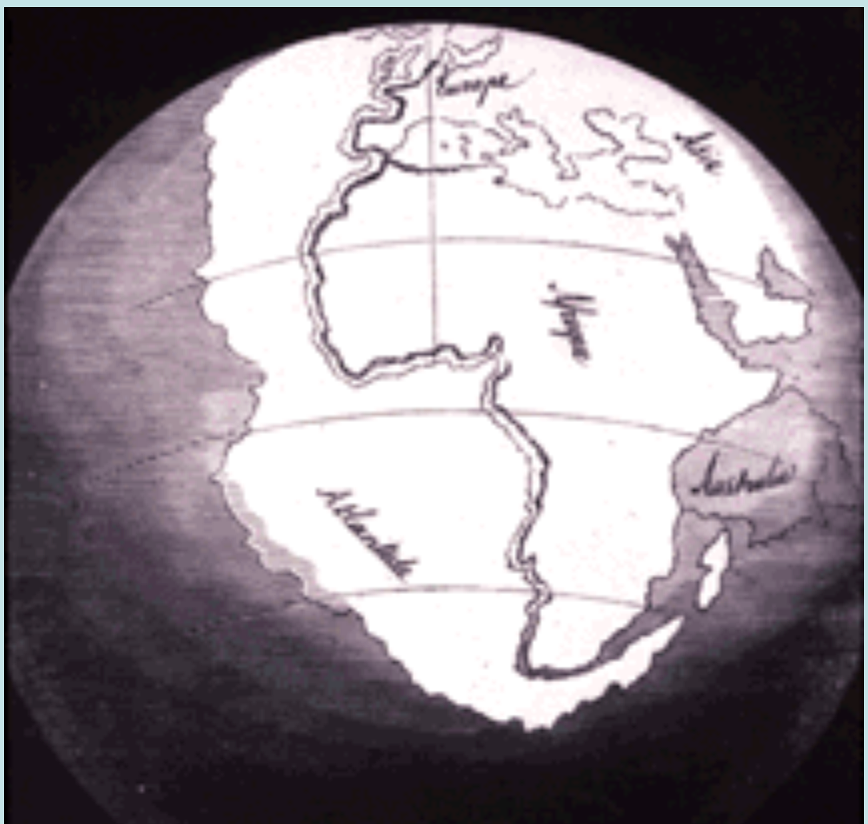
SIO 160 – Intro to Tectonics

- Lecture 1 - Historical perspective



Introduction to Tectonics - SIO 160

http://igpp.ucsd.edu/~fialko/sio160.html

An introduction to geological and geophysical aspects of forces shaping our planet.

Prerequisite: Earth10 (or consent of instructor)

Yuri Fialko; 321 IGPP; yfialko-at-ucsd.edu; Ph. 2-5028

Lecture course, 4-units, letter grade or S/U grade, homework (20%), midterm exam (30%), final exam (50%).

Time: Tue Thu, 2:00-3:20 PM, Hubbs 4500

class@ucsd.edu

SYLLABUS

Date	Topic	Reading/Homework	Lecturer
01 APR	Historical Perspective	Read: KK&V, Ch. 1, 3; Class notes	YF
03 APR	Gravity, Isostasy, and Flexure	Homework 1 Read: KK&V, Ch. 2.11 Class notes	YF
08 APR	Magnetic Anomalies and Seafloor Spreading	Read: KK&V, Ch. 4 Pacific-Antarctic movies Class notes	YF
10 APR	Earthquakes and focal mechanisms	Read: KK&V, Ch. 2.1, 2.10.1-2.10.3	YF
15 APR	Plate tectonics on a plane	Read: KK&V, Ch. 5.10; Cox and Hart, Chapter 2 (Electronic reserves) Tanya Atwater's movies Class notes	DS
17 APR	Plate tectonics on a sphere	Homework 2 Read: KK&V, Ch. 5.1-5.4, 5.8-5.9; Cox and Hart, Ch. 4 (Electronic reserves) Southwest Pacific Movie Class notes	YF
22 APR	Internal Structure of the Earth	Read: KK&V, Ch. 2.3, 2.8, 2.9, 2.12 Class notes	YF
24 APR	Seismo-Tectonics	Read: Class notes	YF

SIO 160 – Intro to Tectonics

SIO 160 SUGGESTED BOOKS (some on reserve at the Geisel Library):

Textbook:

Global Tectonics, Keary, Klepeis and Vine (3rd Ed.), Blackwell, 2008.

Reference Books:

Plate Tectonics Cox and Hart, Allen & Unwin, Boston, MA, 1986.

Principles of structural geology, J. Suppe, Prentice-Hall, Englewood Cliffs, NJ, 1985.

Mantle Dynamics: *Dynamic Earth: Plates, Plumes and Mantle Convection*, Davies, G. F., Cambridge University Press, 1999.

Getting started with Matlab, R. Pratap

- Electronic copies available (roger.ucsd.edu, ted.ucsd.edu)

