Plate tectonics: Earth structure and plate geometry I

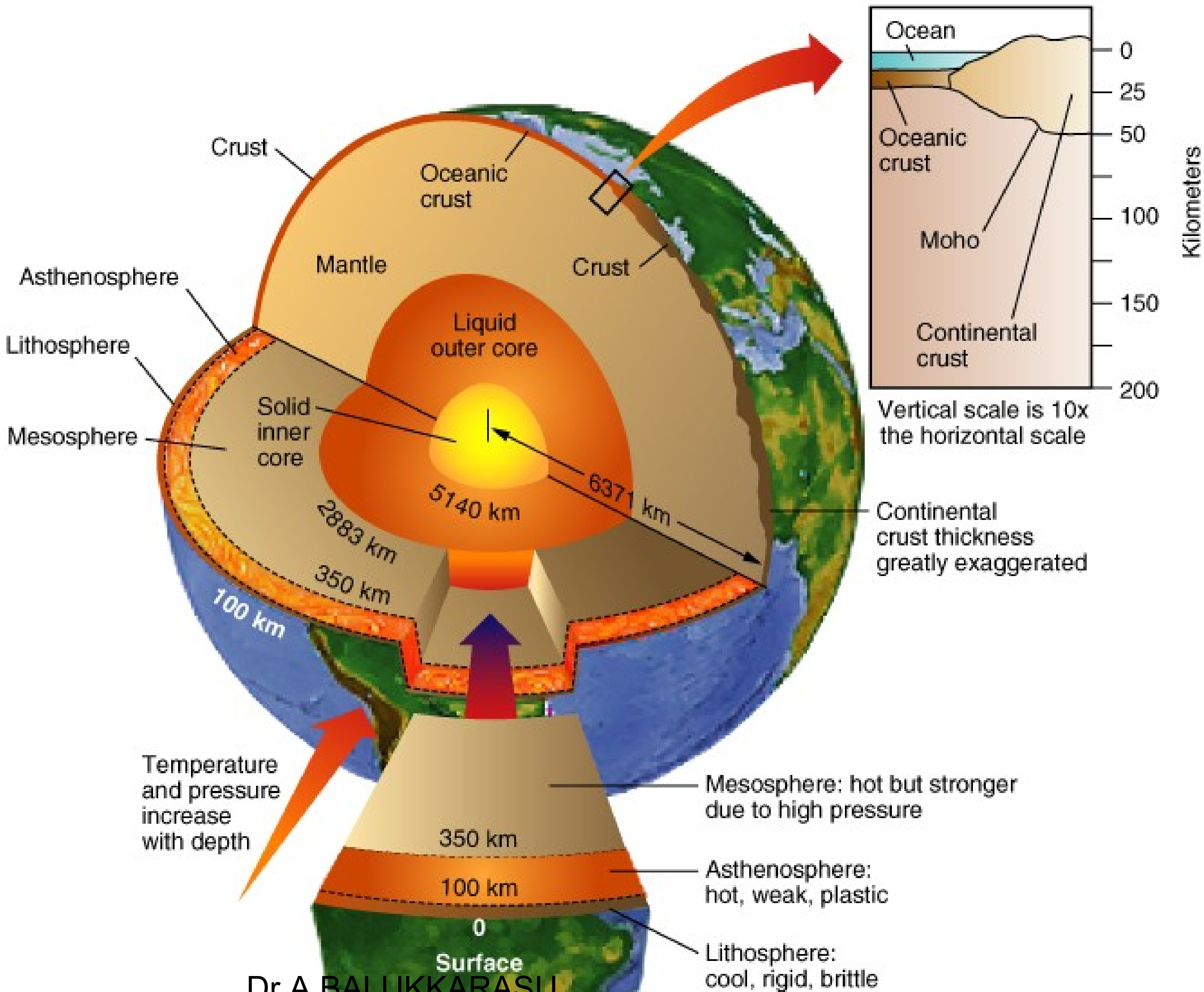
Plate tectonics - a theory that explains the function of the upper most layer of the planet.

Important: This chapter follows mainly on chapter 2 in Fowler's textbook.

Earth structure: The main units

Compositional:
- Crust
- Mantle
- Core

Rheological:
- Lithosphere
- Asthenosphere
- Mesosphere



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Earth structure: The main units

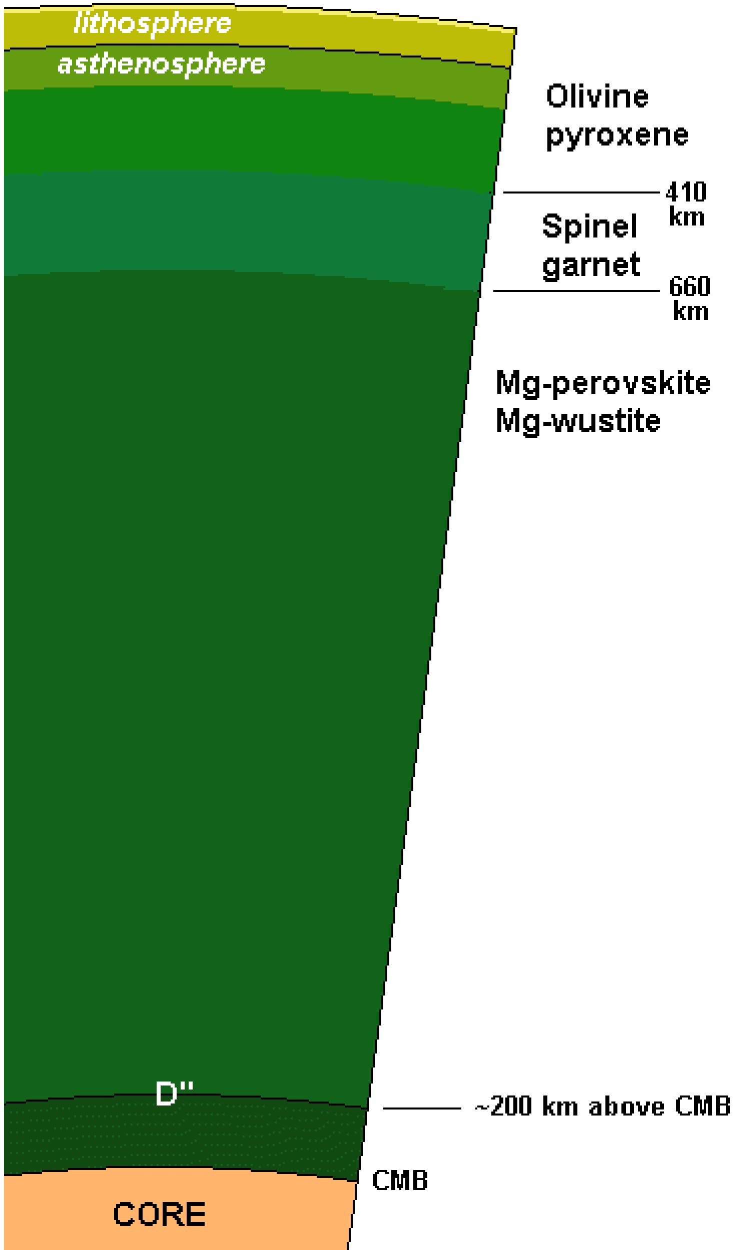
- Crust versus mantle: The crust is a product of mantle melting. Typical mantle rocks have a higher magnesium to iron ratio, and a smaller portion of silicon and aluminum than the crust.

- Lithosphere versus asthenosphere: While the lithosphere behaves as a rigid body over geologic time scales, the asthenosphere deforms in ductile fashion. The lithosphere is fragmented into tectonic plates, which move relative to one another. There are two types of lithosphere: oceanic and continental.

- Upper versus lower mantle: Together the lithosphere and the asthenosphere form the upper mantle. The mesosphere, extending between the 660 boundary and the outer core, corresponds to the lower mantle.

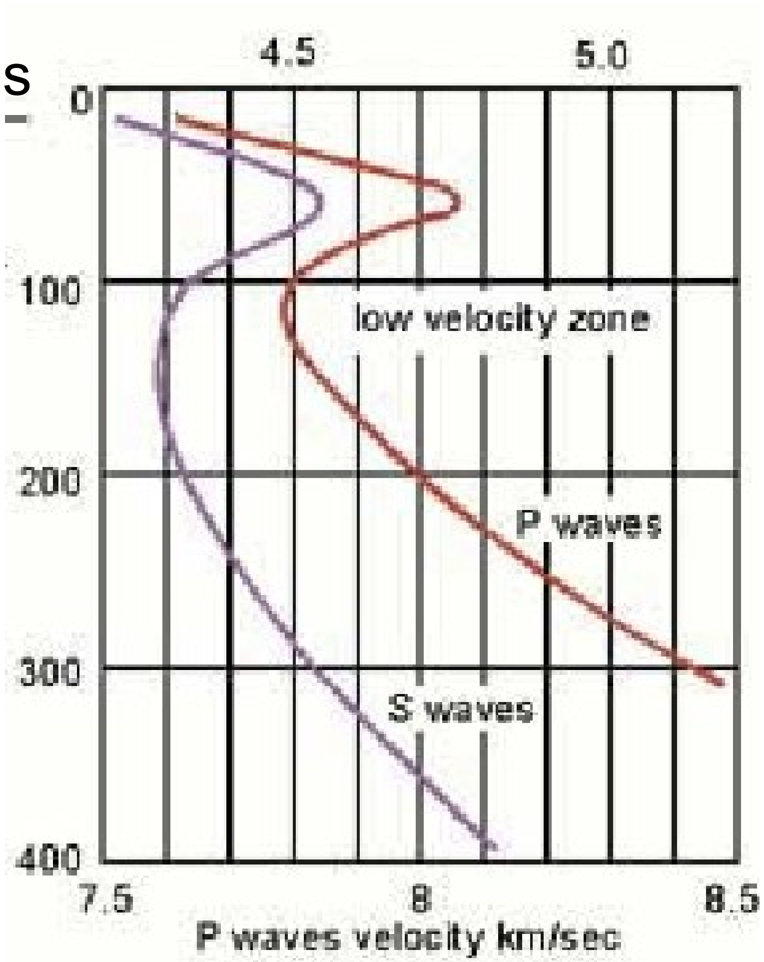
Earth structure: Mantle phase changes

- 410 km: Above this depth the Mg, Fe, Si and O are primarily within olivine and pyroxene. Below this depth the olivine is no longer stable and is replaced by a higher density polymorph - spinel. The material has a similar overall composition but the minerals have a more compact structure.
- 660 km: Below this depth the spinel gives way to the minerals Mg-perovskite and Mg-wustite. (In fact, Mg-perovskite is probably the most abundant solid of the earth since it appears to be stable through much of the mantle.)



