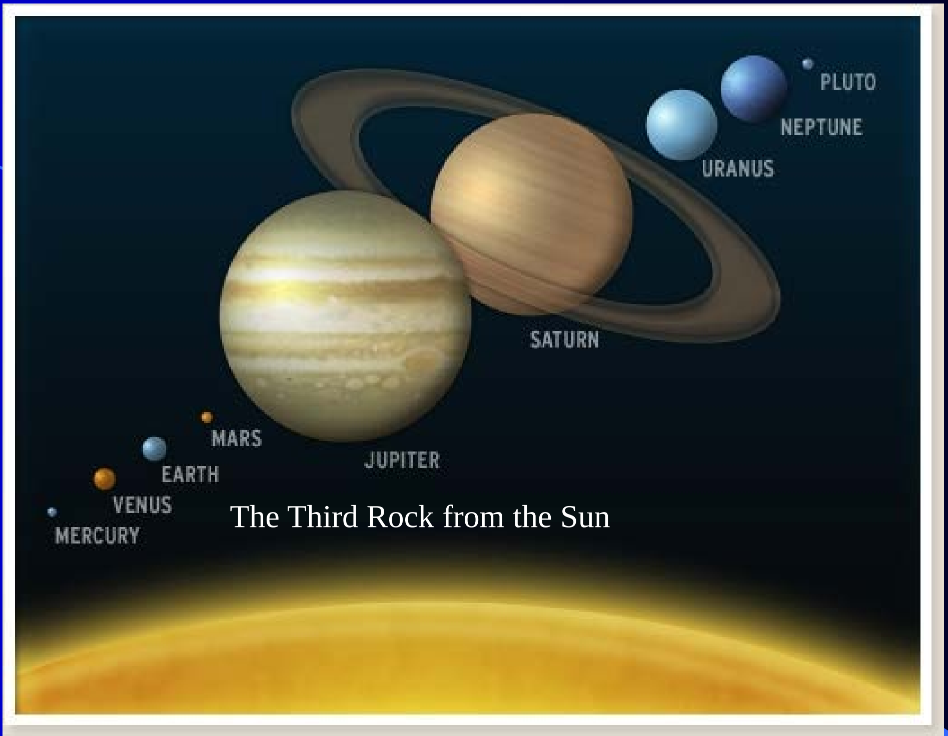
89.325 – Geology for Engineers
Plate Tectonics

"Civilization exists by geologic consent, subject to change without notice"

William Durant

Properties of the Planets

- Size
- Density
- Distance from sun
- Chemistry



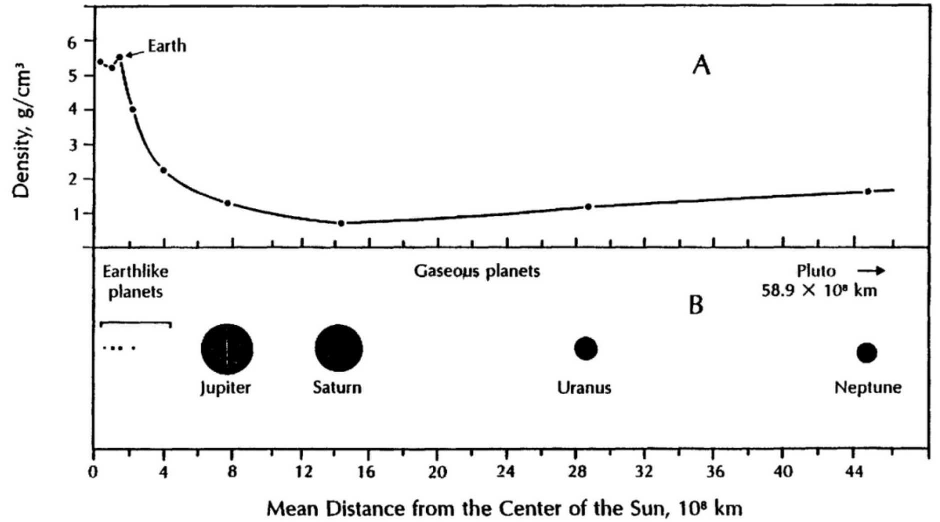
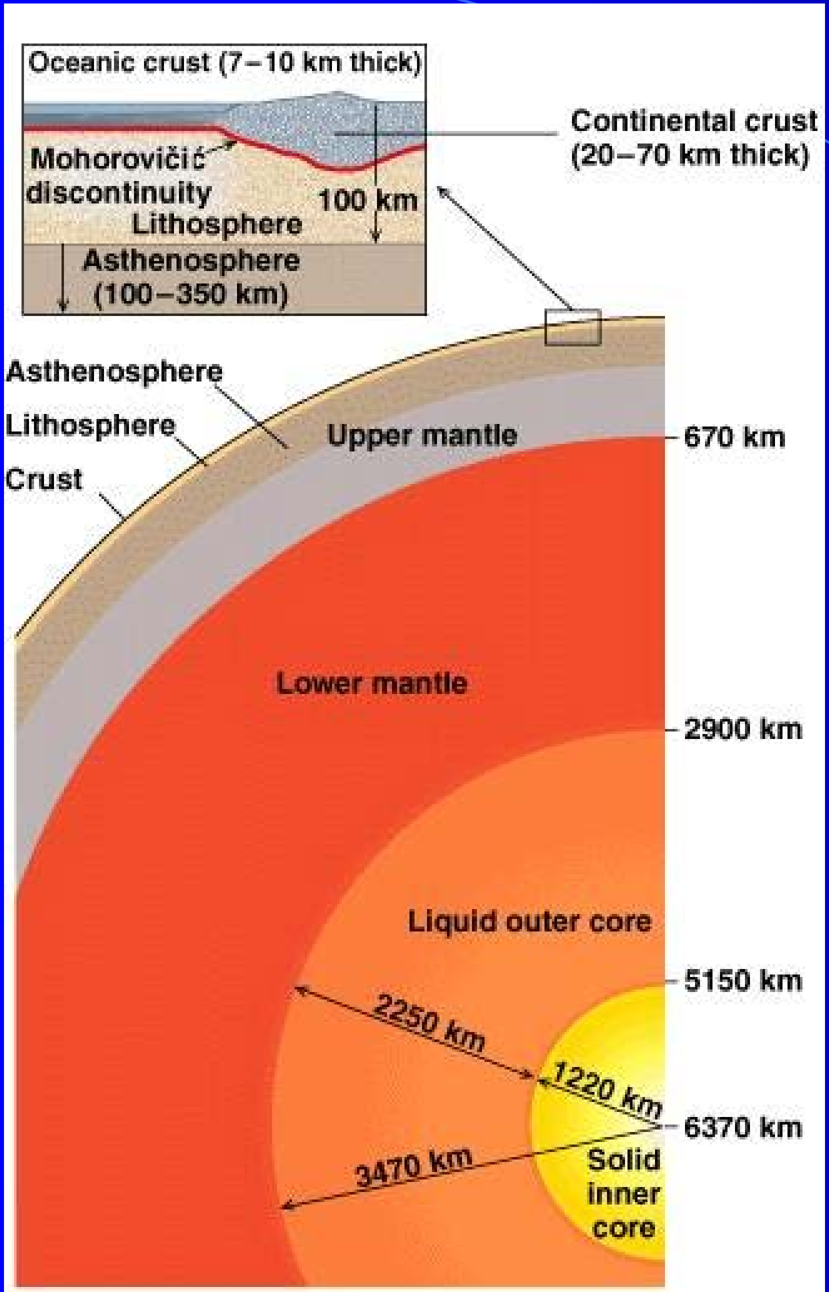
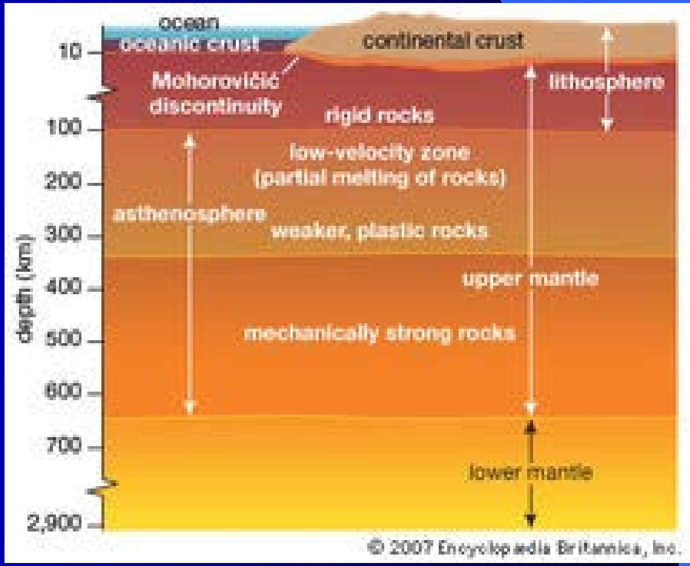


Figure 3.1 **A:** Variation of density of the planets with mean distance from the Sun. Note that the Earth has the highest density among the earthlike planets, which, as a group, are more dense than the outer gaseous planets. **B:** The planets of the solar system magnified 2000 times relative to the distance scale. The earthlike planets are very small in relation to the Sun and the gaseous planets of the solar system.

