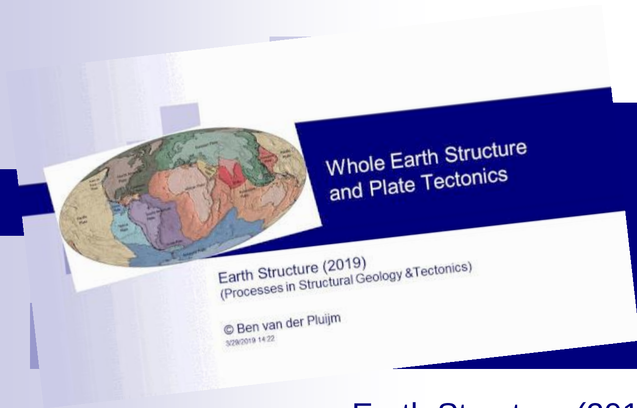


Whole Earth Structure and Plate Tectonics

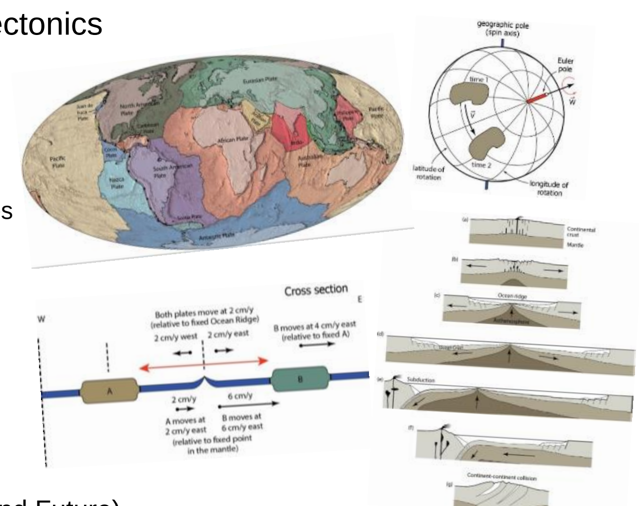
Earth Structure (2019)
(Processes in Structural Geology &Tectonics)

© Ben van der Pluijm
4/23/2019 10:53

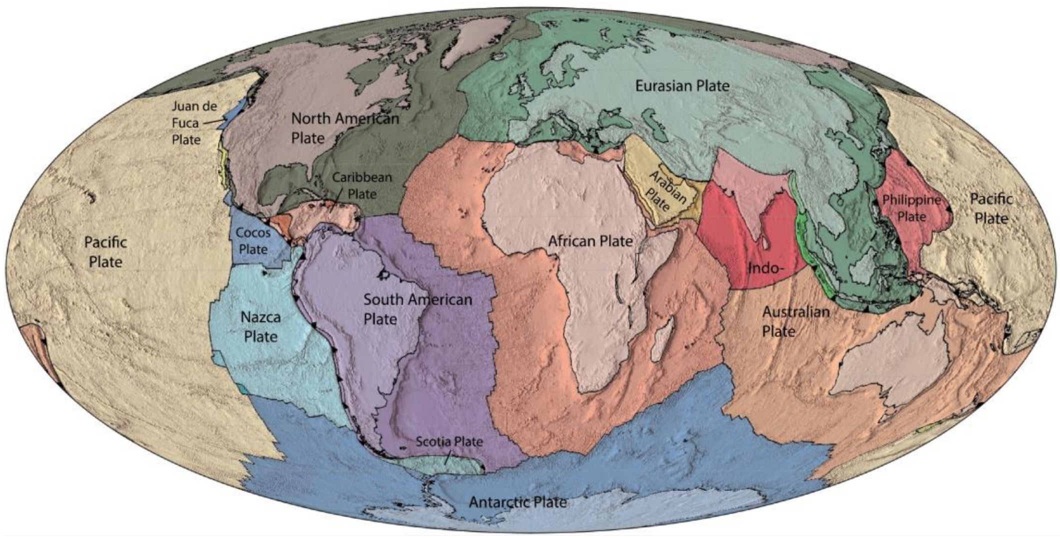
We Discuss …

Whole Earth Structure and Plate Tectonics

- Earth's topography
- Earth's layers
  - The crust
  - The mantle
- Tenets of plate tectonics
  - Insights from earthquakes and volcanoes
  - Today's plates
  - Plate boundaries
- Kinematic of plate tectonics
  - Linear and angular velocities
  - Absolute and relative motions
- Drivers of plate tectonics
- Tectonic cycles
  - Wilson Cycle
  - Supercontinent Cycle
- Reconstructions of plate motion (Past and Future)