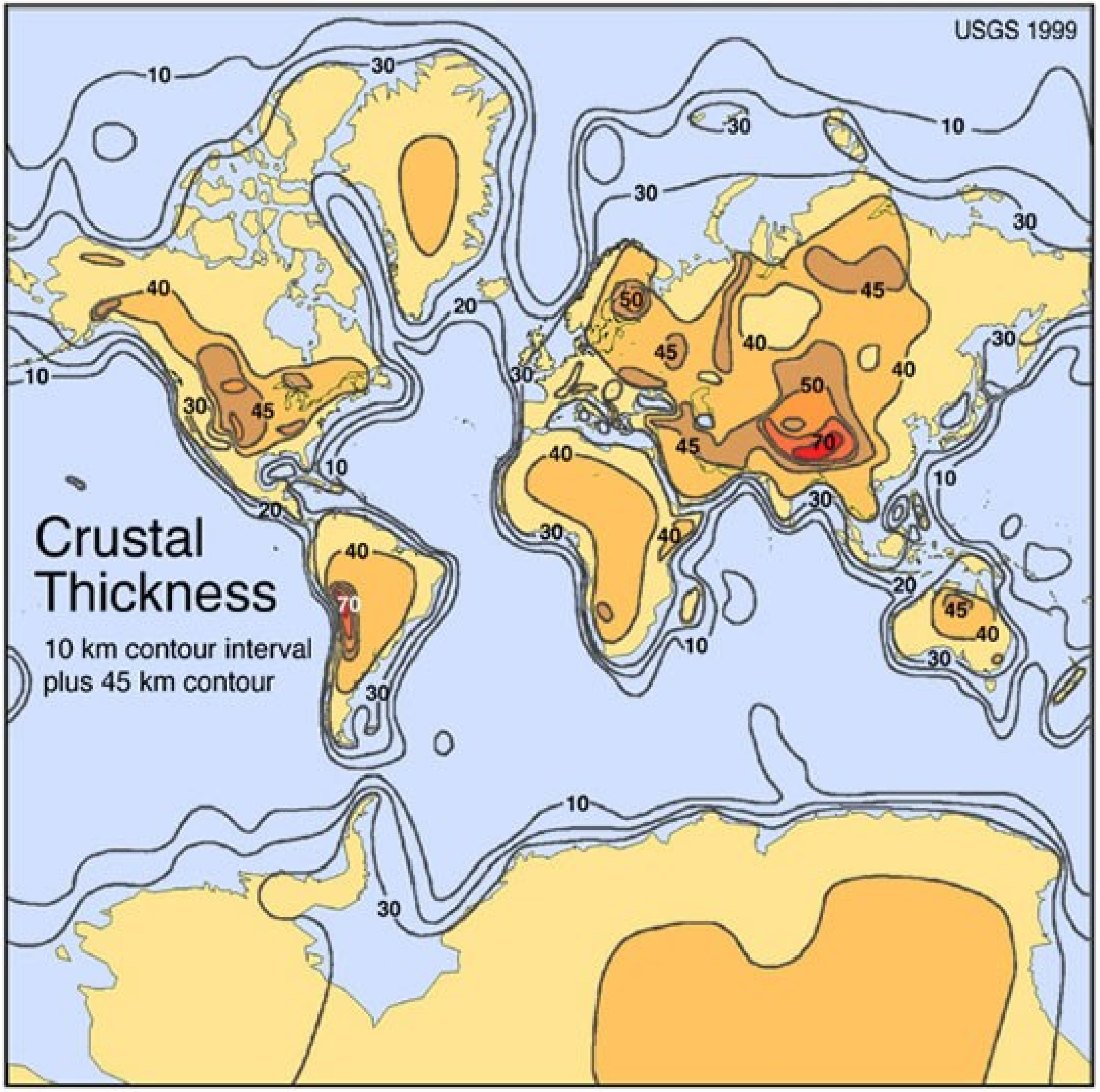
Earth structure: Seismic discontinuities

- Moho: The dept at which the P-wave velocity exceeds 8.1 Km/S is referred to as the moho (after the seismologist Mohorovicic). The moho is both a seismic and a compositional boundary, marking the transition between crust and mantle materials.



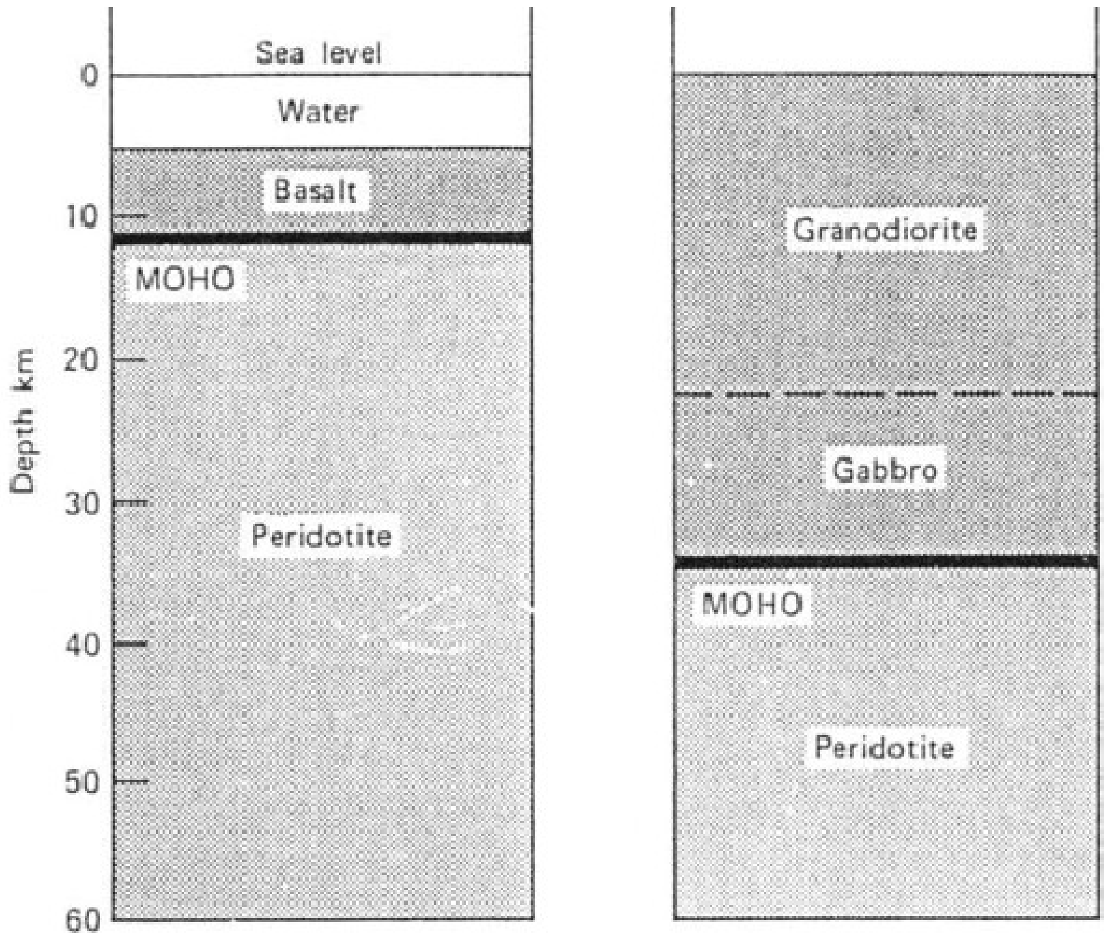
Earth structure: Seismic discontinuities

Thickness of the Earth's crust (by the USGS). Since the Moho is at the base of the crust this map also shows depth to Moho.