SIO 160 – Intro to Tectonics

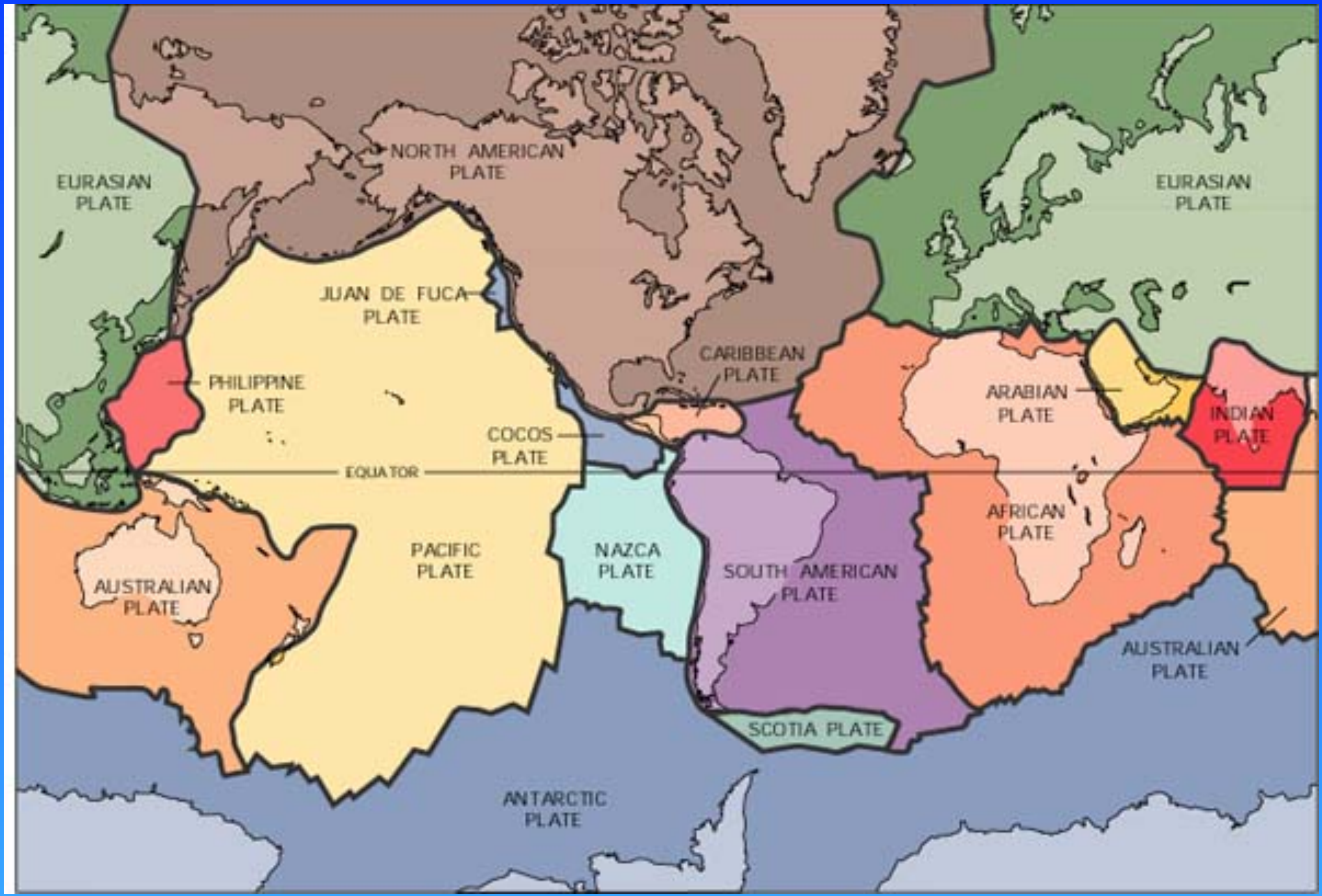
- Lecture 1 - Historical perspective

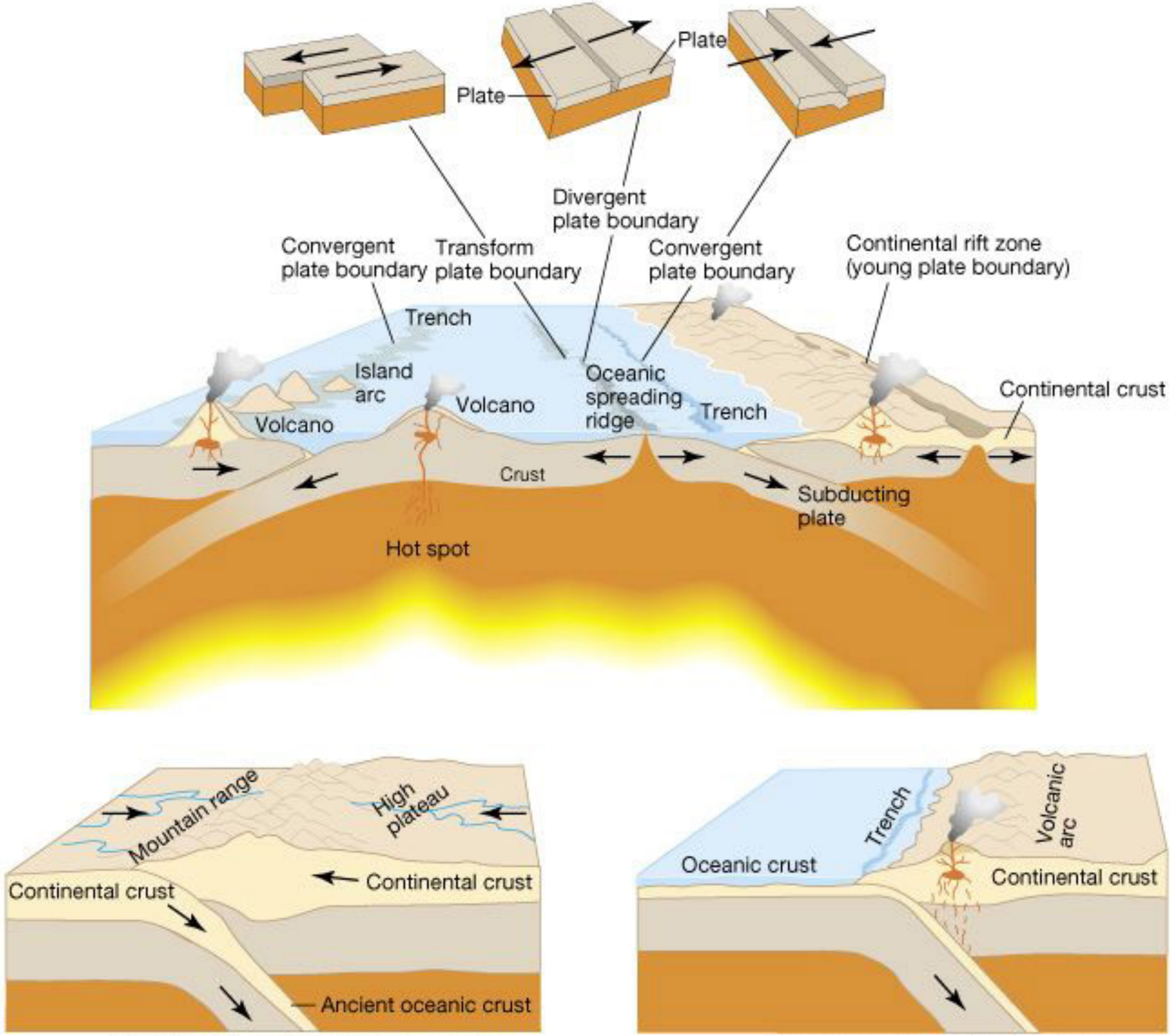
- Read: Chapters 1 and 3, Kearey, Klepeis & Vine

