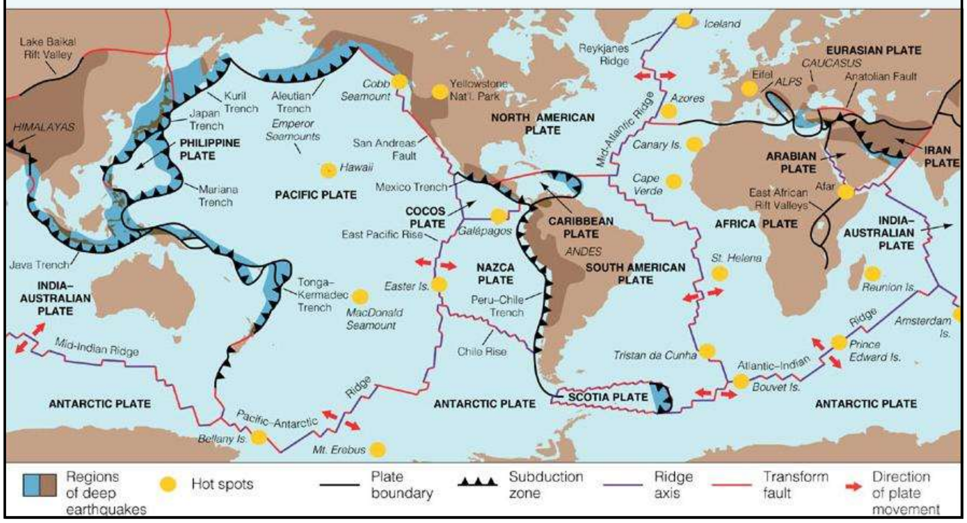
OCN 201
Seafloor Spreading and Plate Tectonics



Question

What was wrong from Wegener's theory of continental drift?

A. The continents were once all connected in a single supercontinent

B. The continents slide over ocean floor

C. The continents are still moving today

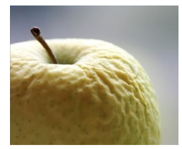
D. All of them are correct

Tectonics theories

Tectonics: a branch of geology that deals with the major structural (or deformational) features of the Earth and their origin, relationships, and history

Late 19th century

- **Shrinking Earth theory**: mountain ranges formed from the contraction and cooling of Earth's surface
- **Expansion of the Earth due to heating**: to explain why continents are broken up



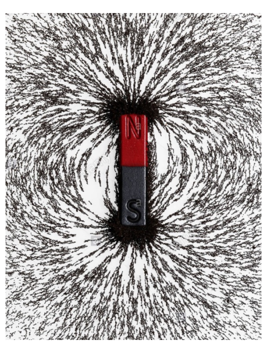
Vertical motion

20th century → A new way of thinking about the Earth!

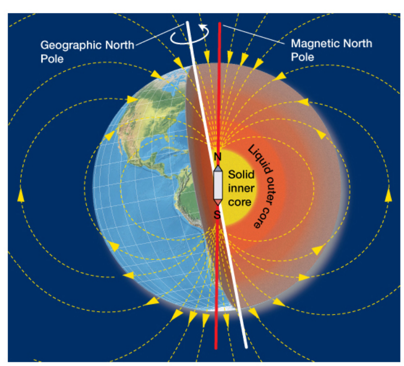
- **Continental drift theory**
- **Seafloor spreading theory**
- **Plate tectonics theory**

Horizontal motion

Earth's Magnetic Field

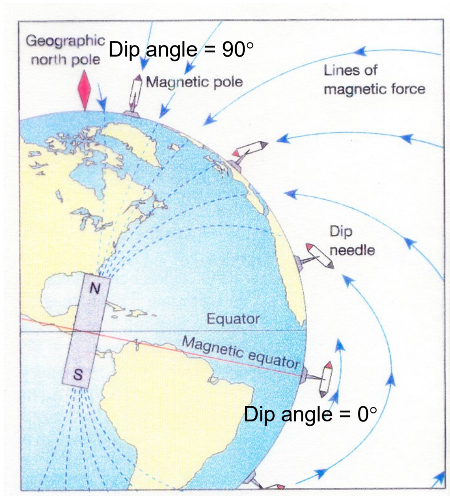


A bar magnet with Fe filings aligning along the "lines" of the magnetic field



Earth's magnetic field simulates a bar magnet, but is caused by convection of Fe in the outer core: the ***Geodynamo…***

