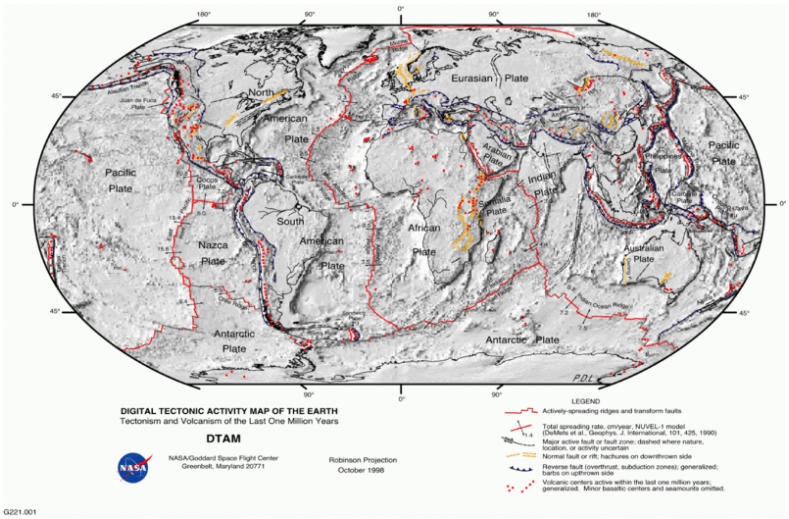
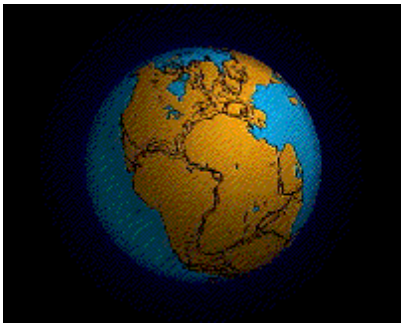
Plate Tectonics

The dance of the continents

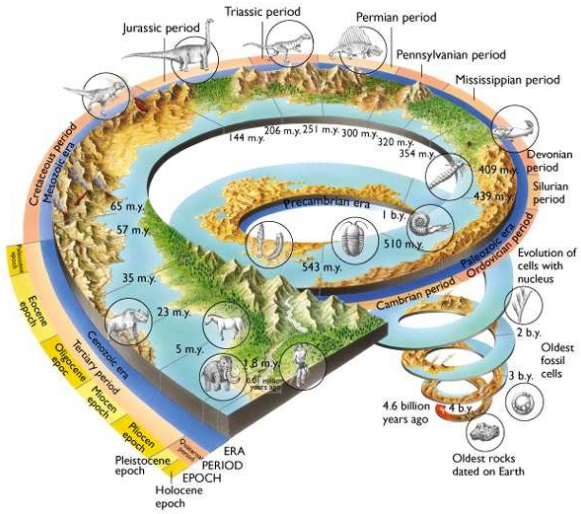


Dismembering the Past

- The continents can be dismembered into microcontinents, and maps adjusted by evidence of connections and splits between organisms, climate as indicated by characteristic rocks (e.g., coal, or fossil sand dunes), and geological activity.
- Global patterns of climate and ocean circulation can be inferred.
- Continental arrangements up to 600 mya are noncontroversial; before that they are hazy.



The Story of Life



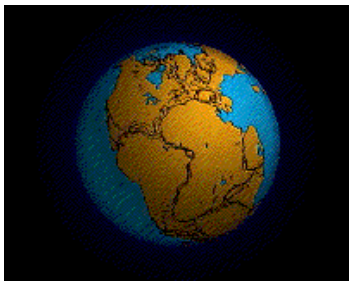
Laurasia and Gondwana

- About 200 million years ago, the supercontinent Pangaea started to split into Laurasia and Gondwana.
- Gondwana began to break up in the late Jurassic (about 160 mya) when Africa became separated and began to drift slowly northwards.
- How do we know this stuff? What is plate tectonics, and what does it explain?

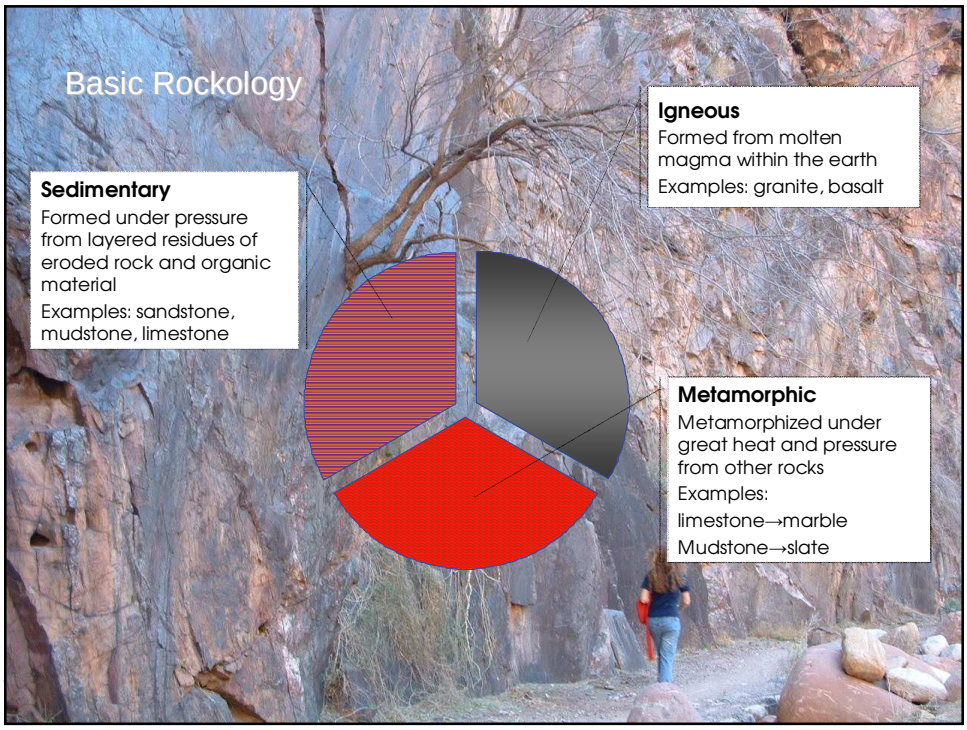
TRIASSIC
200 million years ago

The shifting earth

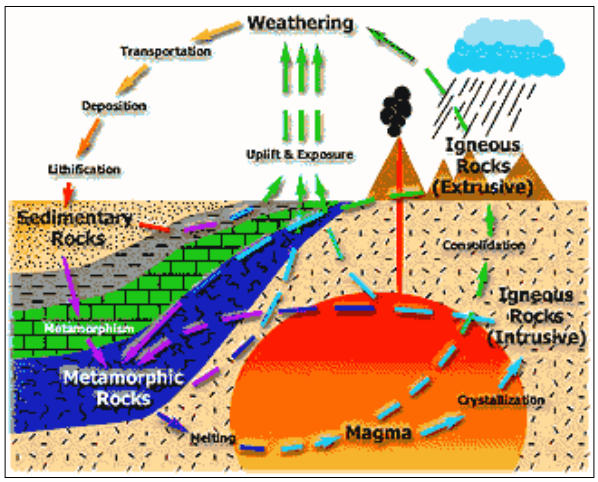
- Plate tectonics, like Darwin's theory of natural selection or Einstein's theory of relativity, is one of those unifying paradigms that suddenly allows a whole lot of disparate findings to make sense.
- Confusing data on geological formations, fossil findings, the distribution of living plants and animals, the composition of the ocean floors, tsunamis, Hawaii and Iceland and Staten Island: all clarified.
- Plate tectonic theory arose out of two separate geological observations: continental drift, conjectured in the early 20th century, and seafloor spreading, observed in the 1960s.



