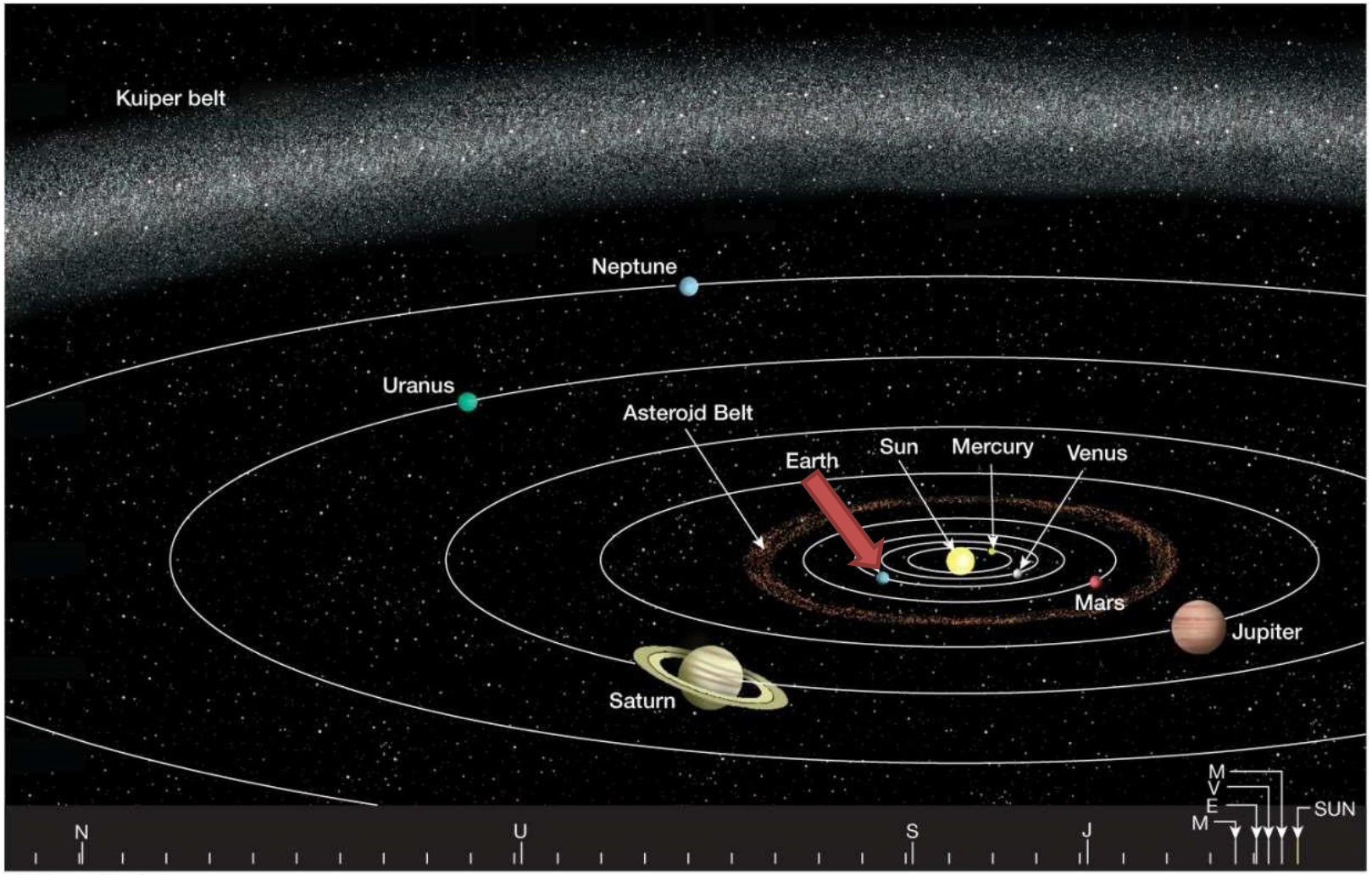
Welcome to Physical Geology GEOL 101

Image by: **Stockli**, Nelson, Hasler
Laboratory for Atmospheres
Goddard Space Flight Center
http://rsd.gsfc.nasa.gov/rsd

Hurricane Linda west of Mexico
September 9, 1997 17:45 UTC
Data from NASA, NOAA, USGS

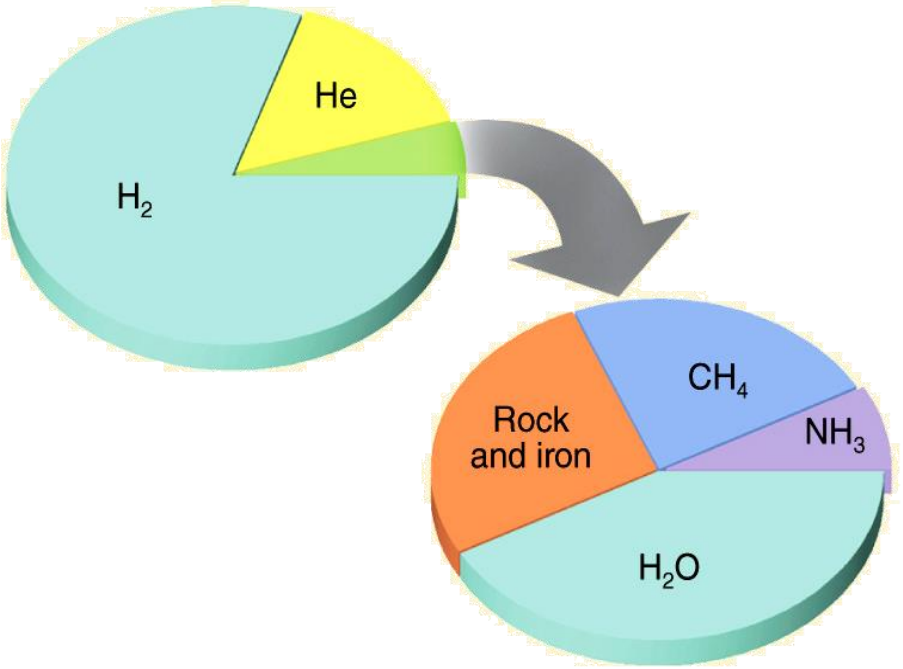
Earth in the Solar System

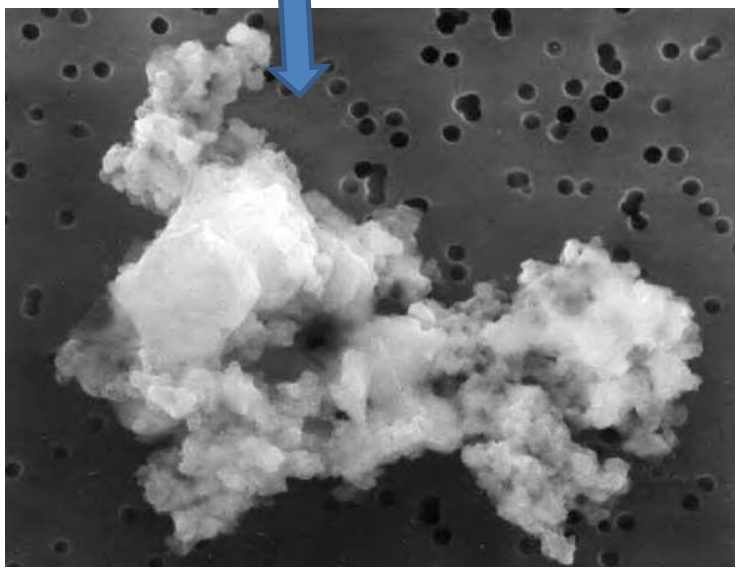


the distance between Earth-Sun ≈ 150 million km = 1 Astronomic Unit

What is the Solar System made of

1. 80% H_2
2. 15% He
3. 5% H_2O, NH_3, CH_4 and other gases, liquids and <u>solids</u>

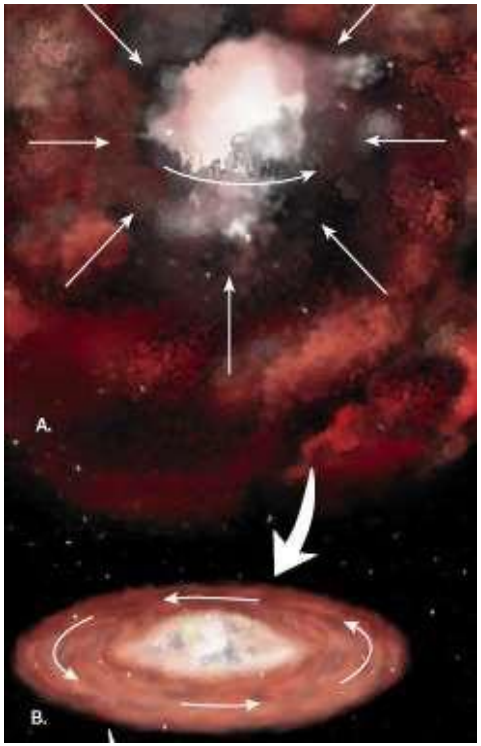




<u>Stardust</u> = Glass, carbon and a conglomeration of silicon-based minerals.

particle length: 10microns

The nebular hypothesis



Artistic representation of the Nebula collapse

- The Solar System formed ~ 4.6 billion years ago from a Nebula of gases and interstellar material.
- A shockwave generated by a nearby exploding star cause the Nebula to collapse, forming a spinning protoplanetary disk
- Gravity pull at the center of the disk generated a pressure so high that hydrogen atoms began to combine and form helium, releasing a tremendous amount of energy and igniting the Sun.

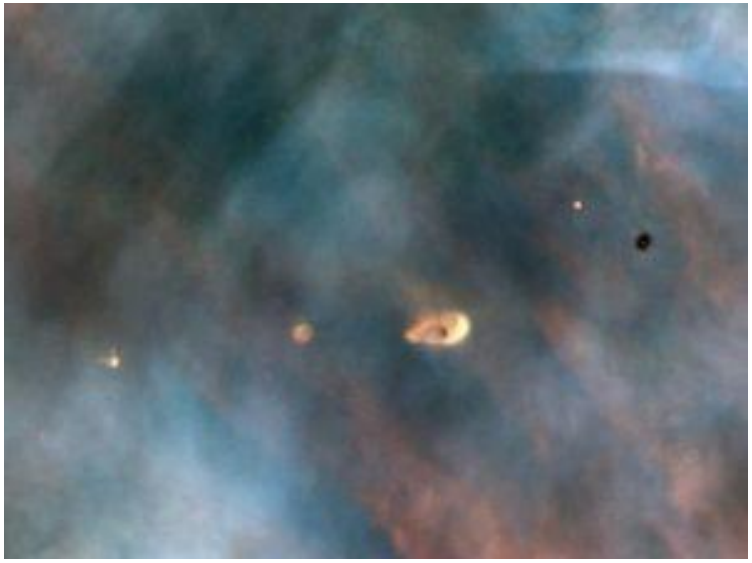
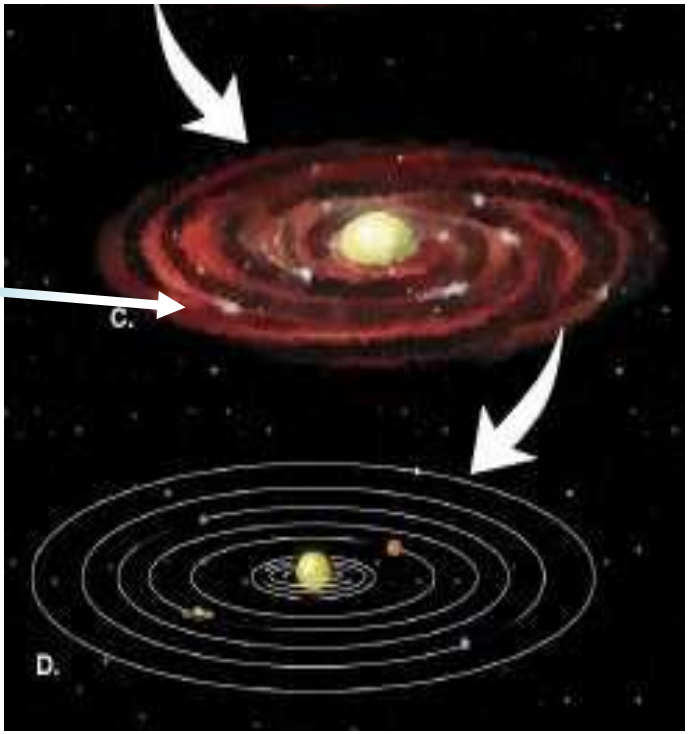


Photo of protoplanetary disks in the Orion Nebula

Matter farther out in the disk formed clumps that grew big enough for their gravity to keep them whole → PLANETESIMALS these were the first stage in the formation of planets.

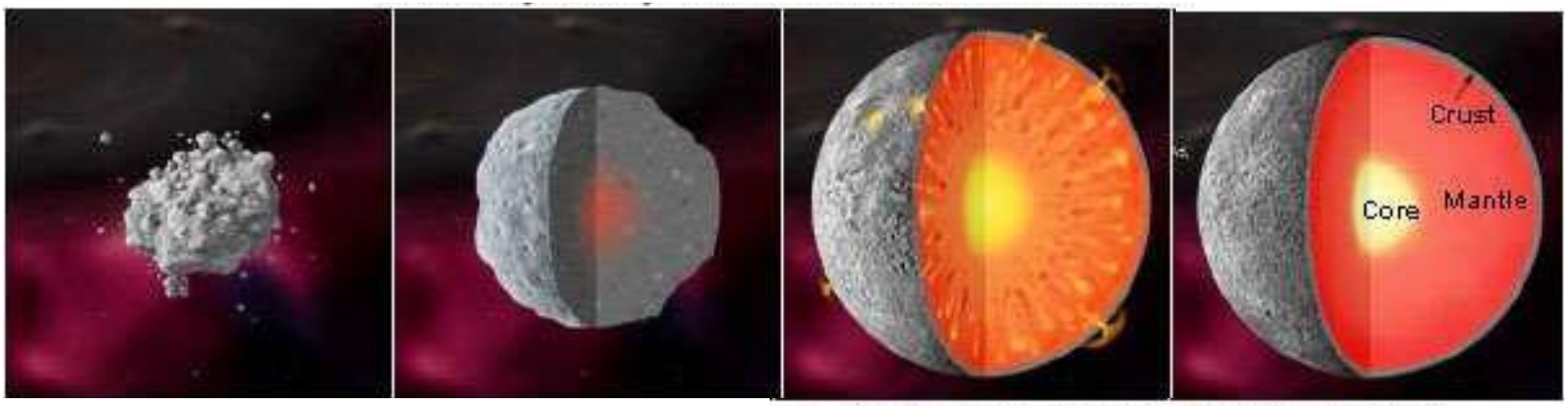


Not all planetesimals became planets; smaller leftover pieces became asteroids, irregular moons, comets...

Leftover material cleared up by falling on planets, attracted by their gravity producing a massive meteorite bombardment these effects still visible on the inactive surface of planets like Mercury and our own Moon.

