

Plate Tectonics and Continental Drift

Jarðsaga 1

- Saga Lífs og Lands -
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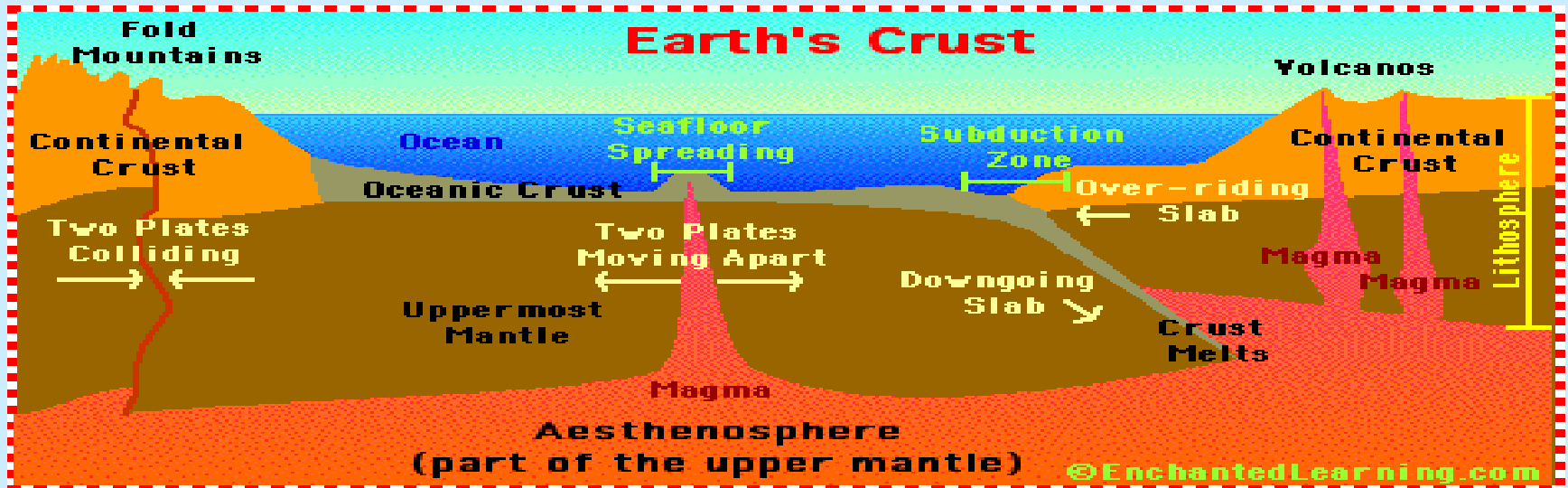




Plate tectonics is the unifying theory of the Earth

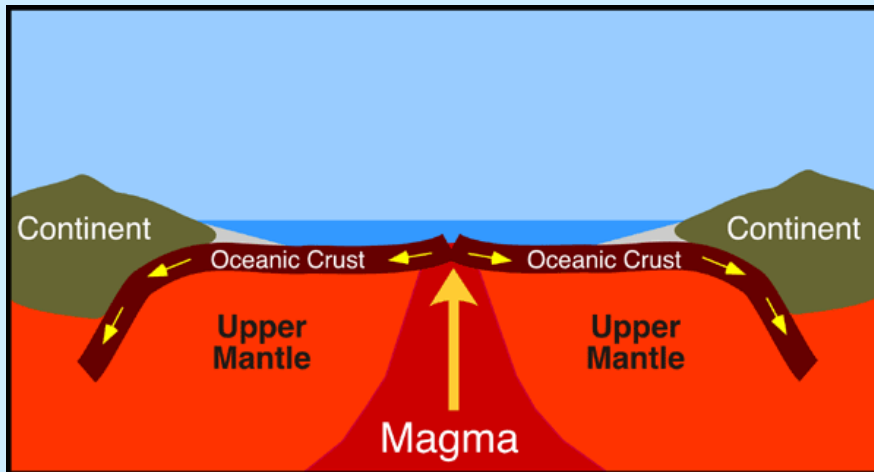
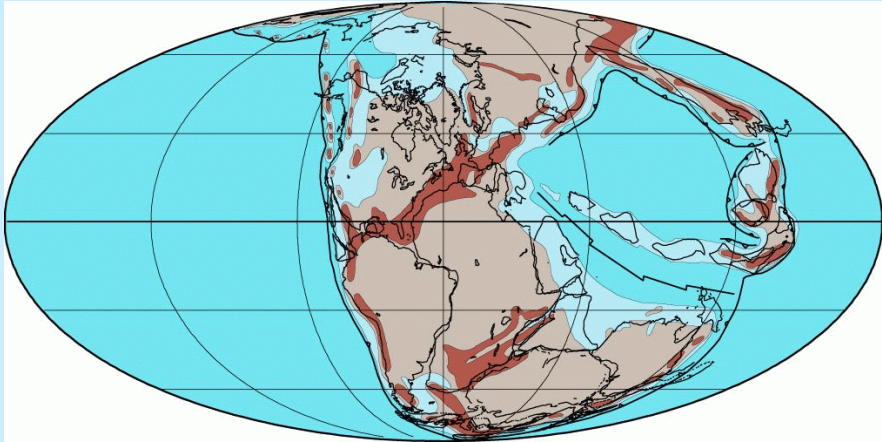
It explains the interrelationships of:

- mountain building (orogeny)
 - earthquakes
 - volcanoes
 - climate change
 - evolution and extinction



How did the theory develop?
What is the evidence based on?

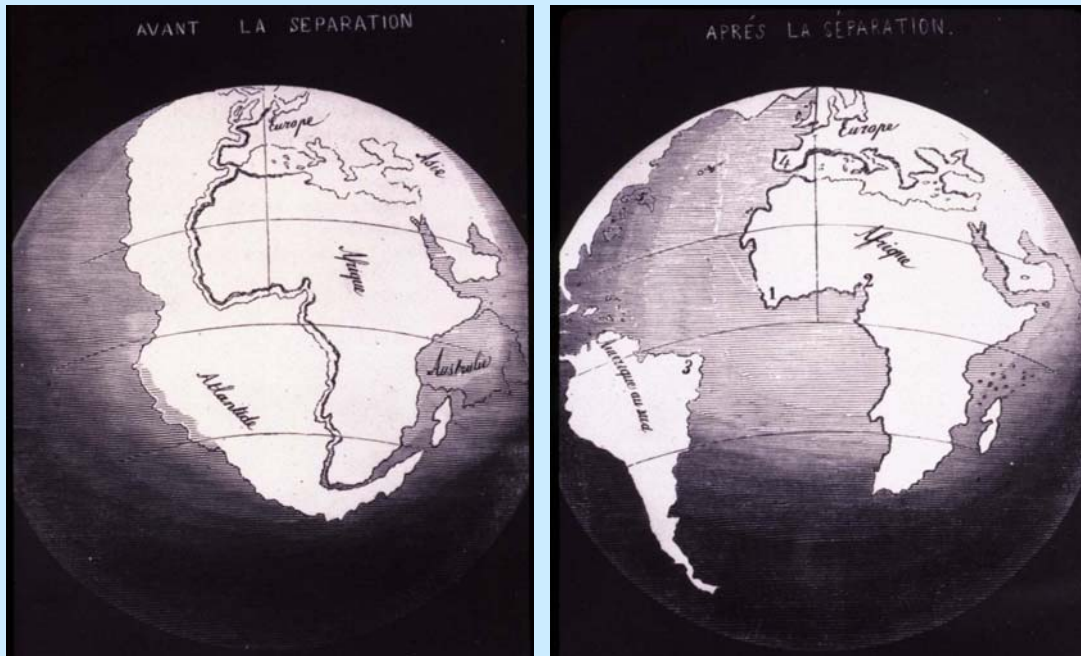
Changing views...



In the early 1960s, the emergence of the *theory of plate tectonics* started a revolution in the earth sciences.

We now know that, directly or indirectly, plate tectonics influences nearly all geologic processes, past and present. Indeed, the notion that the entire Earth's surface is continually shifting has profoundly changed the way we view our world.

Continental scale tectonics too big for early uniformitarianism...?



Antonio Snyder Pellgrini's reconstruction (ca. 1850) of the configuration of the continents

The "Uniformitarian Principle" (*Present is the key to the past*) assumes that the geologic forces and processes acting on the Earth today are the same as those that have acted in the geologic past.

The idea that continents have not always been fixed in their present positions was first suggested in 1596 by the Dutch map maker Abraham Ortelius (*Thesaurus Geographicus*), when he suggested that the Americas were "torn away from Europe and Africa . . . by earthquakes and floods"



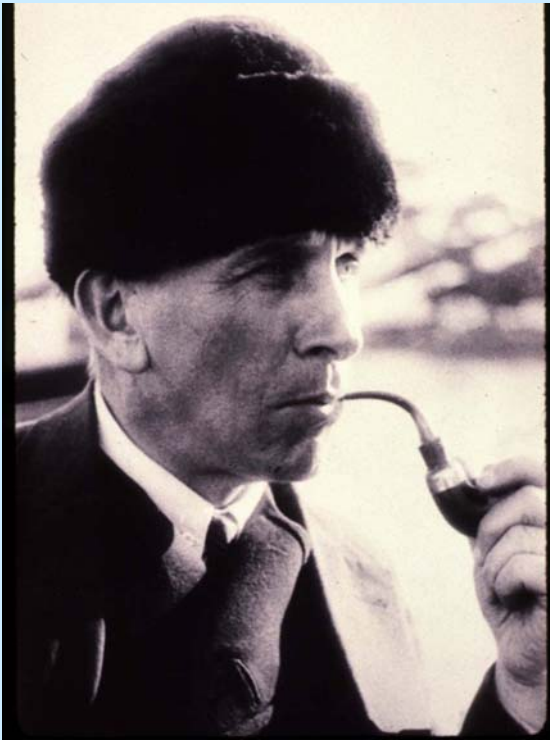
Eduard Suess (1831-1914) was a professor at the University of Vienna, and an expert on the Alps.

He gradually developed views on the connection between Africa and Europe and came to the conclusion that the Alps to the north were once at the bottom of an ocean, of which the Mediterranean was a remnant. He is credited with discovering the Tethys Ocean, which he named in 1893.

His other major discovery was that the fossil *glossopteris* fern was found in South America, Africa, India and Antarctica. His explanation was that the three lands were once connected into a supercontinent, which he named *Gondwana*. Suess believed that the oceans flooded the spaces currently between those lands.

He published a comprehensive synthesis of his ideas in 1885-1901, entitled *Das Antlitz der Erde* (translated into English as *The Face of the Earth*), which was a popular textbook for many years.

Alfred Wegener and continental drift

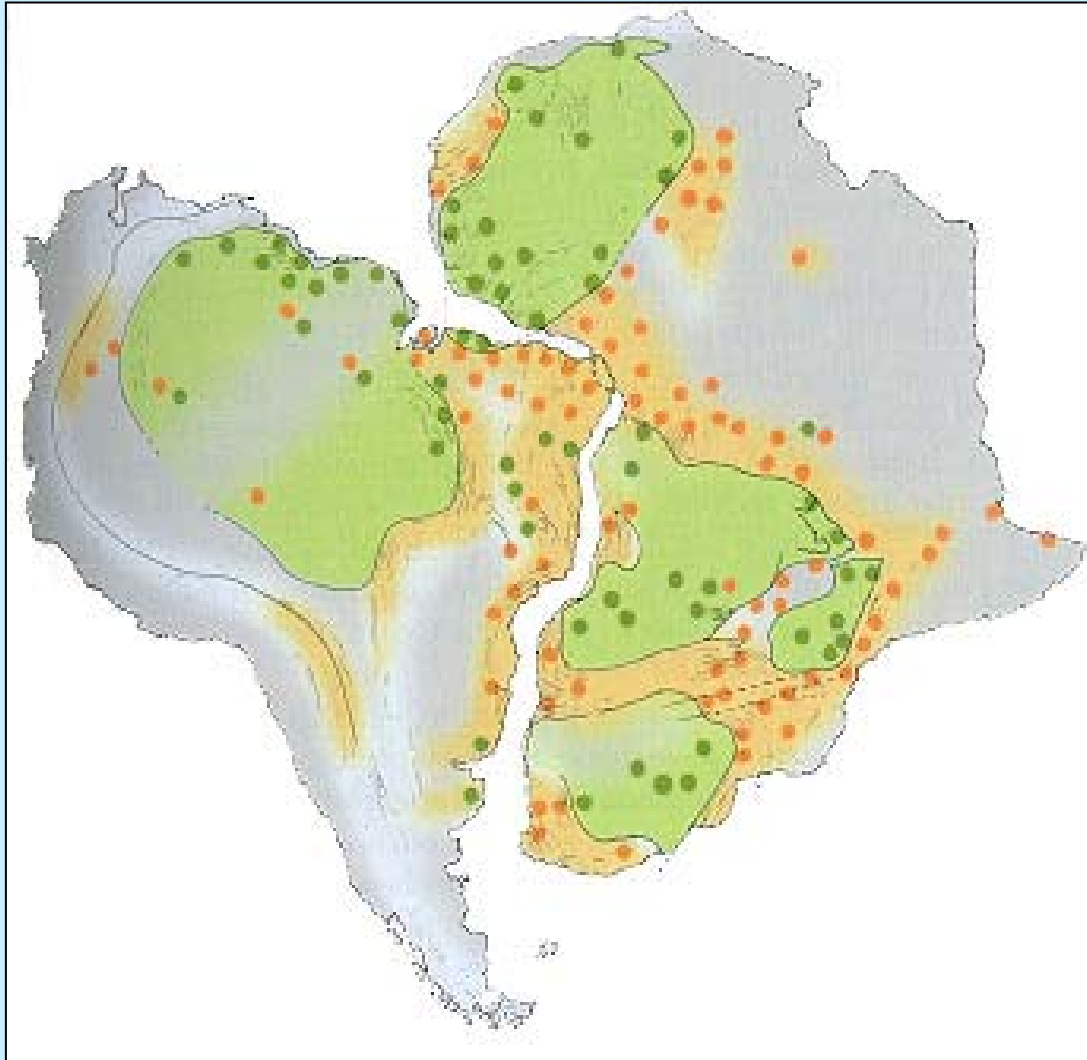


It was not until 1912 that the idea of moving continents was seriously considered as a full-blown scientific theory - called *Continental Drift* - introduced in two articles published by a 32-year-old German meteorologist named Alfred Lothar Wegener

Alfred Lothar Wegener (1880-1930) earned a Ph.D in astronomy from the University of Berlin in 1904. He was also fascinated with the developing fields of meteorology and climatology.

