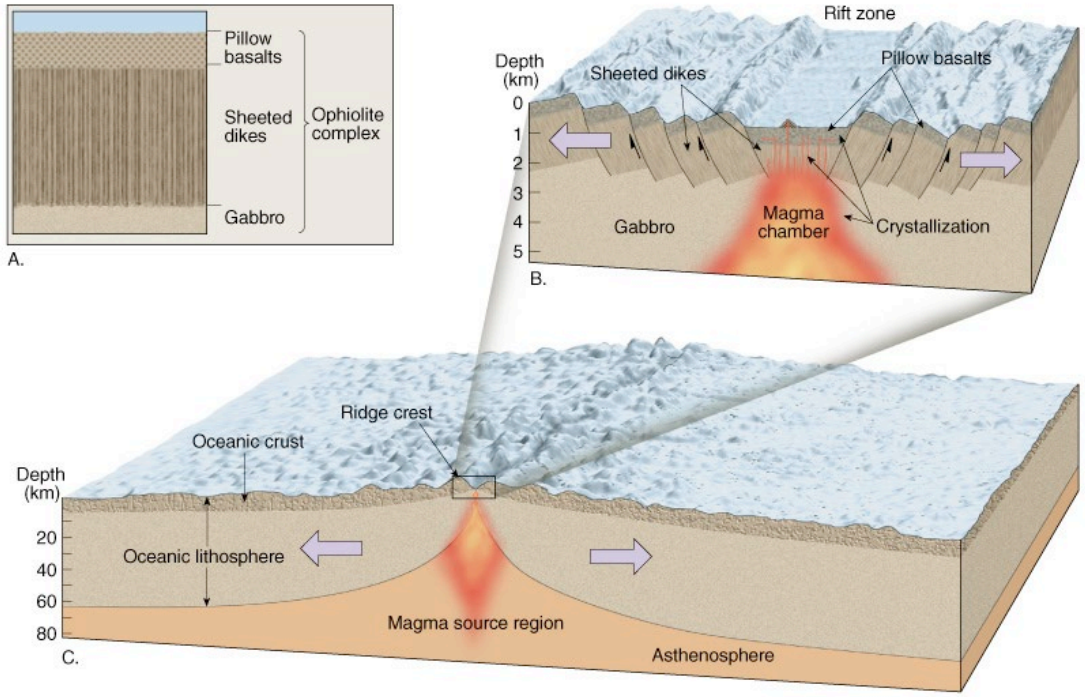
Many geologic processes (including plate movements) occur over immense time scales

Rule of thumb: on average, lithospheric plates move at about the rate that your fingernails grow (about 5 cm/yr).

Took about 200 million years for Atlantic Ocean to reach its present dimensions (by the way, the Maritimes were connected to Africa just before this time !)

DIVERGENT PLATE BOUNDARIES

Divergent plate boundaries are where seafloor spreading occurs, producing new oceanic crust. Material from mantle intruded into fractures as plates are move apart. New oceanic crust is made, so this type of boundary is said to be “constructive.”



- Upper crust of oceanic plate is made of basalt (aphanitic mafic rock)
- Lower part of crust is made of gabbro (phaneritic mafic rock)
- So same composition of magma (from molten mantle), but different textures.

Ocean basins ultimately originate when continental landmasses split apart.

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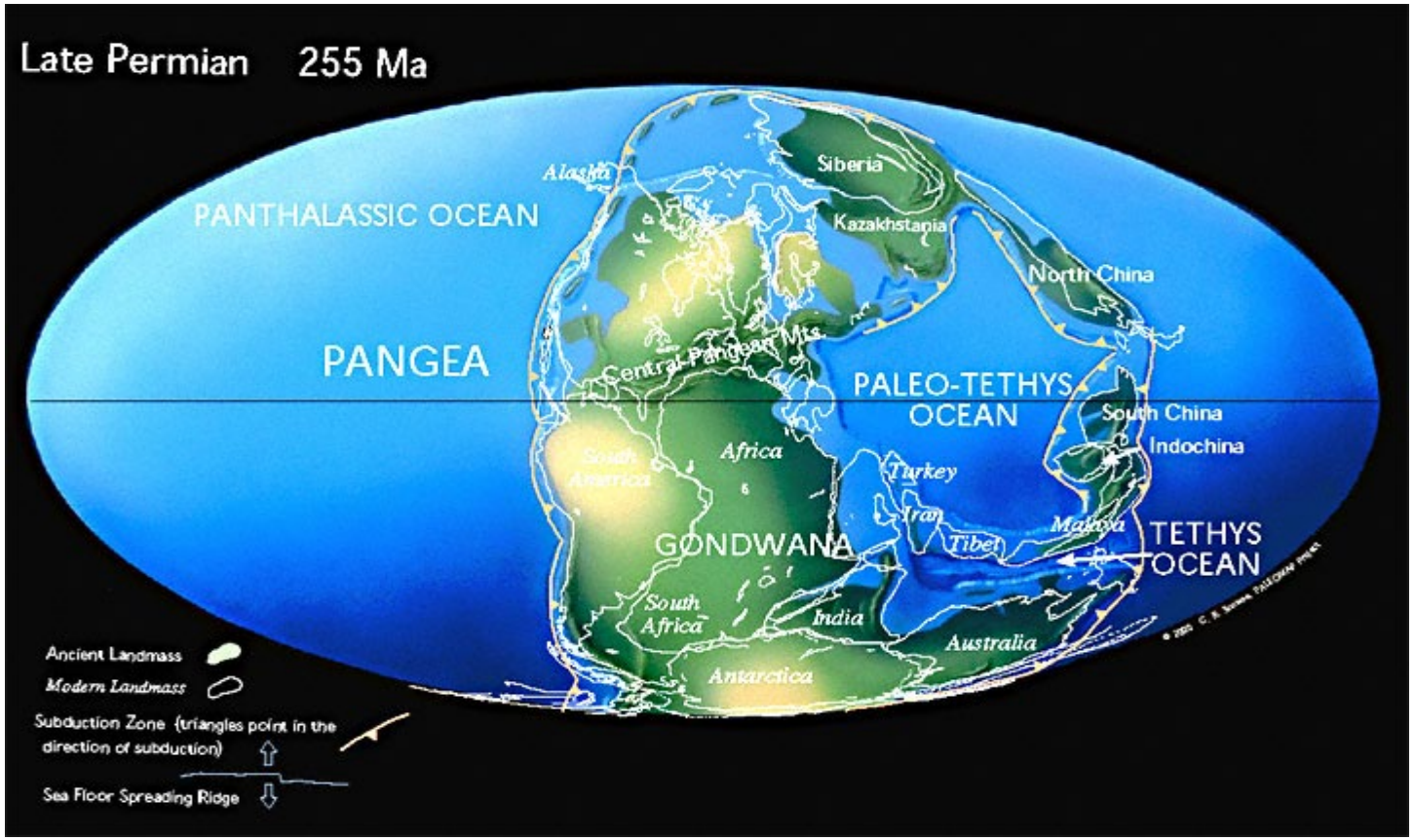
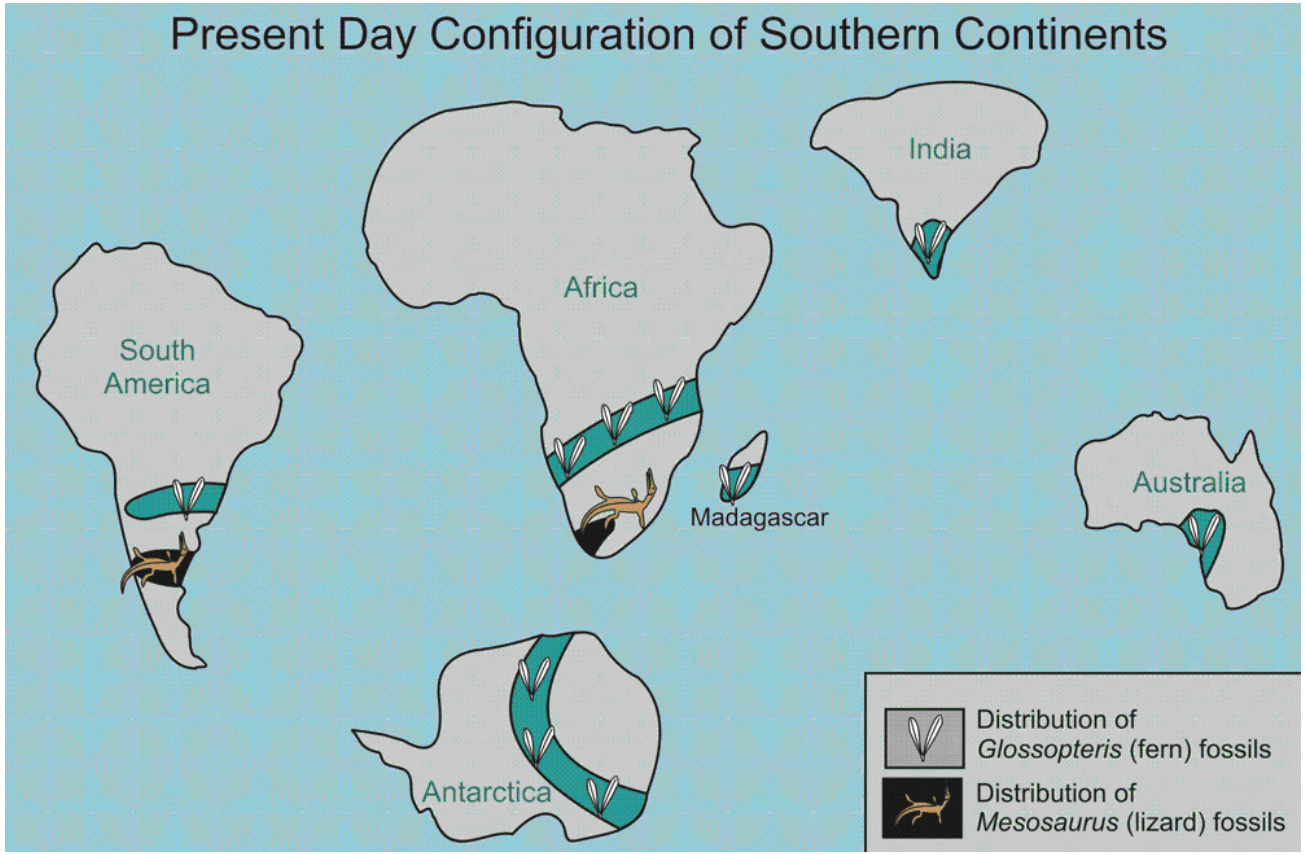
EARLY EVIDENCE OF SEAFLOOR SPREADING

