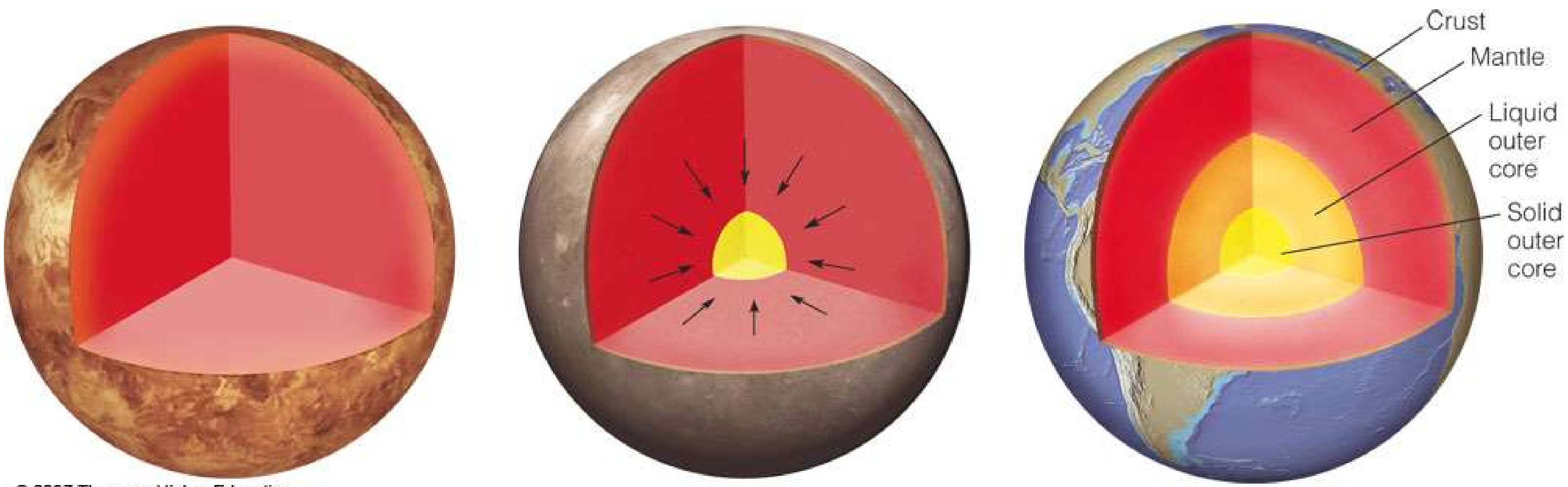
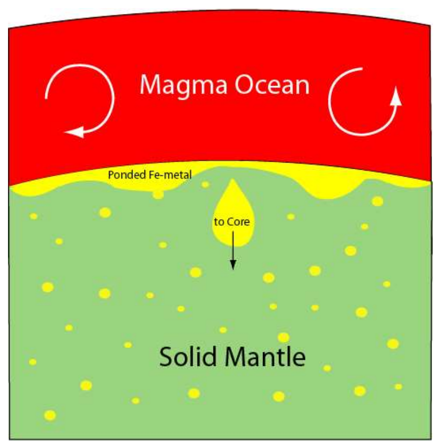
Lecture 2: Before we get to PLATE TECTONICS…..

A brief accounting of Earth's composition, interior structure, and time periods

Proto-Earth was almost entirely molten **Time** ⟶ Iron-nickel core surrounded by silica-rich mantle

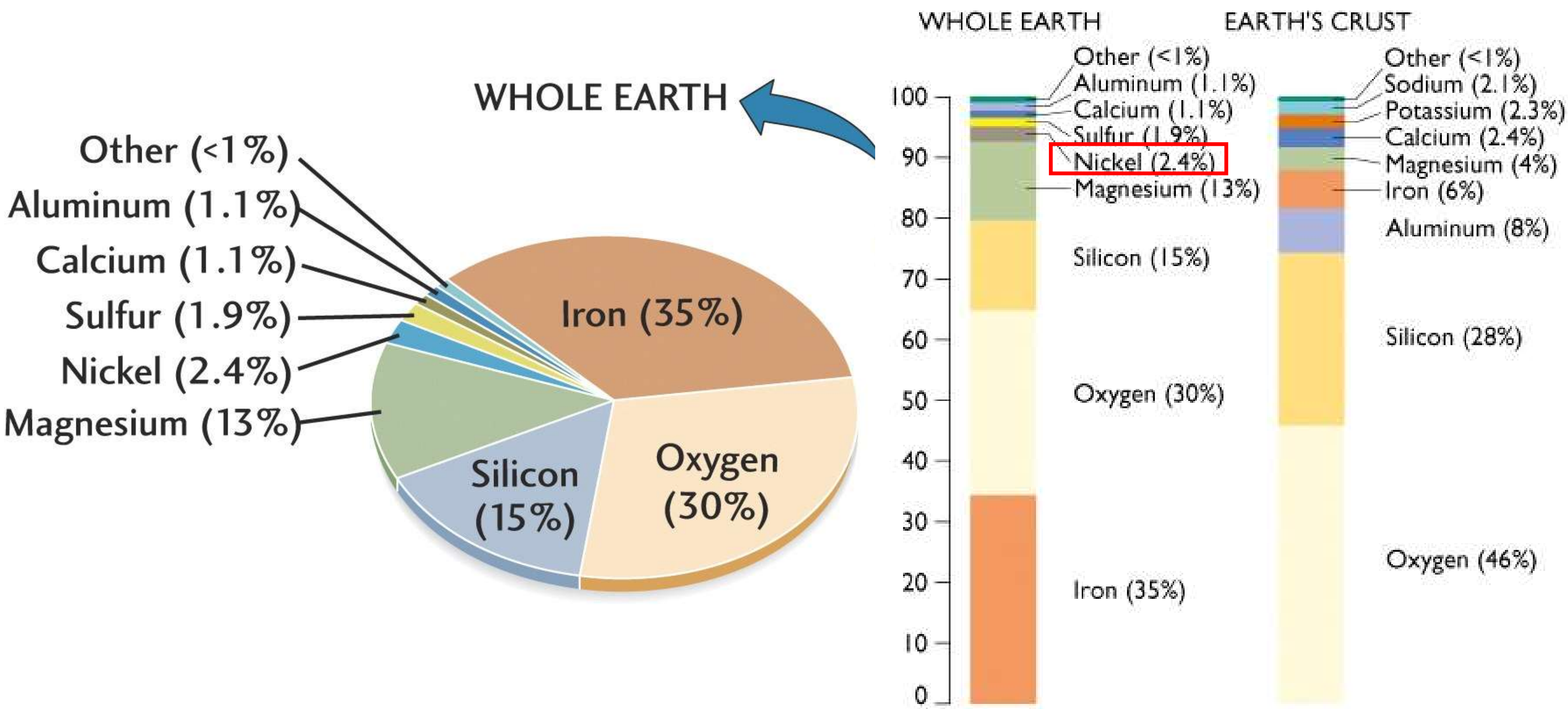




Separation, or *differentiation*, of iron from lighter elements results in stratification, that can happen within hundreds of years in a magma ocean

www.geodynamics.rice.edu/tobias.hoeink/index.php?page=research

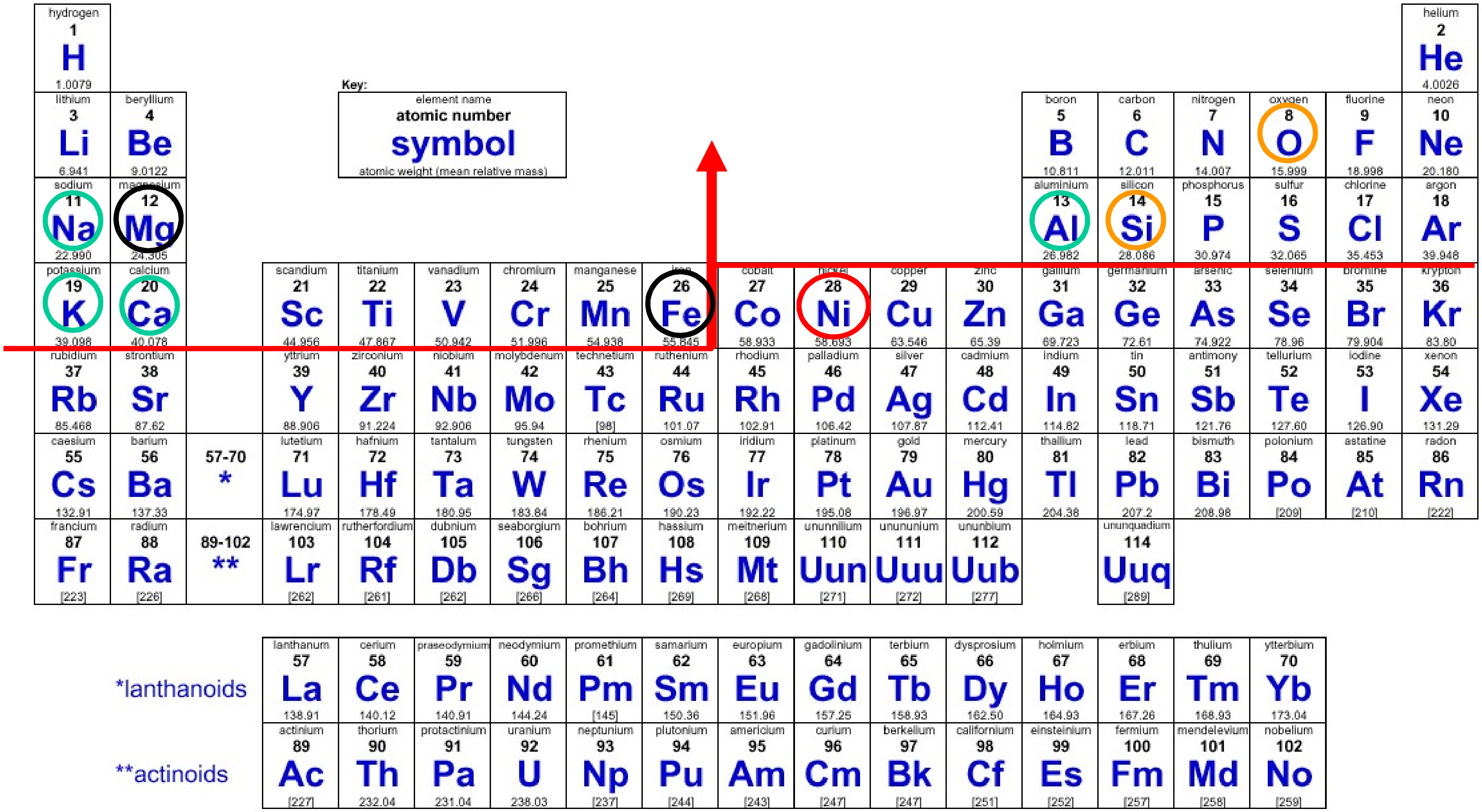
Earth's composition



W. W. Norton

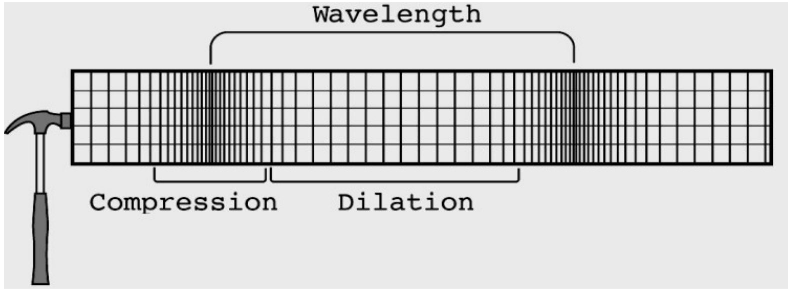
The 26 naturally occurring elements formed by stellar nucleosynthesis

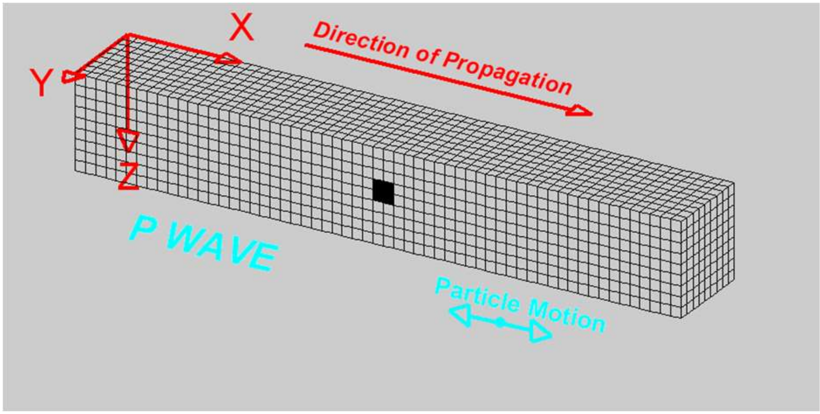
Common in: all crust continental crust oceanic crust and mantle



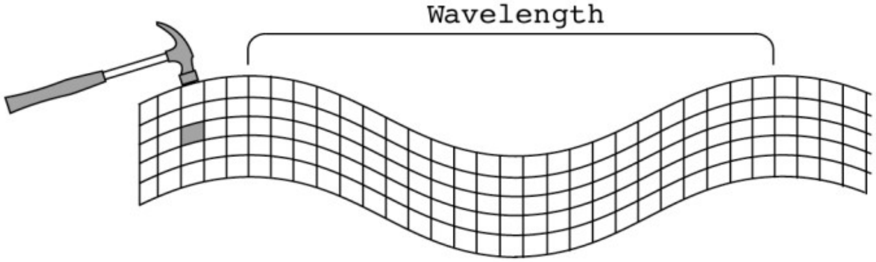
EARTHQUAKES BODY WAVES

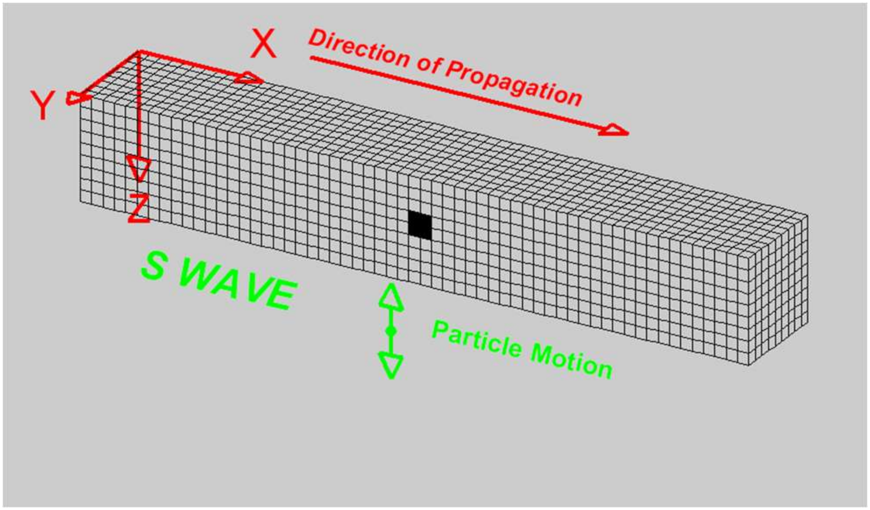
P-waves





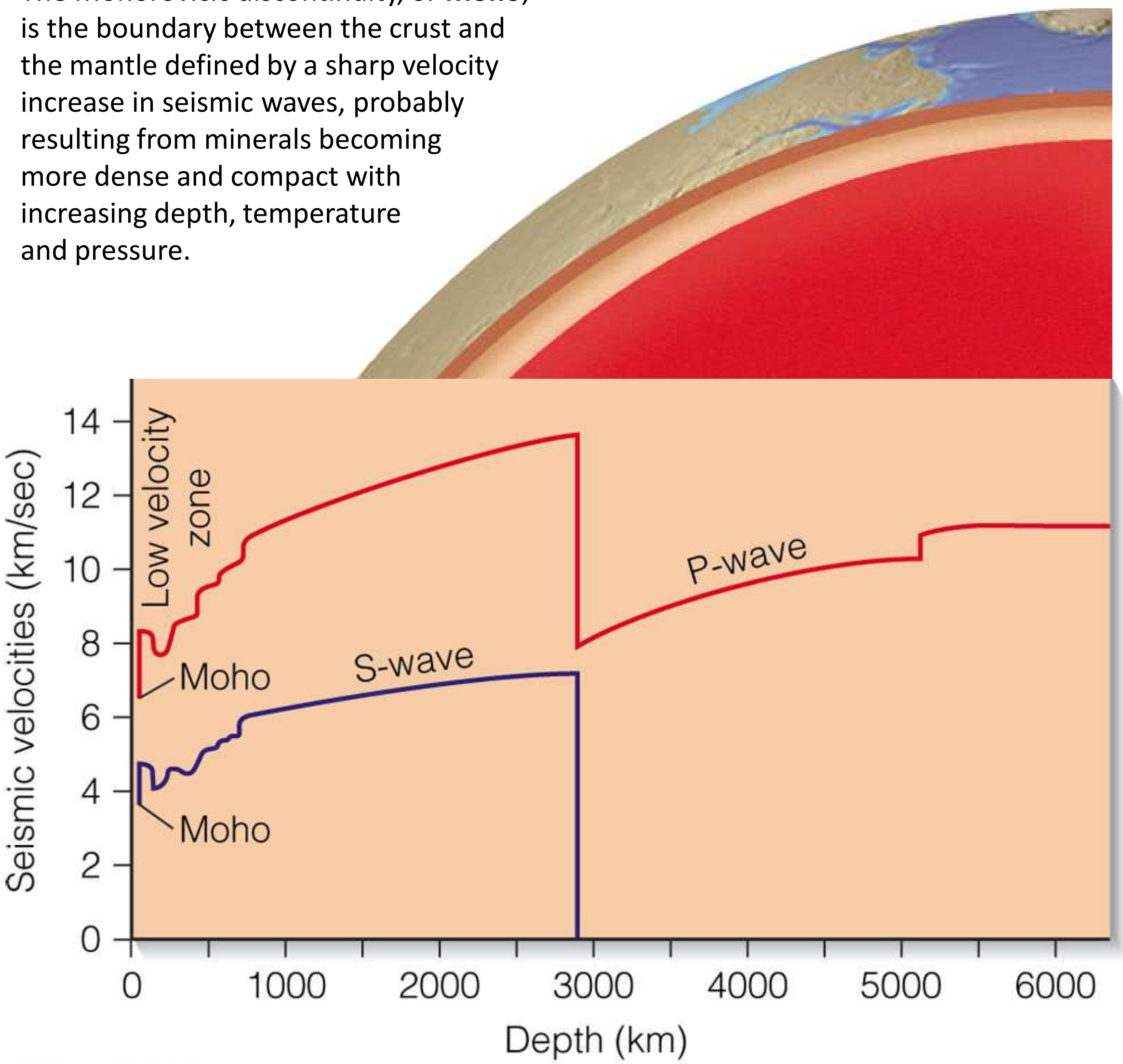
S-waves





Earth's crust, lithosphere, asthenosphere, mantle, and Moho

The Mohorovičić discontinuity, or **Moho**, is the boundary between the crust and the mantle defined by a sharp velocity increase in seismic waves, probably resulting from minerals becoming more dense and compact with increasing depth, temperature and pressure.

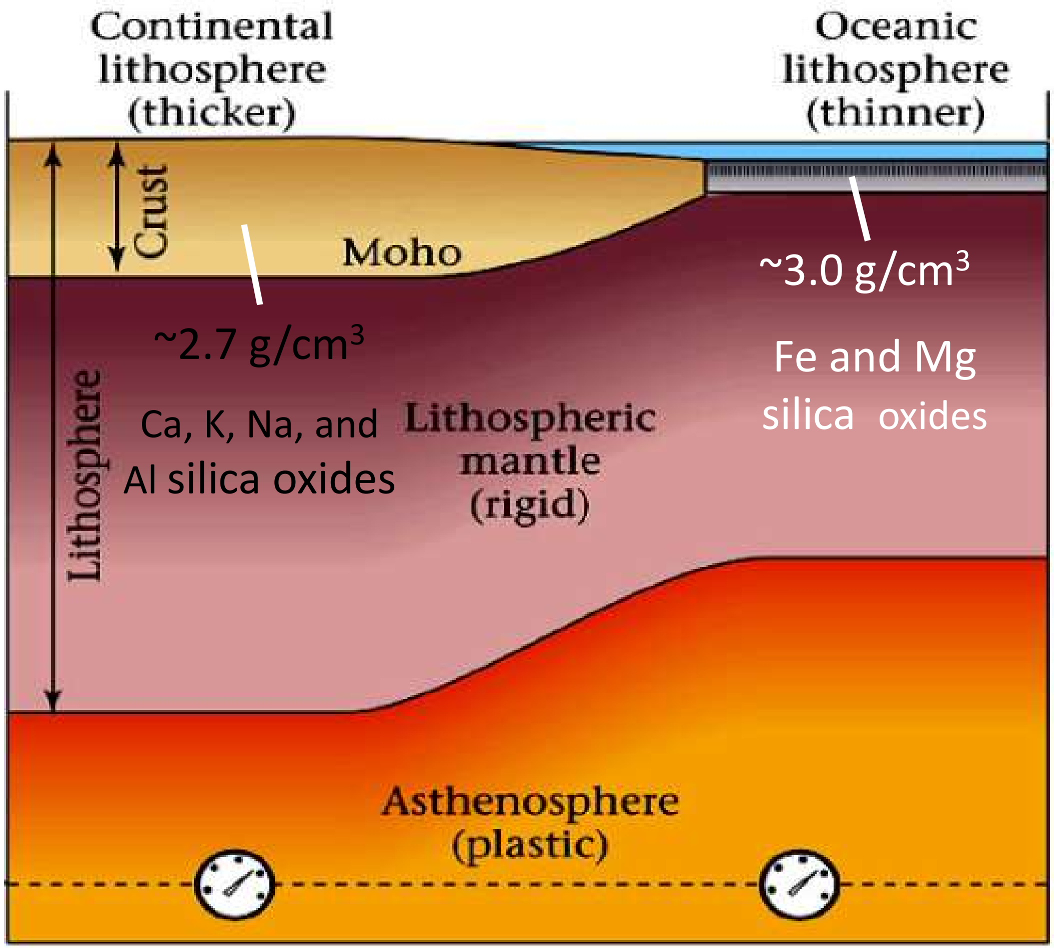


- The lithosphere includes the crust and the uppermost mantle, which constitute the hard outer layer of the Earth that is rigid for very long periods of geologic time in which it deforms elastically and through brittle failure.

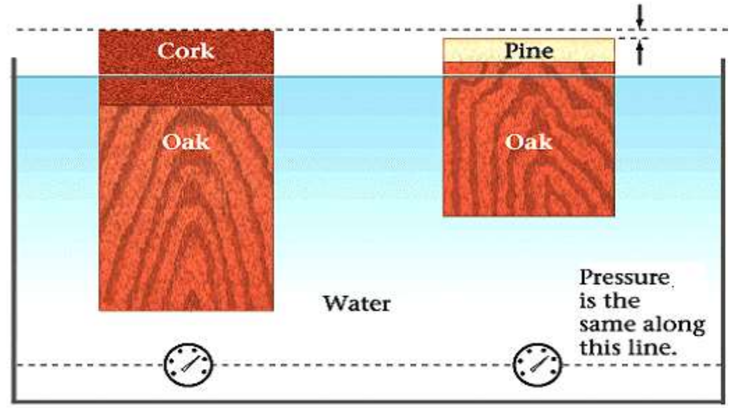
- The lithosphere is underlain by the asthenosphere, the weaker, part of the upper mantle that is hotter than the lithosphere, behaves more like plastic, deforms viscously and accommodates strain through plastic deformation.

- The lithosphere is broken into tectonic plates.