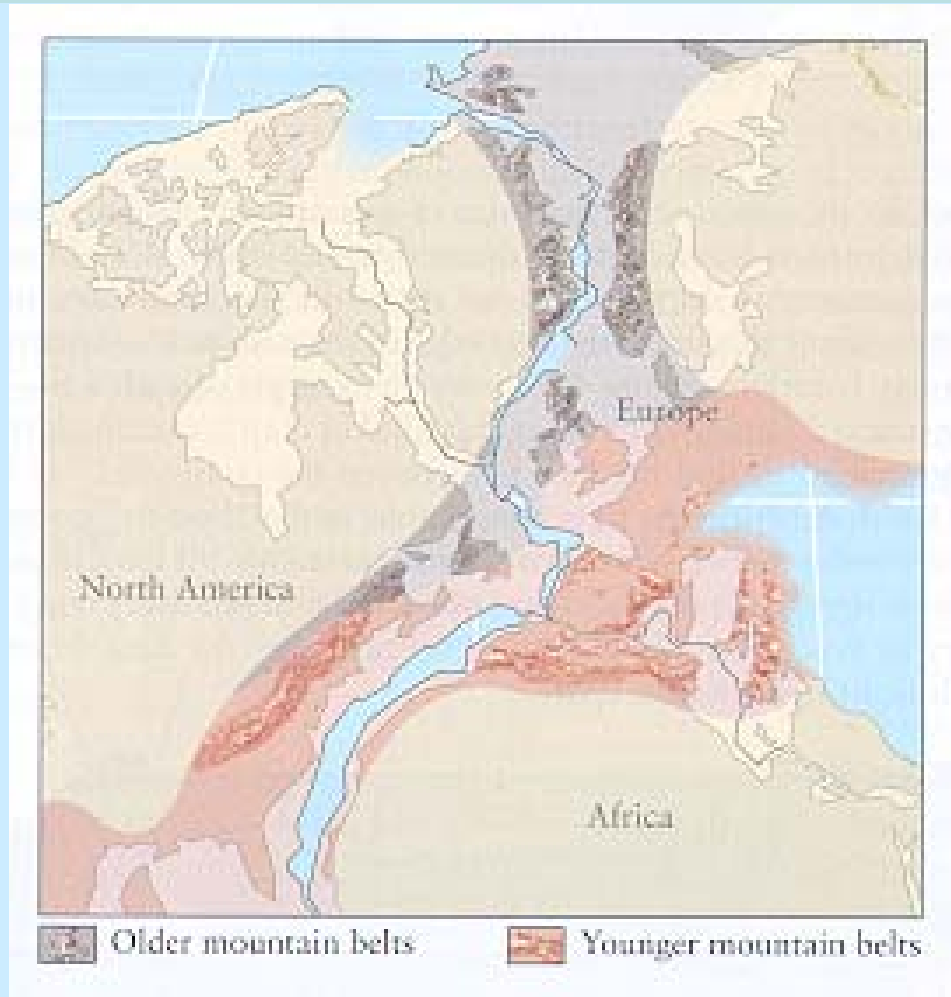
In 1915 the first edition of *The Origin of Continents and Oceans*, a book outlining Wegener's theory, was published; expanded editions were published in 1920, 1922, and 1929.

Wegeners structural evidence



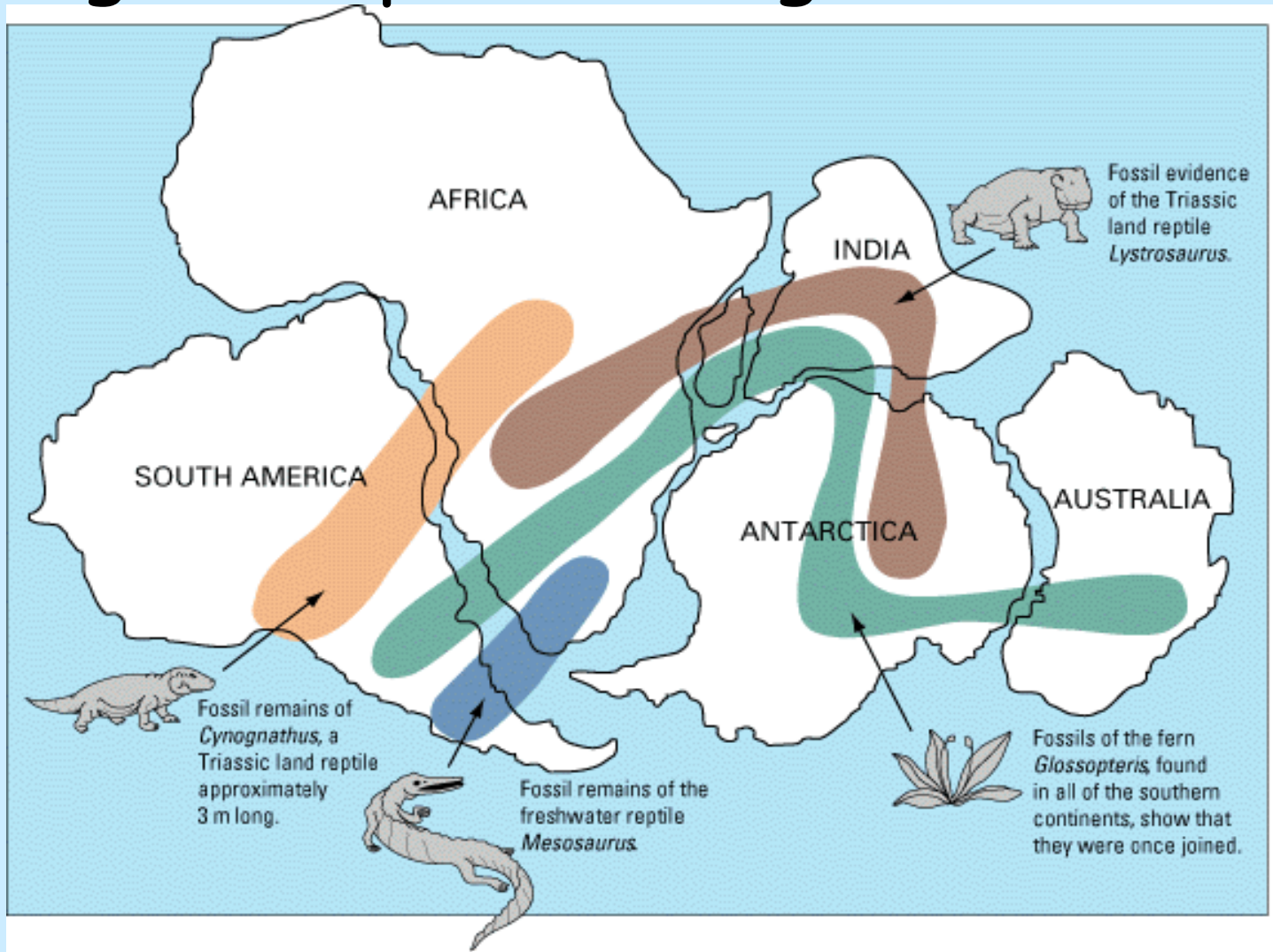
- South America and Africa fit together like a jigsaw puzzle in both outline as well as rock type and geological structure.

Continental Drift: Rock Ages



Even before geochronology, the relative framework of rock ages showed strong correlation across the Atlantic, as did mountain ranges of similar age.

Wegener's paleontological evidence

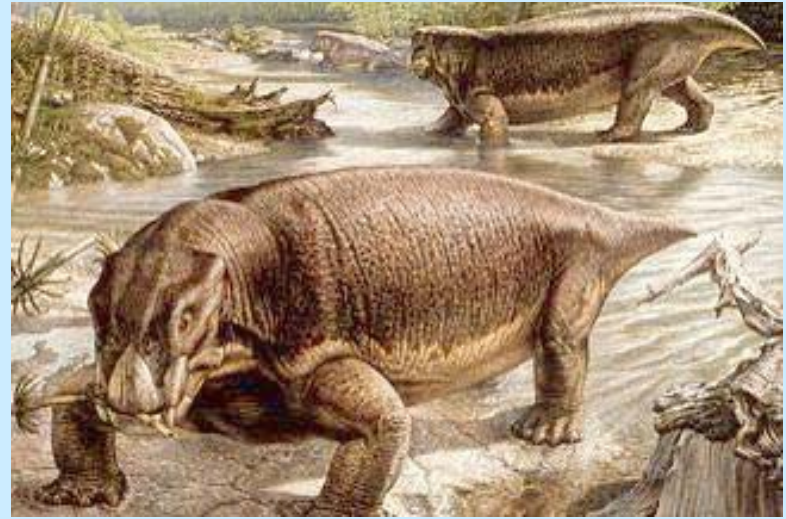


Wegener was intrigued by the occurrences of geologic structures and of plant and animal fossils found on the matching coastlines of South America and Africa, which are now separated by the Atlantic Ocean.

Animals that lived on Southern Hemisphere continents - but cannot have crossed Oceans



Cyanognathus



Lystrosaurus



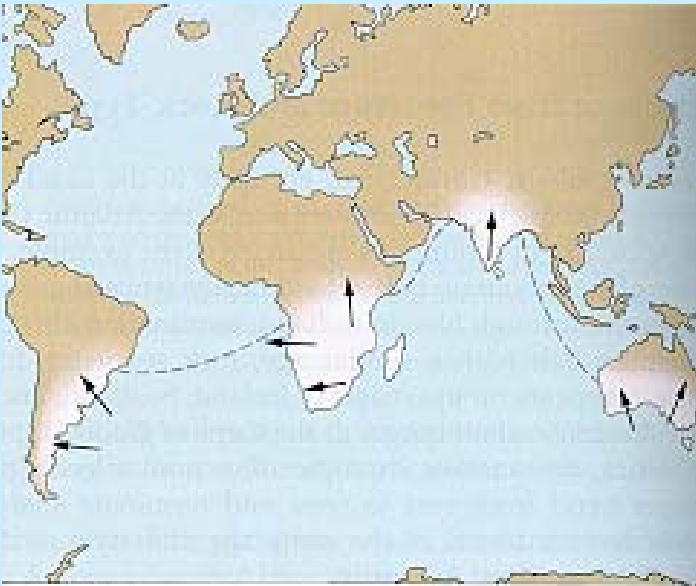
Mesosaurus

Glossopteris...