Earth's Structure

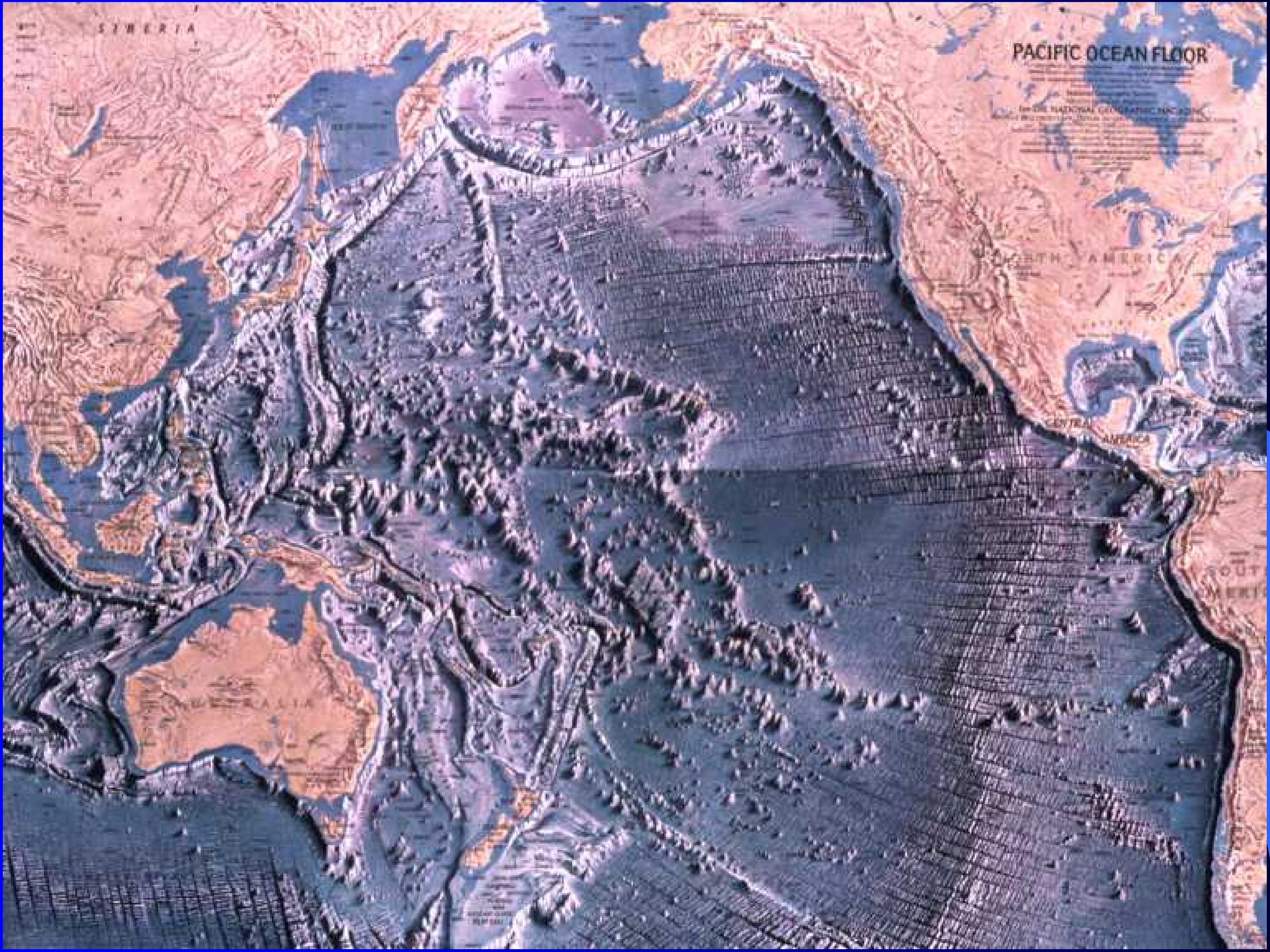


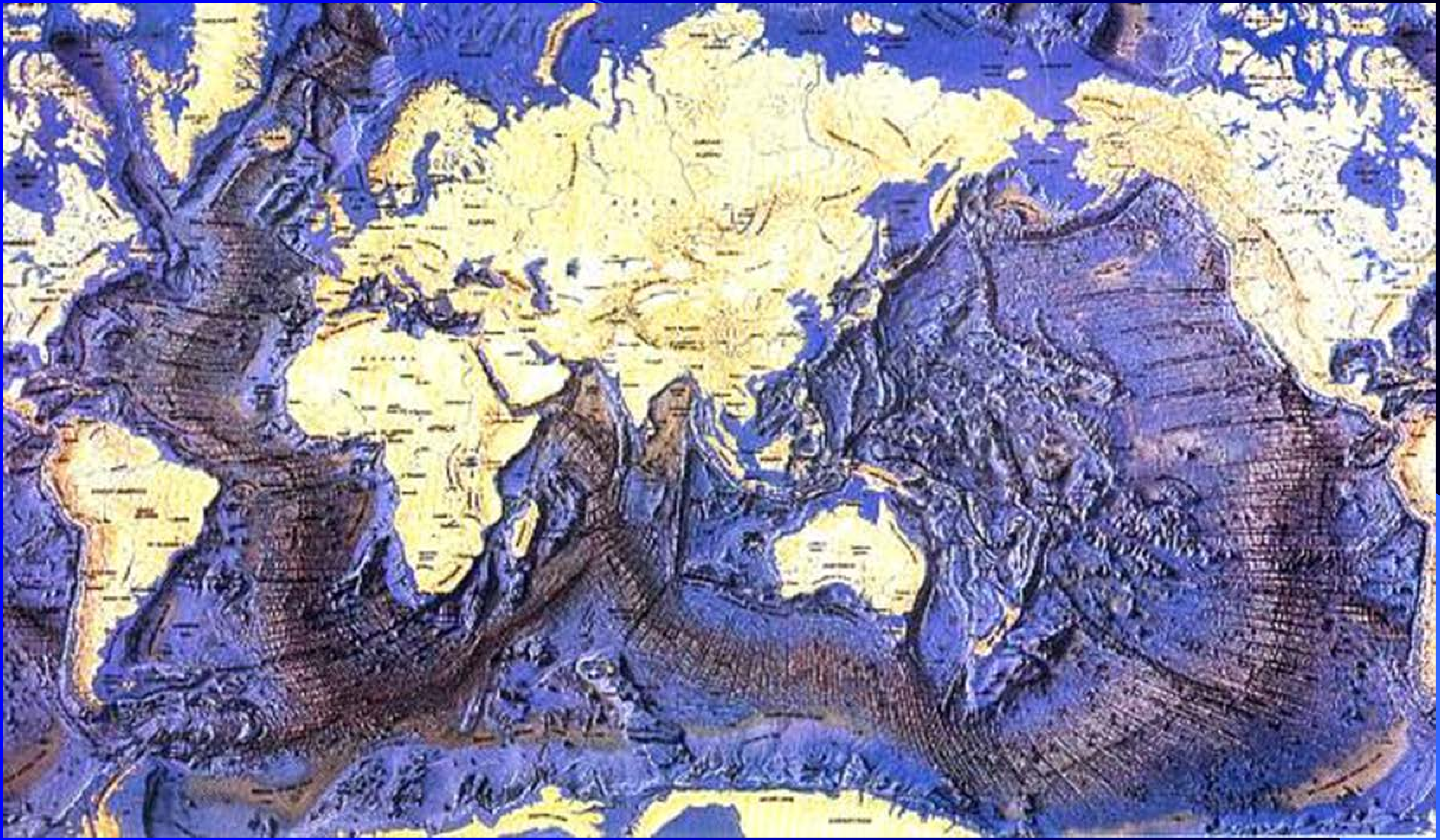
- Iron-nickel core
- Silicate Mantle
- Mohorovicic Discontinuity divides the crust from the mantle
- Asthenosphere – low velocity layer (in the mantle)
- Lithosphere – rigid upper layer that includes the crust and topmost part of the mantle



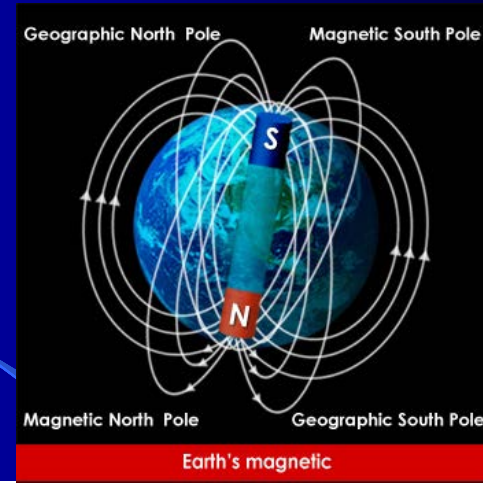
Precision depth sounding has been used to determine the topography of the seafloor. A mountain chain (called the mid-Atlantic ridge) runs down the center of the Atlantic ocean. At various points volcanoes associated with this chain extend above water. There are also deep sea trenches along the Caribbean islands.

The Pacific ocean is rimmed with trenches and volcanoes (the “ring-of-fire”) and has volcanic island chains





The Earth's Magnetic Field



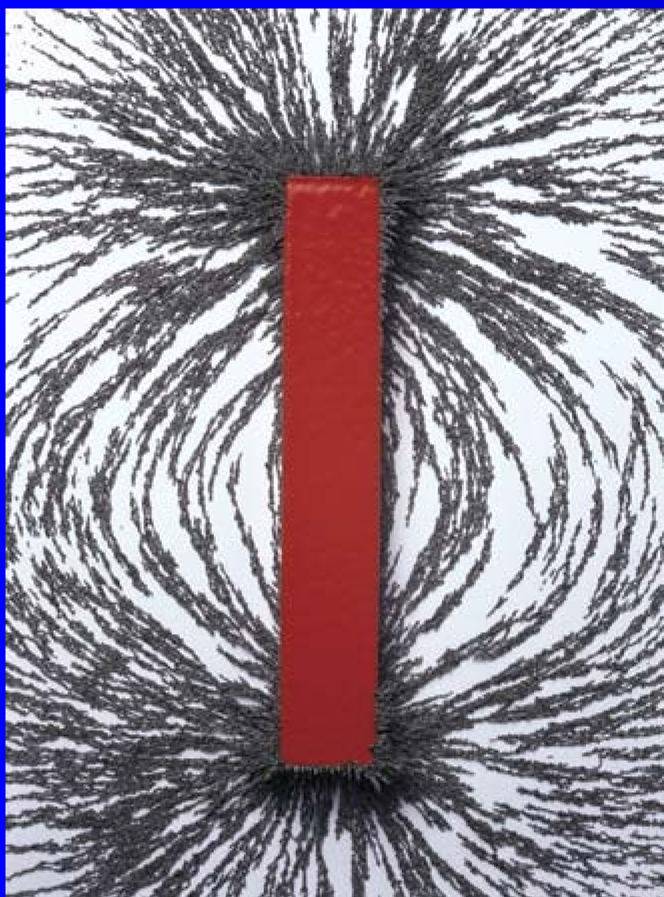
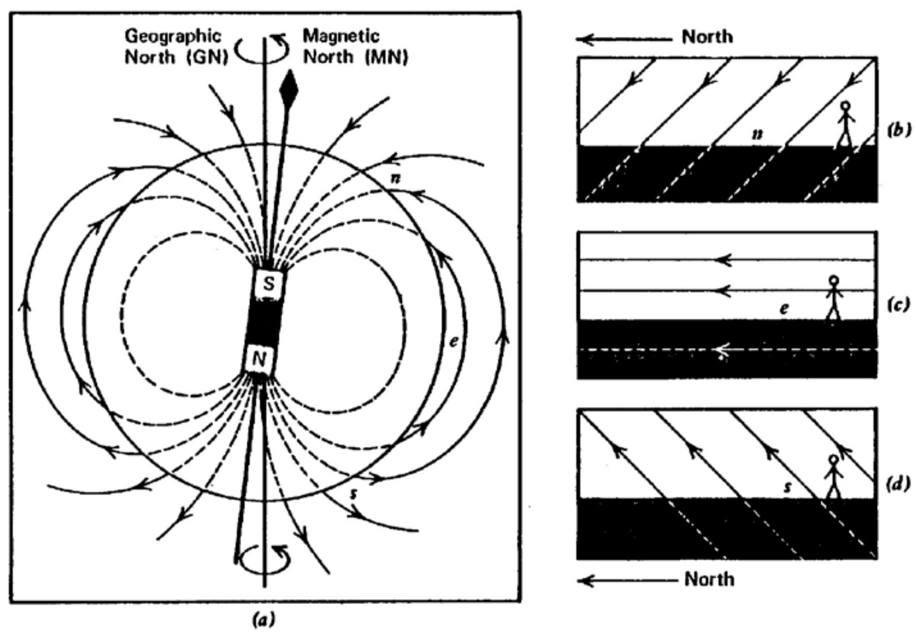


Fig. 8-5 *(a)* Diagrammatic representation of the earth's magnetic field. The directions of the lines of magnetic force at the earth's surface and in space around the earth (measured from satellites) are consistent with the presence of a magnet within the earth in the orientation shown (Figure 8-3). In fact, there is not a magnet within the earth. *(b, c, d)* illustrate in larger scale the lines of magnetic force as they would be measured by a person standing on the earth's surface at points *n*, *e*, and *s*, respectively.



Magnetic Inclination

- The change in magnetic inclination can be related to magnetic latitude.
- If one can determine the magnetic inclination at some time in the past this information can be used to determine paleolatitude.
- Magnetite becomes magnetic at 580ºC (the Curie temperature). When a rock cools below this temperature the mineral records the direction of the magnetic field at that time.