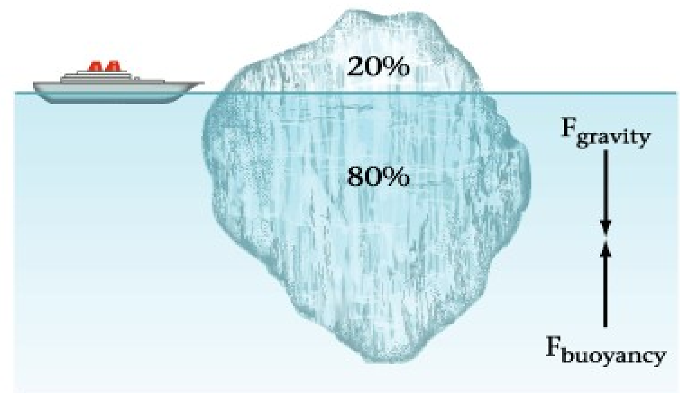
Oceanic crust is composed mostly of iron (Fe) and magnesium (Mg) silica (Si) oxides (O_n) that are more dense and heavy than continental crust that has abundant sodium (Na), calcium (Ca), potassium (K), and Aluminum (Al) silica oxides



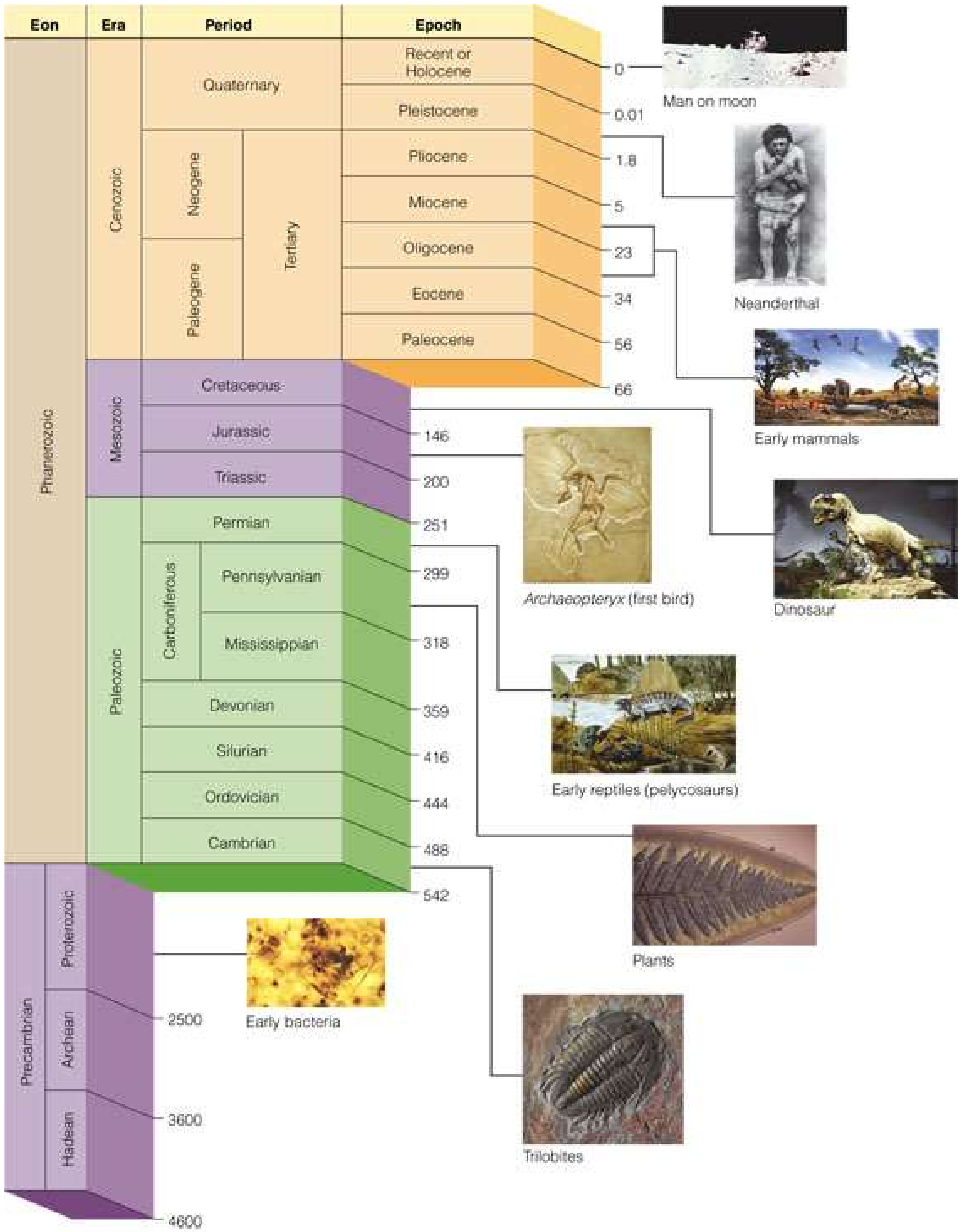
W. W. Norton. Modified from Sloss, NOAA



Continental crust has higher elevations and deeper roots than ocean crust because of gravity and buoyancy.

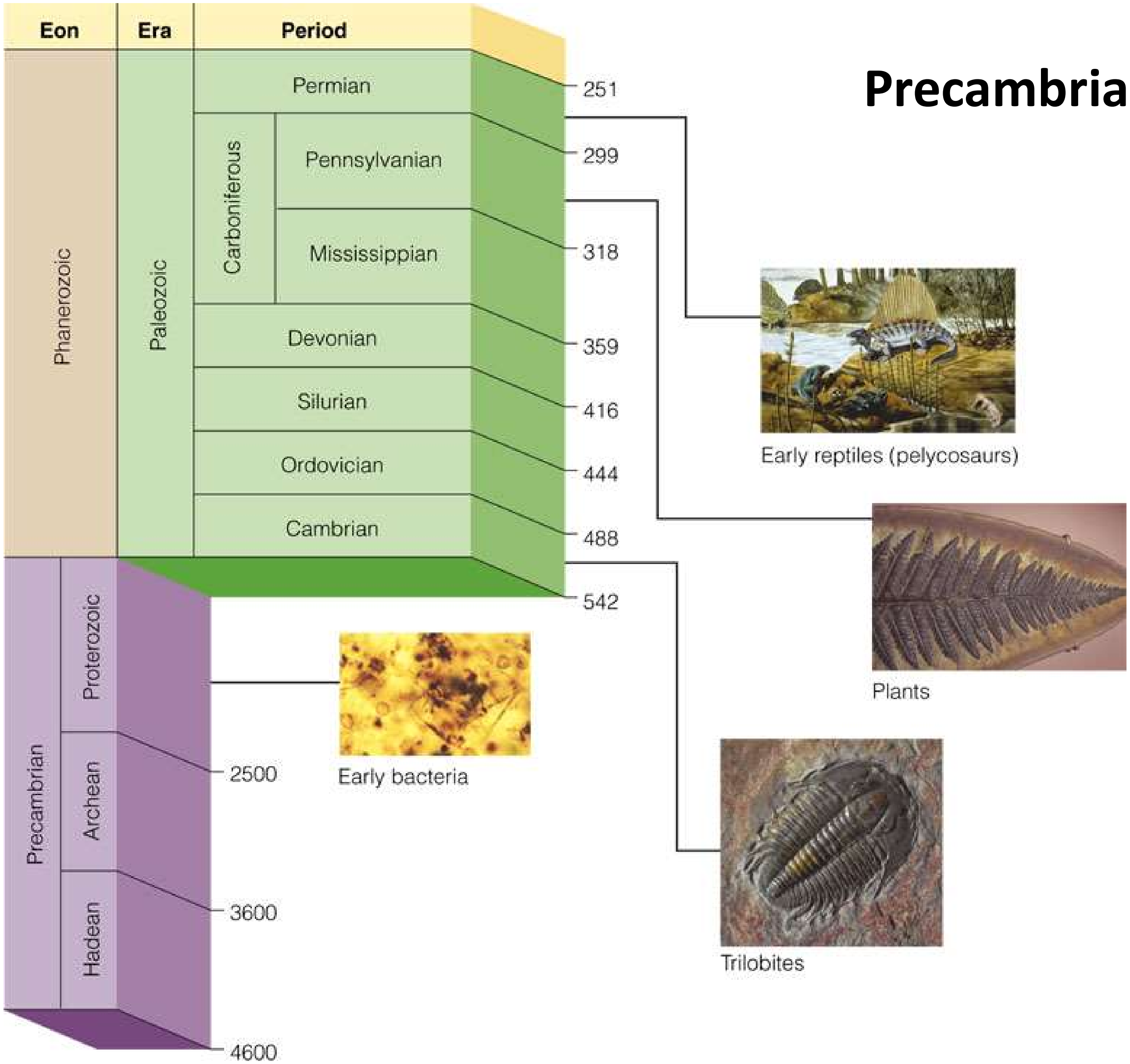


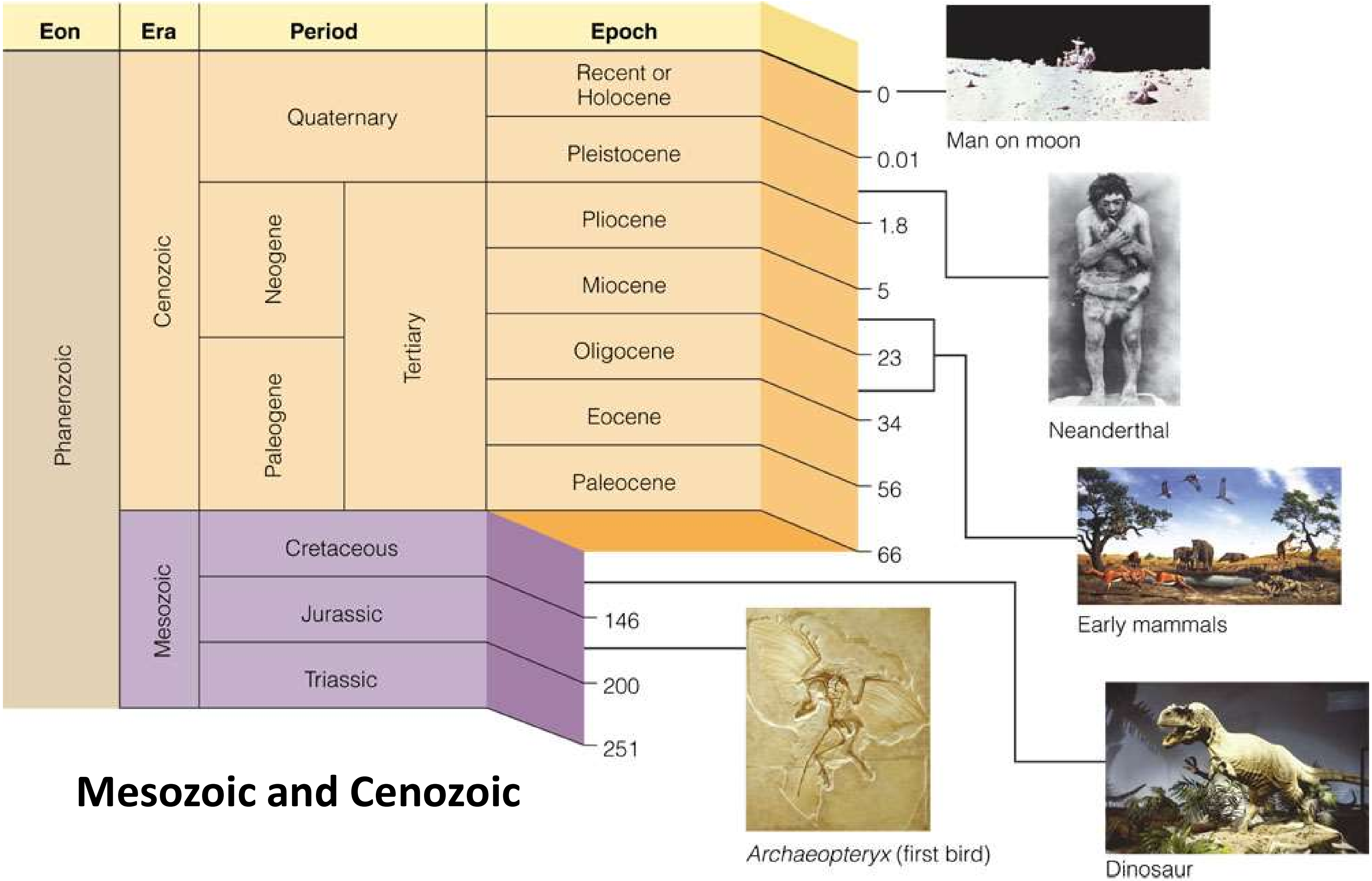
Geologic time on Earth



- 4.6 Ba to the present
- Eon – billions to hundreds of millions
- Era - hundreds to tens of millions
- Period – tens of millions
- Epoch – tens of millions to tens of thousands

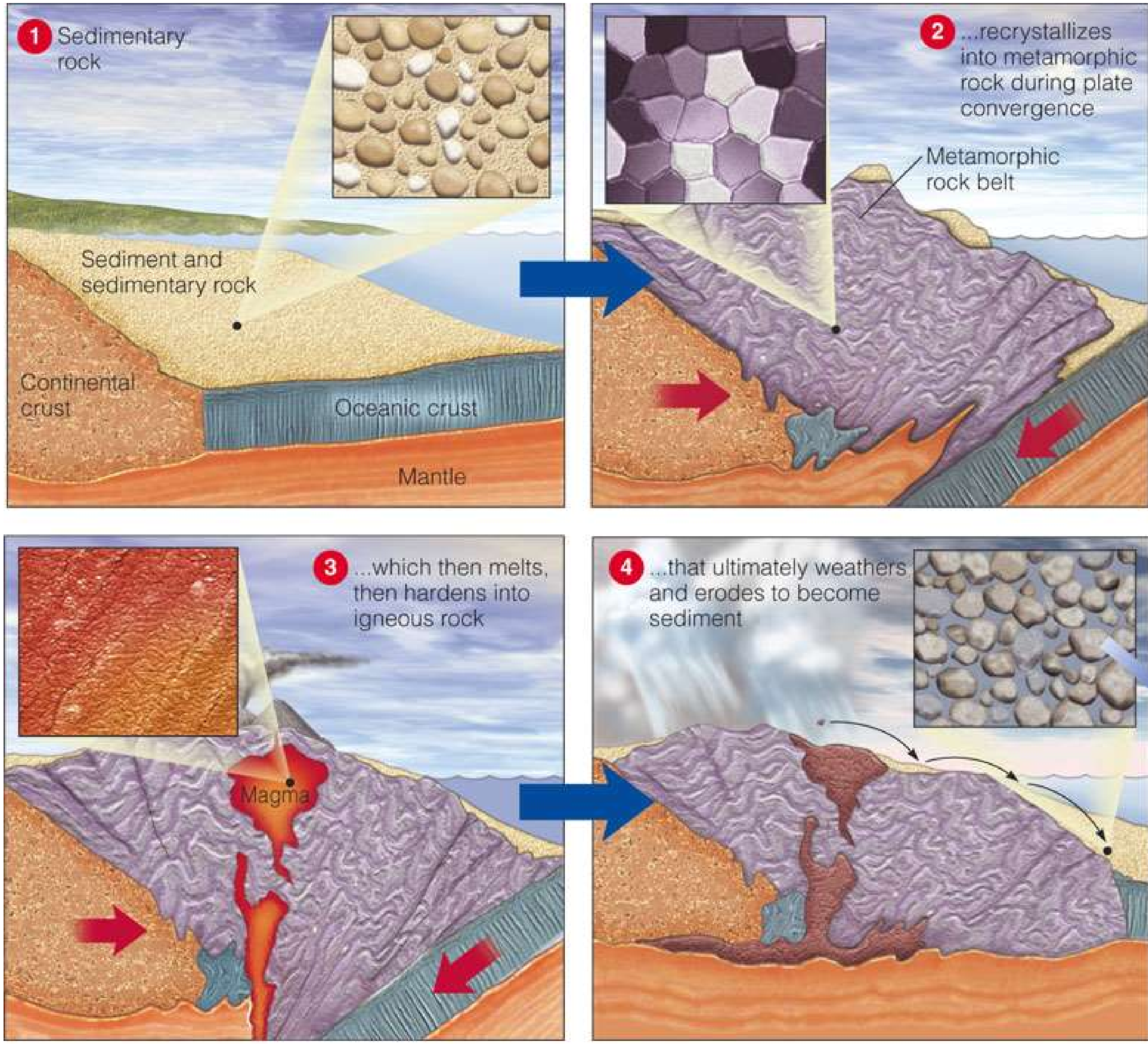
Precambrian and Paleozoic

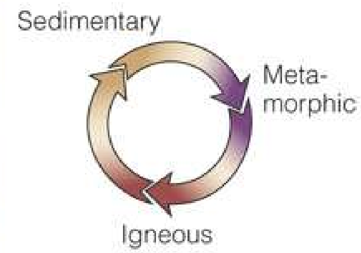


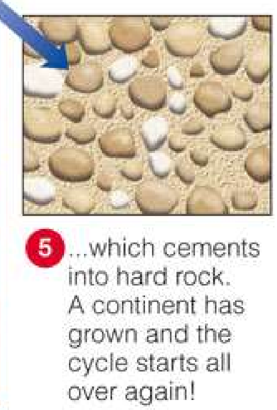


Mesozoic and Cenozoic

The Rock Cycle

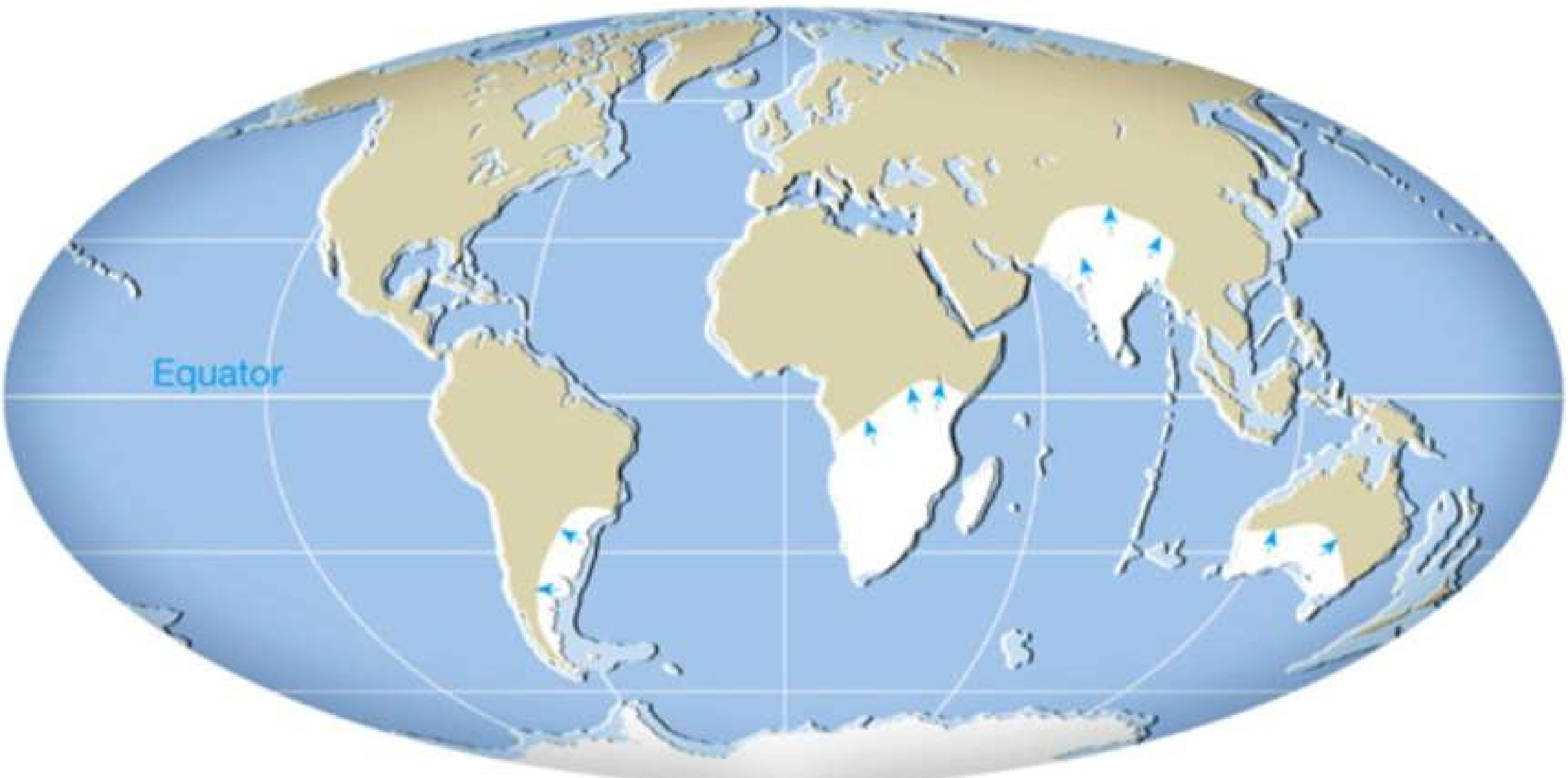




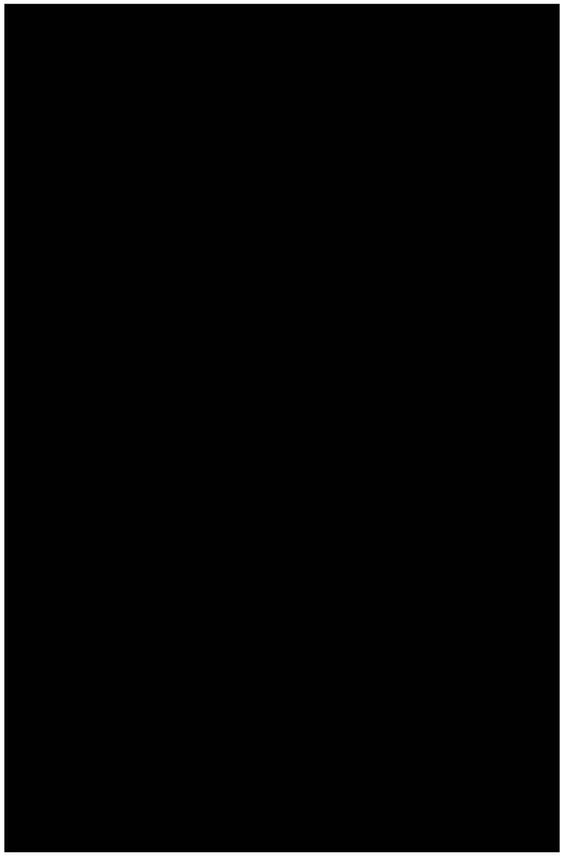


CHAPTER 2 Plate Tectonics: A unifying theory

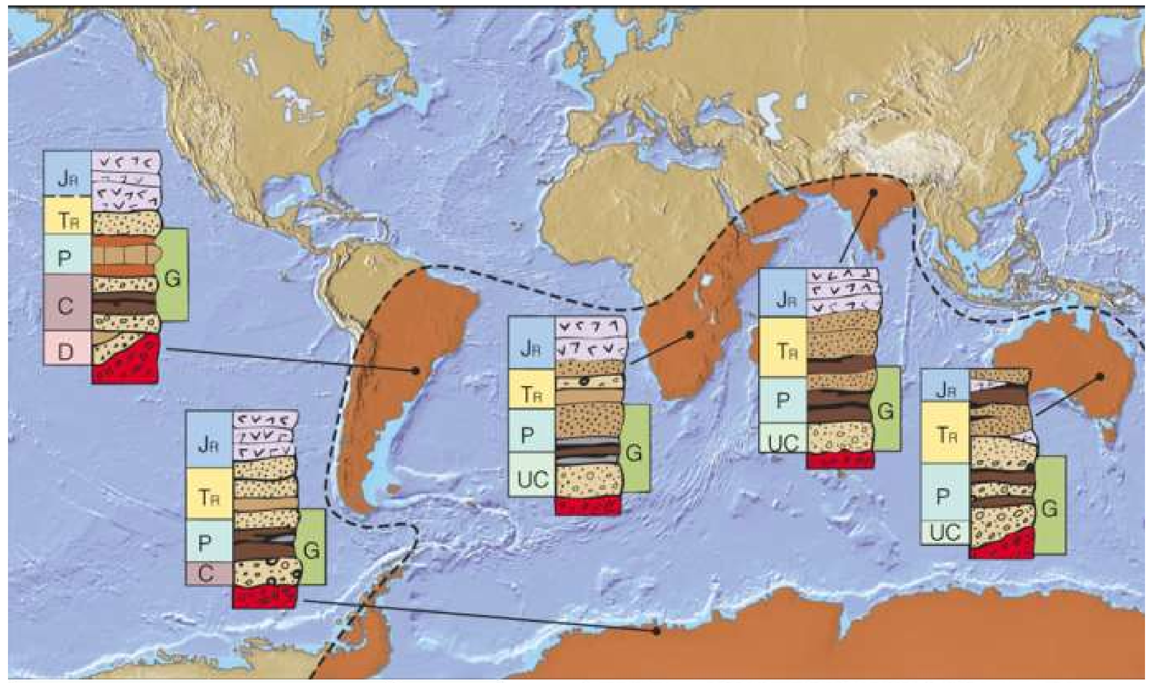
•The concept of continental movement was first suggested when it was noticed that Africa and South America had coastlines which appeared to be counterparts of one another, suggesting they may once have been joined and drifted apart.



• The hypothesis of continental drift is generally credited to Alfred Wegener, a German meteorologist who wrote the book, *The Origin of Continents*, first published in 1915.