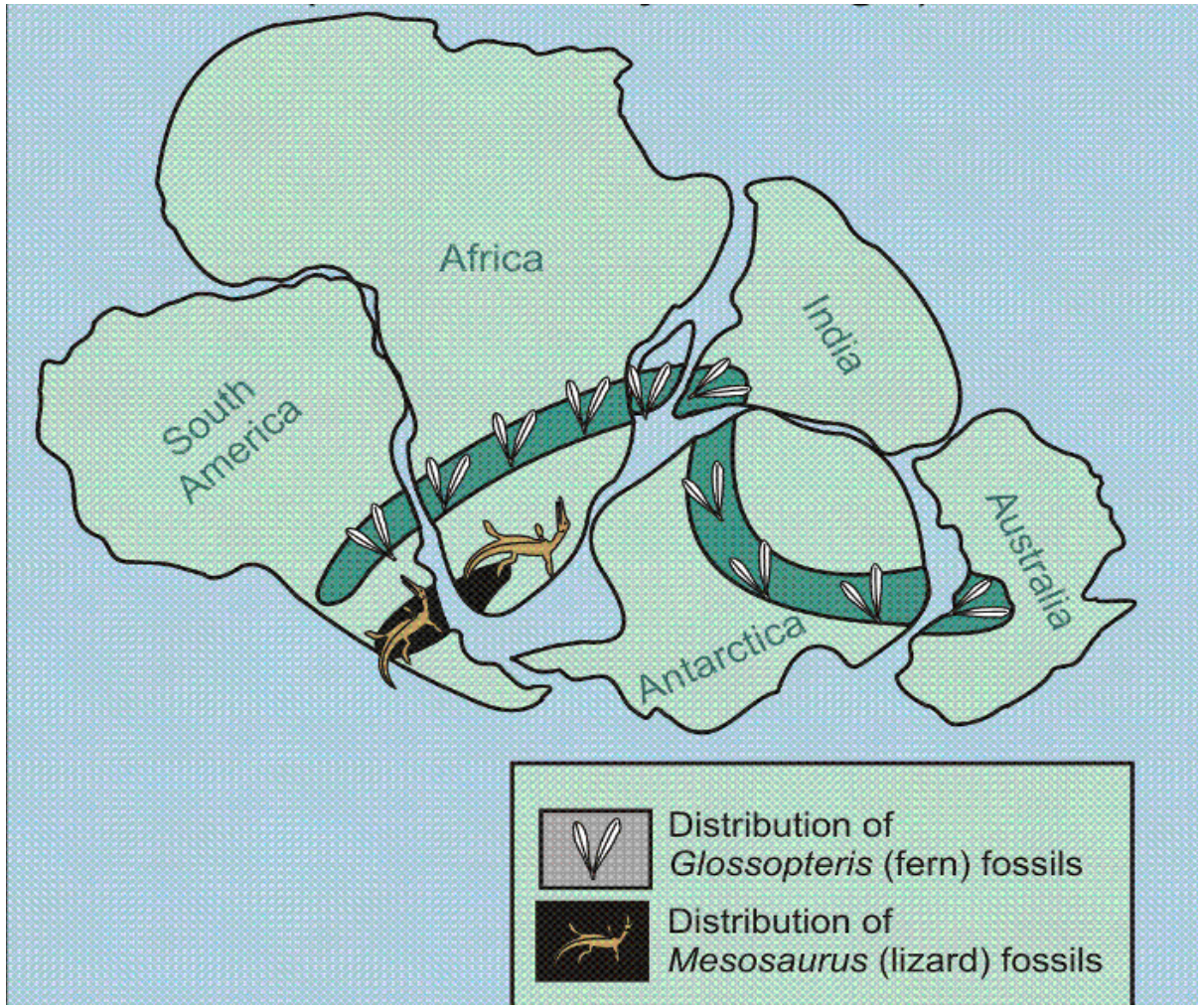
1. Jigsaw puzzle fit of continents (first noted by Alfred Wegener)



2. Fossil evidence



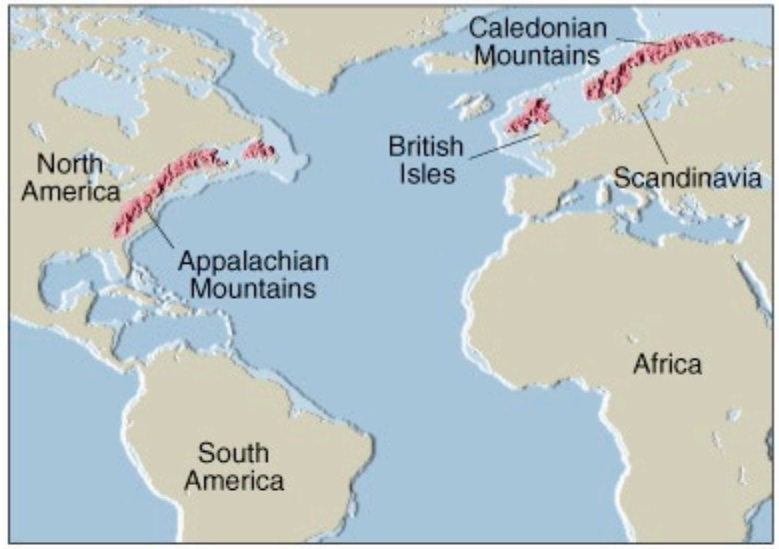
Fossils of land organisms such as the lizard *Mesosaurus* and the fern *Glossopteris* distributed over multiple continents: how did they get from one continent to another ?



Now this makes sense !