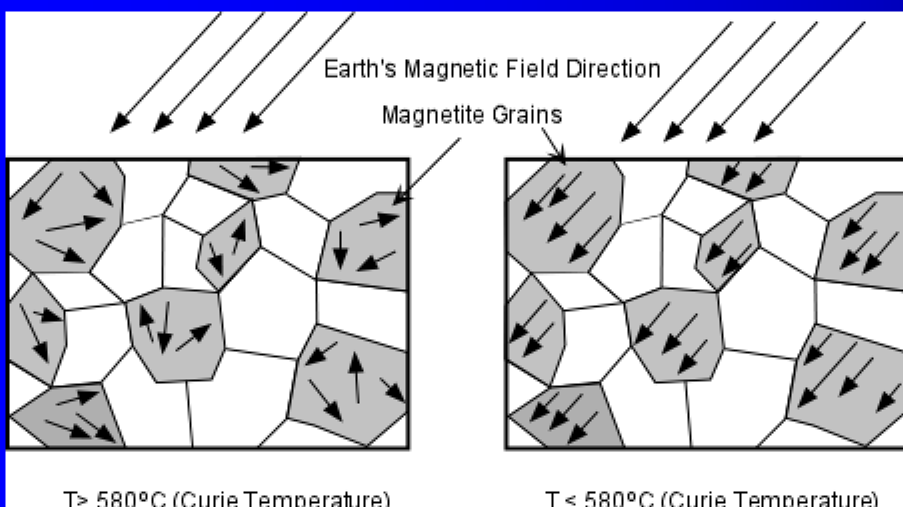
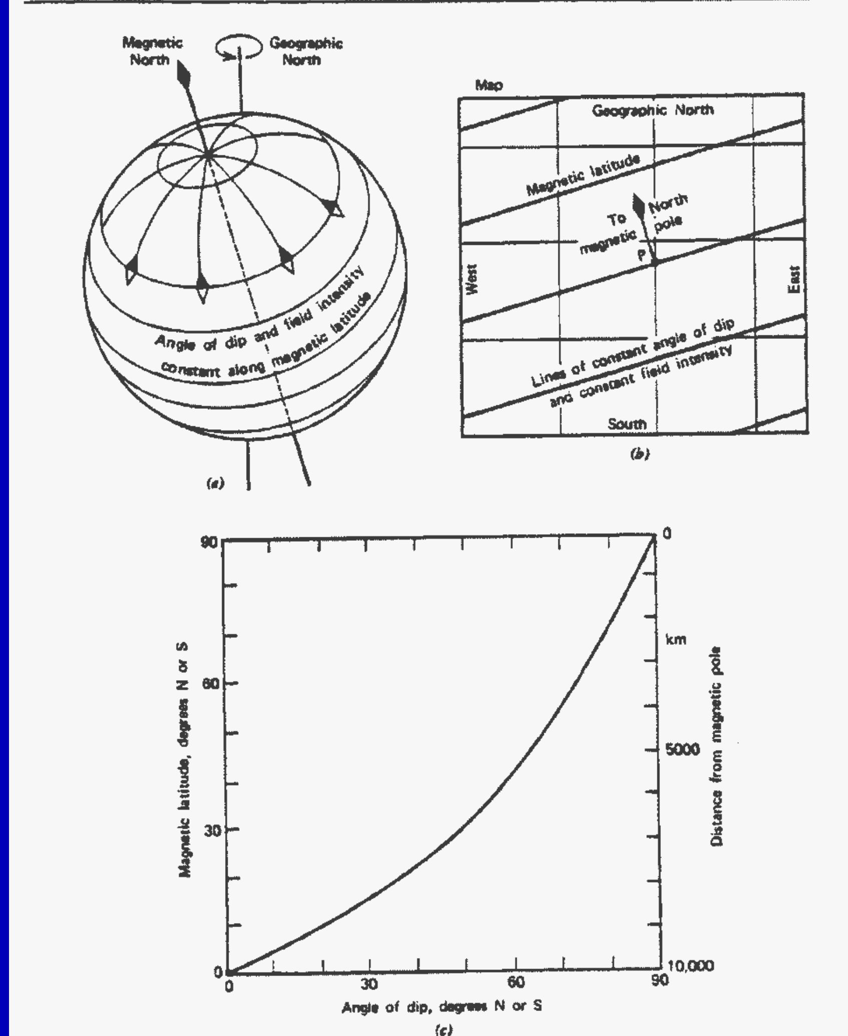
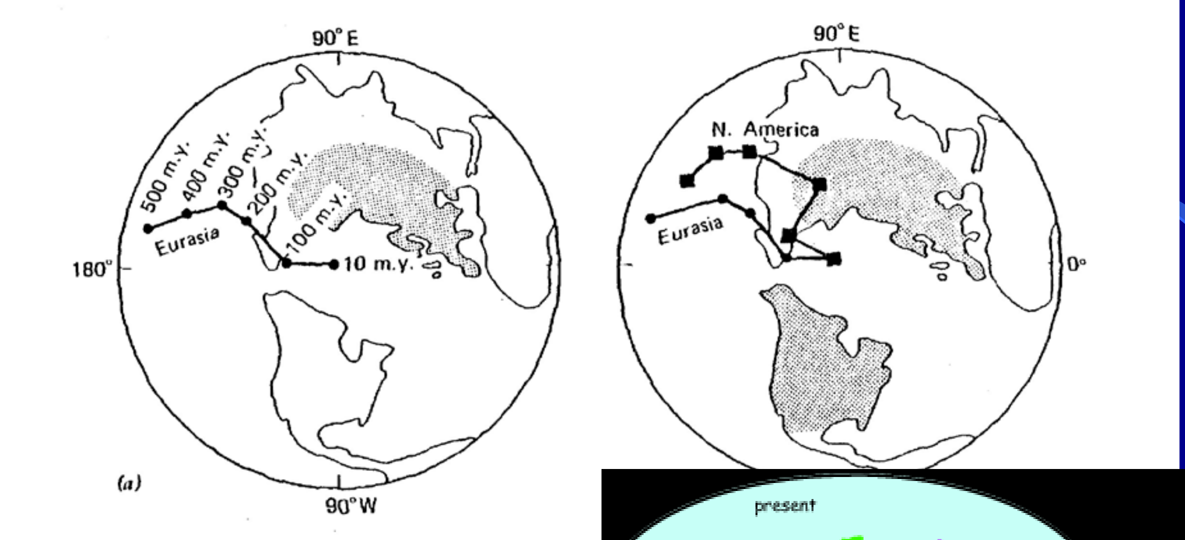


Fig. 8-8 *(a)* Compare Figures 8-5a and 8-6. For an idealized model of the earth's magnetic field, there are lines of magnetic latitude in concentric circles about the magnetic poles. Angles of dip and magnetic field intensities are constant along each of these lines. *(b)* Lines of magnetic latitude compared with geographic latitude and longitude lines on a map. *(c)* The angle of dip is 90° at the magnetic poles, and 0° at the magnetic equator (Figure 8-5). At any magnetic latitude between these limits the angle of dip is given by the graph. For a point with measured angle of dip, the graph gives the magnetic latitude and also the distance to the magnetic pole.

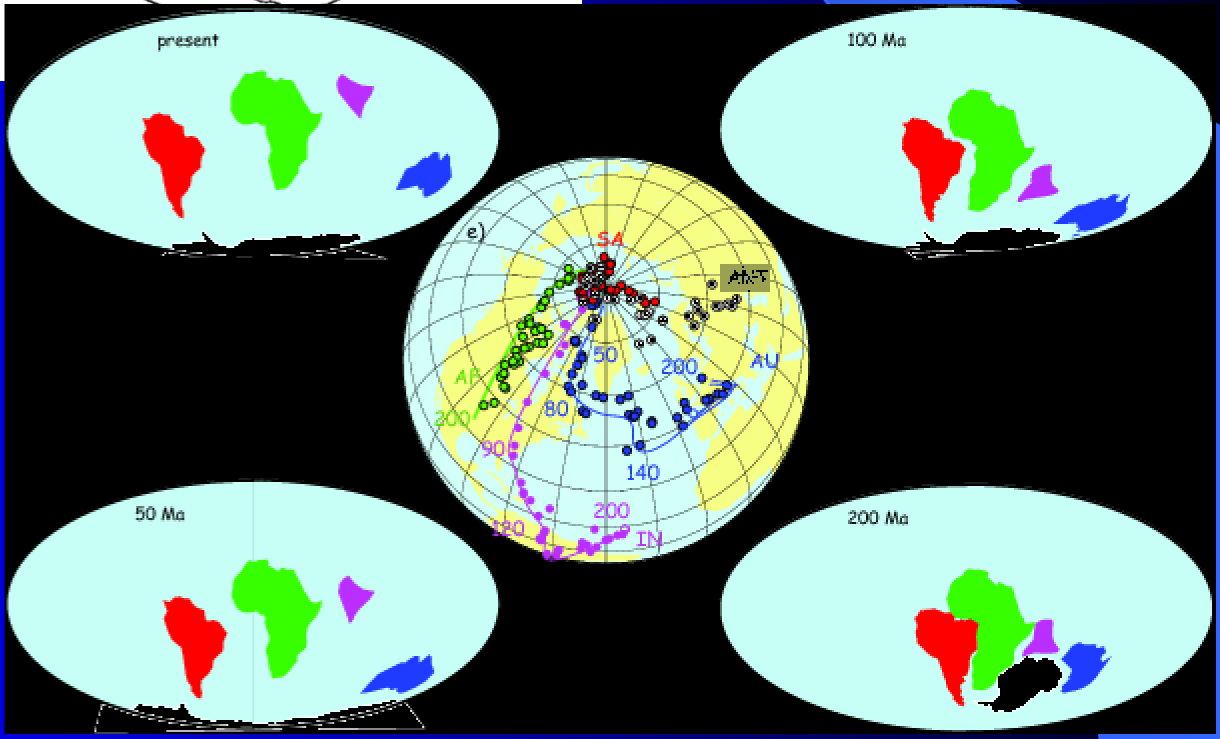


Measuring Paleomagnetism (Remnant Magnetism)

Fig. 12-2 *(a)* Apparent polar wandering path for Eurasia, determined as shown in Figure 12-1, using rocks from Eurasia. *(b)* Comparison of apparent polar wandering paths for North America and Eurasia.



Polar wandering curves. Did the magnetic poles shift or did the continents shift?



Measurements of the magnetic polarity of magnetite as a function of age revealed that the Earth’s magnetic polarity was reversed at different times in the past.

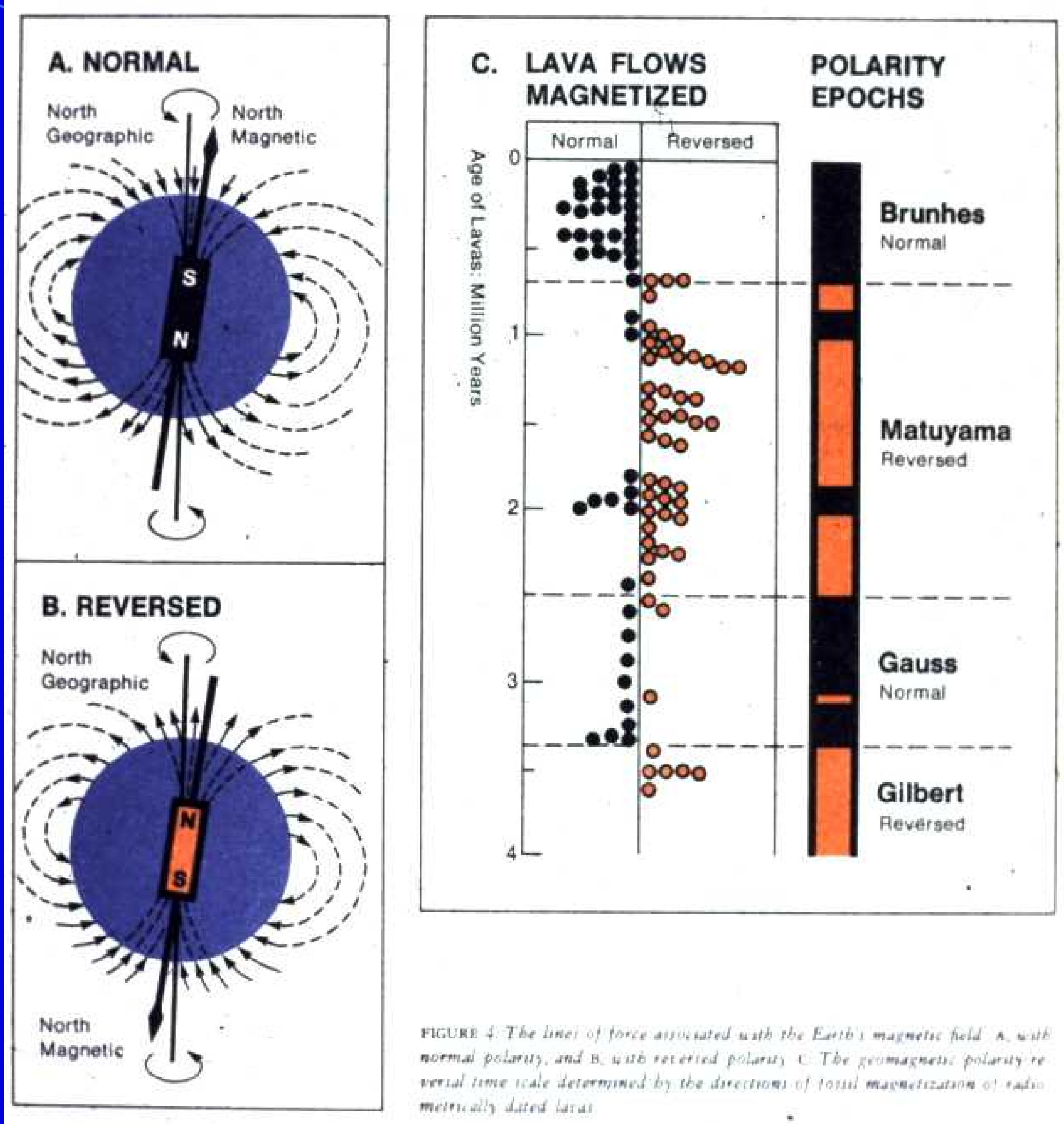
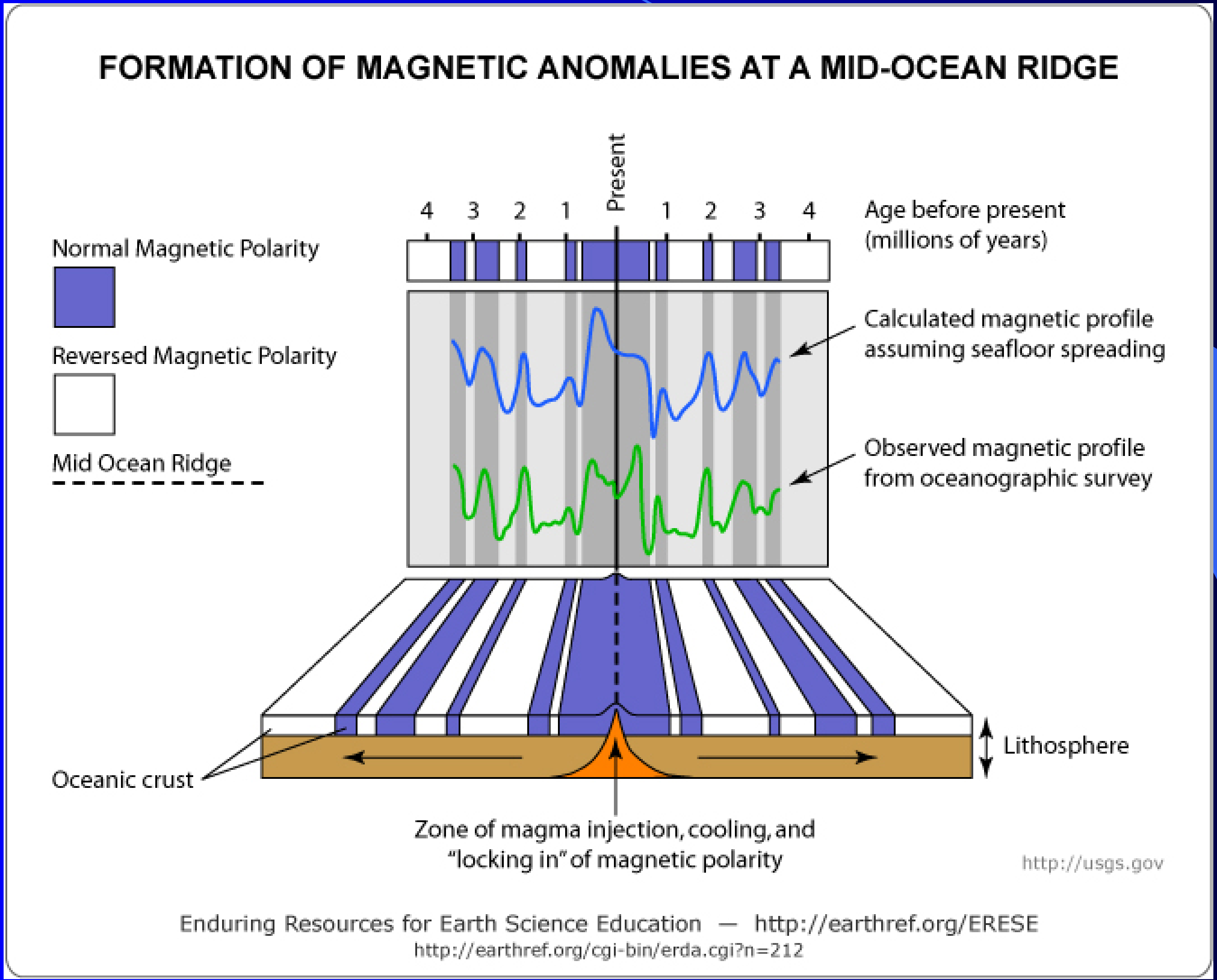