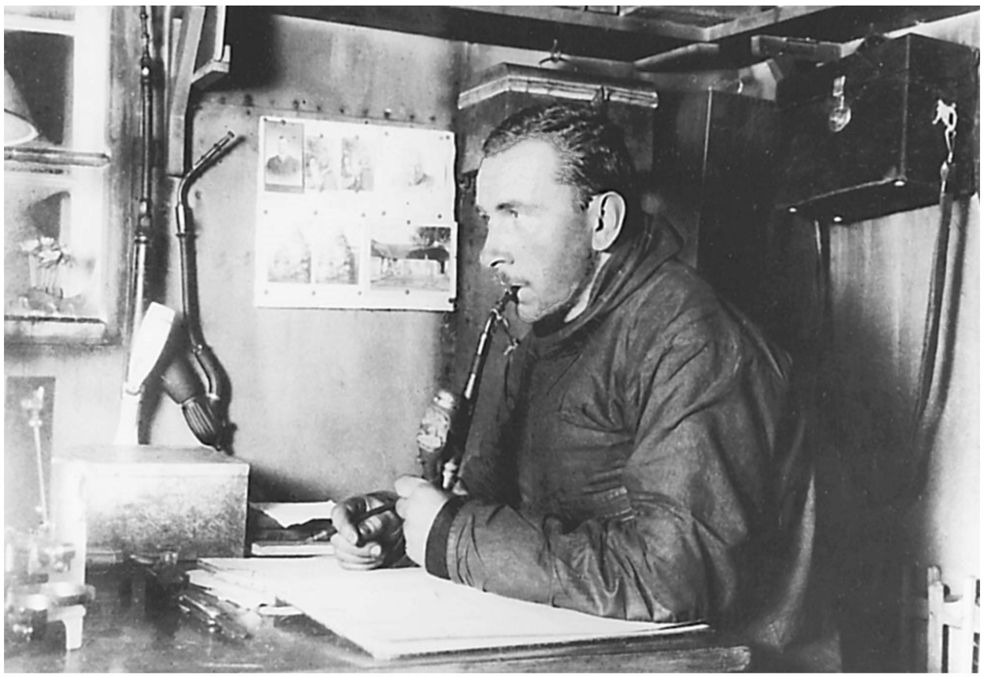
• Wegener presented paleontological and geological evidence that the continents were once united into one supercontinent which he named Pangaea (Greek - "*all land*").



• His treatment and hypothesis were the most extensive and well developed at the time, but he could not provide a convincing mechanism to demonstrate how the continents could have moved, and his ideas were largely ignored.

• Wegener made mistakes identifying fossils, thought that the continents moved rapidly, up to meters per year, and thought that continents moved through oceanic crust, like ice-breaking ships.

• He disappeared in Greenland while trying to measure the rate of continental drift. The textbook reports that his presumed death was not widely mourned…

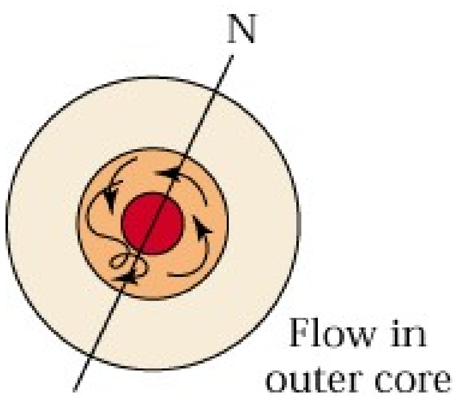


"Progress in science isn't easy, and the arguments that ultimately drive science forward are often unpleasant.

In the case of Alfred Wegener, it is now clear that his insights outweighed his errors."

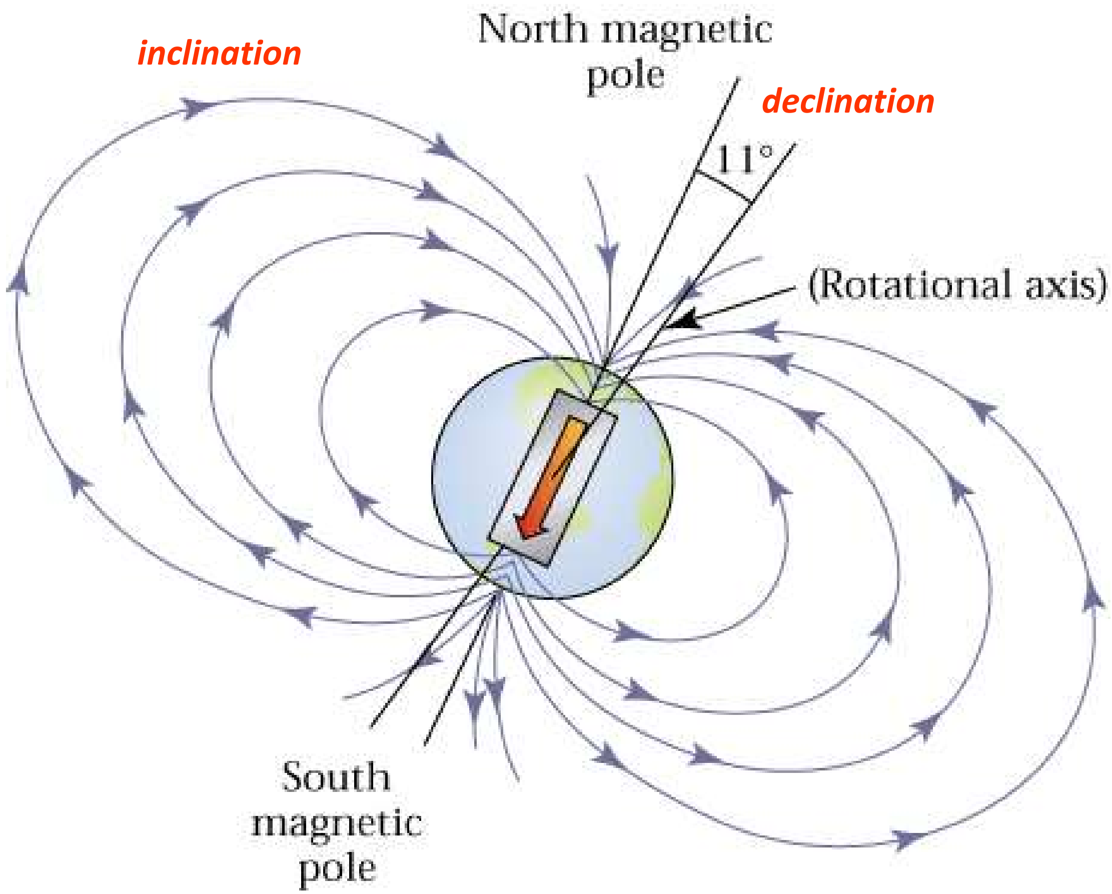
The 1950's brought a renewed interest to continental drift because of paleomagnetic studies.

Paleomagnetism is the remnant magnetism in ancient rocks recording the direction and intensity of the Earth's magnetic field.



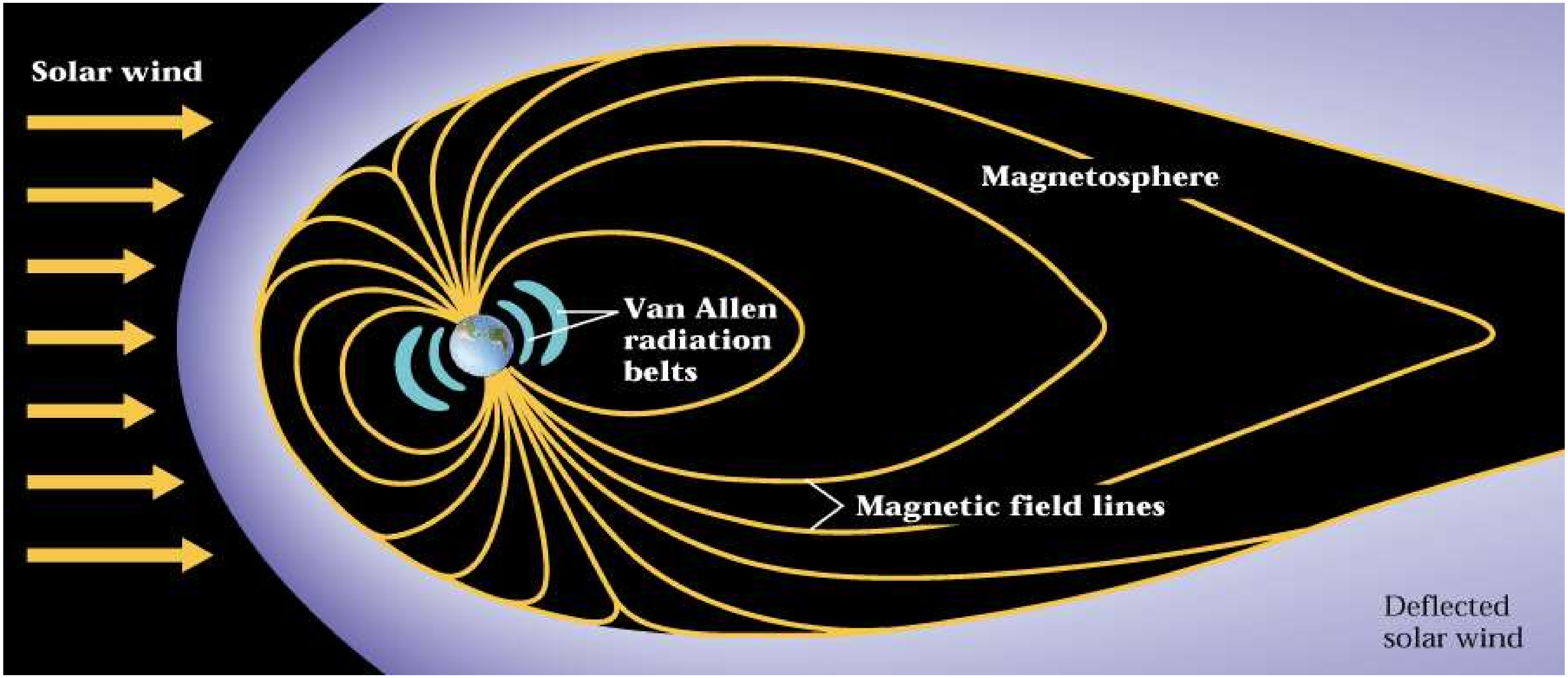
The Earth's magnetic field is generated by iron-rich, magnetic fluids in the outer core circulating around a spinning, solid-iron inner core.

This creates a "self-exciting dynamo".

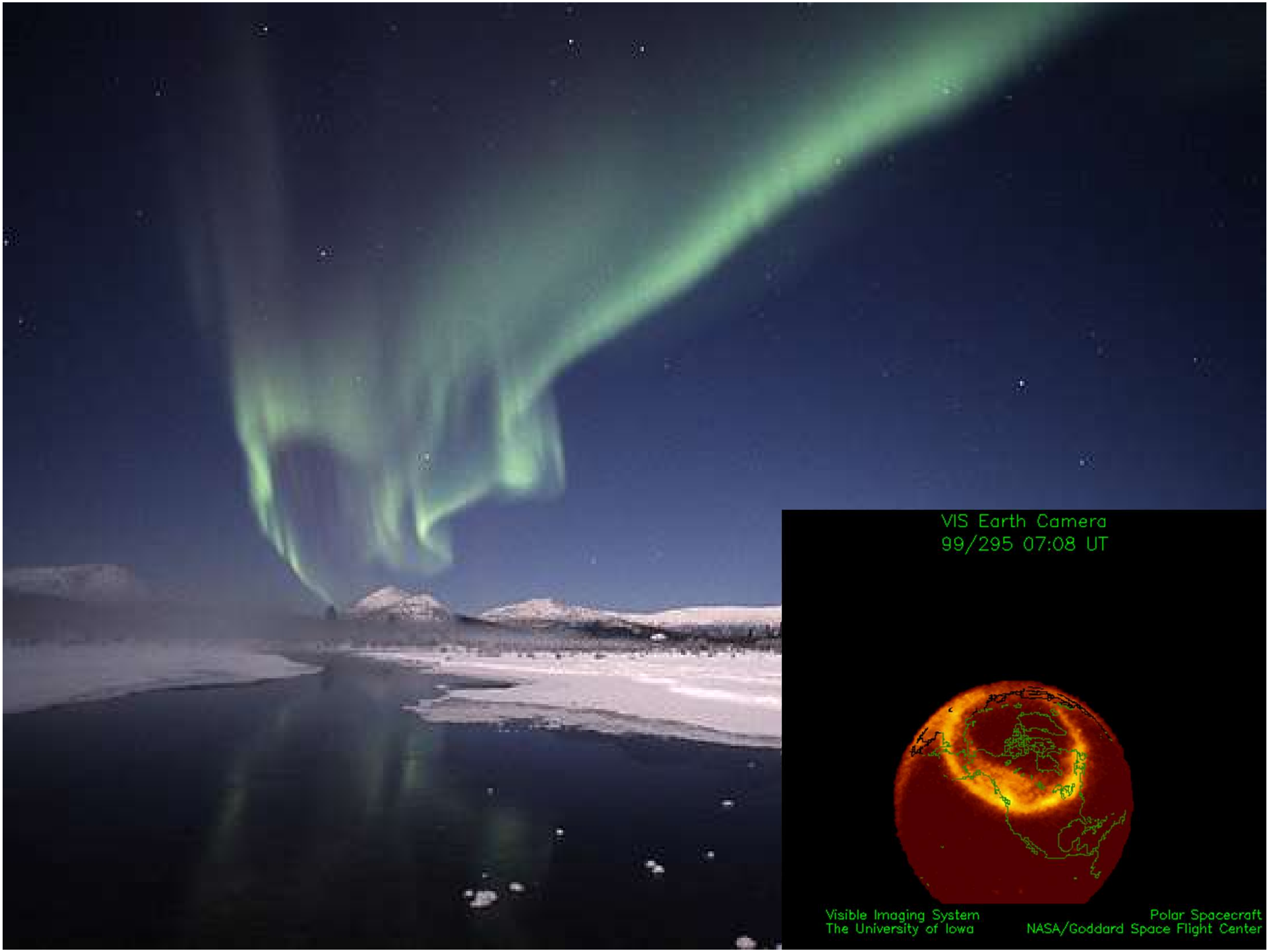


Intensity **of the magnetic field is greatest at poles and least at equator**

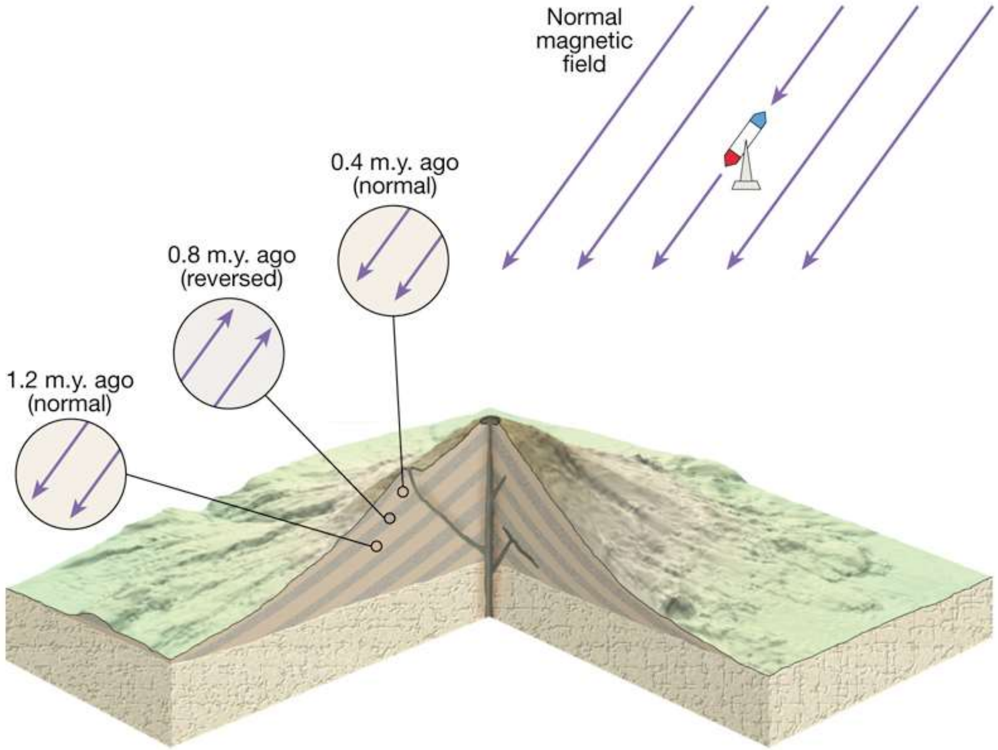
Our magnetic field protects us from UV radiation by deflecting low-energy charged particles *around* the Earth, but some particles become trapped in outer Van Allen radiation belts.

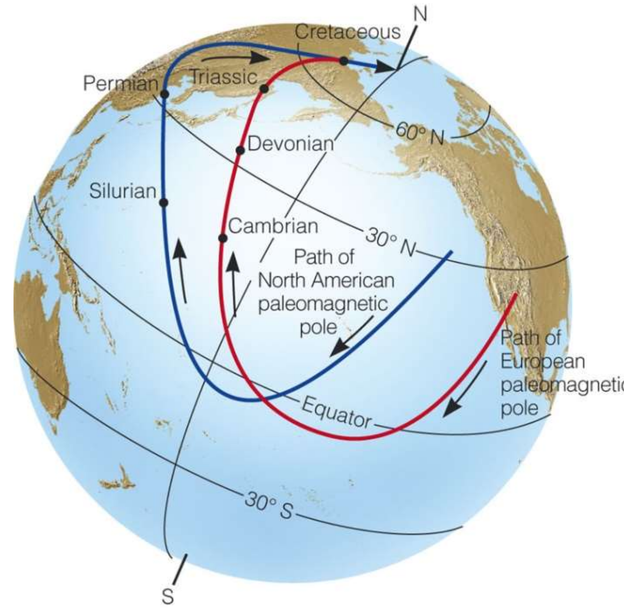


Other high-energy particles are steered into vertical fields above N and S magnetic poles where they collide with ions in Earth's atmosphere and produce...


VIS Earth Camera
99/295 07:08 UT
Visible Imaging System
The University of Iowa
Polar Spacecraft
NASA/Goddard Space Flight Center

• Studies of paleomagnetic poles from continental lava flows of different age show reversals of magnetic polarity.





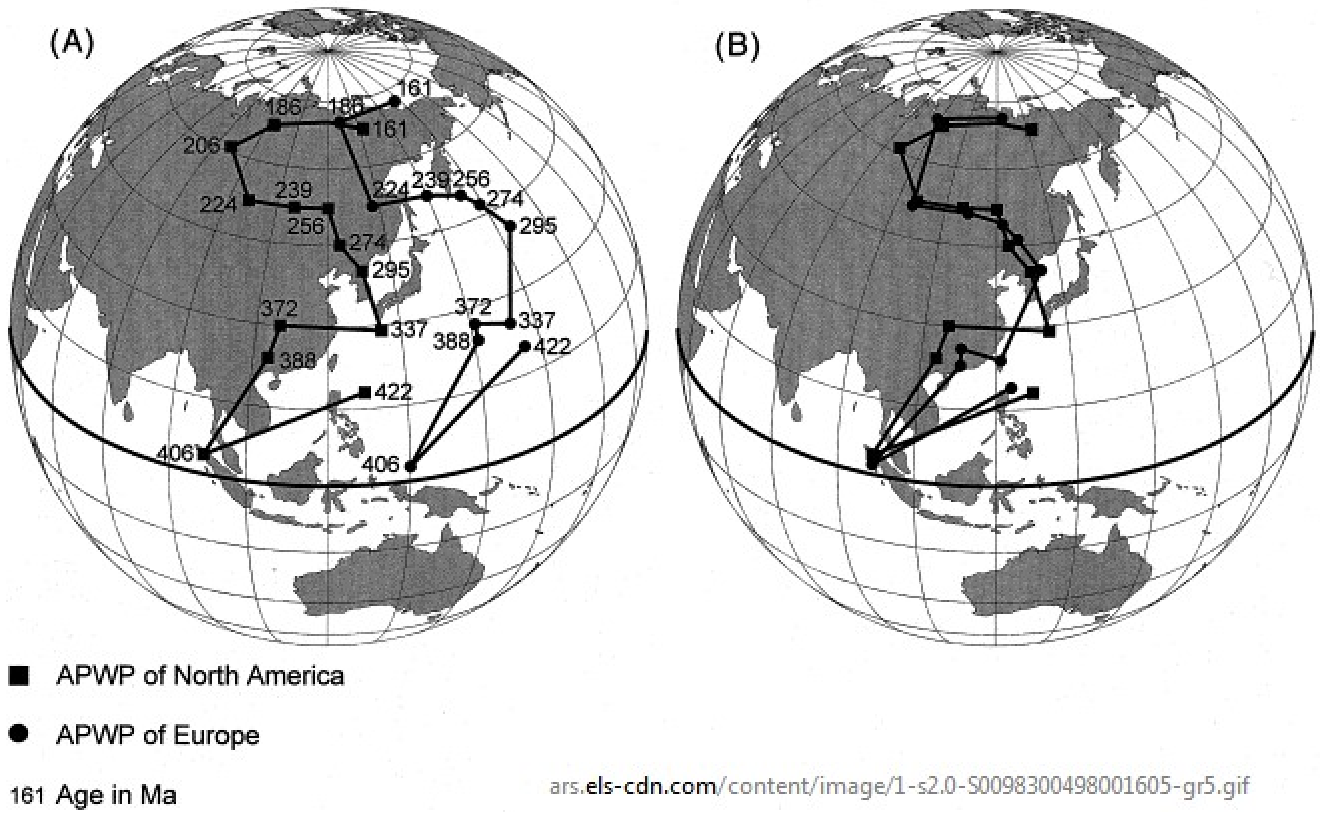
• By measuring the *inclination*, *declination*, and *intensity* of the paleomagnetic direction in stratum of different ages in different places, "polar-wandering paths" can be determined for different continents --- large, continuous land masses.

Different, but similar paths determined for different continents can be explained by:

1) ~~Having different poles for~~ different ~~continents~~

2) Magnetic poles have remained about the same while geographic poles and continents have moved

Comparison of paleomagnetic data



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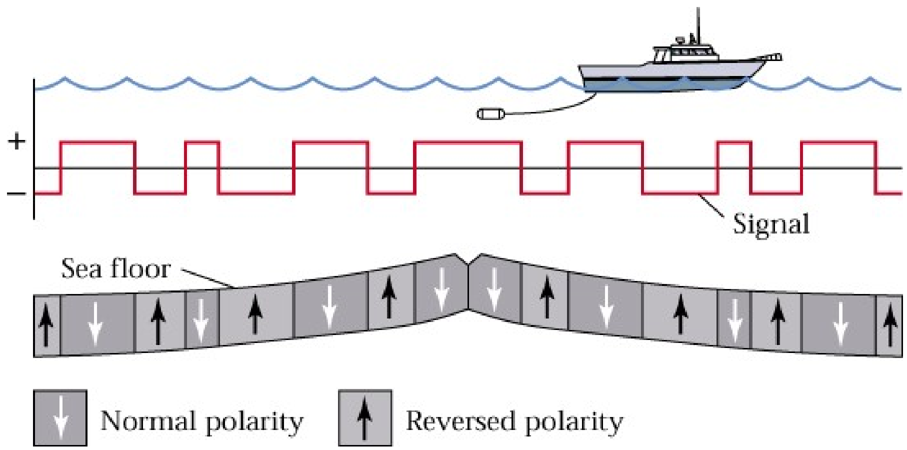
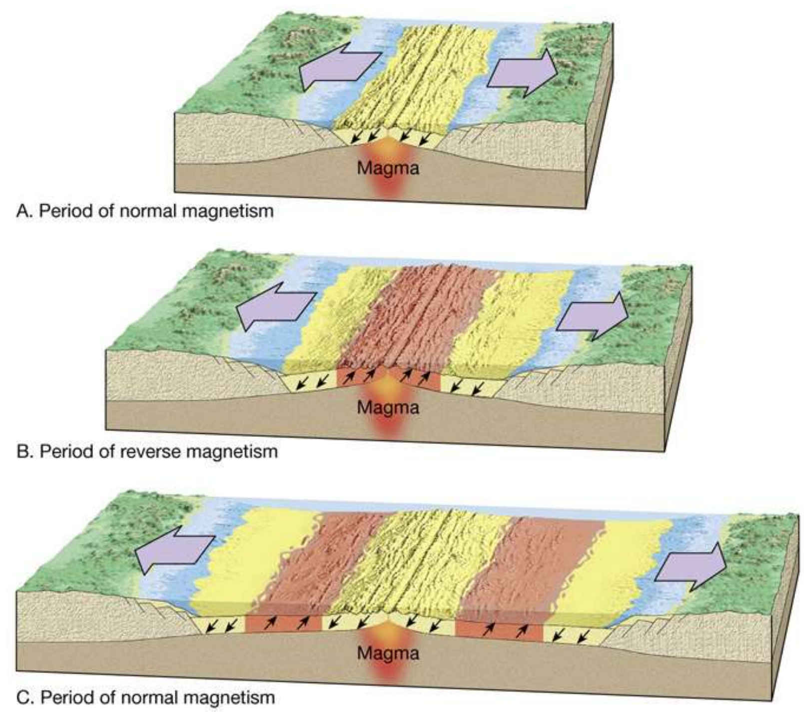
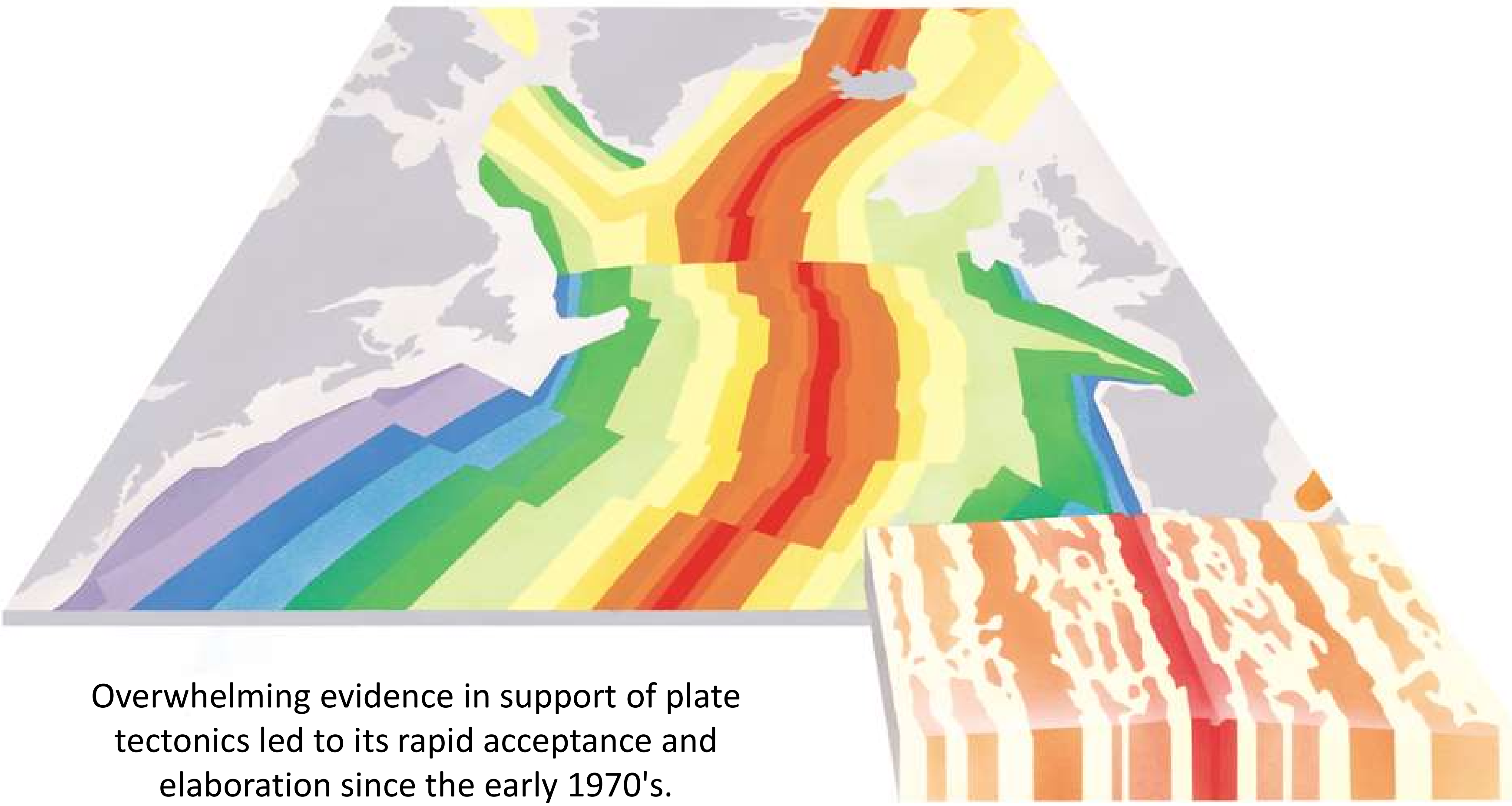
Magnetic surveys in the 1950's and 60's of oceanic crust revealed magnetic anomalies — reversals of magnetic polarity— and that these anomalies were disposed in symmetrical stripes paralleling the oceanic ridges.
This indicates that new oceanic crust must be formed along the spreading ridges.