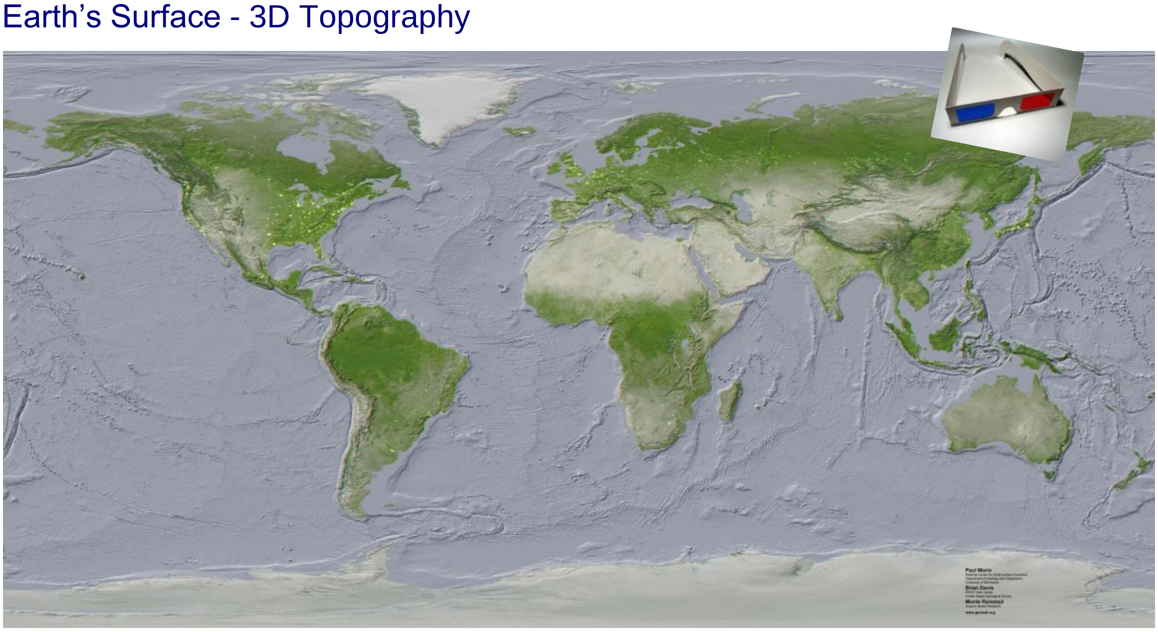


Today’s Plates and Plate Boundaries

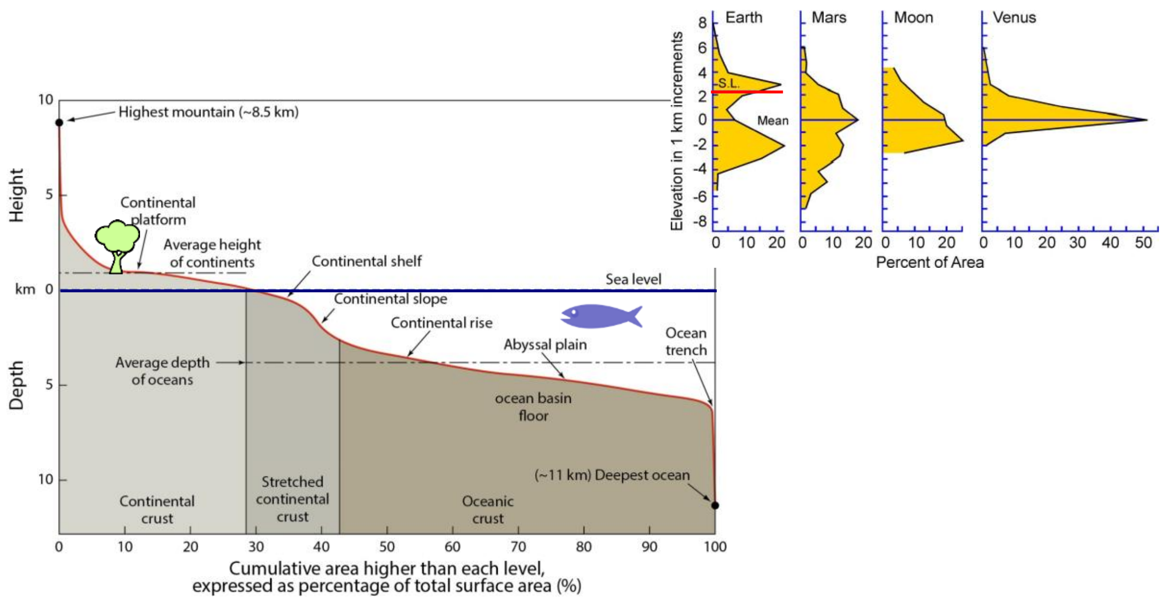


USGS

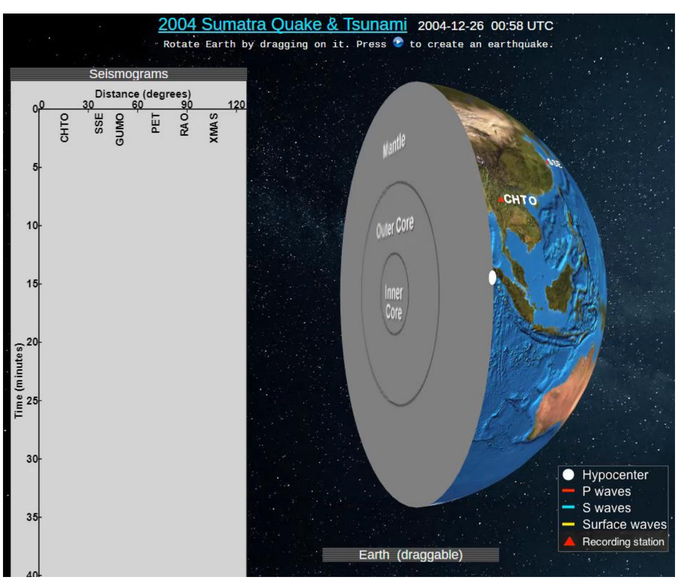
Earth’s Surface - 3D Topography



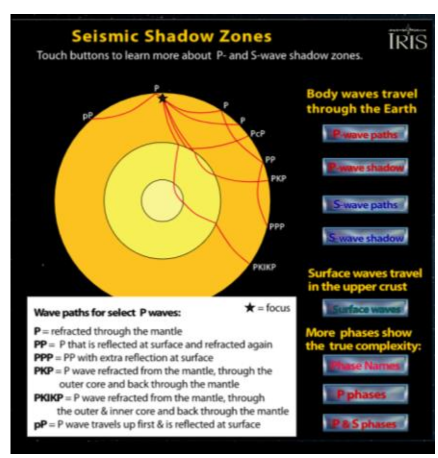
Hypsometric (=cumulative frequency) Elevation Curve



Earth CT-Scan (EQ waves)