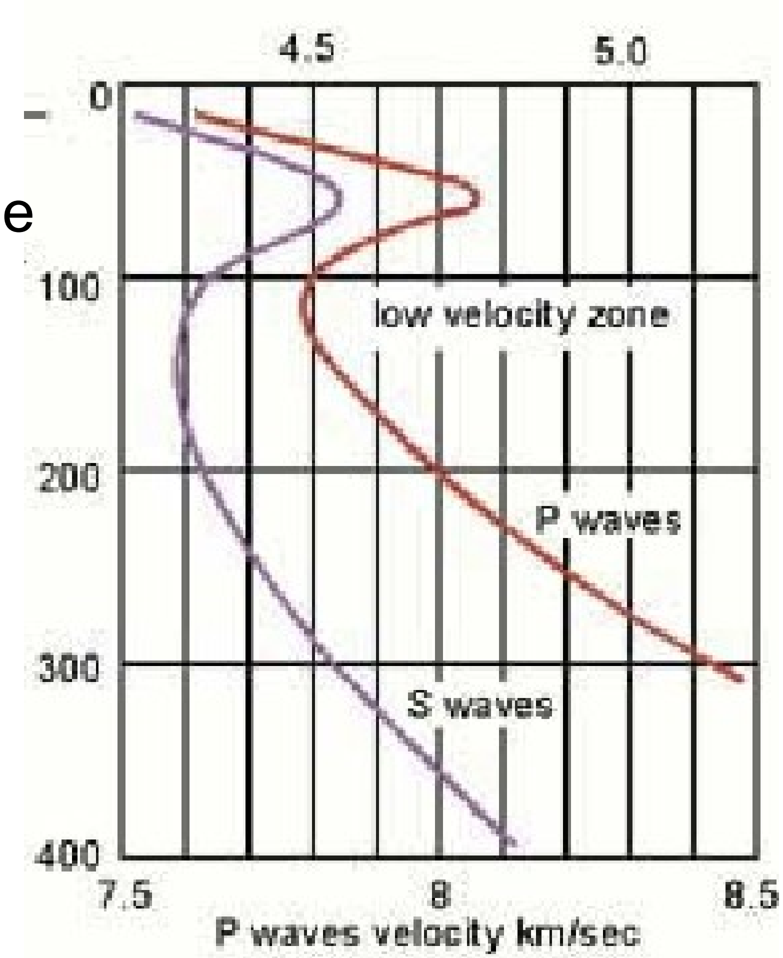
Earth structure: Seismic discontinuities

The composition of the crust



Earth structure: Seismic discontinuities

- Low Velocity Zone (LVZ): The low velocity is more strongly visible for S-waves than for P-waves. It marks the boundary between the lithosphere and the asthenosphere.



Earth structure: Seismic discontinuities

The LVZ is deeper under shield and platforms, than it is under oceanic basins and continental rifts.

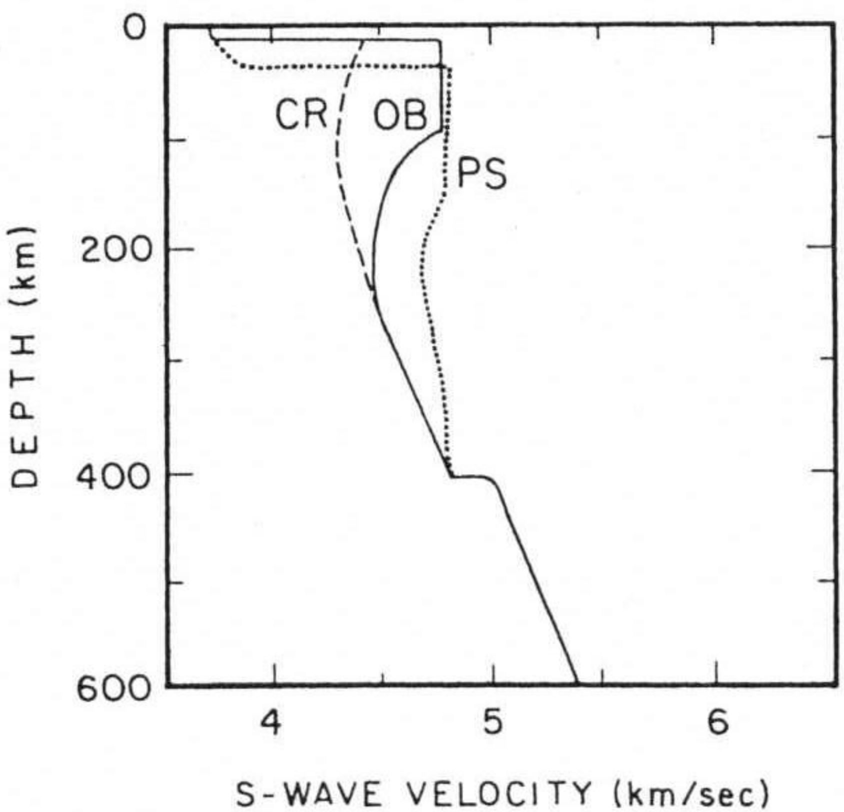
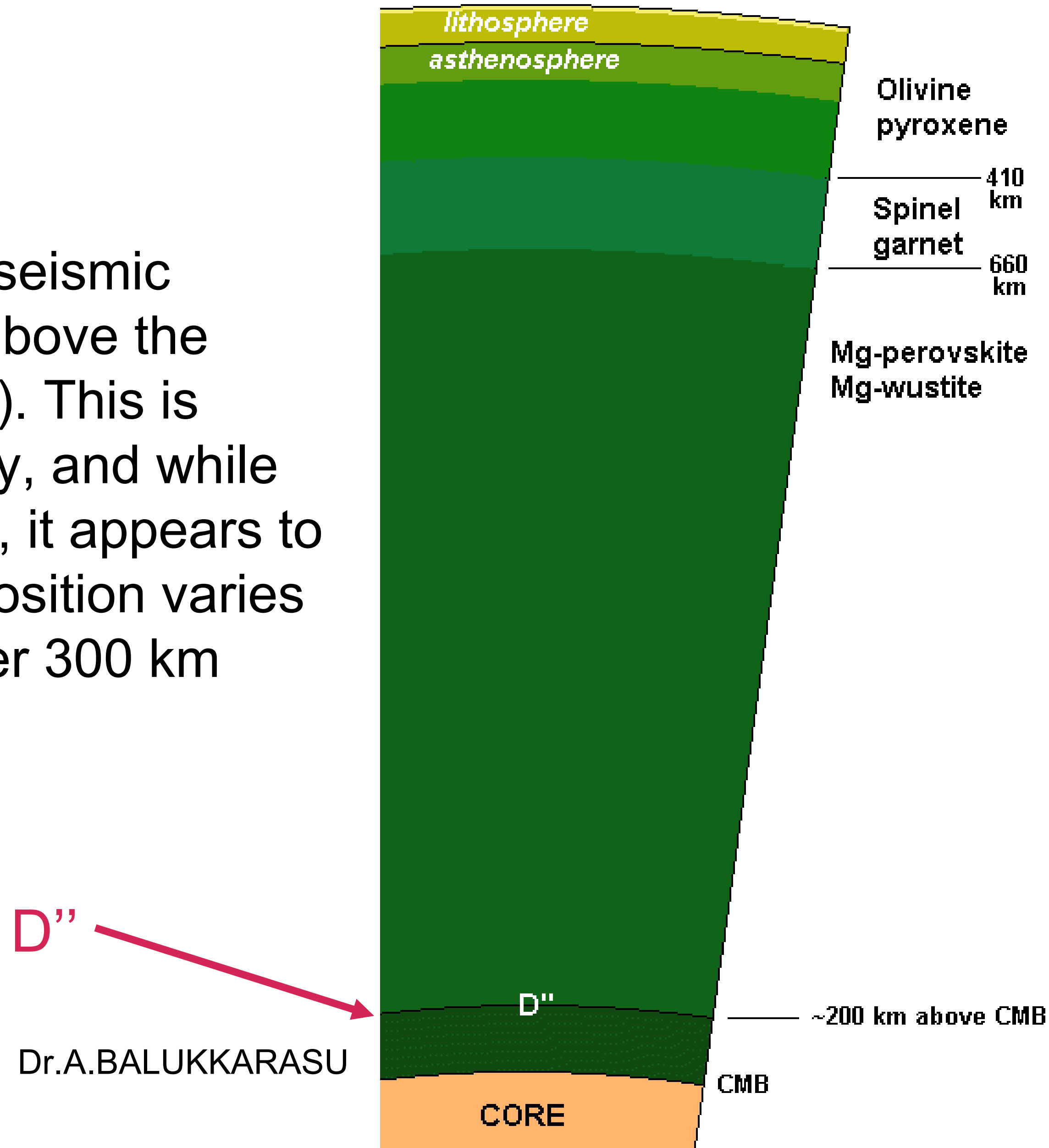


Figure 4.2 S-wave velocity distribution in the upper mantle beneath three crustal types: CR, continental rift; OB, ocean basin: and PS, Proterozoic shield or platform. After Grand and Helmberger (1984).

Earth structure: Seismic discontinuities

- D'': There is evidence of a seismic discontinuity about 200 km above the core-mantle boundary (CMB). This is known as the D" discontinuity, and while we don't know much about it, it appears to be ubiquitous, although its position varies from less than 100 km to over 300 km above the CMB.