3. Distribution of old mountain belts

Old mountains belts (Appalacians and Caledonides) now separated but if continents are fit together, mountain chains form a continuous belt

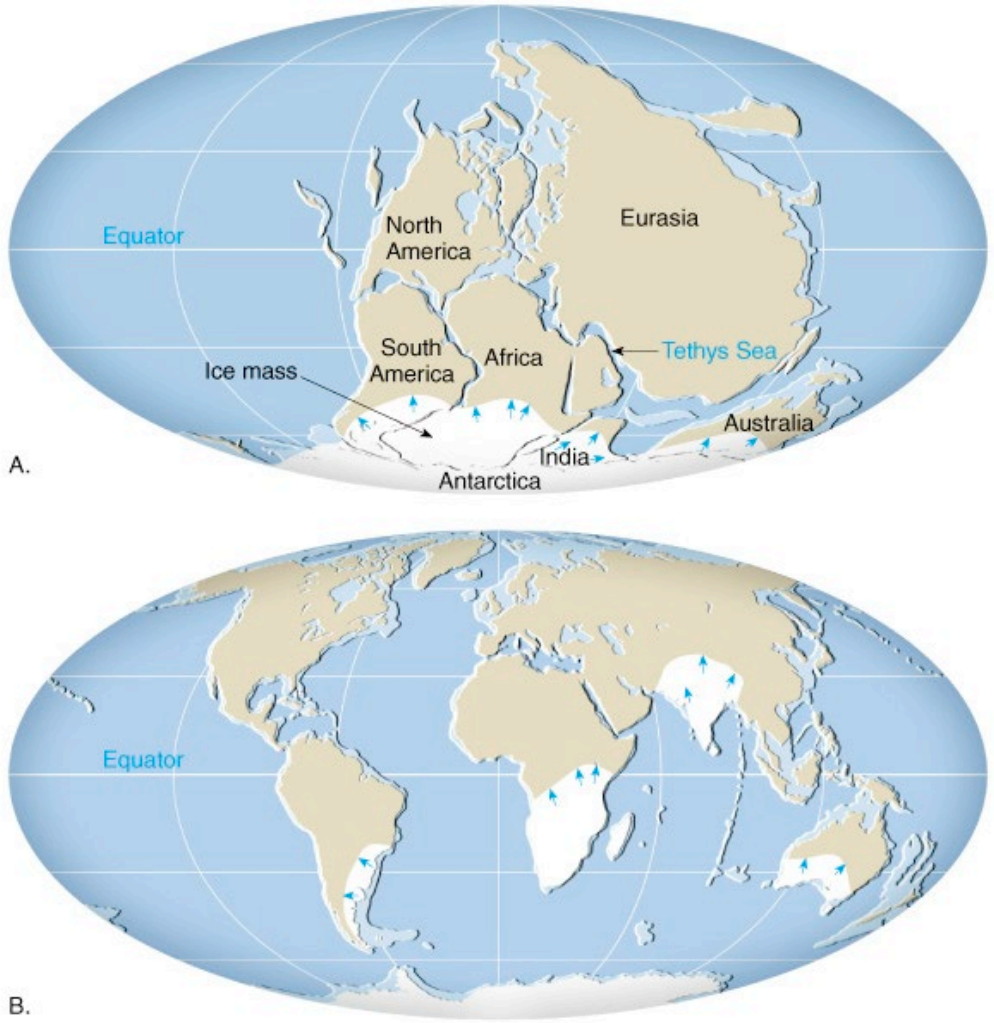


A.

B.

4. Flow indicators of glacial ice during ancient ice age (about 300 million years ago)
-not to be confused with the last ice age that ended only about 10,000 years ago).

Flow directions make more sense if continents are fit together



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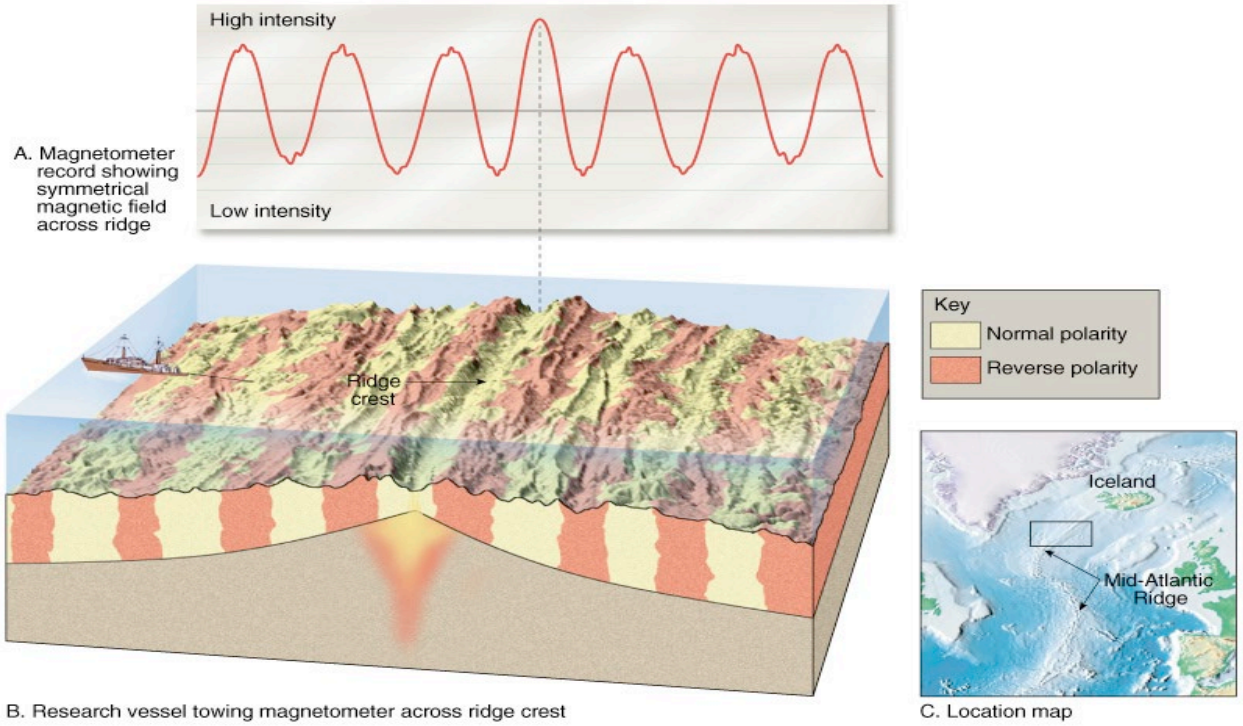
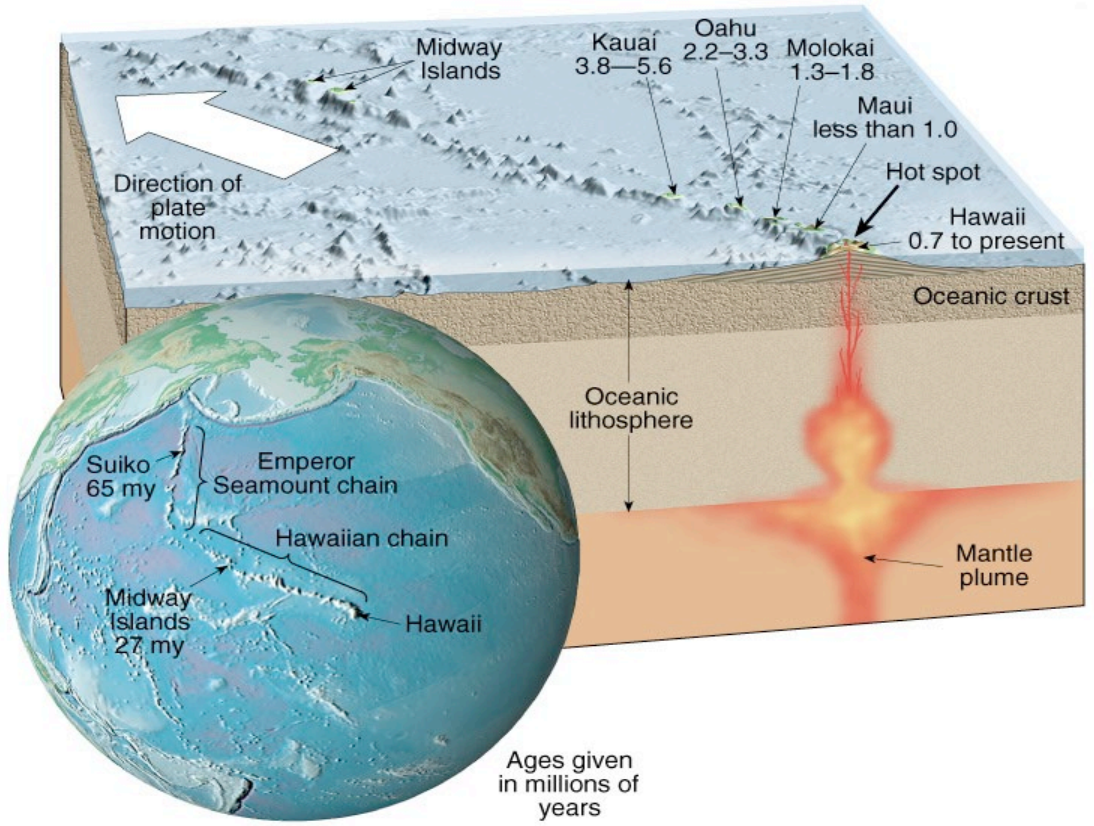
MORE RECENT EVIDENCE OF SEAFLOOR SPREADING