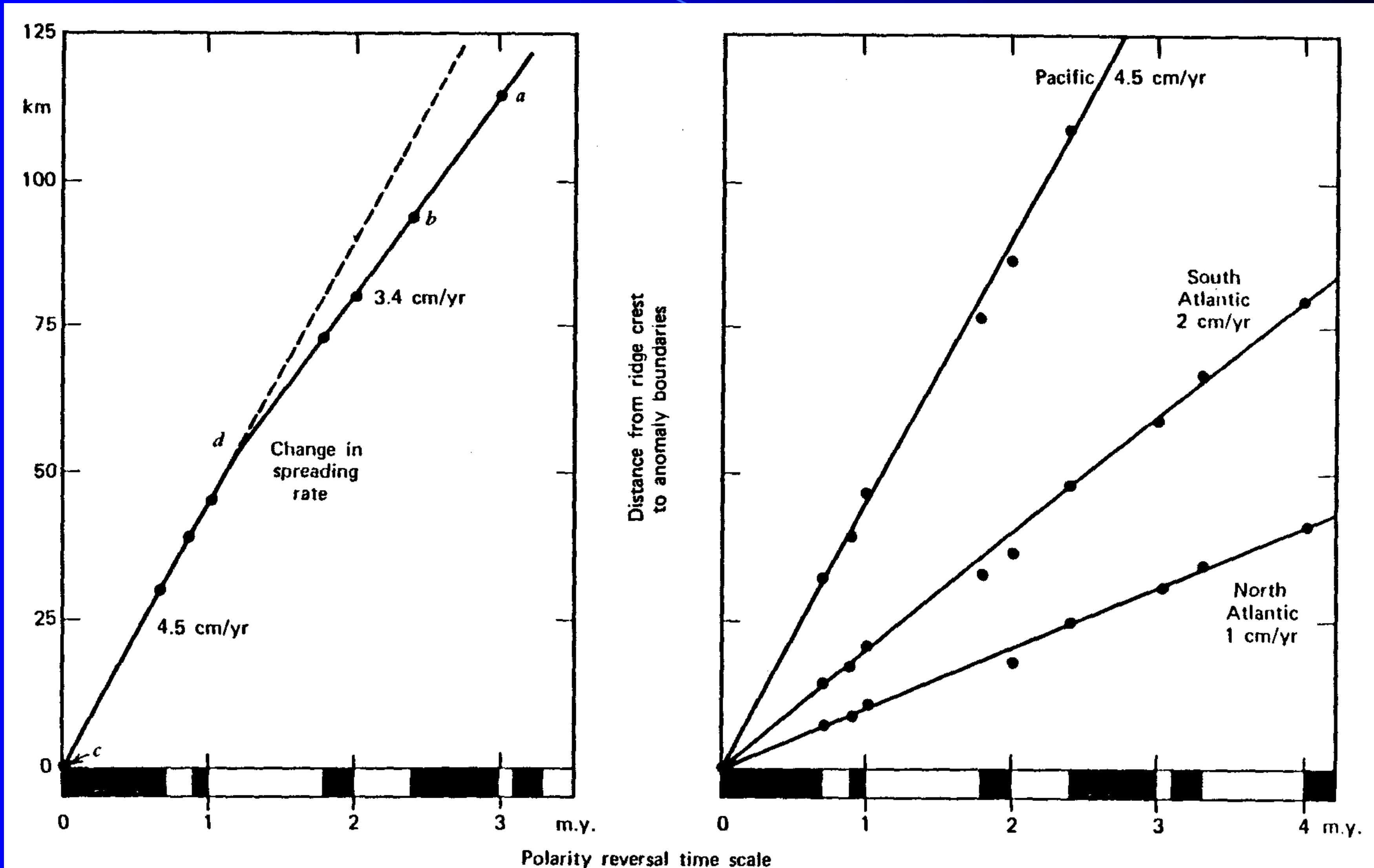
FIGURE 4. The lines of force associated with the Earth's magnetic field: A, with normal polarity, and B, with reversed polarity. C. The geomagnetic polarity reversal time scale determined by the directions of total magnetization of radiometrically dated lavas.

Oceanic Magnetic Anomalies

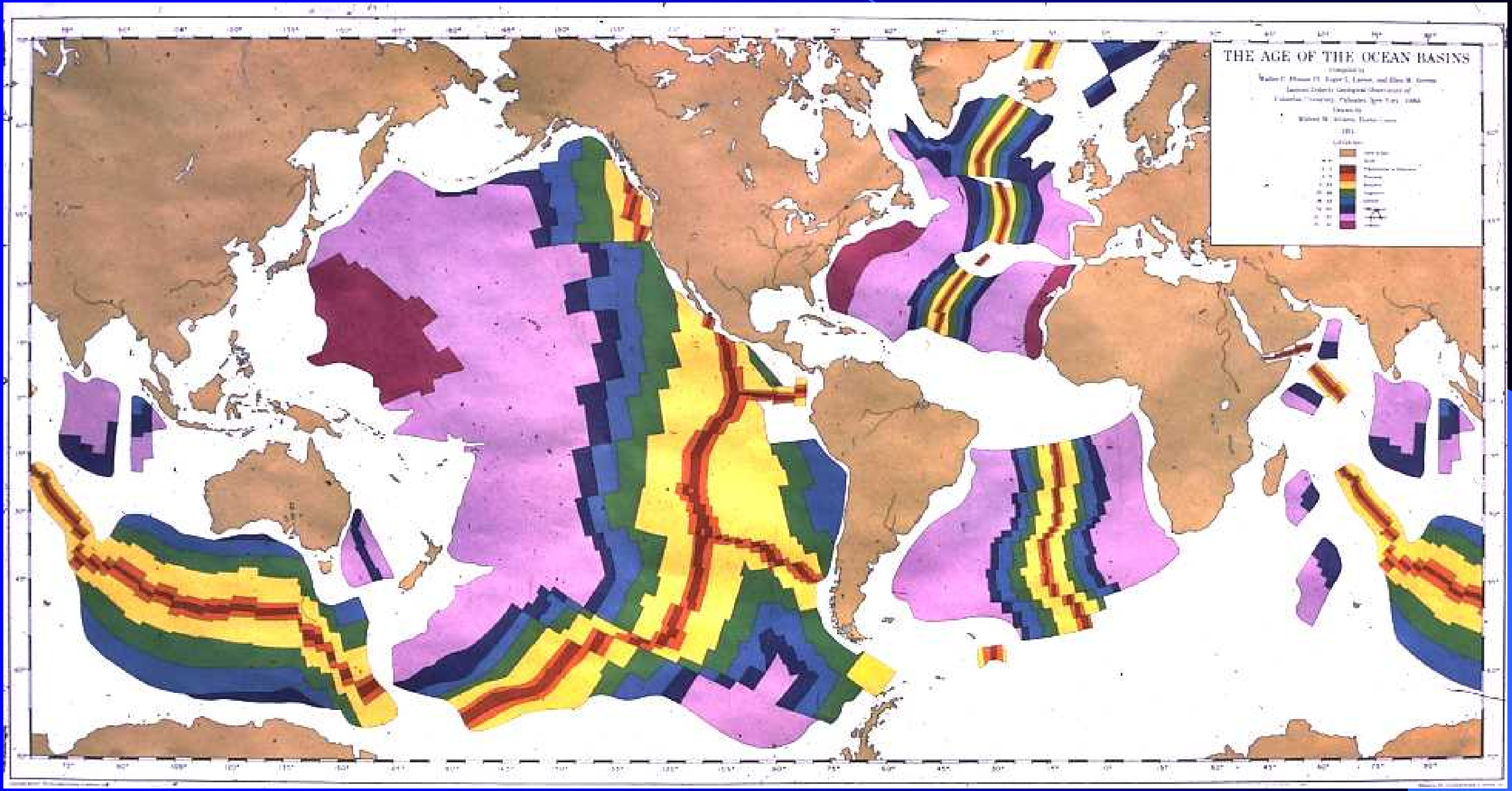
Measurements of magnetism in the ocean basin revealed that magnetic intensity varied as one moved across the ocean basin. How might this happen?



Based on the relationship between geologic age and magnetic reversal, spreading rates were calculated for the various ocean basins.

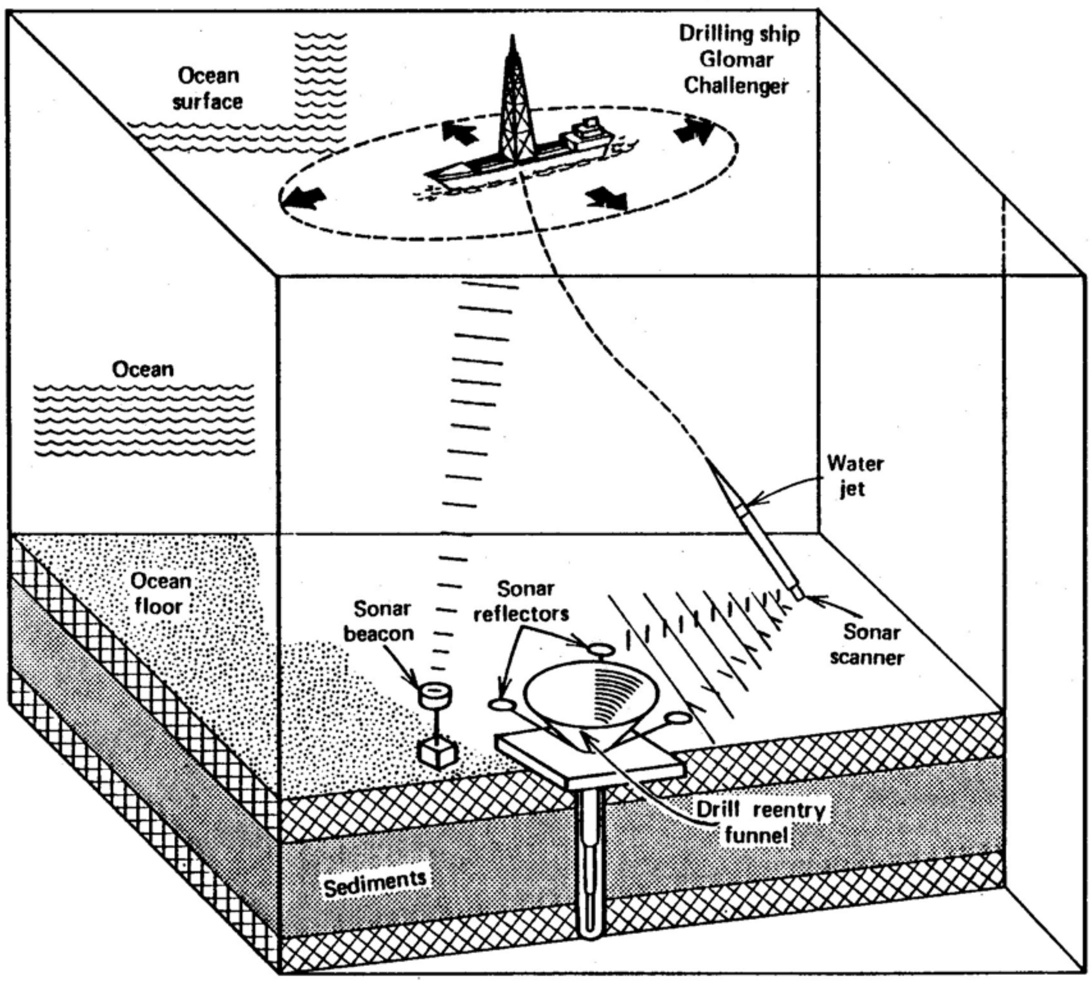


Using the calculated spreading rate for each ocean basin, the age of the various magnetic reversals was determined. The result was a map showing the age of the seafloor. It turned out the oldest rocks in the ocean were about 200 Ma old, much younger than the oceans.