The Glossopteridales are an extinct group of seed plants that arose during the Permian, but went extinct by the end of the Triassic Period (~290-205 MY). The rapid appearance, expansion, and relatively quick extinction of this group, as well as the large number of species (>70), has made the group very important for understanding paleobiogeography

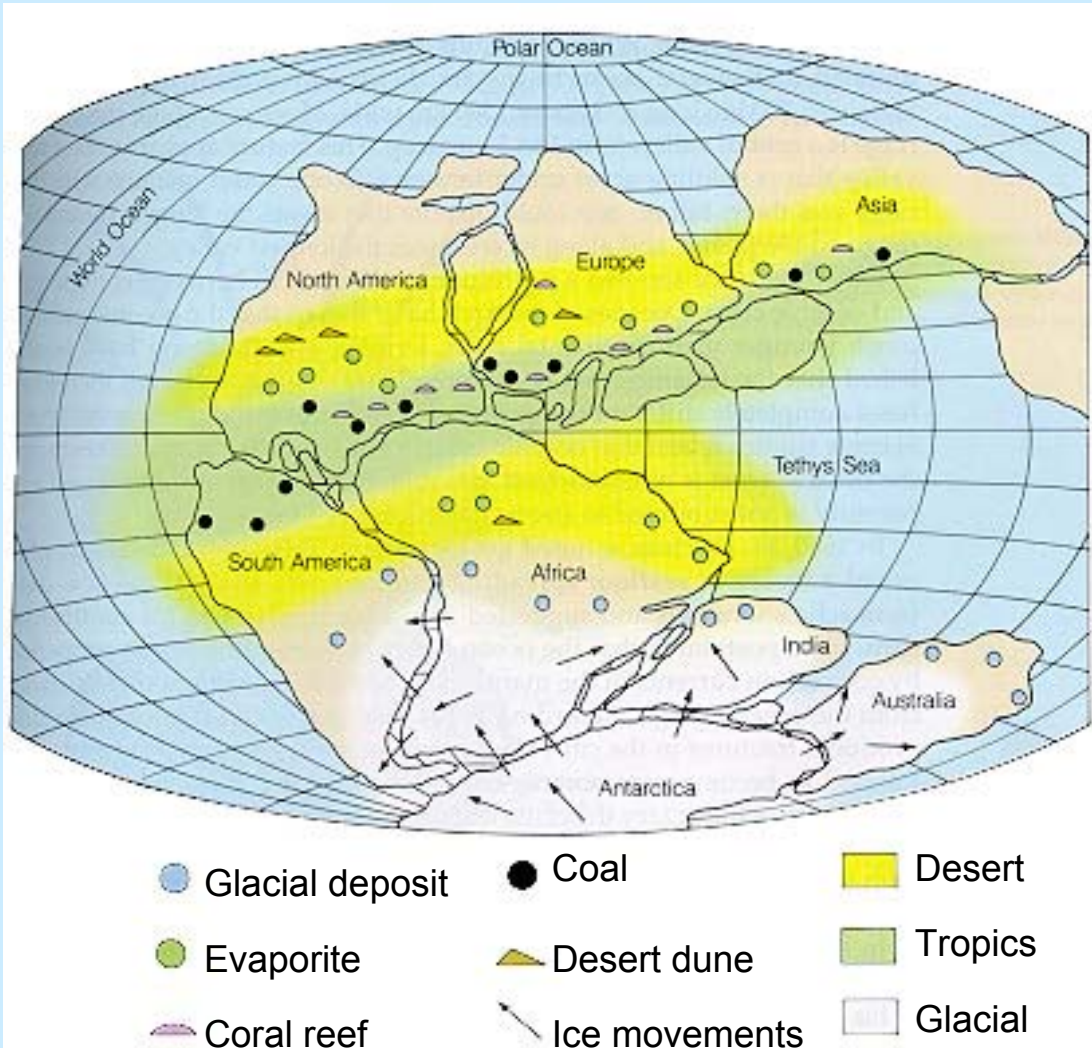


Wegeners evidence from distribution of glacial deposits



The distribution of Paleozoic glacial deposits in the southern hemisphere on today's map makes it seem that the glaciers flowed from the sea to the land.

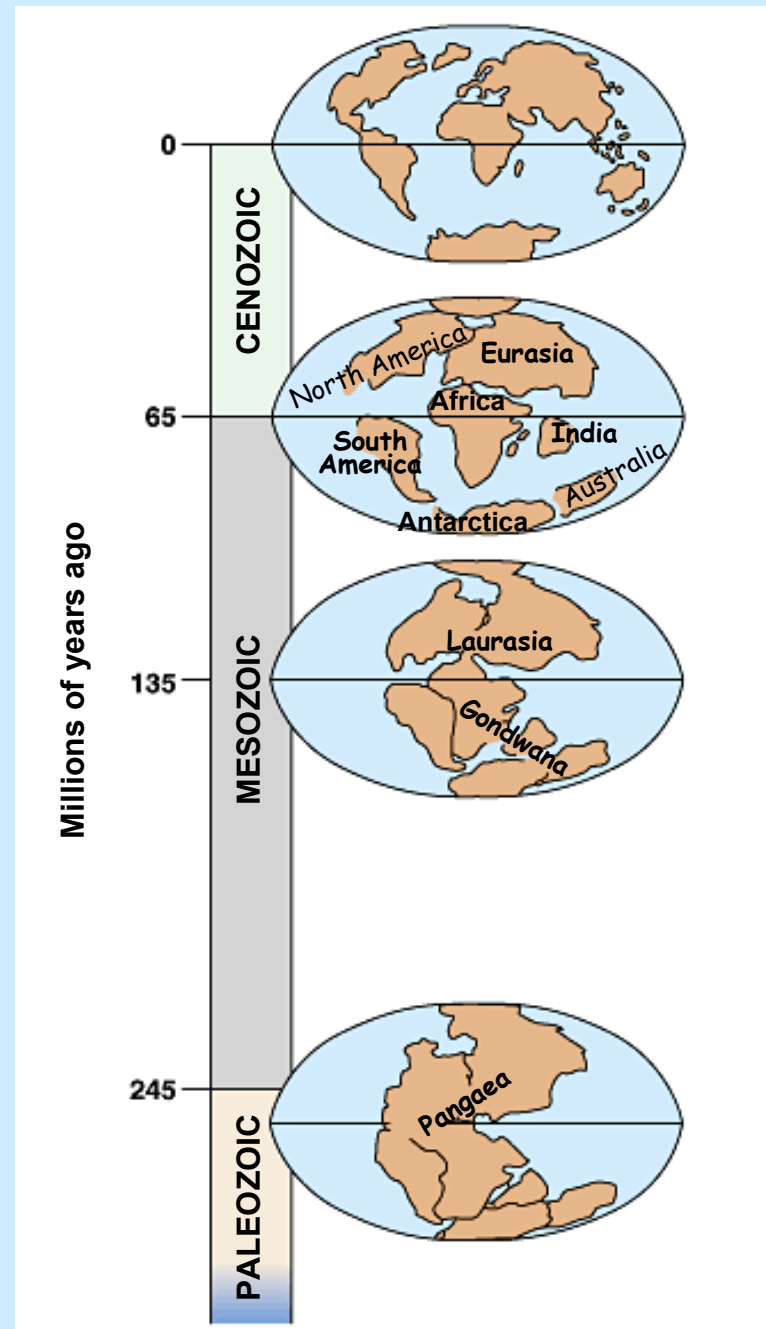
Other paleoclimatological evidence



Other paleoclimatic evidence includes deposits of coal, desert sandstone, rock salt, wind-blown sand, gypsum, and glacial deposits

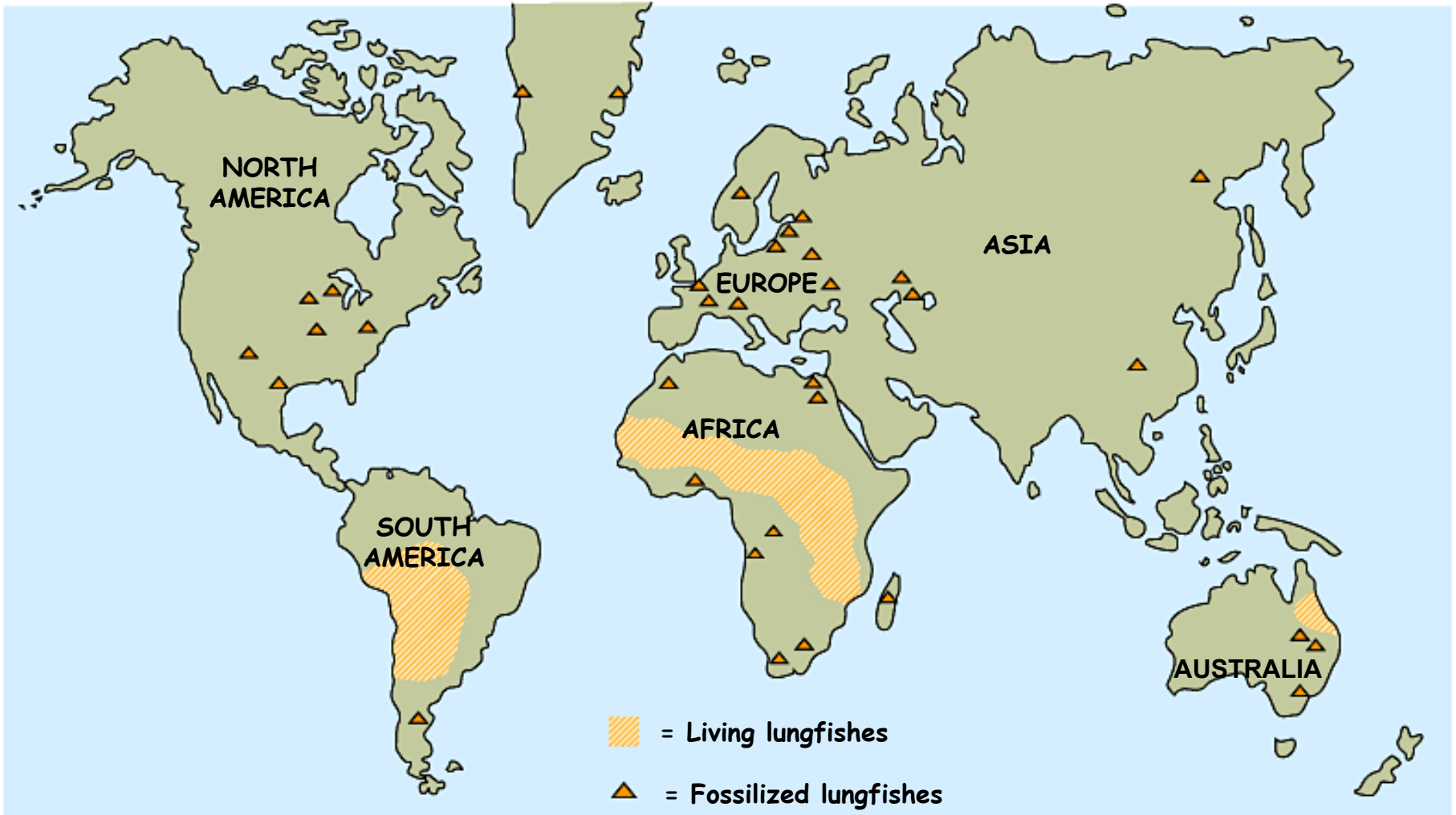
This tectonic cycle has influenced the distribution of organisms and greatly affected the history of life

- Continental mergers triggered extinctions
- Separation of continents caused the isolation and diversification of organisms



- Continental drift explains the distribution of lungfishes
 - Lungfishes evolved when Pangaea was intact





How the Scientific world reacted

- "Utter, damned rot!" said the president of the prestigious American Philosophical Society.
- "Wegener's hypothesis in general is of the footloose type, in that it takes considerable liberty with our globe..." Dr. Rollin T. Chamberlin, University of Chicago.
 - "If we are to believe [this] hypothesis, we must forget everything we have learned in the last 70 years and start all over again", said another American scientist.
 - "Anyone who valued his reputation for scientific sanity would never dare support such a theory", said a British geologist.

The Rejection of Continental Drift:

- Most influential earth scientists were based in the Northern Hemisphere, whereas most of the conclusive data came from the Southern Hemisphere

- There were plausible alternative explanations to the distribution of fossils and glacial deposits

- The geophysicists could not think of a force strong enough to make continents able to plough through Oceanic crust

- Wegener assigned Pangea a far too young age (Cenozoic) and paleontologists found it hard to believe that so much continental drift could have occurred in so short time

Scientific isolation

Thus did most in the scientific community ridicule the concept that would revolutionize the earth sciences and scorn Alfred Wegener who dared to propose it.

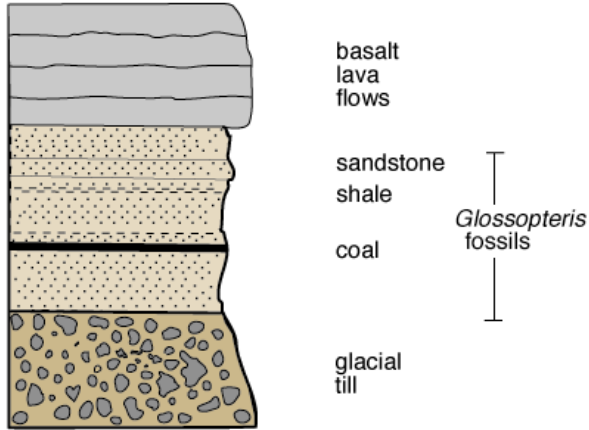


Most of the attacks were aimed at Wegener himself, an outsider who seemed to be attacking the very foundations of geology. Because of this abuse, Wegener could not get a professorship at any German university (he was *"interested in matters that lay outside its terms of reference"*). The University of Graz in Austria was more tolerant of controversy, and in 1924 it appointed him professor of meteorology and geophysics.