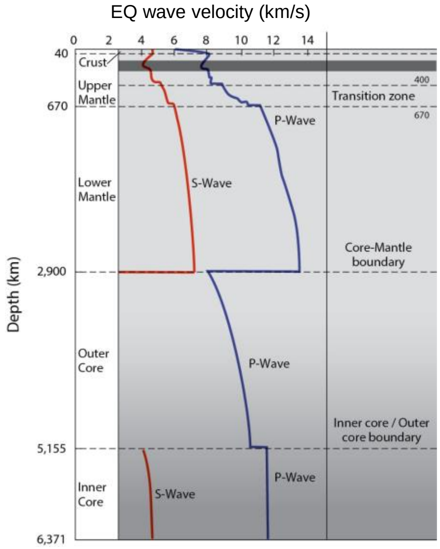


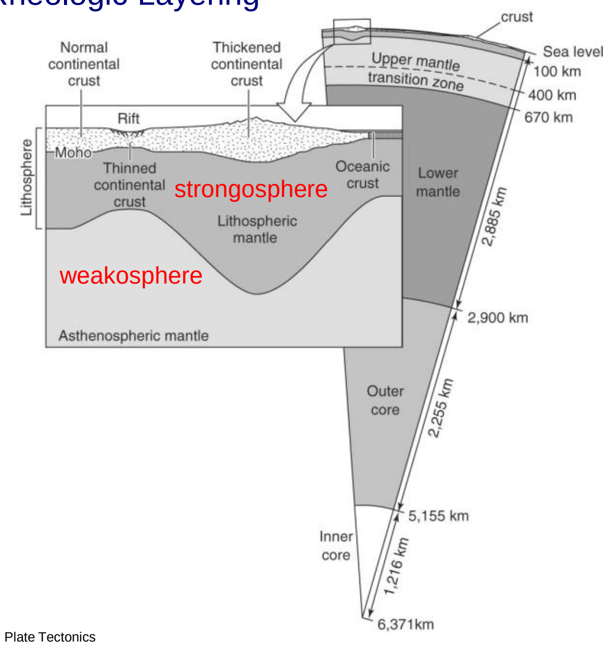
Human CT scan: X-ray energy waves
Earth CT scan: earthquake energy waves



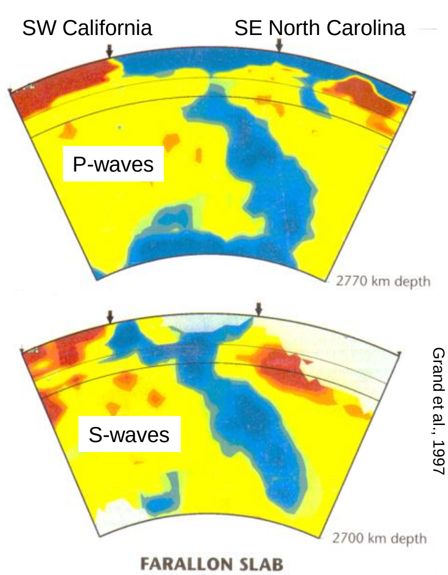
IRIS: http://ds.iris.edu/seismon/swaves/

Earth's Seismologic, Petrologic and Rheologic Layering

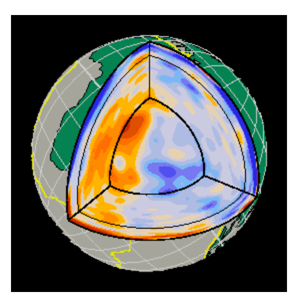




The Mantle - Tomography (CTscan) and Plates

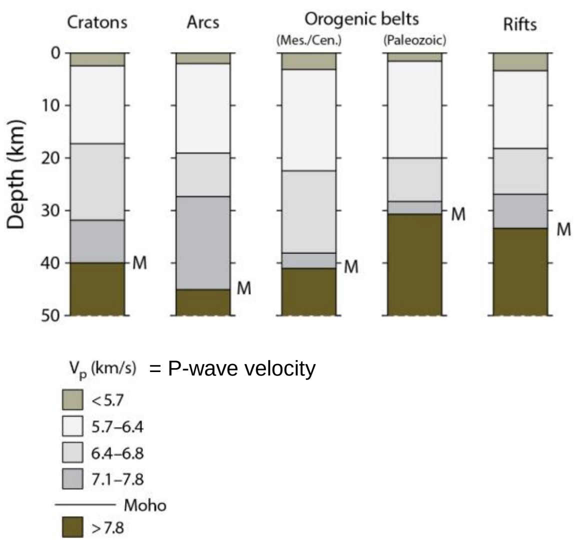


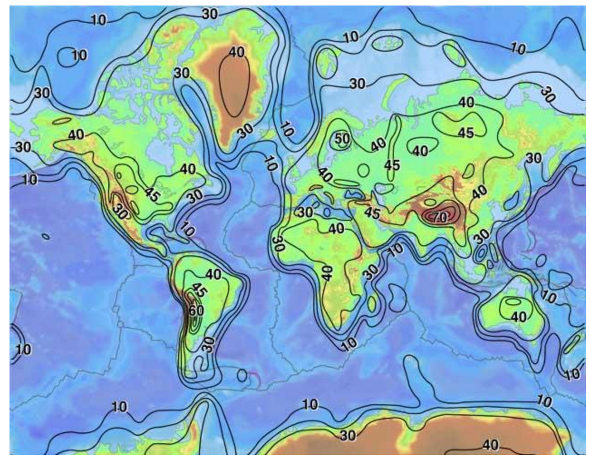
Red is slow, is hot
Blue is fast, is cold