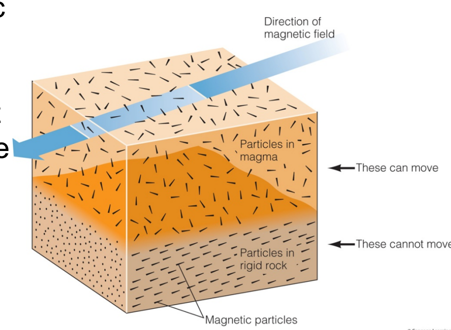
Earth's Magnetic Field



- Earth's magnetic field is toroidal, or "donut-shaped"
- A freely moving magnet lies horizontal at the equator, vertical at the poles, and points toward the "North" pole
- **Magnetic inclination**: angle between the magnet and Earth's surface
- By measuring the inclination and the angle to the magnetic pole, one can tell position on the Earth relative to the magnetic poles

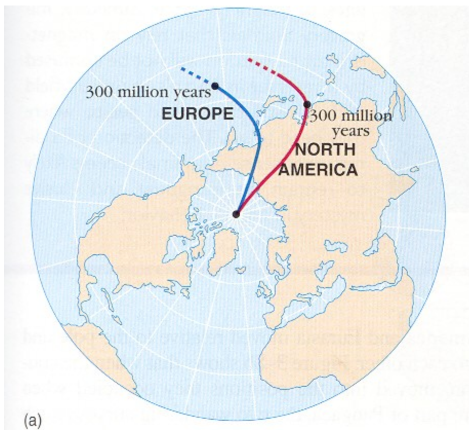
Paleomagnetism

- Igneous rock contains magnetic minerals, such as magnetite (Fe_3O_4), which align with Earth's magnetic field and point towards the magnetic north pole before they solidify
- Once the rocks solidify, this magnetic alignment is "frozen" and retained if rock is not subsequently reheated



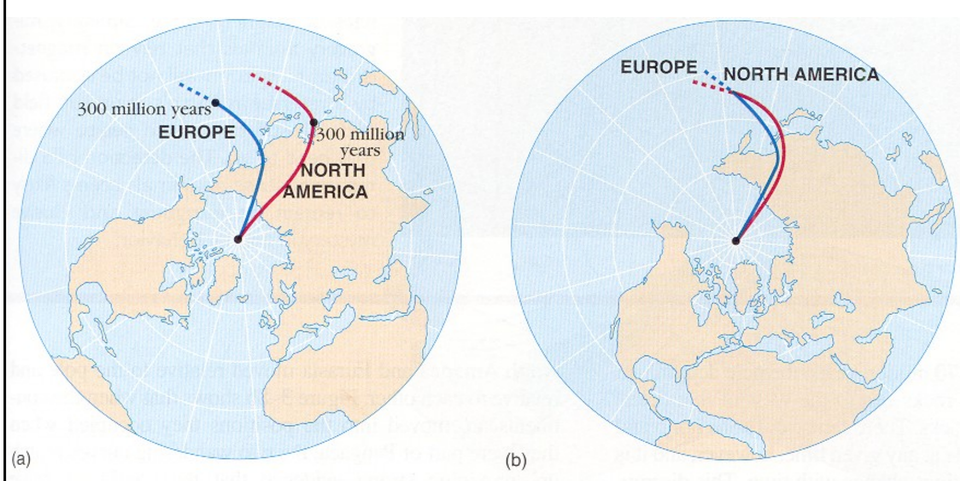
- Can use this information to determine:
  - Direction and polarity of Earth magnetic field
  - Paleolatitude of rock from inclination
  - Apparent position of N and S magnetic poles

Apparent Polar Wander Paths



- Paleomagnetic data from continental rocks: position of magnetic North pole has apparently changed over time
- Rocks from different continents gave different paths! Divergence increased with age of rocks

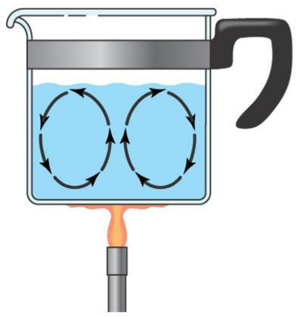
Apparent Polar Wander Paths

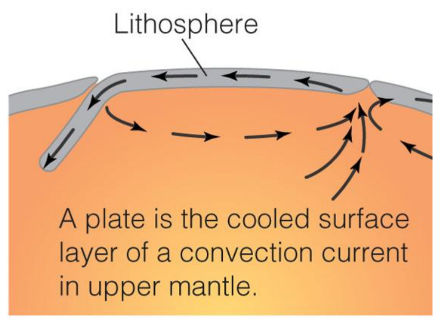


Magnetic poles have never been more the 20^{o} from geographic poles of rotation; rest of apparent wander results from ***motion of continents***!