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Earth structure: Seismic discontinuities

It has been suggested, based on tomography (i.e., seismic imaging), that the D'' is a slab graveyard and/or plume factory

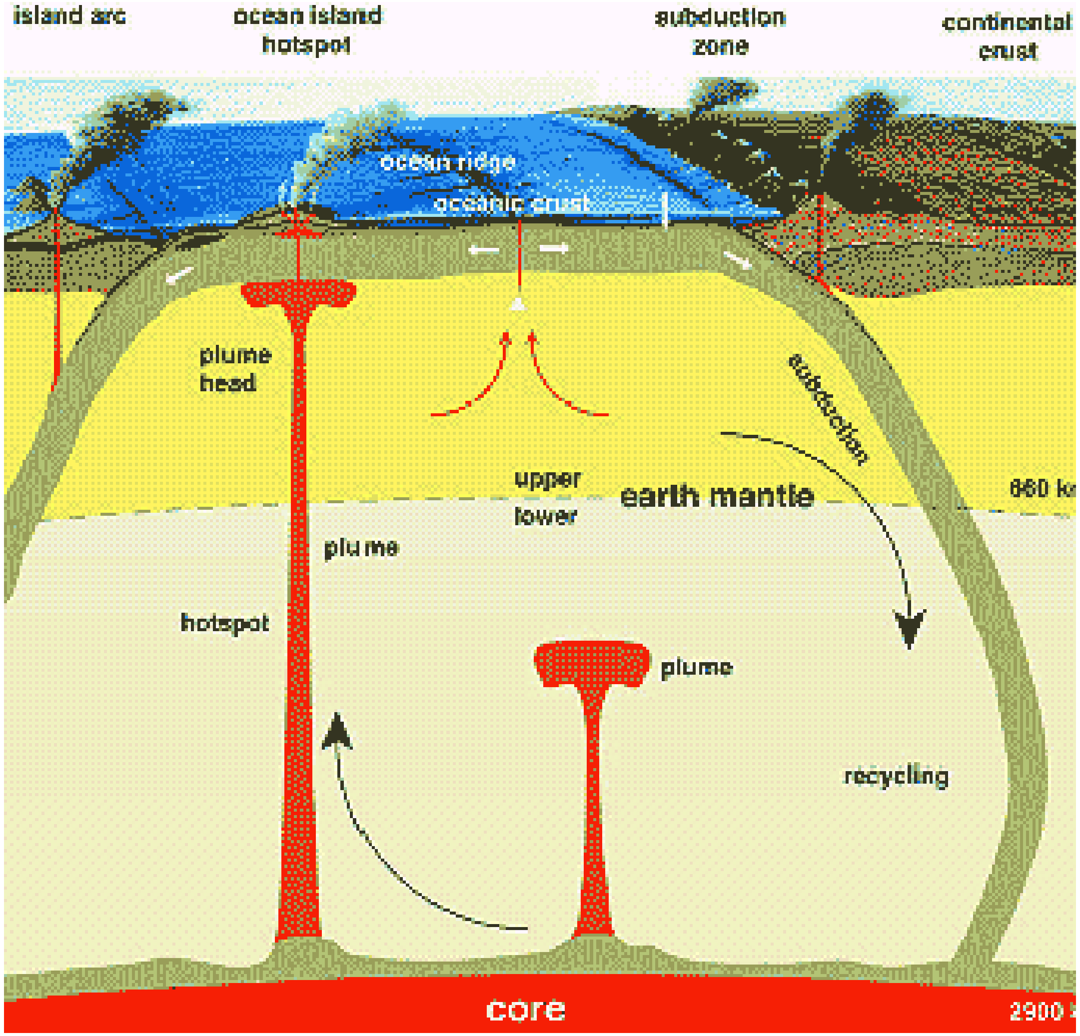

Figure from:
http://www.avh.de/kosmos/titel/2002_011.htm

Earth structure: Seismic discontinuities

Do ascending slabs cross the upper-lower mantle boundary?

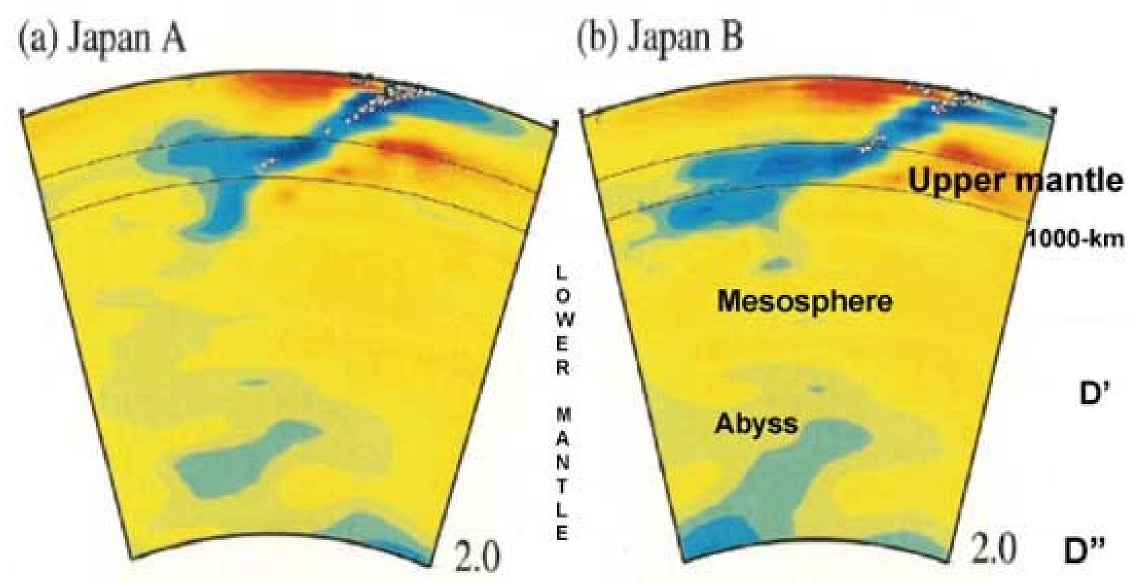

Figure from Fukao et al., 2001

Blue = fast anomaly = dense = cold

Red = slow anomaly = buoyant = hot

Earth structure: Seismic discontinuities

Currently, it seems that the answer to this fundamental question is in the eye of the beholder. (learn more at: http://www.mantleplumes.org/TomographyProblems.html)

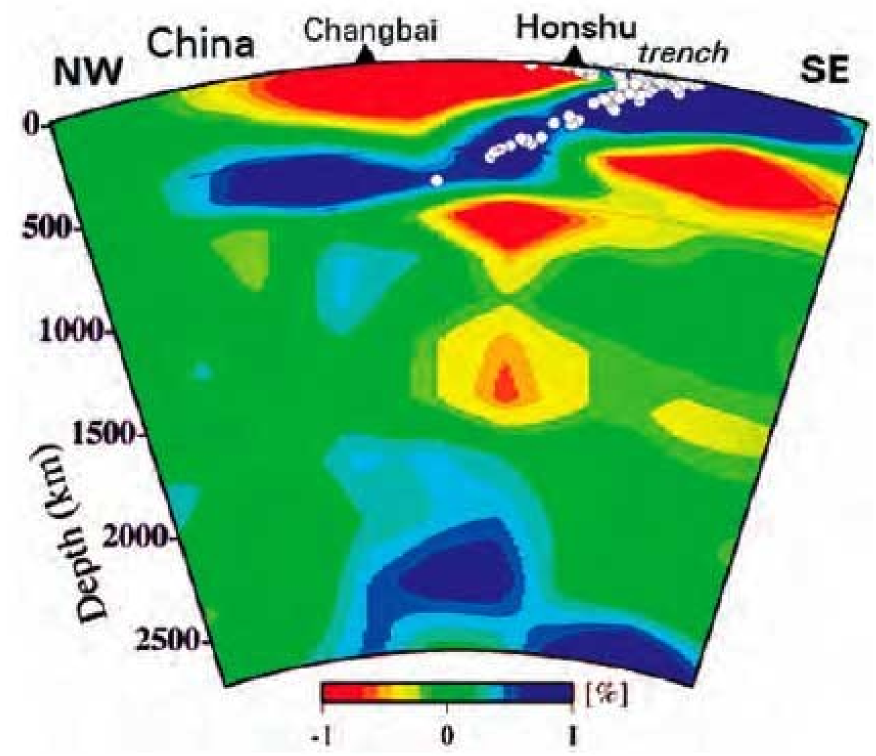

Figure from Zhao et al., 2004

Earth structure: Seismic discontinuities

Seismic images suggesting that some mantle plumes originate at the D''.