Ian H Giddy 7

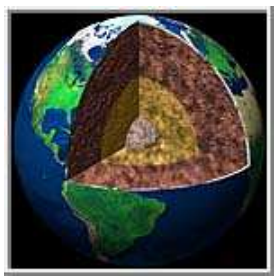


Rock Around the Clock



Oceans versus continents

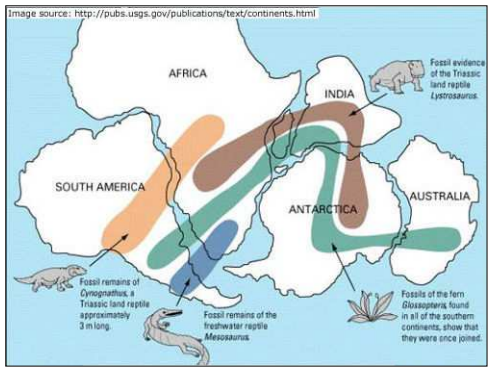
- Oceanic crust: 0.099% of Earth's mass; depth of 0-10 kilometers (0 - 6 miles)
  - The majority of the Earth's crust was made through volcanic activity. The oceanic ridge system, a 40,000-kilometer (25,000 mile) network of volcanoes, generates new oceanic crust at the rate of 17 cubic km per year, covering the ocean floor with basalt. Hawaii and Iceland are two examples of the accumulation of basalt piles.
- Continental crust: 0.374% of Earth's mass; depth of 0-50 kilometers (0 - 31 miles).
  - This is the outer part of the Earth composed essentially of crystalline rocks. These are low-density buoyant minerals dominated mostly by quartz (SiO_2) and feldspars (metal-poor silicates).
- The crust (both oceanic and continental) is the surface of the Earth; as such, it is the coldest part of our planet. Because cold rocks deform slowly, we refer to this rigid outer shell as the lithosphere (the rocky or strong layer).



1915: Alfred Wegener proposes Continental Drift

Continental drift and the fossil trail

- Geology of rock formations, the "jigsaw puzzle" of continents such as Africa and South America, and fossil unities led to the supposition that the continents must have drifted apart
- The picture shows once-unified trails of four species, including *glossopteris* and *mesosauris*.

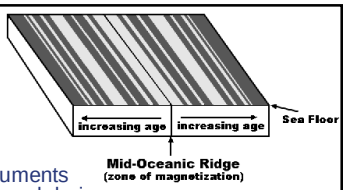


40 years after Wegener: Hess and Seafloor Spreading

Harry Hess, captaining a naval vessel, mapped the sea floor during WWII, found continental ridges, proposed seafloor spreading.

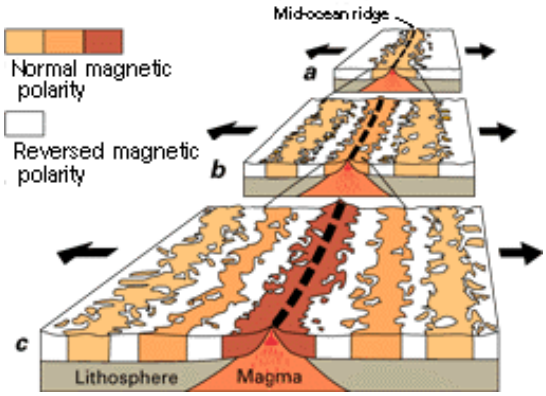
Confirmed by Vine & Matthews, who linked spreading to magnetic stripe reversals.

Magnetic stripes on the ocean floor

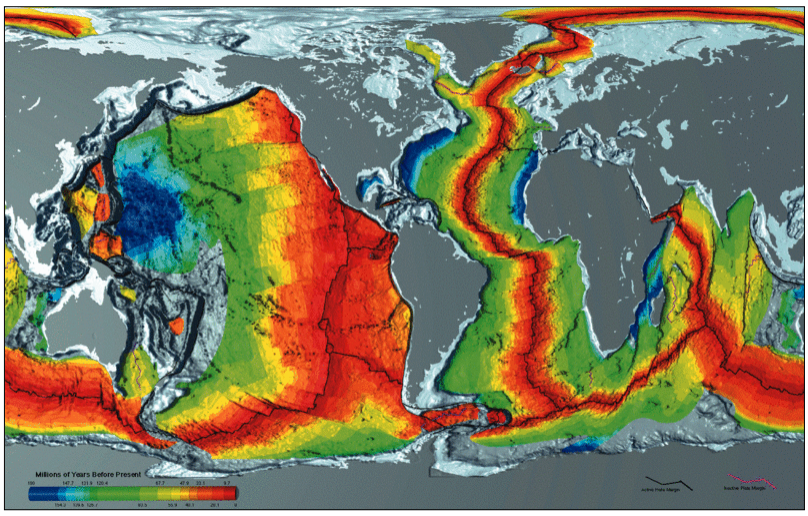


- Beginning in the 1950s, scientists, using magnetic instruments (magnetometers) adapted from airborne devices developed during World War II to detect submarines, began recognizing odd magnetic variations across the ocean floor. This finding, though unexpected, was not entirely surprising because it was known that basalt -- the iron-rich, volcanic rock making up the ocean floor-- contains a strongly magnetic mineral (magnetite) and can locally distort compass readings. This distortion was recognized by Icelandic mariners as early as the late 18th century. More important, because the presence of magnetite gives the basalt measurable magnetic properties, these newly discovered magnetic variations provided another means to study the deep ocean floor. When newly formed rock cools, such magnetic materials recorded the Earth's magnetic field at the time.
- As more and more of the seafloor was mapped during the 1950s, the magnetic variations turned out not to be random or isolated occurrences, but instead revealed recognizable patterns. When these magnetic patterns were mapped over a wide region, the ocean floor showed a zebra-like pattern. Alternating stripes of magnetically different rock were laid out in rows on either side of the mid-ocean ridge: one stripe with normal polarity and the adjoining stripe with reversed polarity. The overall pattern, defined by these alternating bands of normally and reversely polarized rock, became known as magnetic striping.

Magnetic Polarity Reversal

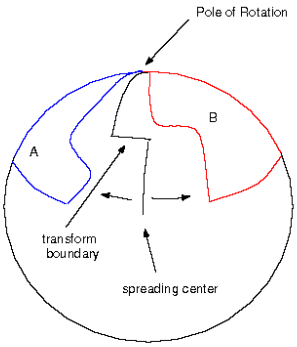


The seafloor is getting younger



Euler's Theorem

- Dan Mckenzie at Cambridge and other showed that plates move according to the rules of rotations on a sphere developed by Euler.
- Imagine that you place your hands on a globe with your thumbs tucked under your palms and your index fingers touching. Now move your hands apart while keeping the tips of your index fingers in contact. Where your fingers touch is the **pole of rotation** ("Euler pole"). Where your fingers were is the spreading center. Note that the farther from the pole of rotation you are, the faster your hands are moving in space, even though the angular rate of rotation is constant.

