Geodynamics

- Course website: http://www.tau.ac.il/~zivalon/geodynamics/
- Grade
- Reading assignments (user and password)
- Syllabus:

1. Plate tectonics, plate kinematics and space geodesy
2. Heat flow
3. Gravity
4. Geomagnetism

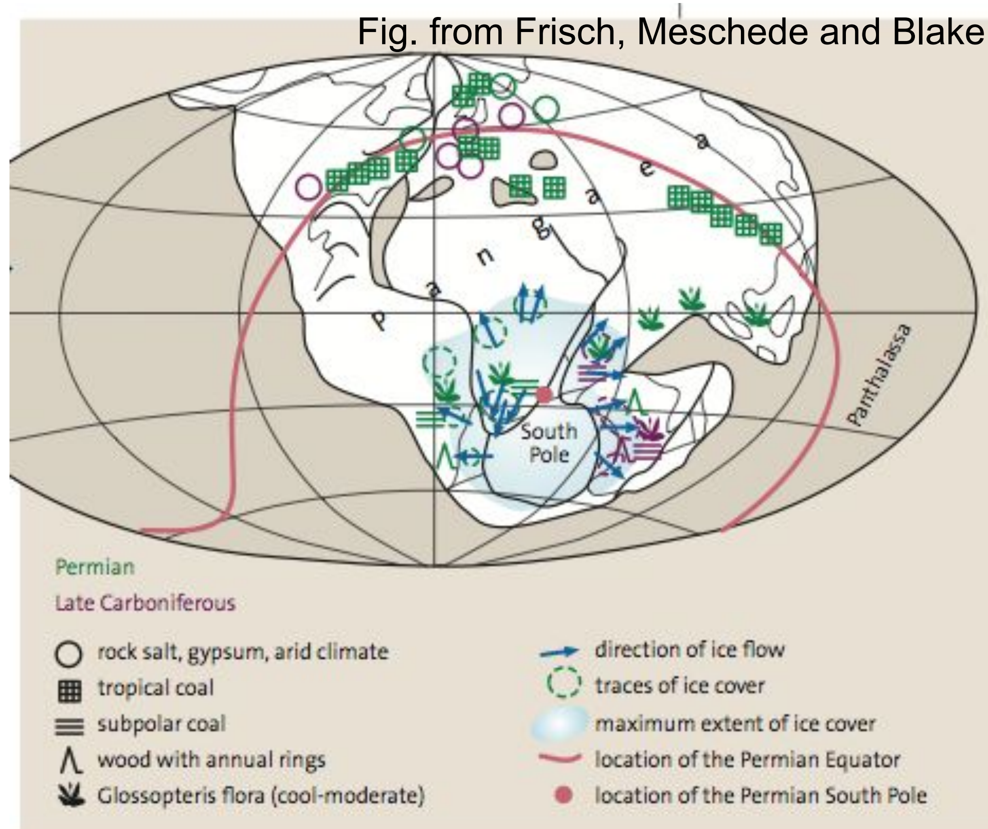
Plate tectonics I: Basic concepts

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

Important: This chapter follows mainly on chapter 1 in Cox and Hart textbook.

Reconstruction of the supercontinent Pangea by Wegener (1915)

Fig. from Frisch, Meschede and Blake



The diverse geological and climatological data from different continents fit like a jig-saw puzzle on this reconstruction.

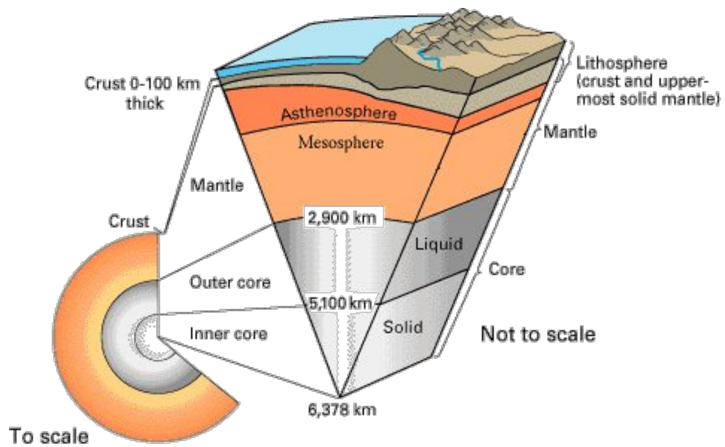
Wegener suggested that tidal forces or forces associated with the rotation of the Earth were responsible for the breakup of this continent and the subsequent continental drift.

Earth layering

Pre plate tectonics:

- Iron ore ~3500 km thick
- Mantle ~2900 km thick
- Crust 5-65 km thick

Co plate tectonics

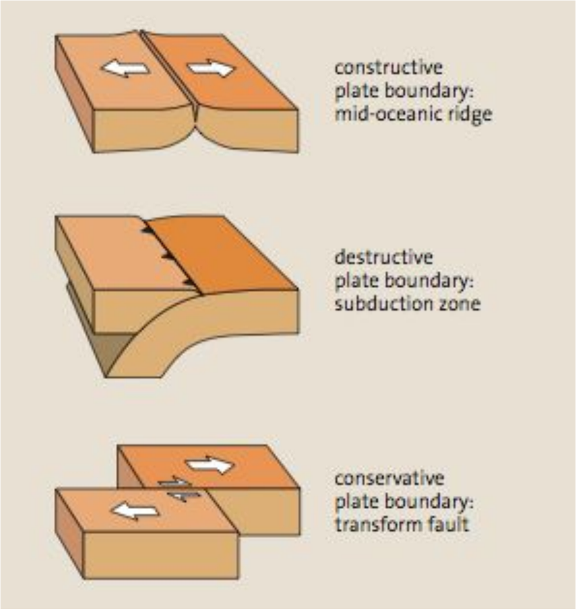


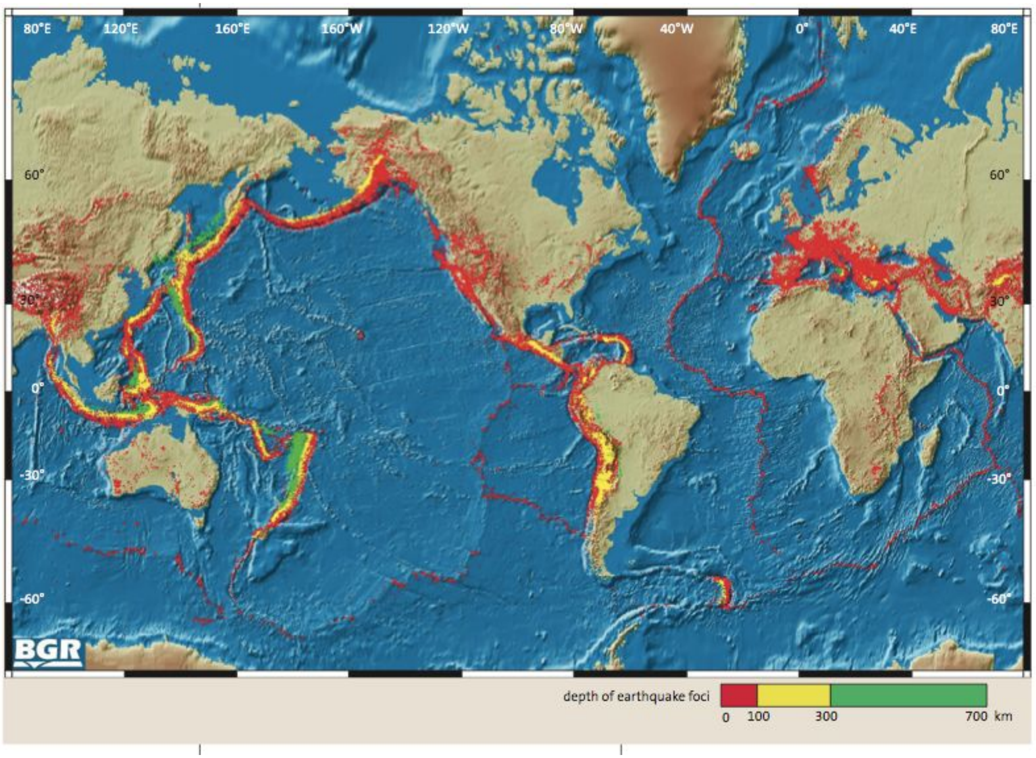
A new pair of layers is added, the lithosphere and the asthenosphere, based not on composition but on rheology, that is, how easily rocks flow.

B.t.w., the word “asthenosphere” was introduced already in 1914.

Plate geometry (Tuzo Wilson, 1965)

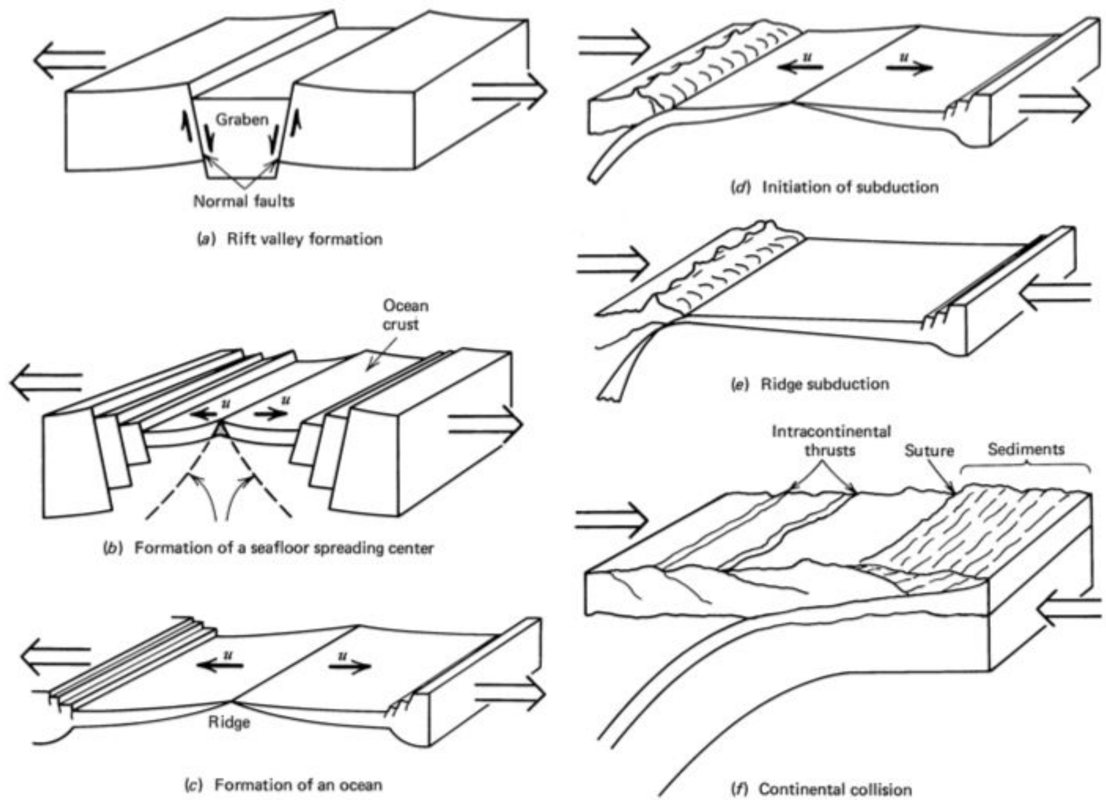
Wilson noted that movements of the earth's crust are concentrated in narrow mobile belts, some are mountain belts, some are deep-sea trenches, and some are mid-ocean ridges.





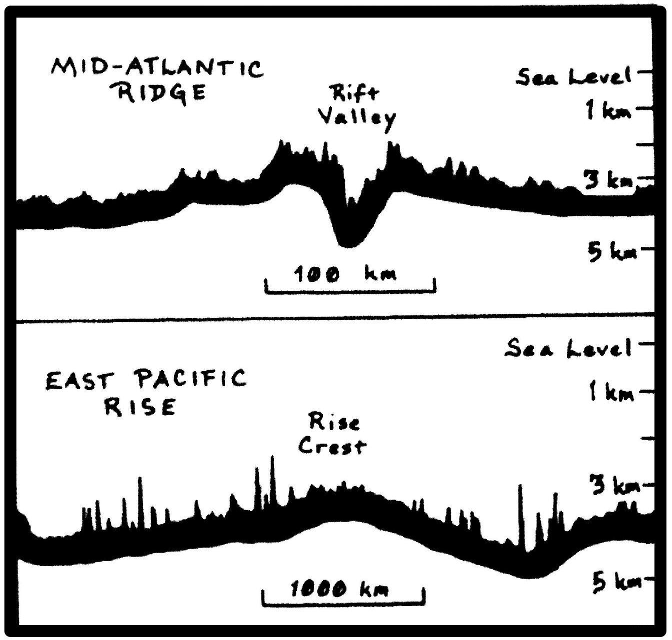
Figs. from Frisch, Meschede and Blake

Plate geometry (Tuzo Wilson, 1965)



Rises

Two physio-geographical provinces: the abyssal plains and the rises or ridges.



What was know is:

- Small-moderate size earthquakes occur at the crests of all rises
- The heat flow near the crest is unusually high
- The gravitational field is not nearly as great as it would be expected from the great mass of the rise.

Some early ideas:

- Oceans are old, probably Precambrian
- Earth was expanding and splitting apart (late 1950s)
- Expression of mantle convection (David Griggs)

Rises

Plate tectonic explanation of rises:

- New ocean floor is formed at the rises as molten rocks come from depth, solidifies near the ocean bottom and spread bilaterally in either direction away from the ridge.