- Lectures are available on class web page

Current paradigm: Plate Tectonics

(relatively young theory!)

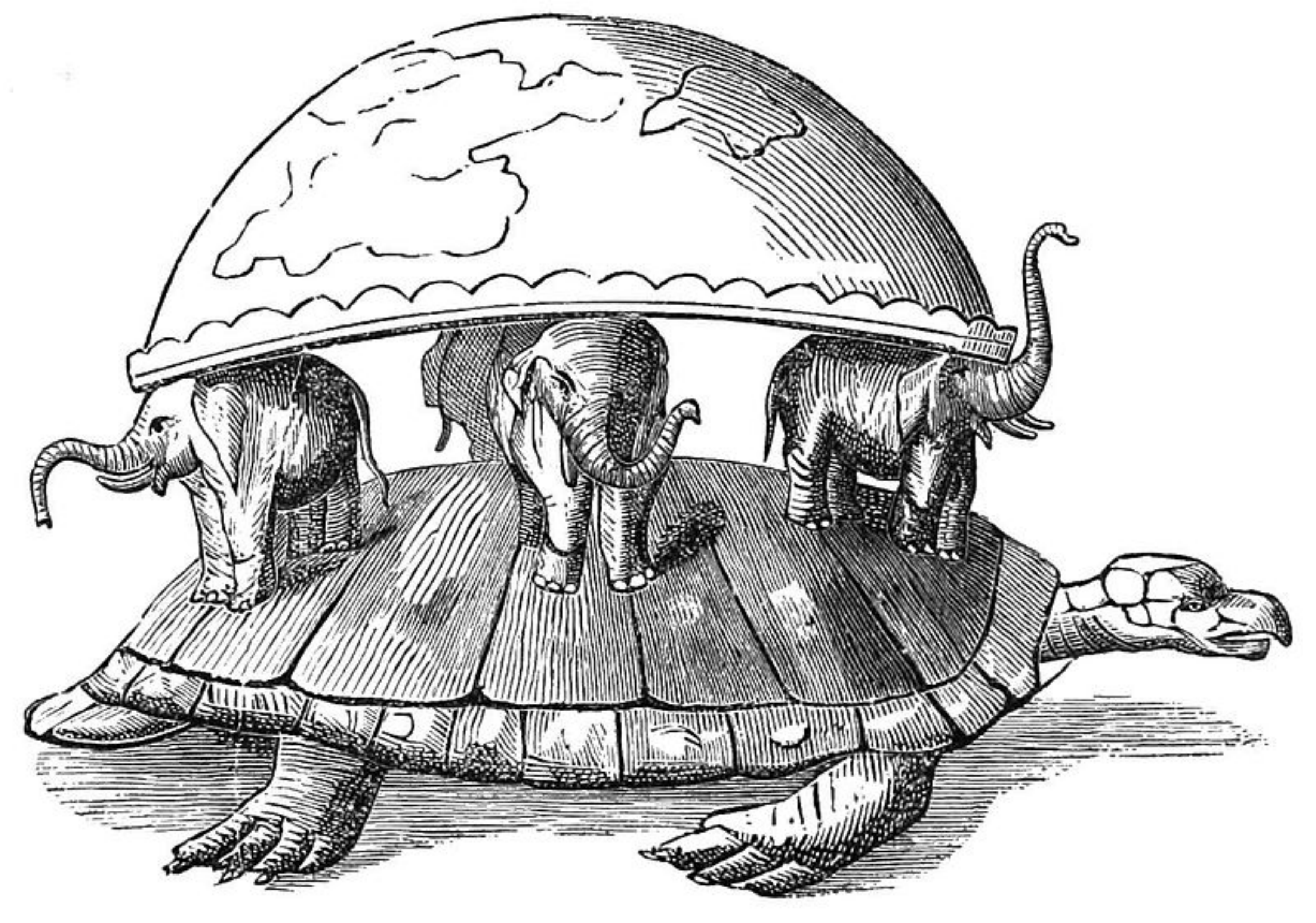




Continental-continental convergence