Summary steps in the formation of planets

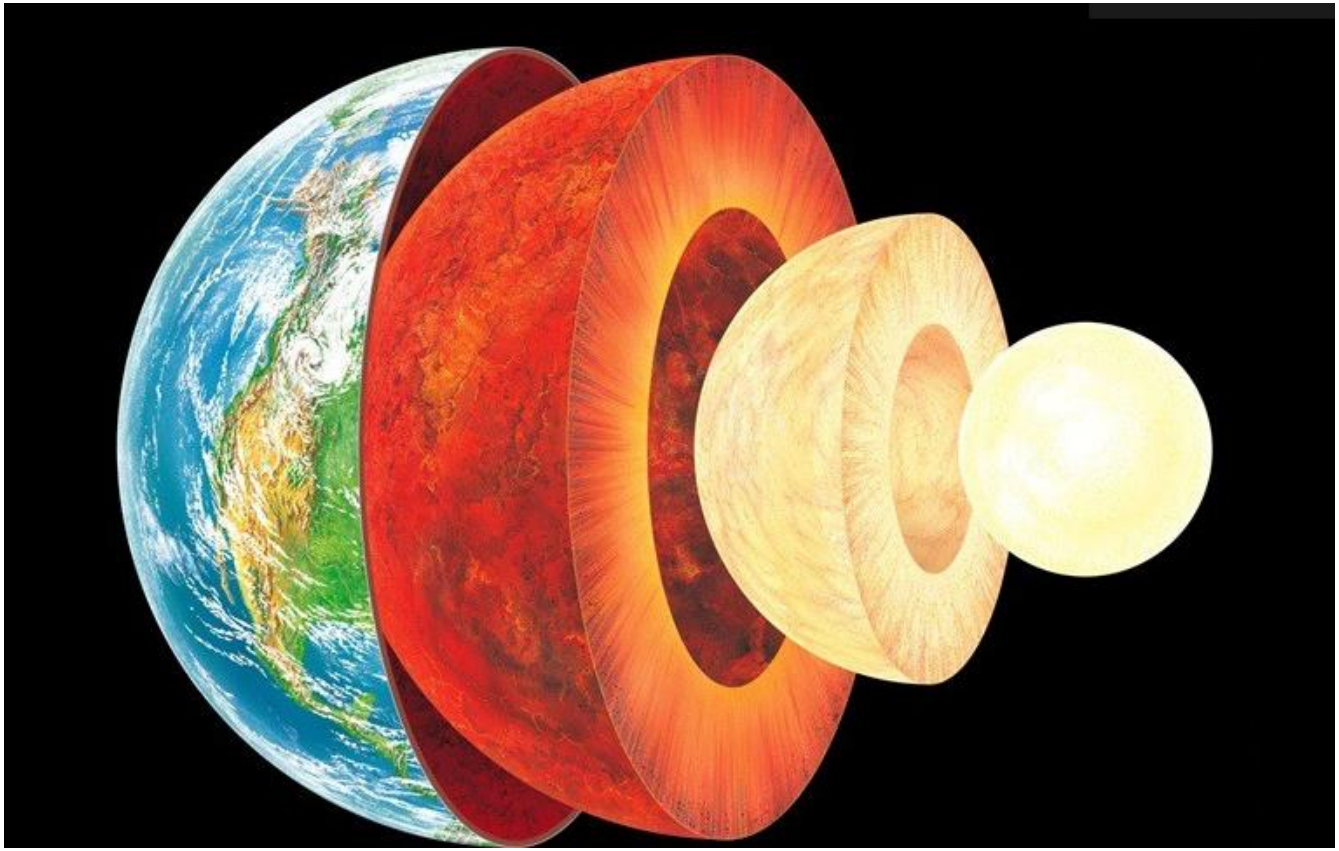
1. Matter in collision formed Planetesimals
2. Repeated collision and accretion formed more stable Protoplanets
3. Because of their internal gravitational pressure and radioactive decay, the interior of the protoplanet started to melt and differentiate by density
4. This process called Planetary differentiation results into a heavier denser core and less dense outer layers



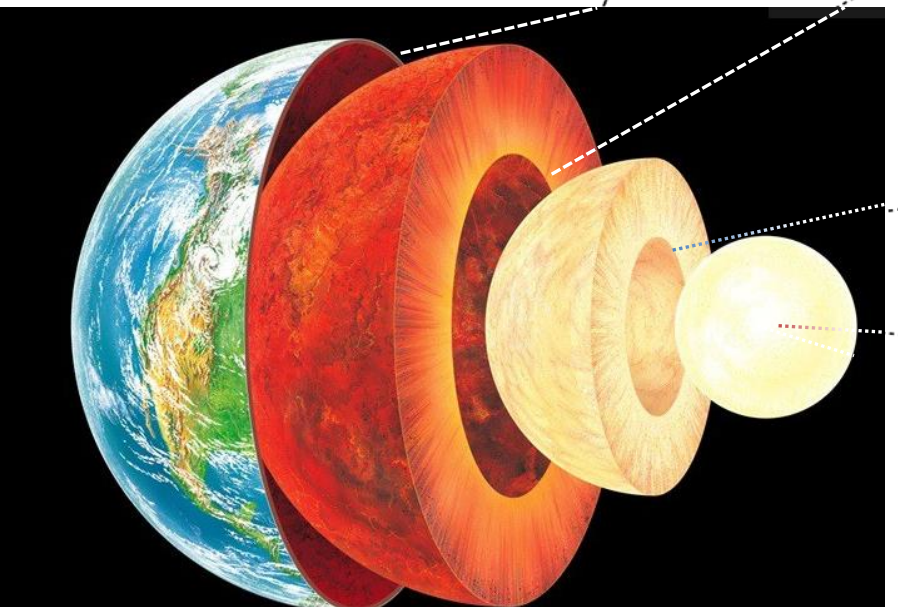
1 2 3 4

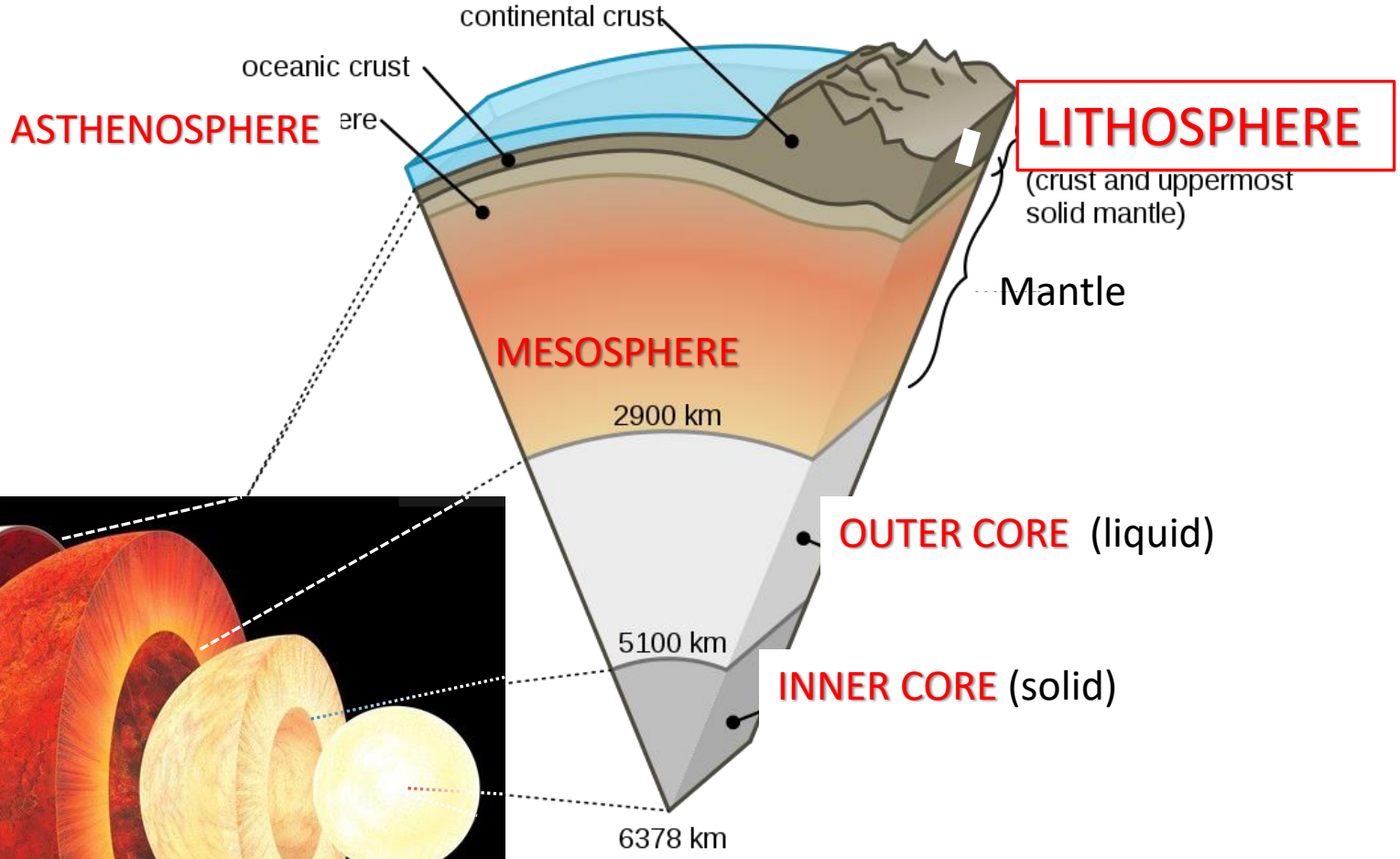
Earth's differentiation → internal structure

- Earth formed 4.6 Billion years ago. It underwent planetary differentiation that resulted in its internal structure



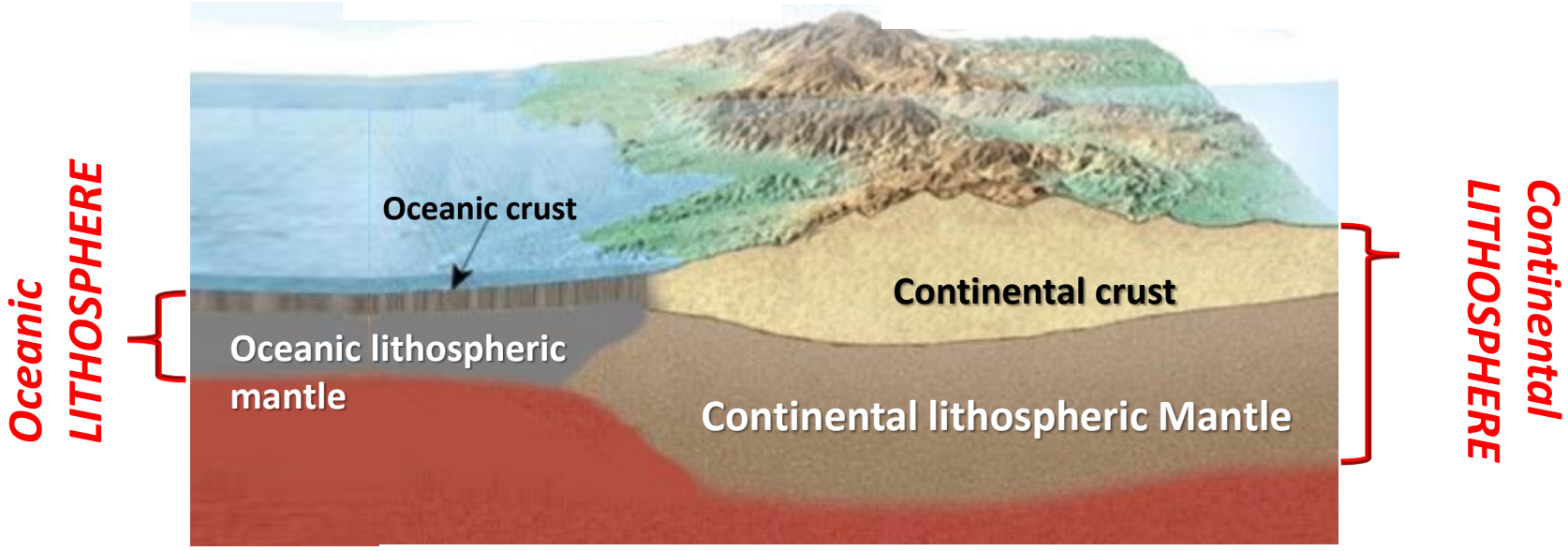
The interior of the Earth
physical layering





Lithosphere

- Earth's outermost layer
  - Rigid and brittle → made of rock. Rocks can break
  - Irregular thickness average~100 km; ~250km @mountains
  - The lithosphere is composed of
    - two layers: the Crust and the Lithospheric Mantle
    - Two types (based on composition): Oceanic and Continental



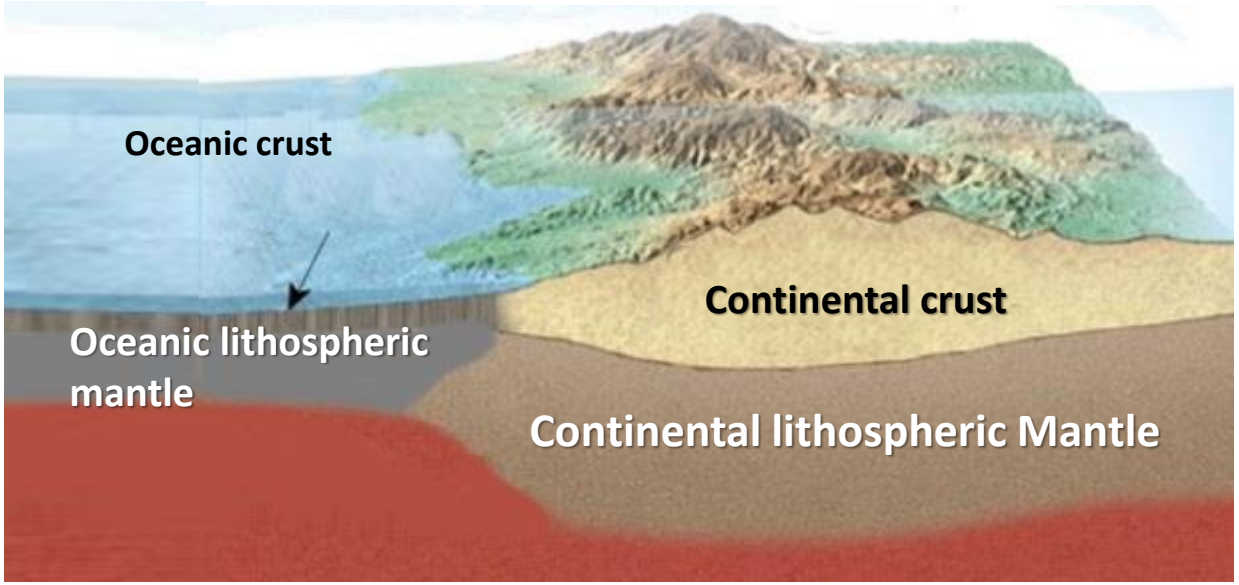
Lithosphere structure and composition

Oceanic lithosphere

Density ~ 3.0 g/cm^3
On average it is “thin” only 3-15 km!
Made of dense, Iron and Magnesium rich minerals

Continental lithosphere

density ~ 2.7 g/cm^3
Thicker, especially under mountains
Made of Silica SiO2 and other low-density compounds



Isostasy

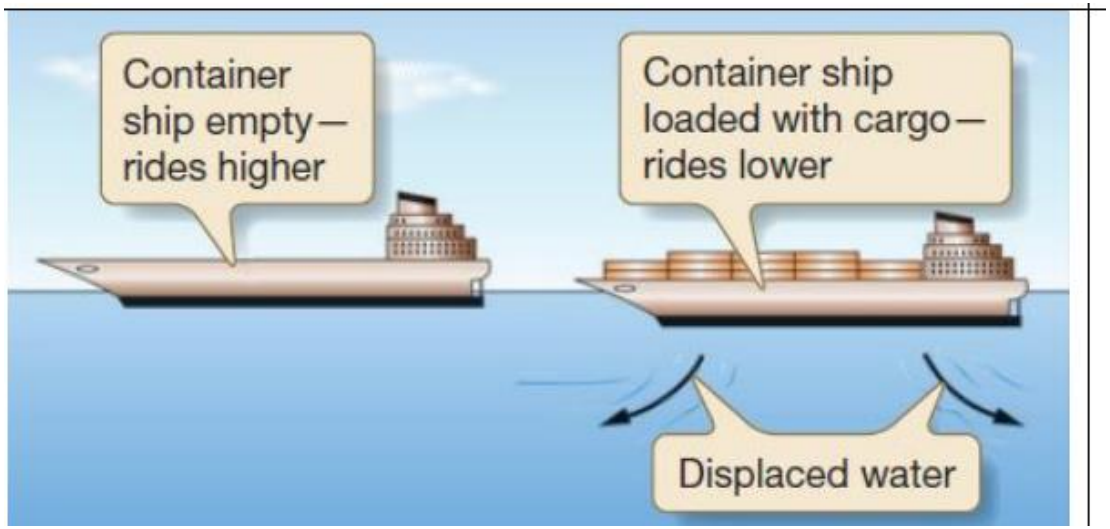
The lithosphere floats on top of the asthenosphere.

The thickness and density of lithosphere determines how high mountains rise above surface on continents and on the ocean floor.

Thickness and density of lithosphere determine how deep ocean basins are.

Density

- Same as with a loaded ship, when loaded, the higher weight displaces more water and the ship sinks

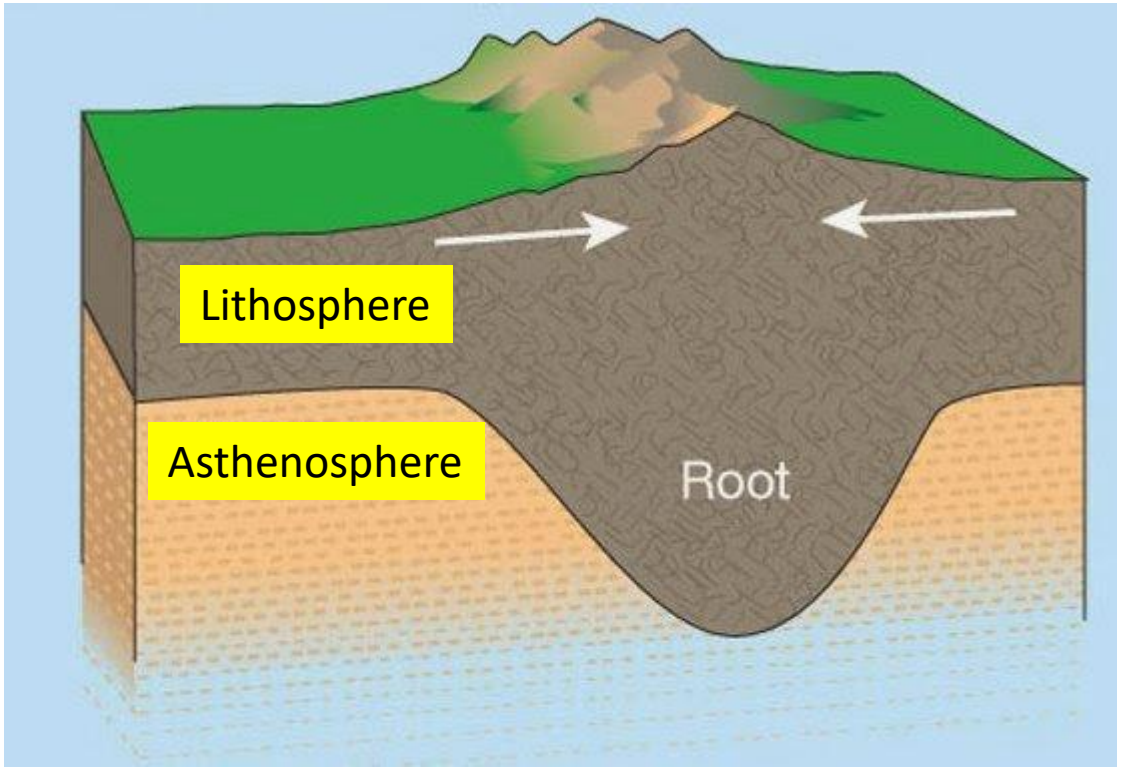


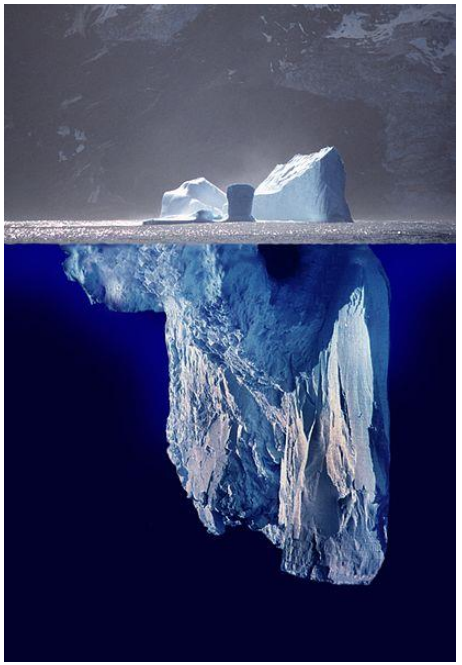
Isostasy

- Thickness

  The thicker the lithosphere, the deeper the amount of material it displaces.