1. Symmetry of magnetic stripes (defined by polarity of magnetic minerals in basaltic rock of seafloor)



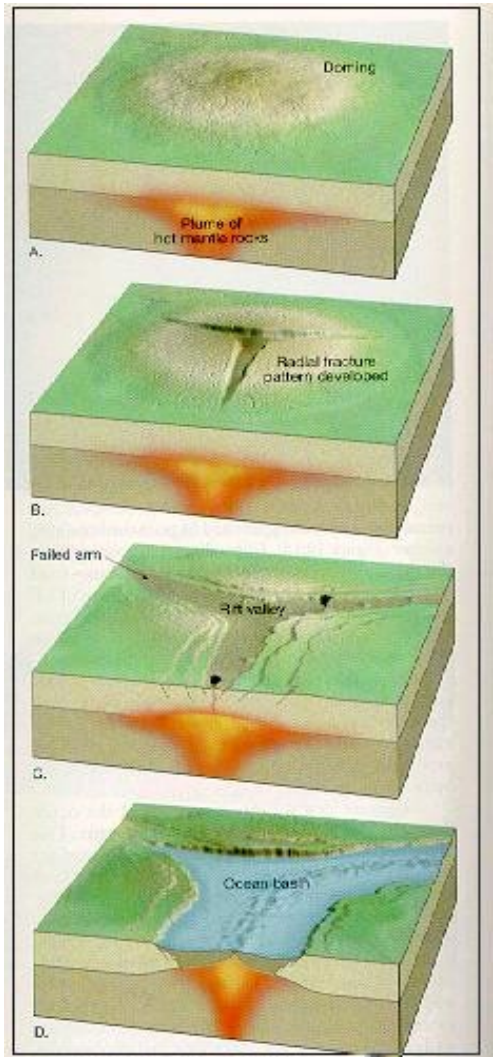
Symmetrical pattern of normal and reverse polarities on either side of a divergent boundary can only be explained if new crust was being formed and repeatedly split apart as magnetic field reversed

2. Linear arrangement and relative heights of hotspot volcanoes (volcanoes produced by movement of plate over stationary magma plume from mantle)



Note: heights of hotspot volcanoes are decreased with increasing distance from point of active volcanism (due to cooling and sinking of lithospheric material)

But how does seafloor spreading (divergence) start ?



Hot plume in mantle upwarps lithosphere of continent

Cracks develop (generally in a triple junction), forming rift valleys

Zones where adjacent fractures connect allow further spreading to produce an ocean

Failed arm ceases to spread (Bay of Fundy basin represents a “failed arm” of the Atlantic Ocean basin)

Red Sea-Gulf of Aden: An ocean basin in the making

East African Rift will probably stop spreading and become a “failed arm”

Future ocean basin

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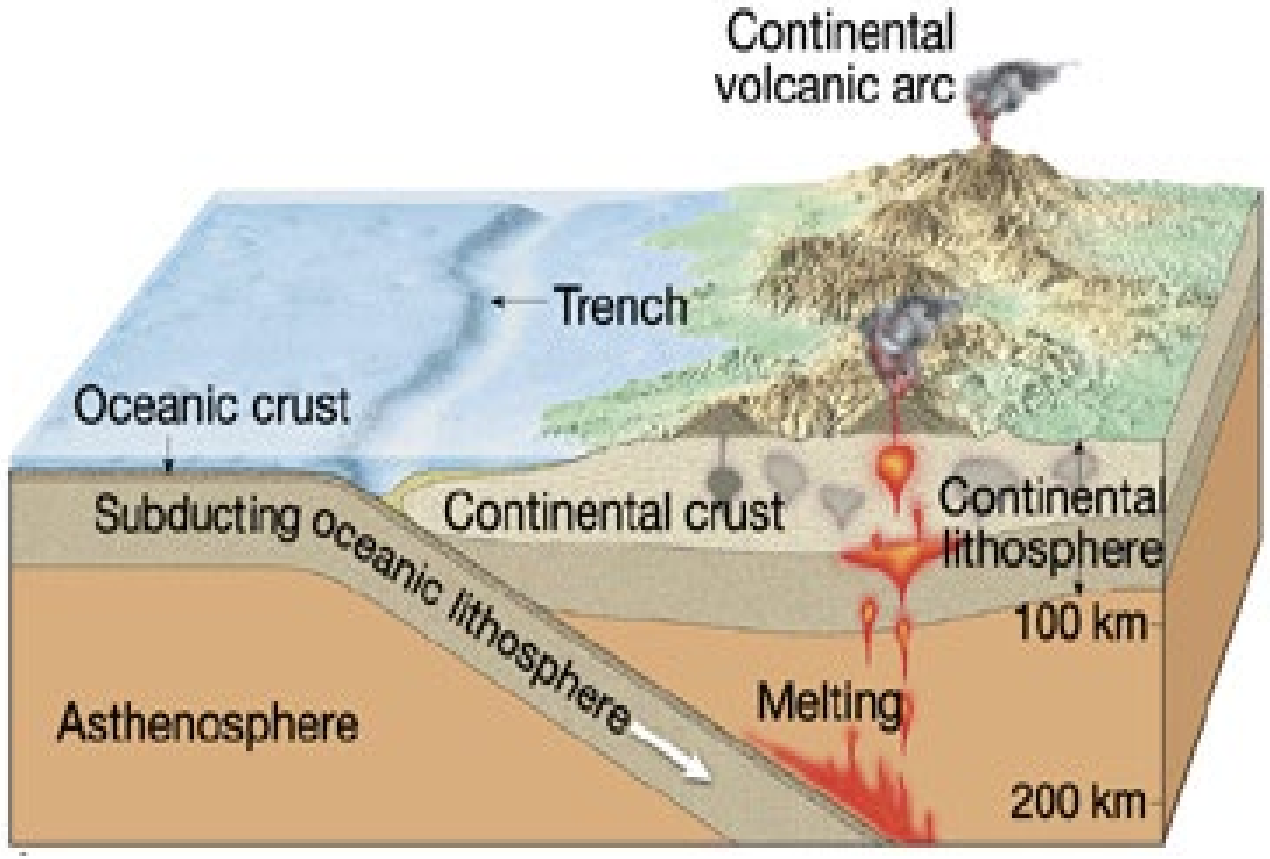
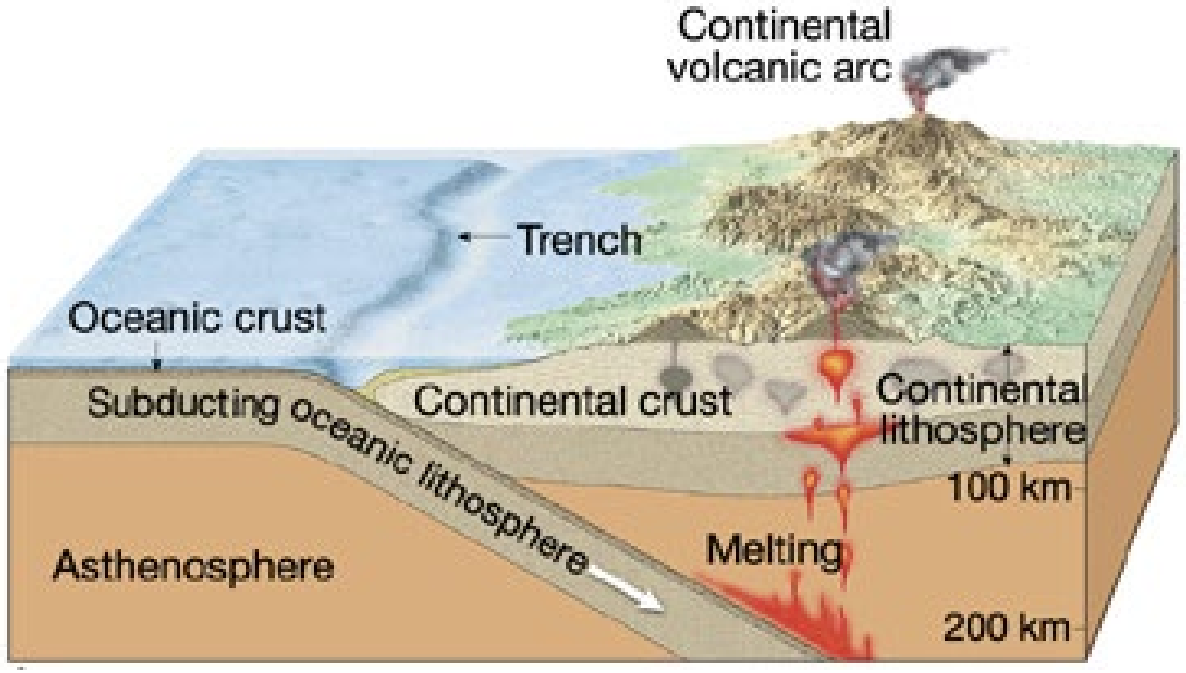
SUBDUCTION

CONVERGENT PLATE BOUNDARIES

- Zones where lithospheric plates move toward one another and where oceanic lithosphere is consumed back into the mantle. Because oceanic lithosphere is destroyed, convergent plate boundaries are commonly called “destructive” plate boundaries
- This process ensures that the Earth retains a constant volume (otherwise the Earth would be expanding- which we know isn’t happening !)
- When plate of oceanic lithosphere descends (is subducted) into the mantle, some material rises to surface to produce explosive volcanoes





At the surface, igneous rocks include pyroclastic deposits and rhyolite

At depth, the magma cools slowly to produce granite.