- The rift at the crest of a rise is simply a few kilometers wide crack between two plates that are moving apart.

- The magma is drawn from adjacent parts of the asthenosphere rather than from a convection cell rising from deep in the mantle.

These explain:

- The absence of sedimentary rocks at the rise crests.
- Most earthquakes in the ocean occur within a narrow zone that is 10 km wide at the crest of the rises.
- The paleo-magnetic strips.

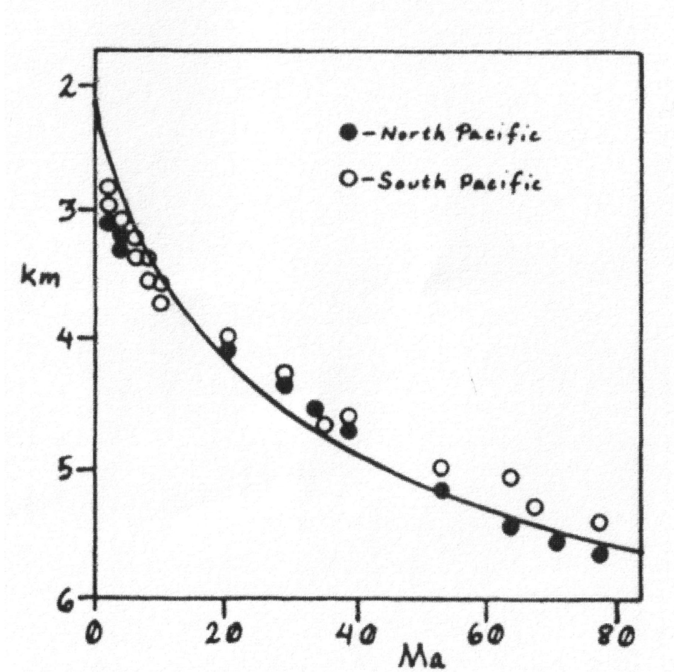
Rises

Plate tectonic explanation of high topography:

These enormous submarine mountain ranges are isostatically compensated.

$$\text{topography} = C\sqrt{\text{age}}$$

C~300.



According to this view, the differences in slope are due to different spreading rate – the slopes of fast spreading seafloor are less steep than that of slow spreading ocean.

Trenches and island arcs

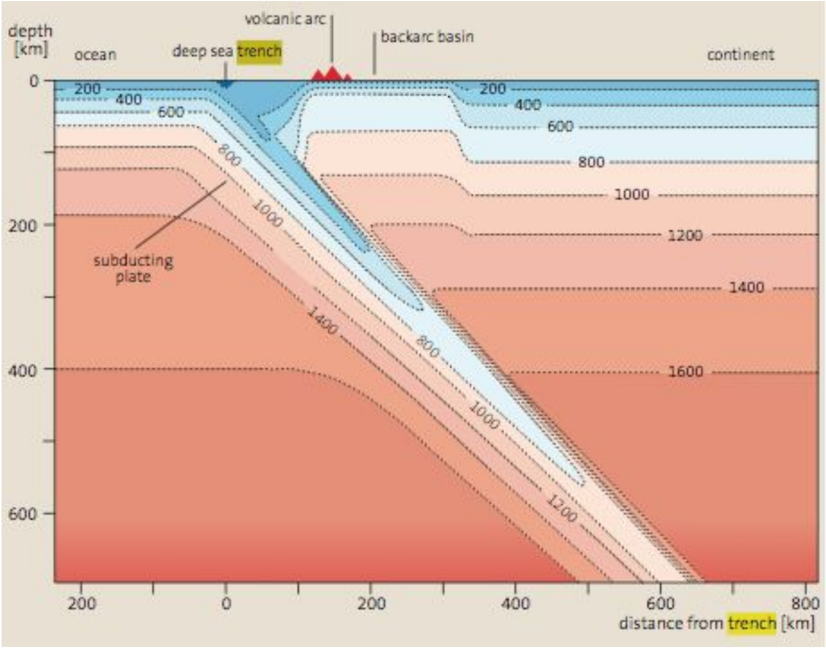
The deepest points on earth occur in trenches.

- Most seismic activity occur along belts on one side of the trenches.
- A belt of volcanoes is almost always found on the same side of the trench as the the belt of deep earthquakes.
- The volcanoes have a mineralogy and chemistry termed andesitic, that is different from volcanoes that form far away from the trenches

Trenches and island arcs

The plate tectonics explanation

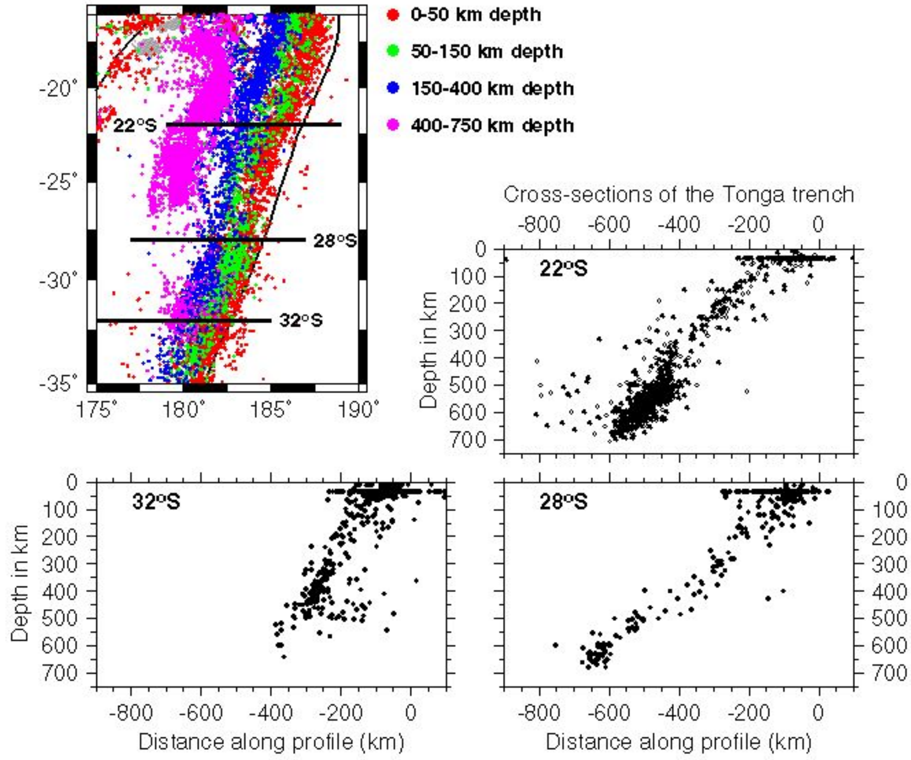
- A trench is a place where the oceanic lithosphere bends downward and sinks into the asthenosphere beneath the overriding plate – a process termed subduction.