Oceanic-continental convergence

… building on a *long* history of knowledge

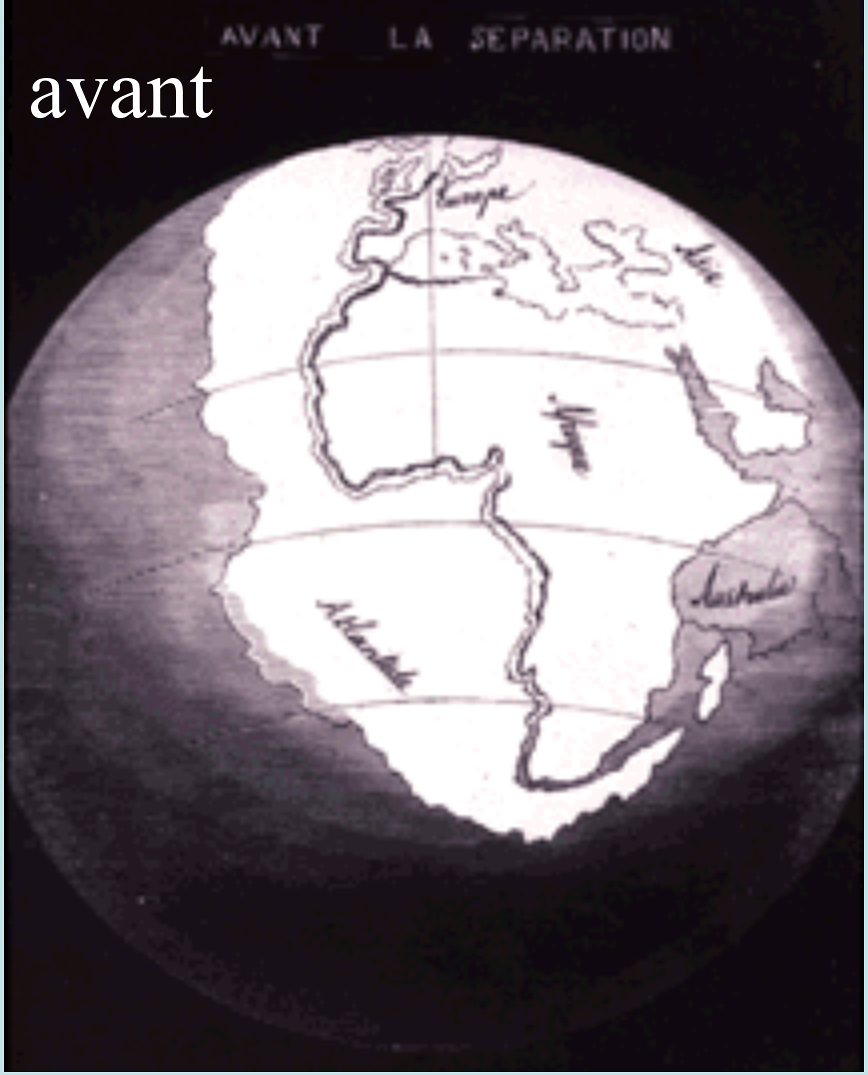


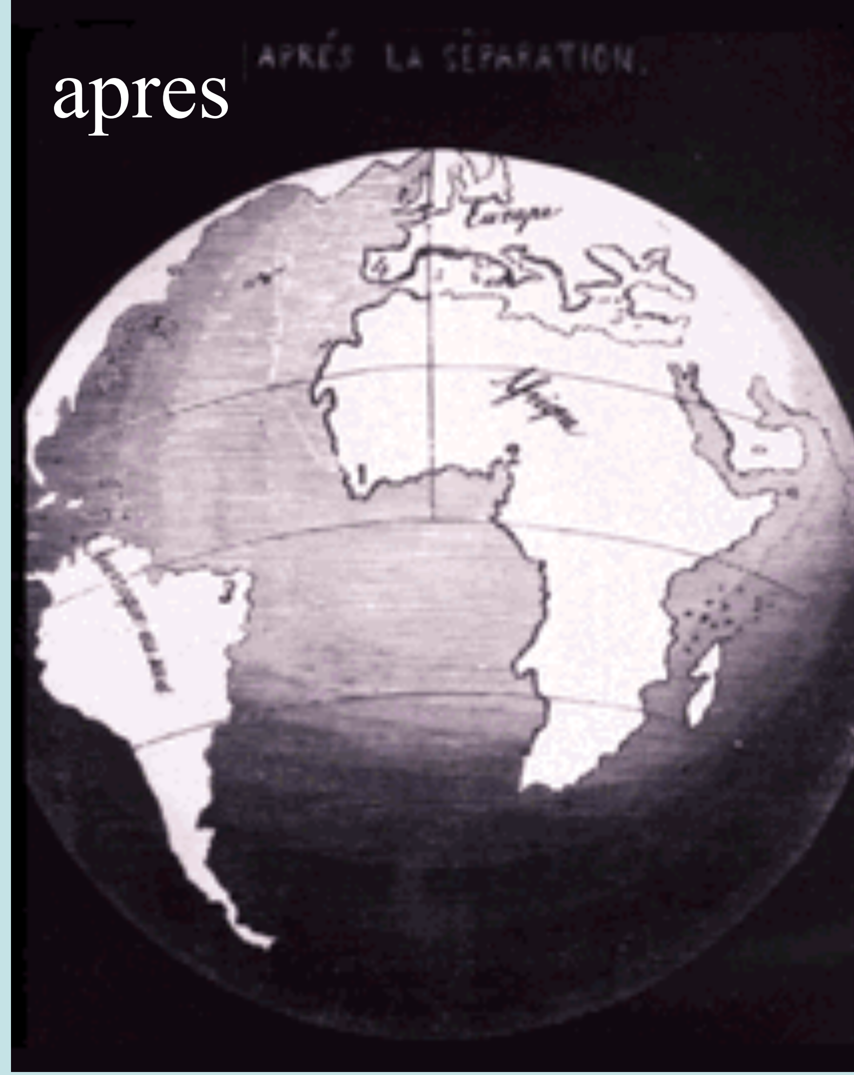
Τέκτων (***tektōn***) - “builder”