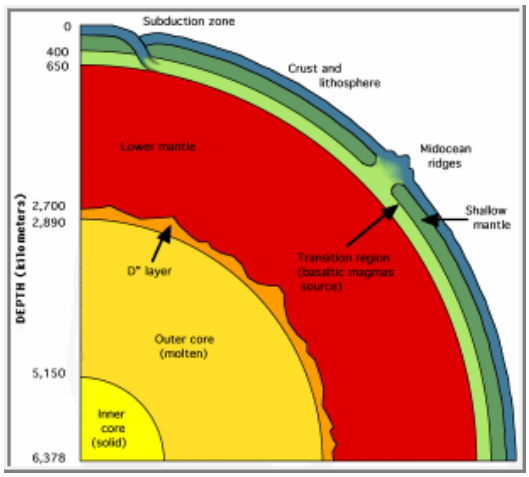


Continents A and B have drifted apart

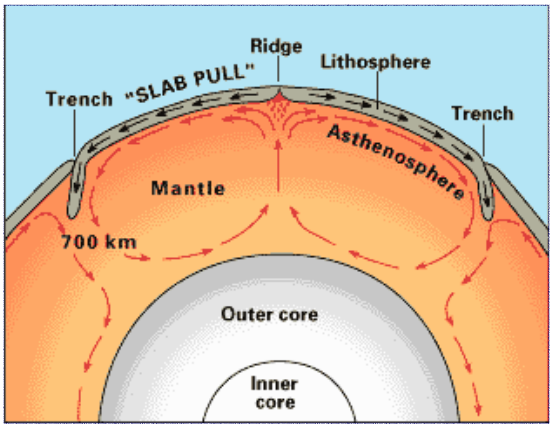
Plate tectonics

- **Plate tectonics** (from the Greek word for "one who constructs", τεκτων, *tekton*) is a theory of geology developed to explain the phenomenon of continental drift, and is currently the theory accepted by the vast majority of scientists working in this area. In the theory of plate tectonics the outermost part of the Earth's interior is made up of two layers, the outer lithosphere and the inner asthenosphere.
- The lithosphere essentially "floats" on the asthenosphere and is broken-up into ten major plates: African, Antarctic, Australian, Eurasian, North American, South American, Pacific, Cocos, Nazca, and the Indian plates.
- These plates (and the more numerous minor plates) move in relation to one another at one of three types of plate boundaries: convergent (two plates push against one another), divergent (two plates move away from each other), and transform (two plates slide past one another). Earthquakes, volcanic activity, mountain-building, and oceanic trench formation occur along plate boundaries (most notably around the so-called "Pacific Ring of Fire").

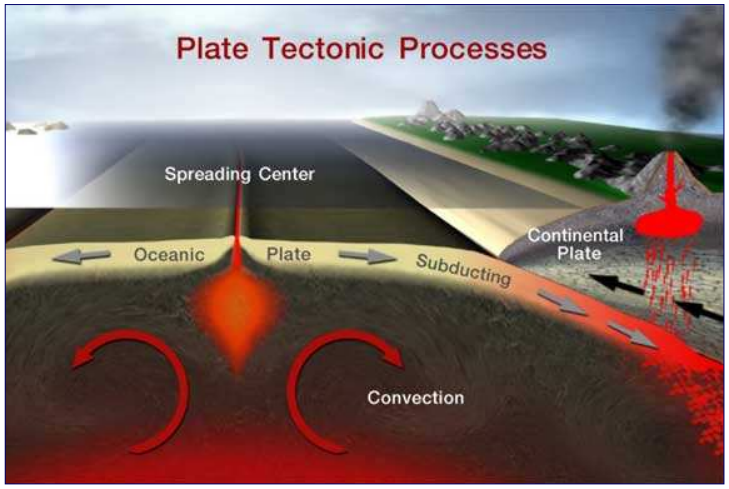
The earth's outer core is hot



Causing convection currents in the earth's mantle

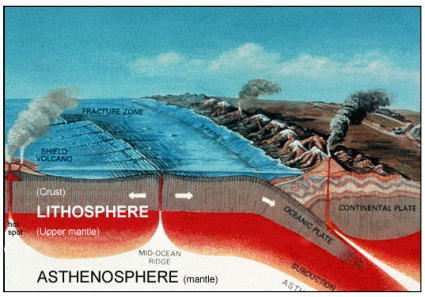


Which drives plate movements

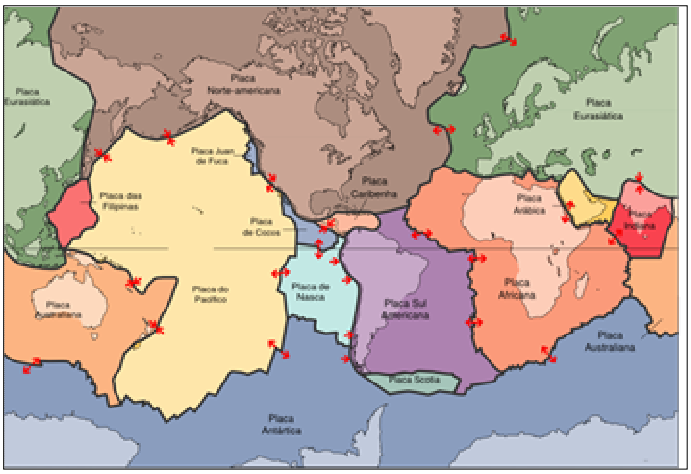


Silly putty

- The asthenosphere is ductile and can be pushed and deformed like silly putty in response to the warmth of the Earth.
- These rocks actually flow, moving in response to the stresses placed upon them by the churning motions of the deep interior of the Earth.
- The flowing asthenosphere carries the lithosphere of the Earth, including the continents, on its back.



The plates today



Mid-Ocean Ridges

- When new crust forms, it is *hot*. Therefore it is less dense, more buoyant and it "sticks up" higher than the surrounding, older colder material. This is why ridges are higher than the surrounding crust.
- As the oceanic crust is pulled away from the spreading center, it cools and sinks. Also, the farther from the spreading center, the older the crust.

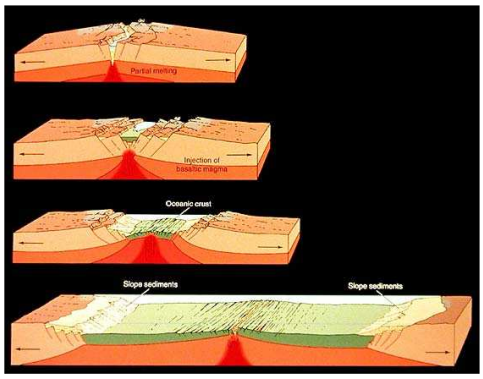
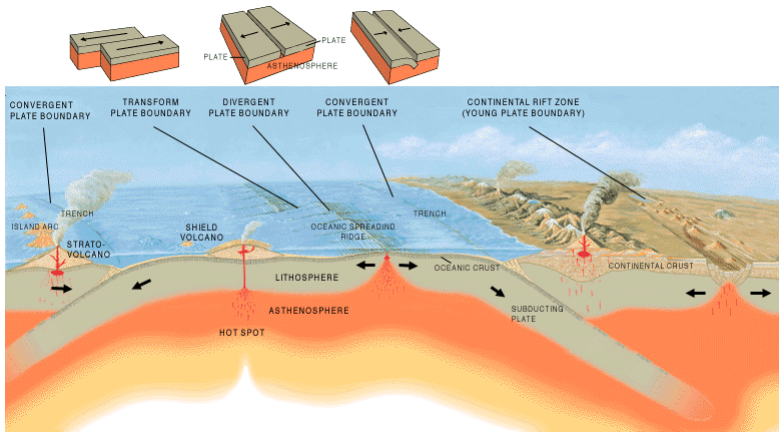


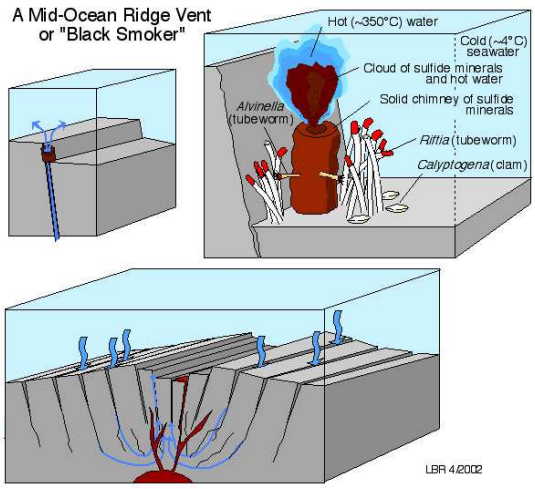
Plate boundaries

- There are three types of plate boundaries, characterized by the way the plates move relative to each other. They are associated with different types of surface phenomena. The different types of plate boundaries are:
- **Transform boundaries** occur where plates slide, or perhaps more accurately grind, past each other along transform faults. The relative motion of the two plates is either sinistral or dextral.
- **Divergent boundaries** occur where two plates slide apart from each other.
- **Convergent boundaries** (or *active margins*) occur where two plates slide towards each other commonly forming either a subduction zone (if one plate moves underneath the other) or an orogenic belt (if the two simply collide and compress).