- The sinking slab tends to carry its isotherms with it. As a result, the slab remains colder than the asthenosphere around it and brittle enough to generate earthquakes.

Trenches and island arcs

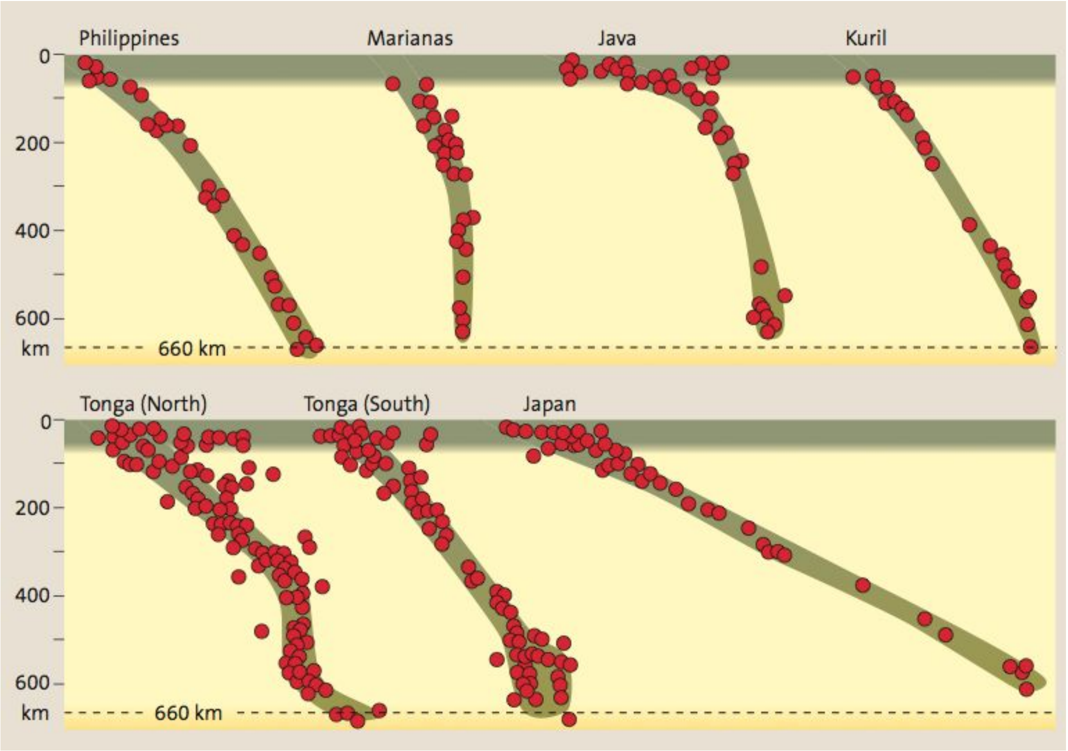
- The slab's earthquakes lie along planes called Benioff-Wadati zones.



Tonga-Kermadec subduction zone in the southwestern Pacific

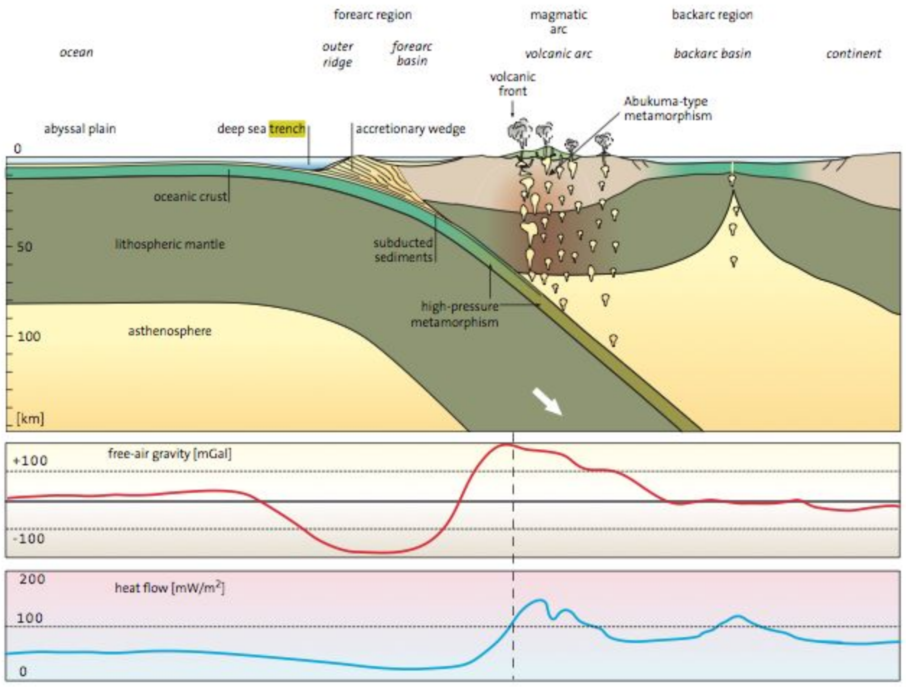
Trenches and island arcs

- The earthquakes lie along planes called Benioff-Wadati zones.
- Where the upper surface of the subducting slab has sunk to a depth of about 100 km, volcanoes form above the slab.
- Volcanic belts are close to the trenches if the subduction zone dips steeply and far from the trench if it dips gently.



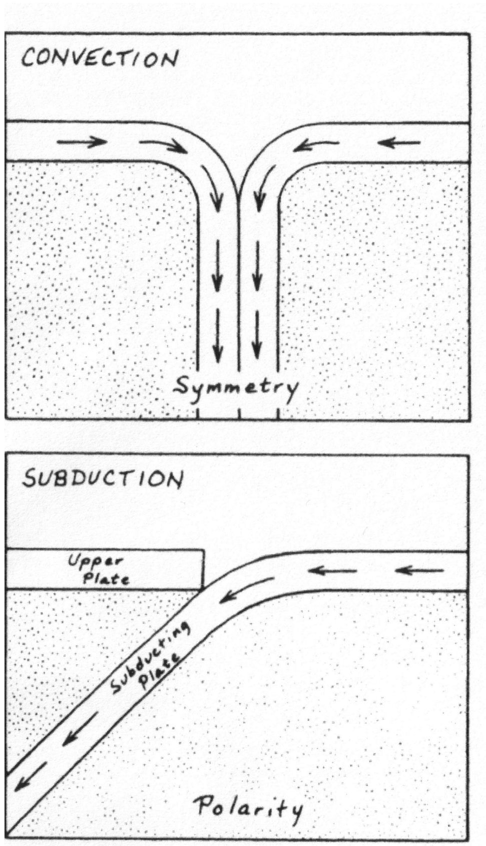
Trenches and island arcs

- The belt of low gravity along the trench reflects the fact that at the trench, the sea floor is being actively dragged down by the dynamics of subduction.