Mantle convection and seafloor spreading

- **Arthur Holmes** hypothesized in 1931 that the mantle underwent convection, suggesting a mechanism that could explain Wegener's theory of continental drift
- He warned that his ideas were "purely speculative"
- Evidence to support this fundamental concept had to wait for ~30 years

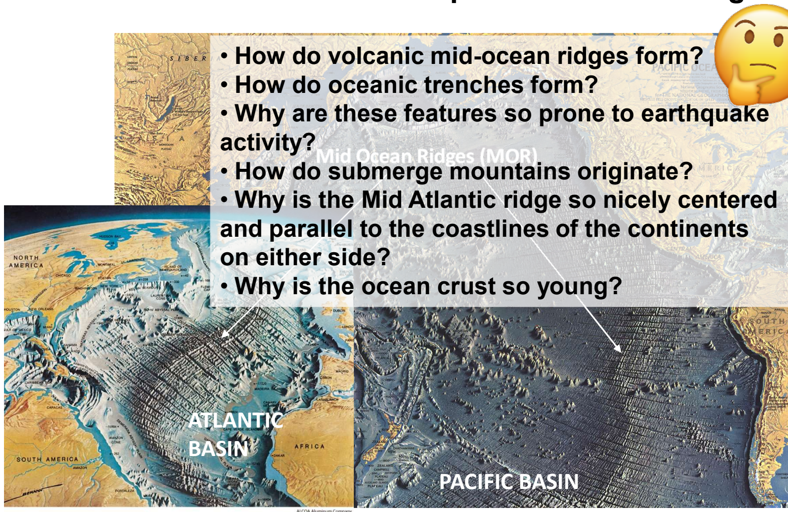




Extensive mapping of the seafloor

Sonar data revealed presence of extensive ridges near the center of ocean basins and deep trenches at the edge

- **How do volcanic mid-ocean ridges form?**
- **How do oceanic trenches form?**
- **Why are these features so prone to earthquake activity?**
- **How do submerge mountains originate?**
- **Why is the Mid Atlantic ridge so nicely centered and parallel to the coastlines of the continents on either side?**
- **Why is the ocean crust so young?**



Question

Where do we find the oldest oceanic crust?

A. In continental margins

B. Away from the oceanic ridges

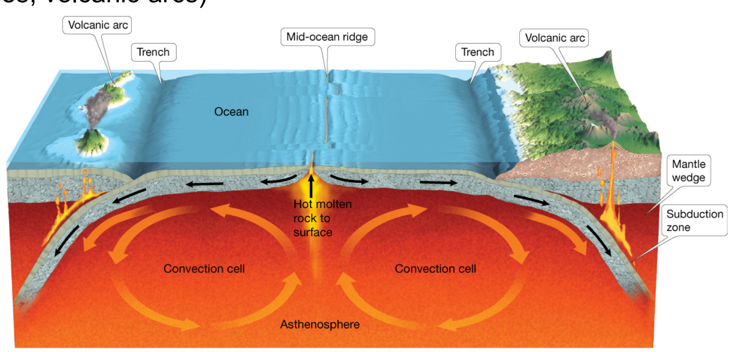
C. At the oceanic ridges

D. In volcanic islands

Seafloor Spreading

Proposed by Harry Hess and Robert Dietz in the early 1960s

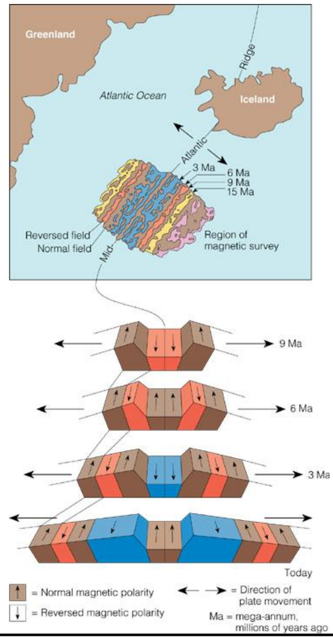
- Convective flow in the mantle causes the Earth's outer shell to move (building on Holme's idea from the 1930s)
- Mantle upwells at Mid Oceanic Ridge (MOR)
- New oceanic crust is created at the MOR, it is split in two and carried away from the MOR spreading axis towards the edges of the basin
- Oceanic crust is dragged down at trenches (compression, mountain ranges, volcanic arcs)



Seafloor Spreading: Evidence

Paleomagnetic evidence: Vine and Matthews (1963)