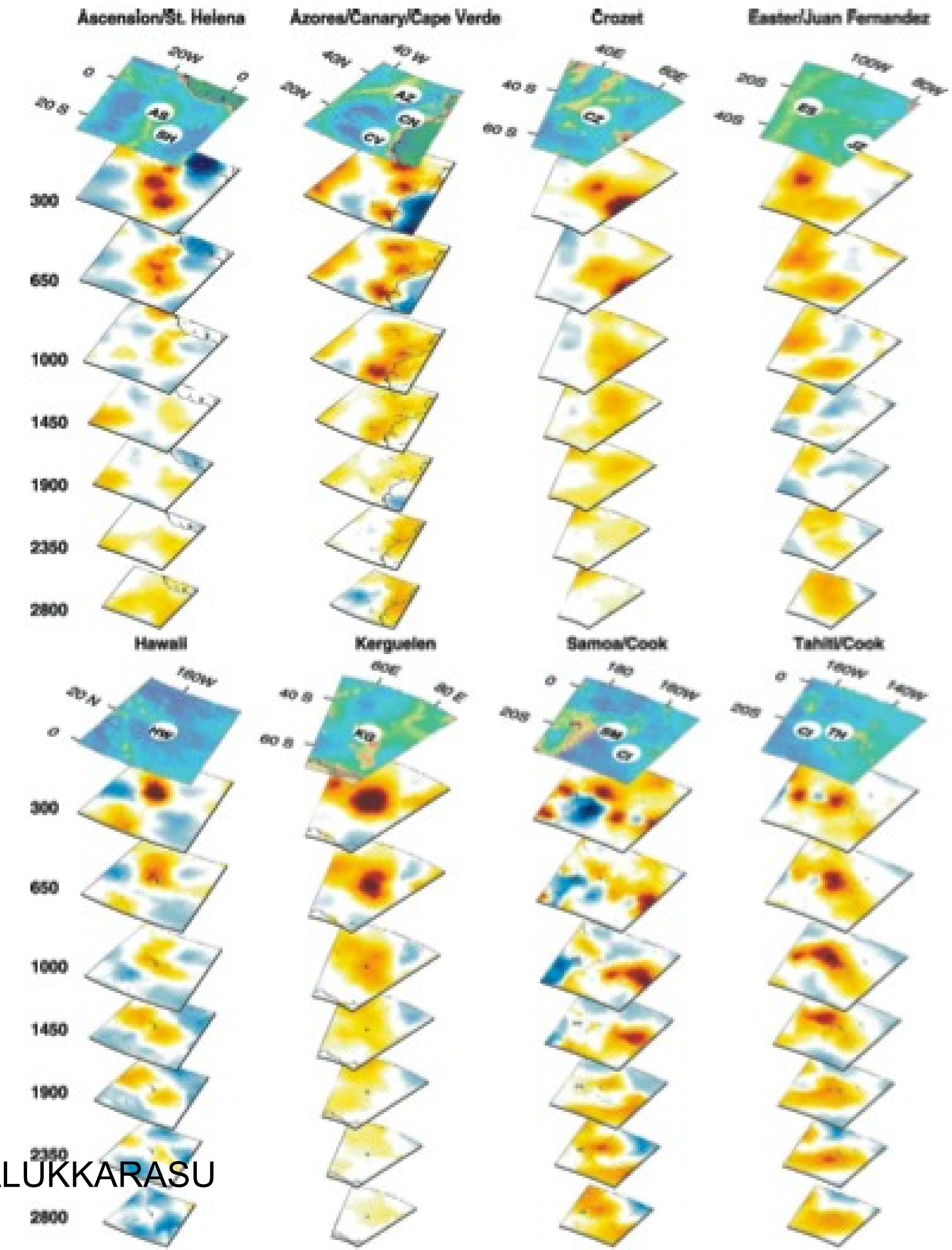

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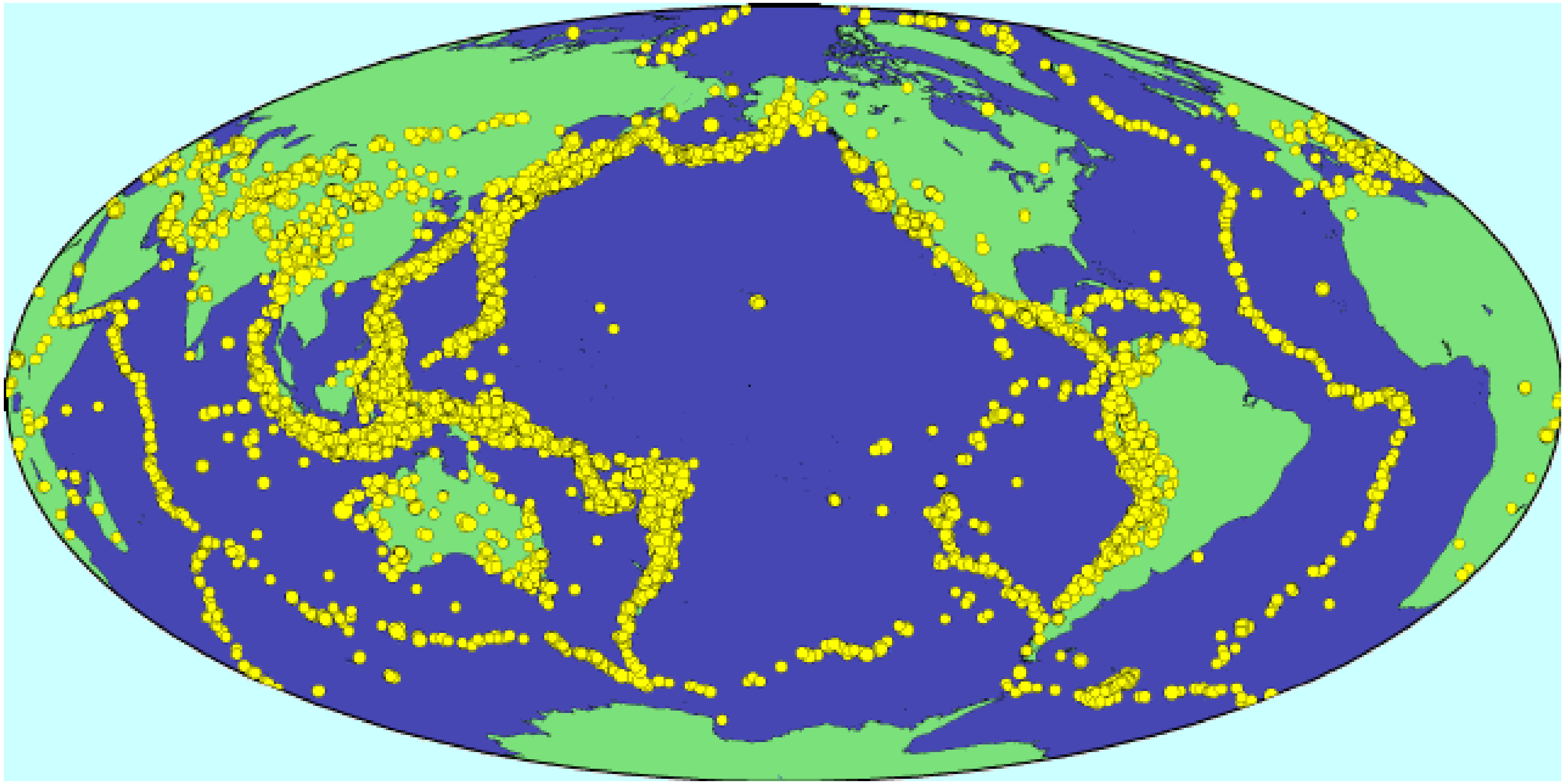
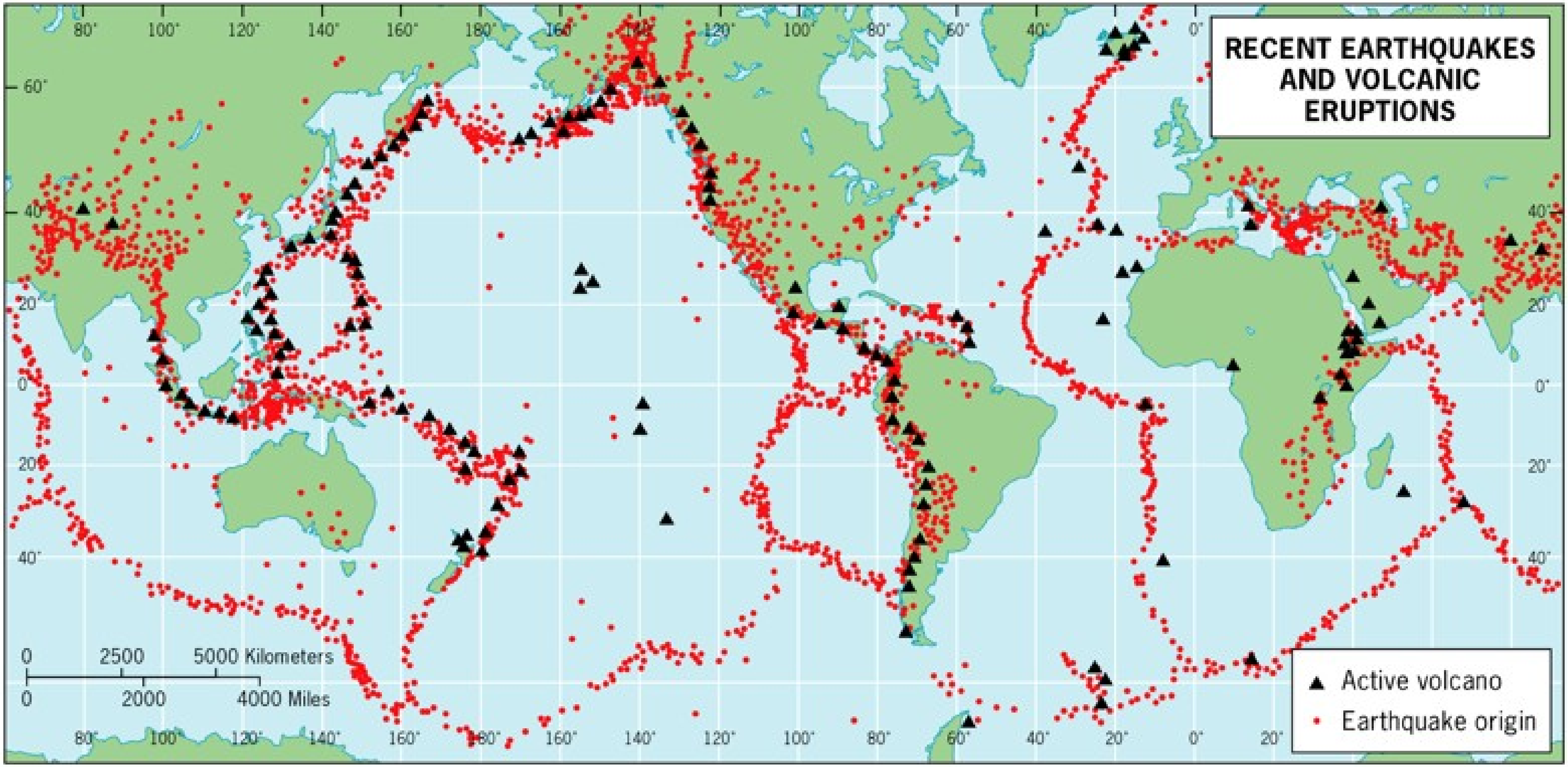
Figure from Montelli et al., 2004