From Ritsema

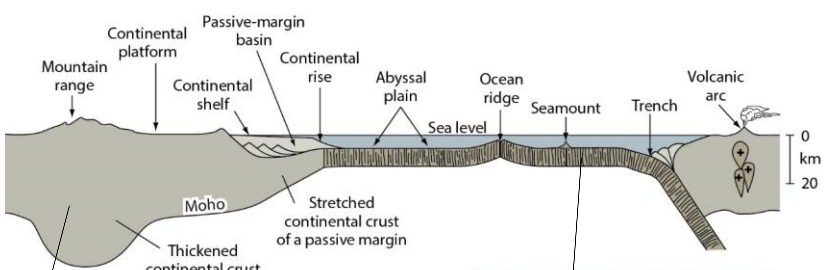
Crustal Thickness

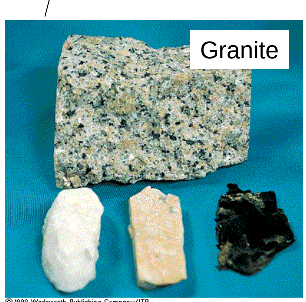




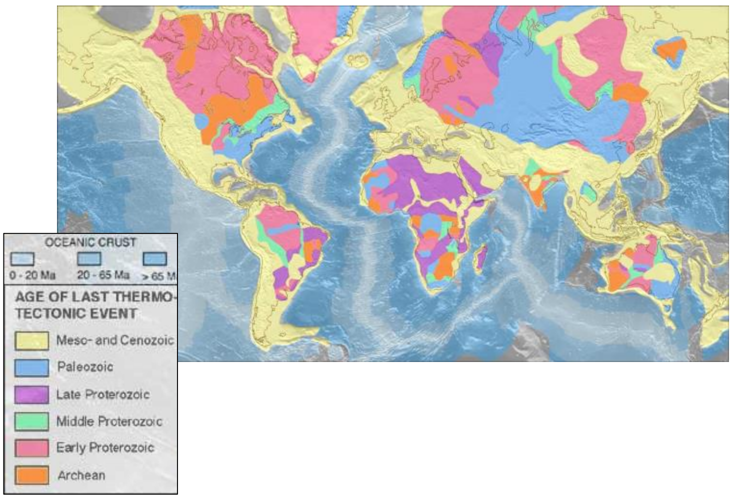
http://earthquake.usgs.gov/data/crust/

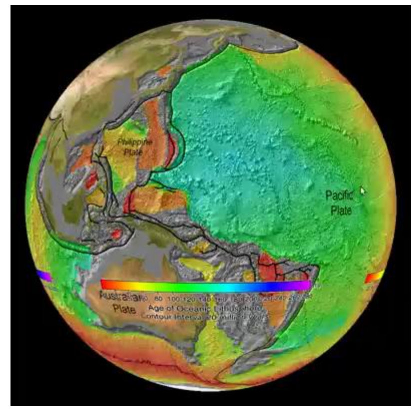
Crustal Section and Characteristic Rock Types