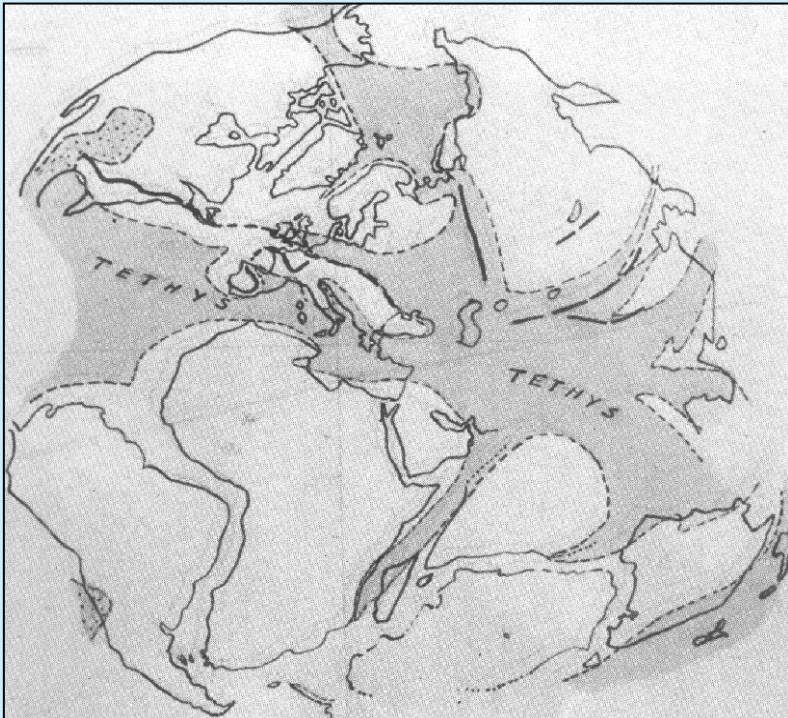
Alfred Wegener died on the Greenland inland ice a day or two after his 50th birthday in November 1930

Alexander Du Toit

was a South African geologist. After a visit to S America in 1923, du Toit became a staunch supporter of Alfred Wegener's theory of continental drift.

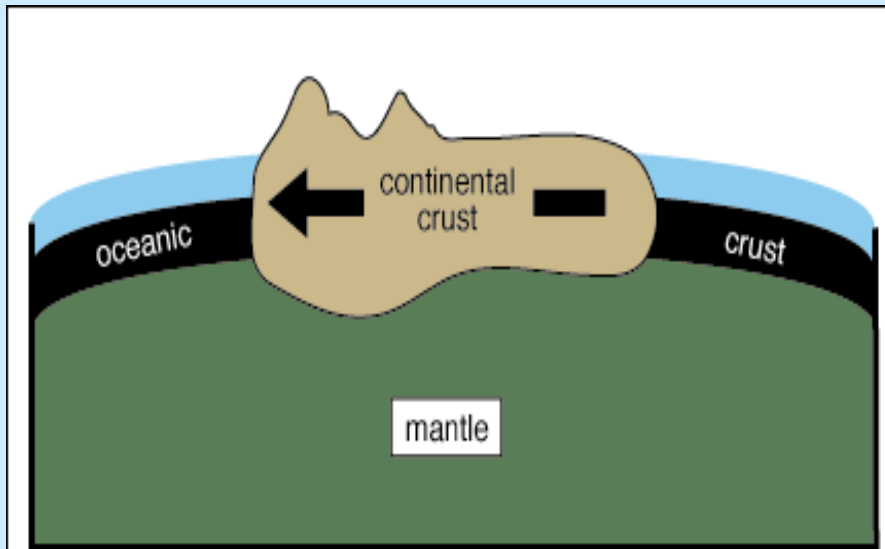


Similar layers of rock were formed in Antarctica, Australia, South America, Africa, and India before Pangea broke apart. Glossopteris fossils were found in the rocks on each continent.



He published his observations in *A Geological Comparison of South America with South Africa* (1927), and later he developed his ideas in *Our Wandering Continents* (1937). There he argued for the separation of Wegener's Pangea into the two super continents, Laurasia and Gondwana.

...the geophysicists killed the theory of Continental Drift

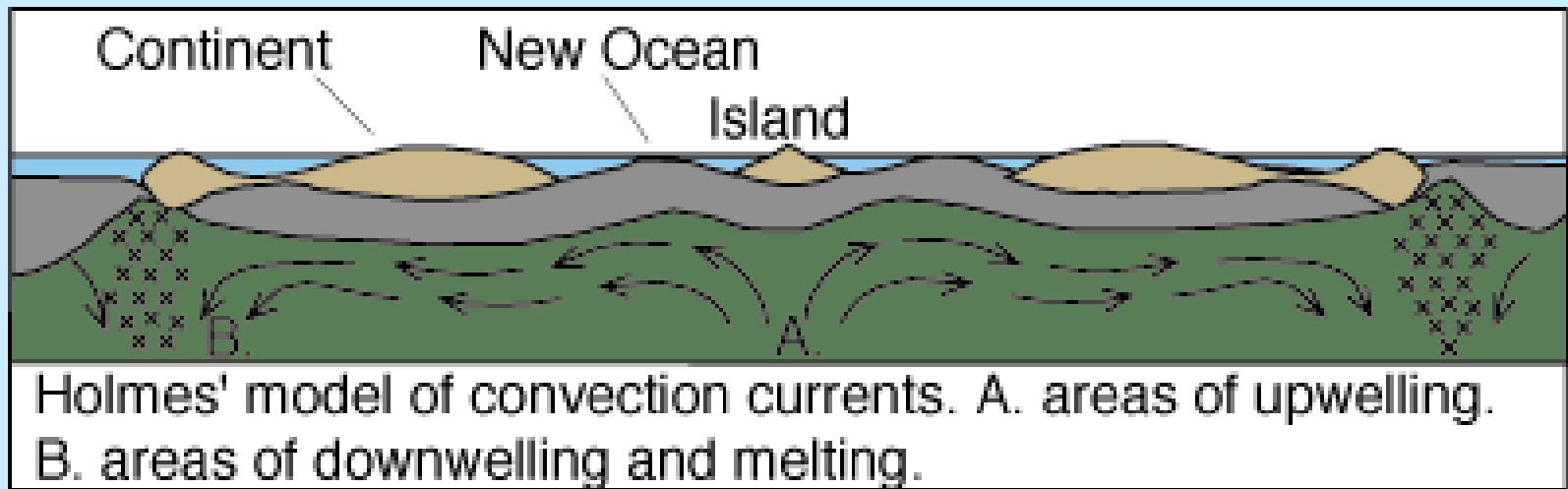


Wegener's proposal that continents plowed through oceanic crust was not accepted by other geologists.

The main reason that Wegener's hypothesis was not accepted was because he suggested no mechanism for moving the continents.

- He thought the force of Earth's spin was sufficient to cause continents to move, but geologists knew that rocks are too strong for this to be true.
- Wegener thought that the continents were moving through the earth's crust, like icebreakers plowing through sea-ice. Geologists noted that plowing through oceanic crust would distort continents beyond recognition.

Arthur Holmes suggests a force that could move continents

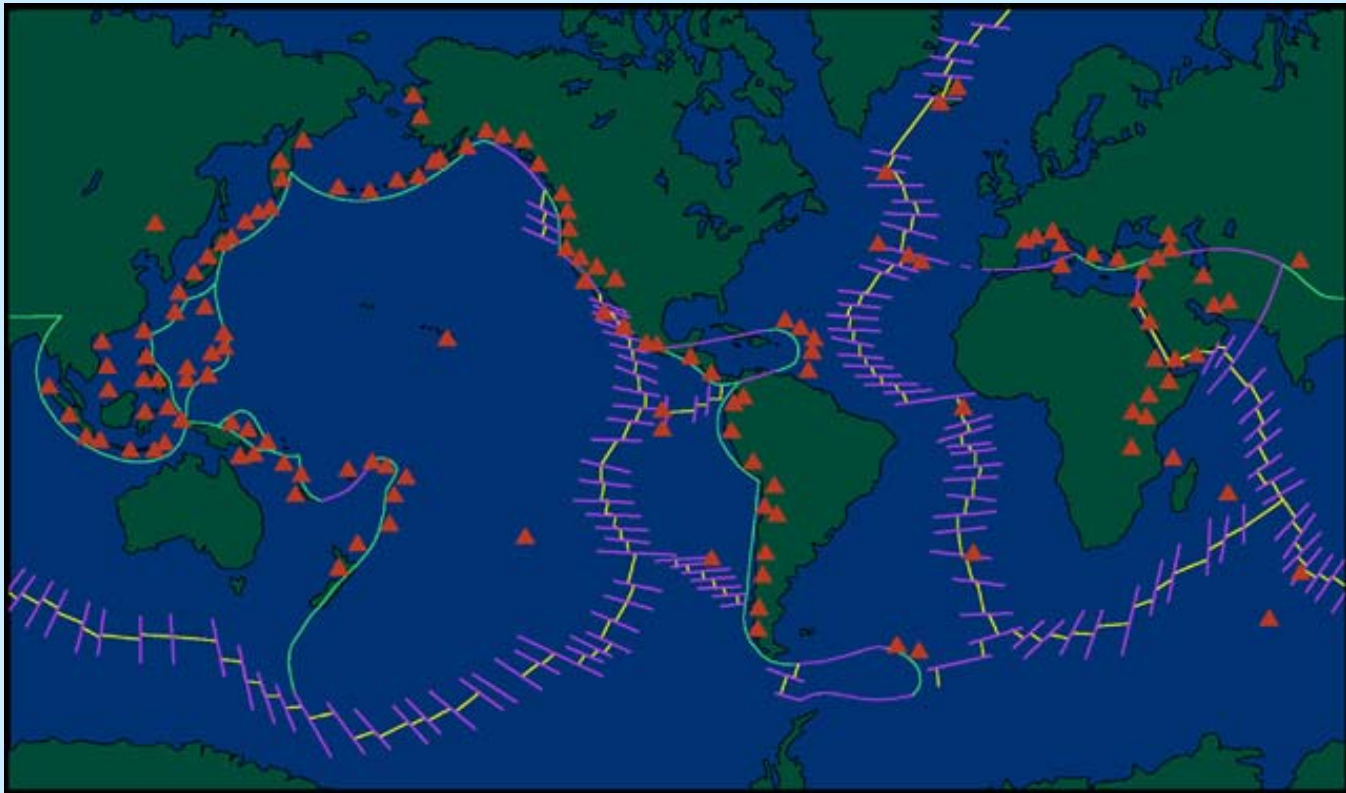


It wasn't until 1928 that a Scottish Geologist, Arthur Holmes, came up with an explanation for why continents move. He believed that heat trapped in the Earth caused convection currents. There were areas where fluids trapped beneath Earth's crust heat up, rise, spread laterally, then cool and drop back down.

Revival of the Continental Drift theory

Wegeners theory just would not go away, despite its defamation...

German geologists tried to prove it in the late 1930's, but the Second World War destroyed that effort





Discovery of the Ocean Ridges

The story on the discovery of the Mid Ocean Ridges starts with Fritz Haber, a prominent German chemist (Nobel Prize in chemistry in 1918).



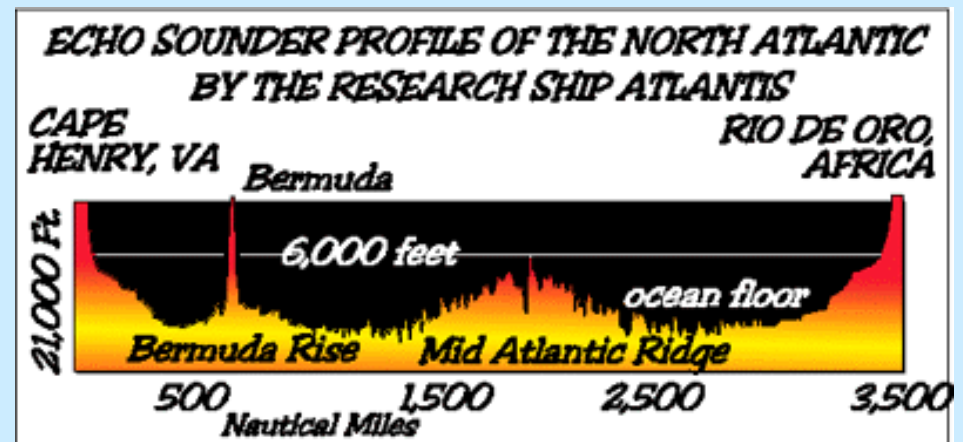
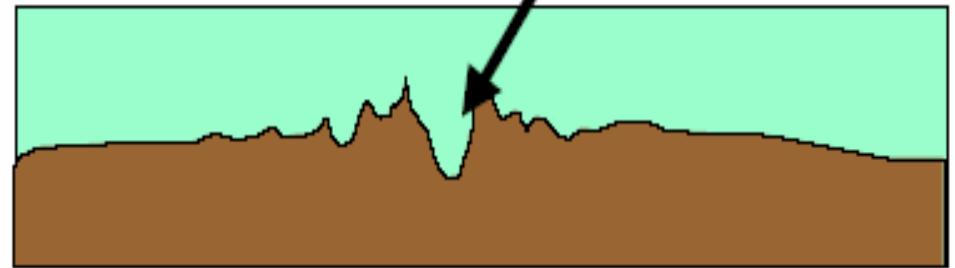
He suggested that Germany could ease its debts after WWI by extracting gold from sea water (theoretically up to 56 mg of gold can be extracted from 1 m³ of sea water). In 1925, Germany outfitted a boat and set out for two years to systematically explore the Atlantic Ocean.

After two years of study, they returned with data that shows the existence of a major Mid-Atlantic Ocean Ridge

The Great Global Rift

The Mid Atlantic Ocean Ridge was later (1953) discovered to extend to other great oceans. In 1953, American physicists Maurice Ewing (1906-1974) and Bruce Heezen (1924-1977) discovered that through this underwater mountain range ran a deep canyon, which they called the Great Global Rift. The rift appeared to be breaks in the earth's crust. The rift outlined chunks of the earth's crust, which were named tectonic plates.

Mid-Ocean Ridges are essentially submerged mountain chains that are characterised by a deep central rift valley



With WWII and the cold war came new data

Harry Hess was an American geologist, born in NYC in 1906. Took his Ph.D at Princeton in 1932; went on to become a professor of geology at that university. Did extensive sea-floor mapping during Second World War.