Early views appealed to catastrophic events that shaped the surface of the Earth (catastrophism) – floods, earthquakes, etc. In 18th century, geologists have adopted a uniformitarian view: slow, gradual changes that take a very long time to occur (James Hutton: “the present is the key to the past”, 1785)

Epoch of great geographic discoveries: shapes of the continents

Abraham Ortelius – similarity of coasts of Africa and S. America (1596)





In 1858, geographer Antonio Snider-Pellegrini *made these two maps showing his version of how the American and African continents may once have fit together, then later separated. Left: The formerly joined continents before (avant) their separation. Right: The continents after (aprés) the separation.*

Intellectual Milestones of the 20th Century

1885-1909 Edward Suess, The Face of the Earth (5 vols.) developed the hypotheses of Gondawanaland

1913 Arthur Holmes, The Age of the Earth, sets the age of the earth at 1.6 billion years

1915 Alfred Wegener, The Origin of Continents and Oceans (4th edition, 1928)

1928 Holmes suggests mantle convection currents could drive continental drift

1937 Alexander Du Toit, Our Wandering Continents

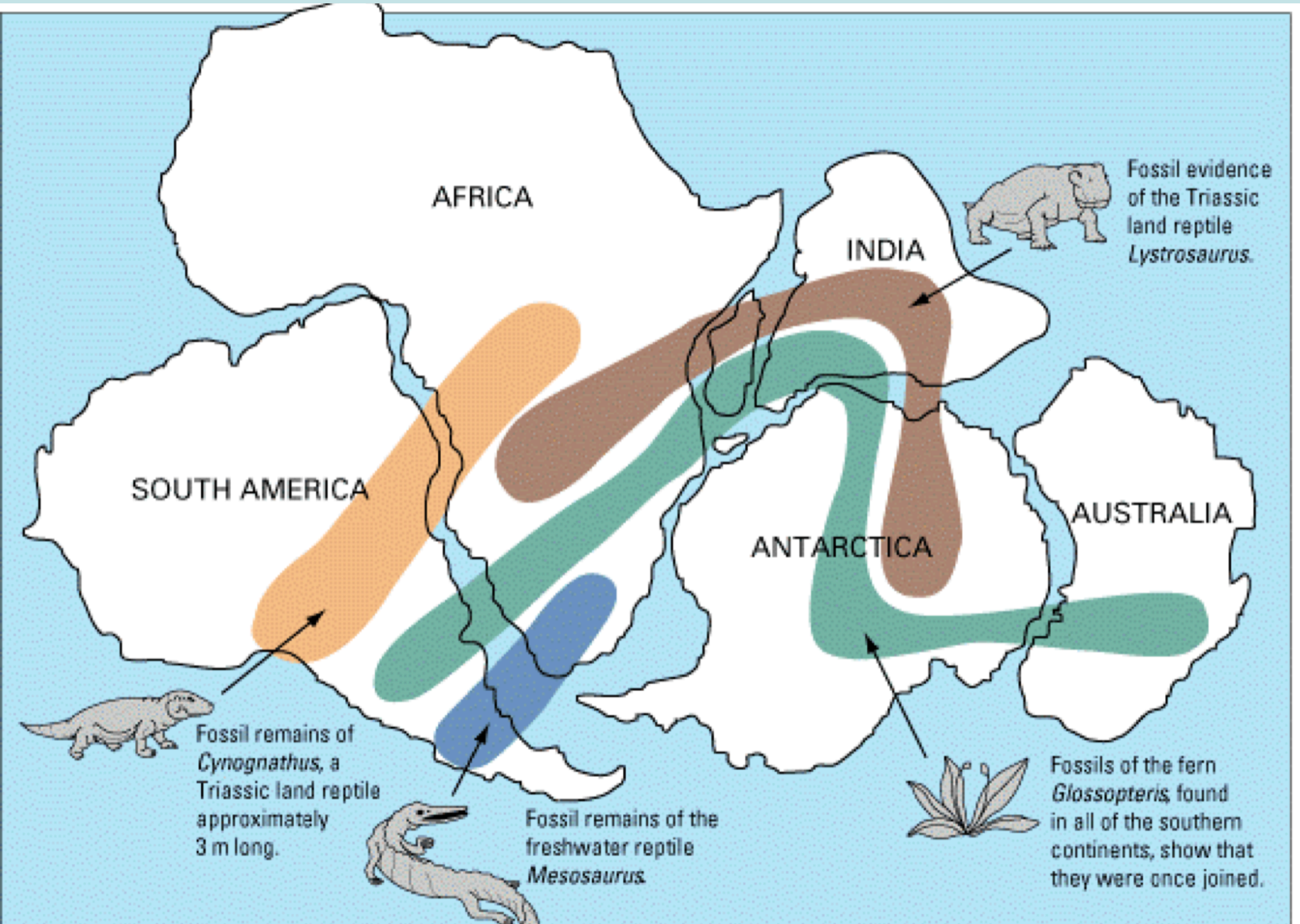
1962 Henry Hess proposes the theory of sea-floor spreading