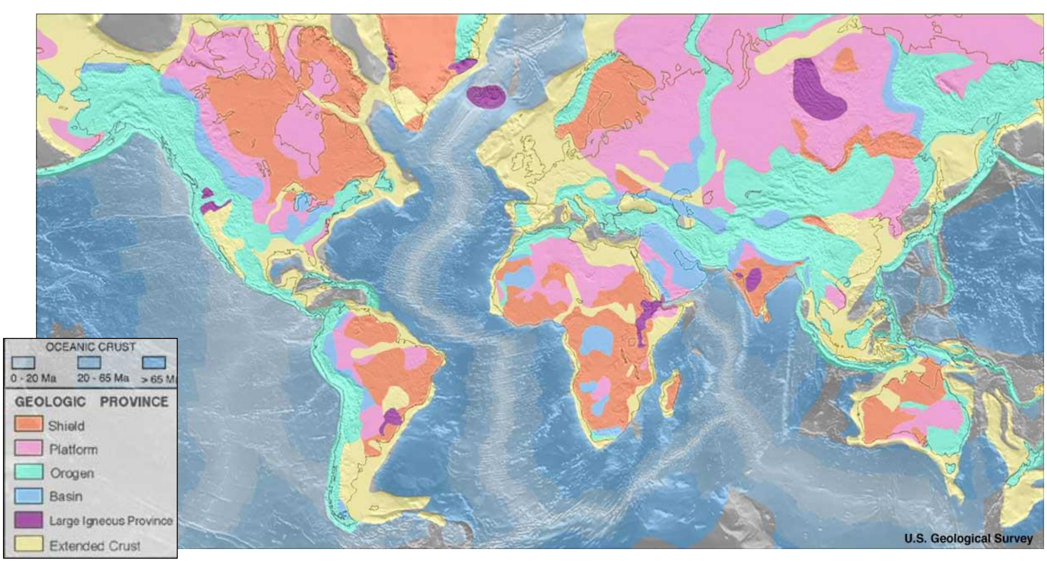
Age of Continental and Oceanic Crust





NOAA

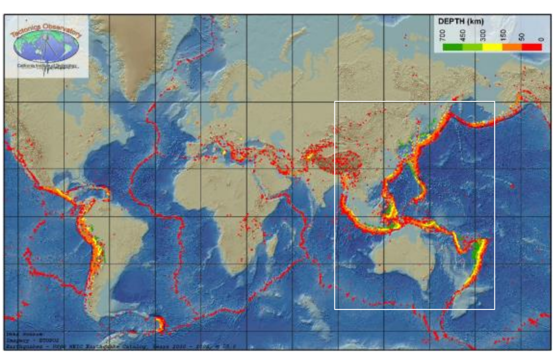
The Crust and Geologic Provinces

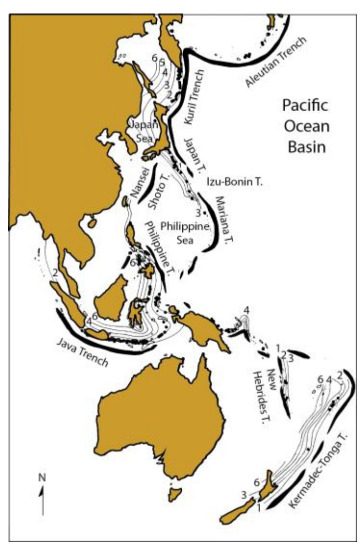


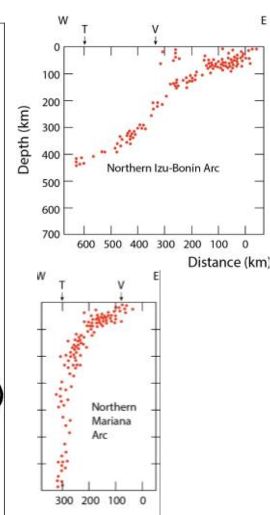
Oceanic vs. Continental Crust

Composition	Continental crust has a mean composition that is less mafic than oceanic crust.
Formation	Continental crust is an amalgamation of rock that originally formed at volcanic arcs and hot spots, and subsequently passes through the rock cycle. Mountain building, erosion and sedimentation, and continued volcanism add to or change continental crust. Oceanic crust all forms at ocean ridges by the process of seafloor spreading.
Thickness	Continental crust ranges between 25 km and 70 km in thickness. Most oceanic crust is between 6 km and 10 km thick. Thus, continental crust is much thicker than oceanic crust.
Heterogeneity	Oceanic crust can be subdivided into distinct layers. Continental crust is very heterogeneous, reflecting its evolution and that different regions of continental crust formed in different ways.
Age	Continental crust is buoyant relative to upper mantle, and cannot be subducted. Thus, portions of the continental crust are very old (oldest known crust is ~4000 Ma). Oceanic crust gets carried back into the mantle during subduction, so there is no oceanic crust on Earth older than ~200 Ma, with exception of oceanic crust that has been emplaced and preserved on continents (ophiolite).
Moho	Moho at base of oceanic crust is sharp, suggesting that the boundary between crust and mantle is abrupt. The continental Moho tends to be less distinct.

Insights from Earthquakes: Location and Depth







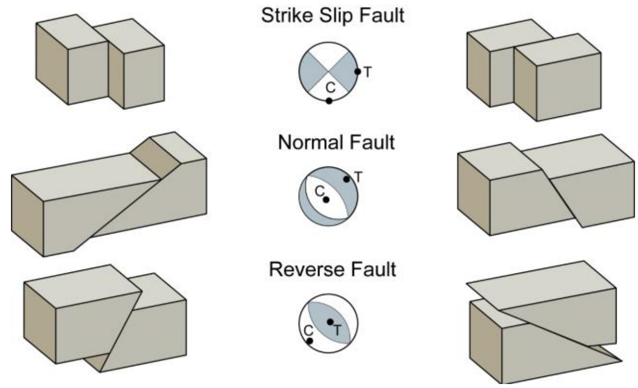
Insights from Earthquakes: Geometry and Displacement

Focal mechanisms and fault-plane solutions

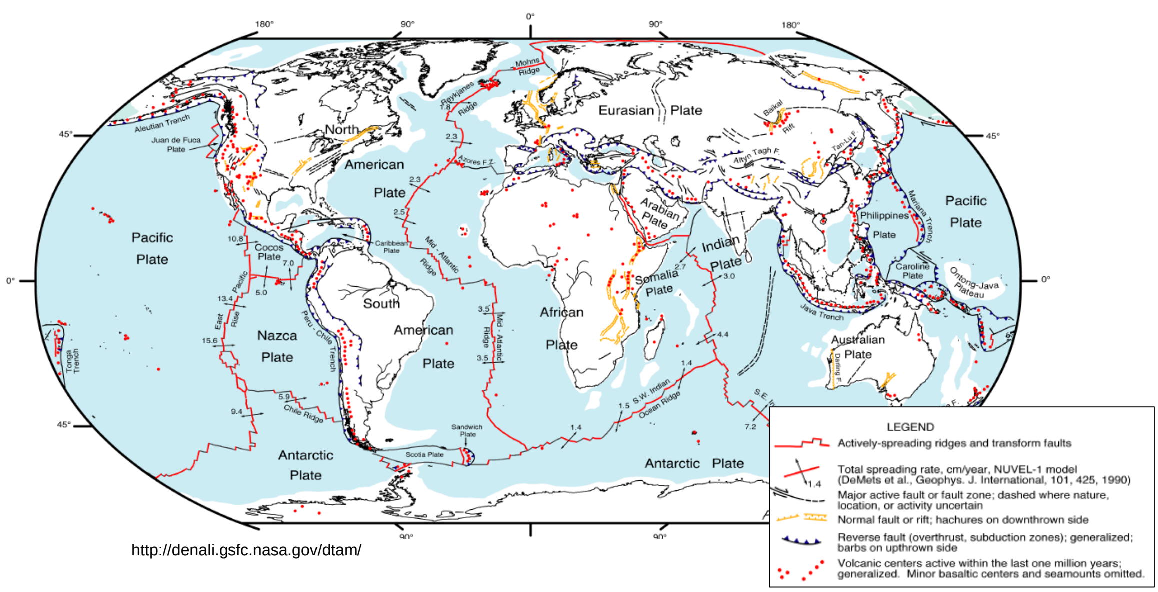
Global seismometer records of first motion define two sectors of compression (C, white) and two sectors of tension (T, shaded), separated by two perpendicular planes.

One is fault plane on which EQ occurred, and from distribution of compressive and tensile sectors, sense of slip is determined.