Trenches and island arcs

- Many elements of plate tectonics were already anticipated by proponents of mantle convection.
- An important innovation of plate tectonics is the emphasis it places on the polarity of subduction zones.



Trenches and island arcs

Subducting plate	Upper plate	Example
Oceanic	Oceanic	Marianas
Oceanic	Continental	Peru
Continental	Continental	Himalayas
Continental	Oceanic	?

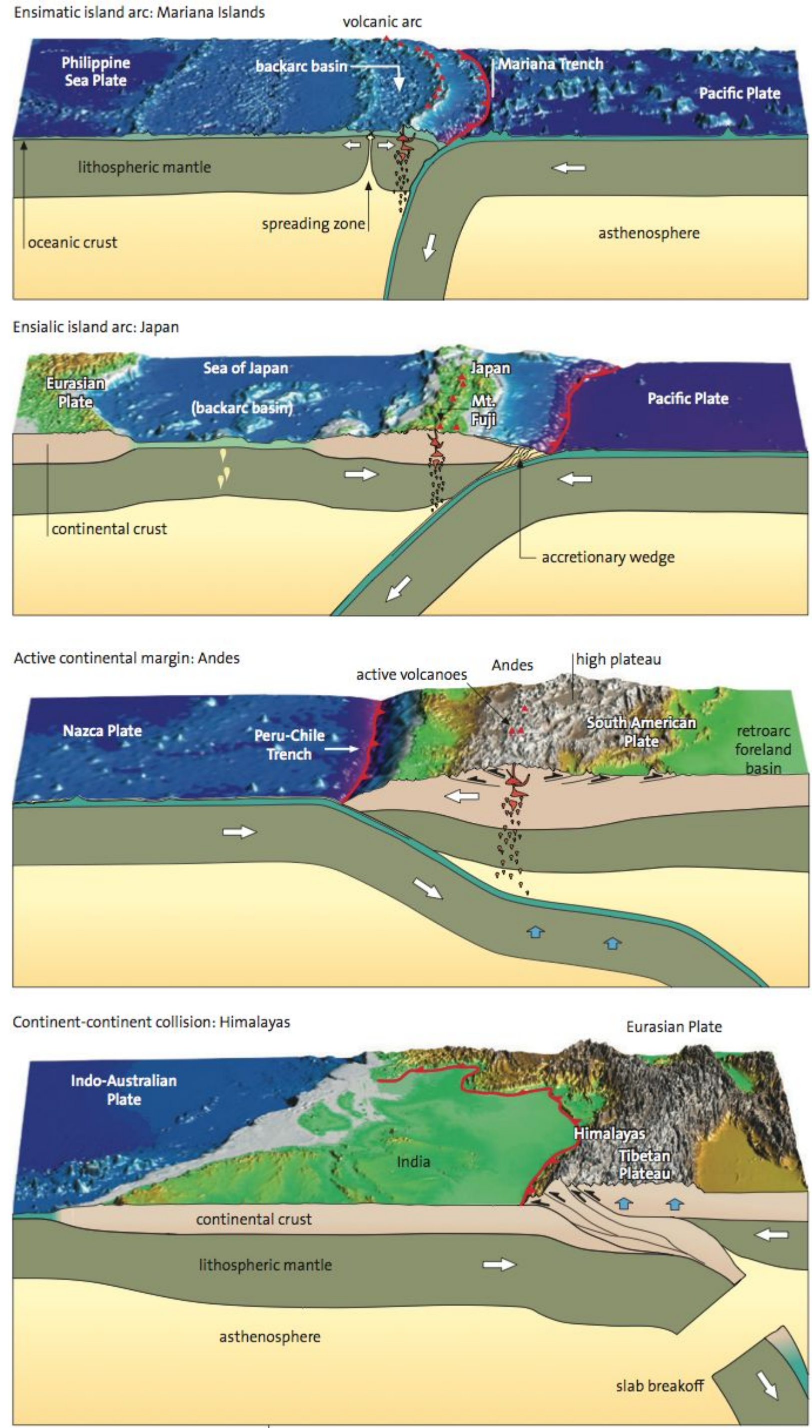
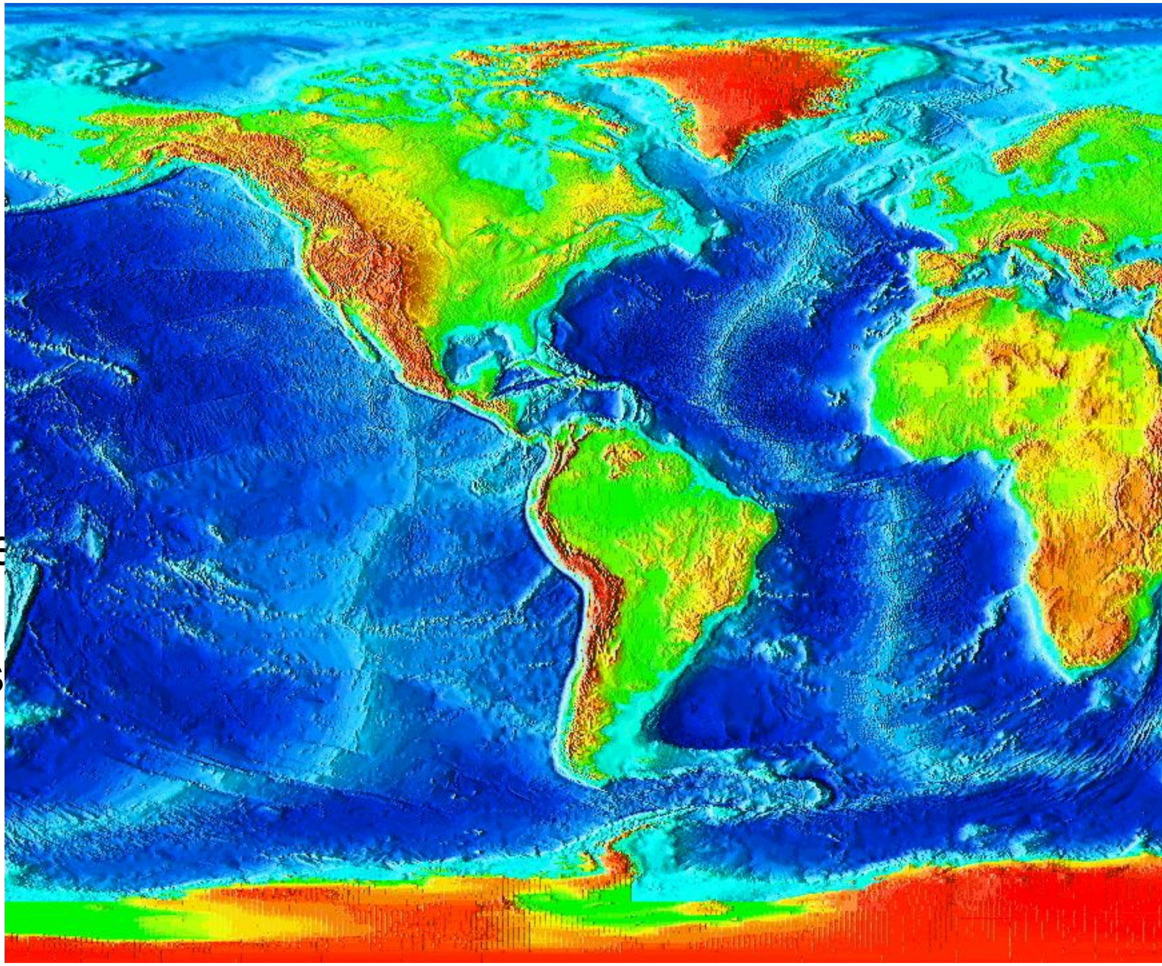