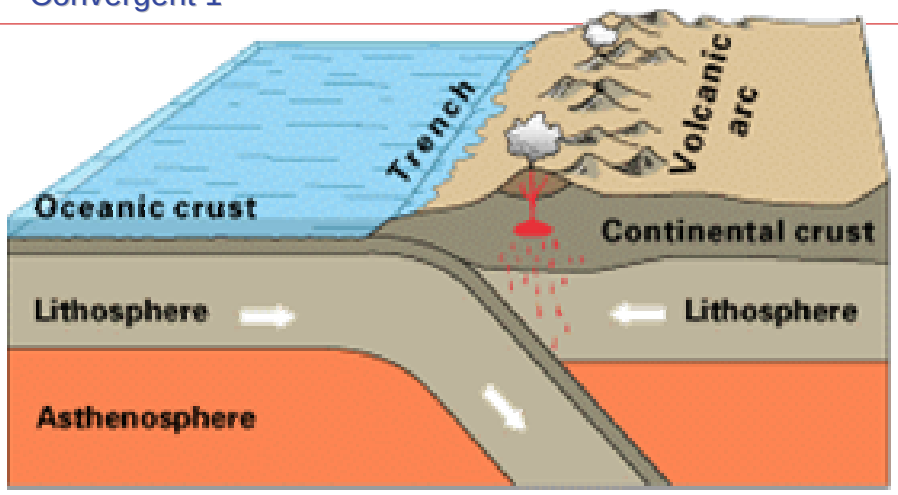
Three kinds of plate boundaries



Mid-Ocean Ridges



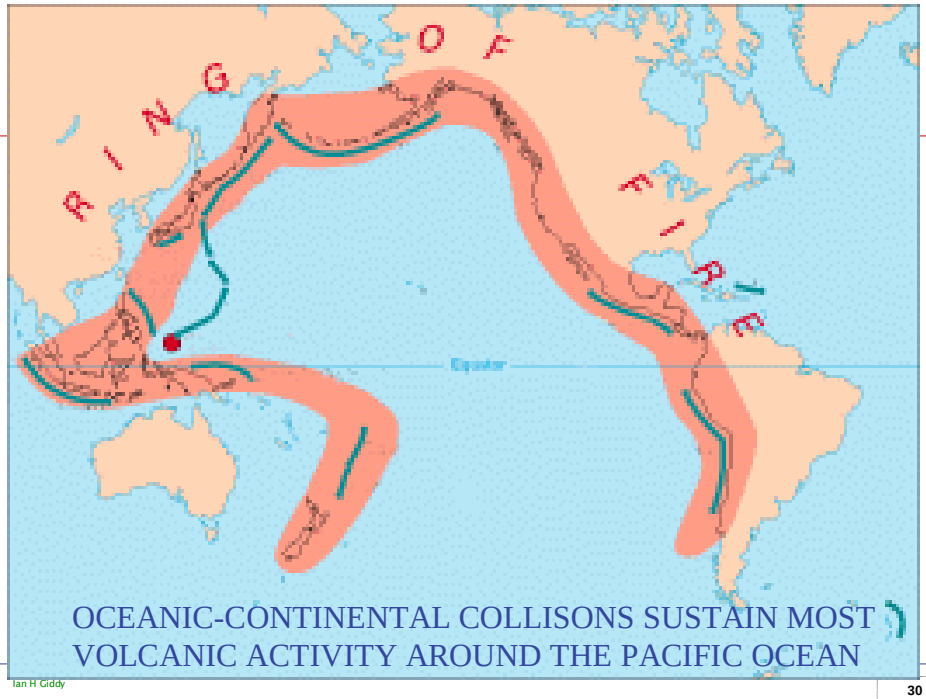
Convergent 1



Oceanic-continental convergence

ANDES: NAZCA-SOUTH AMERICAN PLATE COLLISON
Pachapaqui, Peru

Ian H Giddy 29



OCEANIC-CONTINENTAL COLLISONS SUSTAIN MOST VOLCANIC ACTIVITY AROUND THE PACIFIC OCEAN

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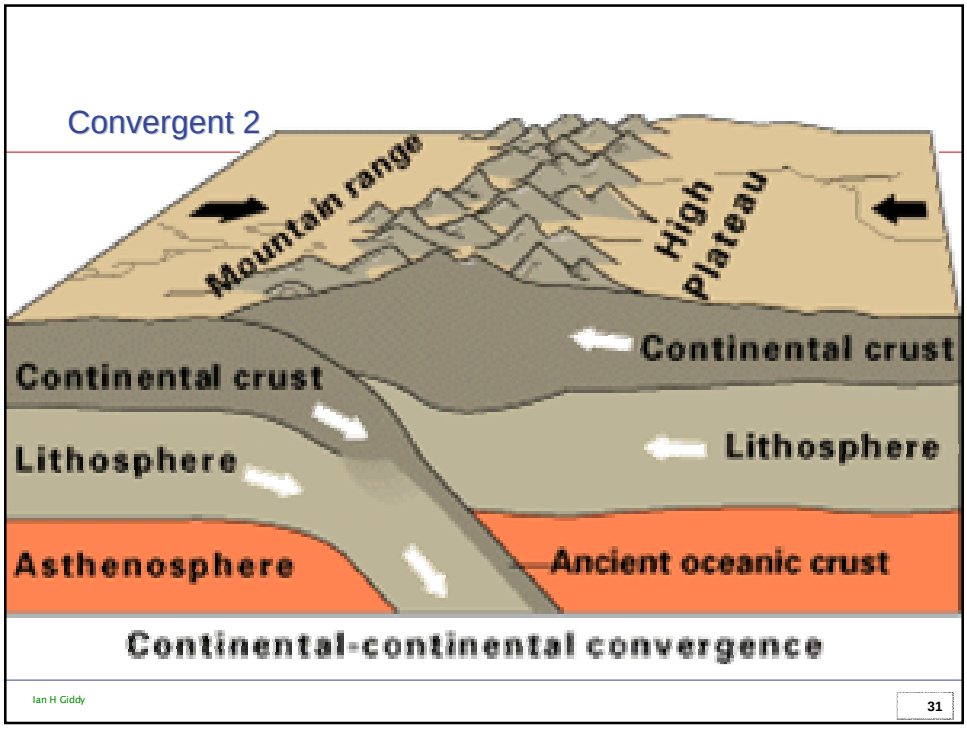
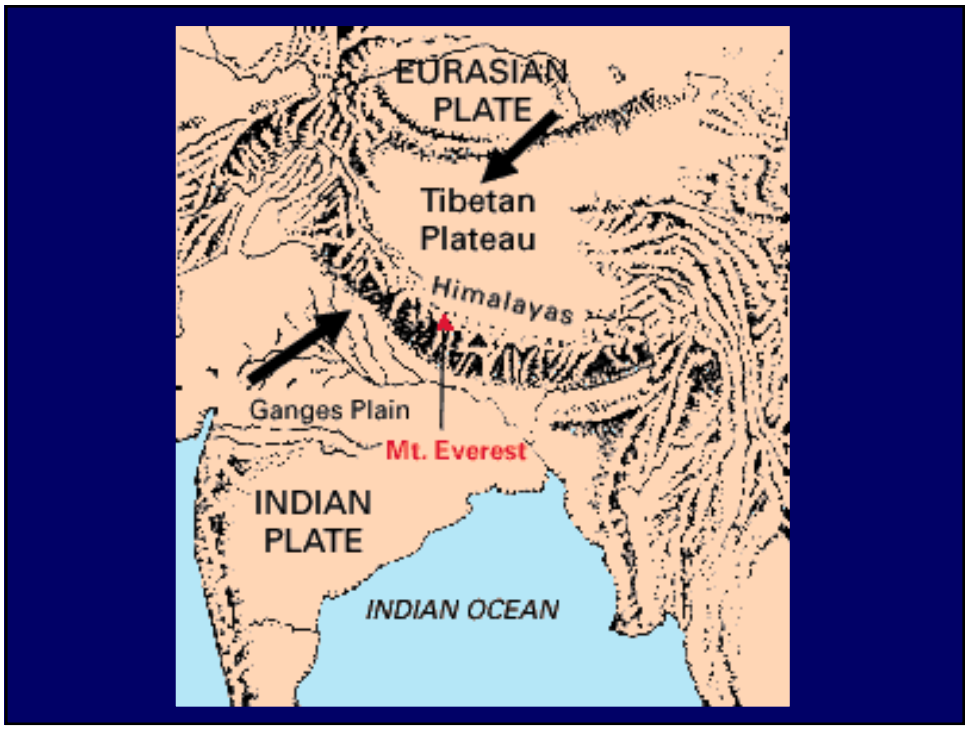
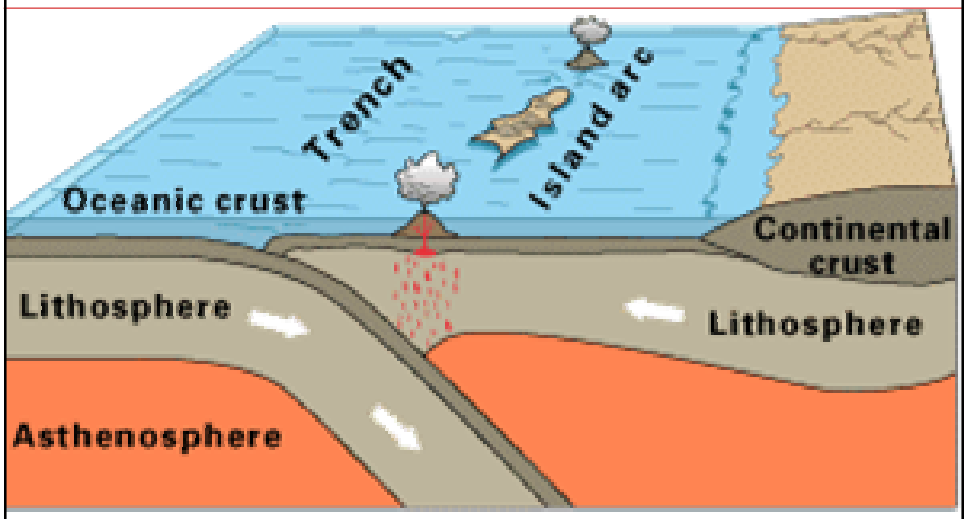