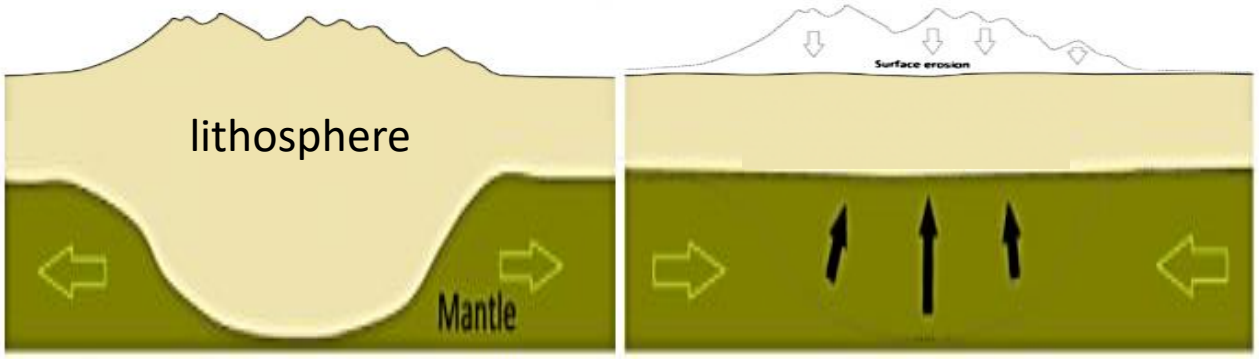
  - For this reason, the lithosphere under Mountains is the thickest.
    - This is the same process as the floating of icebergs



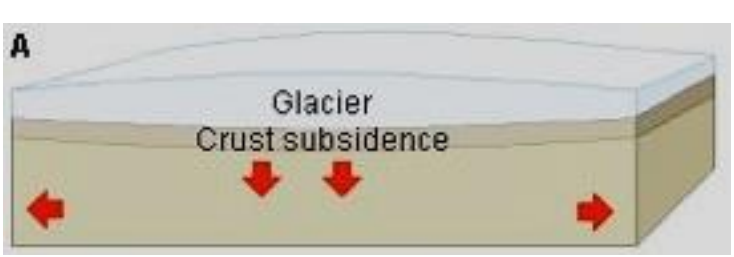


lithosphere adjustments

- The lithosphere is thickest under mountains (cartoon 1)
  - The “roots” of Himalayas are the thickest lithosphere on Earth
- In time, because of weathering, mountains wear away, the lithosphere becomes thinner and lighter so it bounces up to adjust (2)

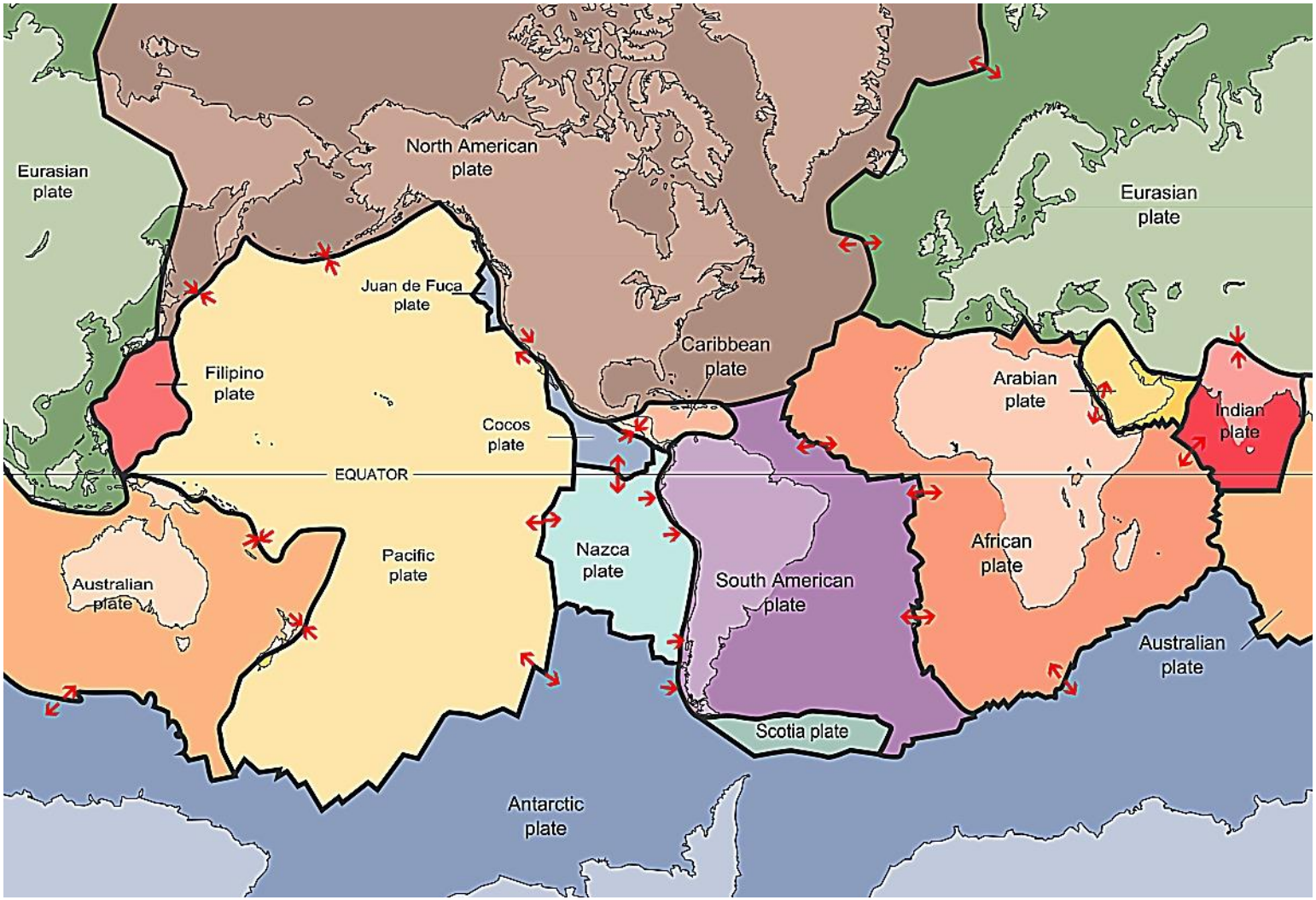


- In a similar way, the lithosphere rebounds up when glaciations end (ice melts away)



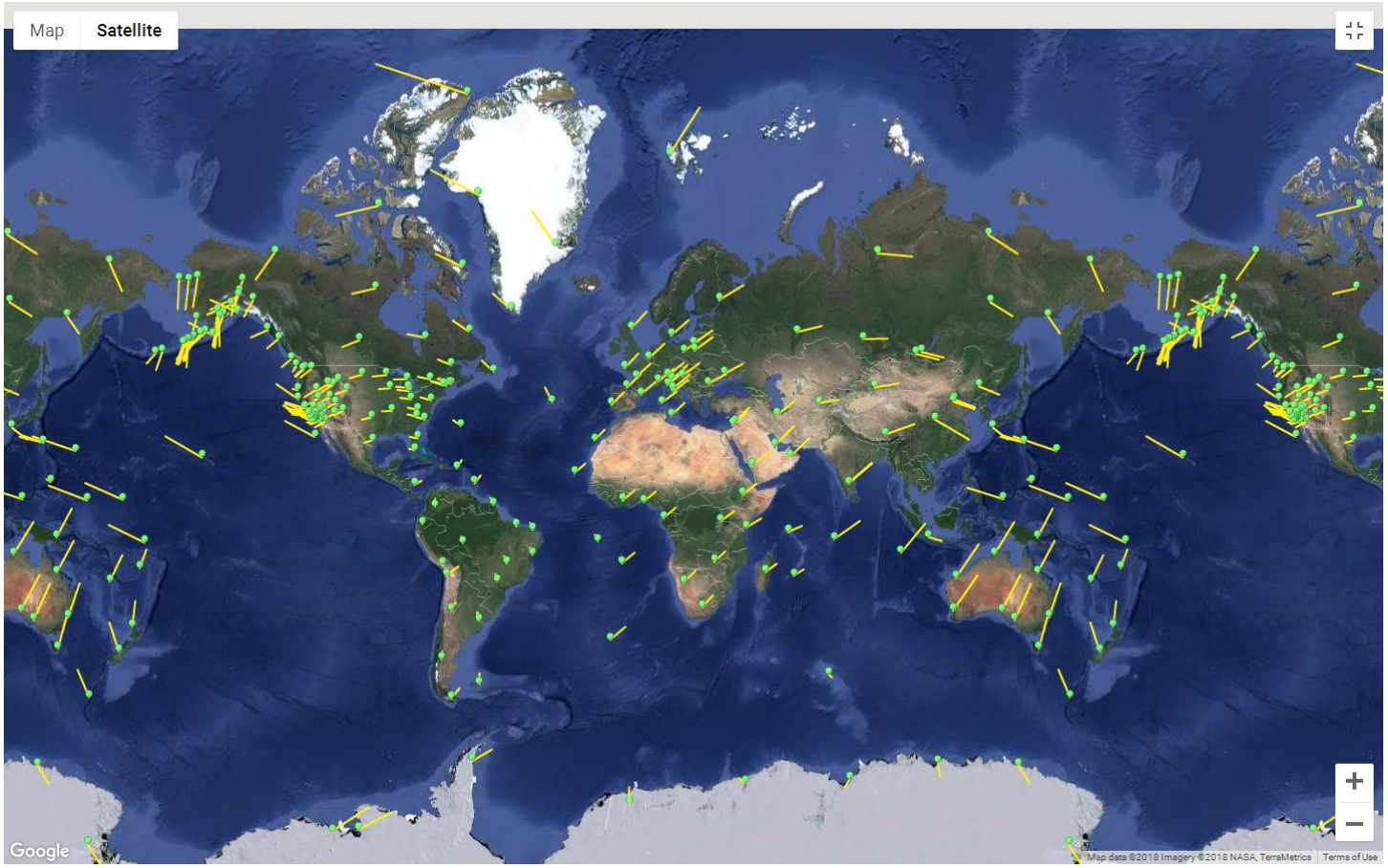
Pieces of lithosphere in motion=Tectonic Plates

The lithosphere is broken up into irregular sections called plates, tectonics means in motion



Tectonic Plates

- GPS evidence that plates are moving is shown by the direction and the speed represented by the yellow segment
- The motion is very slow (cm/year)



Tectonic plates in motion

GMU on the move

GAGE Operated by UNAVCO | UNAVCO

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Software
- Help with Software
- Geodetic Utilities
- Plate Motion Calculator
  - Input
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  - Usage
  - Notes
  - References
  - Other plate motion calculators

Plate Motion Calculator

Before using, please see: Overview Models Usage Notes References

Enter latitude and longitude coordinates (and optionally other selections) and hit *Submit* button:

Latitude:	38	degrees North
	49	minutes North
	47.7	seconds North
	E.g. enter the latitude as **–56.25** degrees or **–56** degrees **15** minutes for **56 degrees 15 minutes South**.	
Longitude:	-77	degrees East
	18	minutes East
	19.3	seconds East
	E.g. enter the longitude as **–102.5** degrees or **–102** degrees **30** minutes for **102 degrees 30 minutes West**.	

Click on the table above if you wish to check the website!

Model	Latitude	Longitude	Speed mm/yr	Azimuth (cw from N)	N Vel. mm/yr	E Vel. mm/yr	Plate (reference)	Site Name
GSRM v2.1	38° 49' 47.7" N 38.829917°	77° 18' 19.3" W -77.305361°	14.65	280.76°	2.73	-14.39	NA(NNR)	

Effects of plate motion: earthquakes

Plates are moving now

As they move, they produce earthquakes at their boundaries and in area of weakness of the lithosphere

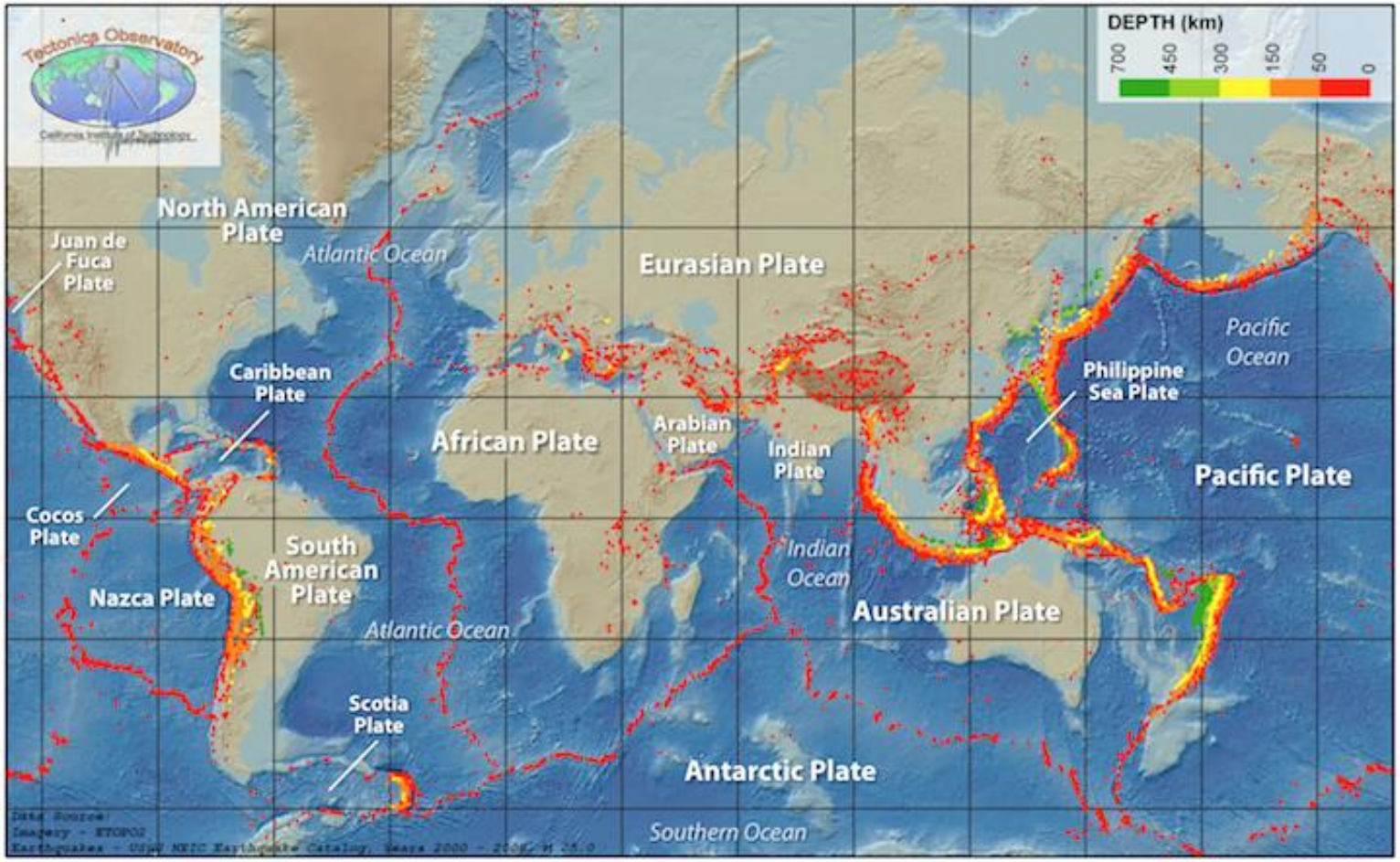
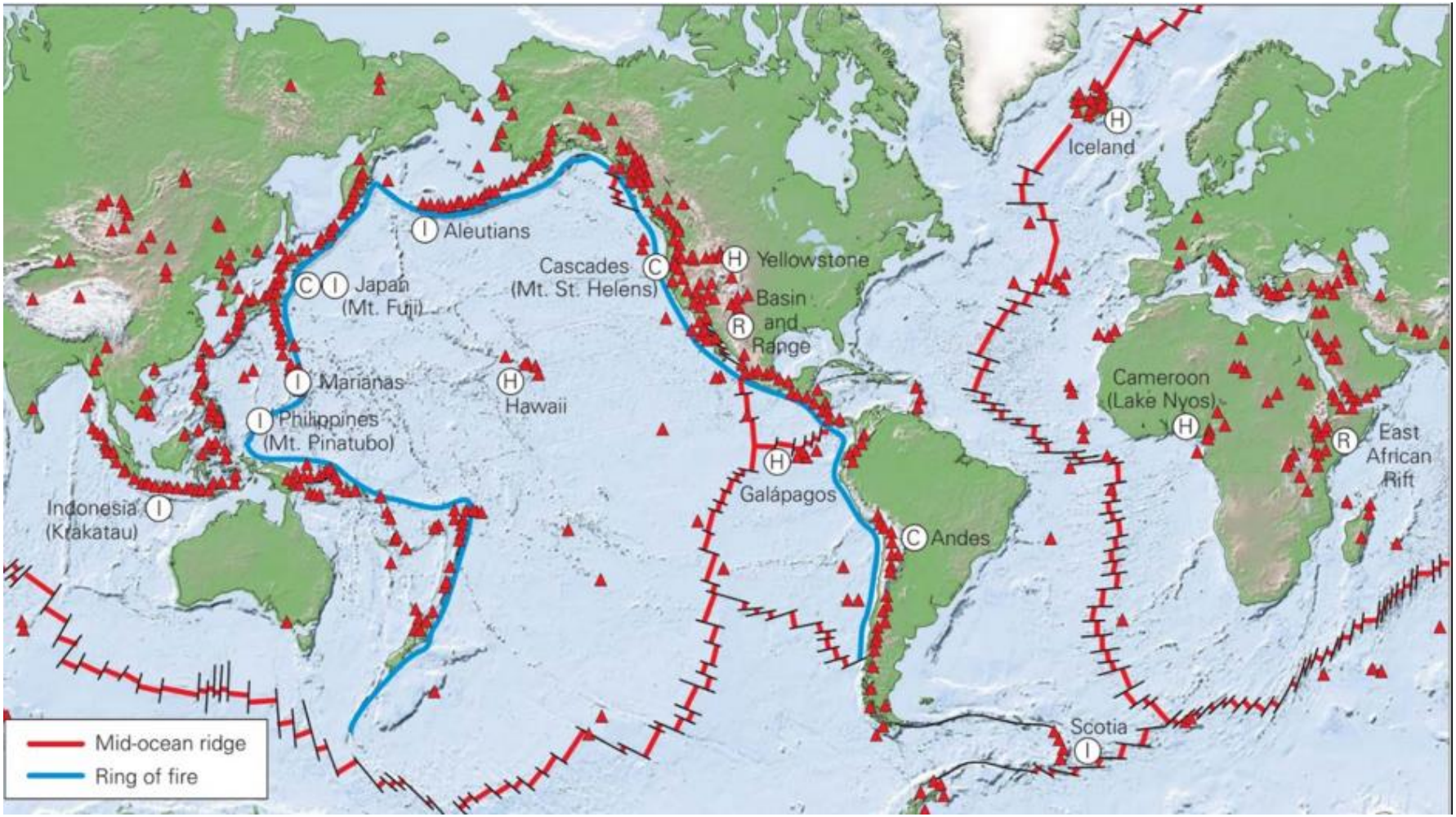