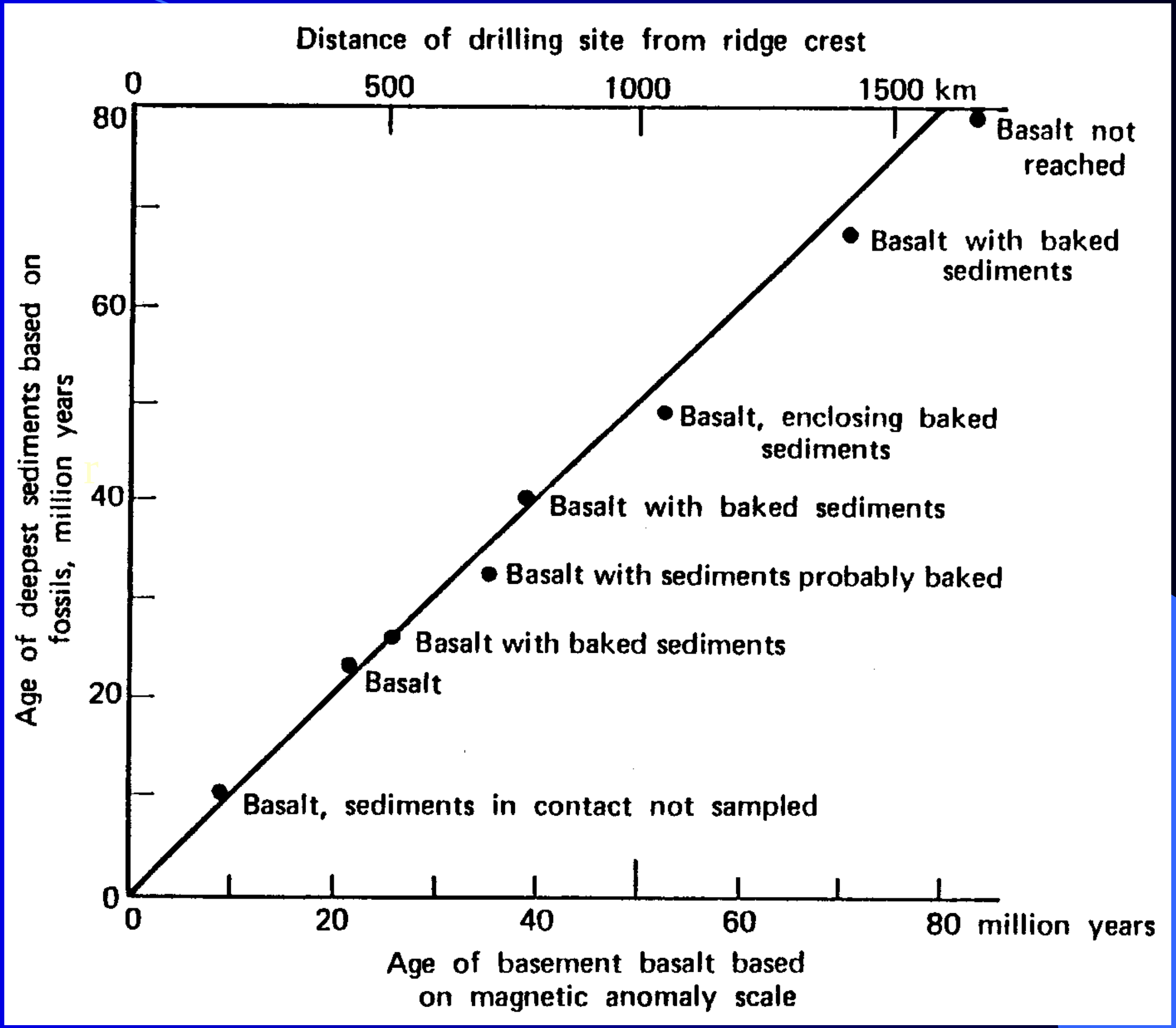


Enter the Deep Sea Drilling Project. Sediment cores were collected from the deep ocean. The cores reached the seafloor basalts, hence we could determine the age of the sediments lying directly on the basalts.

Fig. 14-1 Sketch of the *Glomar Challenger* lowering its drill stem through the ocean toward the drill reentry funnel that has been secured in the ocean-floor sediments. (Based on a National Science Foundation report.)

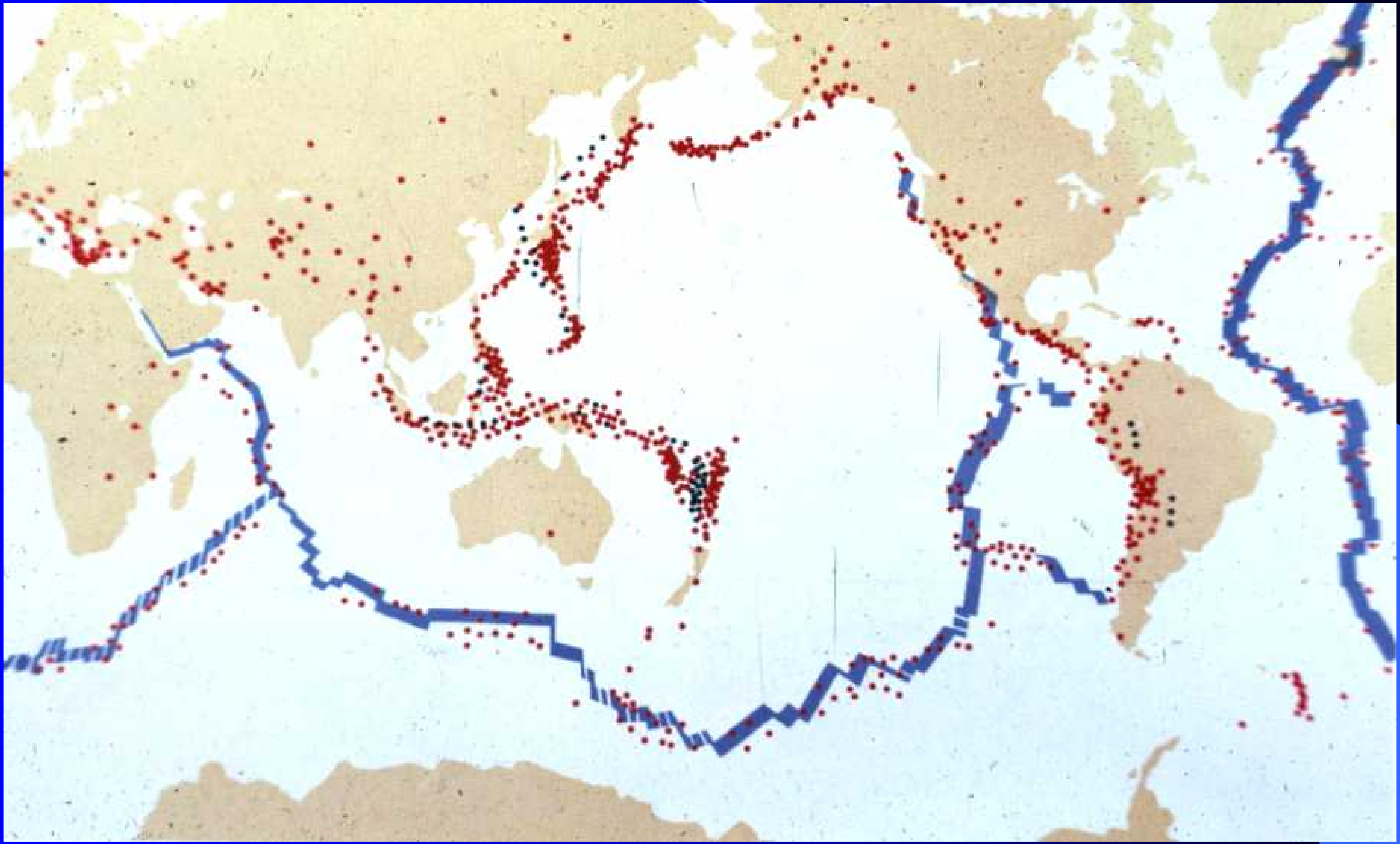


Fossils in the sediments just above the seafloor basalts verified the ages determined using the magnetic anomaly scale.



Earthquake Studies

Earthquakes are not randomly distributed



Earthquakes associated with oceanic trenches extended to great depths. This was a puzzle since for earthquakes to occur rocks must behave as elastic solids. At depths below 70 km rocks ***do not*** behave as elastic solids. Something else must be going on. What can we learn from gravity and heat flow data?

Subduction

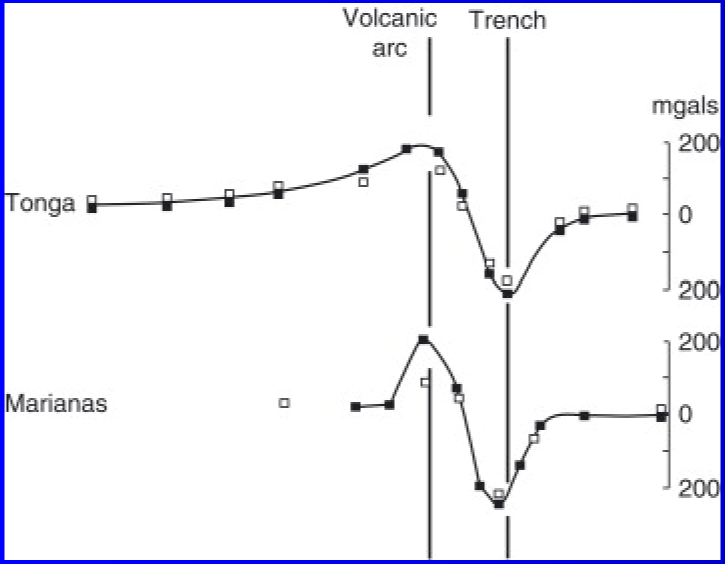


Fig. 4-9 Schematic map of distribution of earthquake epicenters for deep-focus earthquakes between the Tonga trench and the Fiji Islands, north of New Zealand. Locate this on Figures 3-12 and 4-7. (Based on data of L. R. Sykes, 1966, *Jour. Geophys. Res.*, *71*, 2981-3006.)