Earthquake distribution: Earthquake belts



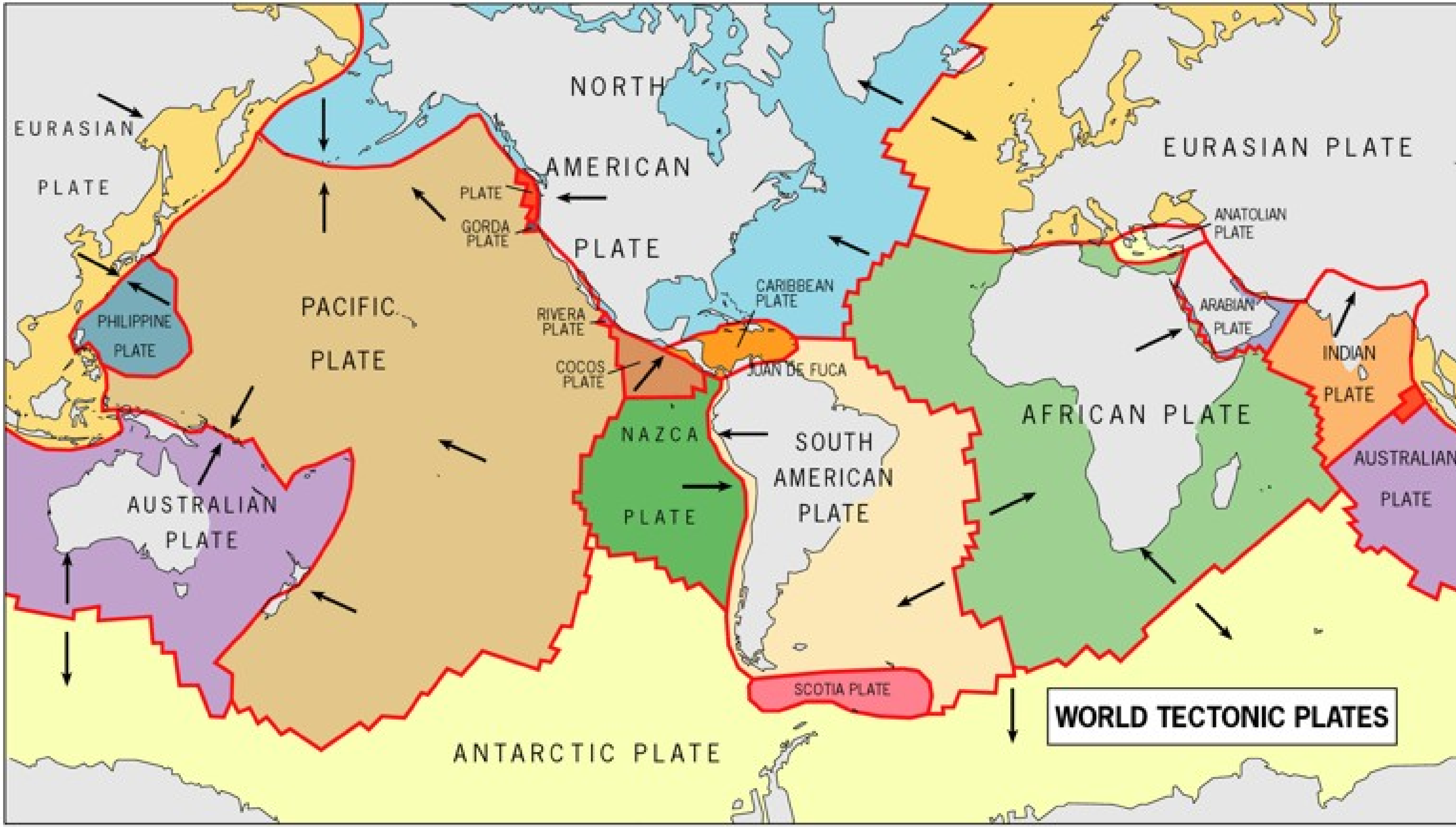
- Earthquakes are organized along belts.
- The world's greatest earthquake belt, the circum-Pacific seismic belt, is located along the rim of the Pacific Ocean.
- The second important belt, the Alpide, extends from Java to Sumatra through the Himalayas, the Mediterranean, and out into the Atlantic.
- The third prominent belt is the mid-Atlantic belt.

Earthquake distribution: Correlation with volcanic activity



• Most of the world's volcanic activity is concentrated along earthquake belts, i.e. the circu-Pacific and part of the Alpide belts.

Earthquake distribution: The plates



- The seismic belts divide the earth surface into plates.
- While some of the plates are huge, e.g. the Pacific, some are tiny, i.e. the Gorda and the Coccos plates.

The key principles: Plate tectonics basic assumptions (from Fowler's book)

- Generation of new plate material occurs by seafloor spreading; that is, new material is generated along mid-ocean ridges.

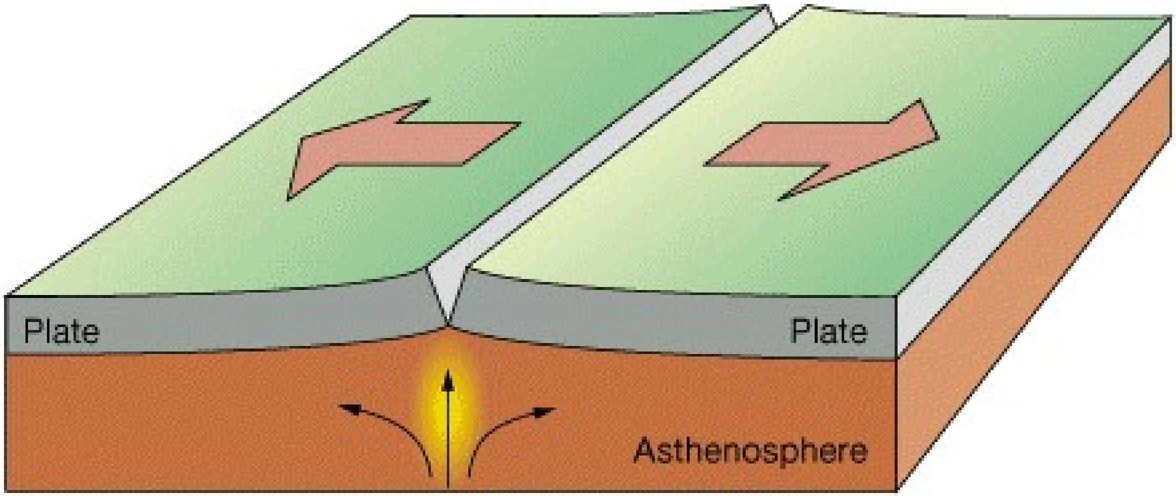
- The new oceanic lithosphere, once created, forms part of a rigid plate.

- The earth's surface area remains constant; therefore seafloor spreading must be balanced by consumption of plate elsewhere.

- The relative motion between plates is taken up only along plate boundaries.

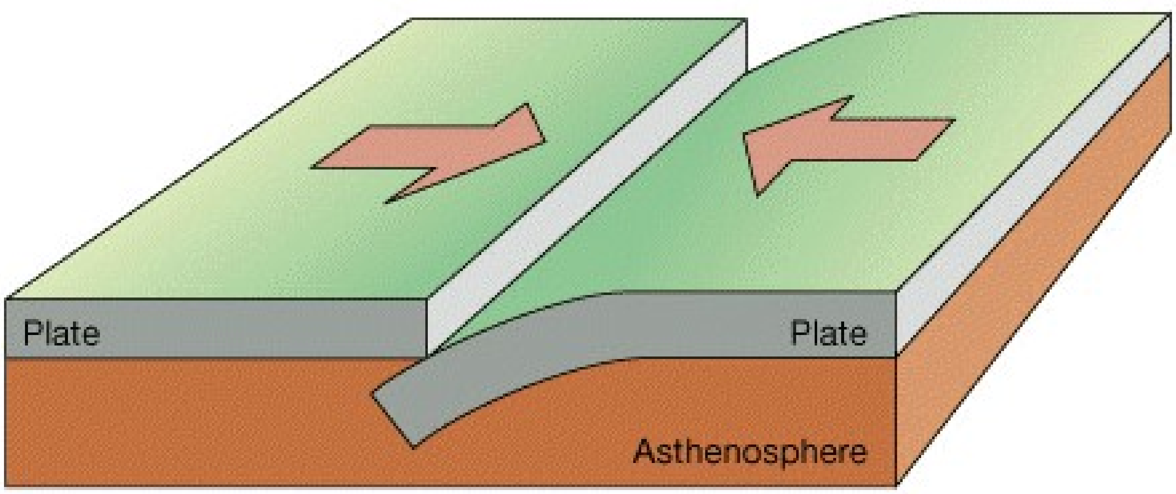
The key principles: Types of plate boundaries

- Divergent boundary, also called accreting or constructive, plates are moving away from each other, and new plate material, derived from the mantle, is added to the lithosphere. The divergent boundary is represented by the mid ocean ridge system.