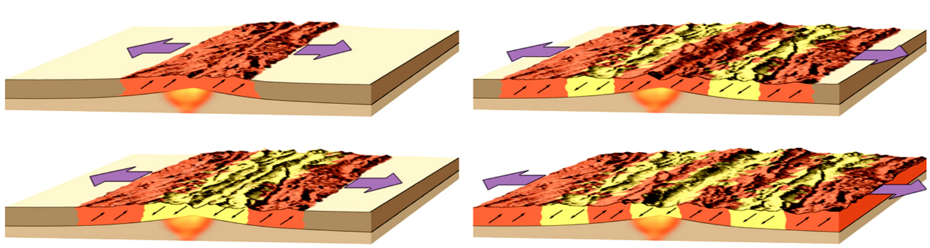
- Magnetic surveys found alternating and symmetric stripes of reversed and normal polarity across the seafloor
- Earth's magnetic field reverses at irregular intervals
- The pattern was symmetrical because freshly magnetized rocks are spread apart and carried away from the ridge by plate movement



Seafloor Spreading: Evidence

Paleomagnetic evidence: Vine and Matthews (1963)

Symmetry of magnetic reversals confirmed that seafloor is spreading!

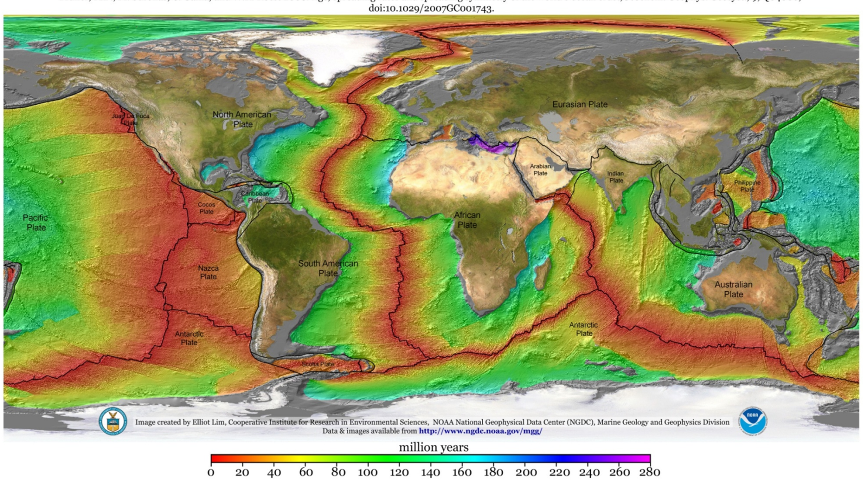


Seafloor Spreading: Evidence

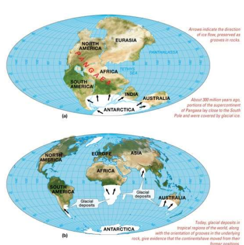
1970 Deep Sea Drilling Project: Age of Seafloor

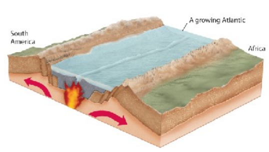
Age of Oceanic Lithosphere (m.y.)

Data source:
Muller, R.D., M. Sdrolias, C. Gaina, and W.R. Roest 2008. Age, spreading rates and spreading symmetry of the world's ocean crust,Geochem. Geophys. Geosyst., 9, Q04006, doi:10.1029/2007GC001743.