Plate motion and Volcanoes

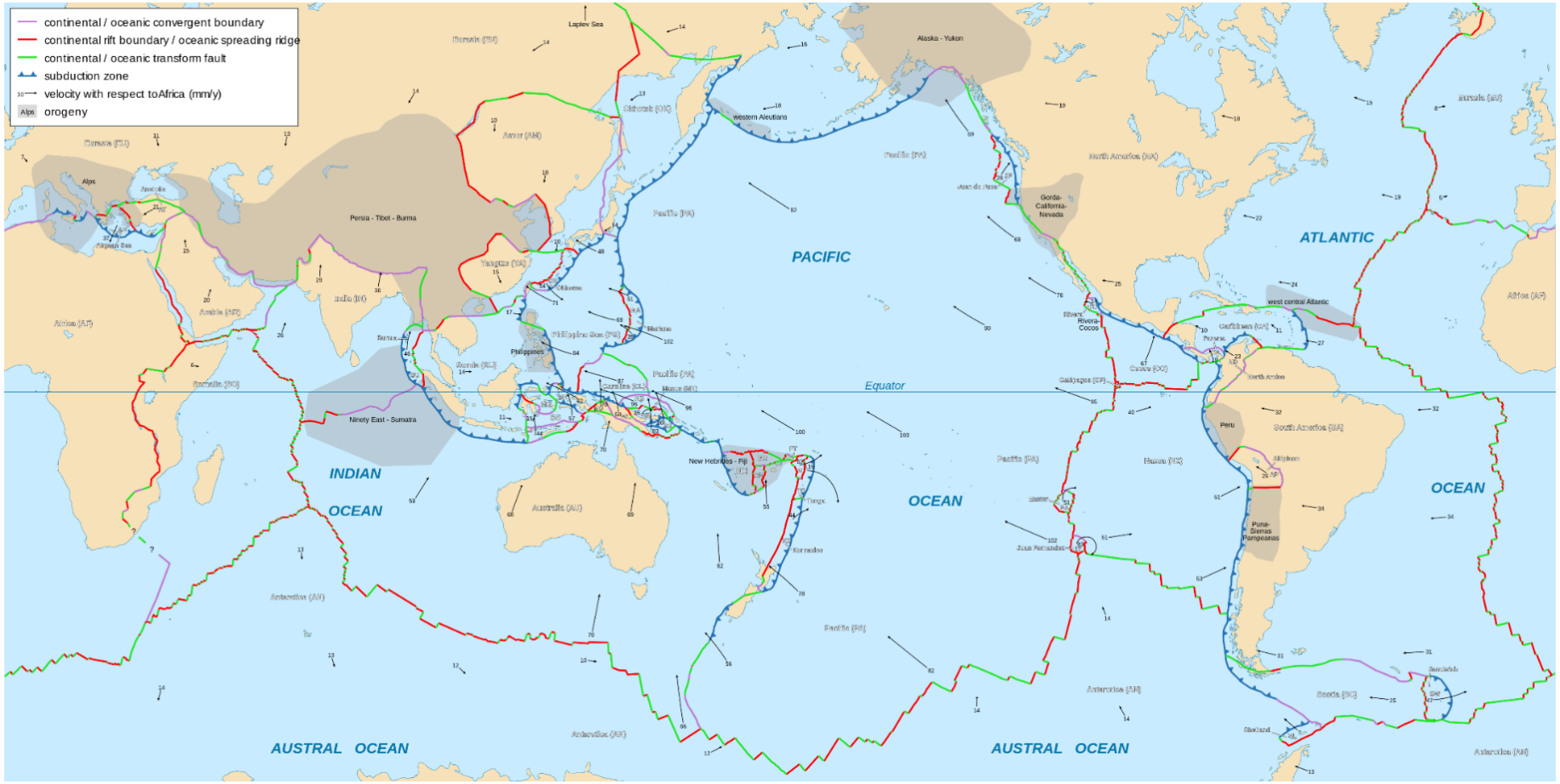
The interactions of the plates at their boundaries and with the underlying mantle produces volcanoes



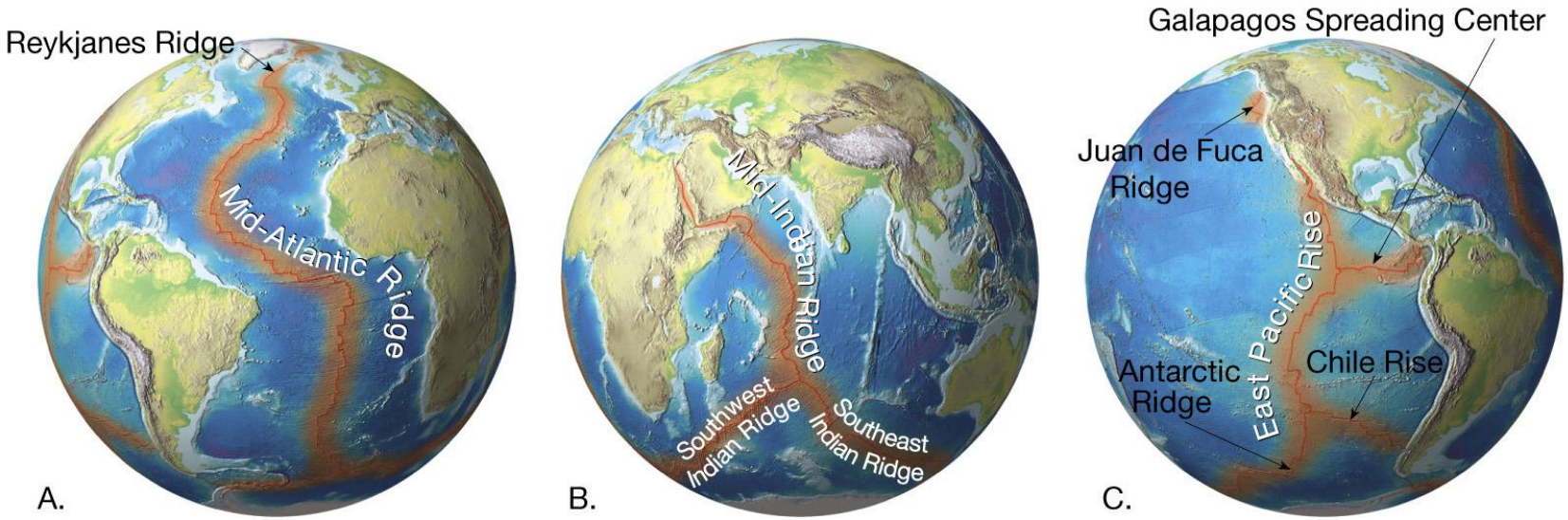
The “Ring of Fire” Volcanoes bordering the Pacific Ocean

The plate boundaries

- 3 types of boundaries: Divergent, Convergent and Transform



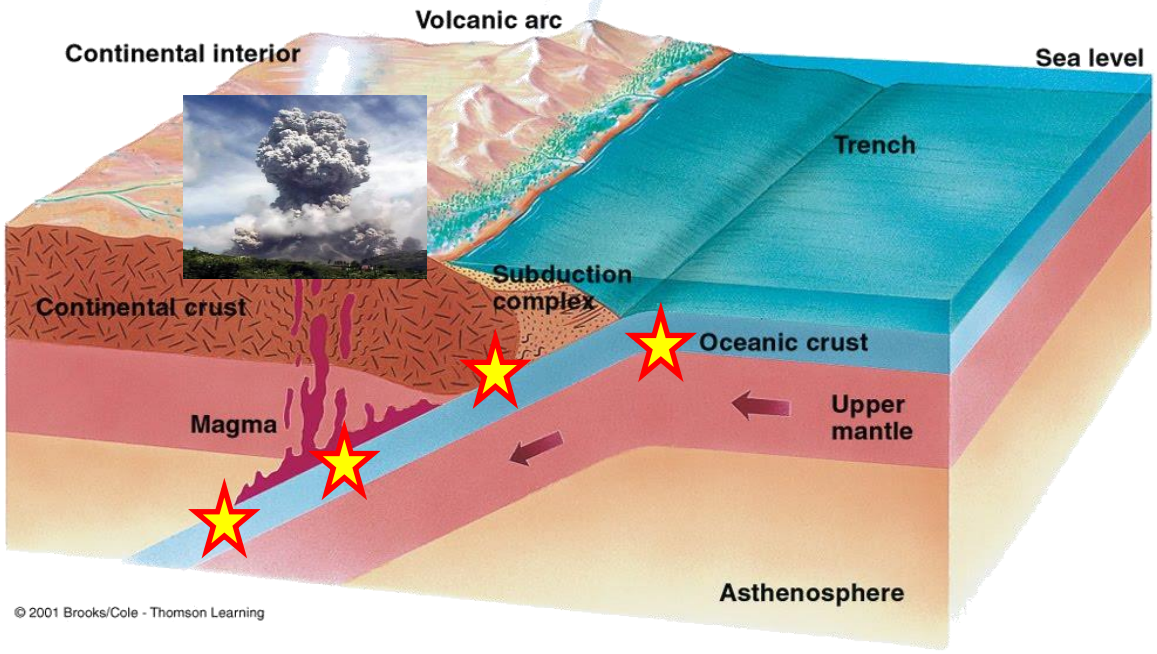
Divergent Plate Boundaries



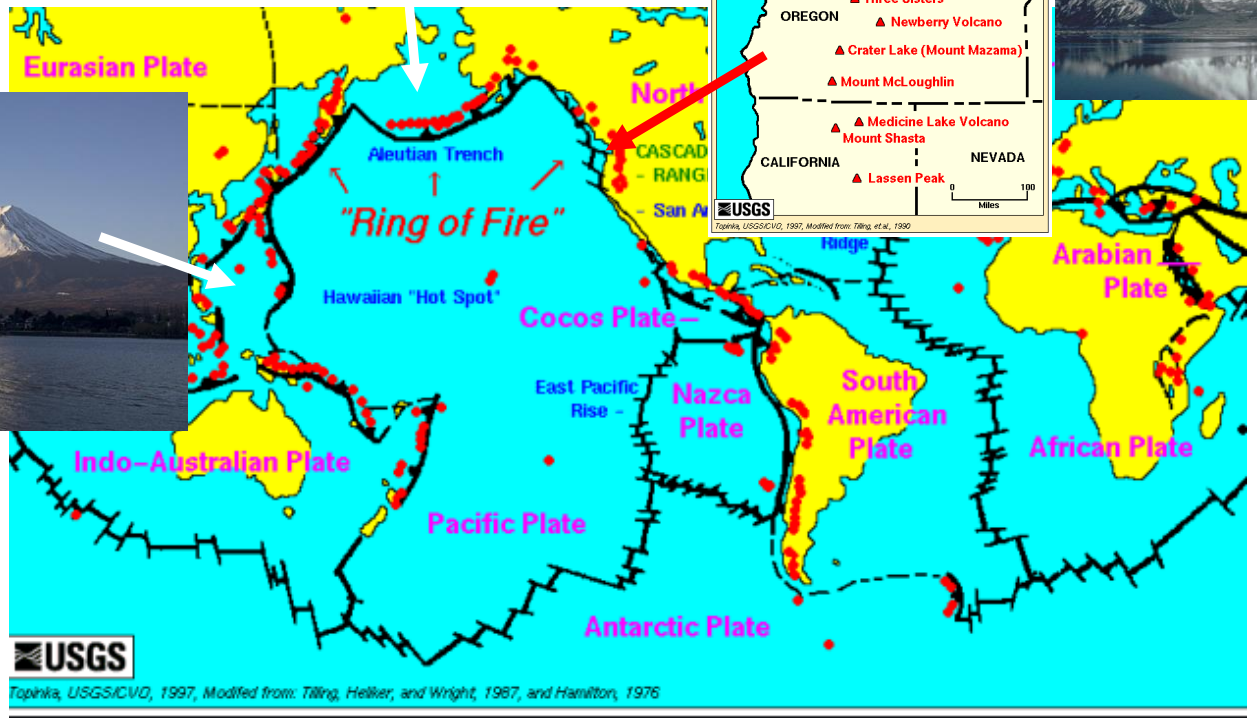
- Where lithospheric plates move away from each other
- Happen on the ocean floor along structures called ridges and rises
- New oceanic lithosphere is built by massive eruption of lava from fissures and volcanoes
- Small earthquakes

Convergent plate boundary: Subduction

- where plates collide, the denser plate dives under less dense plate in a process called **SUBDUCTION**
- During subduction, the plates shake, causing many earthquakes
- **Volcanoes** form on the overriding (less dense) plate; they line up forming a series of volcanoes called a **volcanic arc**

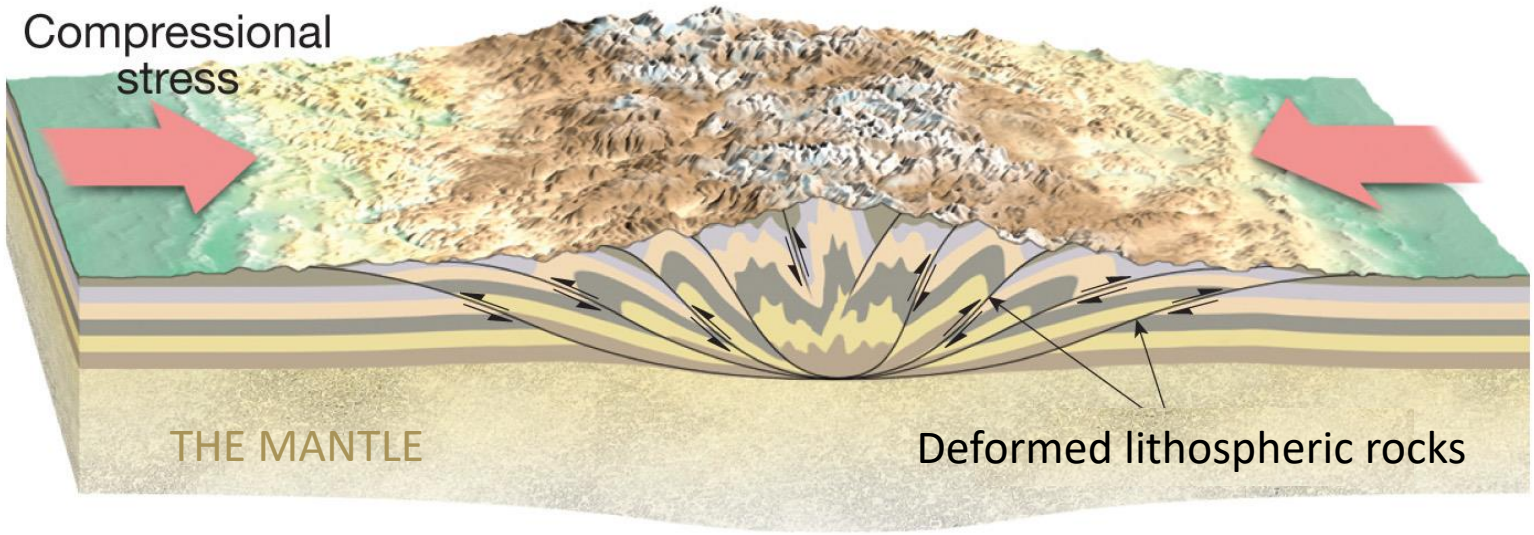


Volcanic arcs of the “ring of fire”