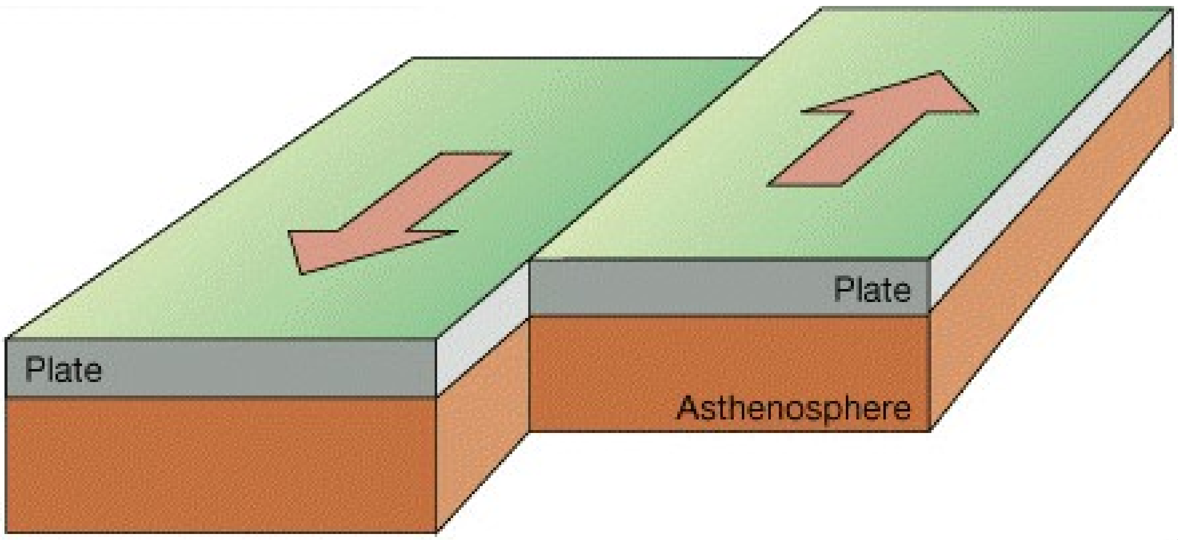
The key principles: Types of plate boundaries

- Convergent boundary, also called consuming or destructive, plates are approaching each other. These boundaries are represented by the oceanic trench, island arc systems or subduction zones where one of the colliding plates descends into the mantle and is destroyed.



The key principles: Types of plate boundaries

• Conservative boundary, lithosphere is neither created nor destroyed. The plates move laterally relative to each other. These plate boundary are represented by transform faults.



The key principles: Types of plate boundaries

• Transform faults can be grouped into six basic classes. By far the most common type of transform fault is the ridge-ridge fault.

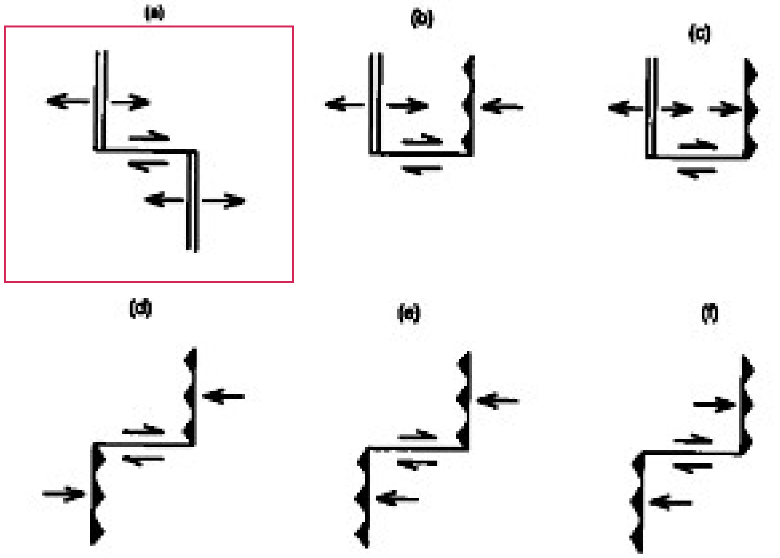
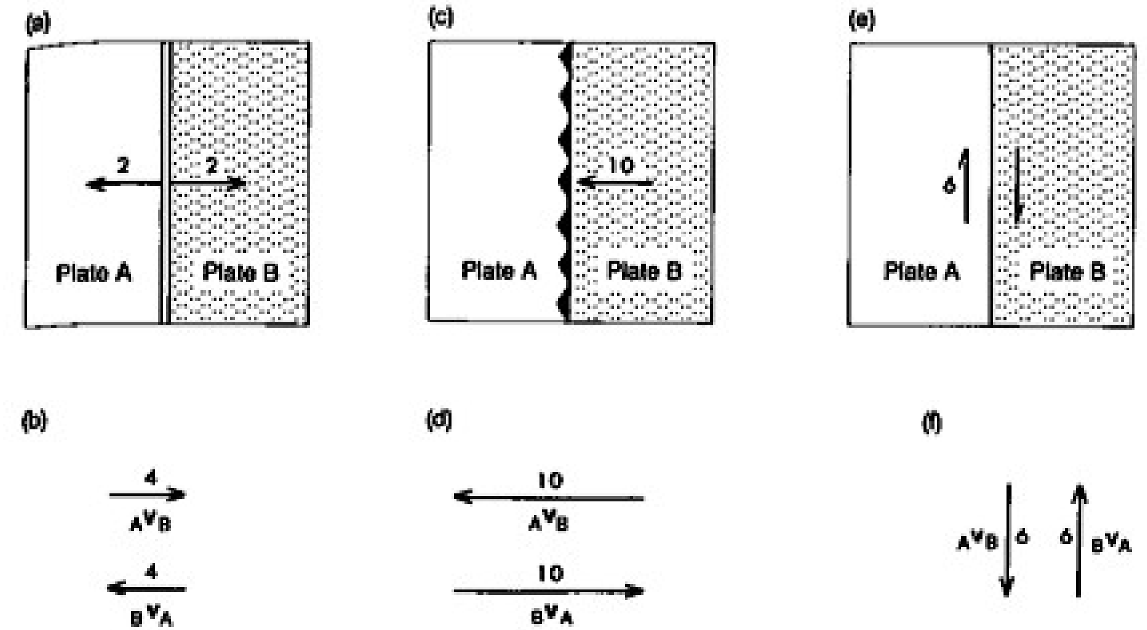


Plate tectonics on a flat earth: Relative velocity between two plates

- The velocity of plate A with respect to plate B is written: ${}_{B}V_{A}$.
- Conversely, The velocity of plate B with respect to plate A is written: ${}_{A}V_{B}$.



$$ {}_{A}V_{B} = -{}_{B}V_{A} $$

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Plate tectonics on a flat earth: Two plates

- The western boundary is a ridge, which is spreading at a half-rate of 2 cm yr^{-1}.
- Since ${}_{A}V_{B}$ is equal to 4 cm yr^{-1}, the eastern boundary is a subduction zone. Either plate A is subducting underneath plate B and the length of plate B increases by 2 cm yr^{-1}, or plate B is subducting underneath plate A and plate B is being destroyed at a rate of 2 cm yr^{-1}.

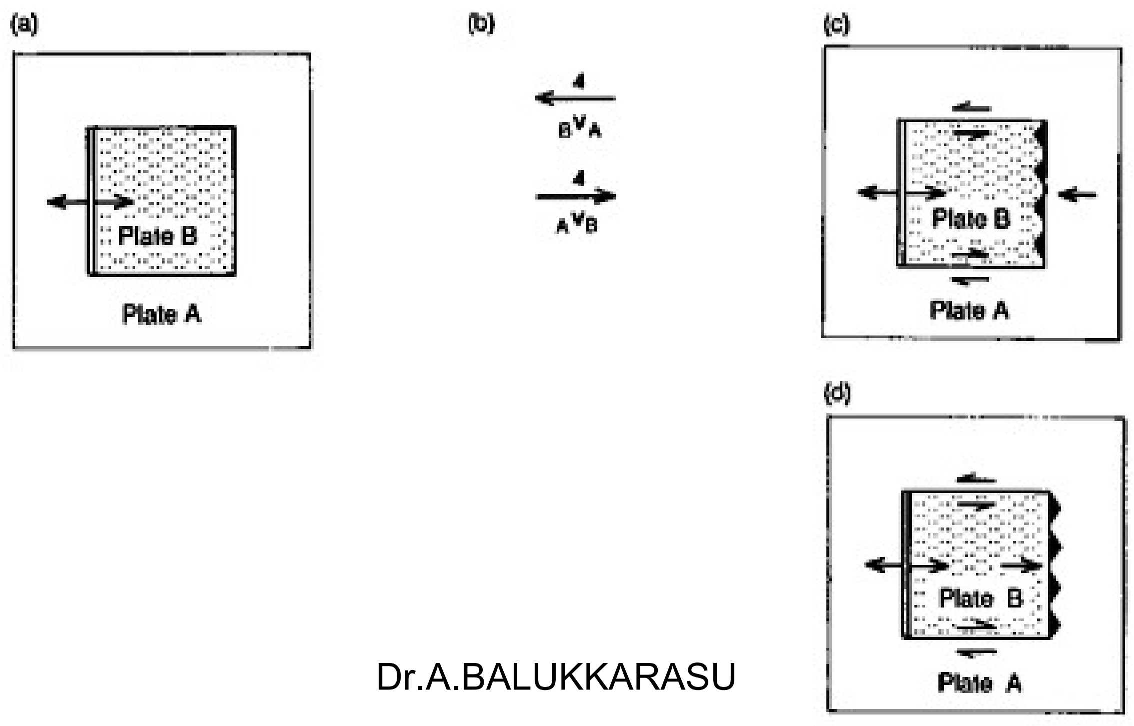

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Plate tectonics on a flat earth: Three plates

• Plates A and B are spreading away at a half-rate of 2 cm yr^{-1}.
• Plate A being subducted underneath plate C at a rate of 6 cm yr^{-1}.
• To determine the relative rate between plate B and C we use vector addition:

$$ {}_{C}V_{B} = {}_{C}V_{A} + {}_{A}V_{B} $$

• Thus, the net rate of destruction of plate B is 8 cm yr^{-1}.