Convergent 2
Mountain range
High Plateau
Continental crust
Continental crust
Lithosphere
Lithosphere
Asthenosphere
Ancient oceanic crust
Continental-continental convergence
Ian H Giddy
31

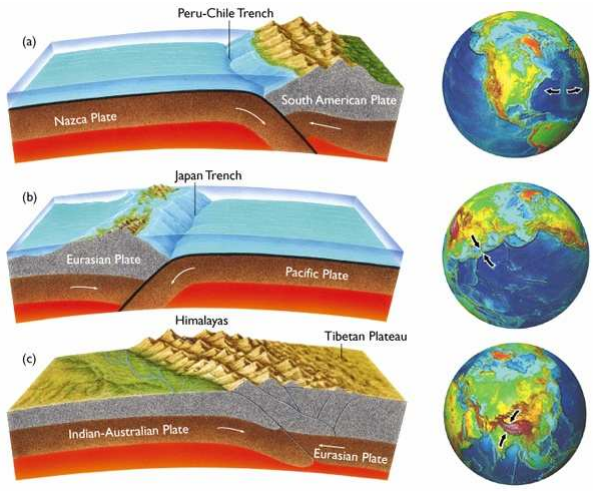

EURASIAN PLATE
Tibetan Plateau
Himalayas
Ganges Plain
Mt. Everest
INDIAN PLATE
INDIAN OCEAN

Convergent 3



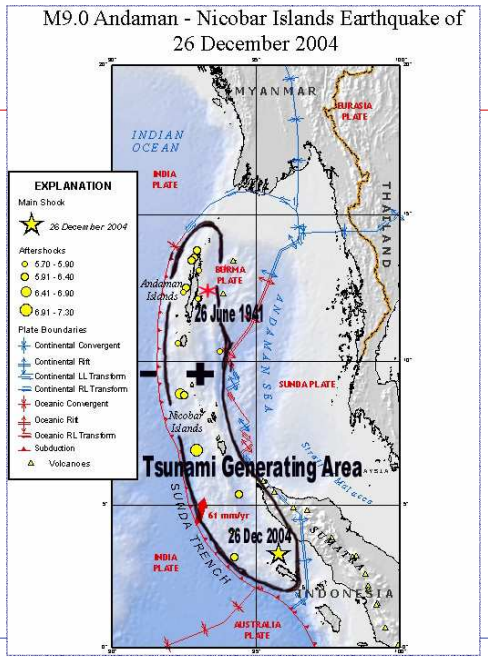
Oceanic-oceanic convergence

Which is which?

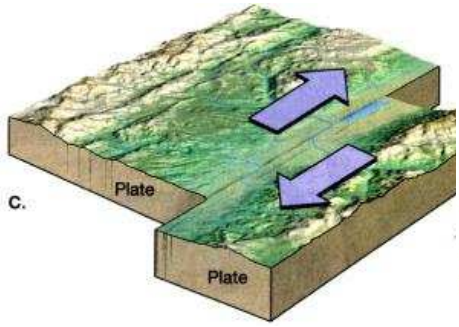


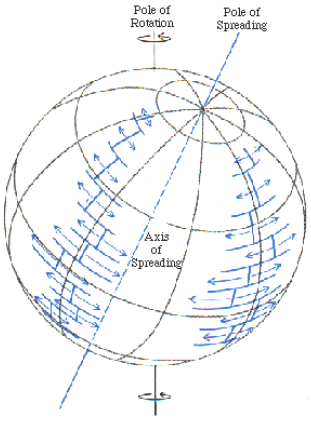
Tsunami!

- Can you see the subduction zone?
- Is that what cause the 2004 tsunami?



Transform Boundary





Euler's theorem again -- because of rotational forces, the axis of spreading is never a straight line, but a curved line, causing **transform faults**. Curving is less pronounced at the poles (less of a curve here) and more pronounced near the equator (more of a curve), so curve of spreading axis varies depending on latitude.

Directions of Plate Movements

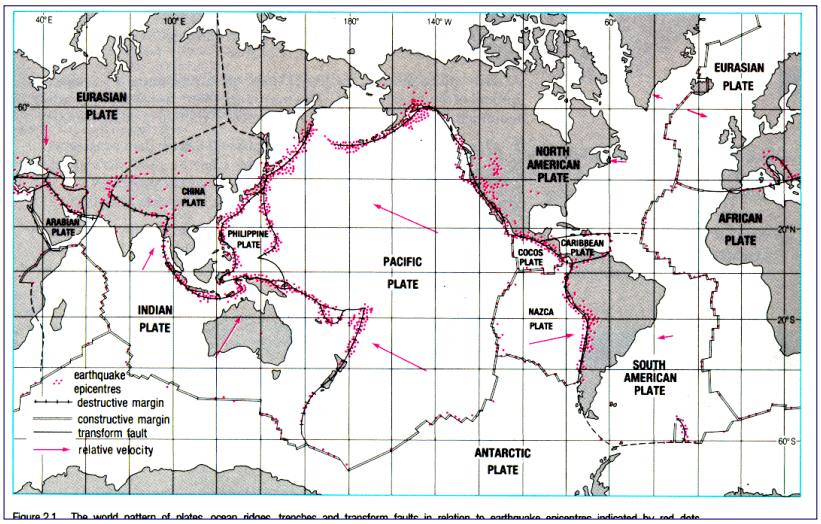
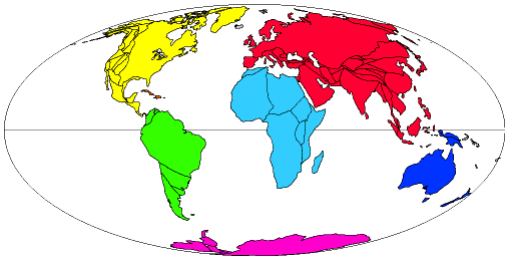
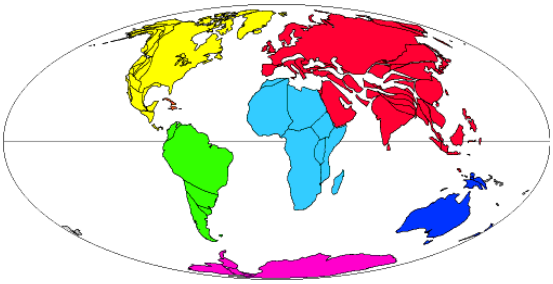