1963 F.J. Vine and D.H. Matthews identify deep ocean paleomagnetic "stripes"

1965 Tuzo Wilson begins developing the theory of plate tectonics

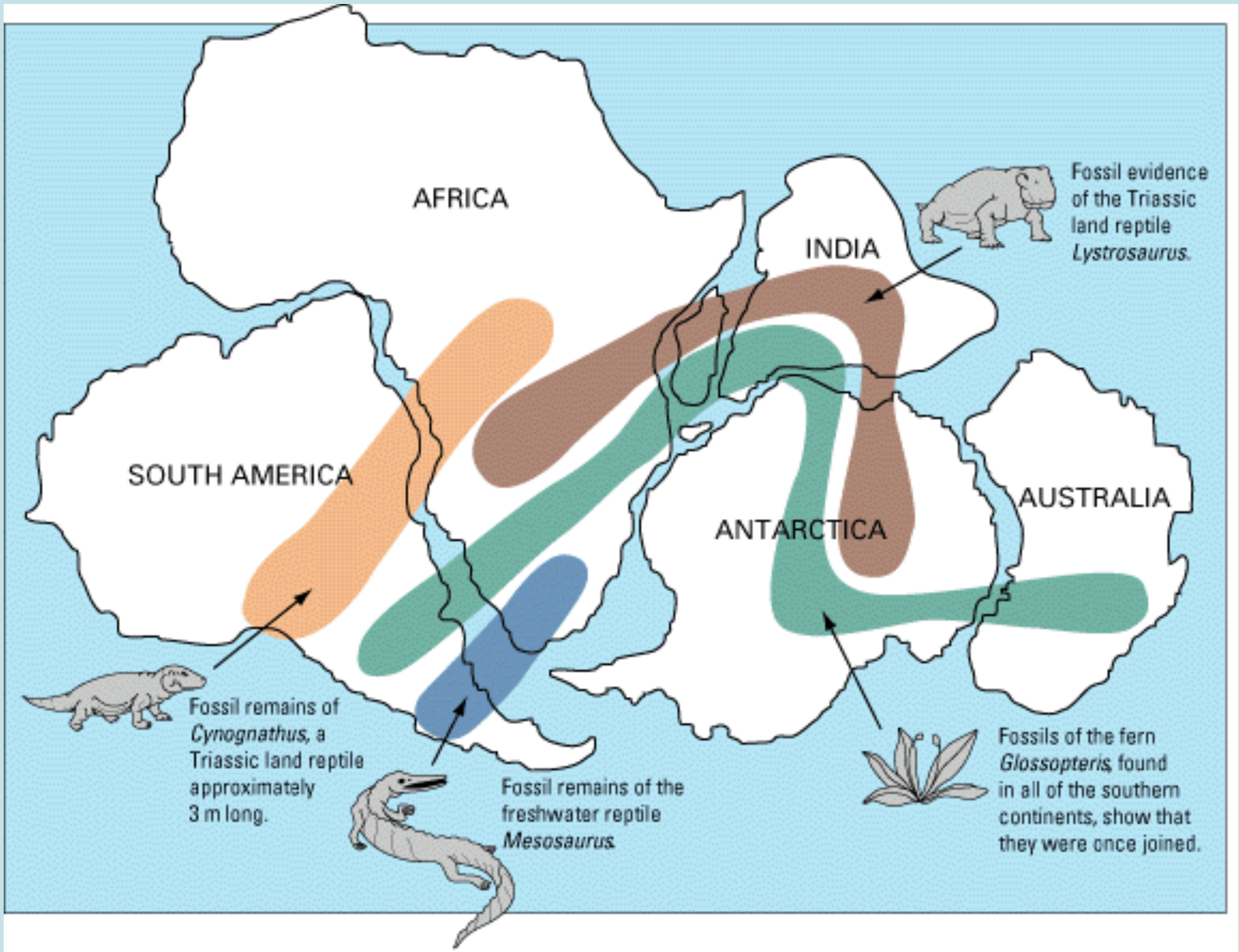
Gondwanaland

The hypothetical former supercontinent in the Southern Hemisphere, which included South America, Africa, peninsular India, Australia, and Antarctica. The name was coined by the Austrian geologist Eduard Suess in 1895 in reference to the Upper Paleozoic and Mesozoic formations of the Gondwana region of central India, which display typical developments of some of the shared geologic features.



Most widely spread common fossil was glossopteris which is very abundant in a part of India where the Gonds live.

Actually, Suess didn't "reconstruct" the continents (as shown here). Instead he had the areas of common flora and fauna connected by "land bridges" which sank in the late Mesozoic. Wegener showed that this violated the principle of isostasy. Suess was a "contractionist."



Newton was also a contractionist – he thought wrinkled mountains were due to a shrinking earth surface

Taylor wanted to explain arcuate mountain ranges south of Asia. He had large continents at poles pre-Tertiary, which then moved towards the equator. He attributed the motion to tidal forces and had them increasing in the Tertiary following the capture of the moon in the Cretaceous. He was a “catastrophist”