C and T define regions of σ_1 and σ_3, but not exact orientation (not a fracture solution).



The Tenets of Plate Tectonics



http://denali.gsfc.nasa.gov/dtam/

Types of Plate Boundaries

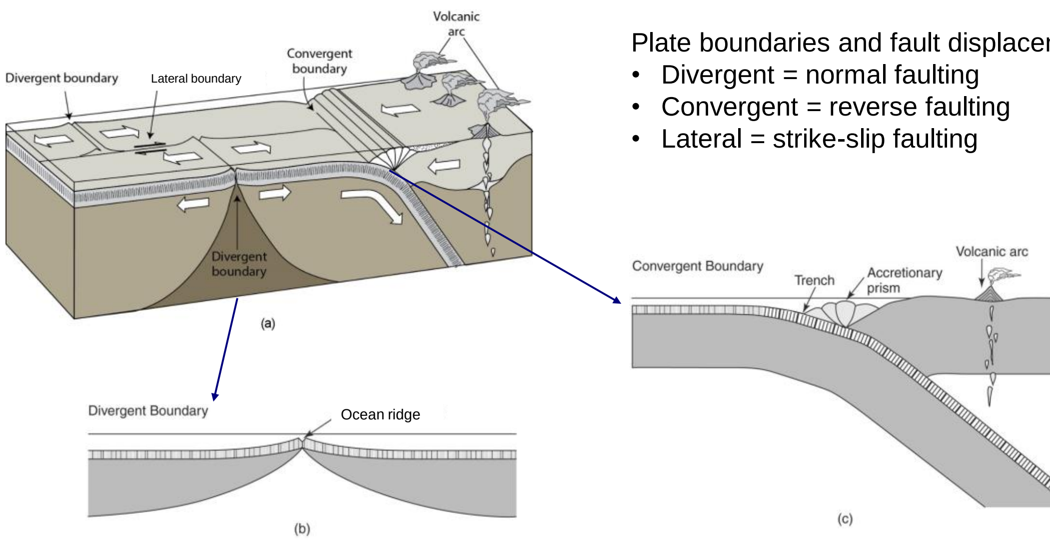


Plate boundaries and fault displacements

- Divergent = normal faulting
- Convergent = reverse faulting
- Lateral = strike-slip faulting

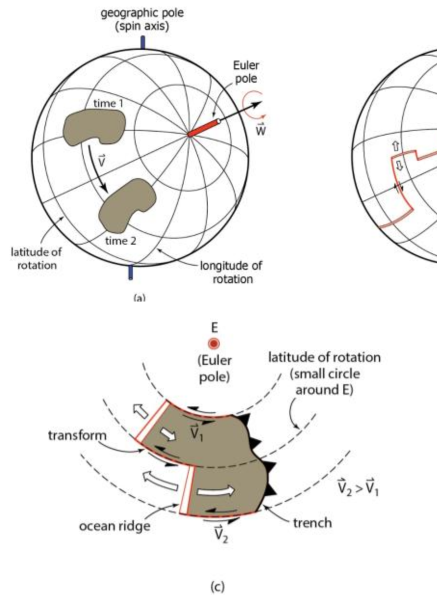
Examples of Plate Boundaries

Divergent: Red Sea

Convergent: Japan

Lateral: New Zealand

Plate Kinematics on a Sphere

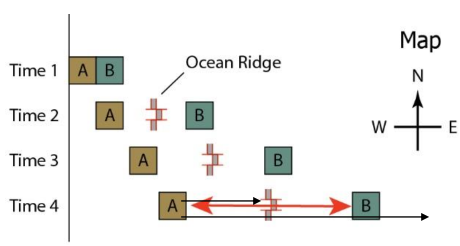


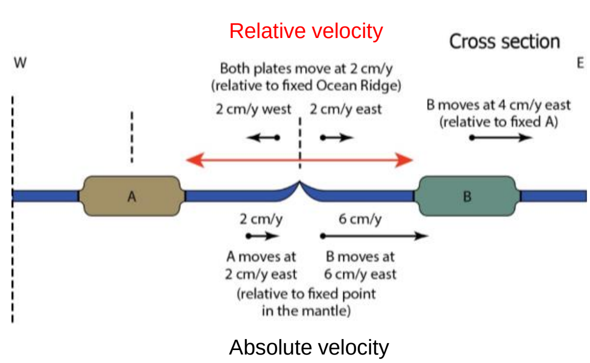
Stereonets

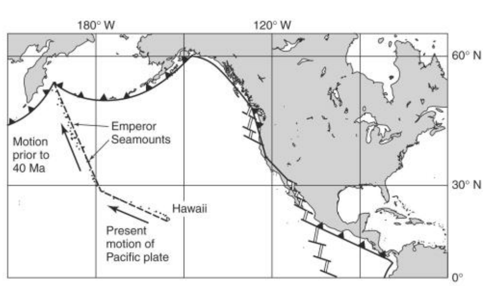
Displacement and Rotation:

a) Displacement follows small circles
b) Oceanic transfer faults (or transforms) parallel small-circle segments
c) Same angular velocity (w) between plates; different linear velocity (v), as function of distance from rotation axis (or Euler pole)