In 1959 he published the paper *History of Ocean Basins*, in which he developed his idea of sea-floor spreading, a forerunner of plate tectonics



Harry Hess (1906-1969) in his Navy uniform as Captain of the assault transport Cape Johnson during World War

The Contribution of Hess

Hess measured the oceans to the deepest points to date, >10,000 m. He discovered hundreds of flat-topped mountains on the Pacific floor. He named them guyots, but found them very puzzling: They looked like their tops were eroded, but they were 2 kilometers under water.

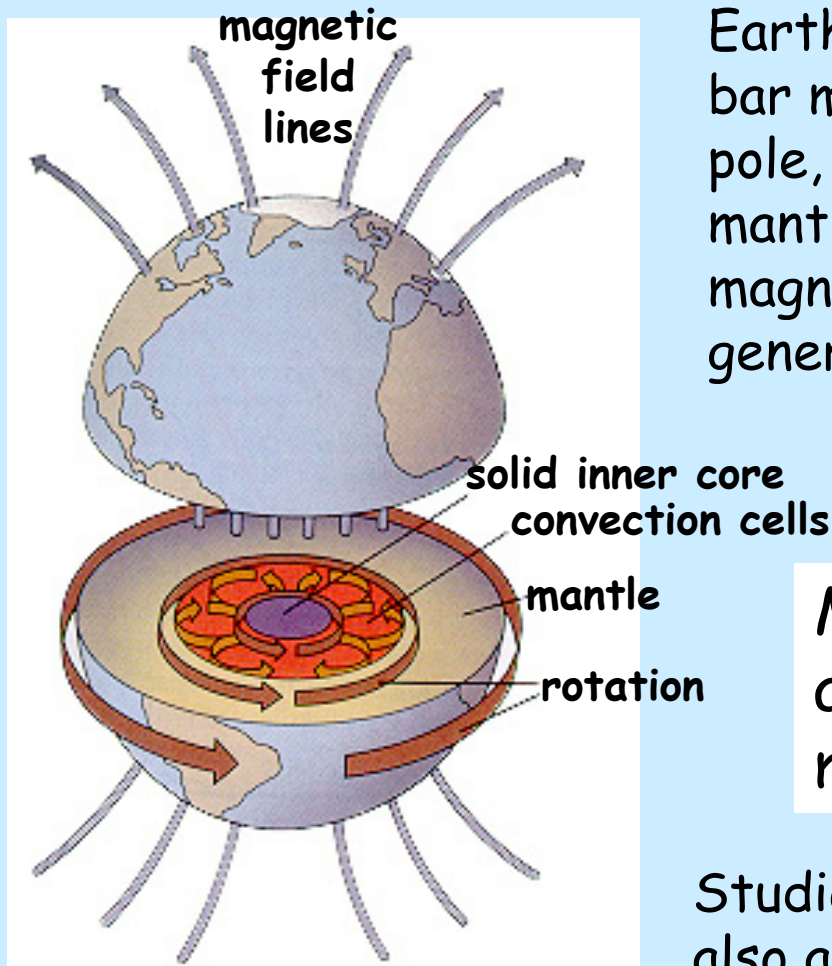


Hess suggestions

- He suggested that the distribution of flat-topped seamounts (guyots), or old volcanoes, rising from the seafloor, showed movements of the crust and subsequent subduction
- That the continents had not plowed through oceanic crust, but that the entire crust had moved
- That the ocean basins were young and thus lacked thick sediments
- That new crust was formed at the mid-ocean ridges and was destroyed in the deep trenches.
- That the crustal movements were driven by convective cells

Paleomagnetism enters the picture...

- Paleomagnetism: fossil magnetic properties frozen in rocks -

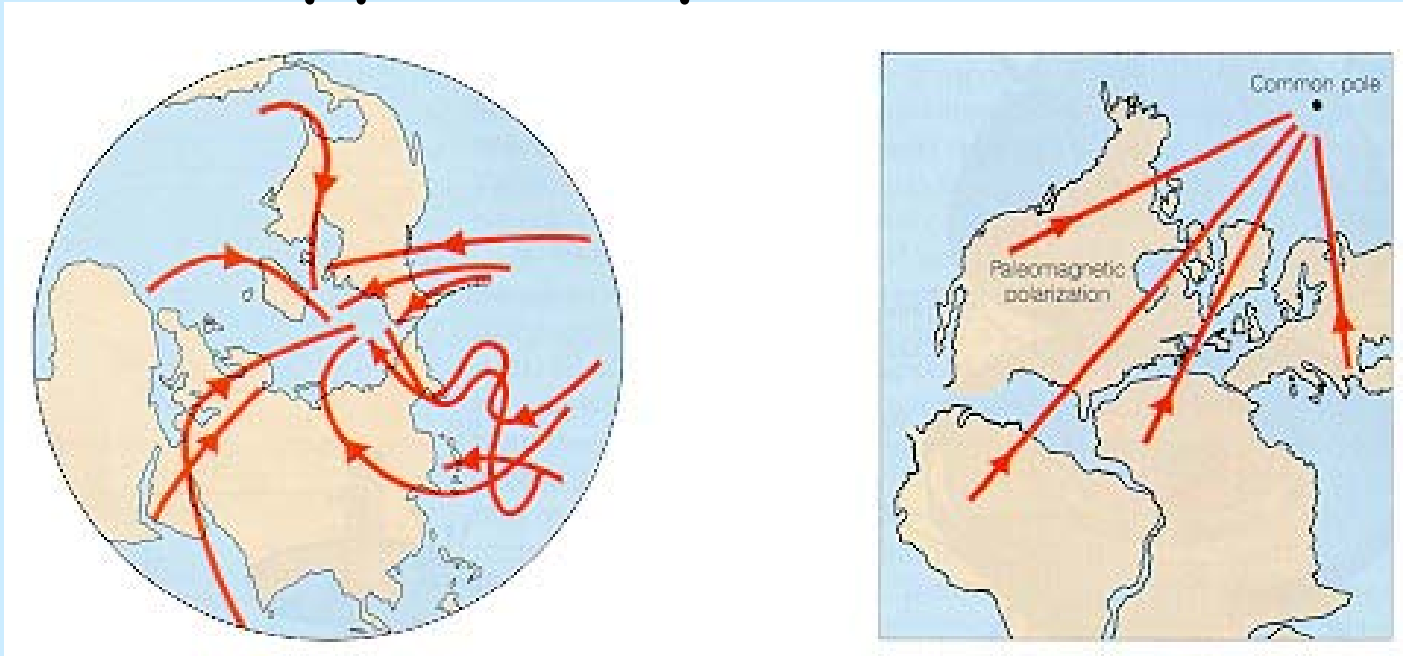


Earth's magnetic field is like a simple bar magnet as it has a north and south pole, but temperatures in the core and mantle are too hot for permanent magnetism. Earth's magnetism must be generated Electromagnetically.

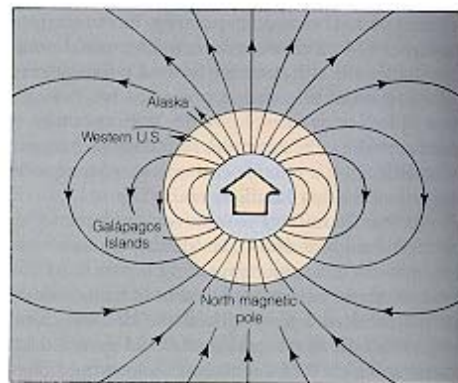
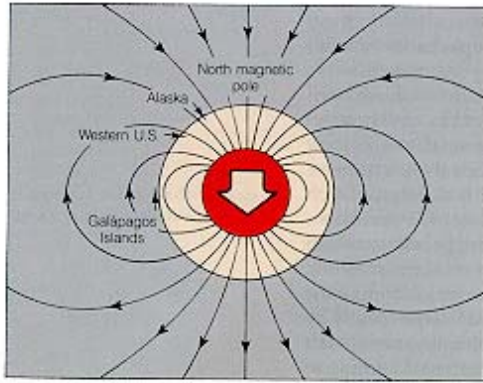
Magnetic particles in lava align according to the magnetic field as lava cools

Studies of magnetics of the sea floor also a product of the WWII and cold war...

Apparent pole wander

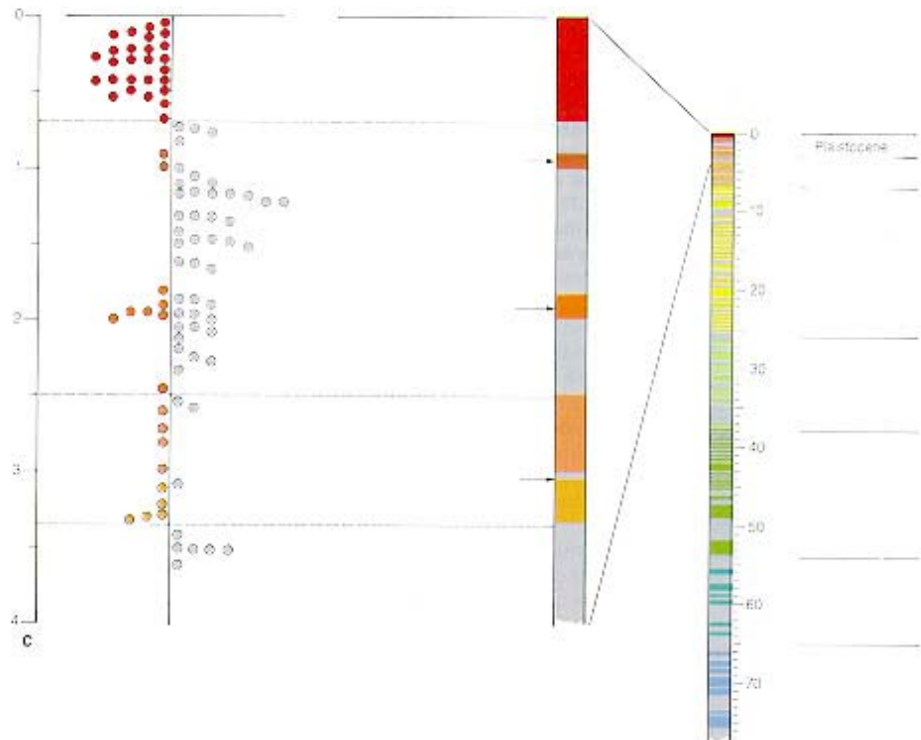


- Early studies of paleomagnetism in rocks of different age seemed to indicate that magnetic north had steadily changed its position.
- But different continents had different wander paths
- If the continents were fixed, different land masses would have different magnetic poles at the same time - an impossibility
- Thus the continents must have moved



Magnetic polarity

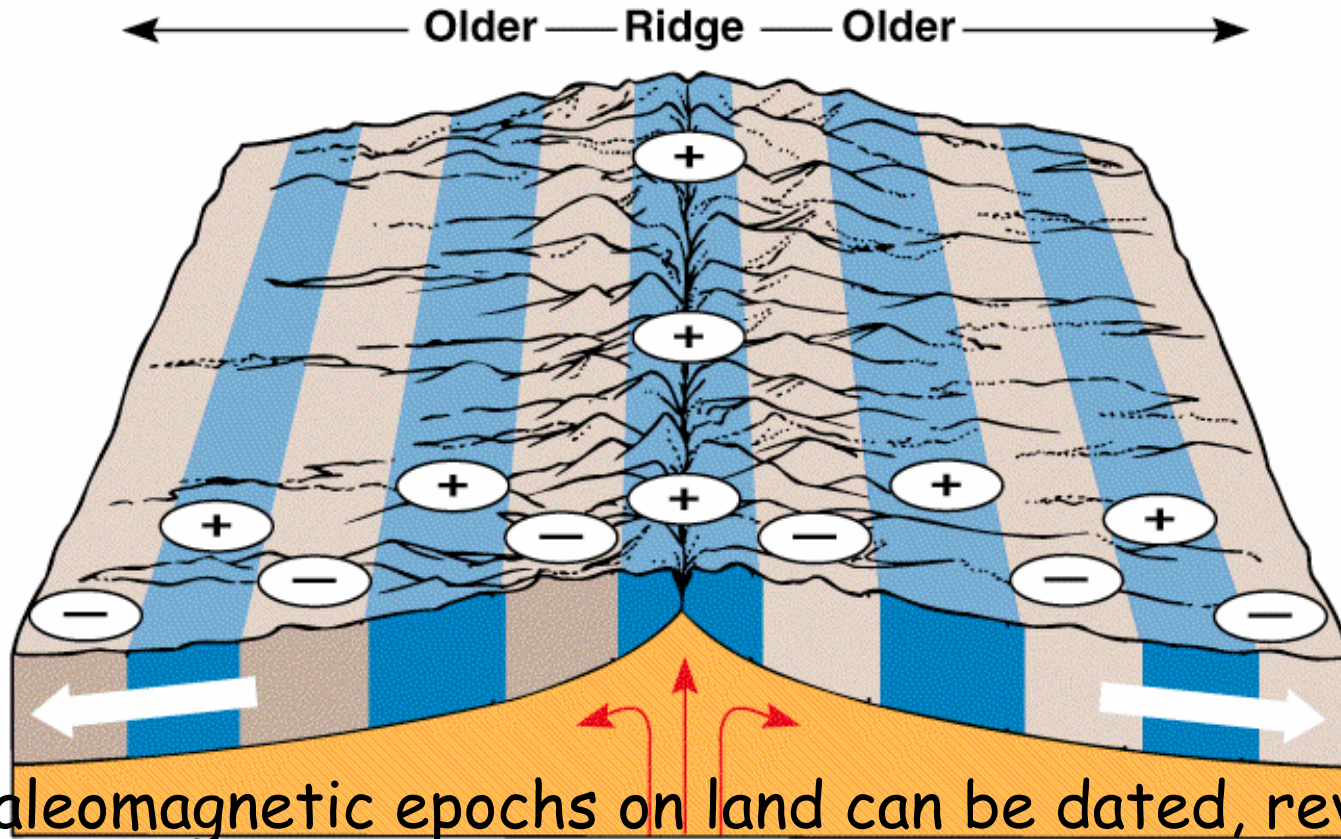
- Paleomagnetic studies of seafloor basalts indicate that Earth's magnetic field has oscillated through time.
 - normal polarity
 - reversed polarity