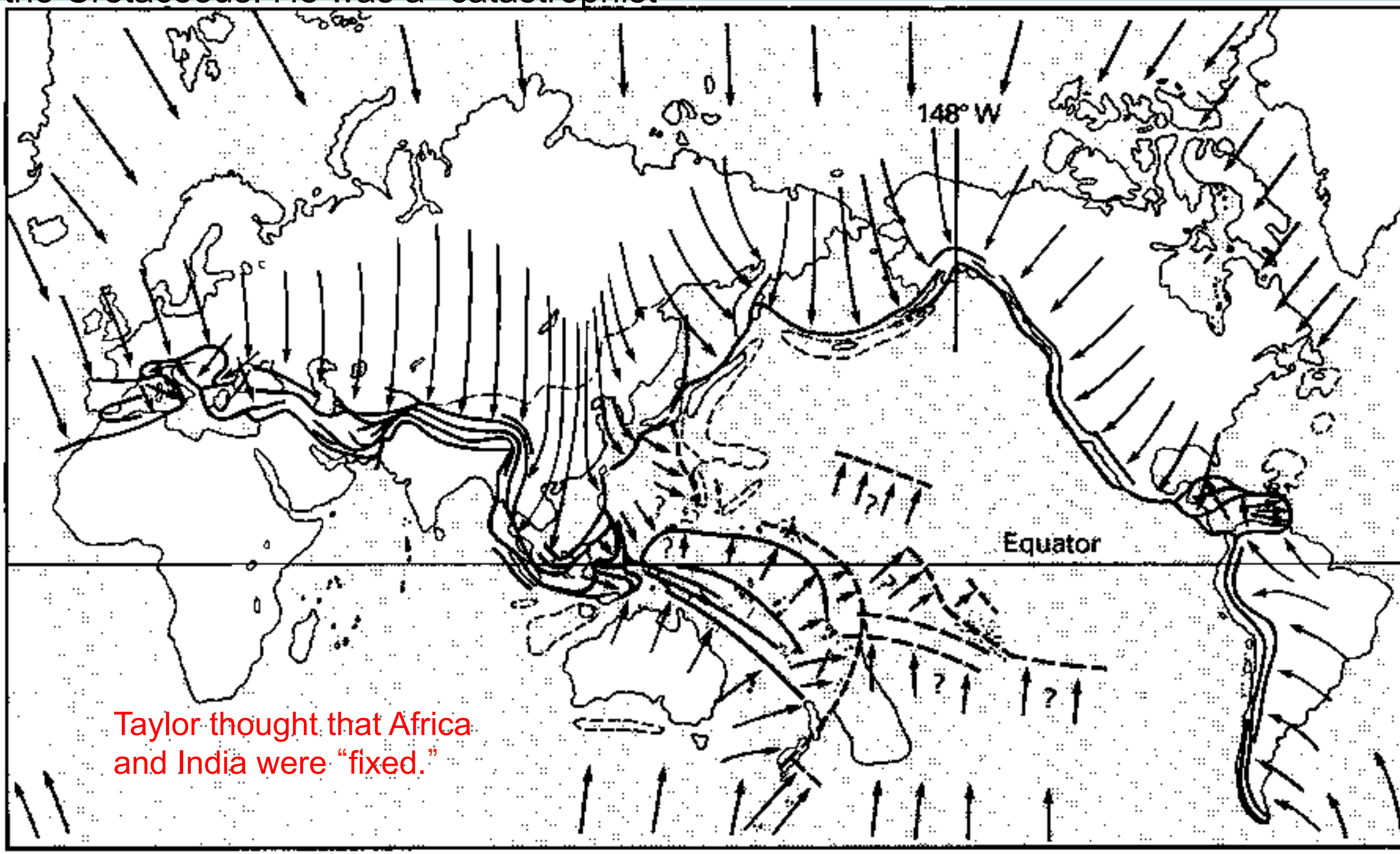
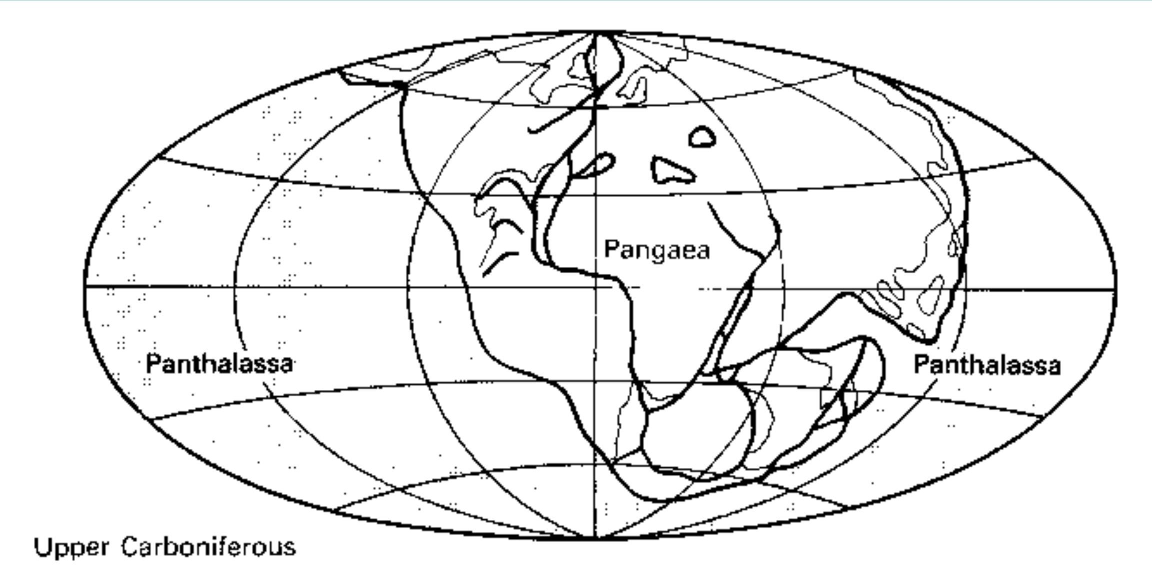