However, basalt can also occur (but this is a complication)

In this case, **magma does not come directly from mantle**.

Magma at a convergent boundary is produced by the partial melting of the downgoing (subducted) slab of oceanic lithosphere. In this process, silica in rocks of the subducted slab melts first. So the magma produced tends to be felsic (rich in light-coloured minerals such as quartz) and very sticky – this is why volcanoes at convergent boundaries are explosive.

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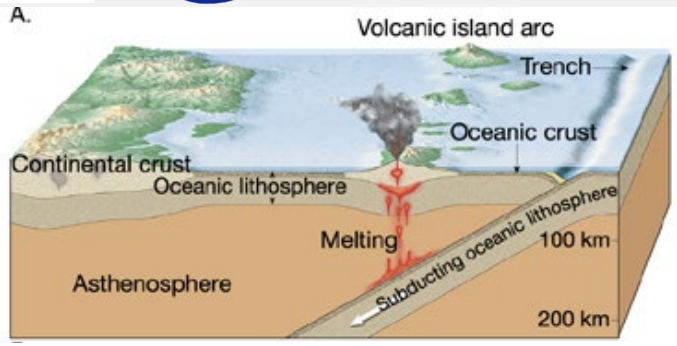
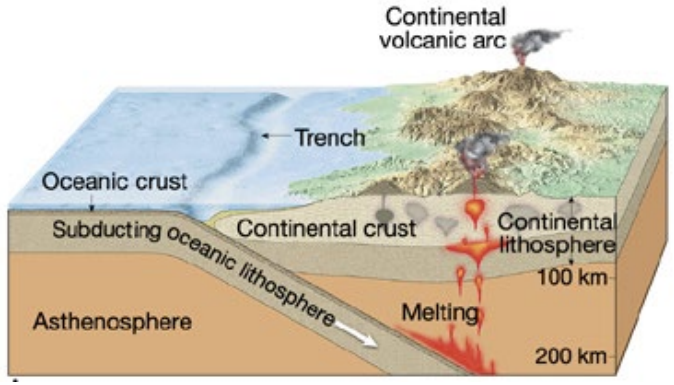
TYPES OF CONVERGENT PLATE BOUNDARIES



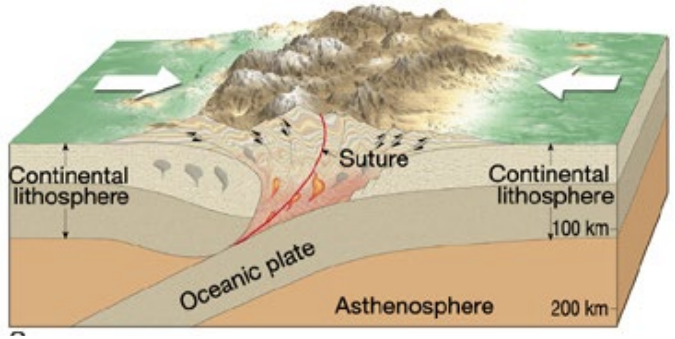
OCEANIC-OCEANIC CONVERGENCE

-subduction of oceanic lithosphere under another plate of oceanic lithosphere
-molten material from subducting slab rises to form an island arc (e.g. Japan)



OCEANIC-CONTINENTAL CONVERGENCE

-subduction of oceanic lithosphere under a continental lithosphere
-molten material from subducting slab rises to form an continental arc (e.g. Cascades with Mt. St. Helens)

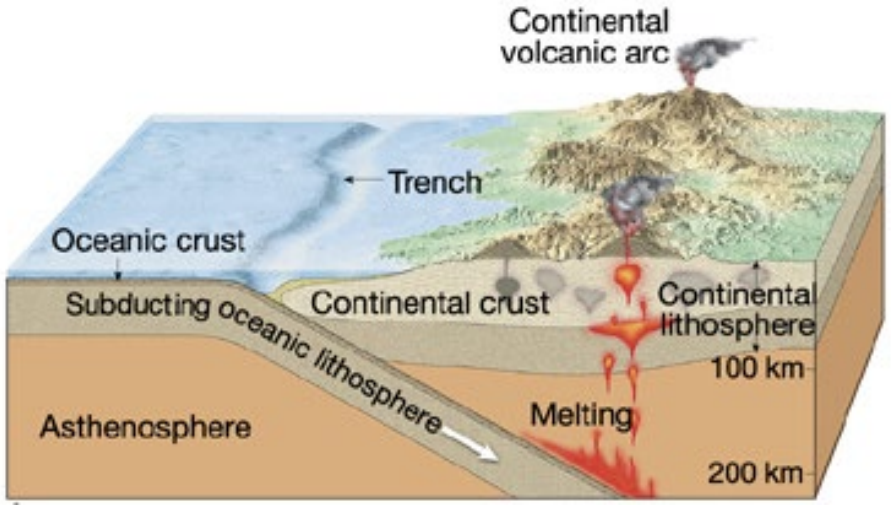


CONTINENT-CONTINENT COLLISION

-where two pieces of continental lithosphere meet (intervening ocean becomes completely closed)
-continental lithosphere can't be subducted, so basically shortens
-Earth's highest mountain belts produced in this way (e.g. Himalayas)