This was a major breakthrough in plate-tectonic theory, because it shows that oceanic crust grows and can move with continental crust rather than having continents plowing through oceanic crust.



Sea floor spreading is confirmed by the ages of fossils in sediments overlying oceanic crust of various ages, and radiometric dating of rocks on oceanic islands. These indicate that oceanic crust is youngest at the spreading ridges and oldest at the farthest points from the ridges.



Overwhelming evidence in support of plate tectonics led to its rapid acceptance and elaboration since the early 1970's.

Note that oceanic crust is thinner than continental crust

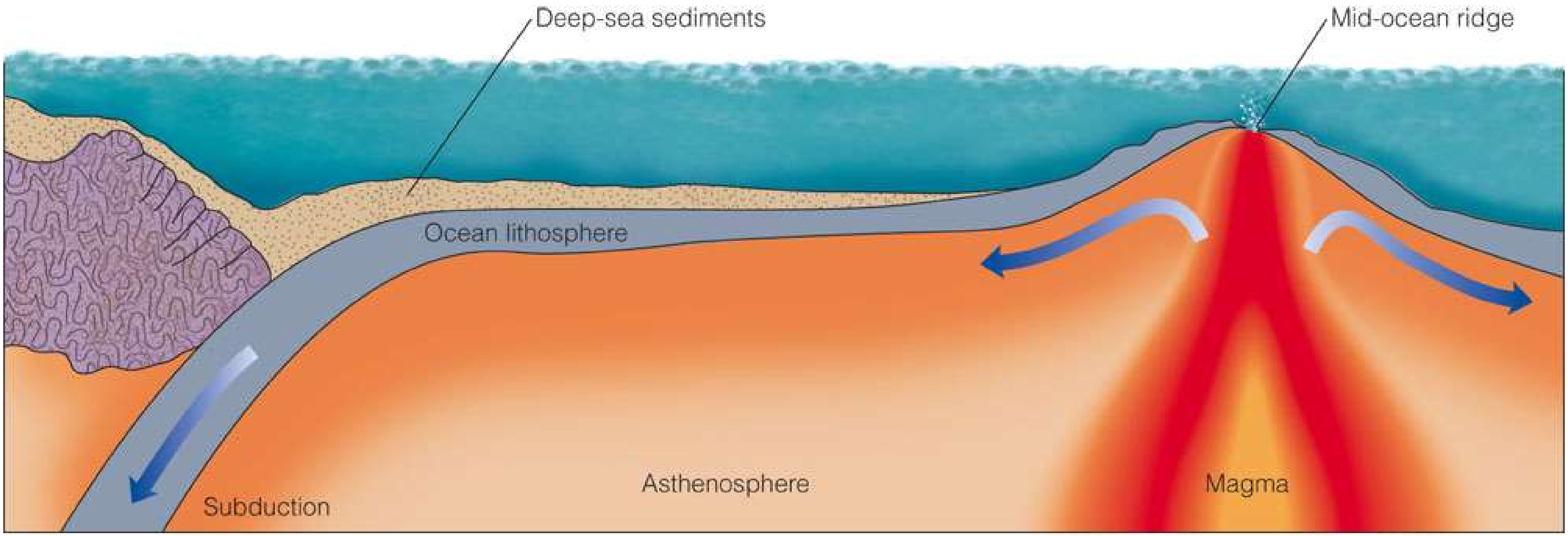
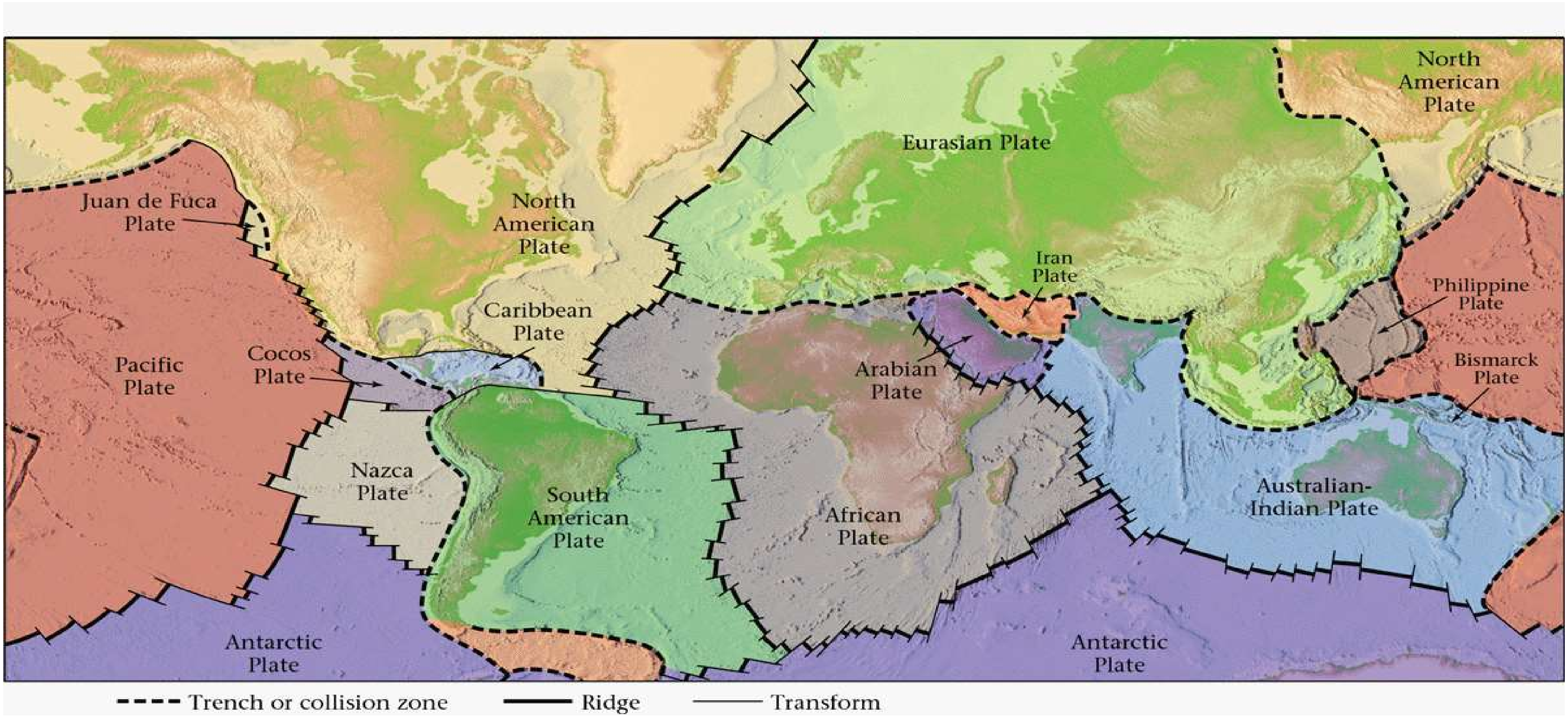


Plate-tectonic theory is widely accepted because it explains so many geologic phenomena, including volcanism, seismicity, mountain building, climatic changes, animal and plant distributions in the past and present, and the distributions of natural resources.

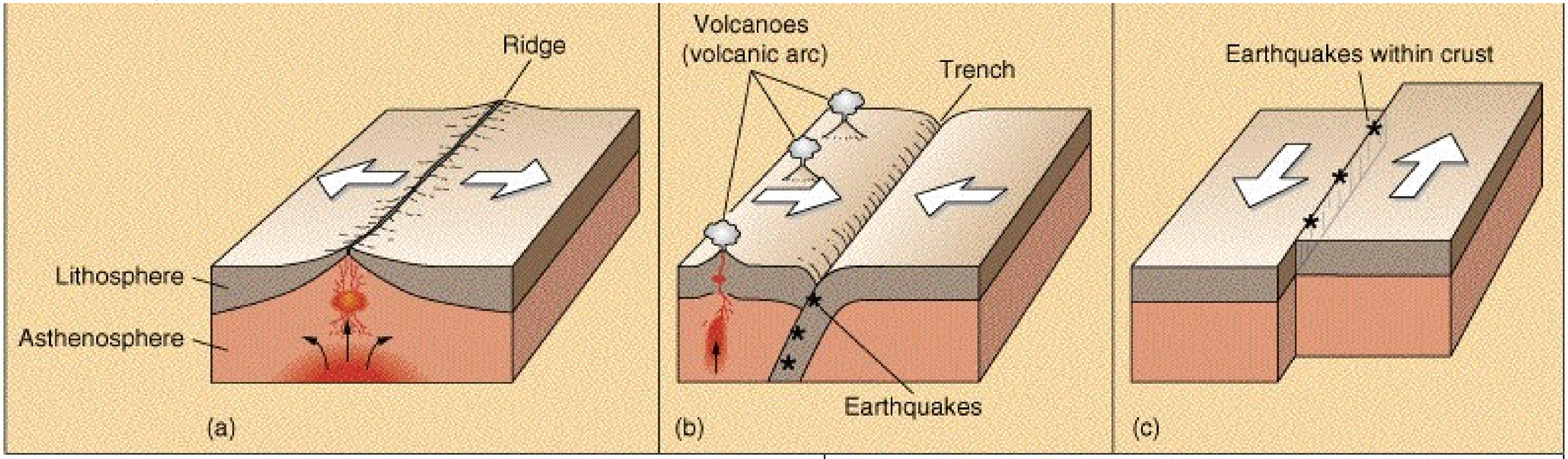
For these reasons, it is known as a *unifying theory*.



There are three types of plate boundaries: divergent, convergent, and transform.

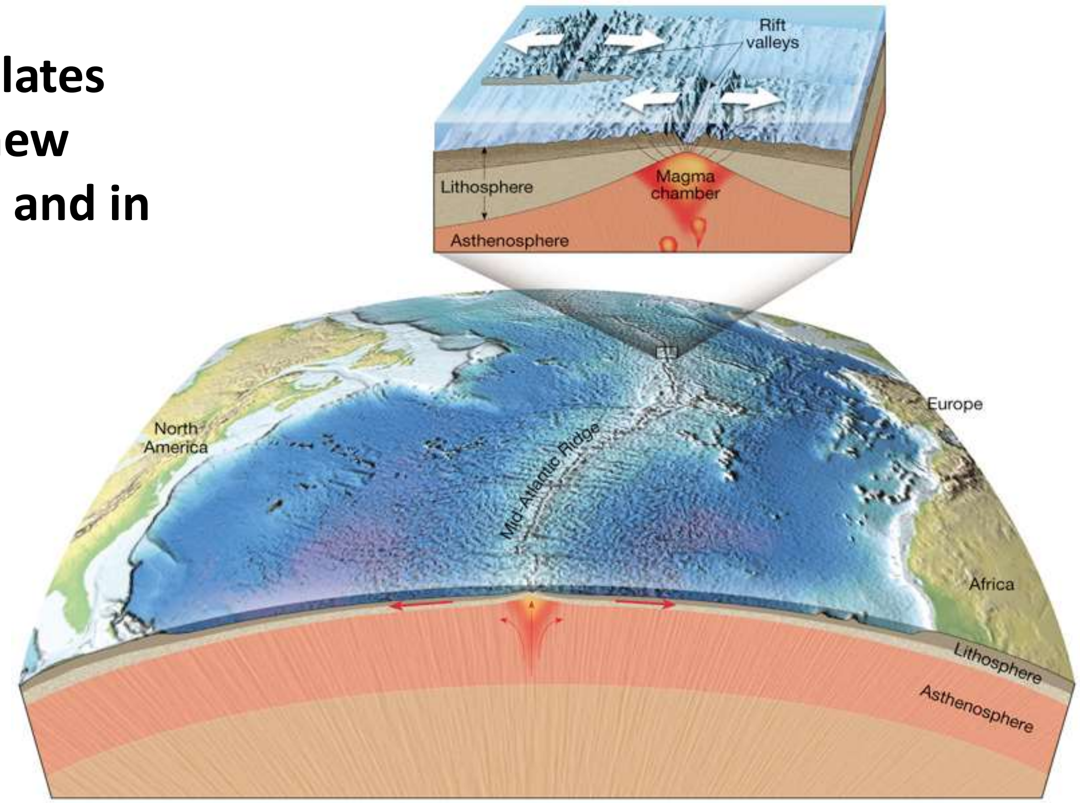
Types of Plate Boundaries

Type	Example	Landforms	Volcanism
Divergent			
Oceanic	Mid-Atlantic Ridge	Mid-oceanic ridge with axial rift valley	Basalt
Continental	East African Rift Valley	Rift valley	Basalt and rhyolite, no andesite
Convergent			
Oceanic–oceanic	Aleutian Islands	Volcanic island arc, offshore oceanic trench	Andesite
Oceanic–continental	Andes	Offshore oceanic trench, volcanic mountain chain, mountain belt	Andesite
Continental–continental	Himalayas	Mountain belt	Minor
Transform	San Andreas fault	Fault valley	Minor



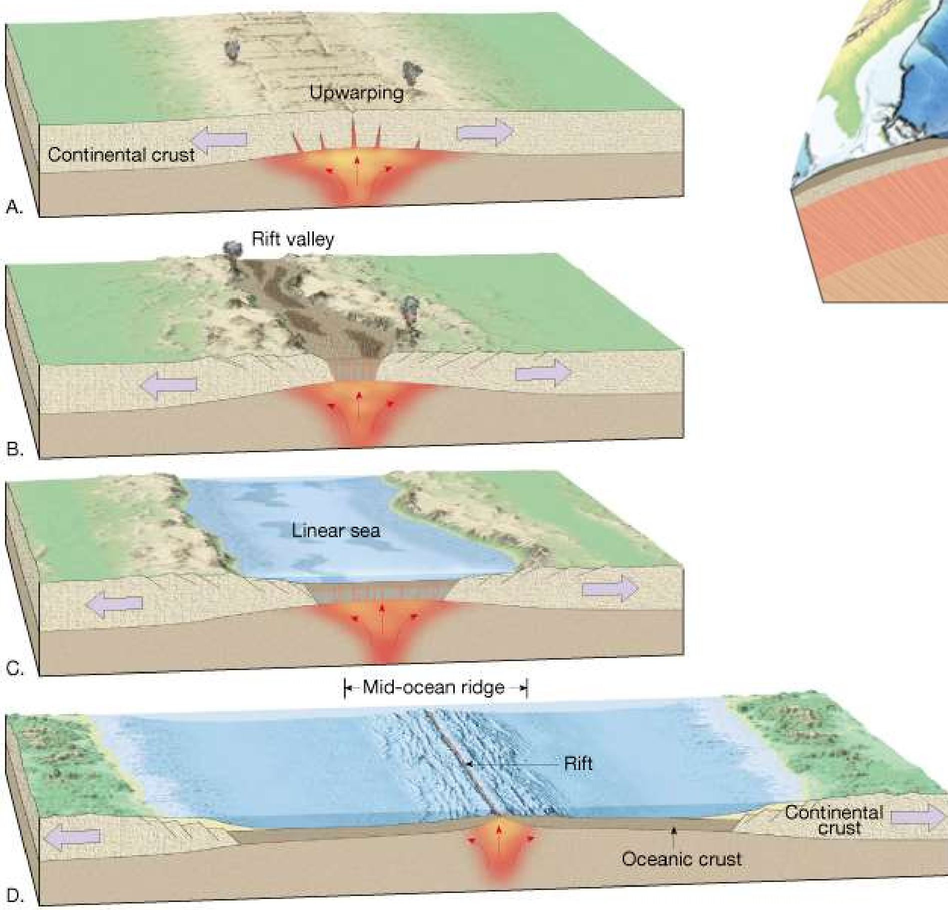
www.age-of-the-sage.org/tectonic_plates/volcanoes_earthquakes.gif

Divergent boundaries are where plates move away from each other and new crust is formed along ocean ridges and in continental basins