Fig. from Frisch, Meschede and Blake

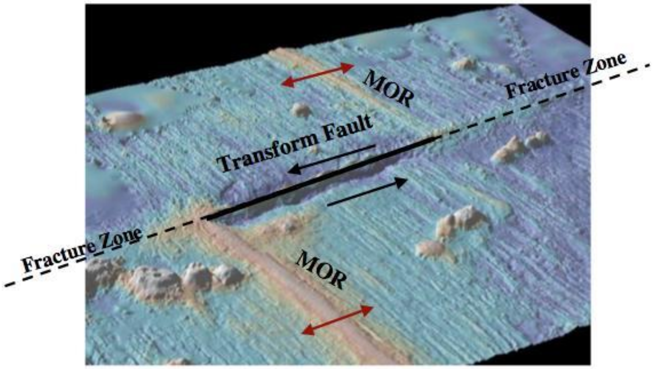
Fracture zones

- Long, narrow mountain ranges that were discovered in the early 1950s.
- The depth of the of the ocean floor commonly changes across a fracture zone.
- On a map, fracture zones are arcuate features of great length.

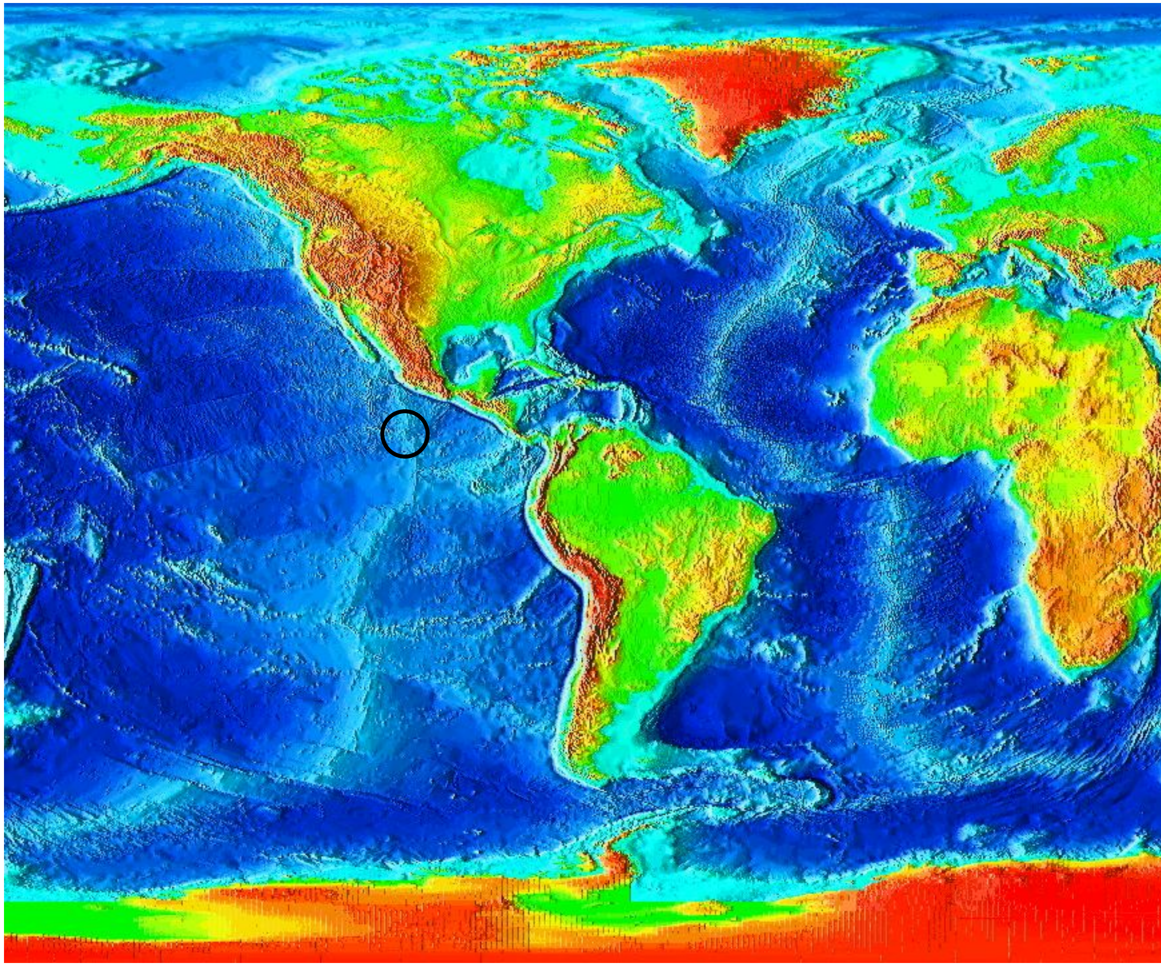


Fracture zones

- Fracture zones have many of the characteristics of transform faults, as they seem to offset mid-ocean rises and magnetic anomalies.