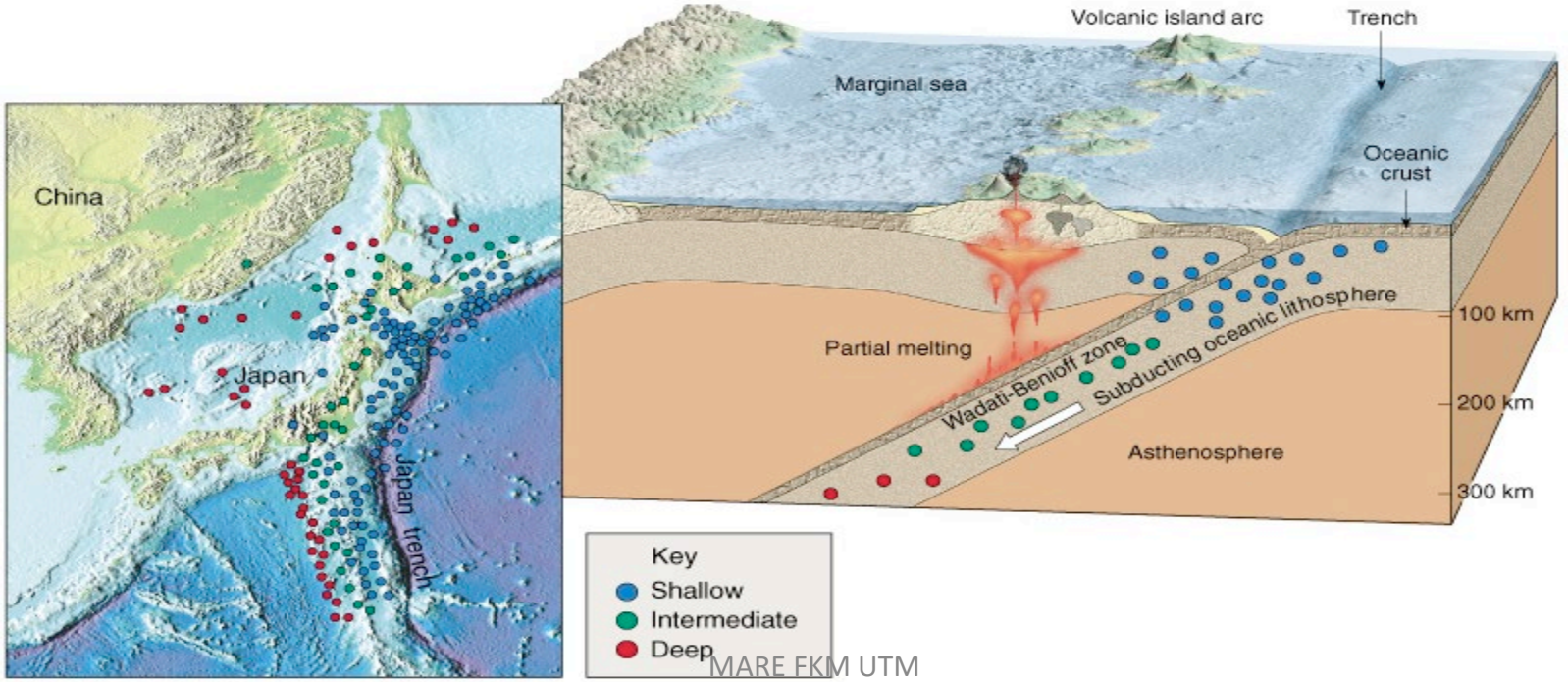
EVIDENCE OF SUBDUCTION

1. Existence of ocean trenches (deepest areas of the ocean) -mark zones where oceanic lithosphere descends downward)
2. Explosive volcanoes (partial melting of top of subducted slab produces thick, viscous magma)



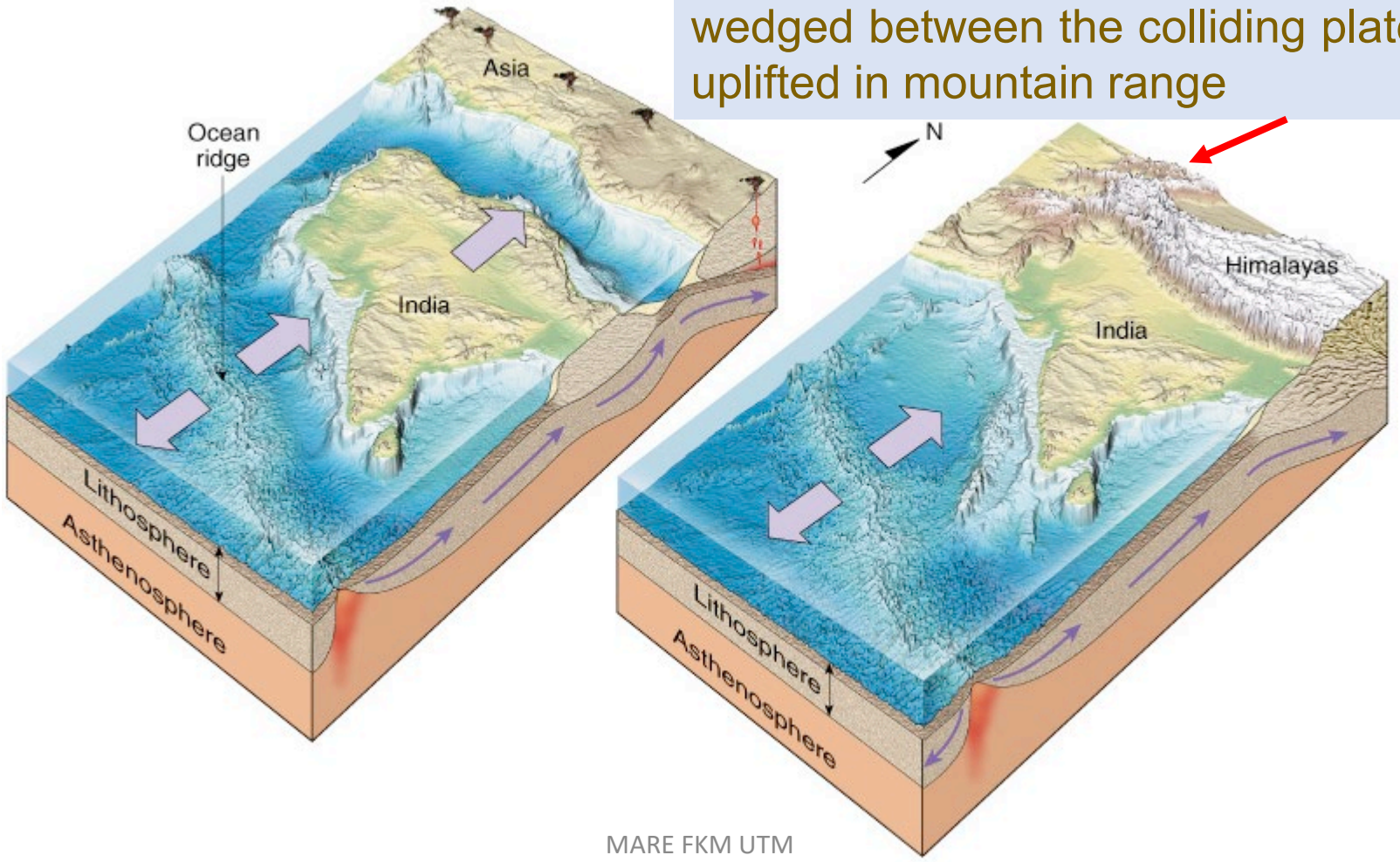
3. Areas with most severe earthquakes (indicating severe compression and subsequent release of energy)

- focal points of earthquakes are deeper inboard of the trench
- the oblique array of earthquake occurrences that indicate the position of the descending slab is called a “Wadati-Benioff” zone (but you don’t have to remember this name).



4. Rocks of oceanic origin found high and dry in the largest mountain ranges.

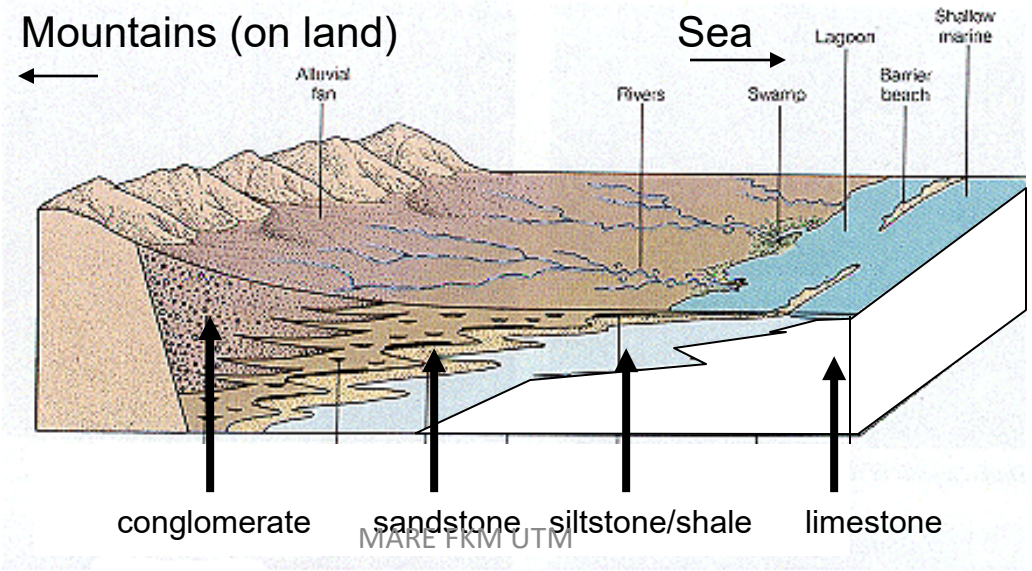
Marine rocks of former ocean become wedged between the colliding plates and are uplifted in mountain range