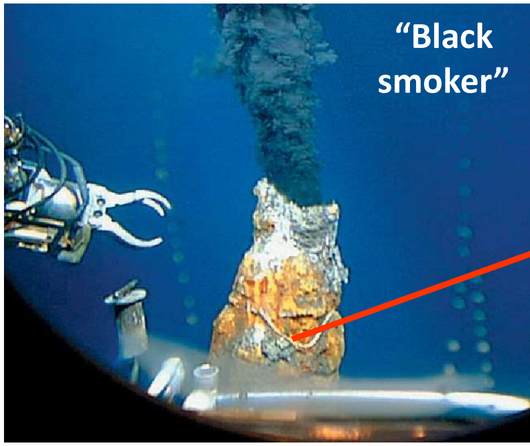
Type 1 oceanic

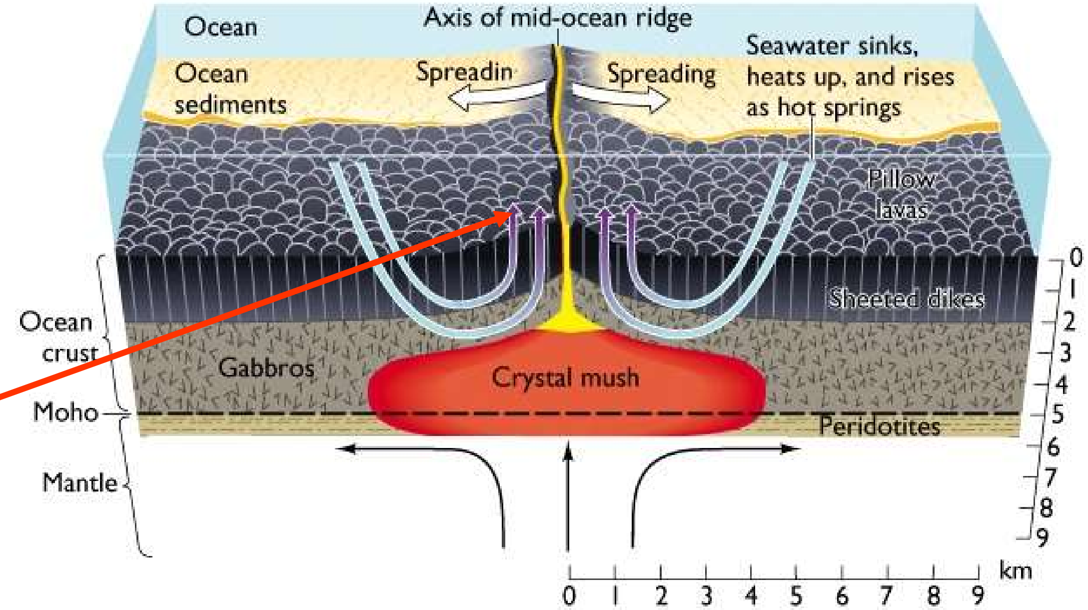
Type 2 continental

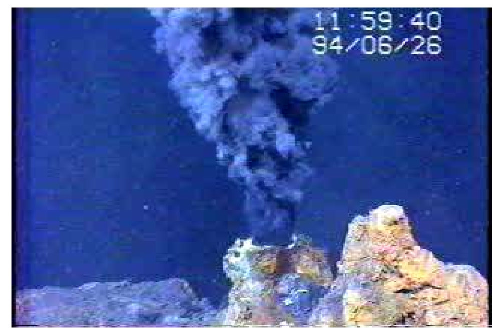


Two different types but have something in common

Oceanic divergent boundaries

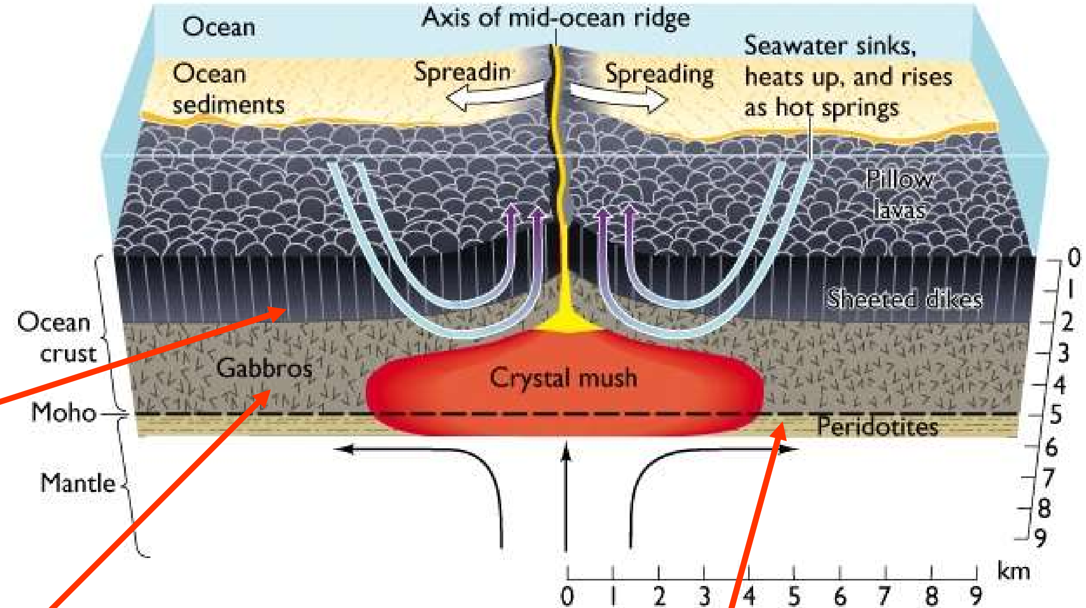


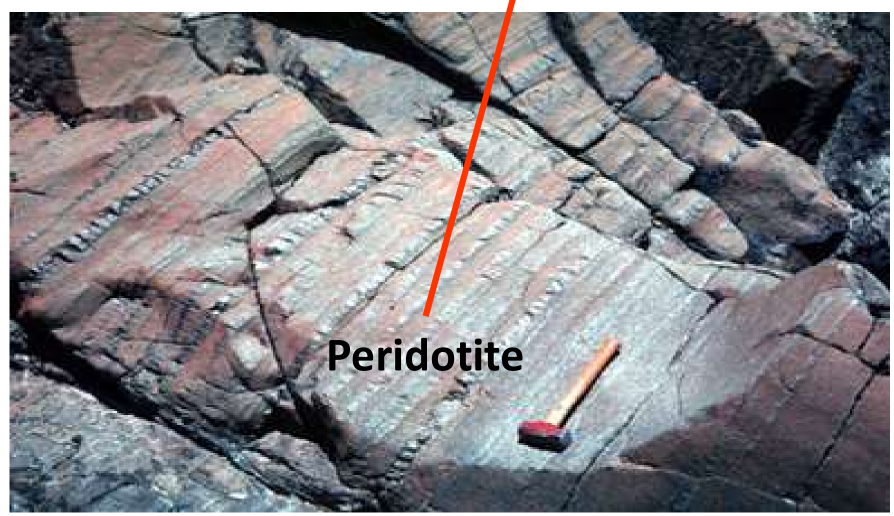




Precambrian basalt from 2-billion-year-old slice of seafloor, Quebec, Canada

Oceanic divergent boundaries

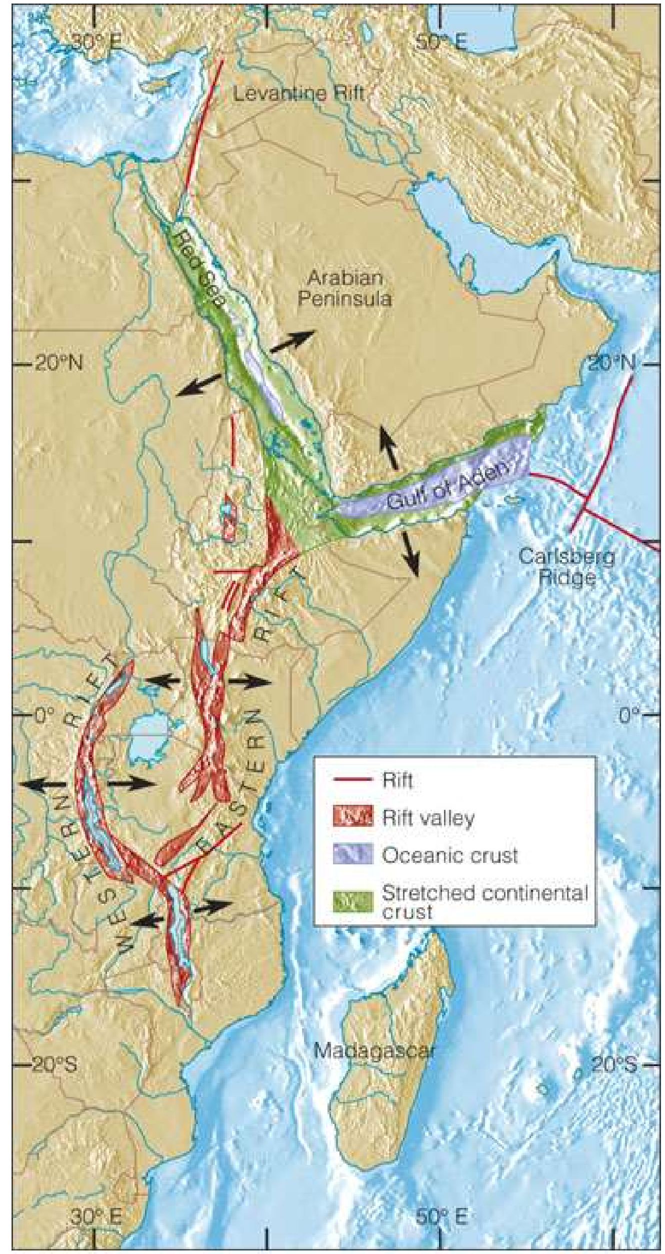


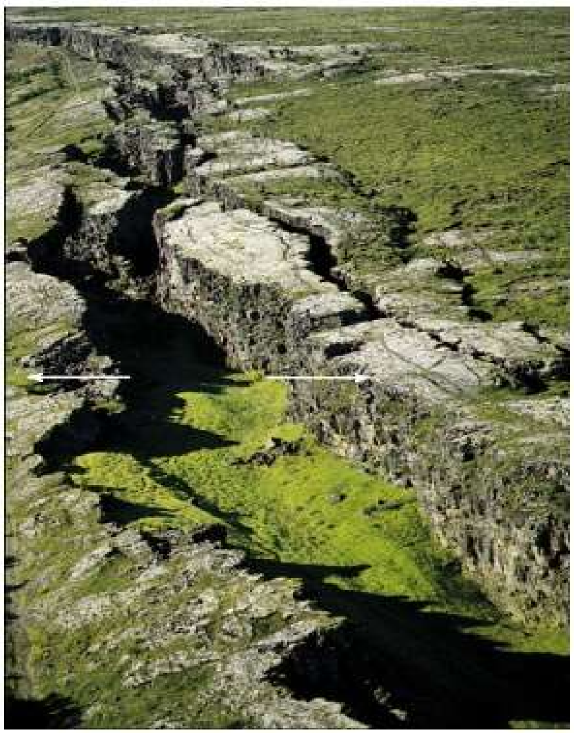


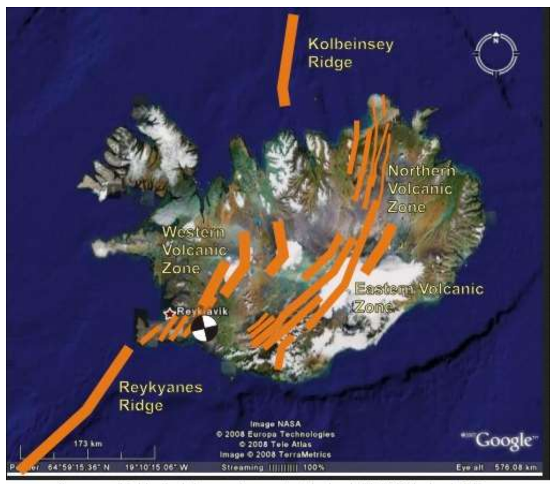
Continental divergent boundaries

Wright, T.J., C. Ebinger, J. Biggs, A. Ayele, G. Yirgu, D. Keir, A. Stork, 2006, Magma-maintained rift segmentation at continental rupture in the 2005 Afar dyking episode, Nature, 442, 291-294

East-African rift







all-geo.org/highlyallochthonous/wp-content/uploads/2010/07/iceland_rift.jpg

Icelandic rifts

Continental divergent boundaries – closer to home

Eastern North American continental rift system and the Newark basin

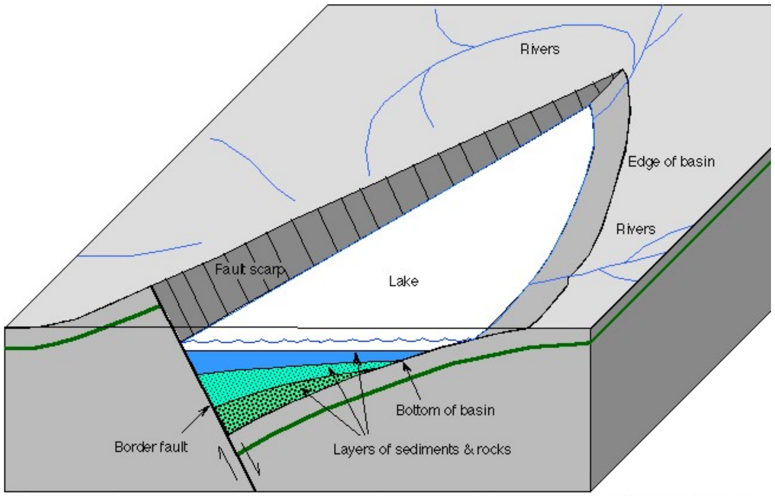
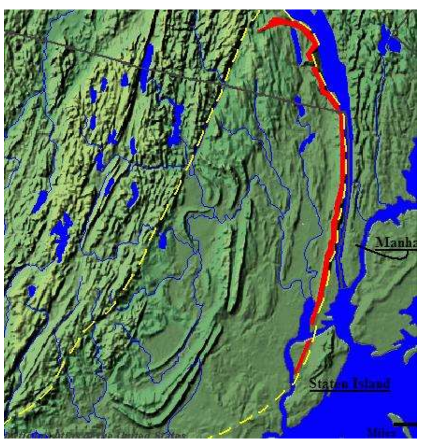
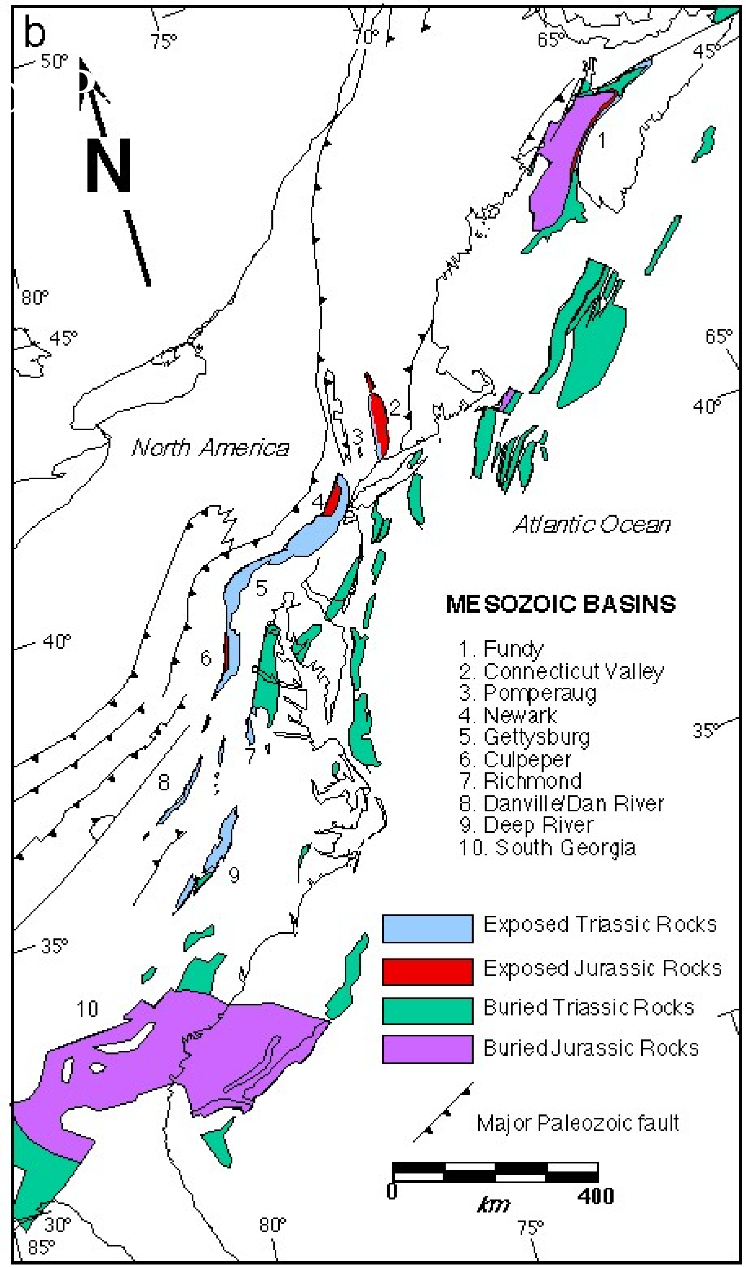
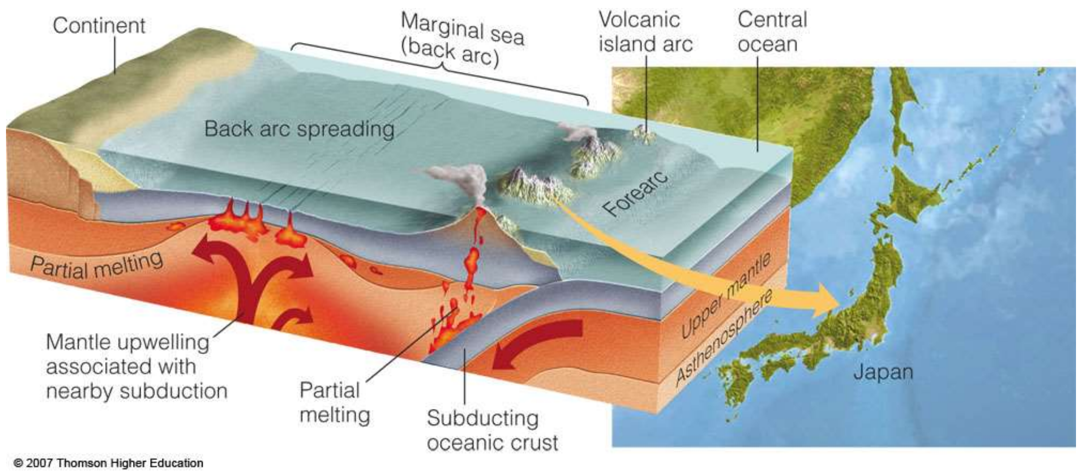


Figure 4: Cutaway block diagram of a rift basin. Note the half-graben geometry (triangular) in the cross section view (front panel).

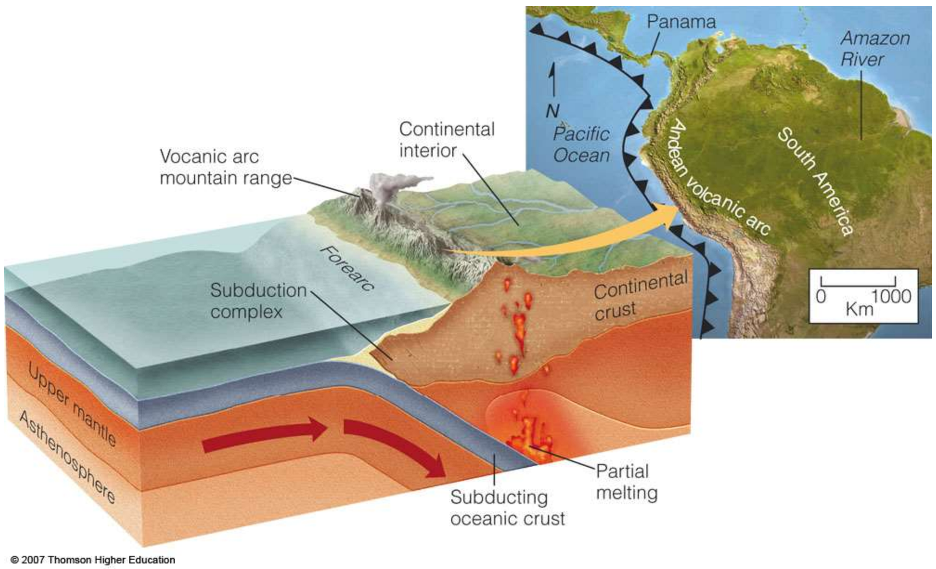




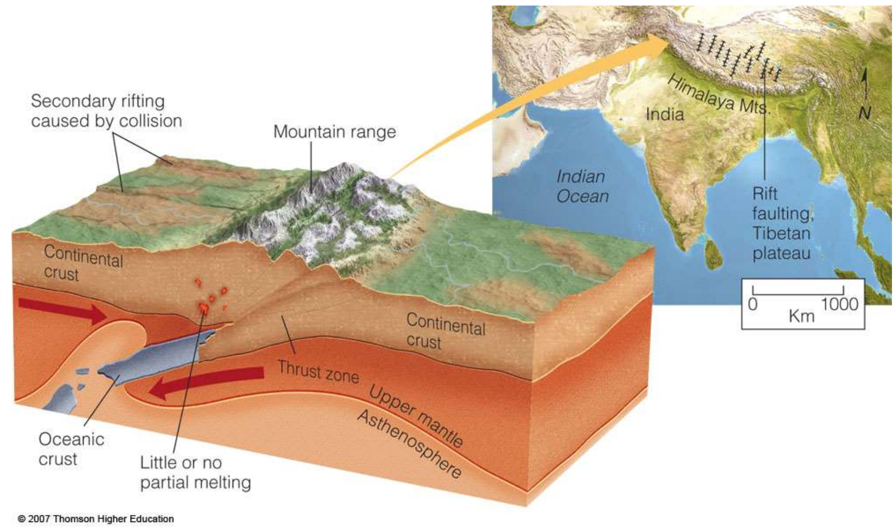
Convergent boundaries exist where one plate is *subducted* beneath another and crust is destroyed, and/or two plates with continental crust on their leading edges collide, and mountains are formed



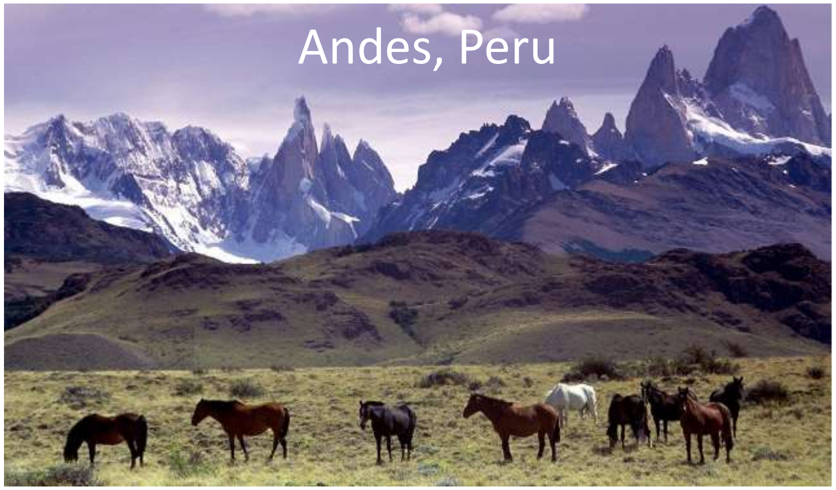
Type 1 ocean – ocean



Type 2 ocean – continent



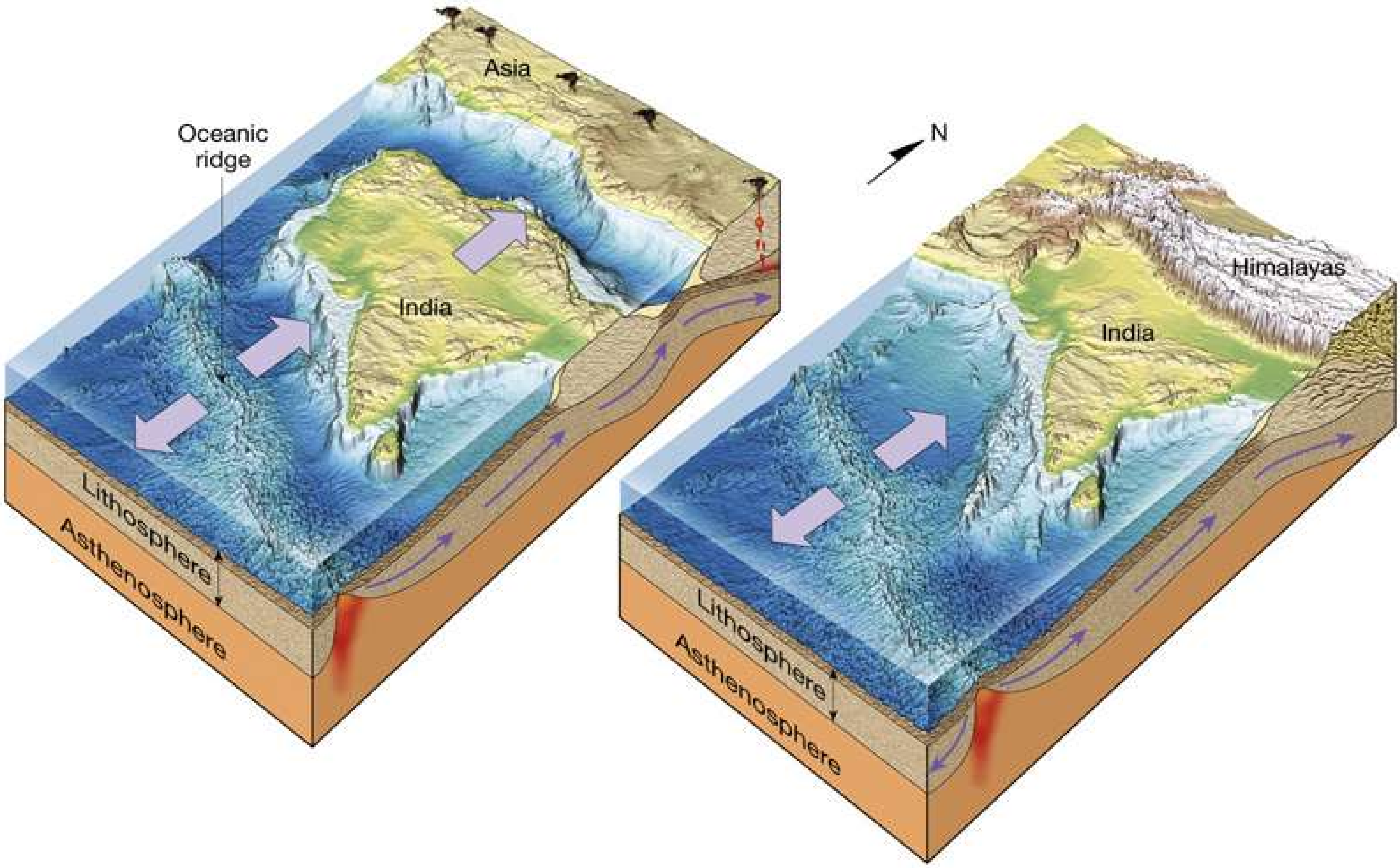
Type 3 continent – continent



www.openwalls.com/image/19113/horses_andes_mountains_argentina__1400x1050.jpg

www.socialmediastrategiessummit.com/blog/wp-content/uploads/Mount_Everest.jpg

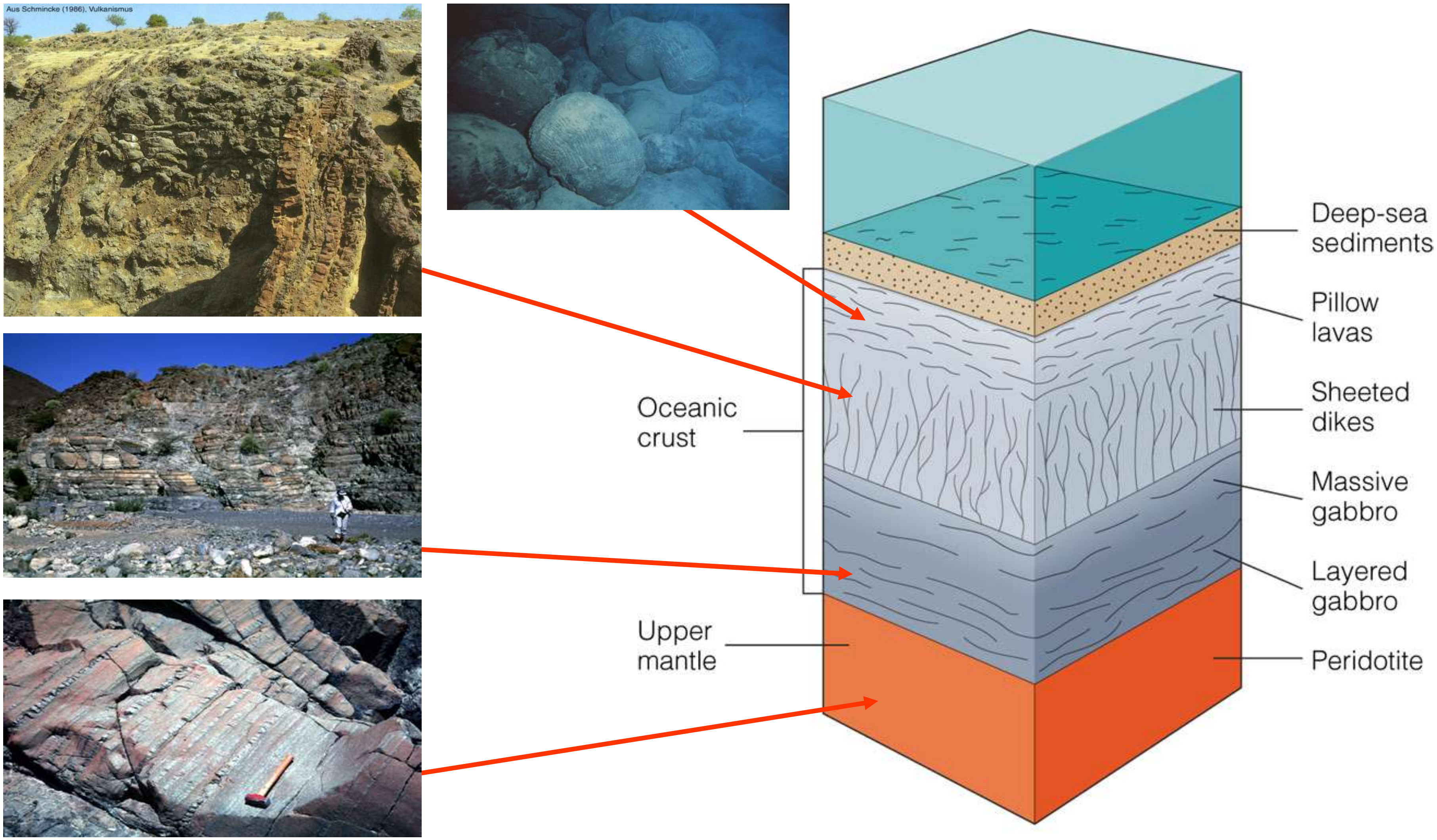
Himalayas, Mongolia - China



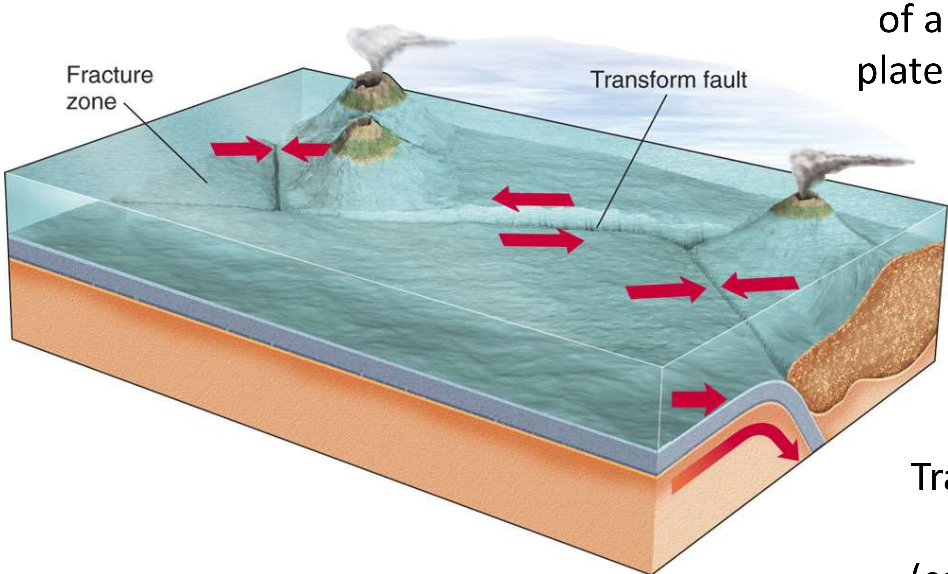
Examples of alpine folding and faulting in continental mountain belts