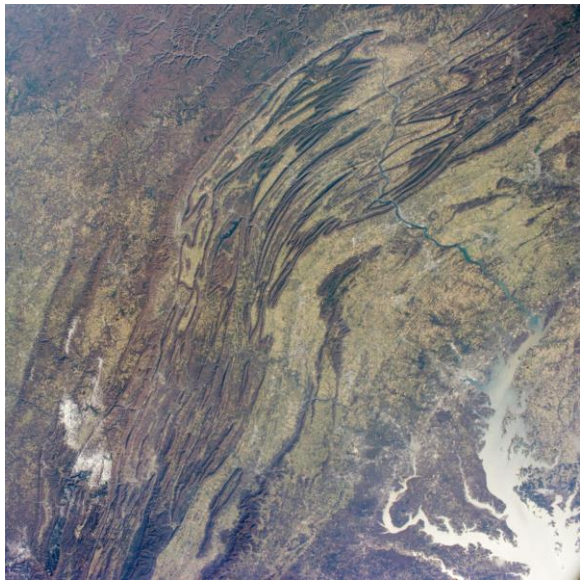
Convergent plate boundaries: Orogeny

- When <u>continental</u> lithosphere plates collide, they do not subduct because they are not dense enough; instead, they deform → rocks fold and pile up forming an **Orogeny = mountain building**
- When two or more smaller lithosphere plates add up to form a larger plate → **accretion = the making of a larger plate by adding up smaller ones**

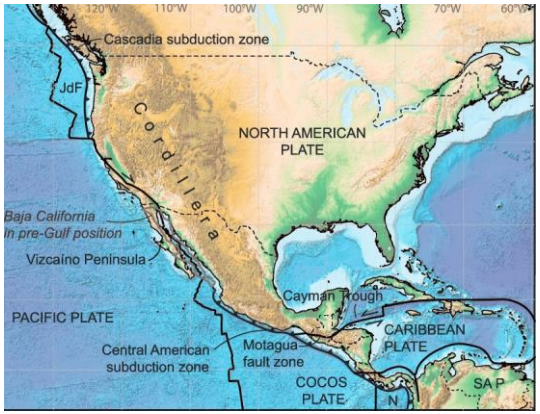


Mountain Ranges

- Mountain ranges form from the collision of continental plates
- Examples: The Appalachians

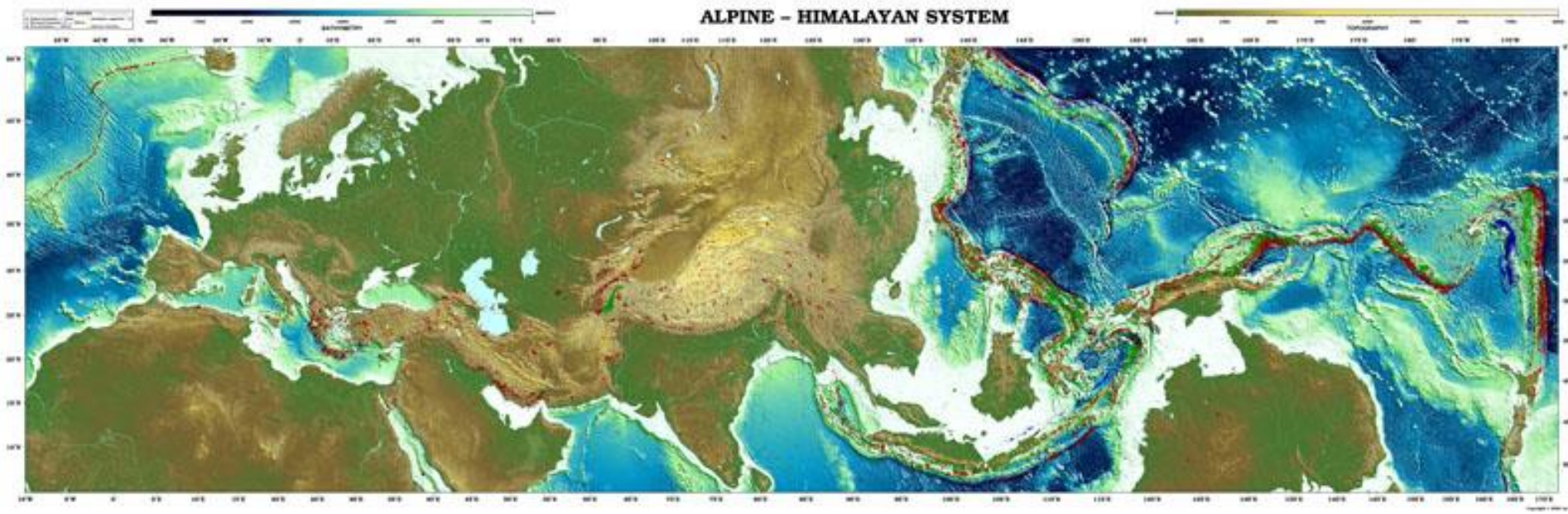


  - The American Cordilleras



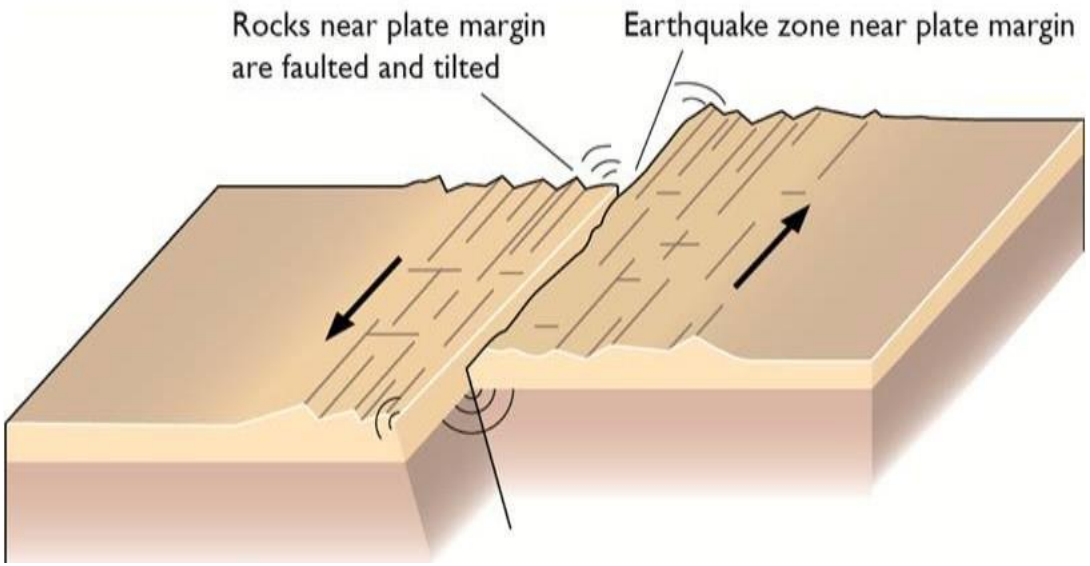
The Alpine -Himalayan Orogeny

- The plates of Africa, Eurasia, Arabia and India are colliding together
- This complex collision formed the Atlas Mts, the Alps, the Dinarides, the Carpatians, all the way to the high Himalayas

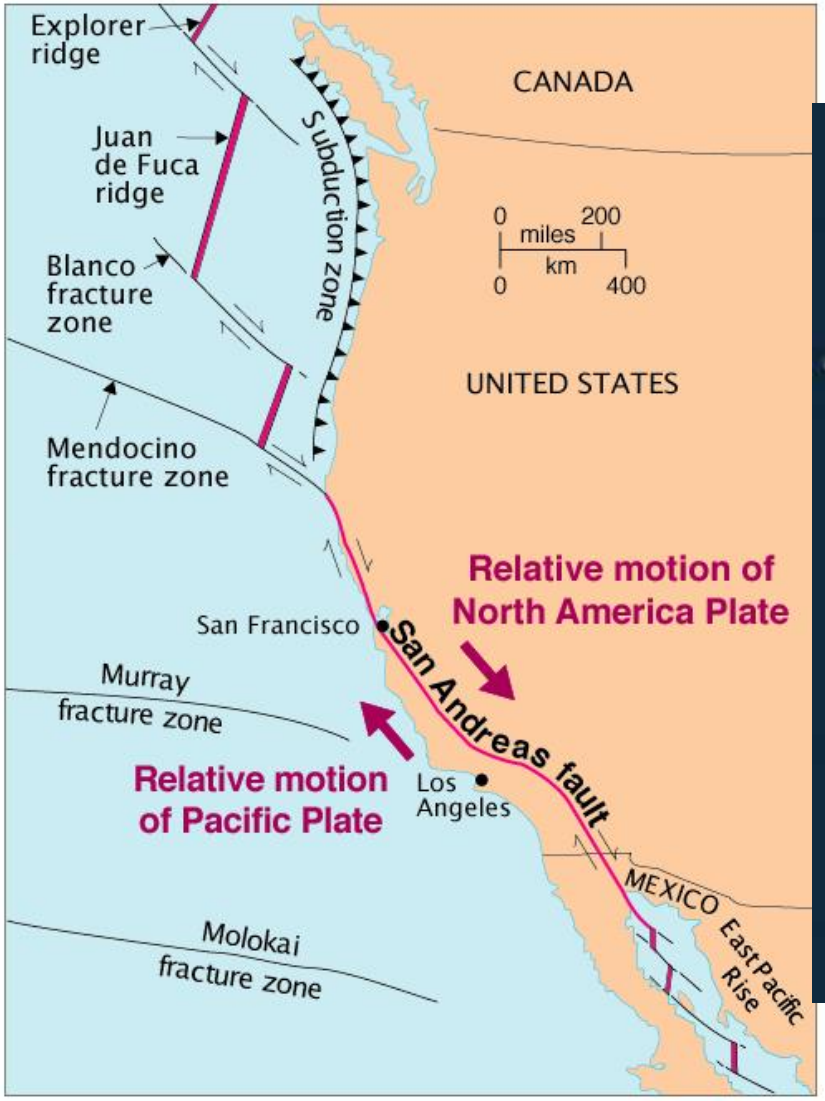


Transform plate boundary

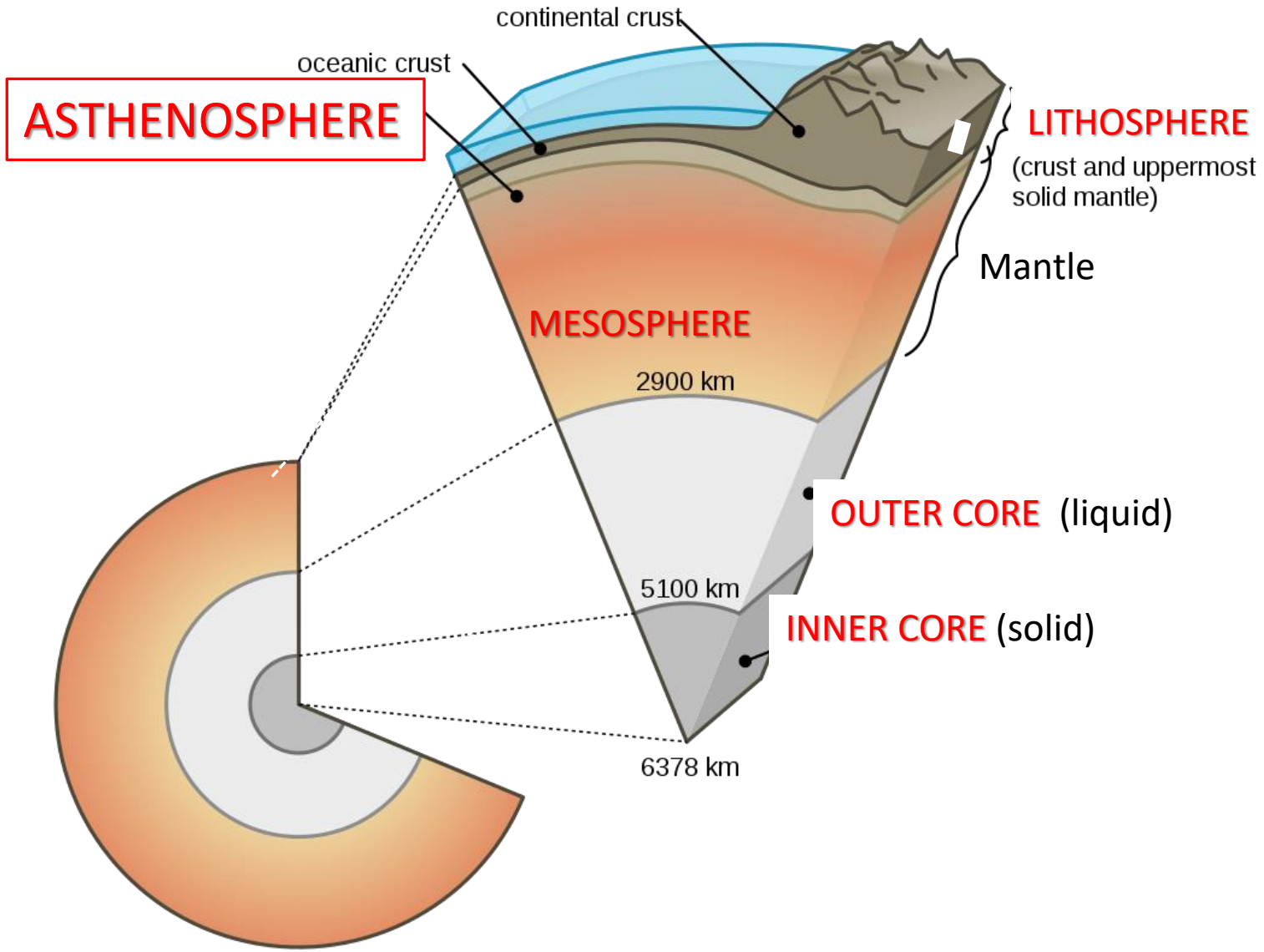
- Plates slide past one another
- Significant earthquakes occurs but no volcanoes form
- The boundary between the two plates is an irregular set of fractures called Transform faults



Transform plate boundary example: San Andreas fault zone

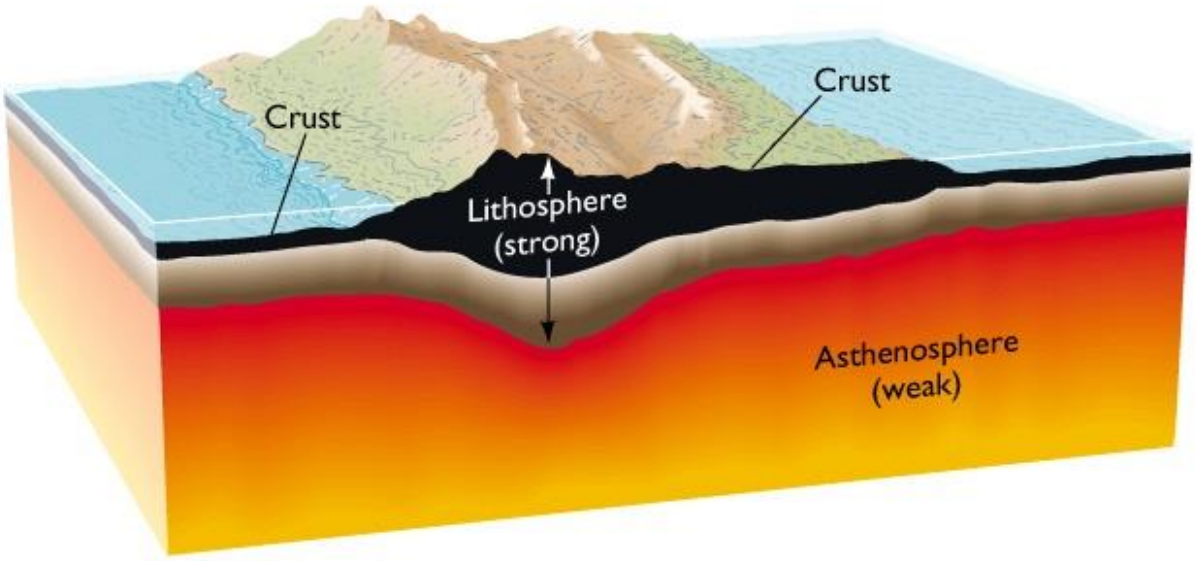


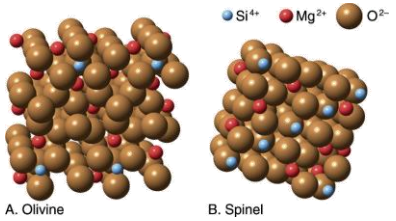
The interior of the Earth
physical layering