Figure 2.1 The world pattern of plates, ocean ridges, trenches and transform faults in relation to earthquake epicentres indicated by red dots

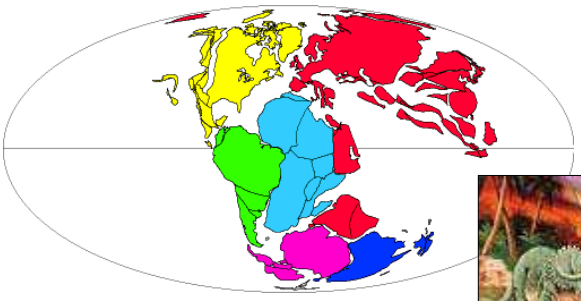
The Dance of the Continents

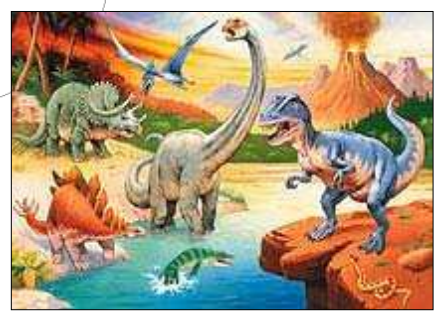


30 MYA: Age of Mammals

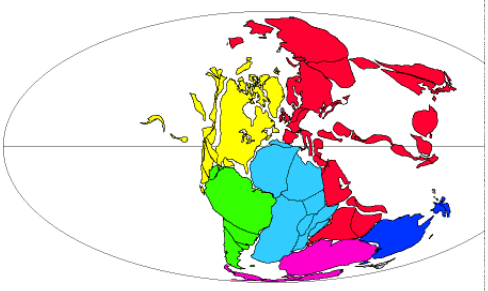


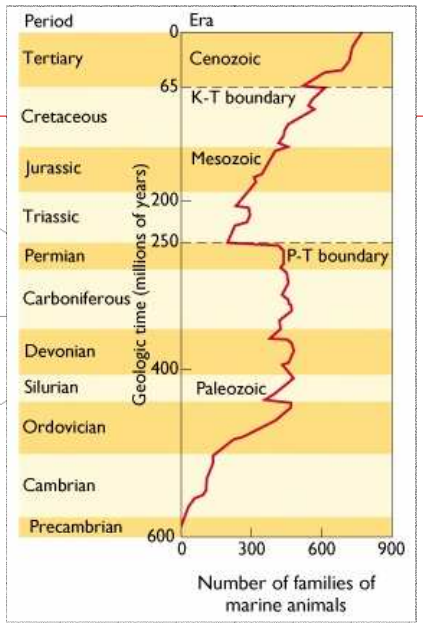
150 MYA: When Dinosaurs Ruled



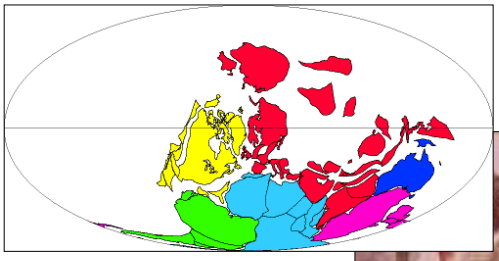


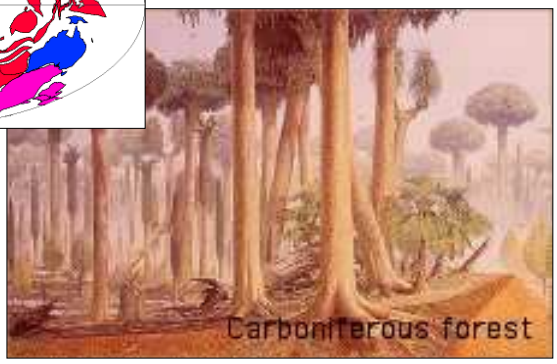
250 MYA: The Permian Extinction



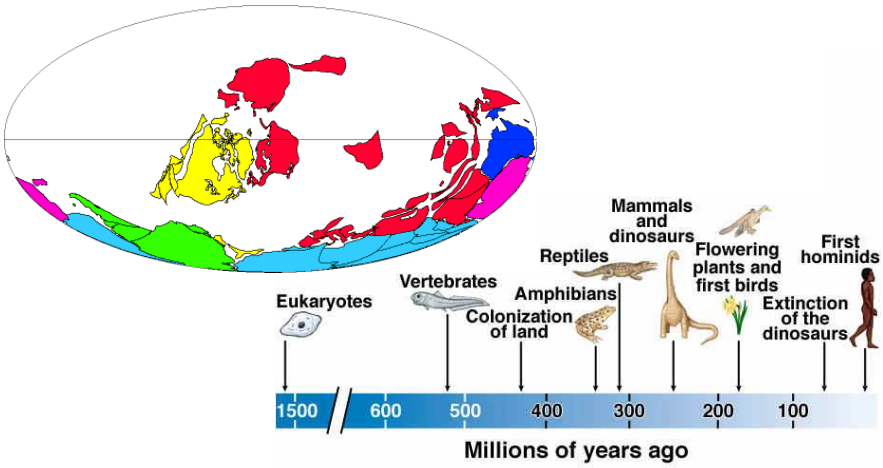


360 MYA: The Carboniferous Period

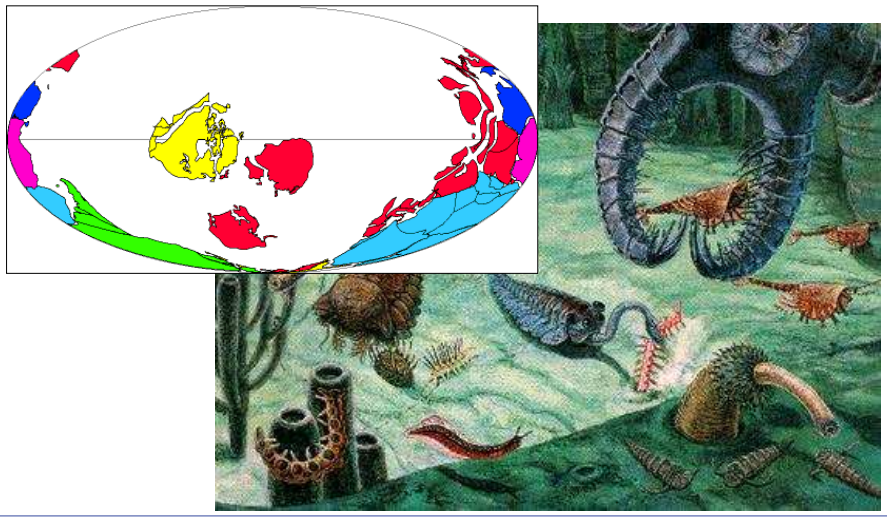




420 MYA: Animals Crawl Ashore



520 MYA: The Cambrian Explosion



620 MYA: Algae and Amoebas