Paleomagnetic stripes on the sea floor

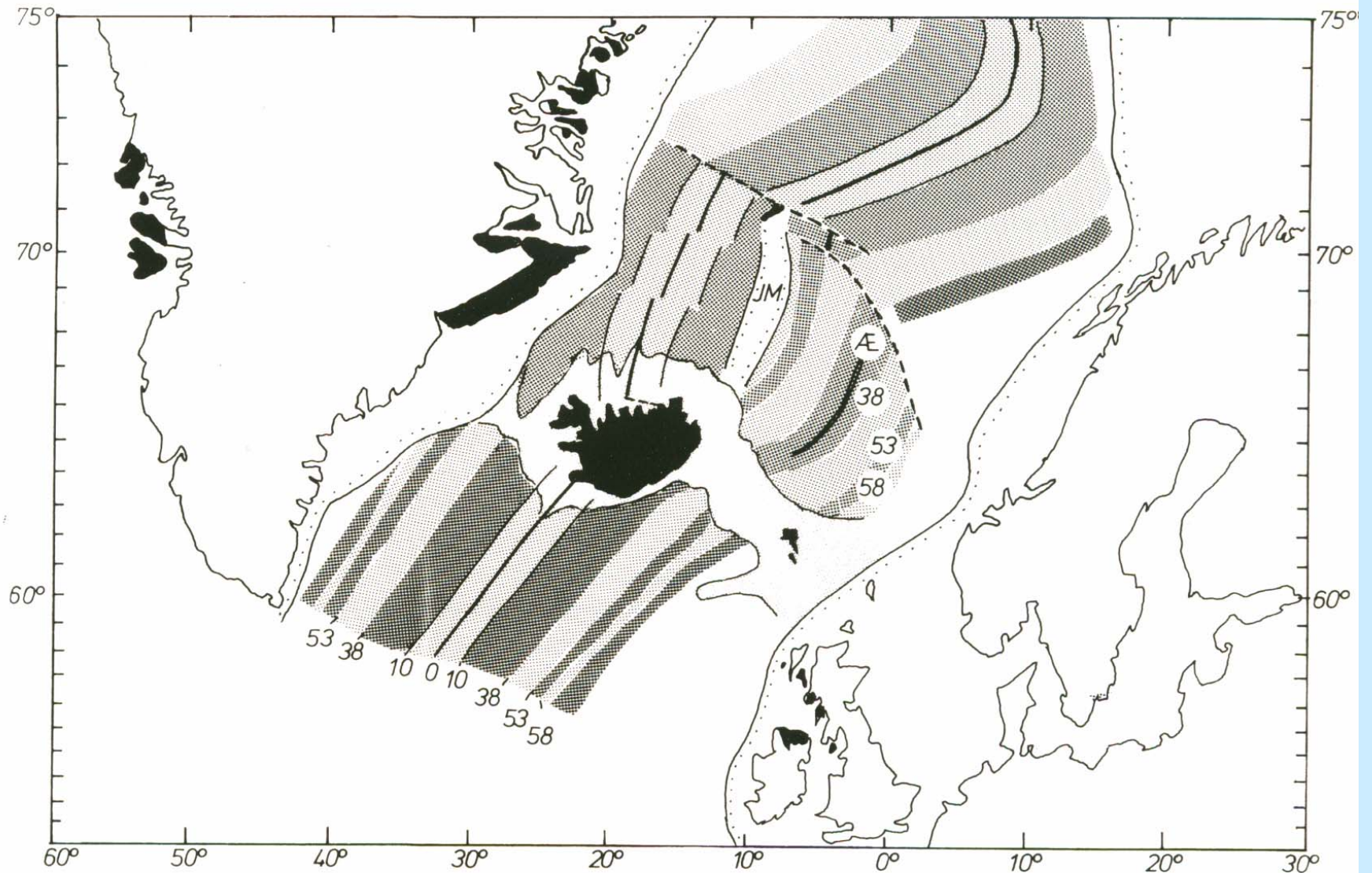
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Levin, The Earth Through Time, 6/e
Figure 5-49

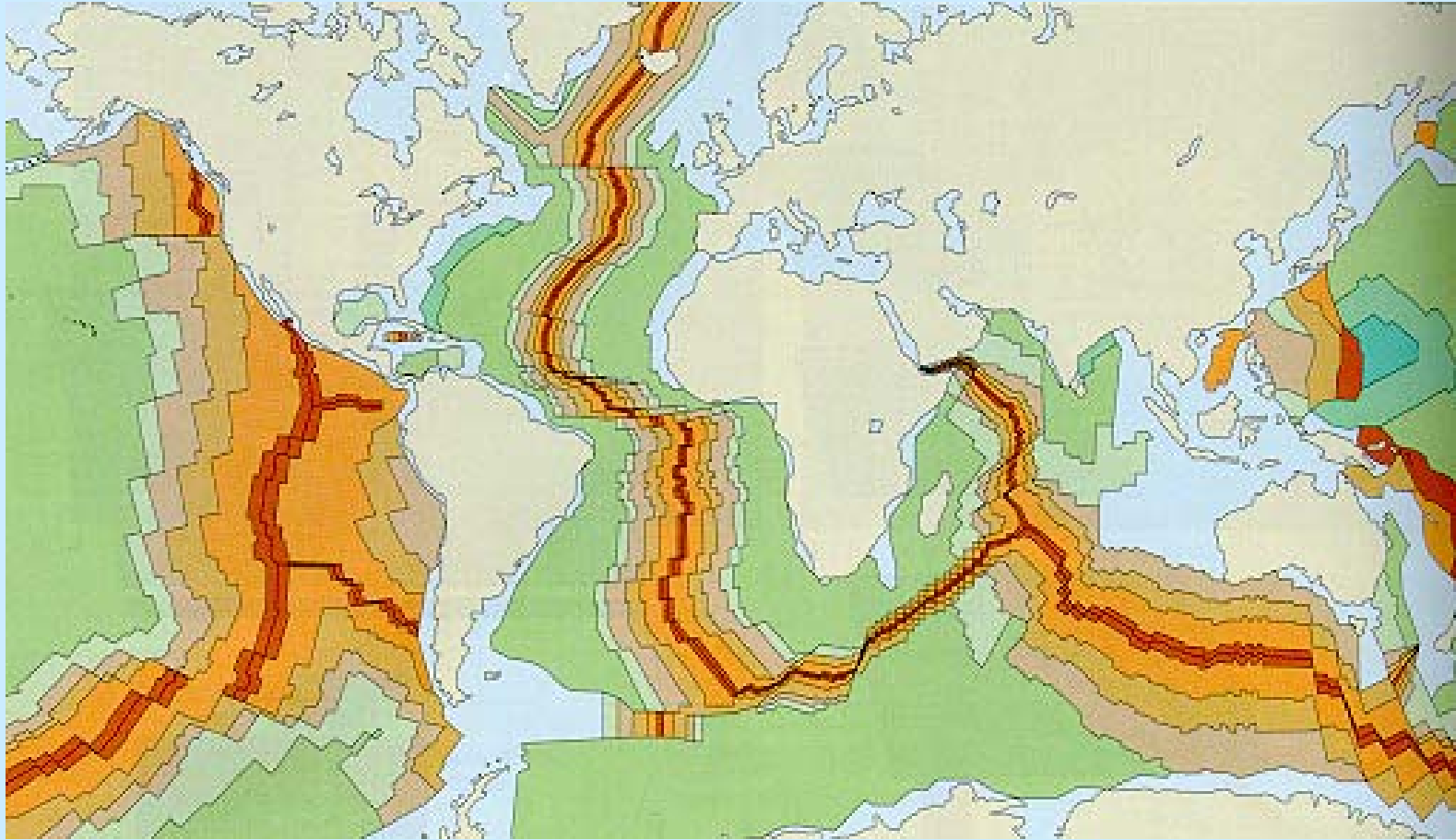


Since paleomagnetic epochs on land can be dated, reversals recorded in the sea reveal the age of the ocean crust.

Iceland a key part of the puzzle

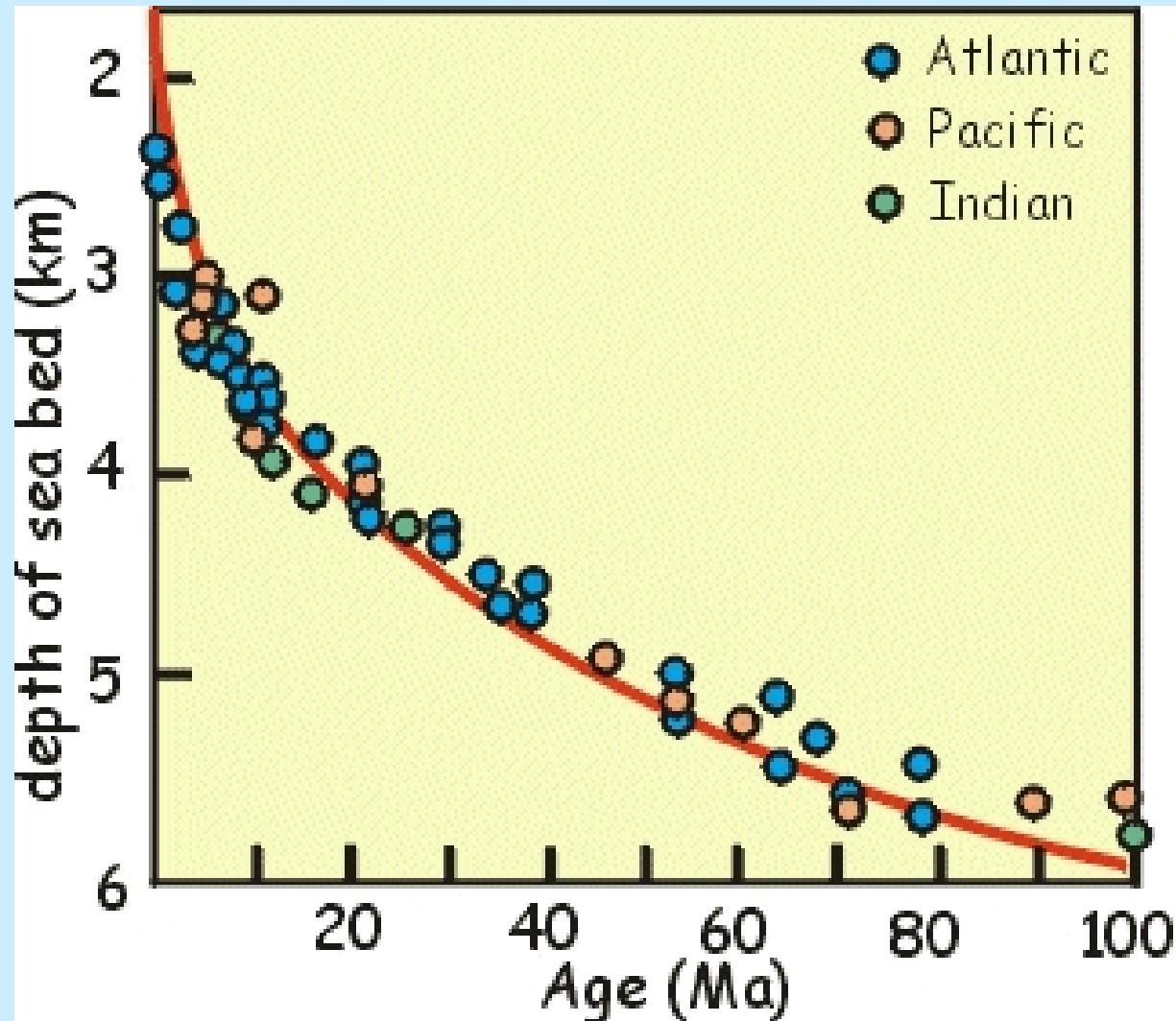


Paleomagnetic record of seafloor spreading

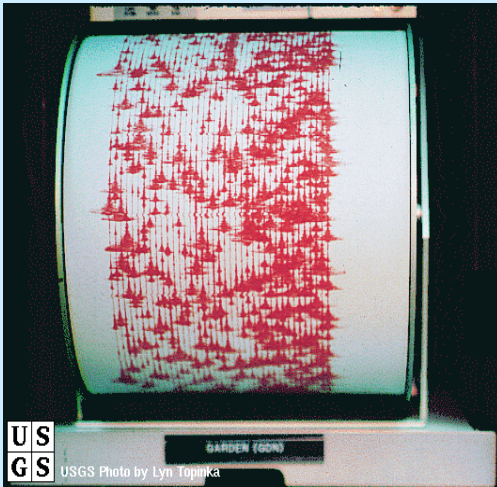


- Magnetic patterns on the seafloor are symmetrical with respect to the ocean ridge.
- By correlation with rocks on land, the age of the seafloor is nowhere >200 million years old (Jurassic Period).