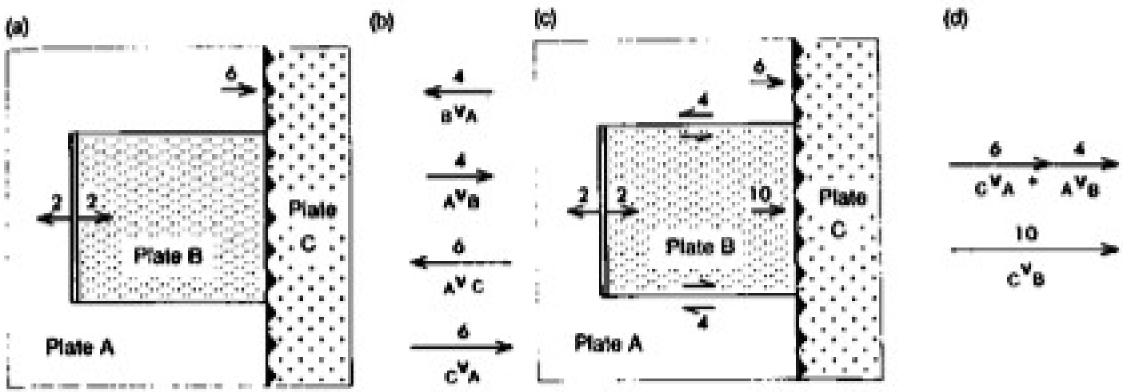


Plate tectonics on a flat earth: Three plates

- Plates A and B are spreading away at a half-rate of 2 cm yr^{-1}.
- The boundary between between plates A and C is a transform fault with a relative motion of 3 cm yr^{-1}.
- Again, to determine the relative rate between plate B and C we use vector addition as before.
- So either plate B is subducting underneath C (as shown), or C is subducting under B.

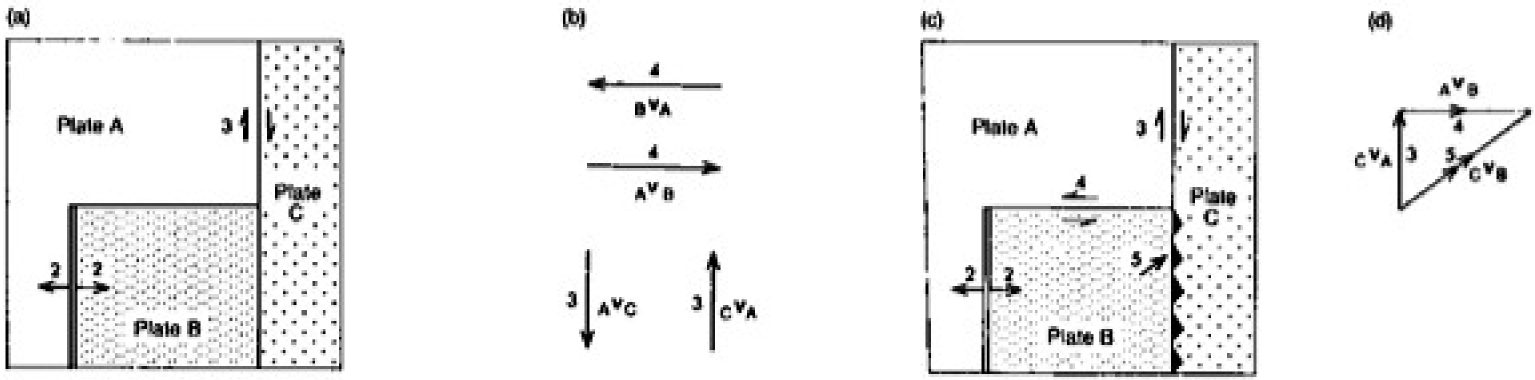
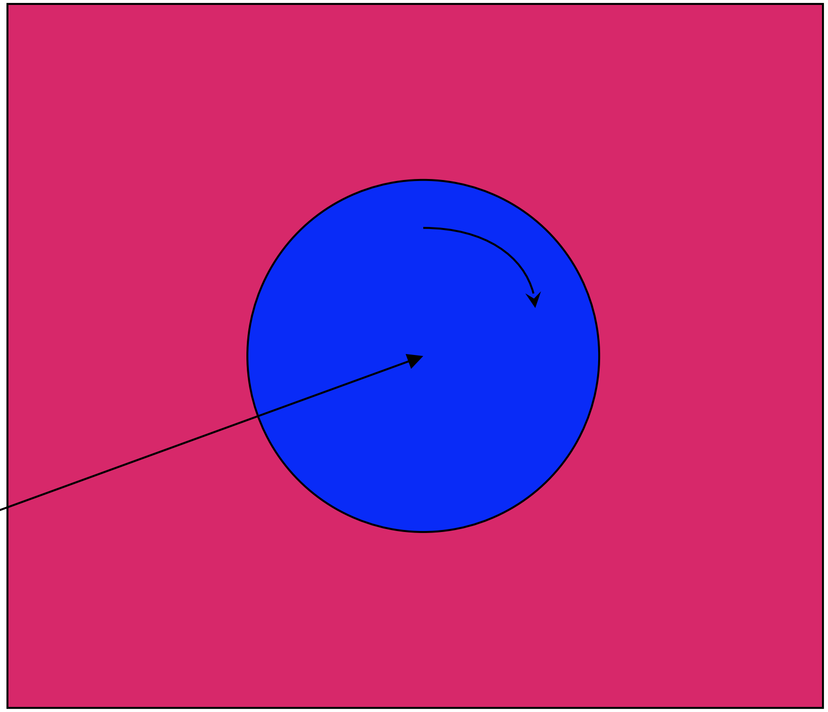


Plate tectonics on a flat earth: Two plates

Question: it that possible to have a plate who’s relative motion is constant at all directions?



pole of rotation

Plate tectonics on a spherical earth: Rotation axes and rotation poles

Euler's fixed point theorem: "Every displacement from one position to another on the surface earth can be regarded as a rotation about a suitably chosen axis passing through the center of the earth."

The axis of rotation is the suitably chosen axis passing through the center of the earth.

The poles of rotation or the Euler's poles are the two points where the axis of rotation cuts through the earth surface.

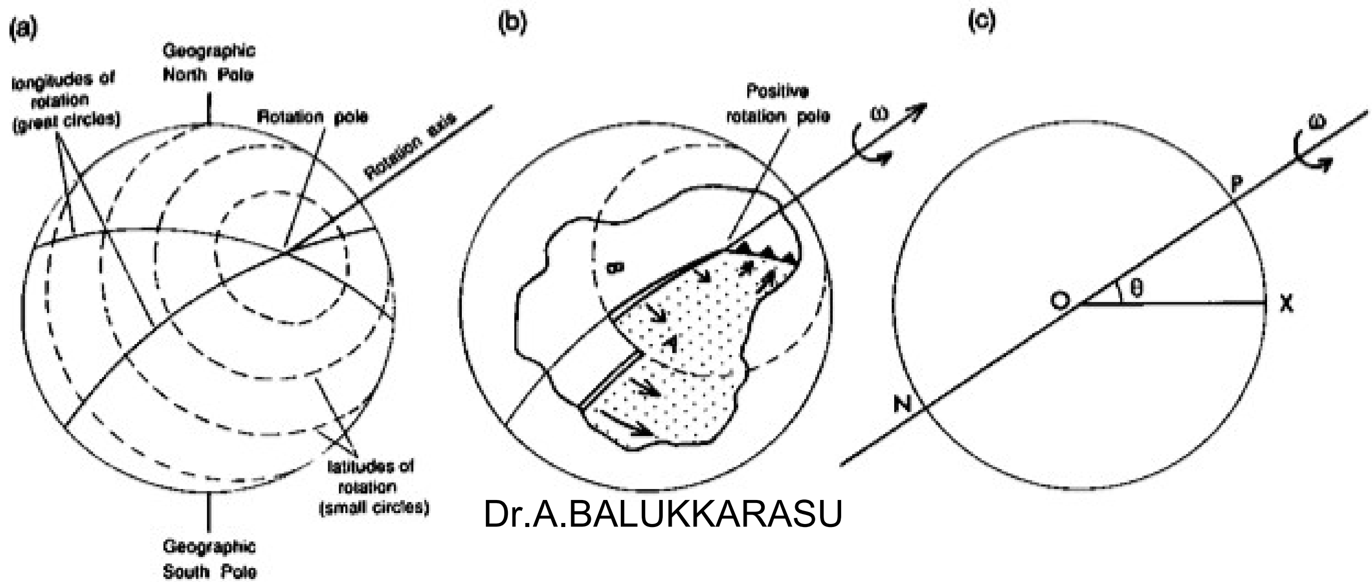


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Plate tectonics on a spherical earth: Angular velocity and relative velocity

• The relative velocity, v, of a certain point on the earth surface is a function of the angular velocity, ω, according to:

$$v = \omega R \sin\theta,$$

where R is the earth radius and θ is the angular distance between the pole of rotation and point in question.

• Thus, the relative velocity is equal to zero at the poles, where θ=0 degrees, and is a maximum at the equator, where θ=90 degrees.

• The relative velocity is constant along small circles defined by θ=constant.

• Note that large angular velocity does not mean large relative velocity.