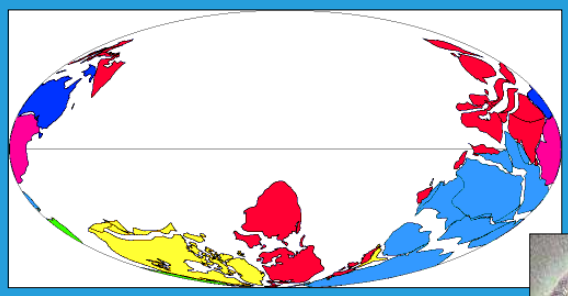
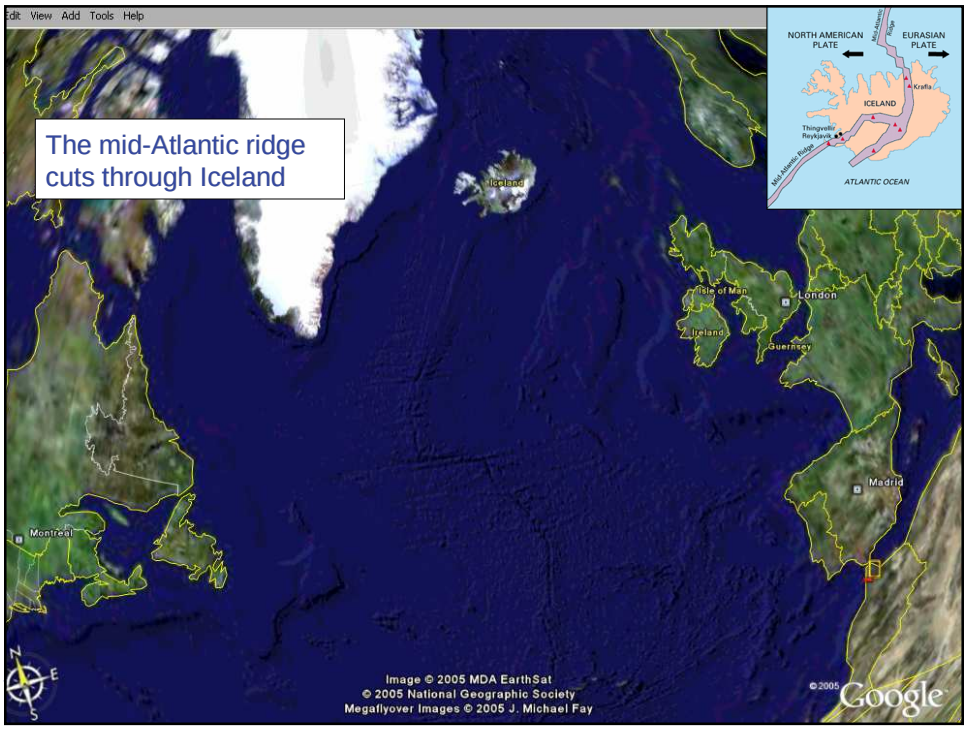


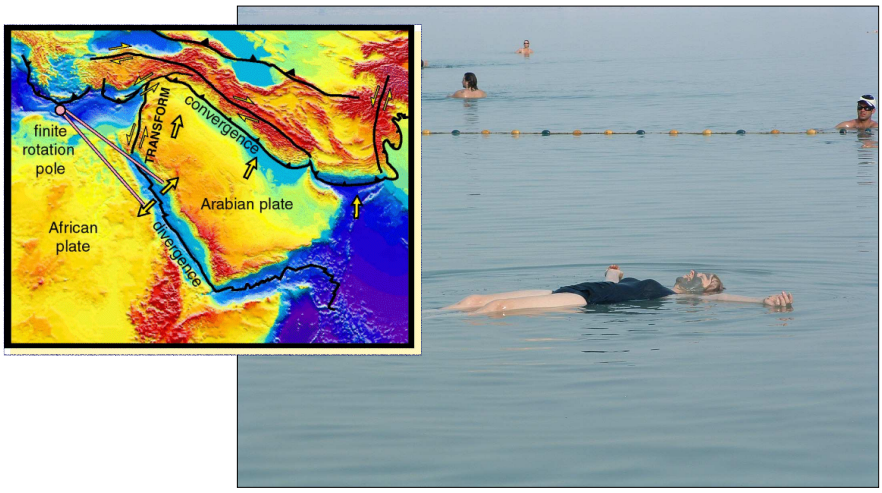
Plate Places

- Schizoid Iceland
- Better Dead than Red
- Creating Everest
- Hawaii: something old, something new
- California: Living with The Terminator
- Sleepless in Seattle
- “The most dangerous place in the world”

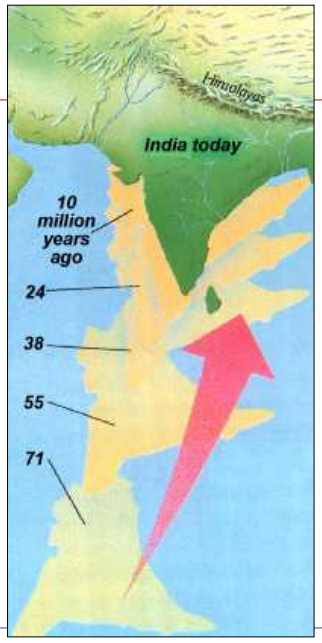

Iceland

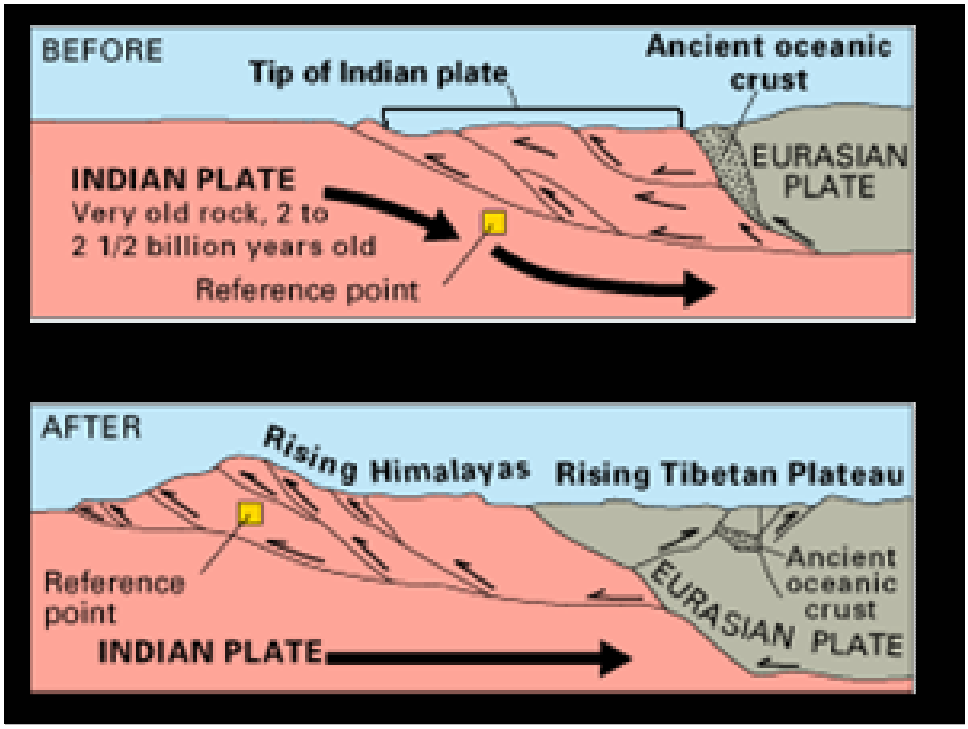

The mid-Atlantic ridge cuts through Iceland
NORTH AMERICAN PLATE
EURASIAN PLATE
ICELAND
Krafla
Thingvellir
Reykjavik
Mid-Atlantic Ridge
ATLANTIC OCEAN
Iceland
Isle of Man
London
Guernsey
Madrid
Montreal
Image © 2005 MDA EarthSat
© 2005 National Geographic Society
Megaflyover Images © 2005 J. Michael Fay
Google