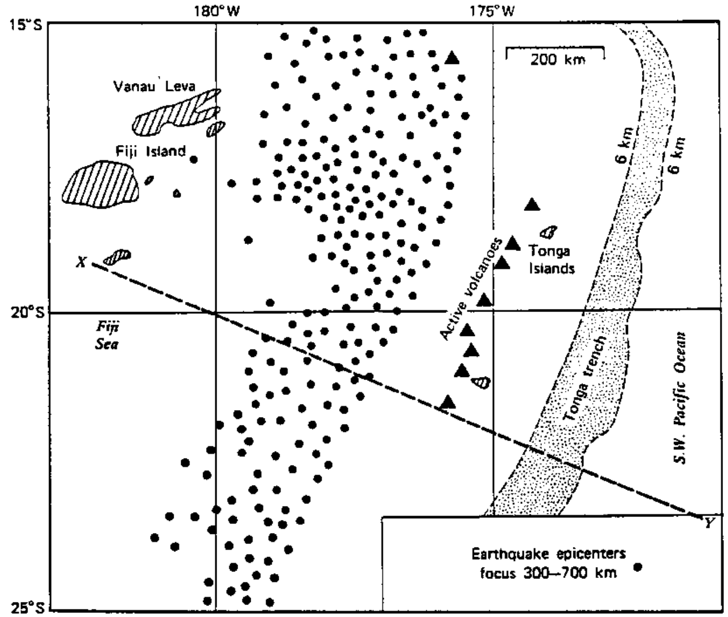
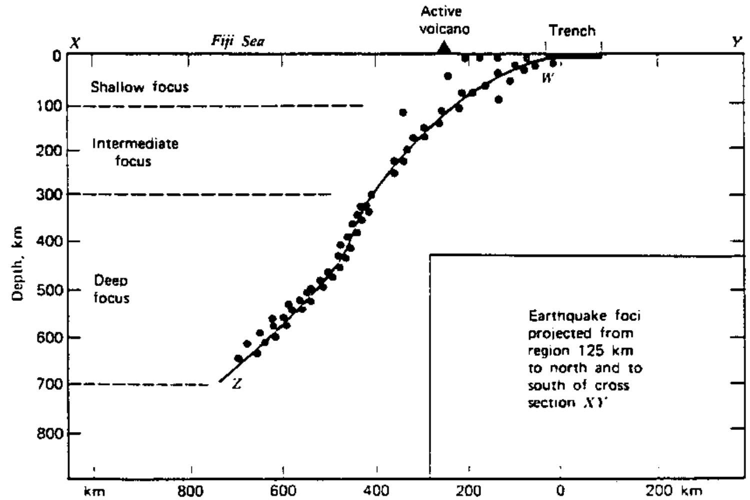
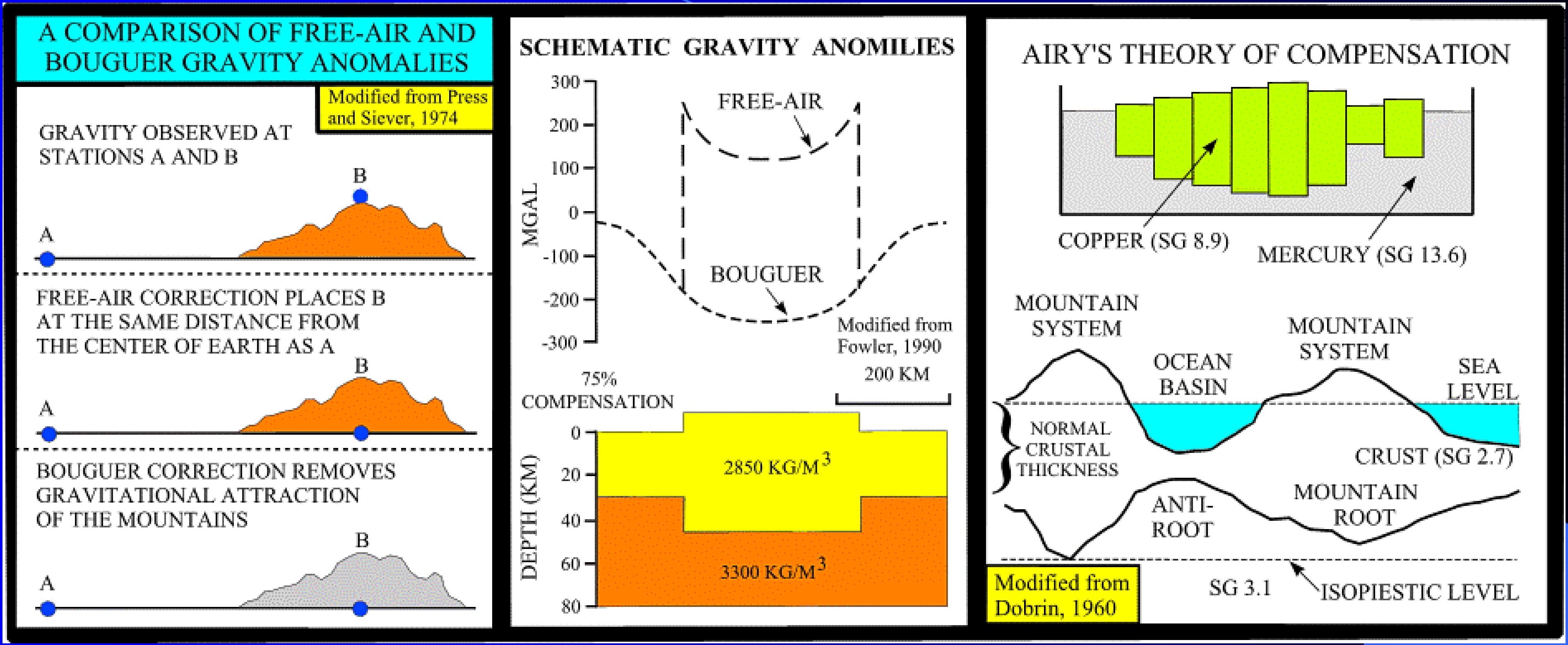


Fig. 4-10 Vertical cross section through line *XY* in Figure 4-9, showing schematically the distribution of earthquake foci down to depths of 700 km. The foci lie close to line *WZ* extending downward from the ocean trench. (Based on data of L. R. Sykes, 1966, see Figure 4-9.)





A COMPARISON OF FREE-AIR AND BOUGUER GRAVITY ANOMALIES
Modified from Press and Siever, 1974
GRAVITY OBSERVED AT STATIONS A AND B
A
B
FREE-AIR CORRECTION PLACES B AT THE SAME DISTANCE FROM THE CENTER OF EARTH AS A
BOUGUER CORRECTION REMOVES GRAVITATIONAL ATTRACTION OF THE MOUNTAINS
SCHEMATIC GRAVITY ANOMILIES
MGAL
300
200
100
0
-100
-200
-300
FREE-AIR
BOUGUER
Modified from Fowler, 1990
75% COMPENSATION
200 KM
DEPTH (KM)
0
20
40
60
80
2850 KG/M3
3300 KG/M3
AIRY'S THEORY OF COMPENSATION
COPPER (SG 8.9)
MERCURY (SG 13.6)
MOUNTAIN SYSTEM
OCEAN BASIN
MOUNTAIN SYSTEM
SEA LEVEL
NORMAL CRUSTAL THICKNESS
CRUST (SG 2.7)
ANTI-ROOT
MOUNTAIN ROOT
SG 3.1
ISOPIESTIC LEVEL
Modified from Dobrin, 1960

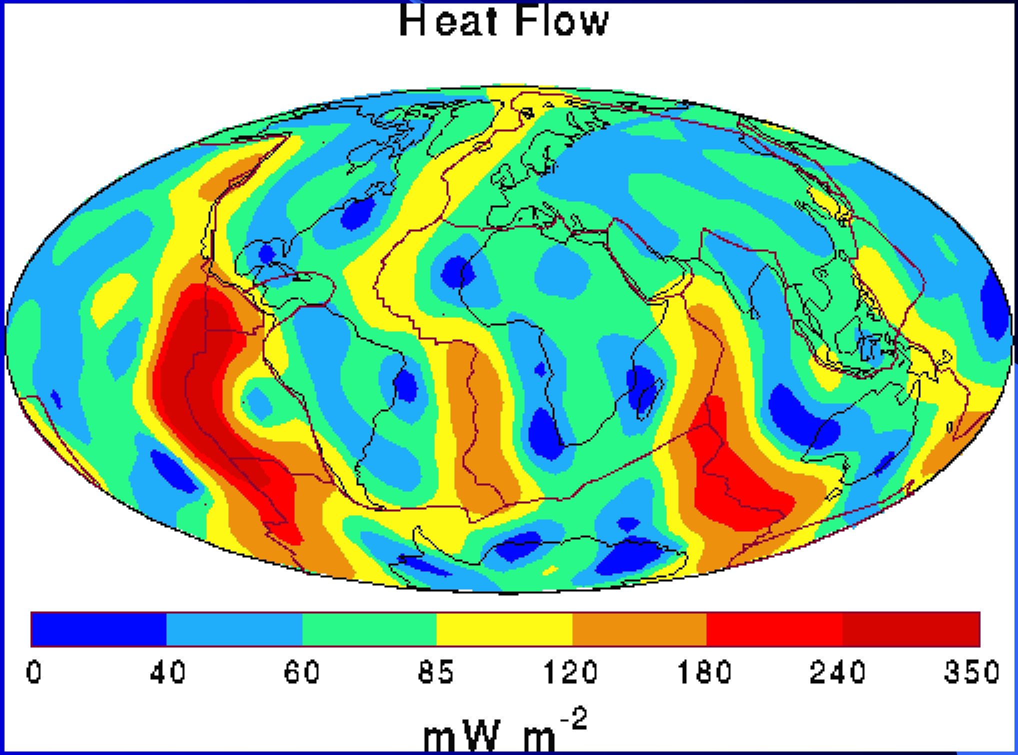
Isostasy

Heat Flow varies across the Earth's surface

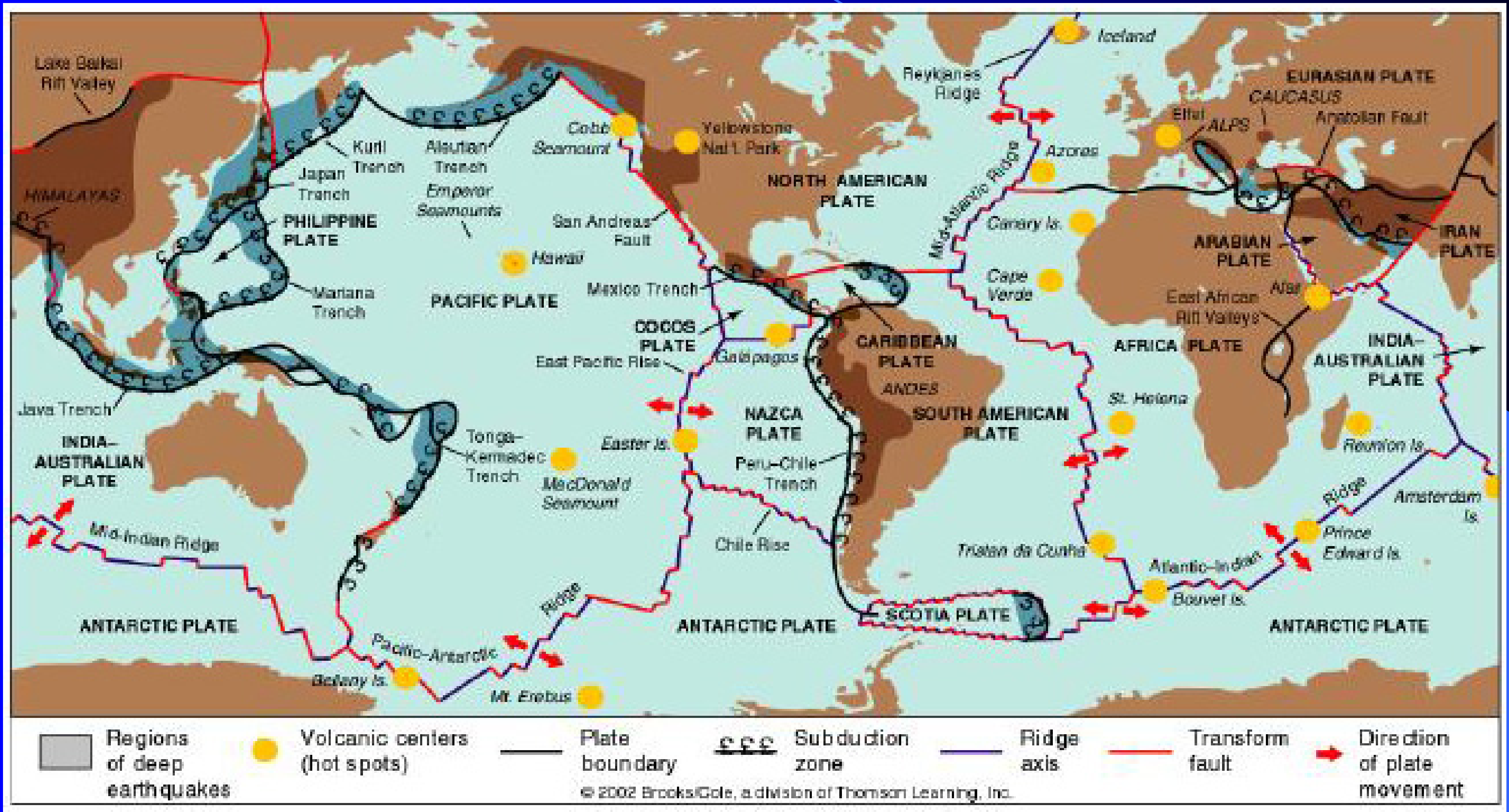
HFU = Heat Flow Unit = 1 x 10^{-6} cal/cm^2 · min = 41.86 mW/m^2 · min

Heat flow variations:

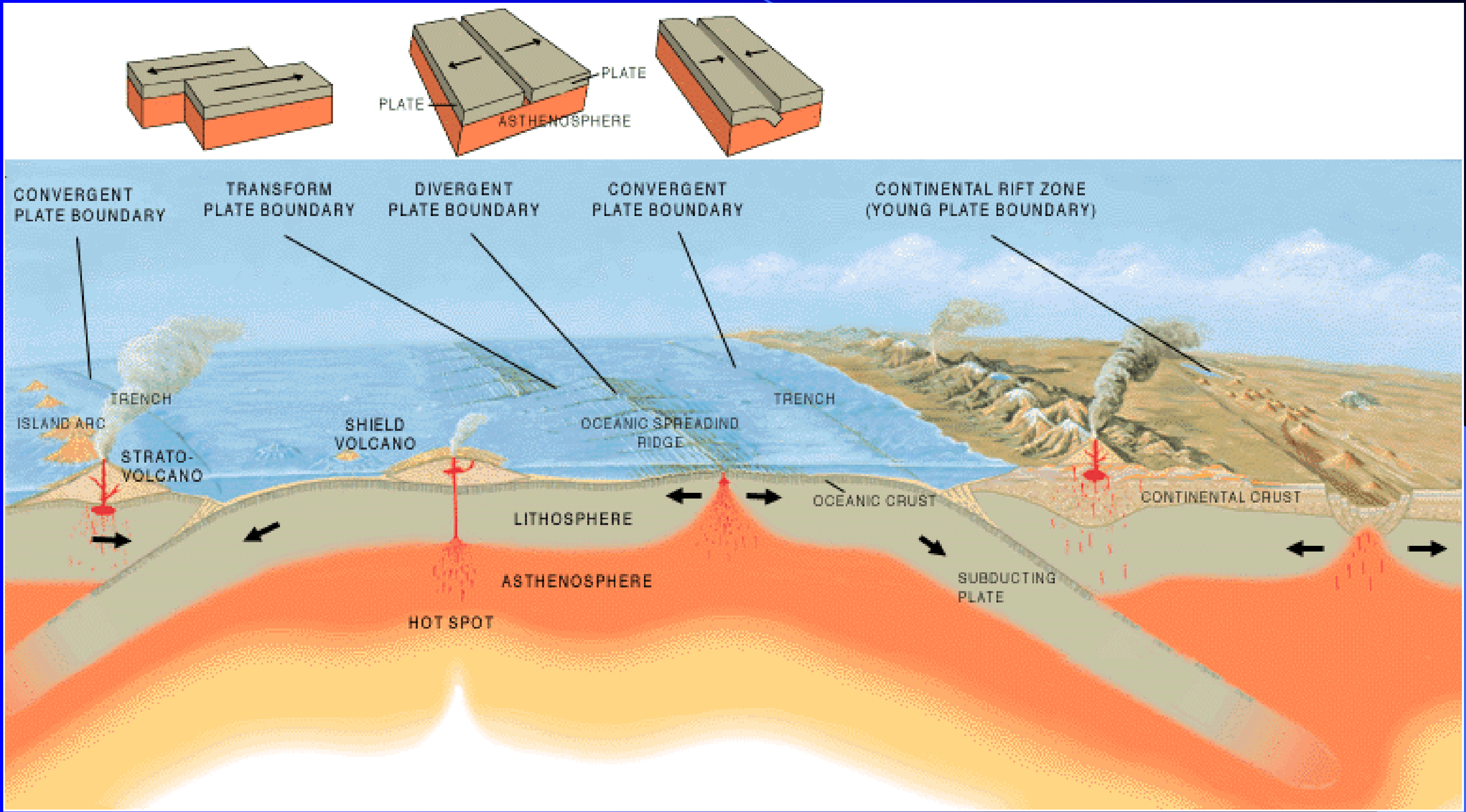
- 1-2 HFU over trenches
- 2-3 HFU ocean average
- 4-6 HFU over ocean ridge



The lithosphere of the Earth was divided into about a dozen large pieces called tectonic *plates*. Plate boundaries are marked by spreading centers, subduction zones, and faults.



Types of plate boundaries



Fault boundaries (transform faults)

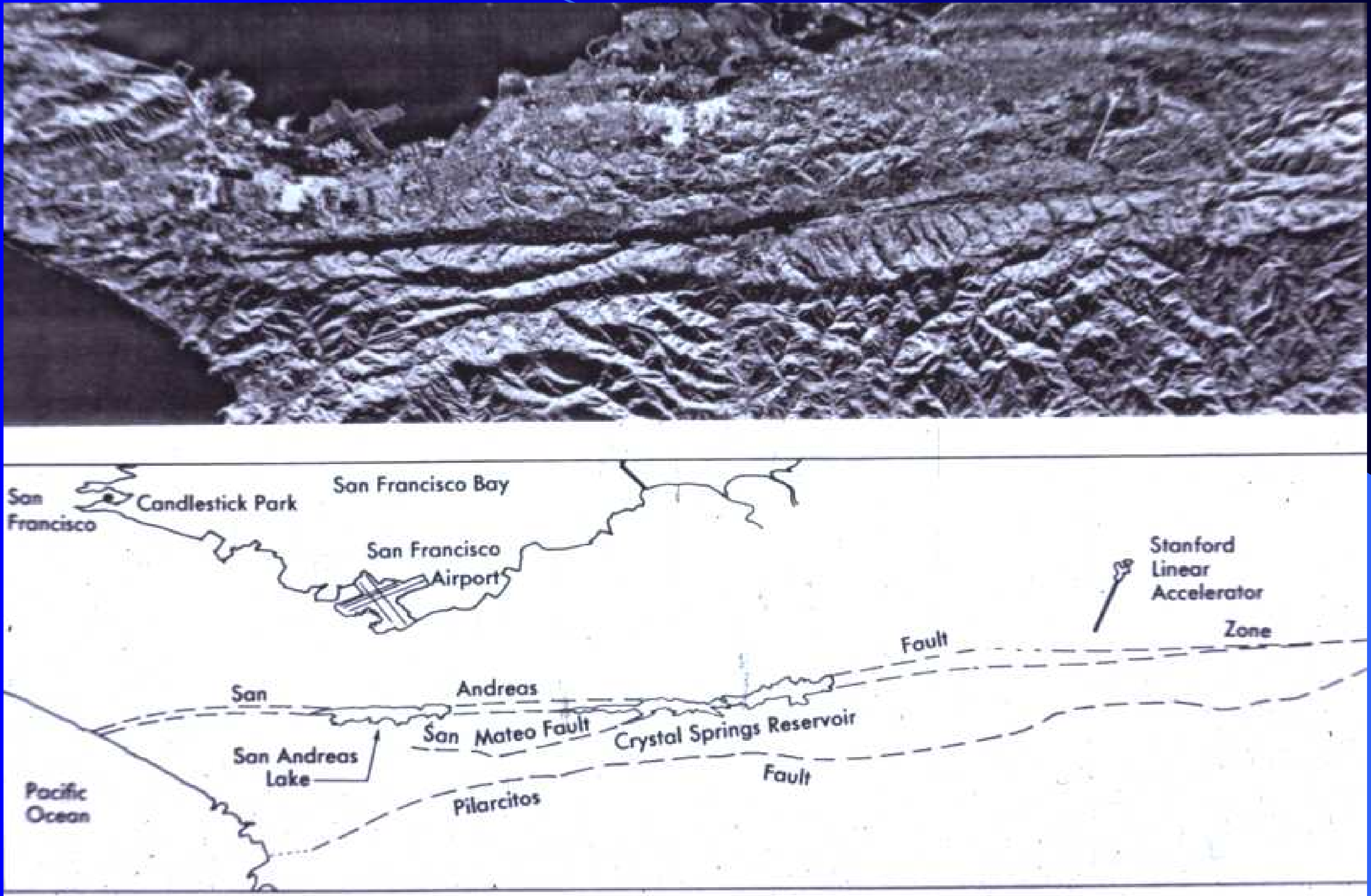
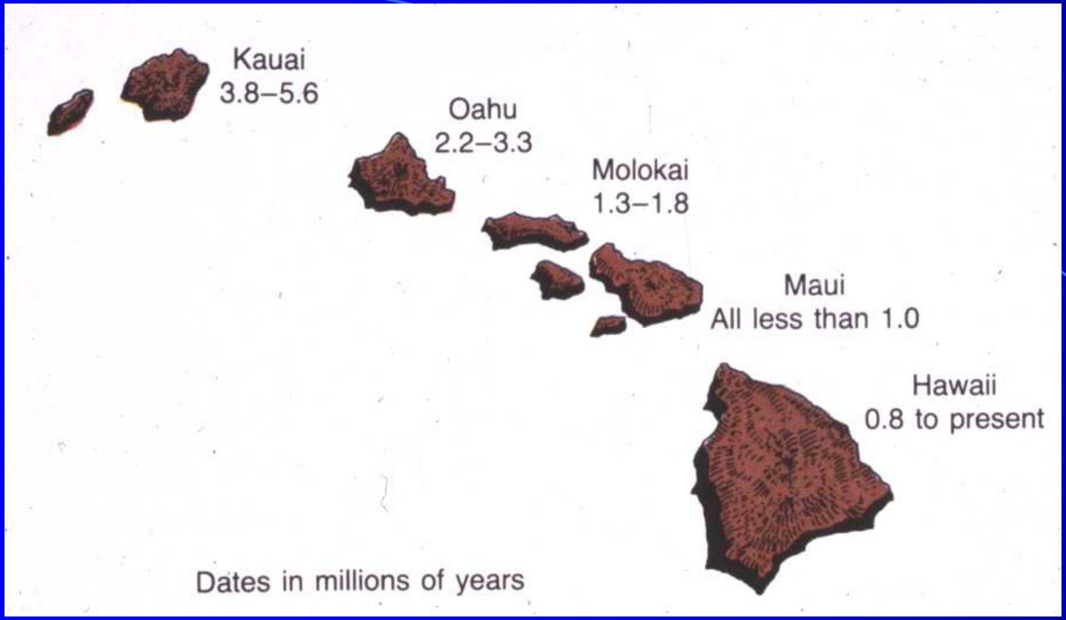
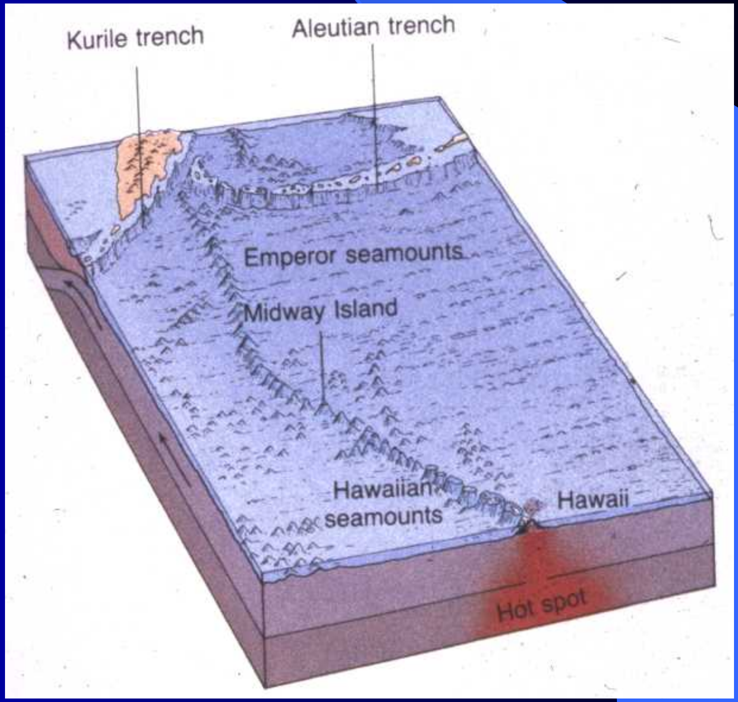


FIG. 1-5. Radar images. A. San Francisco Peninsula. Unlike conventional aerial photos, radar images can be obtained in cloudy weather or even at night. The radar penetrates the vegetation and reveals the actual surface. The bottom (west) part of this area has thick redwood forests. From U. S. Geological Survey in cooperation with NASA and Westinghouse Electric Co.