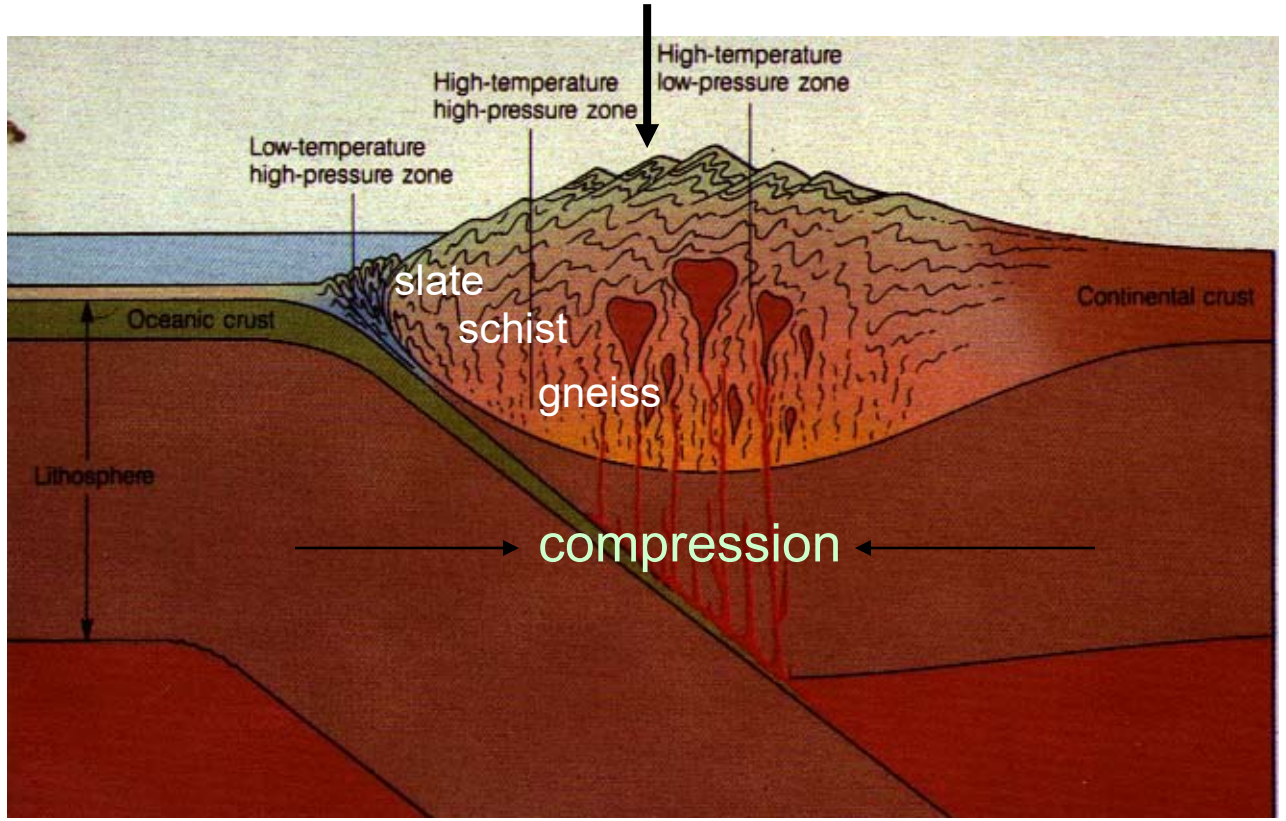


Clastic sediments are derived from wearing-down of mountains that ultimately owe their existence to the convergence of plates (remember how mountains are formed when stuff between plates gets crumpled).

If a mountain chain is close to the sea a “clastic wedge” can form (more on this in next lecture):

- conglomerates generally occur on land, close to the mountains
- sands occur close to the shoreline
- mud (silt + clay) is generally deposited offshore
- beyond the reach of mud (i.e. where water is clear), limestone can be deposited on a “carbonate platform”

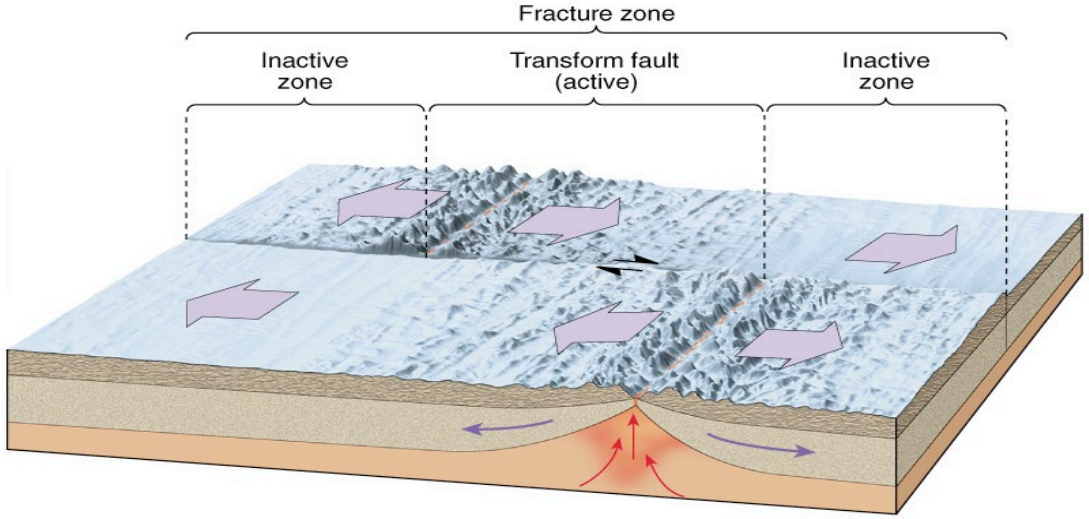


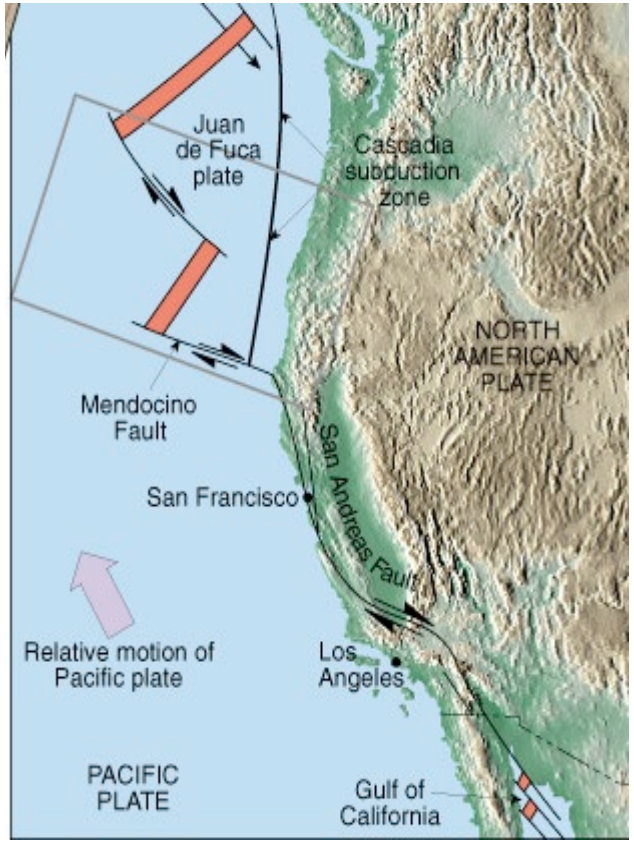


Mountains (without volcanoes in this case)

Compression created by converging plates, together with heating of rock as the crust is thickened and lowered downward produces regional metamorphism (metamorphic grade increases with depth)

- Zones where lithospheric plates move alongside one another
- No oceanic lithosphere is created or destroyed (sometimes called “strike-slip” boundaries)