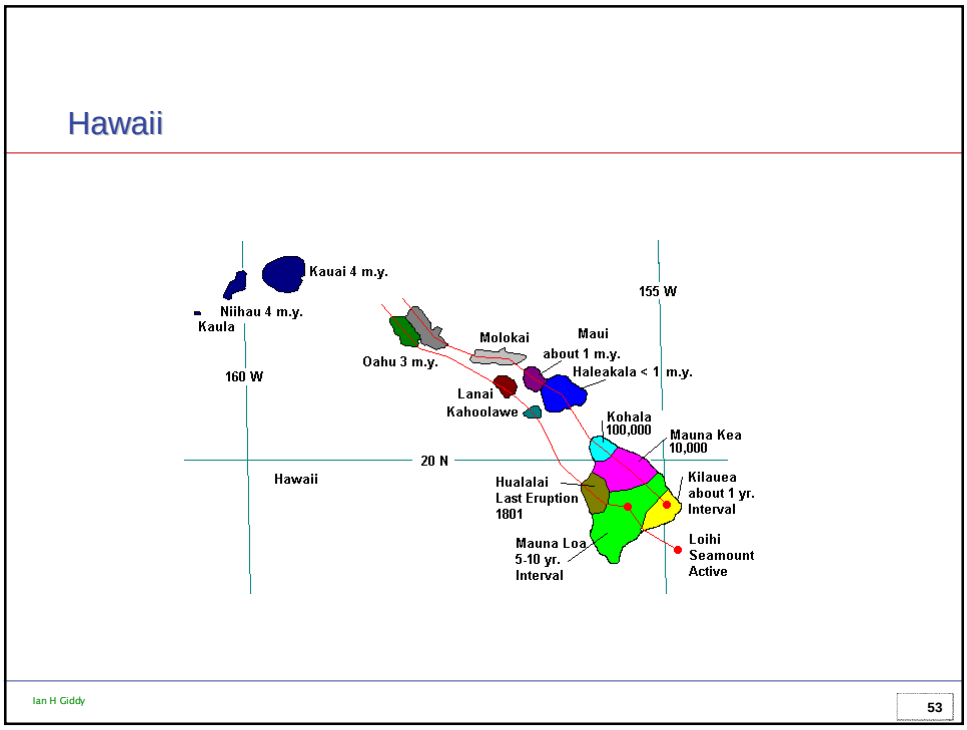
Better Red than Dead



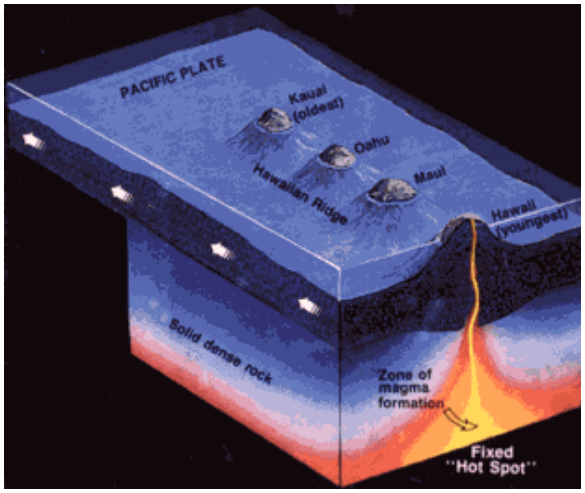
Creating Everest



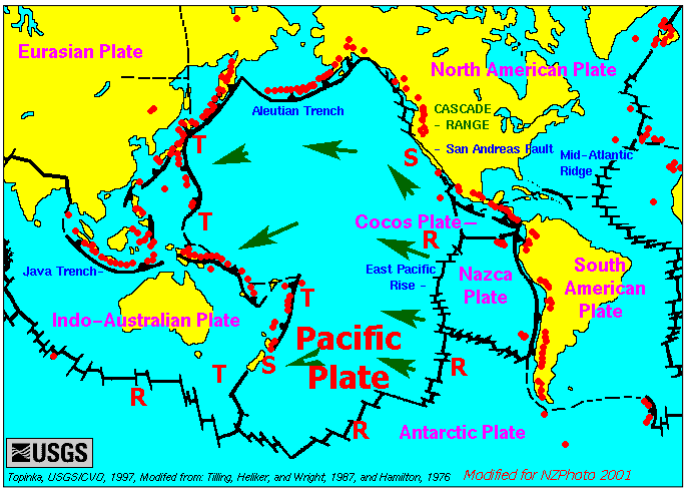

BEFORE
Tip of Indian plate
Ancient oceanic crust
EURASIAN PLATE
INDIAN PLATE
Very old rock, 2 to 2 1/2 billion years old
Reference point
AFTER
Rising Himalayas
Rising Tibetan Plateau
Ancient oceanic crust
EURASIAN PLATE
Reference point
INDIAN PLATE


Hawaii
Kauai 4 m.y.
Niihau 4 m.y.
Kaula
160 W
155 W
Oahu 3 m.y.
Molokai
Maui
about 1 m.y.
Haleakala < 1 m.y.
Lanai
Kahoolawe
Kohala
100,000
Mauna Kea
10,000
20 N
Hawaii
Hualalai
Last Eruption
1801
Kilauea
about 1 yr.
Interval
Mauna Loa
5-10 yr.
Interval
Loihi
Seamount
Active
Ian H Giddy
53

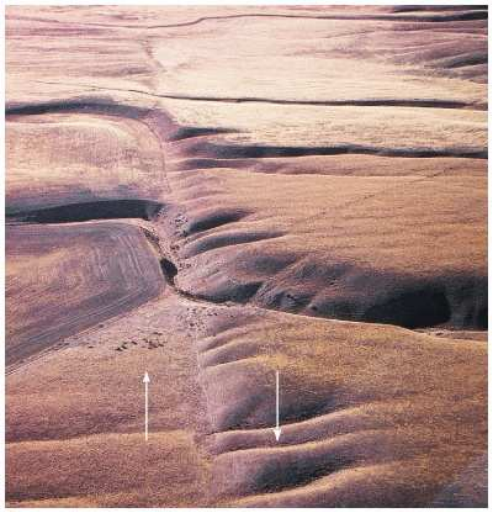
Hawaii: the hot spot



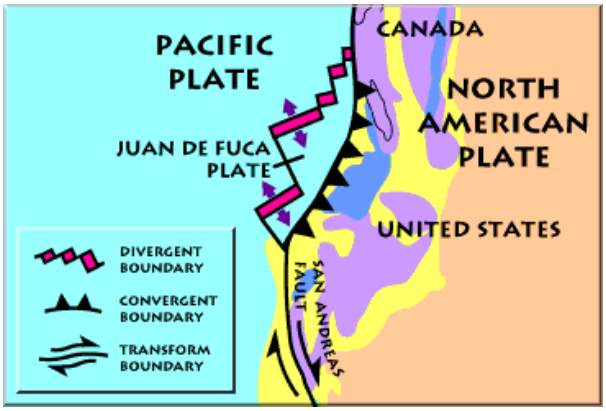
California: Terminator Territory



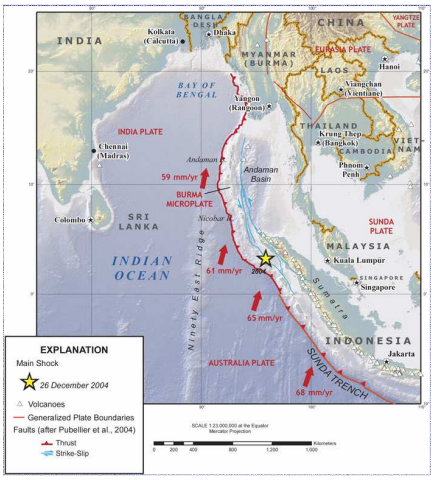
San Andreas Fault



Sleepless in Seattle



“The most dangerous place on earth”



Further exploration

giddy.net/tectonics
USGS, *This Dynamic Earth*
Richard Fortey, *Earth*

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