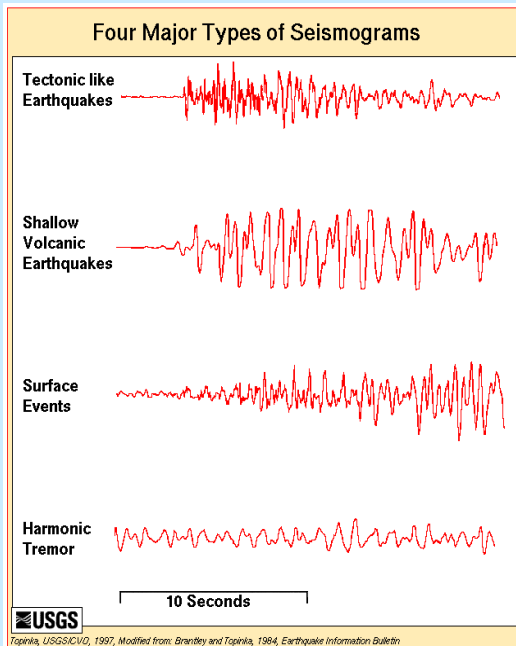
The relationship between the age of the sea floor and its bathymetry



Earthquakes and Plate Tectonics

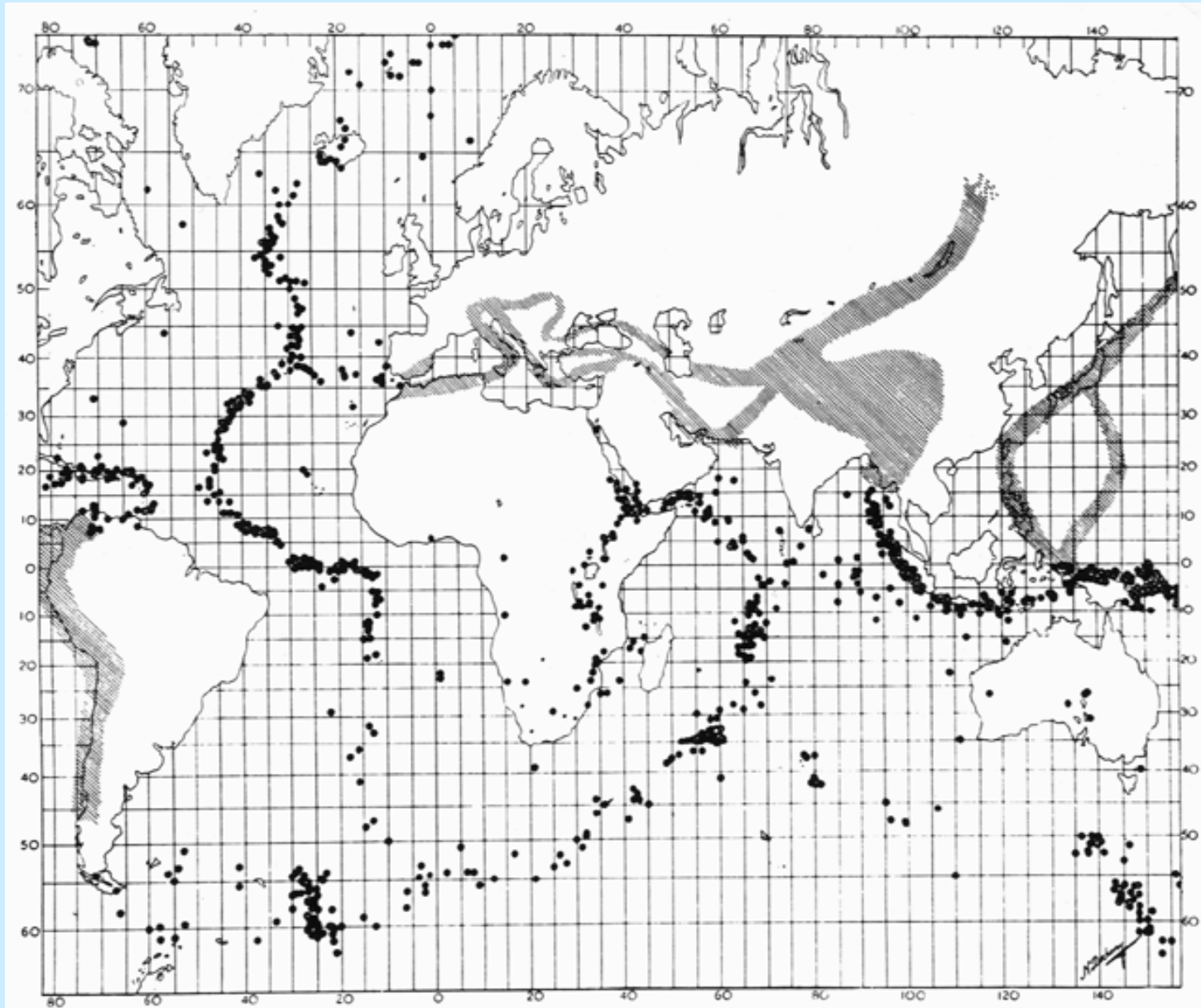


- First seismometer constructed in 1890.
- Richter logarithmic scale for measuring energy release at earthquake epicentre constructed in 1935
- Very few centers for seismological studies until the 1960's; global monitoring networks poorly developed until then.

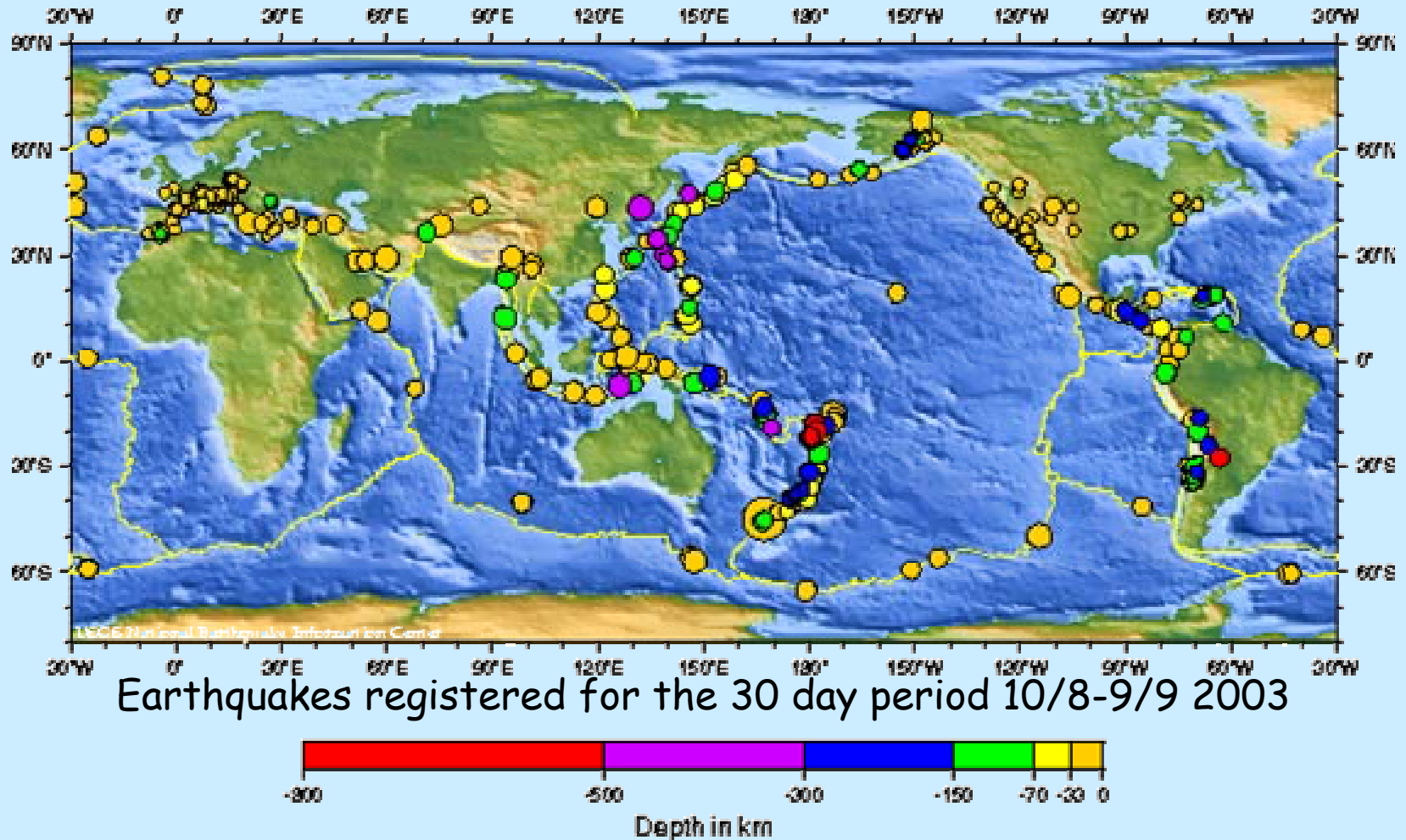


- Data already from the 1940's and 1950's shows that earthquakes almost exclusively occur at what we now know are Mid Ocean Ridges and Continental Plate margins. The significance of this were not well understood before the 1960's.

J.P. Rothé's 1954 map of global earthquake zones



Global distribution of Earthquakes



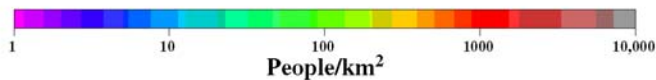
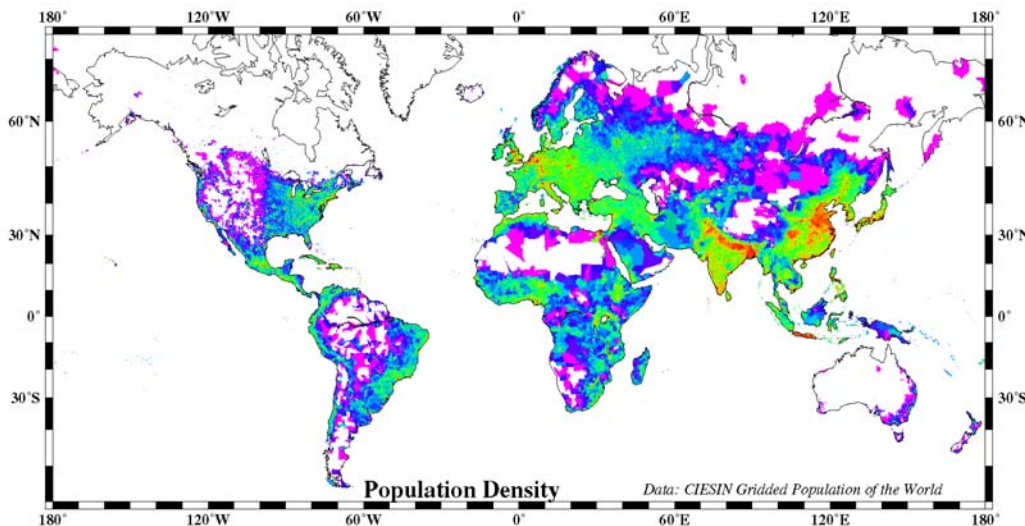
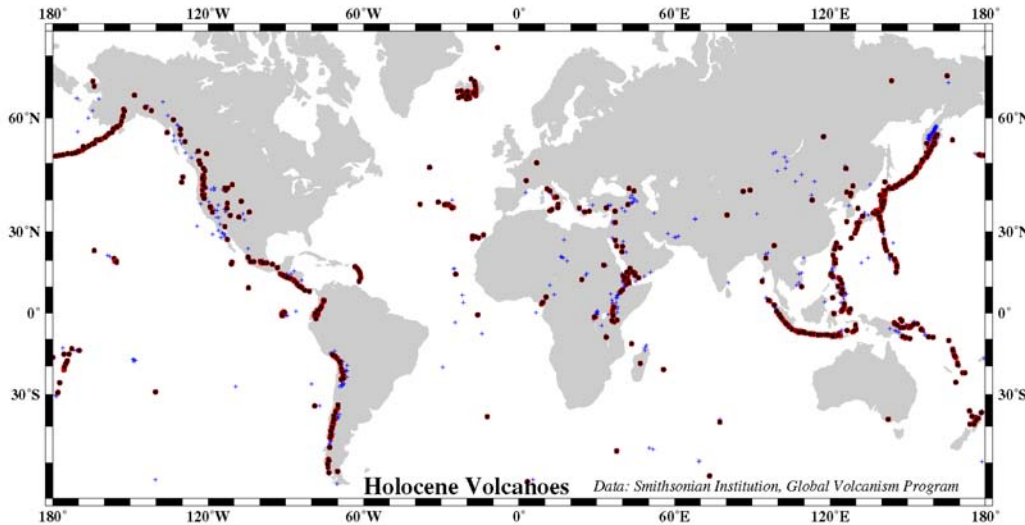
Tight global grid of seismometers first developed during the 1960's - yet another result of the cold war!