The Kinematics of Plate Tectonics

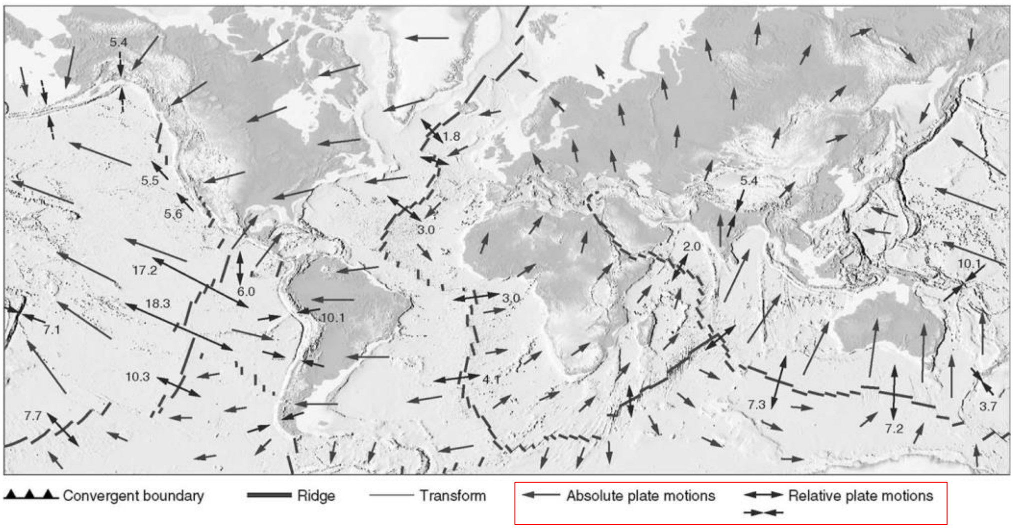




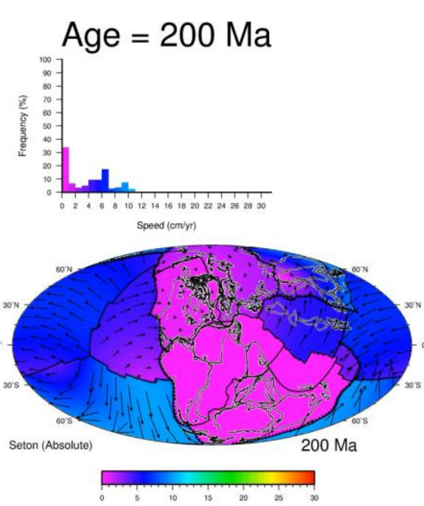


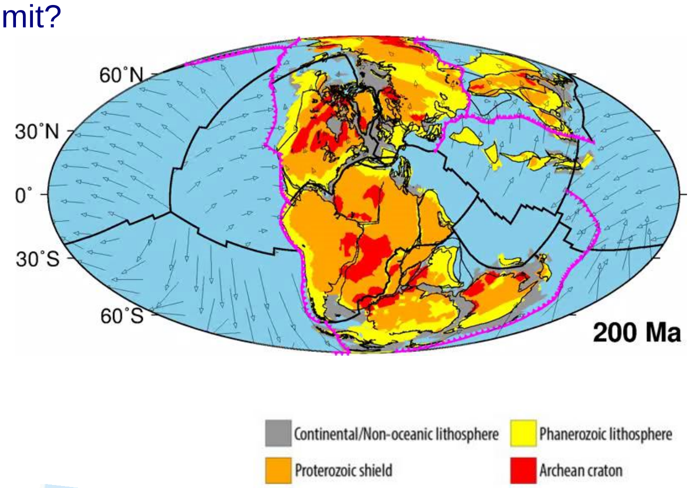
Mantle hotspots as "fixed" reference frame

Today's Plate Motions (Absolute and Relative Velocities)



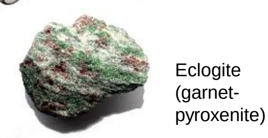
Absolute Motions and Speed Limit?





Zahirovic et al., 2015

Mechanics of Plate Tectonics - Driving Forces and Plate Mineralogy



Gravitational forces (colored):

- Ridge push: topographic spreading
- **Slab pull: negative buoyancy of slab**

Resistive forces (black) are relatively small

Plate Tectonic Cycles: The Wilson Cycle

a) -b) Continent rifts, such that crust stretches, faults and subsides.
c) Seafloor spreading begins, forming a new ocean basin.
d) The ocean widens and flanked by passive margins.
e) Subduction of oceanic lithosphere begins on one margins, closing ocean basin.
f) -g) Ocean basin is destroyed by continent-continent collision.

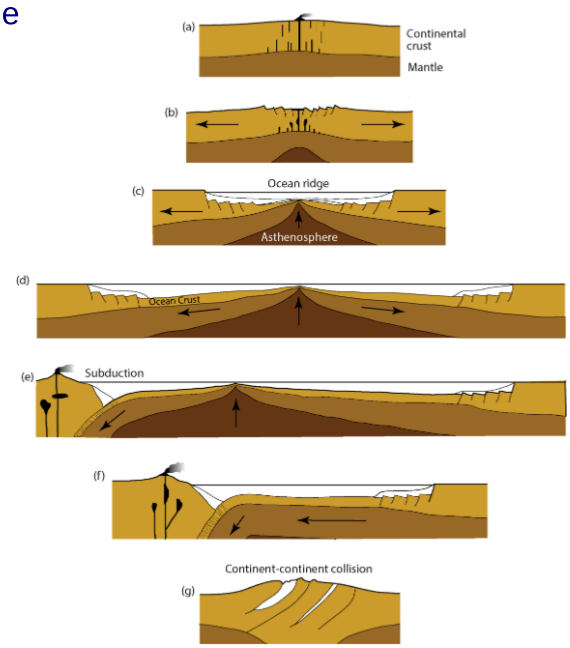
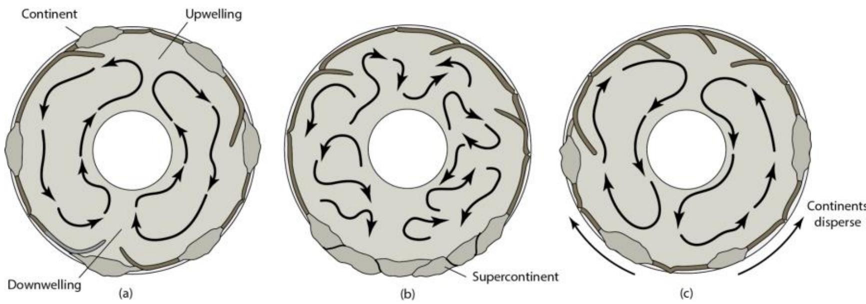