The Asthenosphere

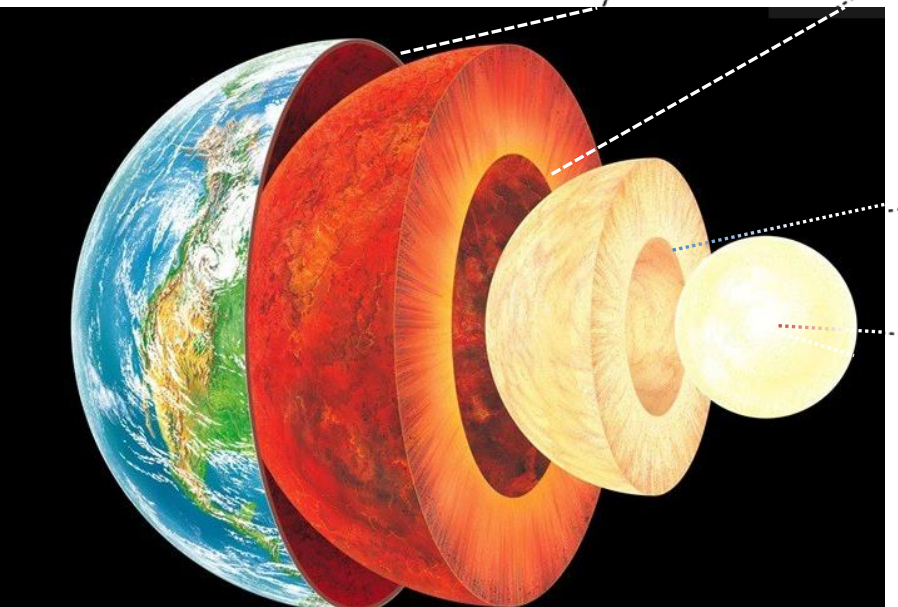
- The asthenosphere is a solid layer under the lithosphere that extends to depths of ~660 km
- Pressure and temperature increase → Asthenosphere is denser and hotter than Lithosphere
  - It behaves plastically → It can flow
  - Isostatically interacts with the lithosphere

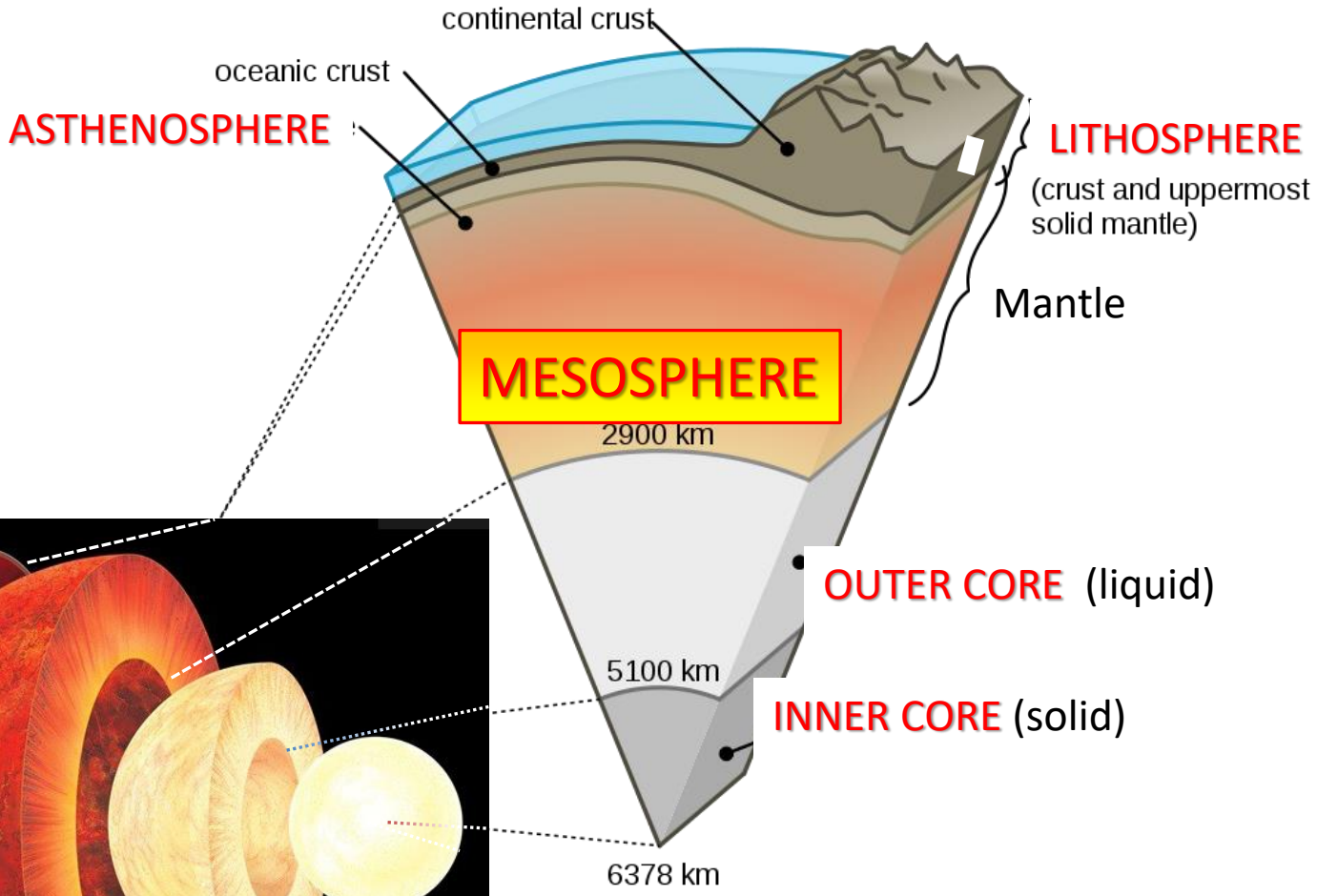




Because of the high pressure, the minerals form much more compact crystalline structures

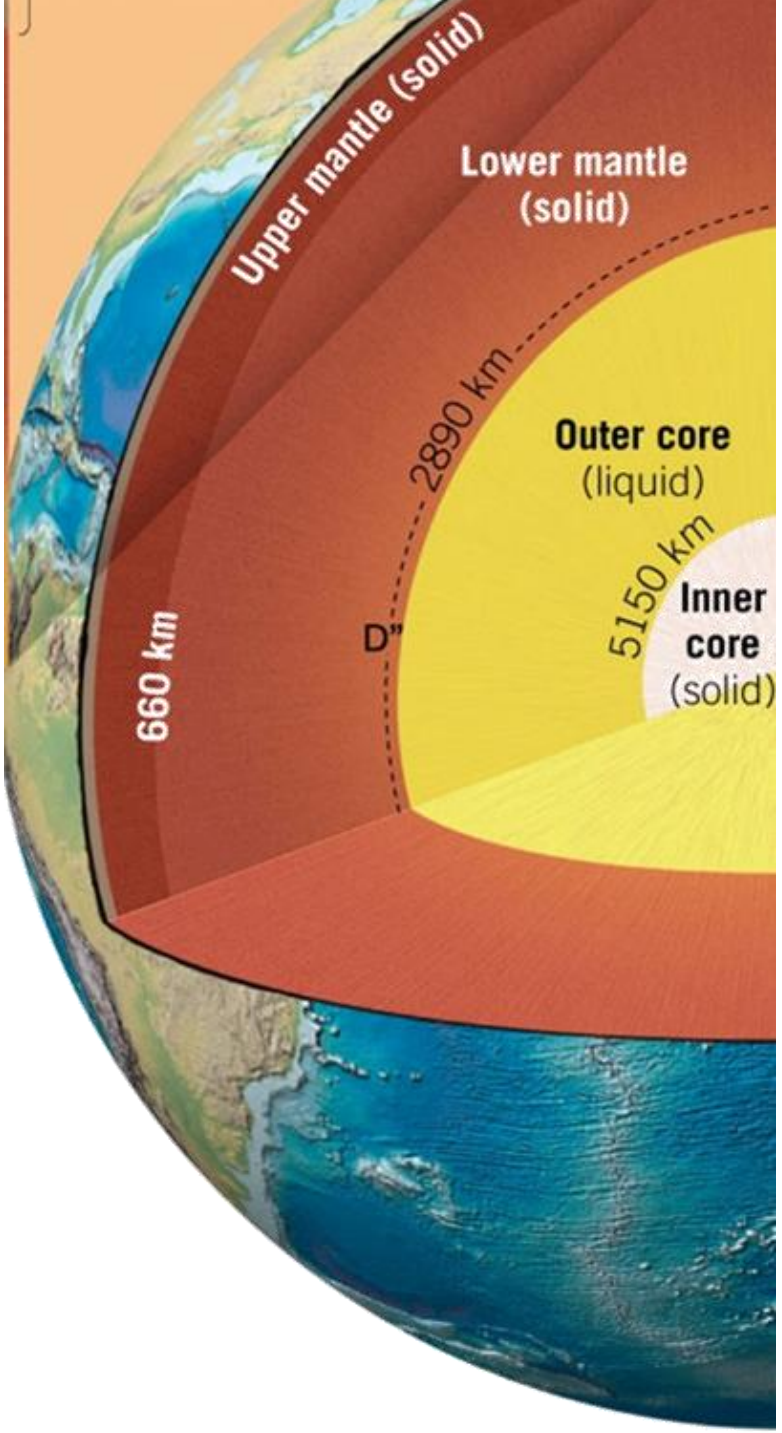
The interior of the Earth
physical layering





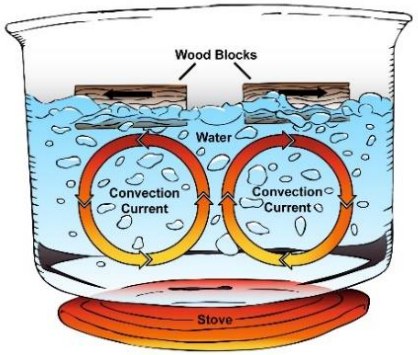
The Mesosphere or Lower mantle

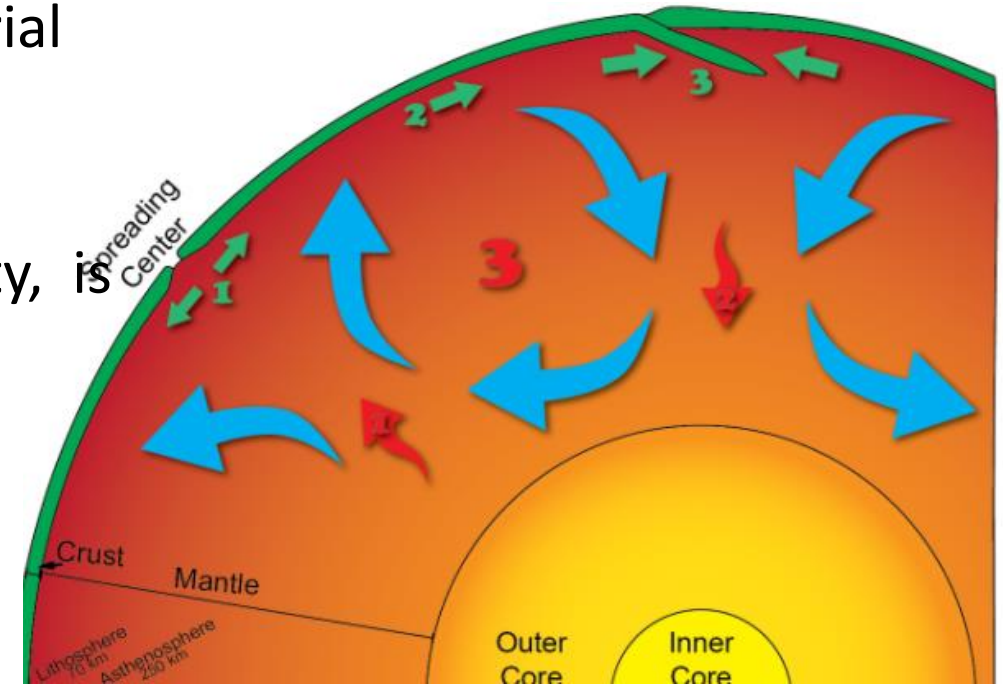
- Solid layer that extends from below the asthenosphere to ~ 2900 km of depth
- The Mesosphere is denser than the Asthenosphere, solid, very hot and capable of very gradual flow → **mantle convection**



Mantle Convection

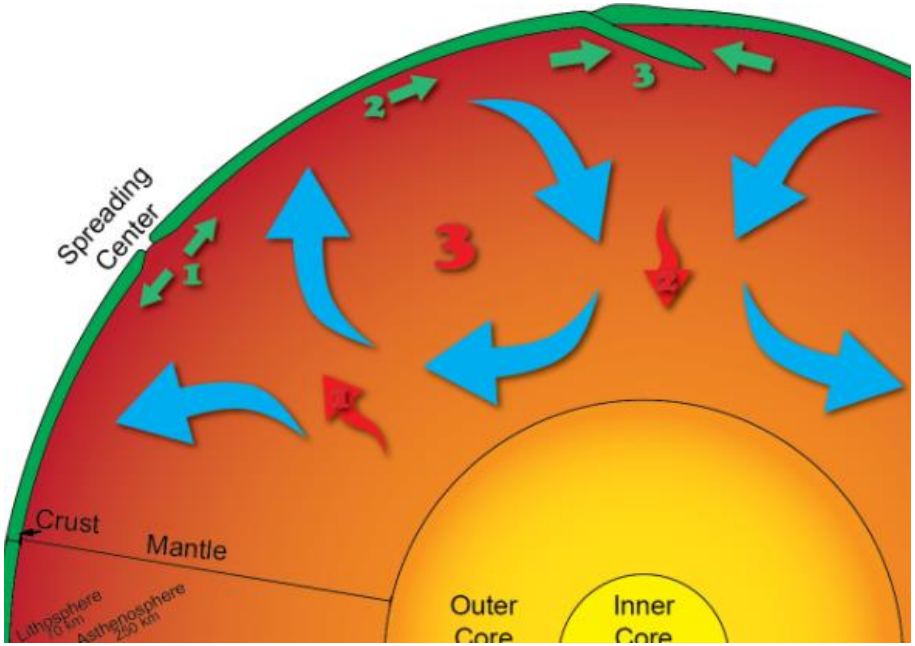
- the Mantle is thick and increasingly hotter with depth → there is a heat gradient across the mantle
- The mantle is not rigid, so the less dense hot mantle material rises (1); the cooler, denser mantle material sinks (2).
- This motion, driven by gravity, is called CONVECTION (3)