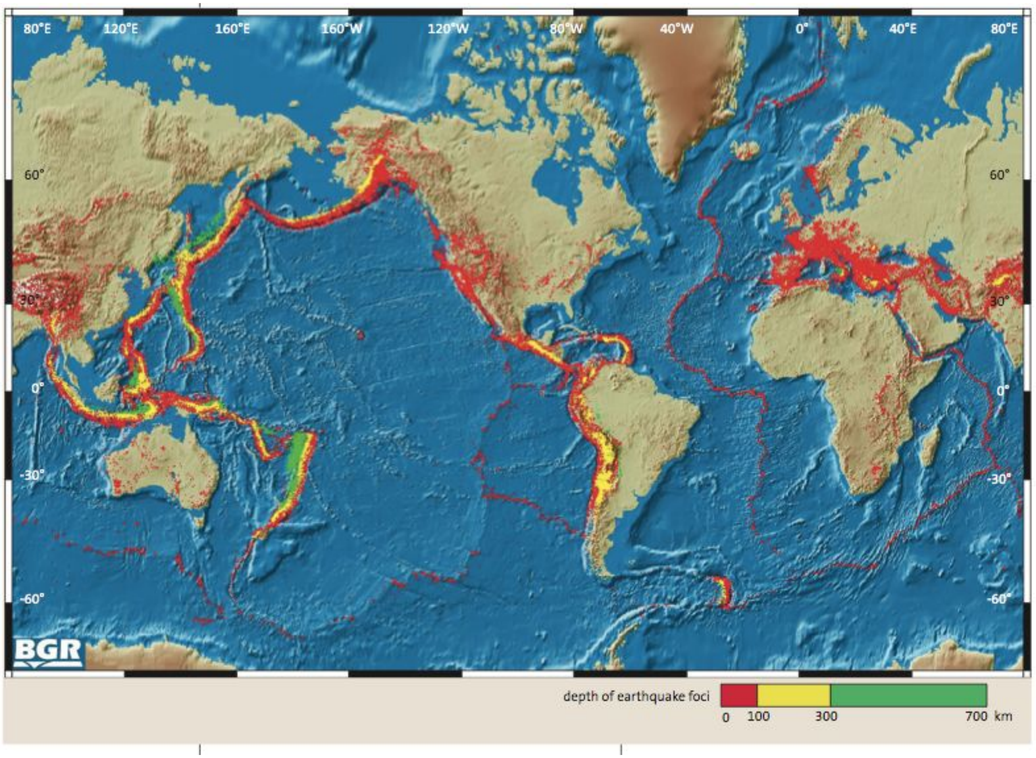


Clipperton Fracture Zone (EPR - 9º N) Pockalny (1997)
Offset = 85 km (~1.5 Myr age offset), Slip Rate ~107 mm/a



Fracture zones

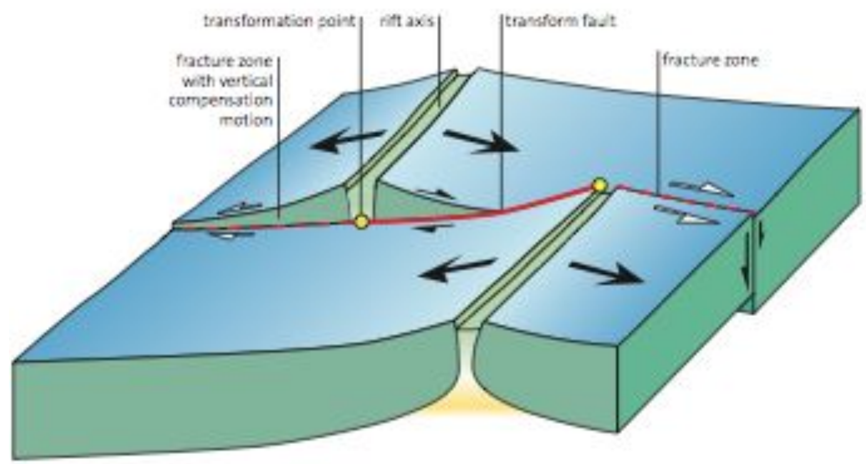
- If fracture zones were regular faults, they should be characterized by vigorous seismicity along their entire length.
- The occurrence of earthquakes along fracture zones is intermittent; they only occur along parts of the fracture zones that are between two seemingly offset rise crest.



Fracture zones

The plate tectonics explanation:

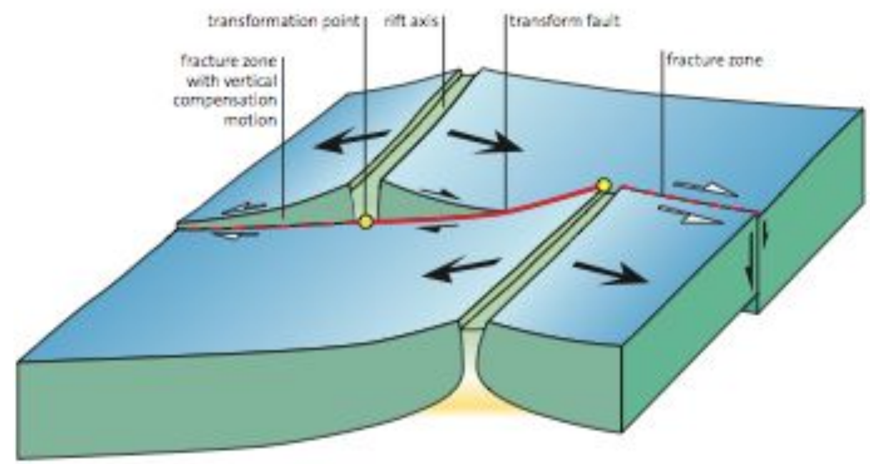
- The boundaries between the two plates initially formed in a stair-step pattern of perpendicular ridges and transforms.
- The amount of offset today is the same as at the time of formation.
- Between two rise crests, rocks on opposite sides of the transform are moving past each other as fast as 100 mm/year.
- Beyond the zone between the rise crests, rocks on opposite sides are moving together.



Fracture zones

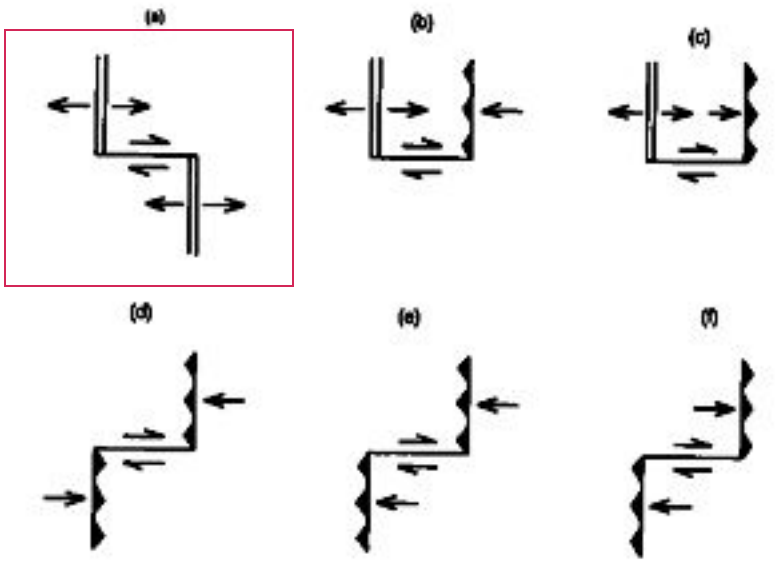
The plate tectonics explanation:

- Rocks on either side of the fracture zone are of different ages, therefore have subsided by different amounts.
- The greater the amount of ridge crest offset across a transform, the greater the age difference and the difference in ocean depth.



Fracture zones

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



Summary of 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.