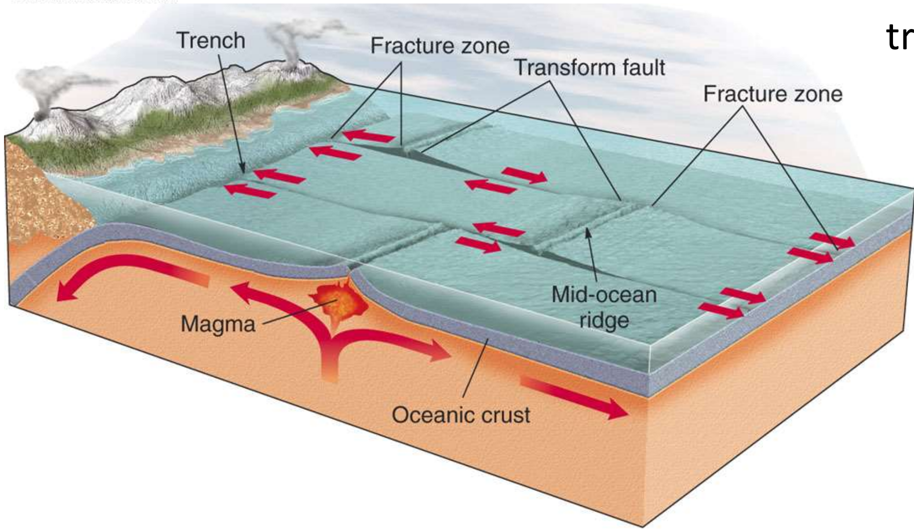
www.teachers.sduhsd.net/hherms/herms/GEOLOGY/mtn-bldg/folds.jpg

Ancient, oceanic crustal rocks that formed at divergent boundaries that are locally thrust onto onto land (obducted) at oceanic-continental concergent plate boundaries, are called ophiolites.



Transform boundaries are where the margins of two plates slide horizontally past one another.



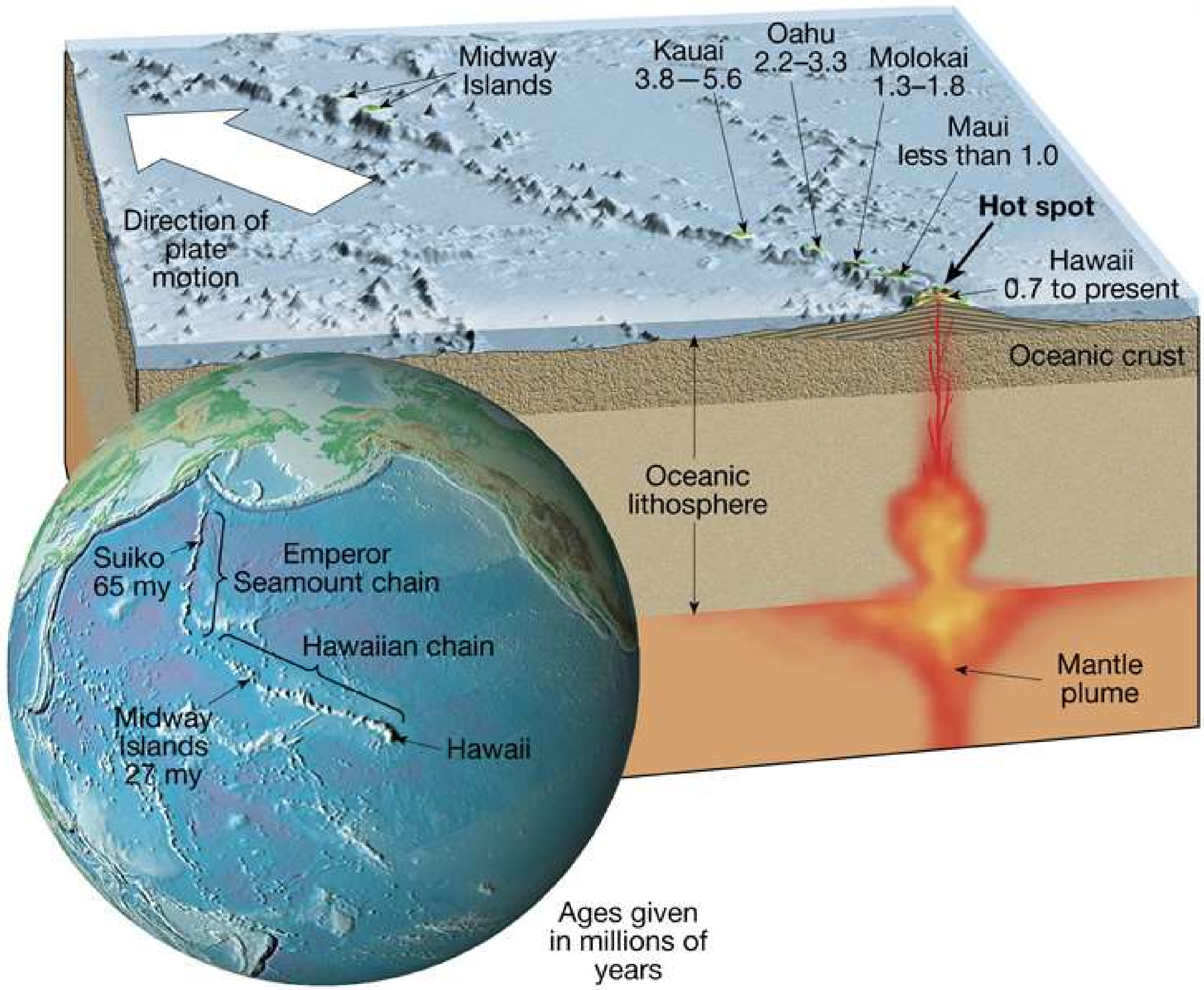


Transform faults (oceanic) as part of a complex plate boundary

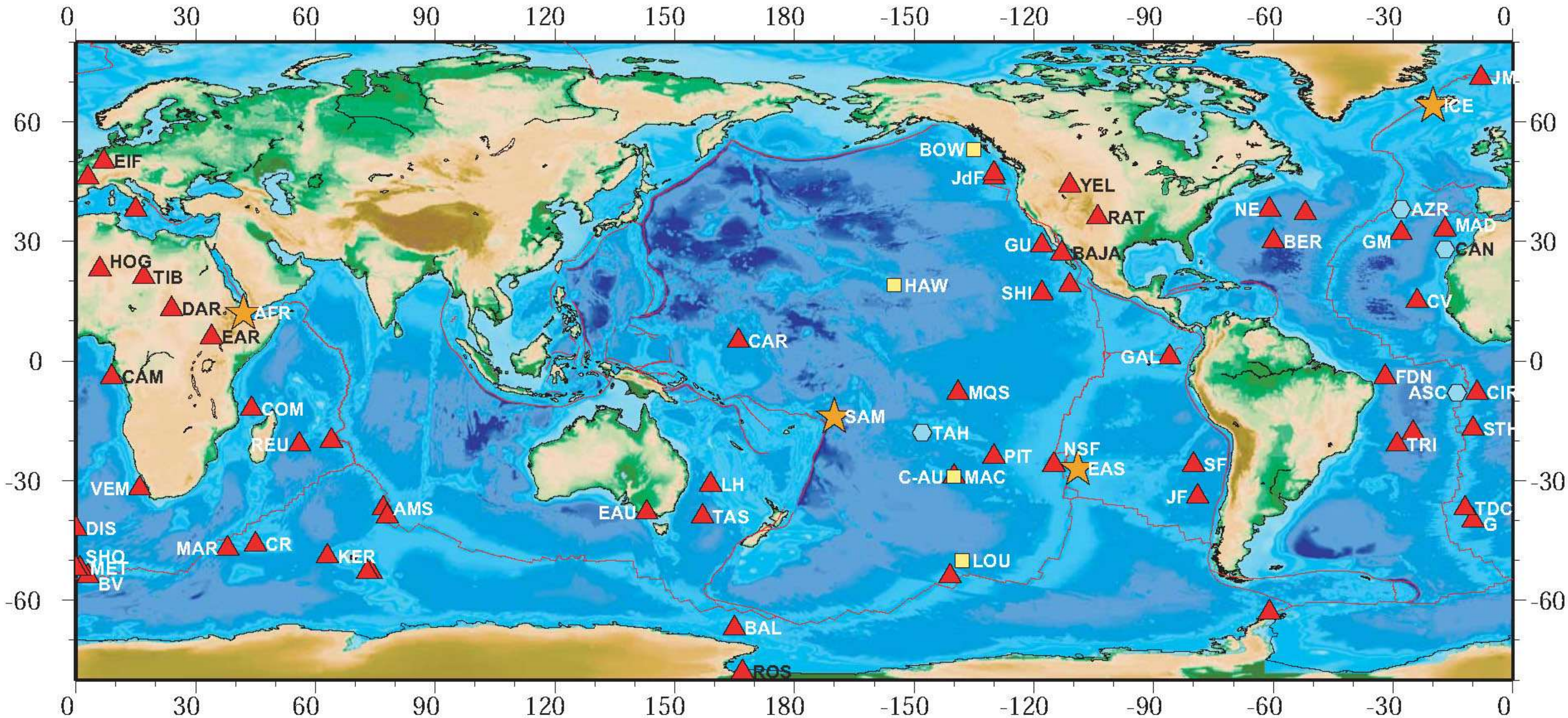
Transcurrent fault (continental) transform plate boundary

Hot Spots – An intraplate feature

A location on Earth's surface where a stationary (?) column of magma, originating deep within the mantle (mantle plume), has risen to the surface to form a volcano.



Hot Spots – An intraplate feature



www.faculty.gg.uwyo.edu/dueker/Yellowstone/YEL%20PLUME%20TALK%202005_files/slide0036_image003.jpg

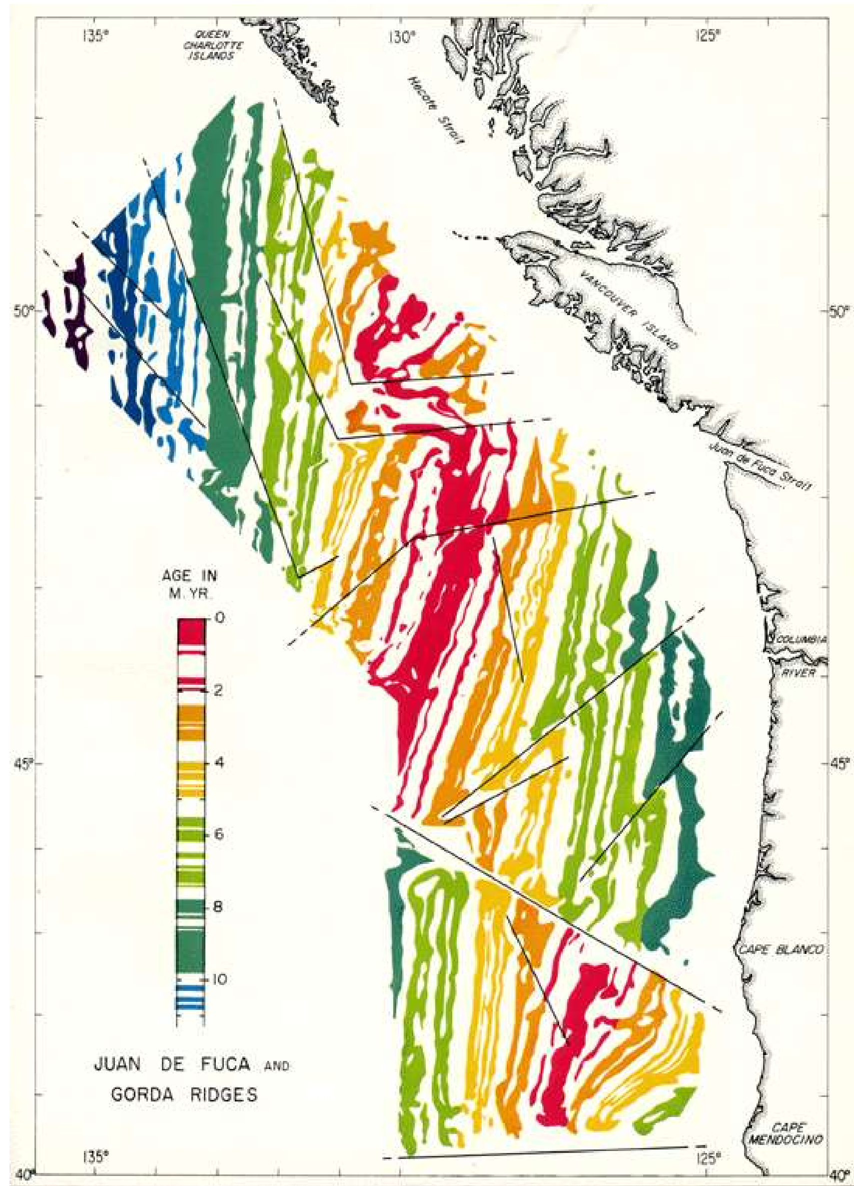
How do we measure plate motions?

Old ways:

1) Measure sediment thickness on ocean plates and divide by distance from a ridge (least accurate)

2) Dating magnetic anomalies on the ocean floor. Knowing the age of the anomaly, and the distance between them, divide the distance by the difference of the bounding ages.

3) Similar to No. 2 but using chains of hotspots.

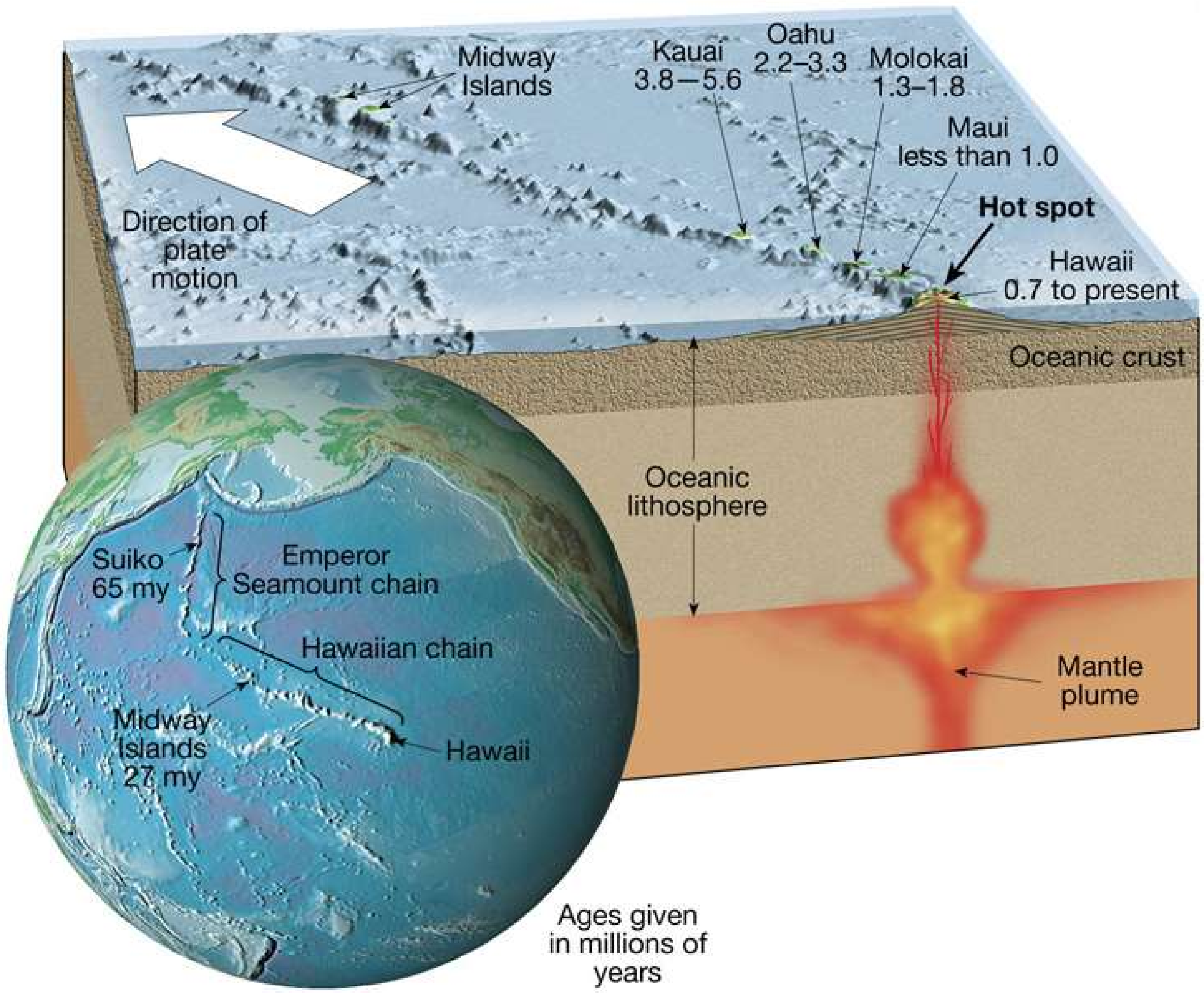


www.serg.unicam.it/images/Fig10.gif

How do we measure plate motions?

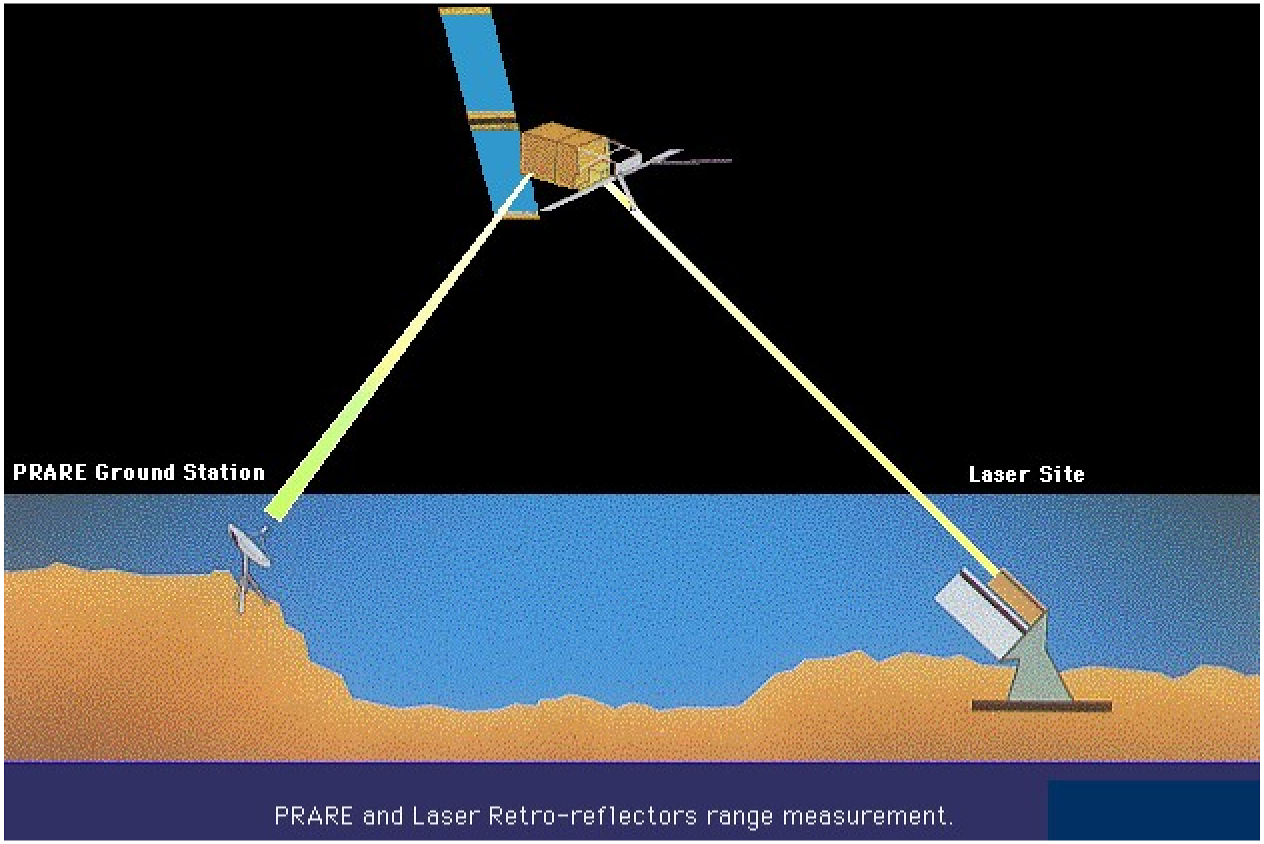
Old ways:

3) Similar to No. 2 but using oceanic-mountain chains formed by a hotpsot



How do we measure plate motions?

New ways: 1) Laser – satellite ranging



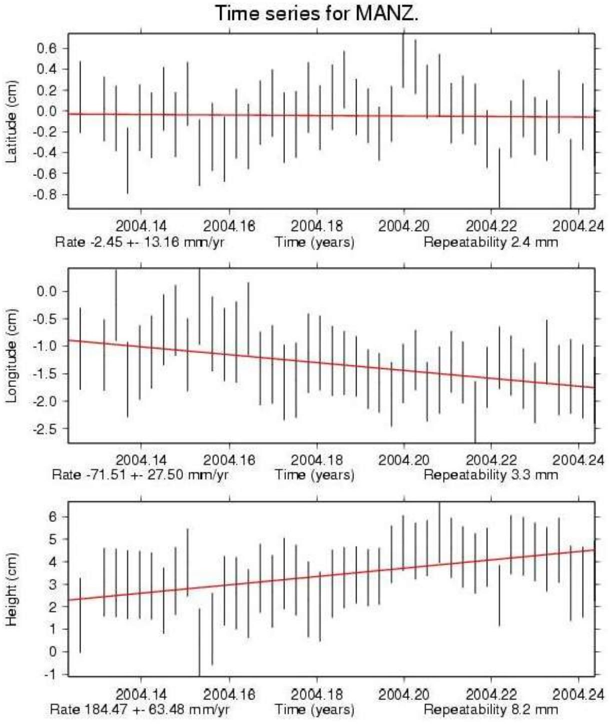
www.earth.esa.int/rootcollection/eeo4.10075/_PRARE_and_Laser_RETRO-Reflectors_range_measurements_Image.gif

How do we measure plate motions?