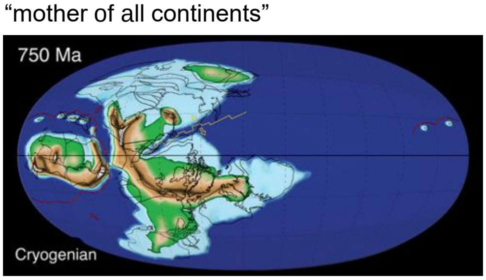
Plate Tectonics Cycles: The Supercontinent Cycle

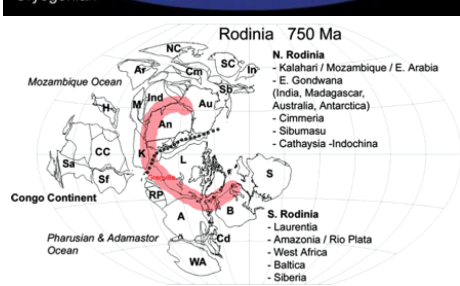


a) Continents gradually aggregate over a mantle downwelling zone.
b) While supercontinent exists, large-scale convection in the mantle reorganizes.
c) Upwelling begins beneath supercontinent and weakens it, leading to rifting and breakup.

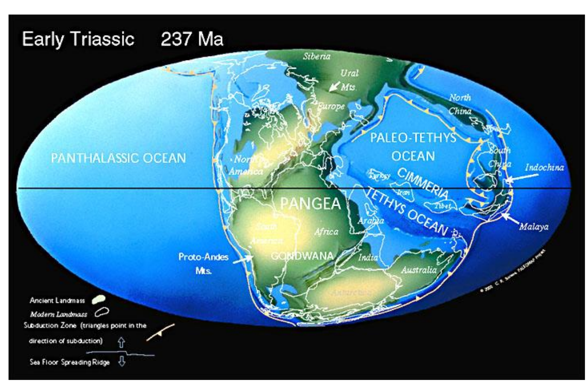
Supercontinents

Rodinia (L Proterozoic; 1100-750Ma)
“mother of all continents”





Pangea (L Paleozoic; 320-175Ma)
“all land”

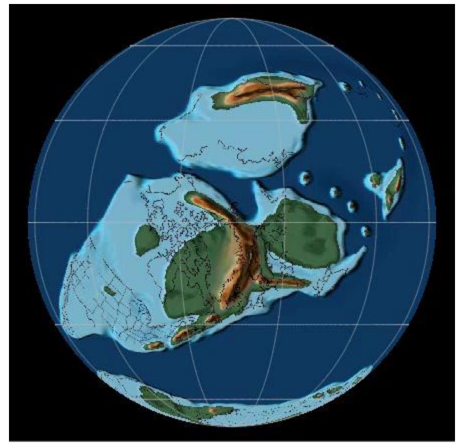


From C. Scotese

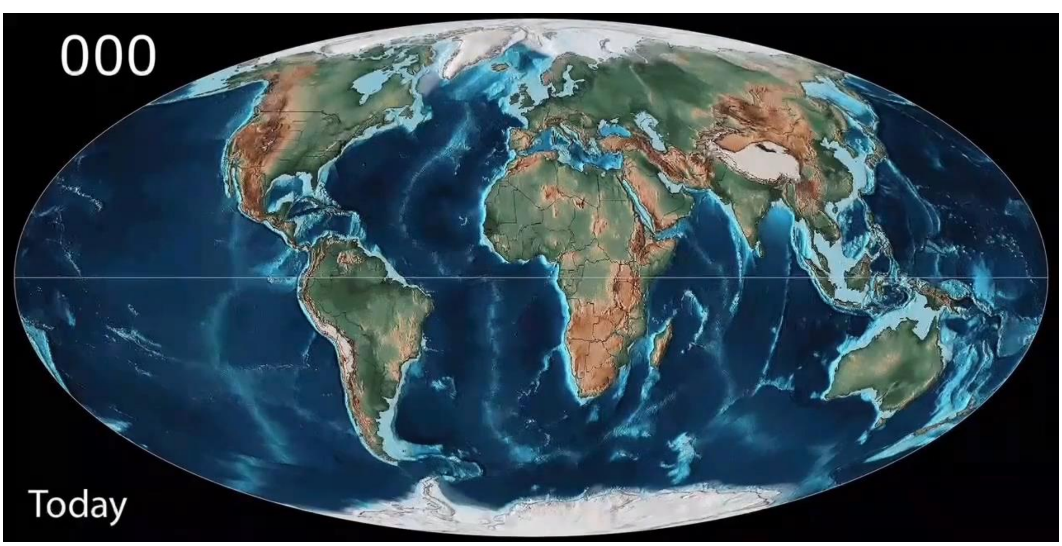
Plate Tectonic Cycles: The Wilson Cycle and Supercontinents

- Continent rifts and breaks up (divergent boundary).
- Seafloor spreading forms new ocean basin.
- Subduction of oceanic lithosphere closes ocean basin (convergent boundary).
- Ocean basin destroyed by continent-continent collision (collisional boundary).

- Continents aggregate over whole-mantle downwelling.
- Convection in mantle reorganizes.
- Upwelling beneath supercontinent weakens continental lithosphere, leading to rifting and breakup.



Today to Precambrian-Paleozoic Boundary (0-540Ma)



Chris Scotese