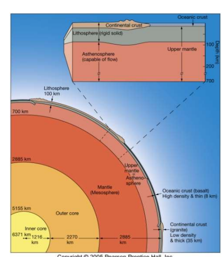


The Theory of Plate Tectonics Scientific revolution

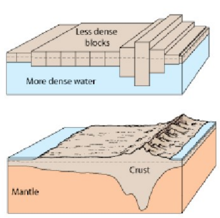

Continental Drift



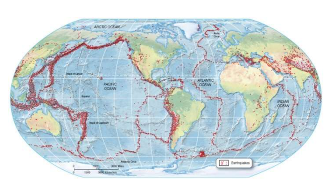
Seafloor Spreading



Earth's Interior

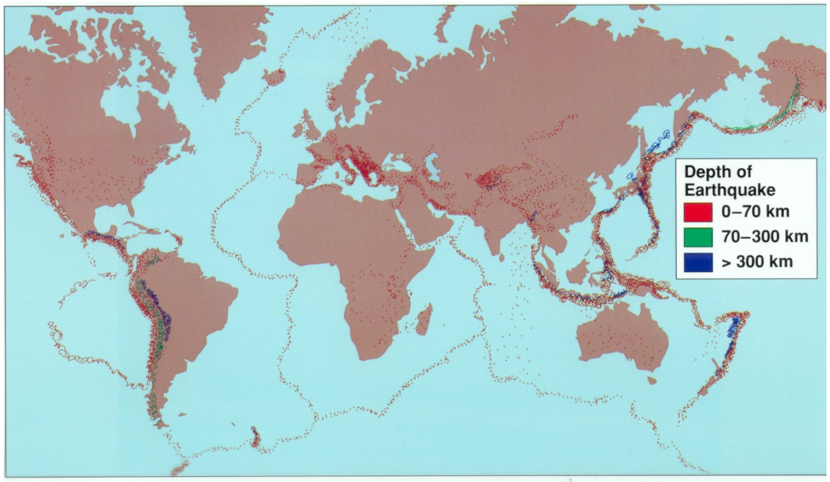


Isostasy


Earthquakes

Global seismicity

Zones of concentrated earthquakes were found in regions of crustal formation (spreading centres) and crustal destruction (subduction zones)



Question

Where do most earthquakes happen?

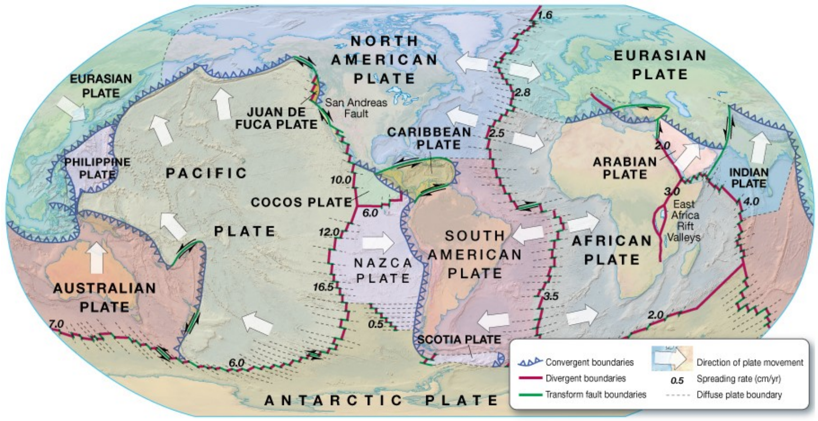
A. At mid-oceanic ridges

B. At subduction zones

C. At plate boundaries

D. Earthquakes are randomly distributed

The Theory of Plate Tectonics



- Formulated by J. Tuzo Wilson (1965)
- Incorporates concepts from continental drift and seafloor spreading
- Lithosphere is broken up into mobile rigid slabs called ***lithospheric plates***
- The lithospheric plates “float” on the asthenosphere

The Theory of Plate Tectonics

- The plate motion is driven by ascending mantle material (convection) and slab pull (pulling of plate at subduction zones).
- New seafloor is created at MORs (***spreading centers***), old seafloor is destroyed at plate boundaries (***subduction zones***)
- Interactions of plates produce most of the tectonic activity of the Earth
- Plate tectonics **remakes the surface of Earth**, expands and split continents, and forms and destroys ocean basins

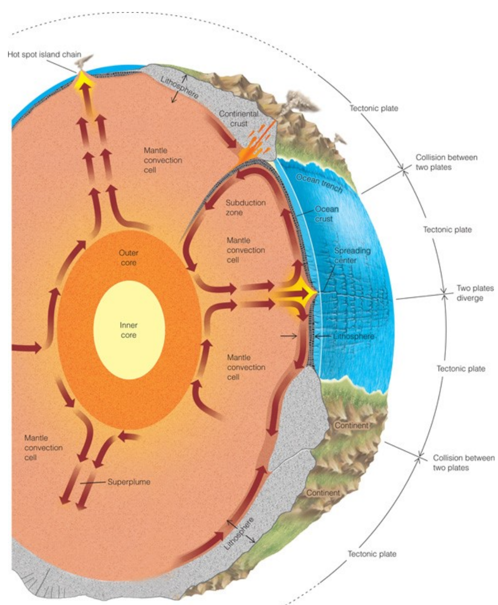


Plate Boundaries

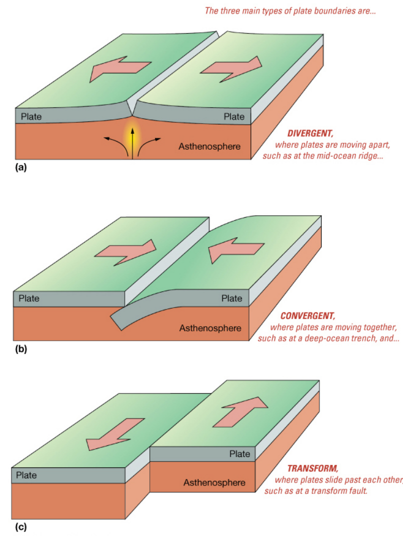
Three types of plate boundaries and interactions:

1. Divergent Boundary
Oceanic Ridges: seafloor spreading
Creation of new oceanic plate

2. Convergent Boundary
Subduction Zone: denser plate subducts
Destruction of old oceanic plate

3. Conservative Boundary
Transform Faults: plates slide past each other
No creation or destruction

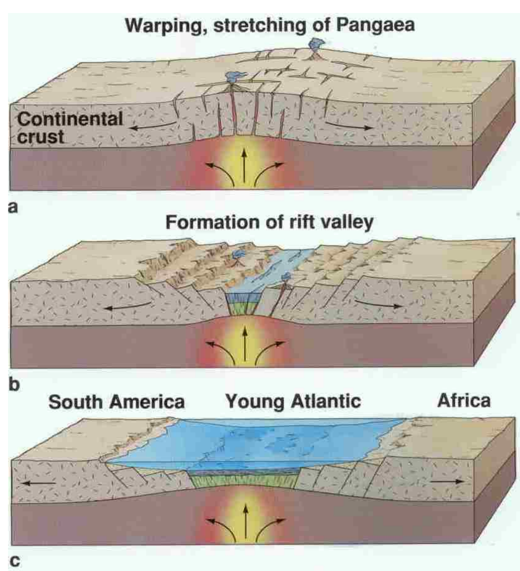
Earth's size is fixed so destruction of plate must be balanced by new construction



Divergent plate boundaries

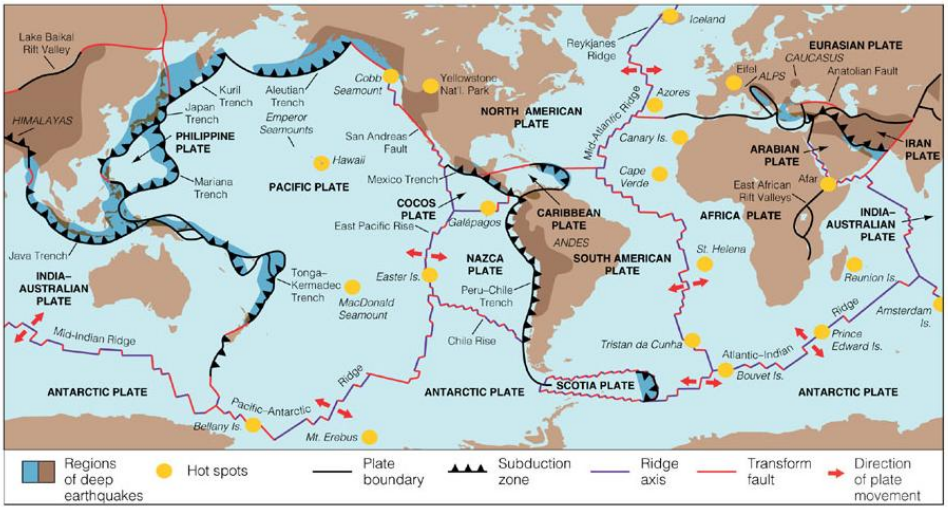
Ocean ridges

- Shallow seismicity
- Basaltic volcanism
- High heat flow
- Zero to very young crustal age
- Absent to thin sediment cover
- Tensional stress, produces rifting
- Half spreading rates: 1-8 cm/yr