New ways:

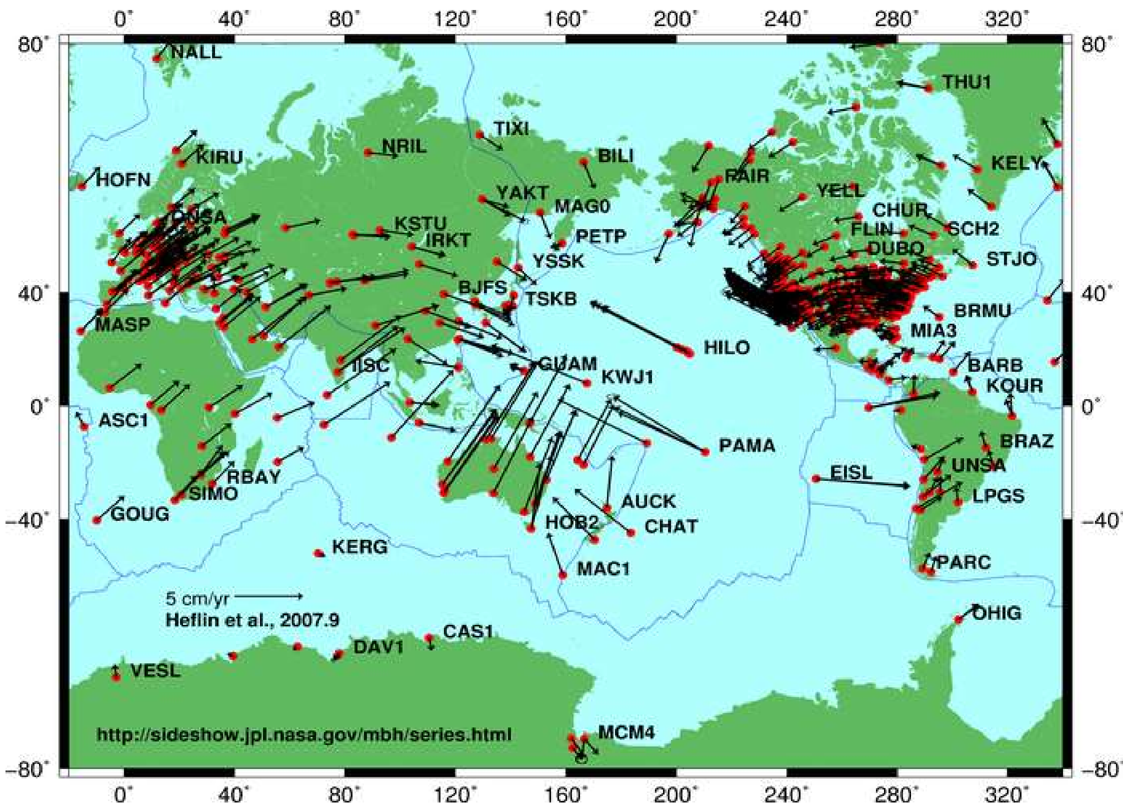
2) Ground-based, Global-Positioning-Systems (GPS)

http://www.nist.gov/pml/div688/grp40/images/GPS_Constellation_2.gif



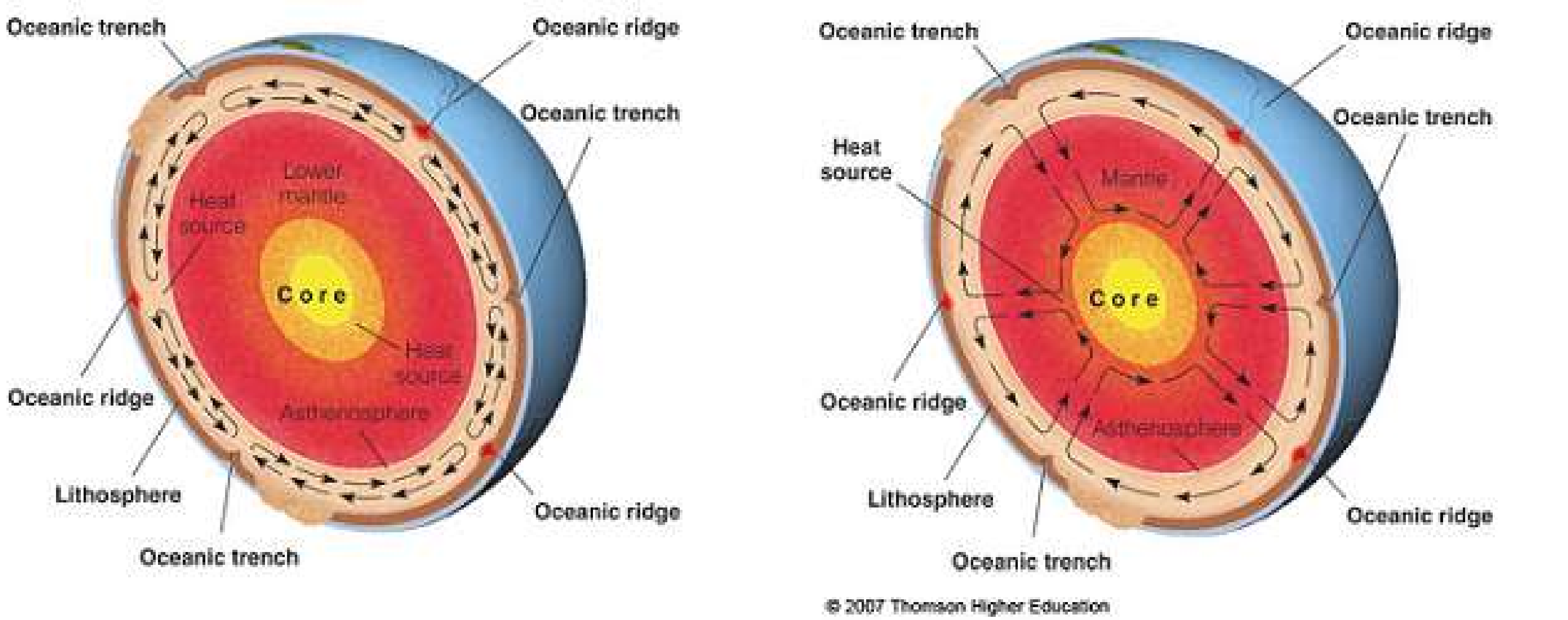
http://sideshow.jpl.nasa.gov/mbh/series.html

How fast are plate velocities?



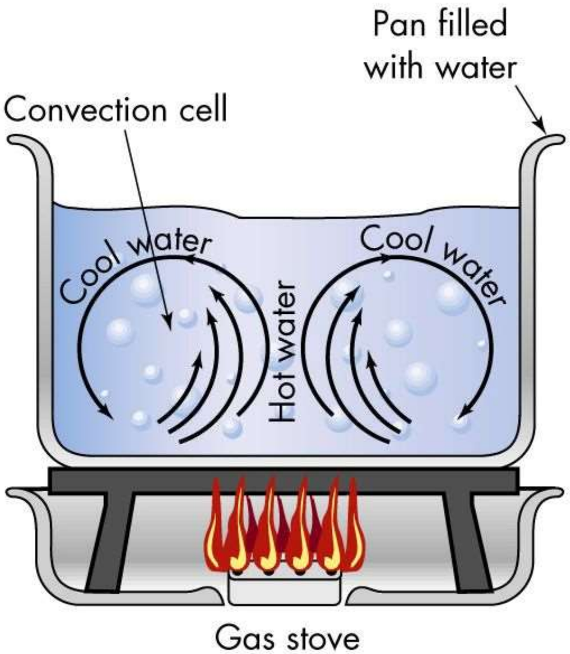
For 909 stations, 1 mm to 79 mm per year horizontal velocity, average 26 mm/yr

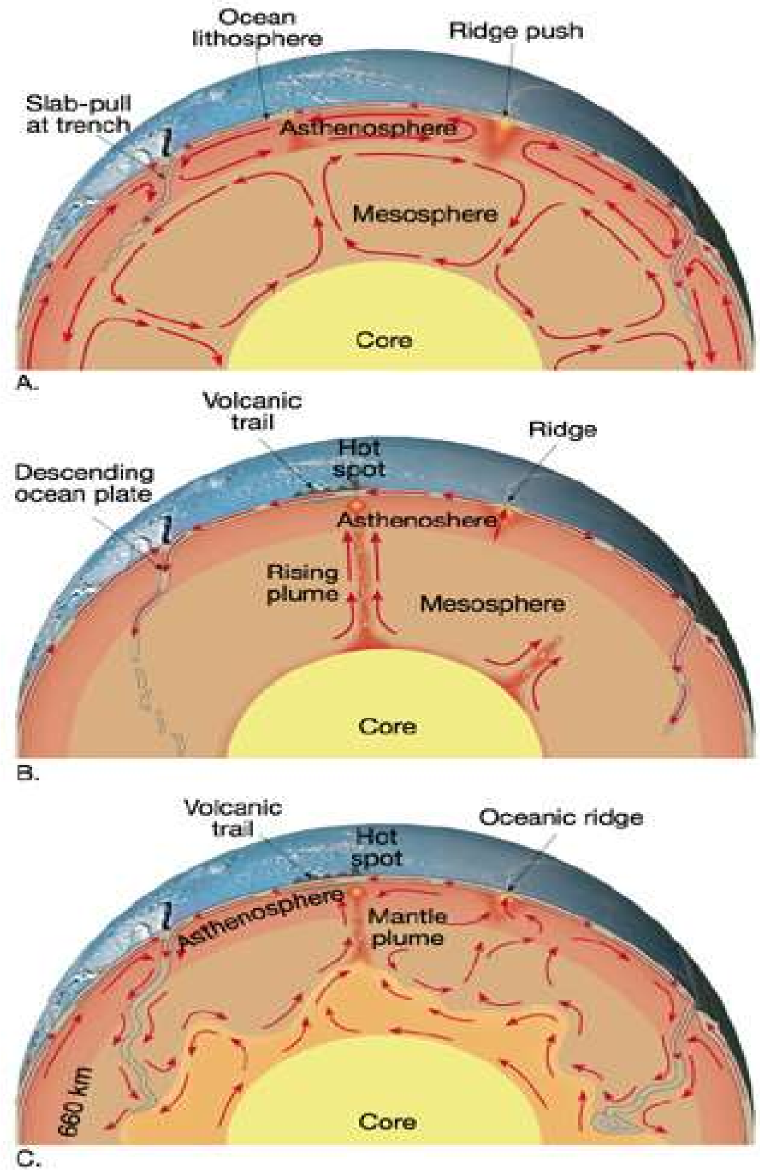
What drives plate motions?



1) Thermal convection cells act as a ‘conveyor-belt, carrying the crust along

What drives plate motions?

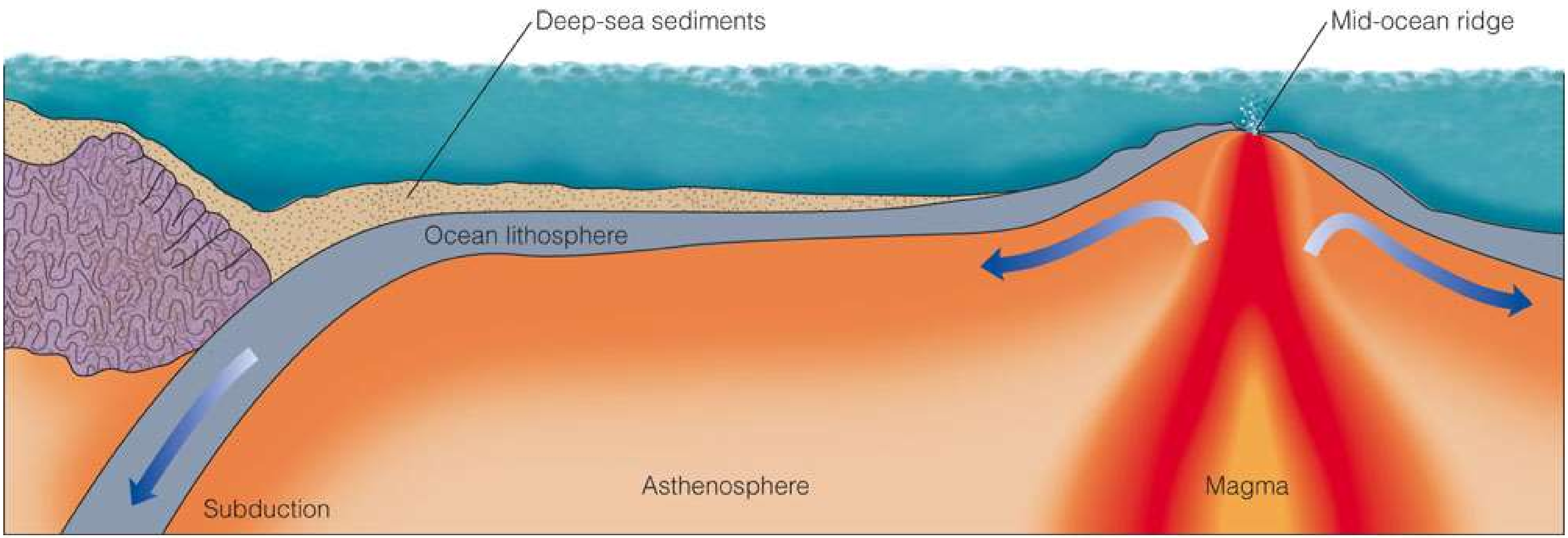




Various models for mantle convection have been proposed

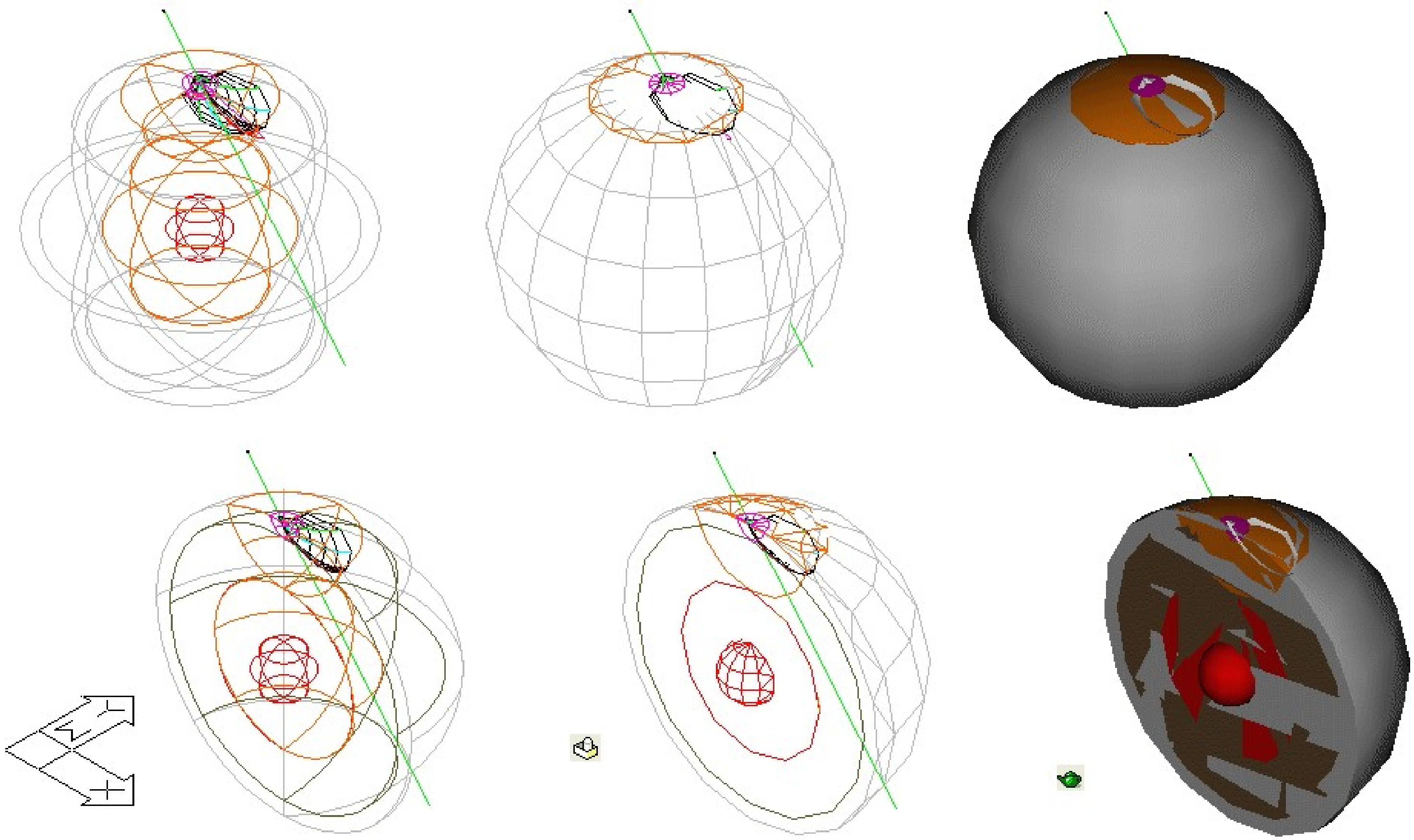
What drives plate motions?

2) Gravity including the effects of 'ridge push' and 'slab pull'



What drives plate motions?

3) Directed push from, oblique, hypervelocity (> 3km/sec to 30 km/sec), bolide impacts ?



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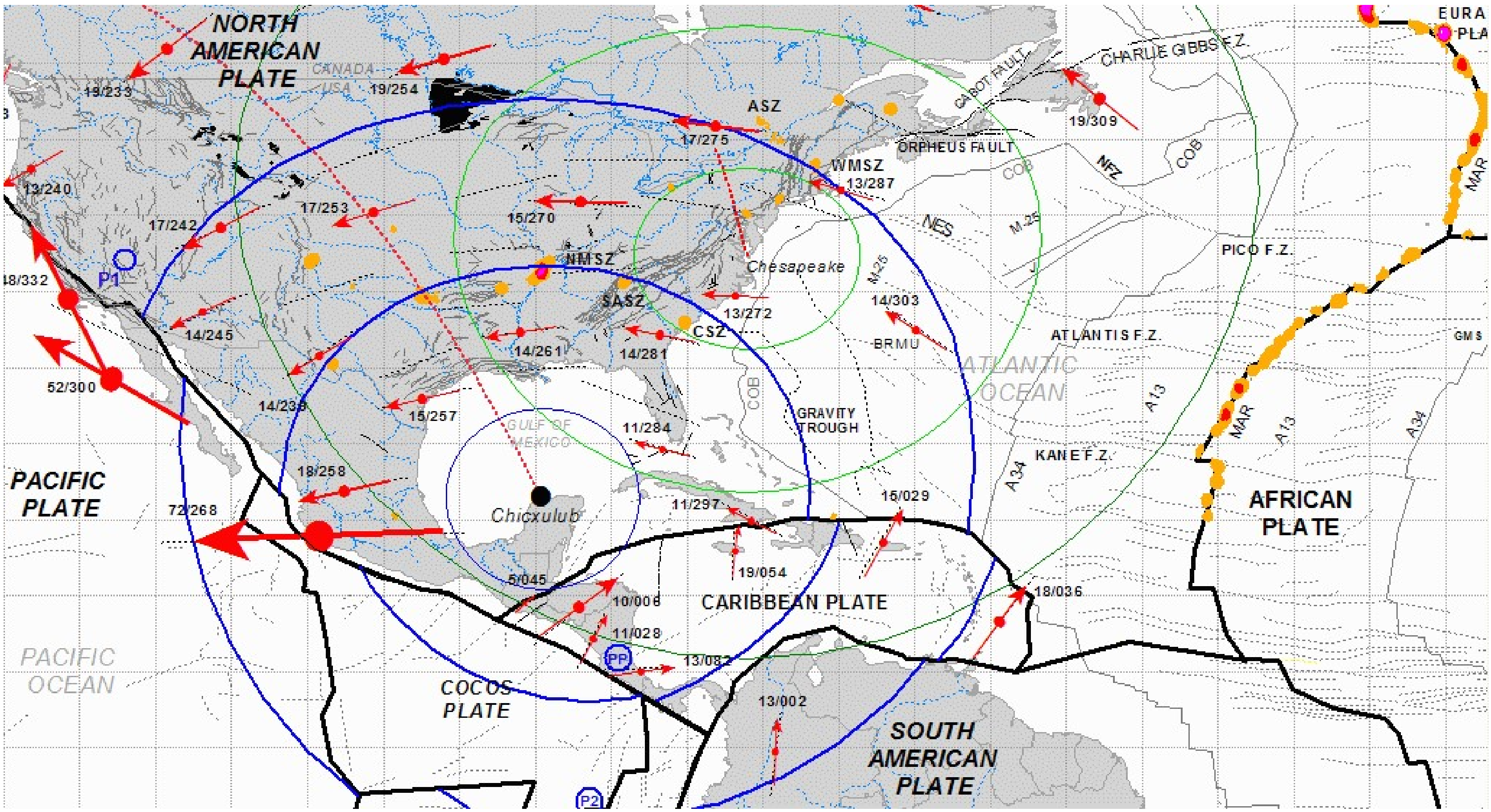
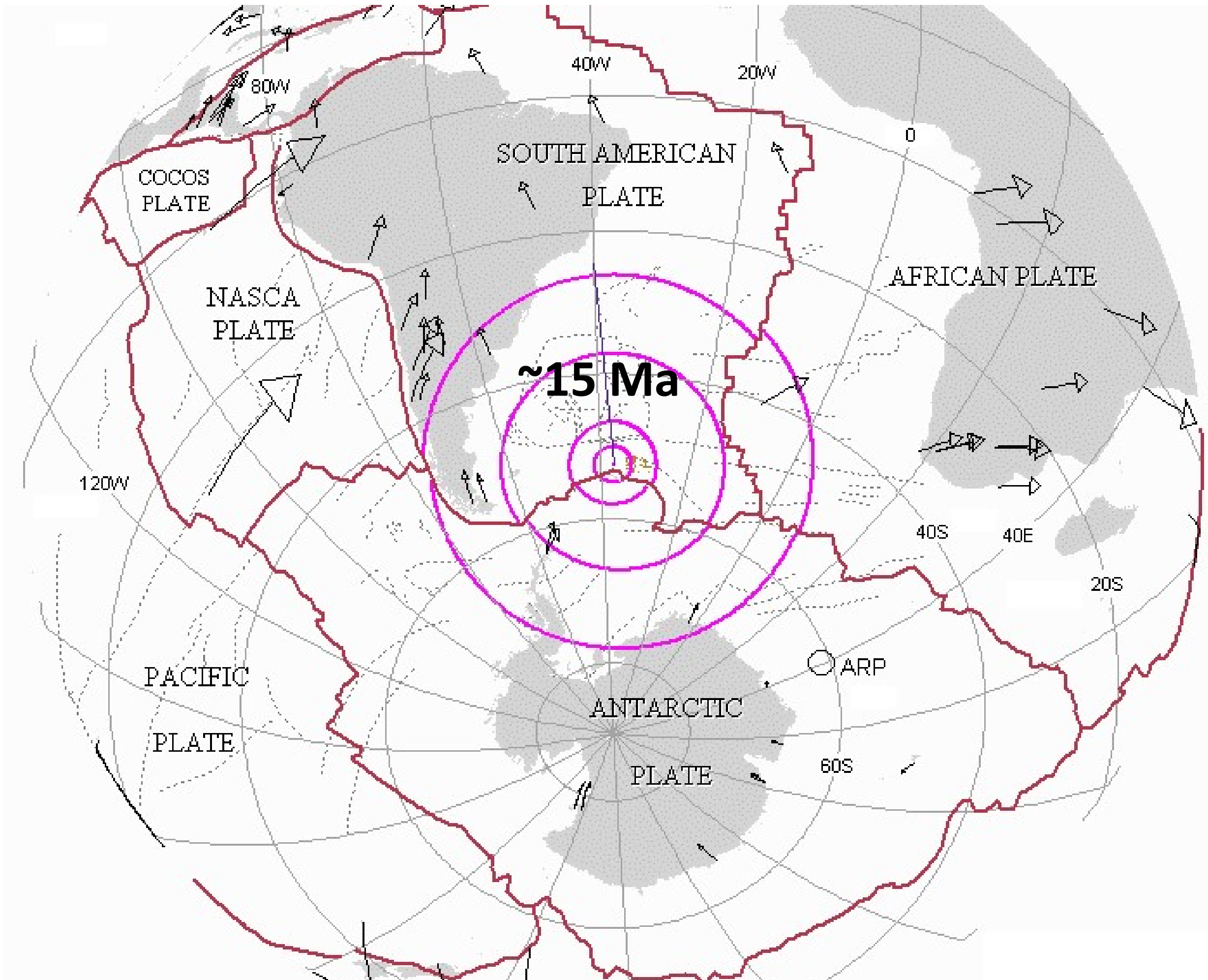


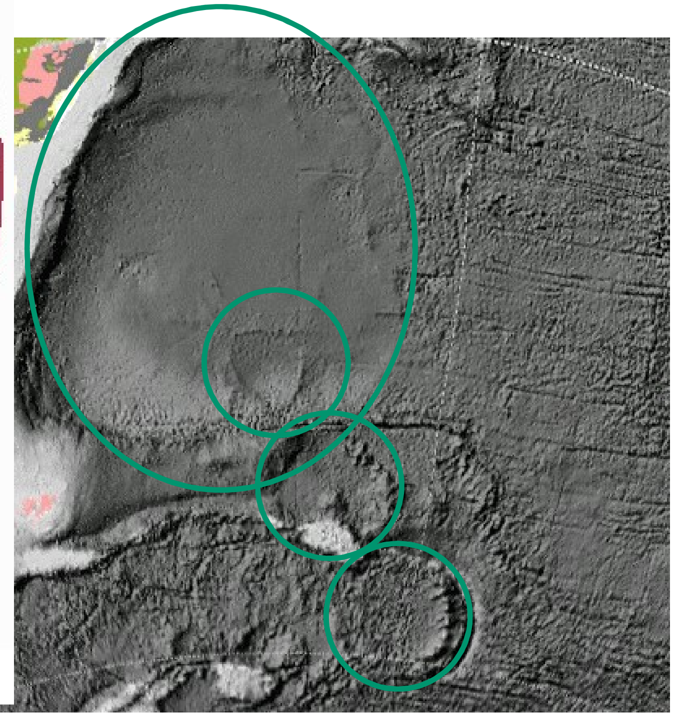
The North American and Caribbean plates move in concert around the Chicxulub impact

What drives plate motions?