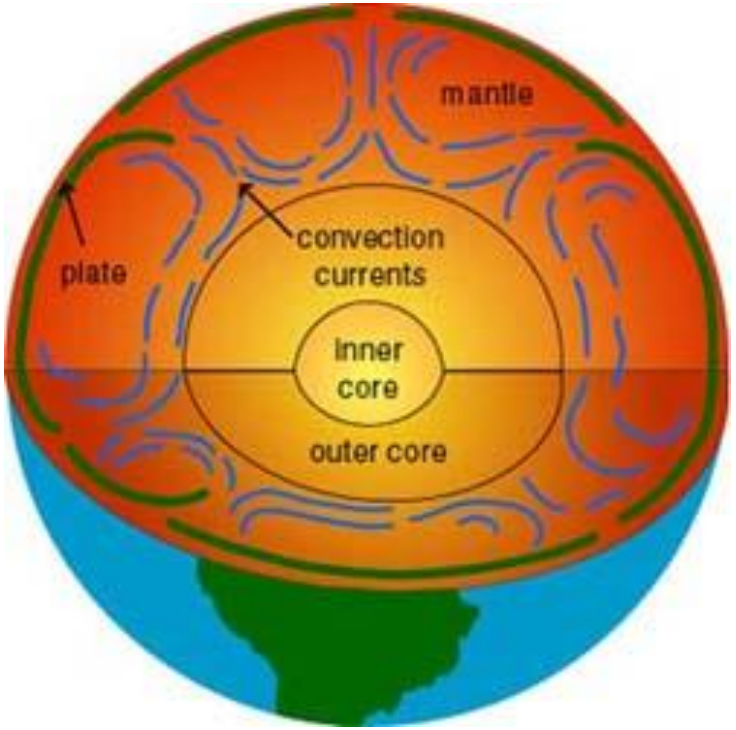




Mantle Convection-2

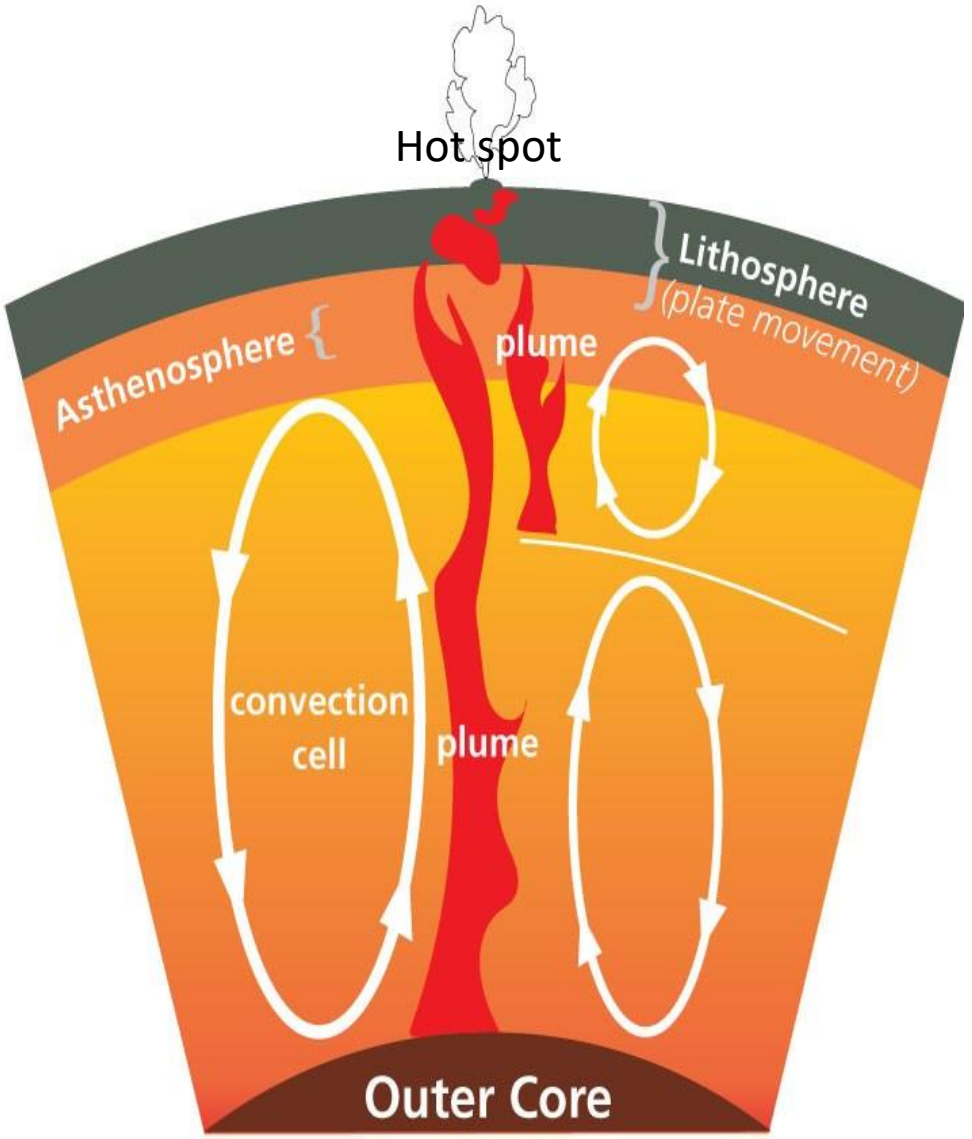
- Convection cells of the mantle drag on the bottom of the lithosphere, moving the plates (2) pulling sections of - the tectonic plates – apart (1), or pushing them towards each other (3), so one is often forced below another.
- The mantle controls plate movement



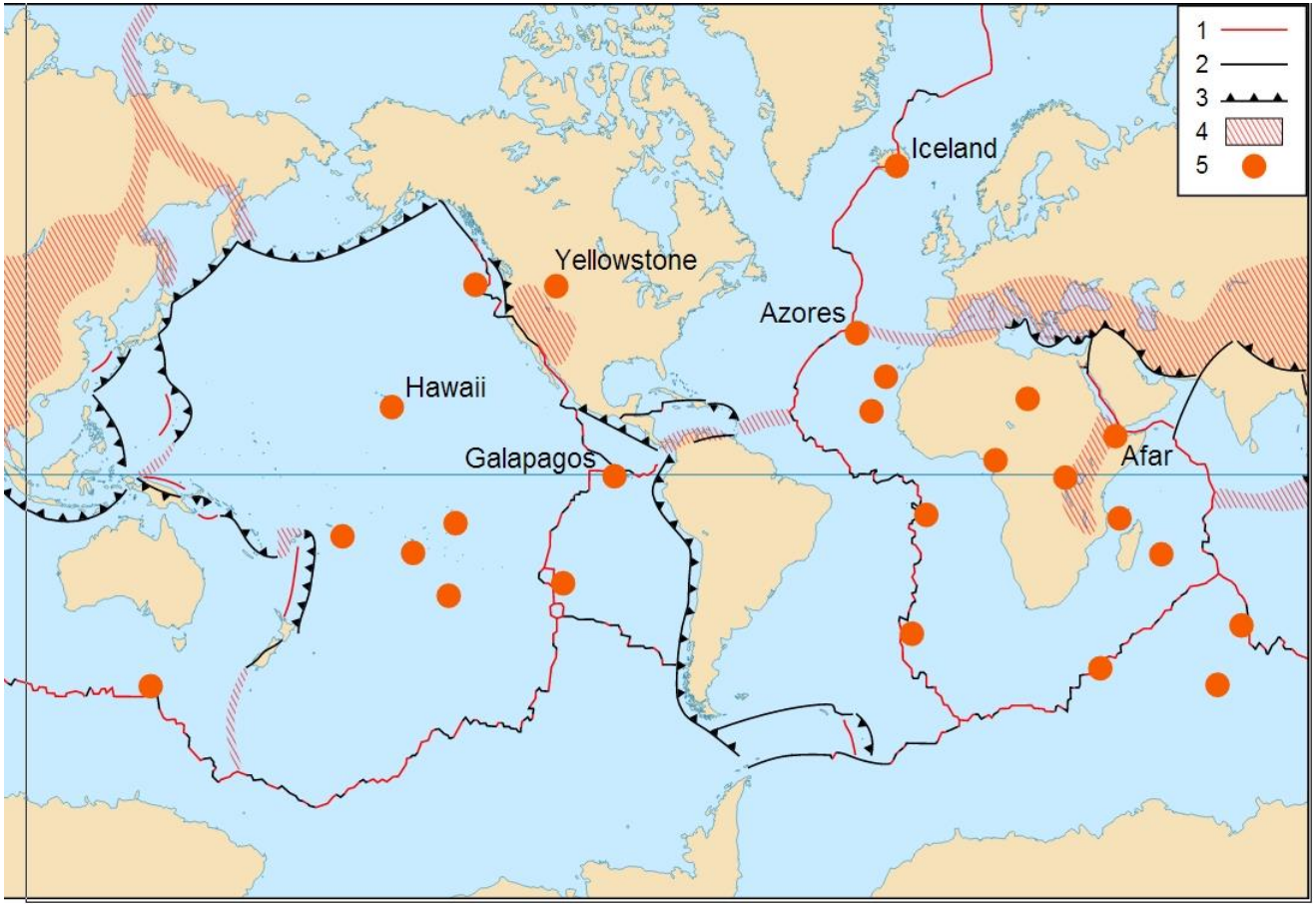


Mantle plumes and Hot Spots

- A mantle plume is place where the mantle material is hotter than its surroundings
- It can form at the core/mesosphere boundary but also in other parts of the mesosphere.
- The heat rises upwards towards the lithosphere
- When the hot material reaches the base of the lithosphere, it generates a hot spot where large eruptions of magma and volcanoes can occur



Hot spots



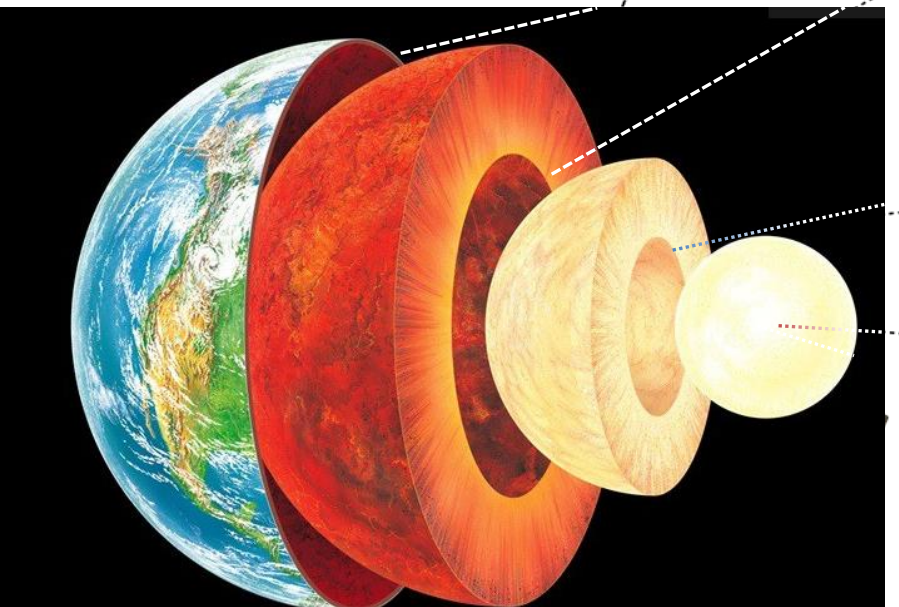
- Hot spots form on the lithosphere as it feels the effect of the mantle plumes. There are many hotspots, these are just some of the most famous
- Hotspot can happen anywhere, not just at plate boundaries!

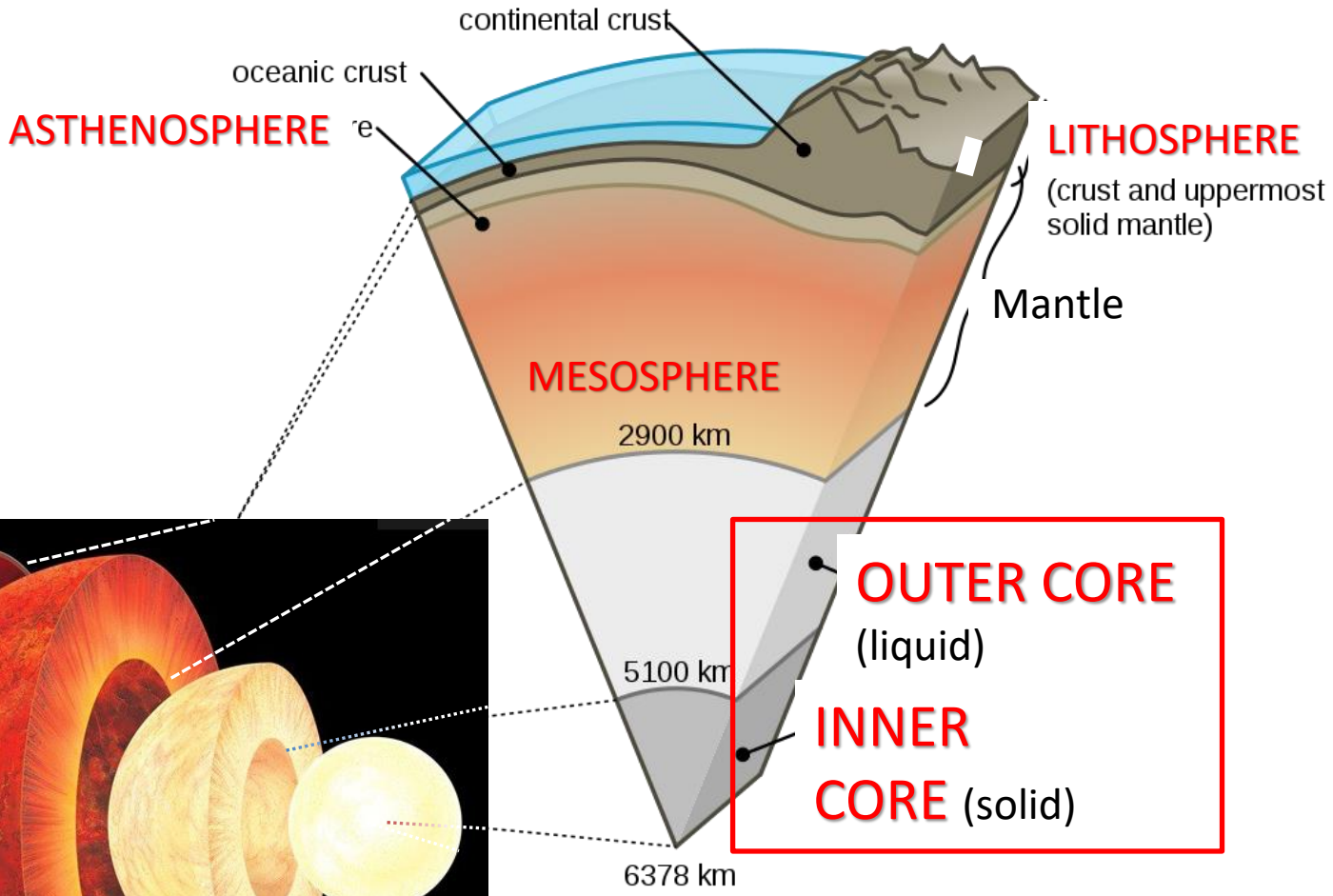
Famous US Hotspots

- Hawaiian Islands

- Yellowstone NP caldera

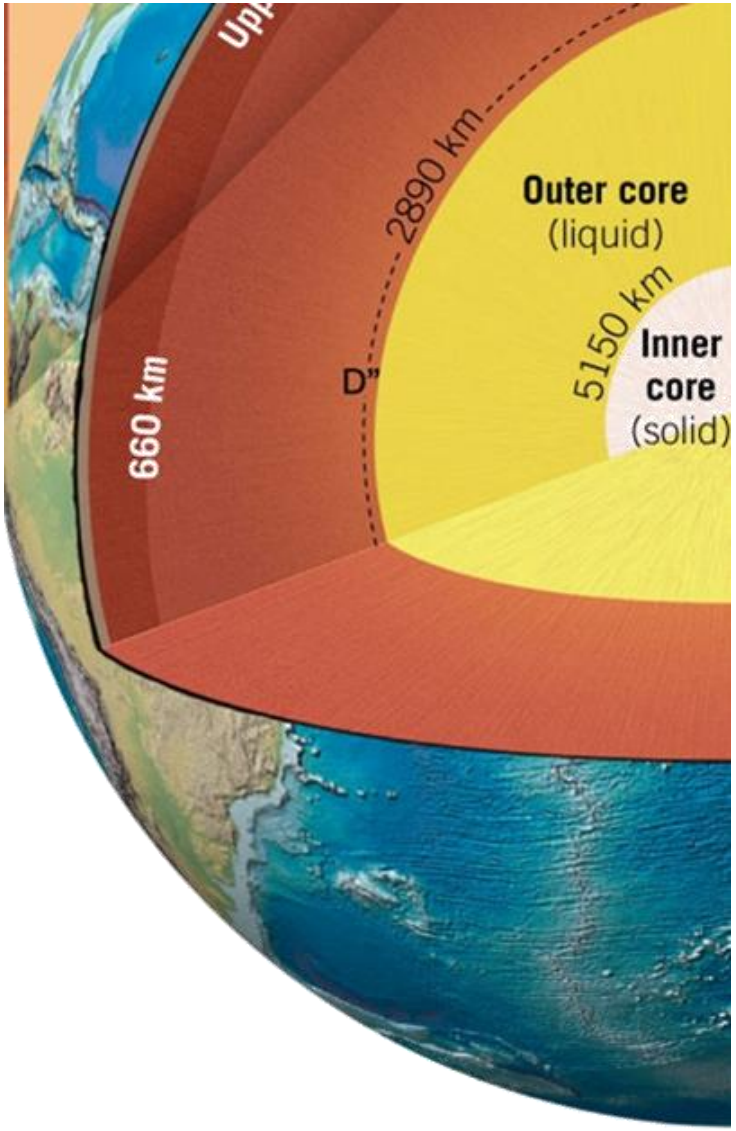
The interior of the Earth physical layering





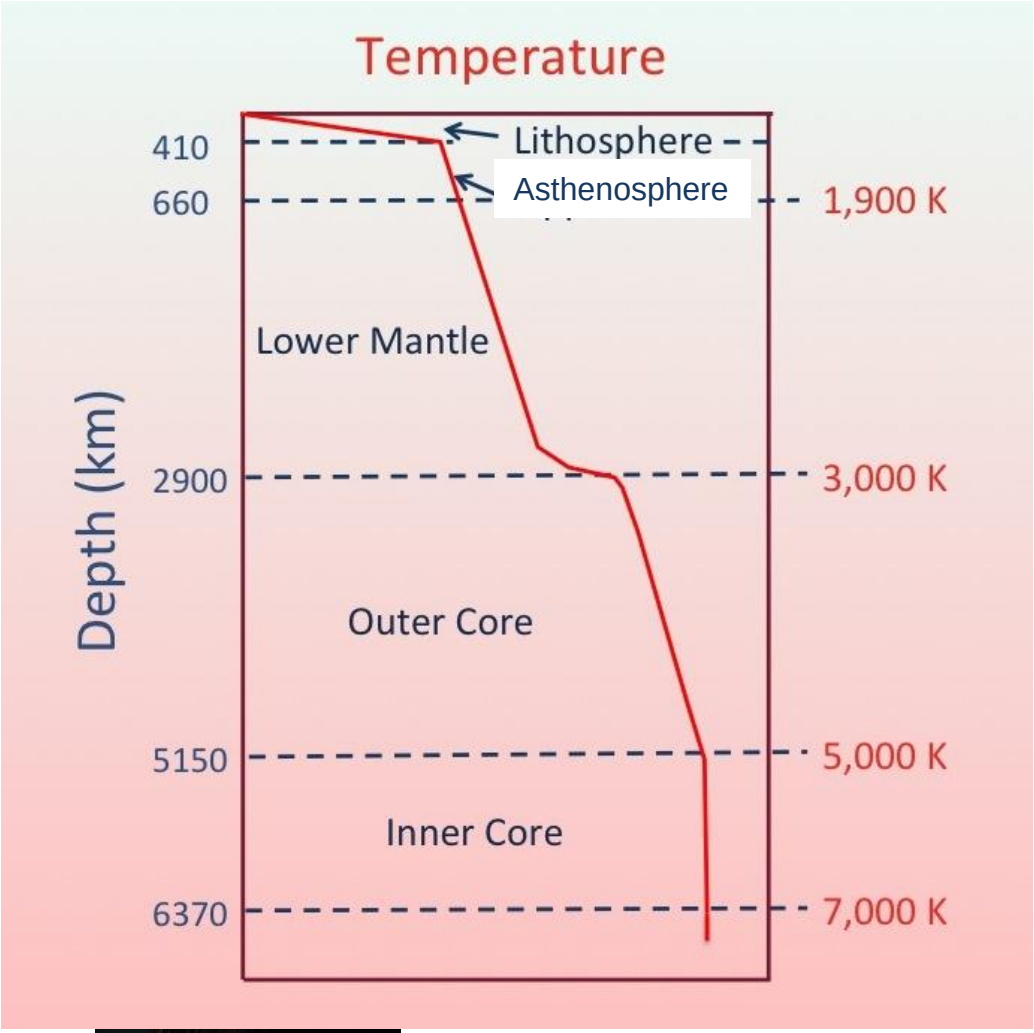
The Core

- Larger than Mars (3486 Km radius)
- Very dense!
    - Average density ~ 11 g/cm^3
        - At Earth's center ~x14 density of water!
- Mostly made of iron, + 5-10% Nickel, and other elements
- Two parts
    - Outer core - liquid outer layer ~ 2270 km thick
    - Inner core - solid inner sphere ~ 1216 km



What is like at the center of the Earth?