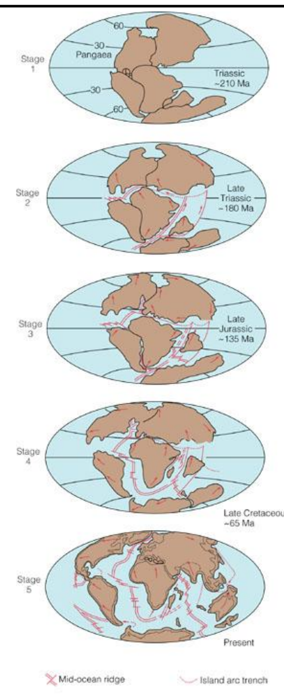


Model for the formation of a new plate boundary

World's lithospheric plates

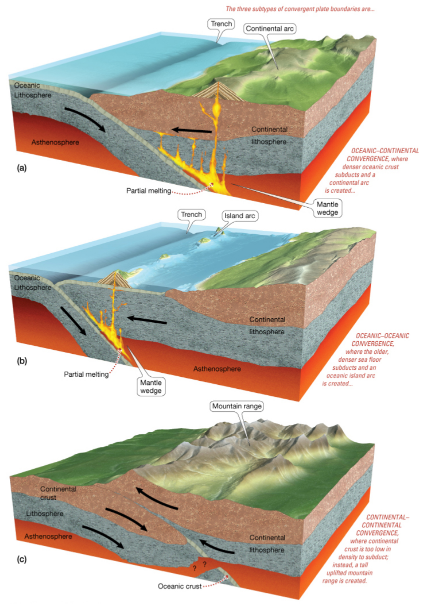


Breakup of Pangaea



- Comparable to current day situation in East Africa Rift
- Demonstrates how initiation of seafloor spreading leads to formation of new ocean basins

Convergent Plate Boundaries



Oceanic-Continental

- Deep sea trenches and earthquakes
- Denser oceanic plate subducted
- Volcanic Arc at edge of continent (Andes)

Oceanic-Oceanic

- Trench (Mariana Trench)
- Deep Earthquakes
- Denser plate subducts
- Island Arc: Aleutians, Indonesia, Marianas

Continental-Continental

- No subduction occurs, crust very thick
- Tall mountains
- Collision of India with Asia, Himalayan Chain

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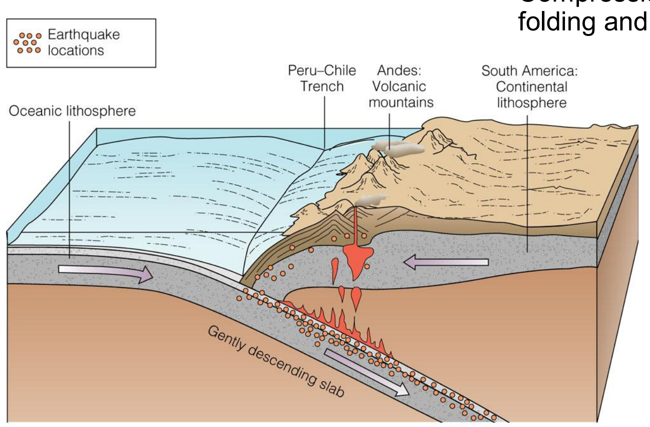
Oceanic-Continental Convergence

- Ocean plate is subducted
- Volcanic arc at edge of continent, explosive andesitic volcanic eruptions
- Deep sea trenches
- Low heat flow at trench, high heat flow under volcanic arc
- Thick sediment cover
- Old crustal age
- Compressional stress produces folding and thrust faulting

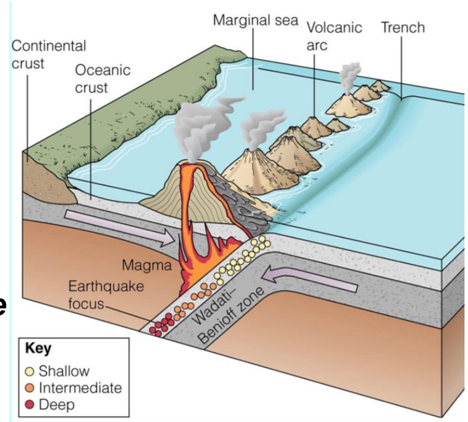


Subduction Zone

Oceanic-Oceanic Convergence

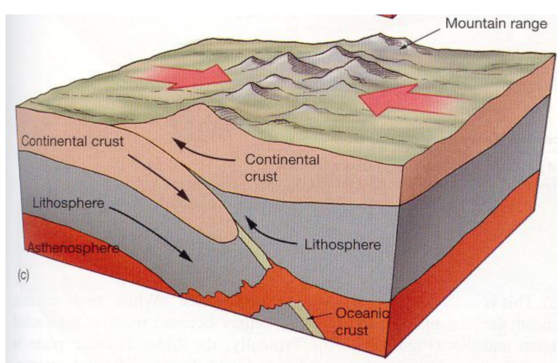
- Denser plate is subducted
- Deep trenches generated
- Volcanic **island arcs** generated (e.g. Japan island arc, Aleutians, Indonesia, Marianas)
- Volcanic island arc lies ***above*** the down-going slab