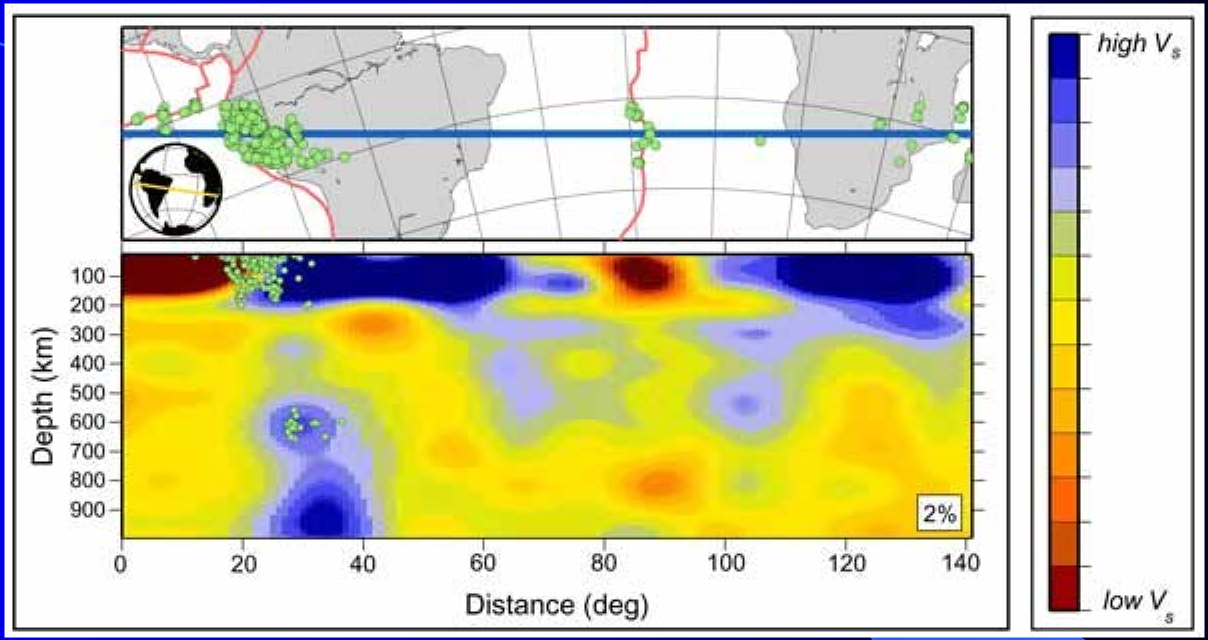


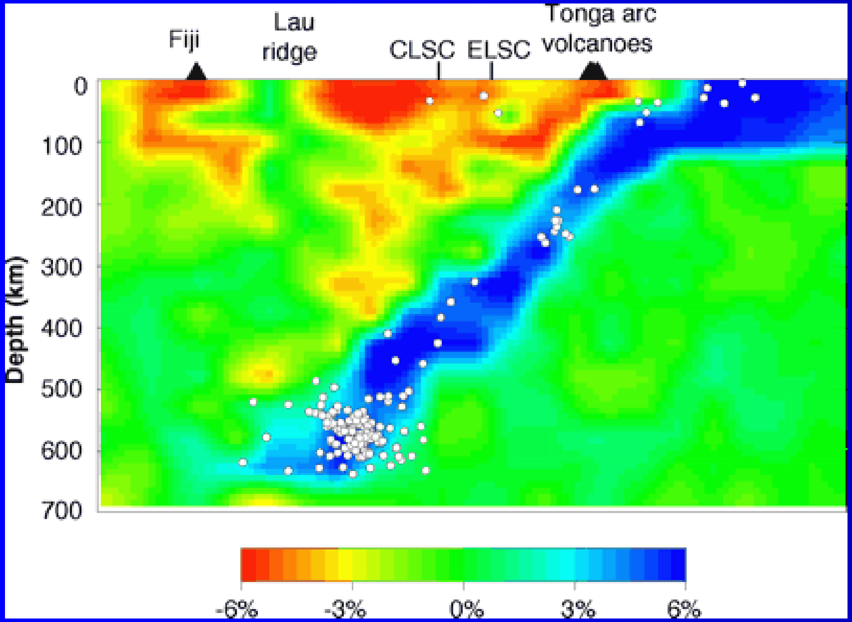
There is a regular age progression for the Hawaiian volcanoes. Similarly for the entire Hawaii-Emperor Seamount chain.

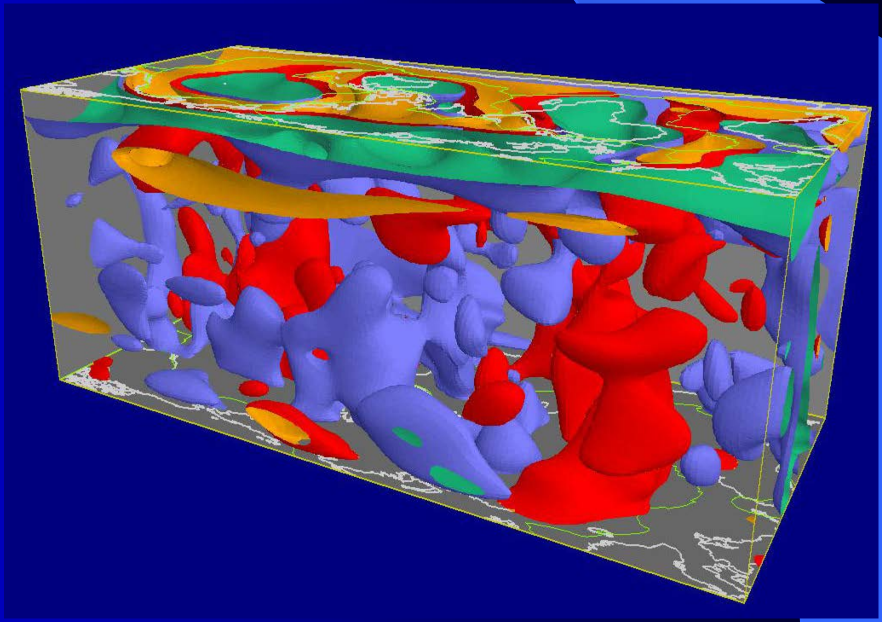
The interpretation of this observation is that there is a fixed mantle hotspot that is traversed by the oceanic lithosphere. The volcanoes represent the time when a particular piece of oceanic lithosphere was over the hotspot. This interpretation is still debated today.



Seismic Tomography

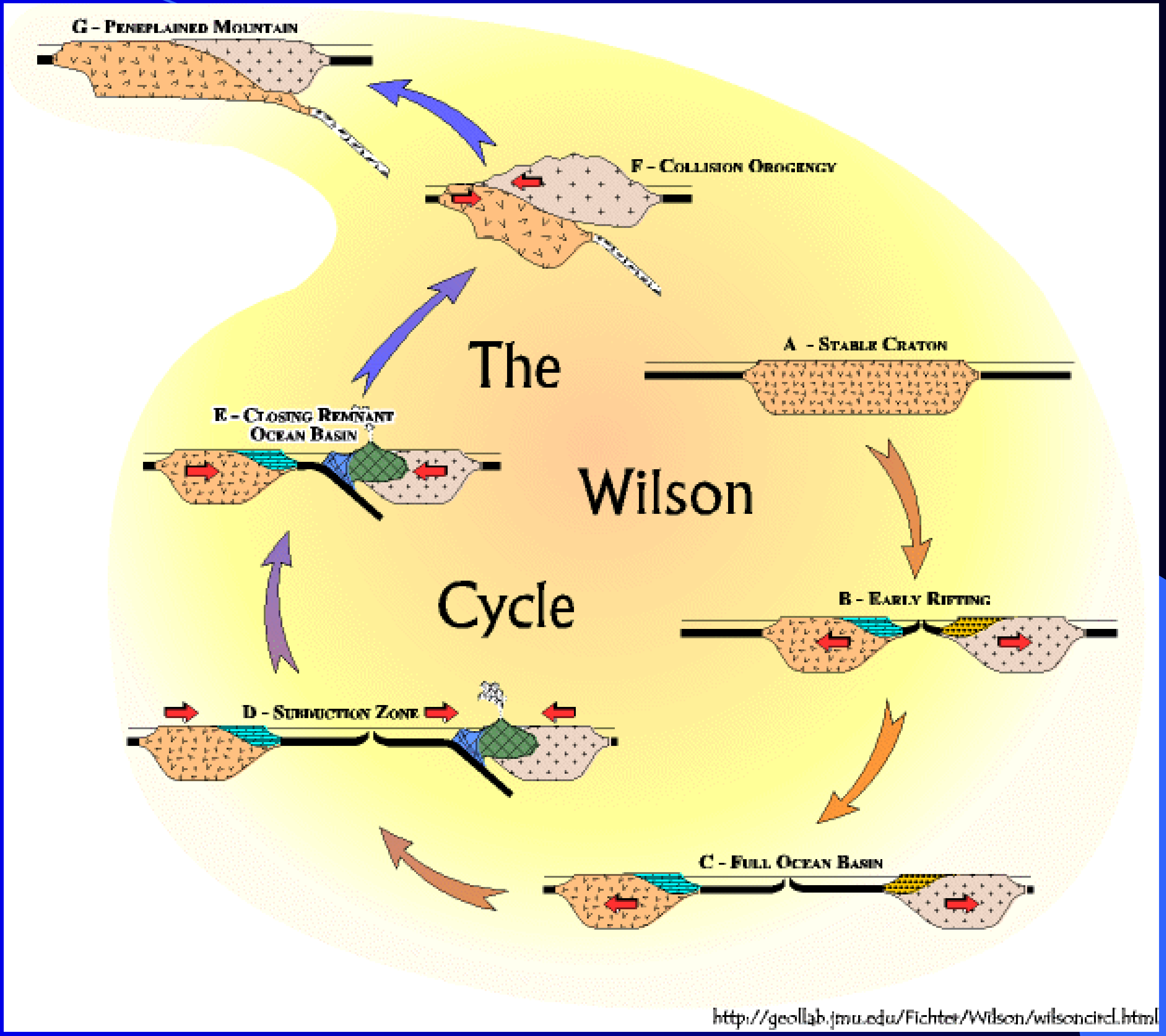


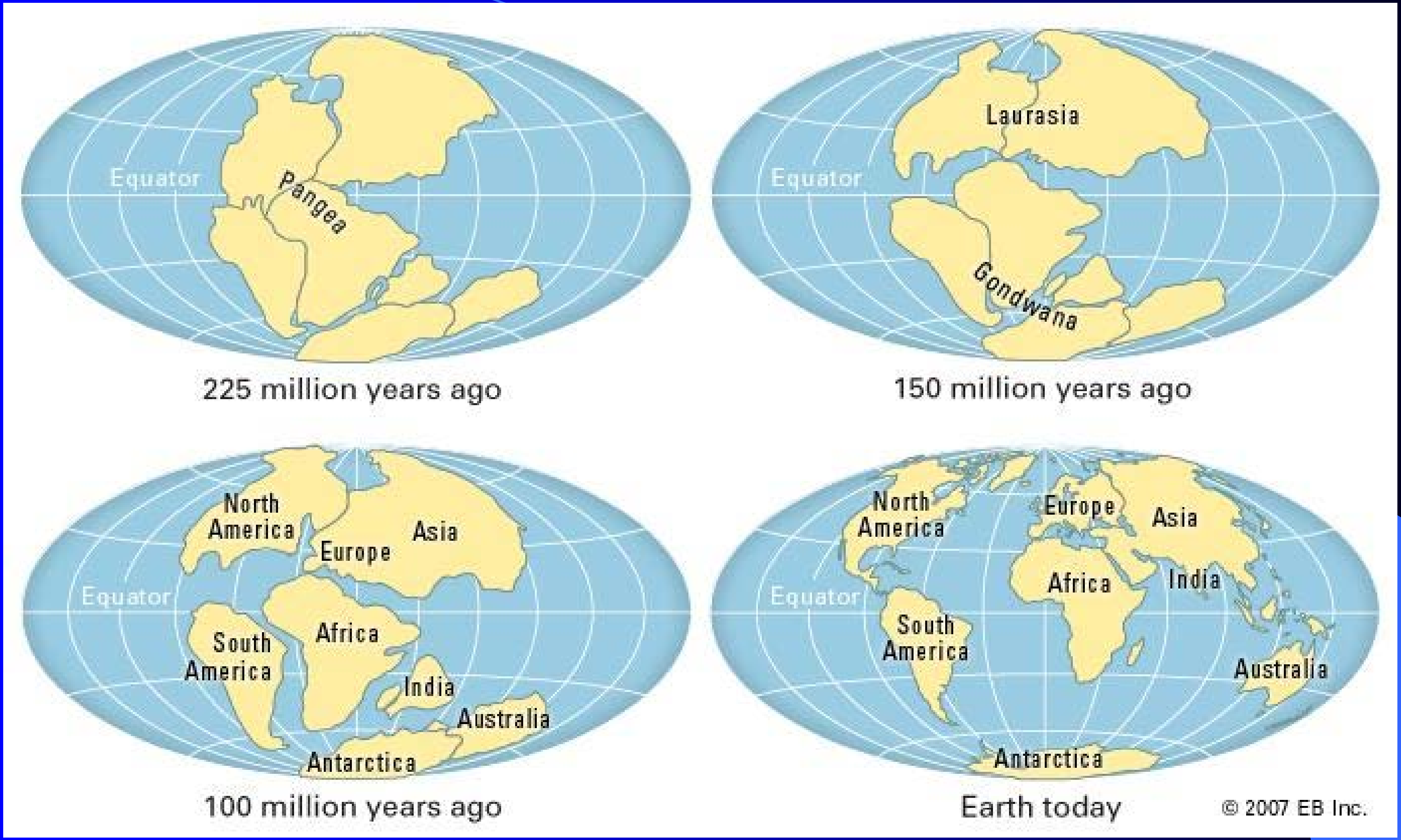




The Wilson Cycle

Opening and closing of ocean basins. Continent-continent collision leads to thickening of the crust and the formation of relief. The European block provided the sediment for the Appalachian mountains. Horizontal tectonics with a vertical component.




Equator
Pangea
225 million years ago
Equator
Laurasia
Gondwana
150 million years ago
North America
Europe
Asia
Equator
South America
Africa
India
Australia
Antarctica
100 million years ago
North America
Europe
Asia
Africa
India
Equator
South America
Australia
Antarctica
Earth today
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