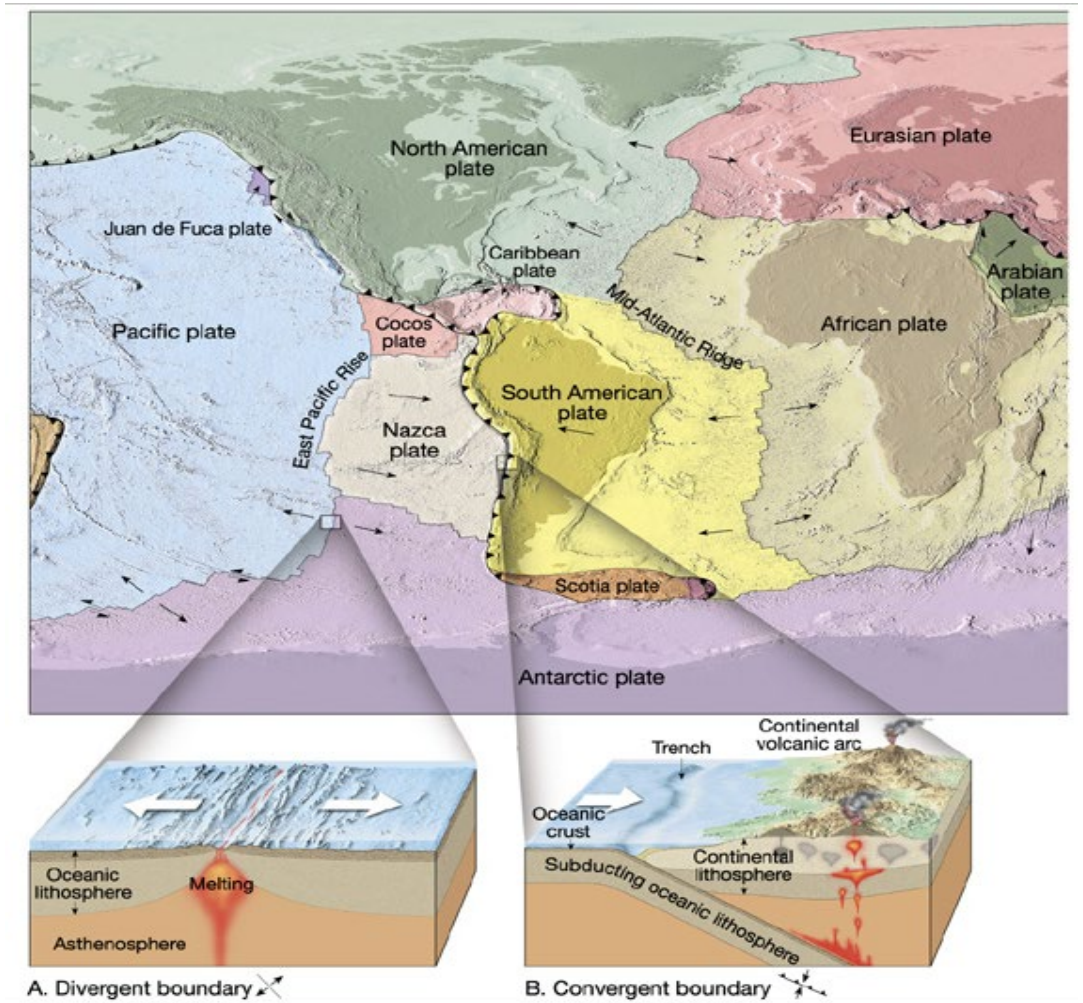




- Most common in oceanic lithosphere of ocean basins (offset segments of divergent plate boundaries)
- Sometimes occur in continental lithosphere (e.g. San Andreas fault)
- No magma is generated in this type of boundary

IMPLICATIONS OF PLATE TECTONICS

- So…Oceanic lithosphere is constantly being created at divergent plate boundaries, destroyed at convergent plate boundaries, and offset at transform plate boundaries
- Oceans are temporary features
- In the past 600 million years, Atlantic has opened, closed and reopened (we are now witnessing only the latest opening event)



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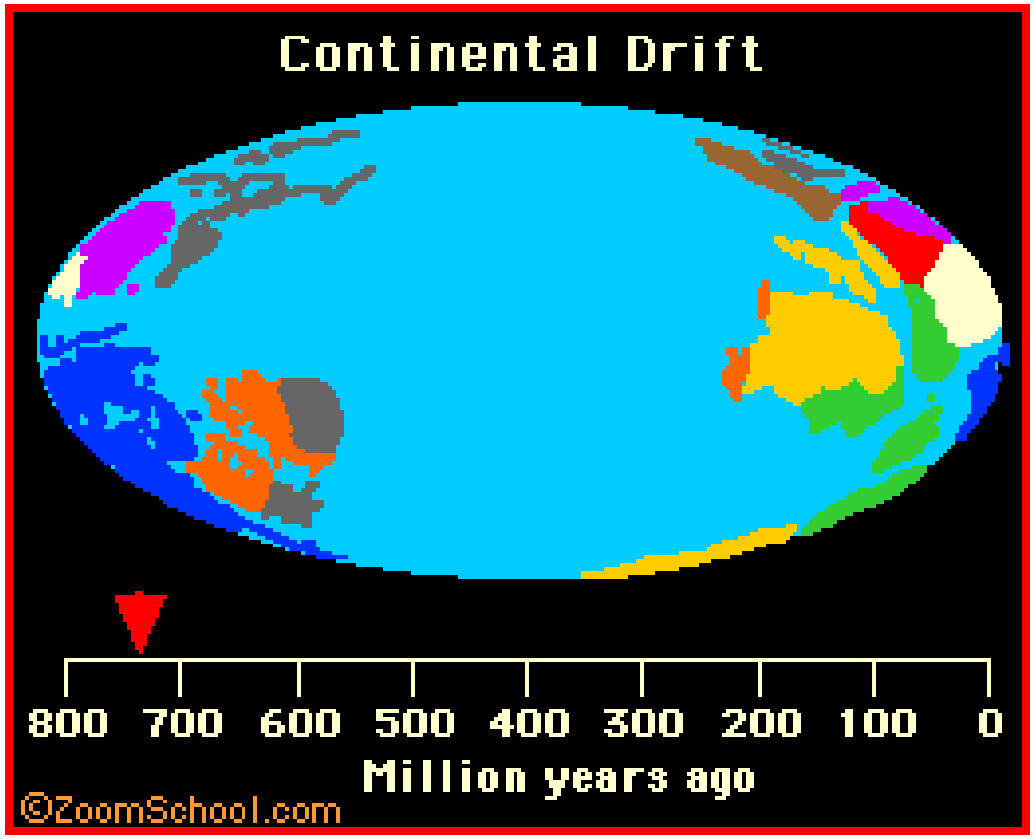
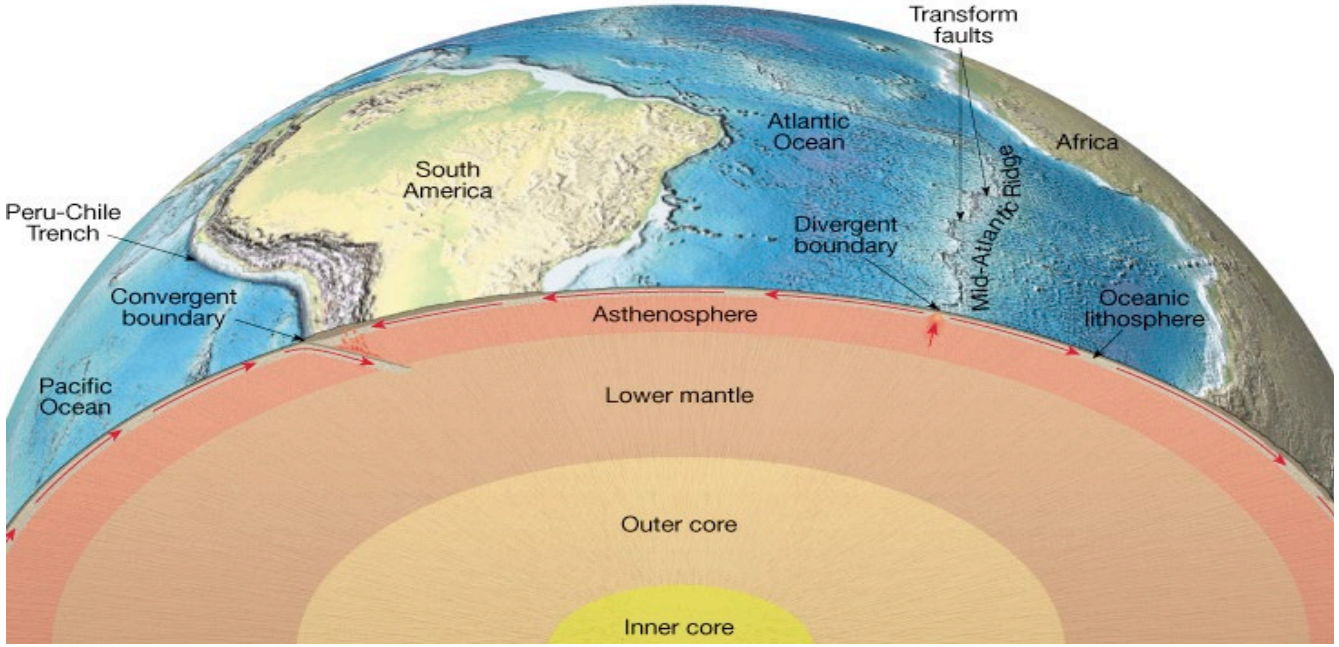
IMPLICATIONS OF PLATE TECTONICS

While ocean basins are created and destroyed continents are too light to be subducted, so simply break apart and collide.

Continental Drift: 750 years ago to present



WHAT DRIVES PLATE MOVEMENT ?



- Convection (plates move in response to convection in mantle) ?
- Ridge push (plates pushed apart at divergent boundaries due to downward sliding of plates from top of mid-ocean ridge) ?
- Slab pull (oceanic plates dragged down at convergent boundaries due to increasing density as they cool) ?
- Or…combination of these ?

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Thank you