Subduction Zone



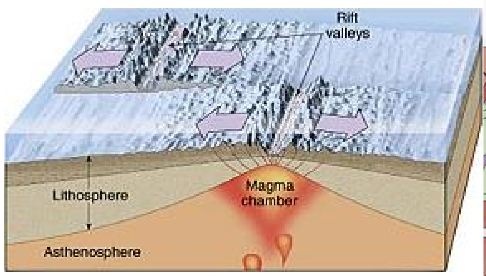
Continental-Continental Convergence

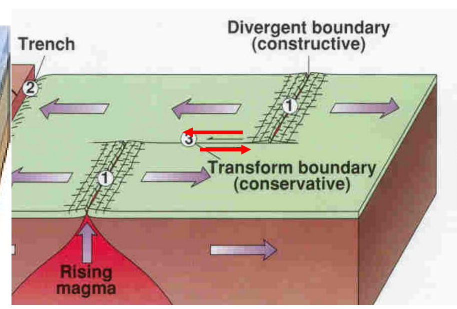
- No subduction
- Crust twice as thick
- Tall mountains uplifted (e.g. Himalayas)
- Continental crust is too buoyant to subduct



Conservative Boundaries: Transform Faults

- Active zone of movement along a vertical fault plane located between two offset segments of ridge axis
- Relative motion is in opposite direction to that which would have produced such an offset in the absence of seafloor spreading
- San Andres fault is one of the largest transform faults





World's lithospheric plates

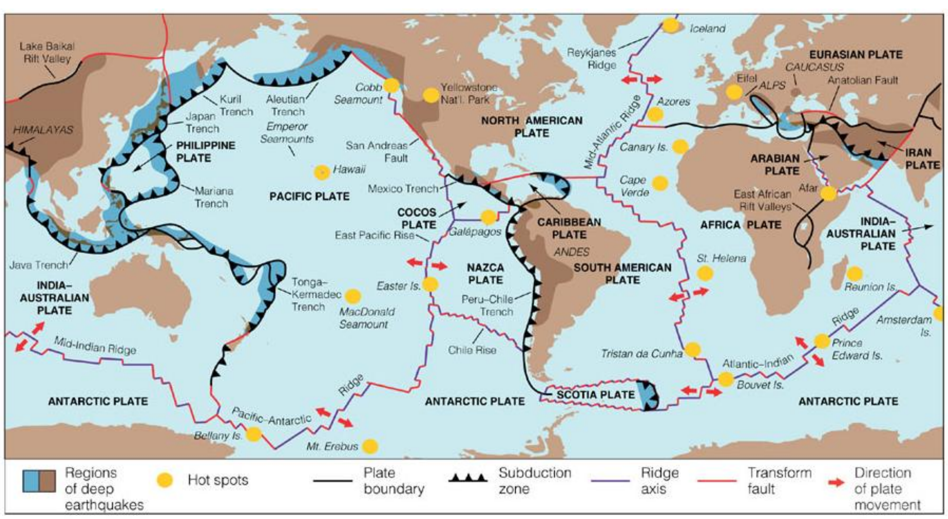
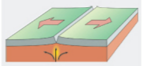
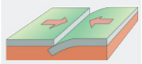
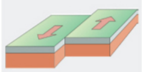


Plate boundaries: summary

SmartTable 2.1 CHARACTERISTICS, TECTONIC PROCESSES, FEATURES, AND EXAMPLES OF PLATE BOUNDARIES

Plate boundary	Plate movement	Crust types	Sea floor created or destroyed?	Tectonic process	Sea floor feature(s)	Geographic examples
Divergent plate boundaries	Apart 	Oceanic–oceanic	New sea floor is created	Sea floor spreading	Mid-ocean ridge; volcanoes; young lava flows	Mid-Atlantic Ridge, East Pacific Rise
		Continental–continental	As a continent splits apart, new sea floor is created	Continental rifting	Rift valley; volcanoes; young lava flows	East Africa Rift Valleys, Red Sea, Gulf of California
Convergent plate boundaries	Together 	Oceanic–continental	Old sea floor is destroyed	Subduction	Trench; volcanic arc on land	Peru–Chile Trench, Andes Mountains
		Oceanic–oceanic	Old sea floor is destroyed	Subduction	Trench; volcanic arc as islands	Mariana Trench, Aleutian Islands
		Continental–continental	N/A	Collision	Tall mountains	Himalaya Mountains, Alps
Transform plate boundaries	Past each other 	Oceanic	N/A	Transform faulting	Fault	Mendocino Fault, Eltanin Fault (between mid-ocean ridges)
		Continental	N/A	Transform faulting	Fault	San Andreas Fault, Alpine Fault (New Zealand)

Question

The motion of lithospheric plates across the Earth's surface is caused by:

A. The Geodynamo

B. Centrifugal force and Earth rotation

C. Convection in Earth's mantle

D. The shrinking Earth

E. Continental drift