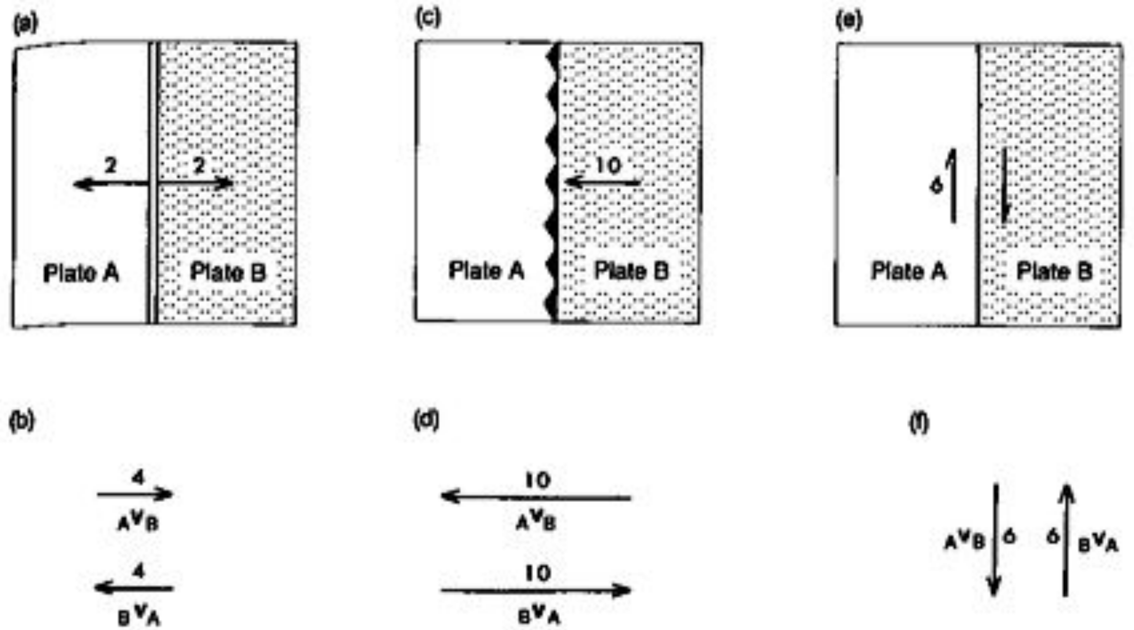
- The new oceanic lithosphere, once created, forms part of a rigid plate.

- 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.

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

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



$$ {}_AV_B = -{}_BV_A $$

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 $_AV_B$ 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}.

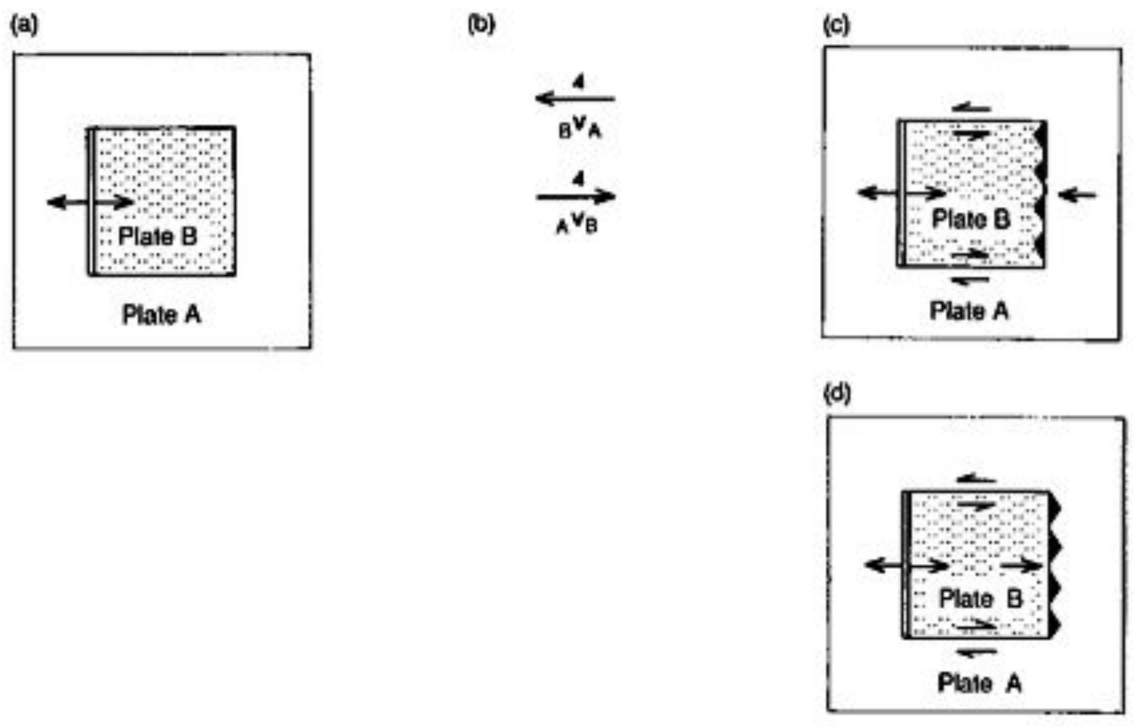


Plate tectonics on a flat earth: Three plates

- 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}.

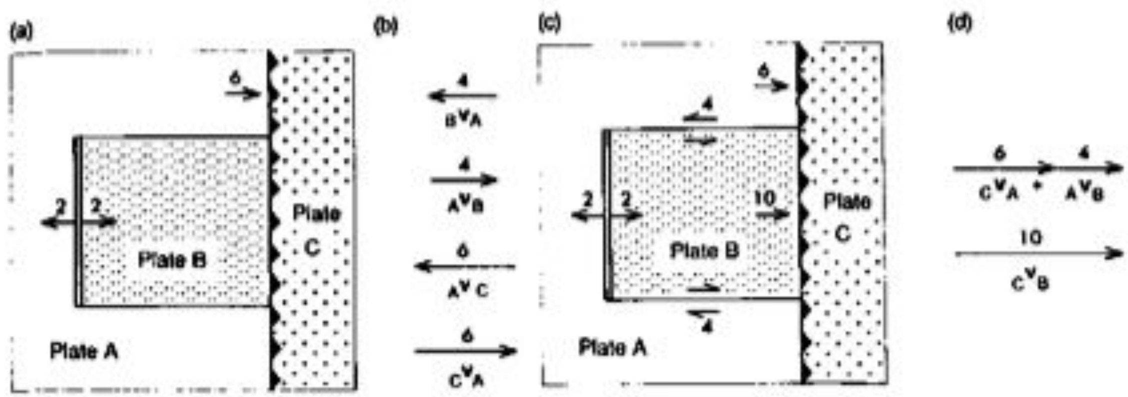


Plate tectonics on a flat earth: Three plates

- 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.