3) Large, hypervelocity (> 3km/sec to 30 km/sec) bolide impacts ?



The South American Plate is moving in moving northward away from a suspected, ~15 Ma impact crater in the South Atlantic



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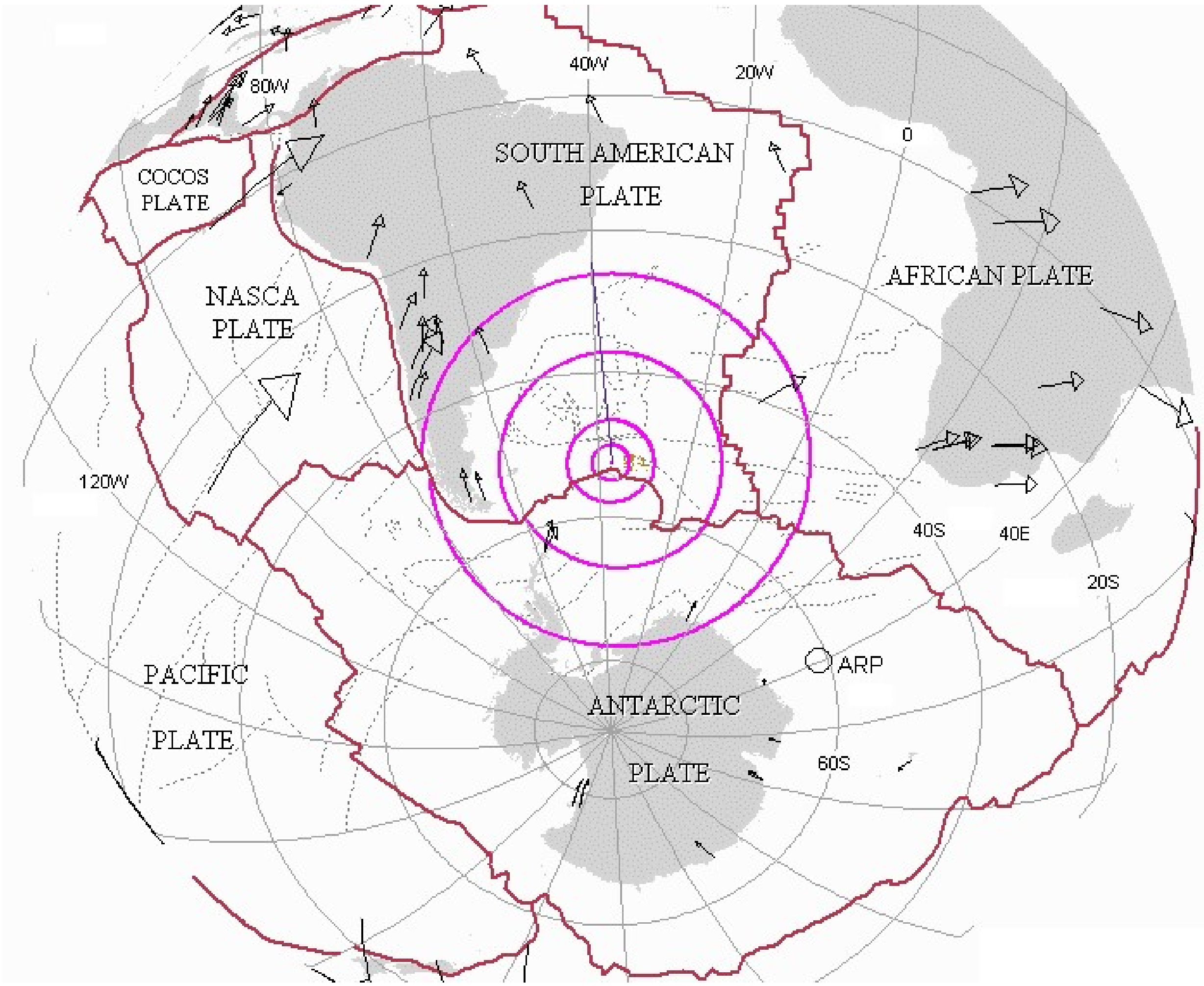

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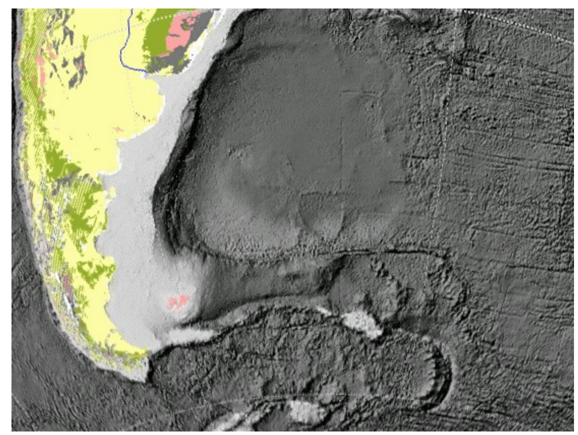
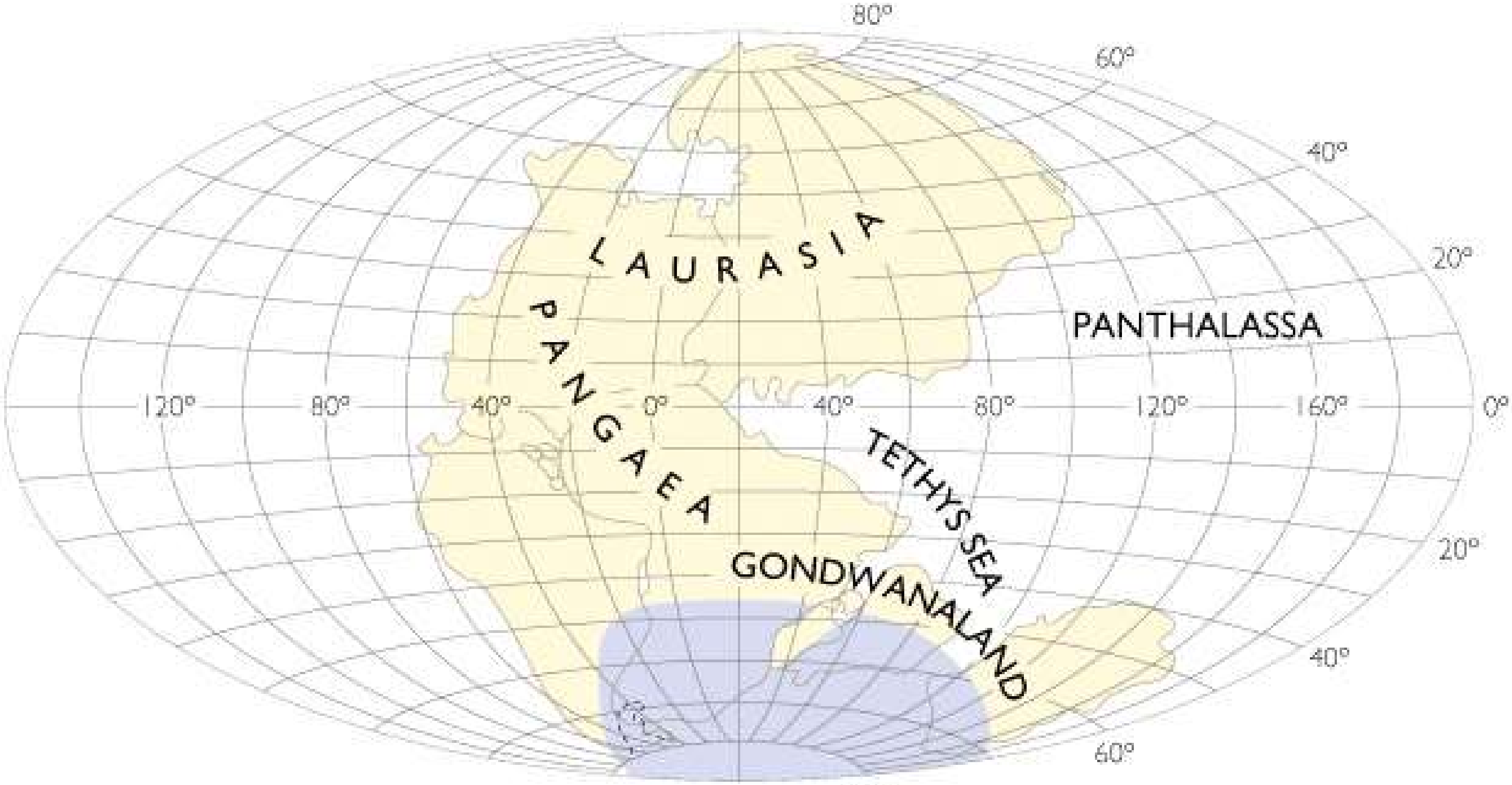


Breakup of Pangaea



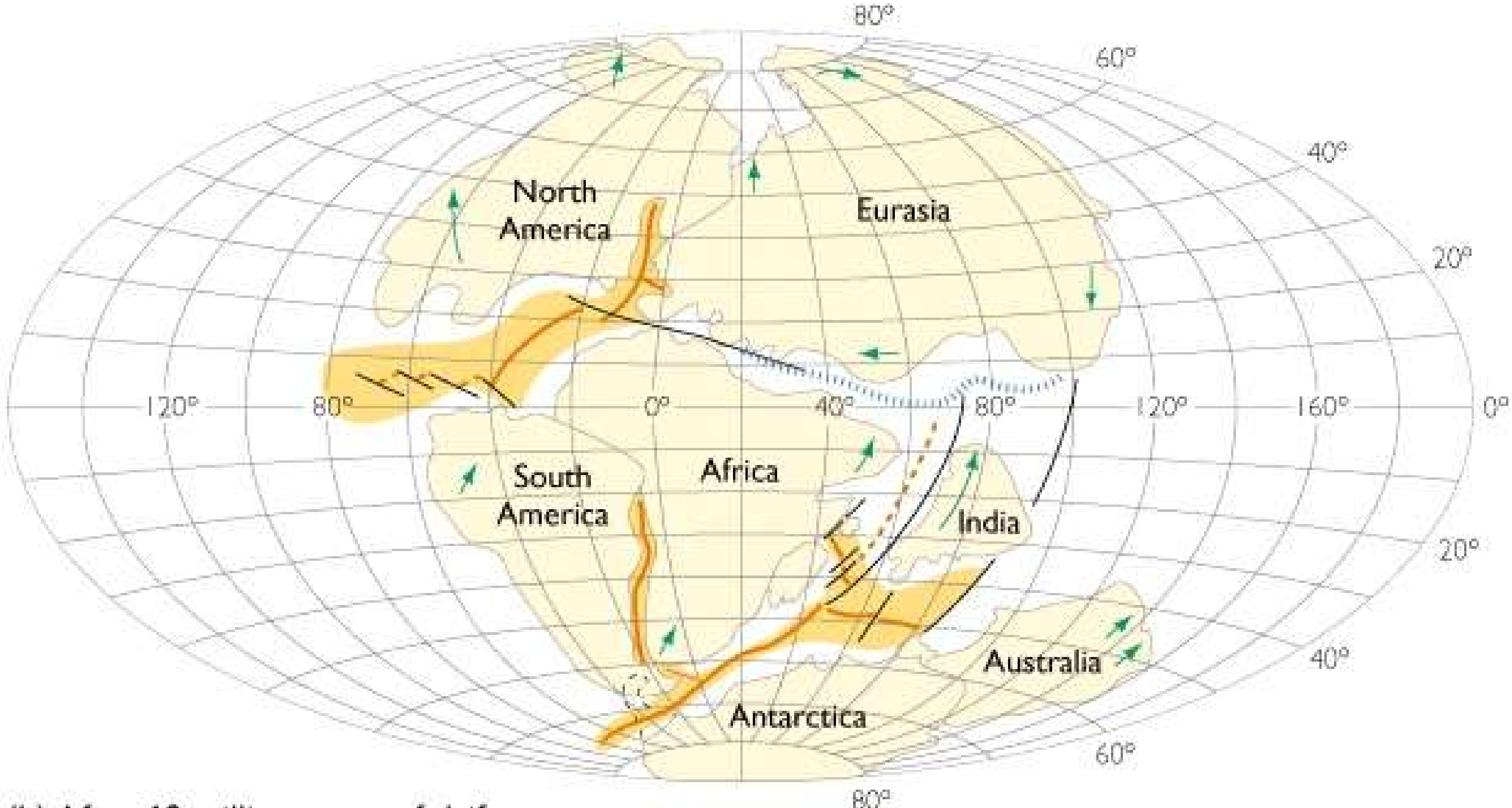
(a) World 200 million years ago

After Dietz & Holden, 1970

200 Ma

After Dietz & Holden, 1970

Breakup of Pangaea

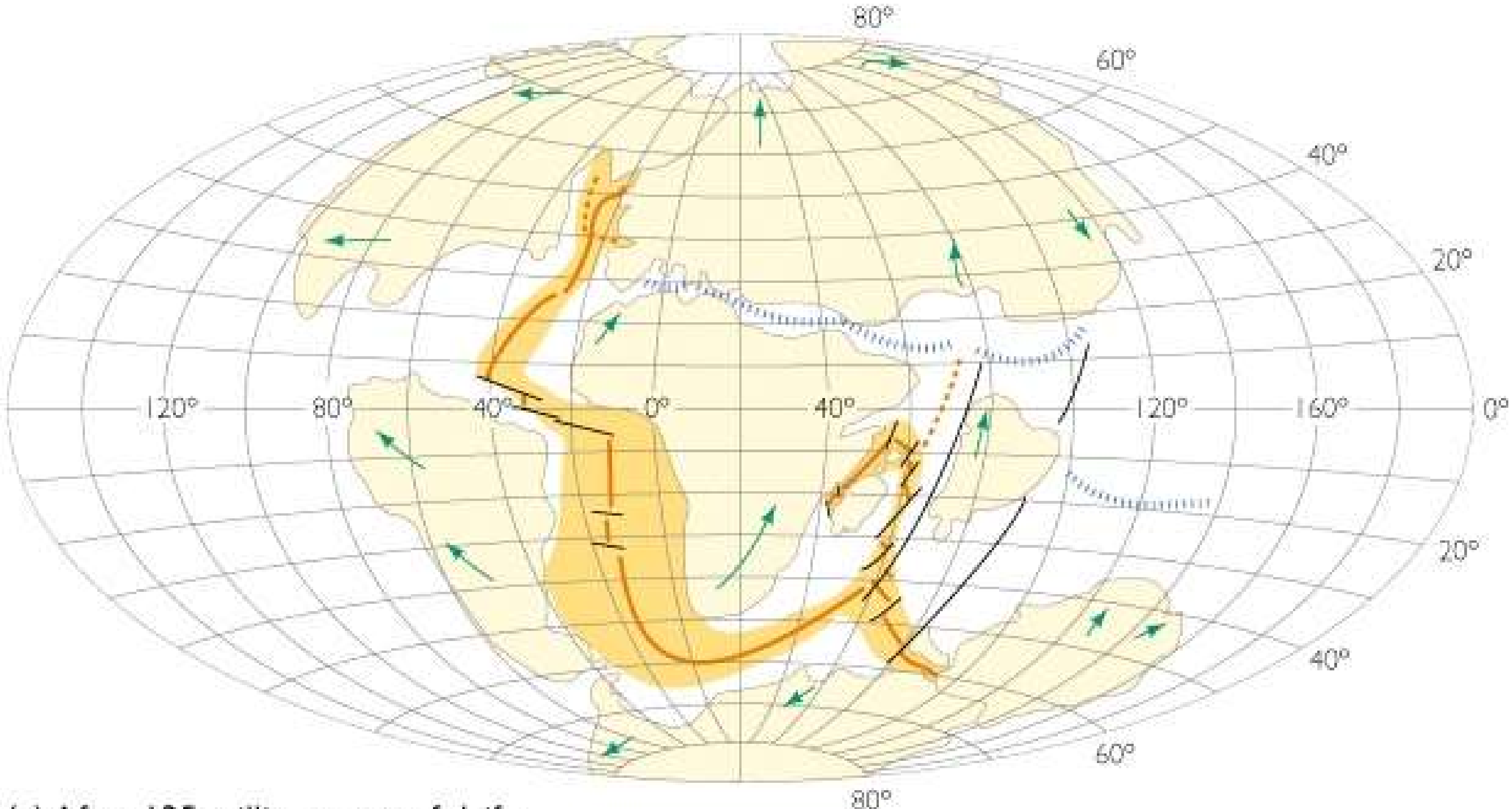


(b) After 60 million years of drift
(140 million years ago)
After Dietz & Holden, 1970

After Dietz & Holden, 1970

140 Ma

Breakup of Pangaea

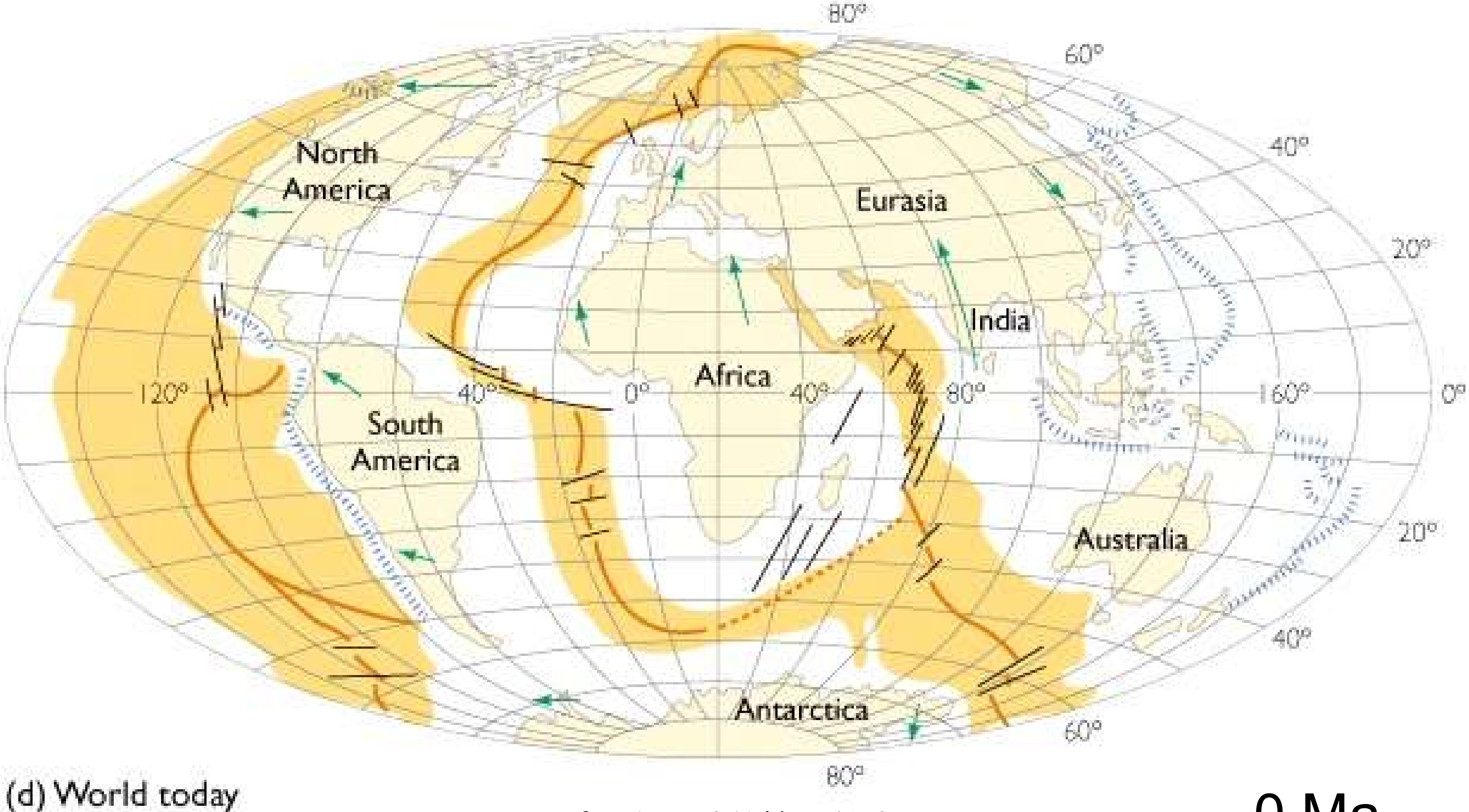


(c) After 135 million years of drift
(65 million years ago)

After Dietz & Holden, 1970

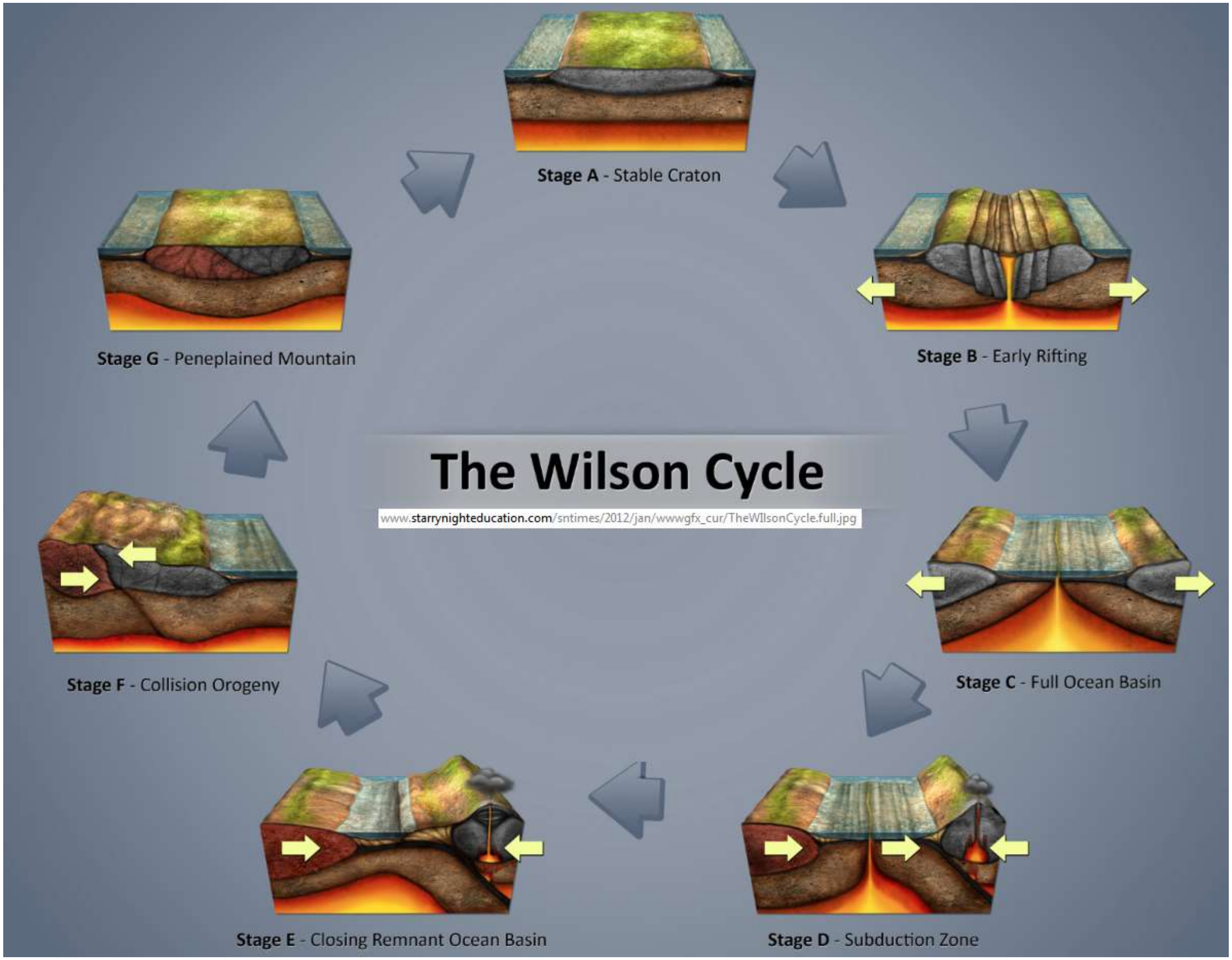
65 Ma

Breakup of Pangaea



After Dietz & Holden, 1970

0 Ma



Geological data indicate that supercontinents like Pangea form, break up, and re-form in a cycle spanning about 500 million years.

The breakup forms rift valleys within the supercontinent that eventually becomes a long, linear sea as the crust is depressed below sea level.

As the width of the narrow sea continues to expand an open ocean develops and the continental masses drift apart.

For some reason, the continental masses aggregate anew, and the cycle begins again.