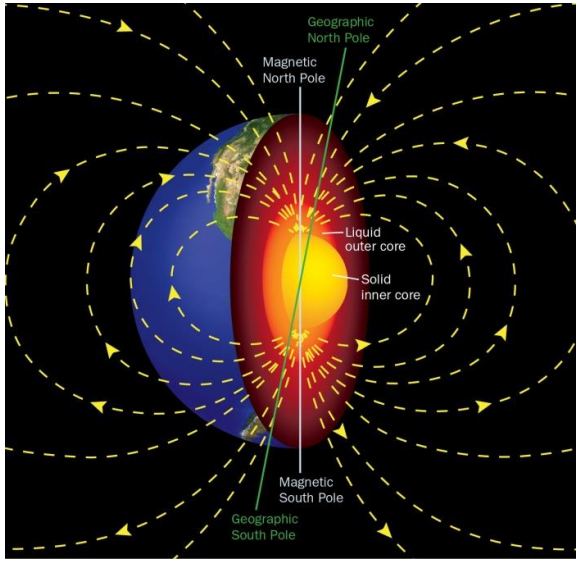
- Very high pressure and temperature – the geothermal gradient shows how these increase with depth



- P.s. No waste of space, so no caverns, no living conditions for any mega fauna/flora

Earth's magnetic field: outer core Electromagnetism

- The outer's core liquid metal is ionized → electrically charged
- Because of its thickness and thermal gradient, convections currents form in the outer core.
- The electrically charged liquid metal in motion generates electrical currents and the associated Magnetic Field
- The magnetic starts in the outer core, and it presence (field flux lines) is felt by magnets, as they align with the flux and indicate the North on a compass.

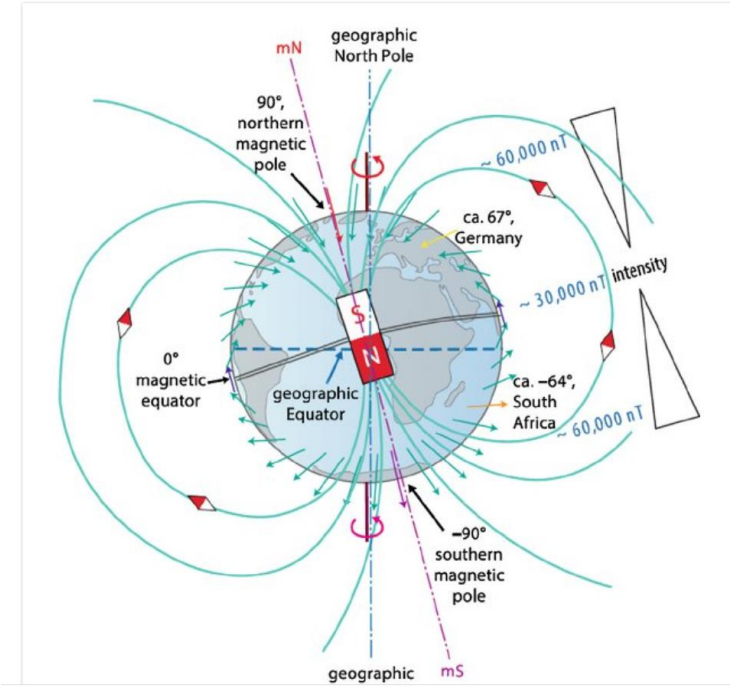


Lines of magnetic flux: from south to north!

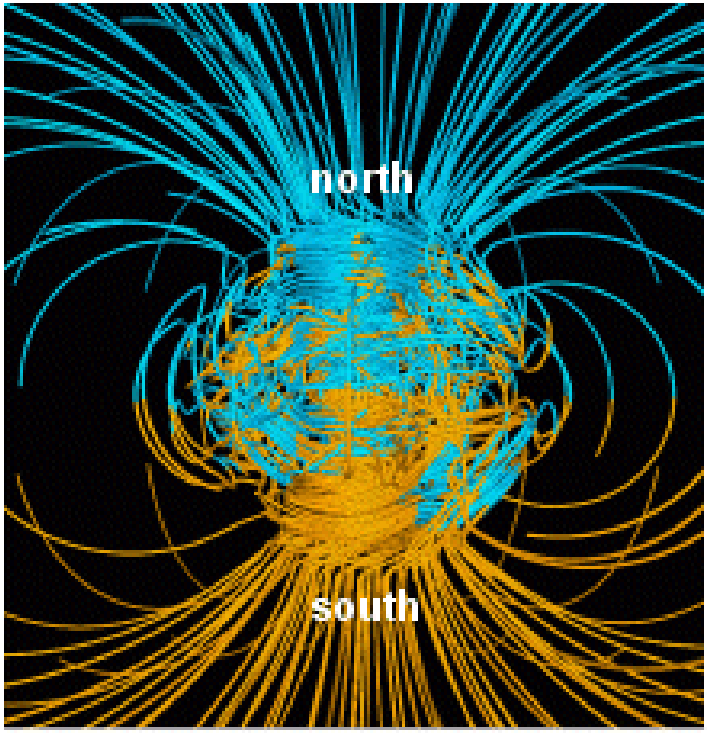
Core complexity

While it is simpler to model the magnetic field of Earth like a dipolar magnet (with a North and a South Pole) the magnetic field of Earth is much more complex, more like a multipole!
The magnetic field is thought to be made of several of these magnetic poles that are also moving

Not so simple



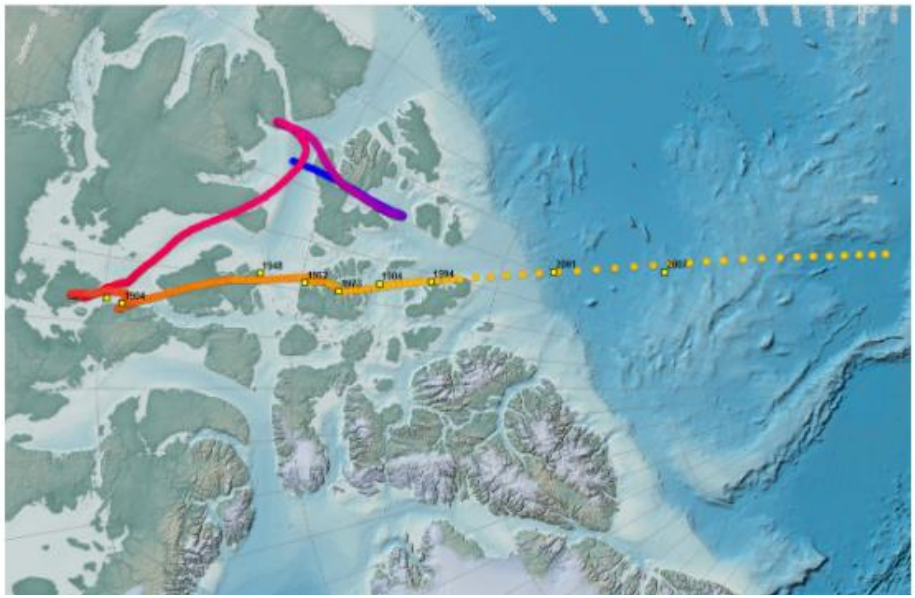
much more complex!

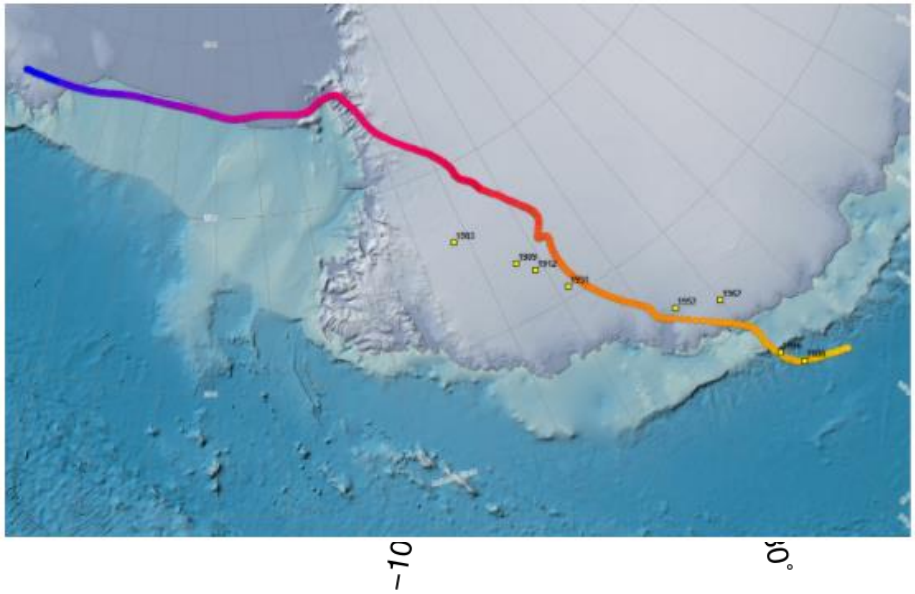


Magnetic poles on the move

- the location of the magnetic poles is not the same as that of the geographic poles

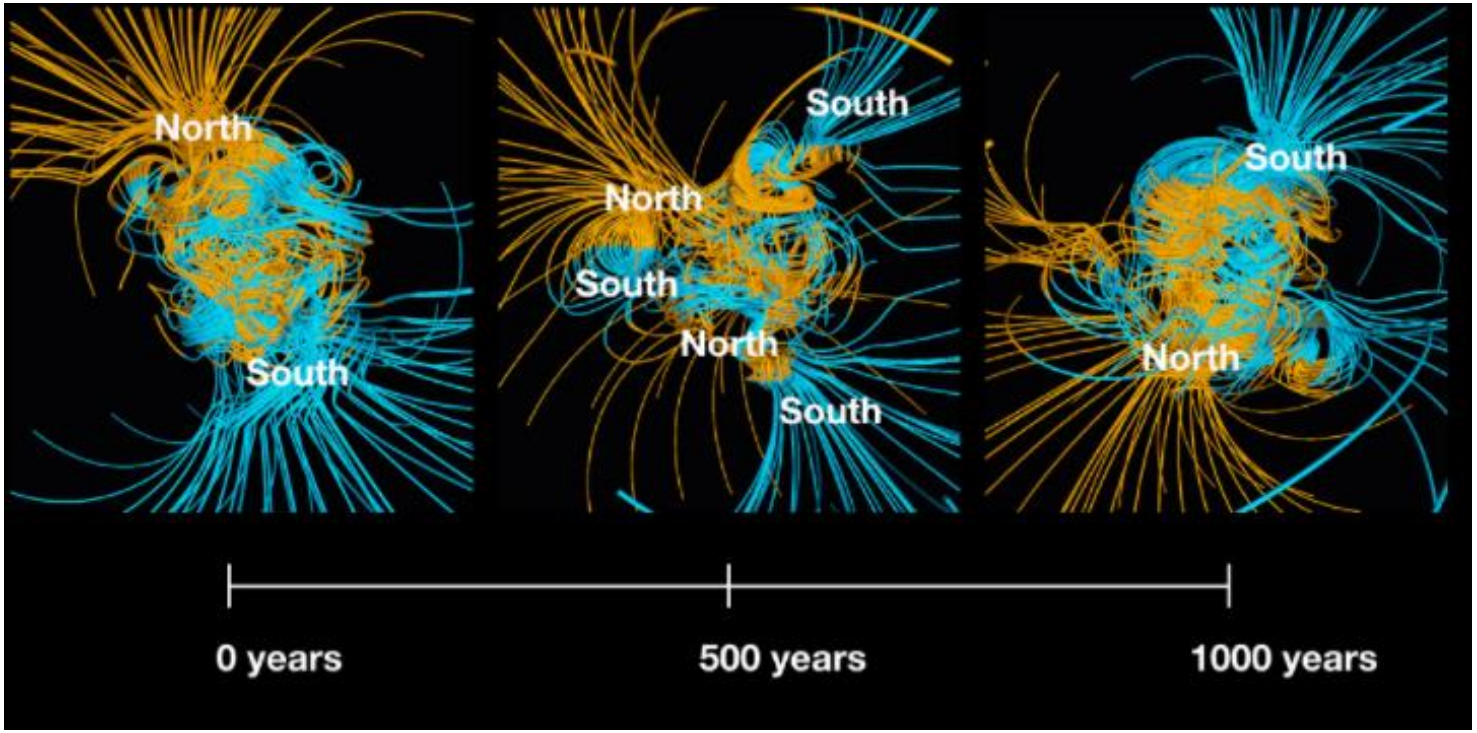
- The magnetic poles (a.k.a. the magnetic dip pole) position changes in time but are not changing in the same way
- The maps show where the magnetic poles in the Artic and Antarctic areas have been “wandering” from 1590 to 2020 (from blue to yellow, in yellow the measured values).





Magnetic reversal

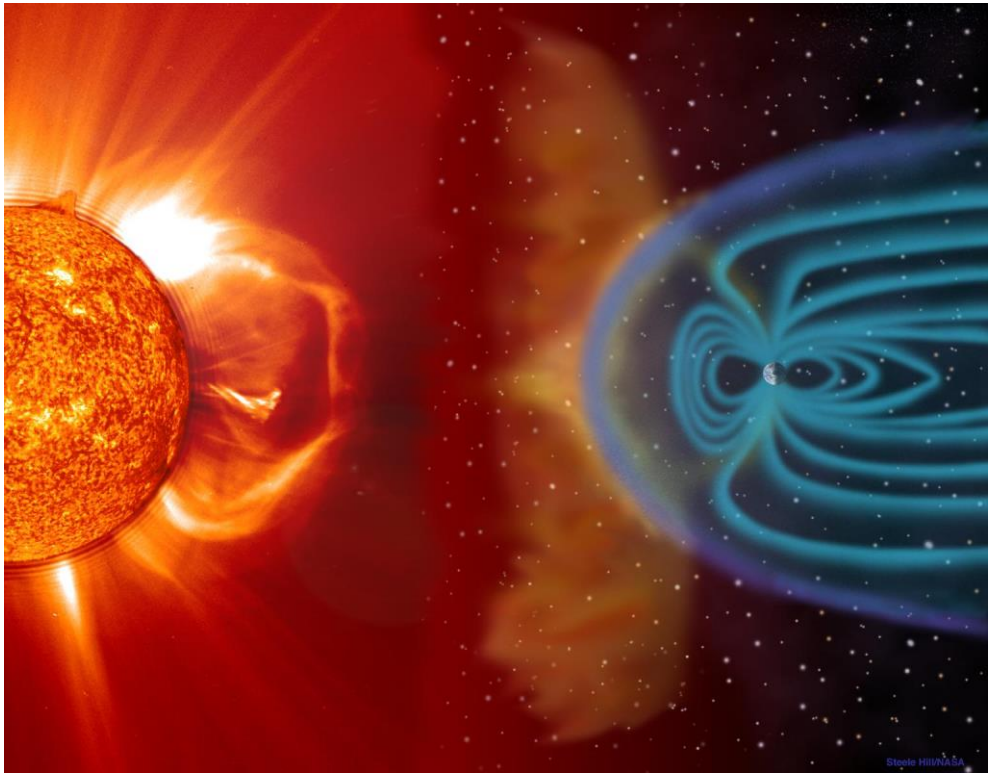
The magnetic field can flip polarity: there is evidence that this has happened several times in Earth's history and that the reversal process takes only thousands of years (much faster than plate movements!).



Mathematical models of how this can happen show the magnetic field disassembling and re-assembling itself flipping its polarity

The magnetic Field – magnetosphere

- Earth's magnetic field works as a shield, it traps the highly charged particles (electrons and protons) from solar winds, preventing them from reaching Earth.
- The particles are forced to spiral along the field lines



Artistic rendering of the magnetic field successfully shielding Earth.

[What is the Sun up to today?]

Van Allen Belts and the Aurora

- The two regions of particularly high concentration of charged particles are called the *Van Allen radiation belts;* these are visible mostly in polar regions as the *aurora* (Northern and Southern Lights)