Global distribution of Volcanoes

- There are more than 500 active volcano systems in the world

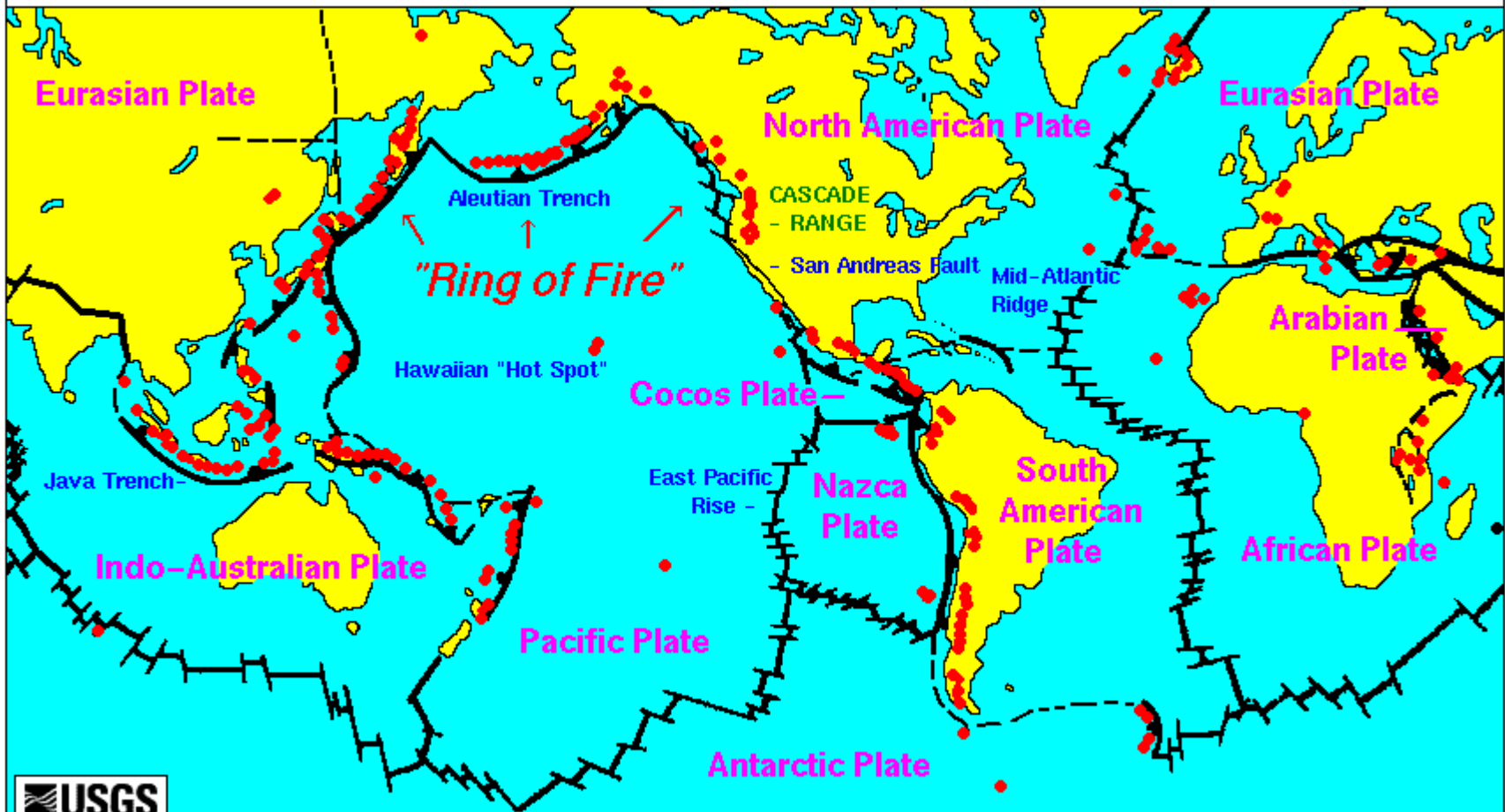
- Their global distribution was reasonably well known by the 19th Century.

- The significance of the distribution was not realized until the theory of Plate Tectonics.



When it is all put together, the plates are outlined

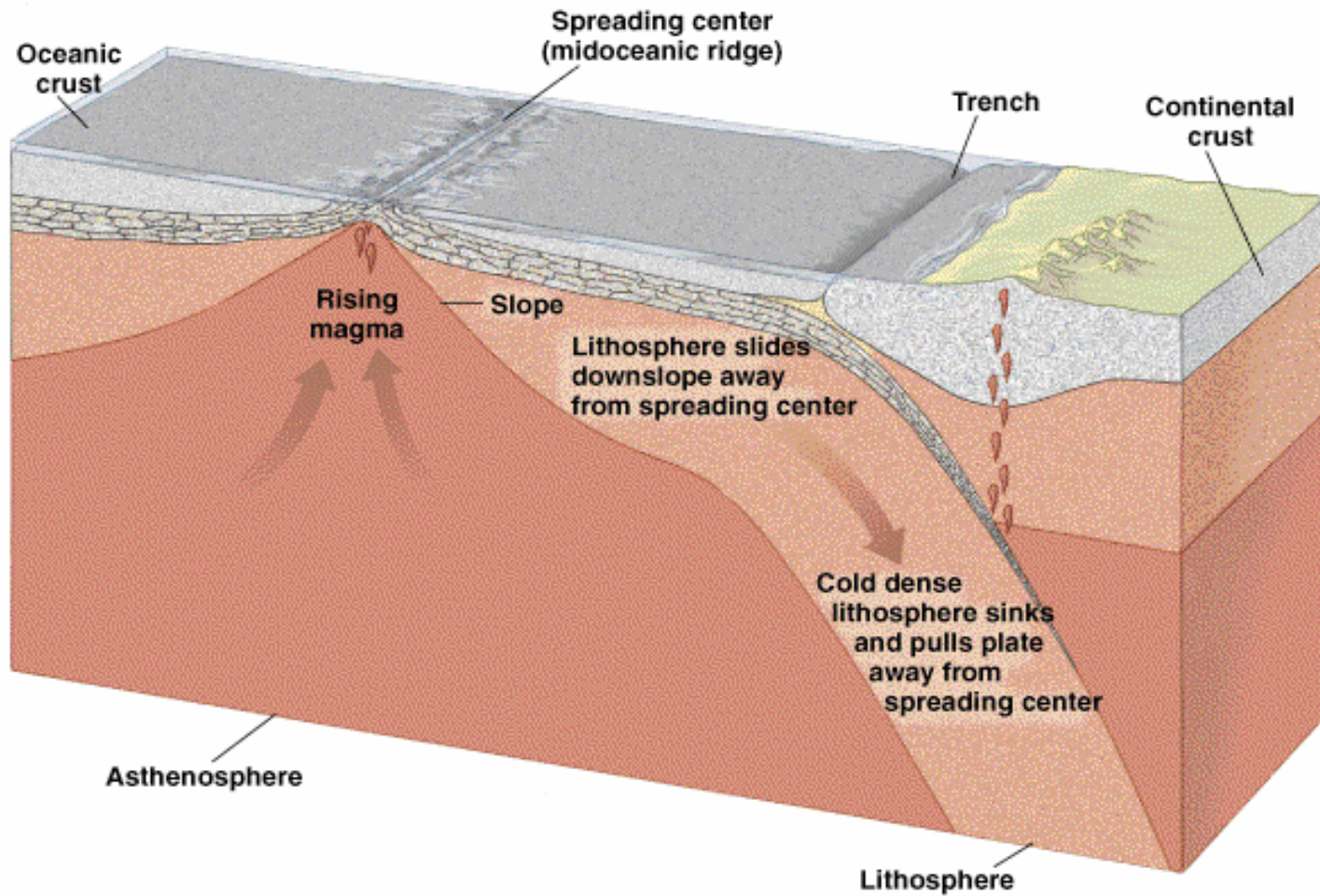
Active Volcanoes, Plate Tectonics, and the "Ring of Fire"



Is the theory perfect? No!

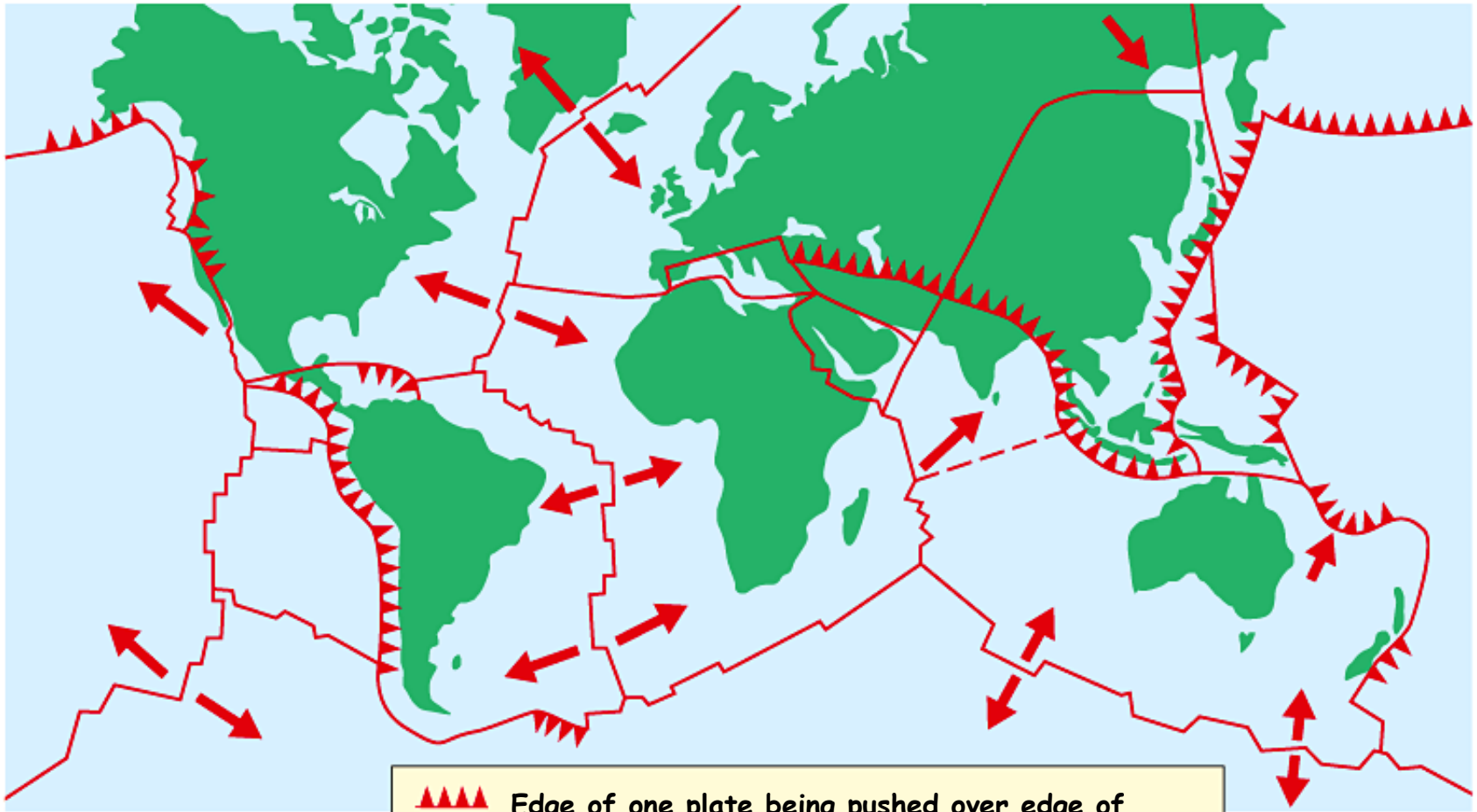
- Problems:
 - How do we explain earthquakes that occur in the middle of plates?
 - What drives the whole system?
 - Is there another major process occurring?
- Provides a starting point for addressing
 - How variable are the plate motions?
 - Why have motions changed in the past?

The forces driving continental drift



References, web sites etc

- Stanley, Earth System History, chapters 8 and 9.
- *Stórgóð vefsíða: This Dynamic Earth - The Story of Plate Tectonics:*
<http://pubs.usgs.gov/publications/text/dynamic.html#anchor10790904>
- *Kort yfir forna legu meginlanda og veðurfar í gegnum jarðsöguna:*
<http://www.scotese.com/earth.htm>
- <http://www.ucmp.berkeley.edu/geology/tectonics.html>
- <http://volcano.und.nodak.edu/vw.html>
- http://en.wikipedia.org/wiki/Eduard_Suess
- <http://www.geology.utoronto.ca/glg105h/lecture16/CDsummarylast.htm>
- Introduction to Alfred Wegener and Continental Drift
<http://www.ucmp.berkeley.edu/history/wegener.html>
- "Wrath of Science & Obligation to be a Hero"
<http://pangaea.org/wegener.htm>



▲▲▲▲ Edge of one plate being pushed over edge of neighboring plate (zones of violent geologic events)