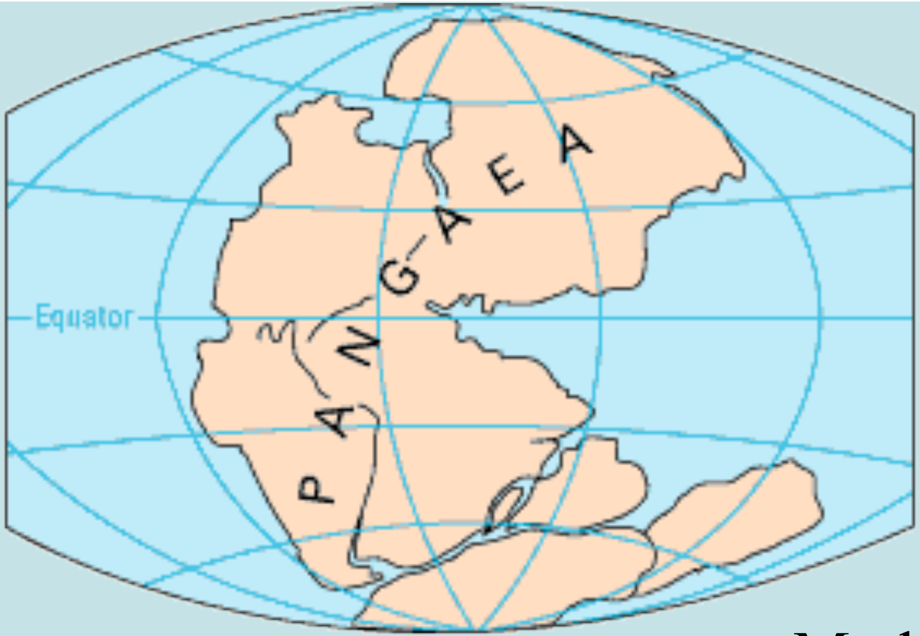
Fig. 1.2 Taylor's mechanism for the formation of Tertiary mountain belts by continental drift (after Taylor, 1910).

Alfred Wegener



Wegener recognized a super-continent and called it Pangaea

Taylor and Wegener were the first to think of drifting continents as a normal, continuous process



PERMIAN
225 million years ago

Modern view

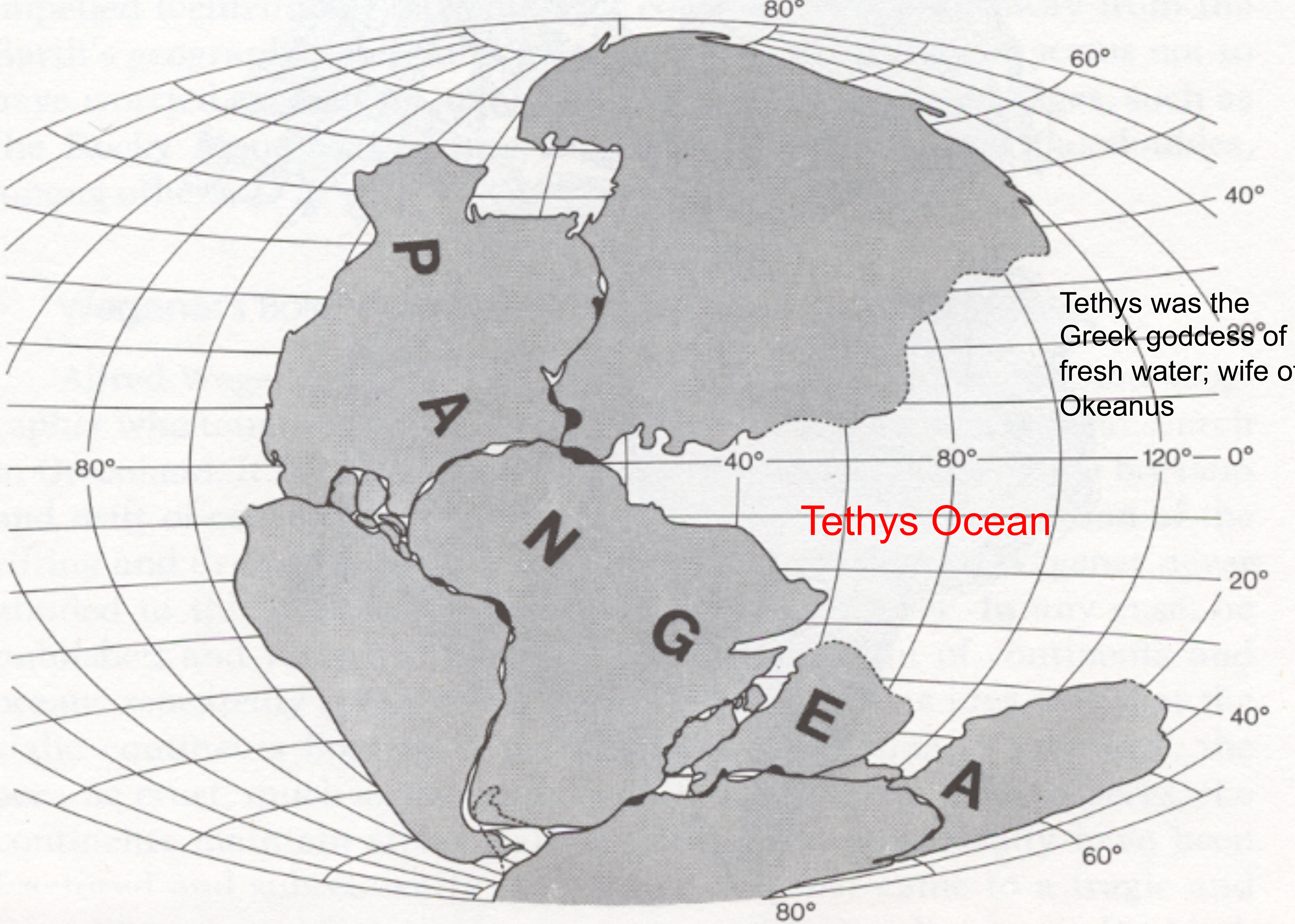
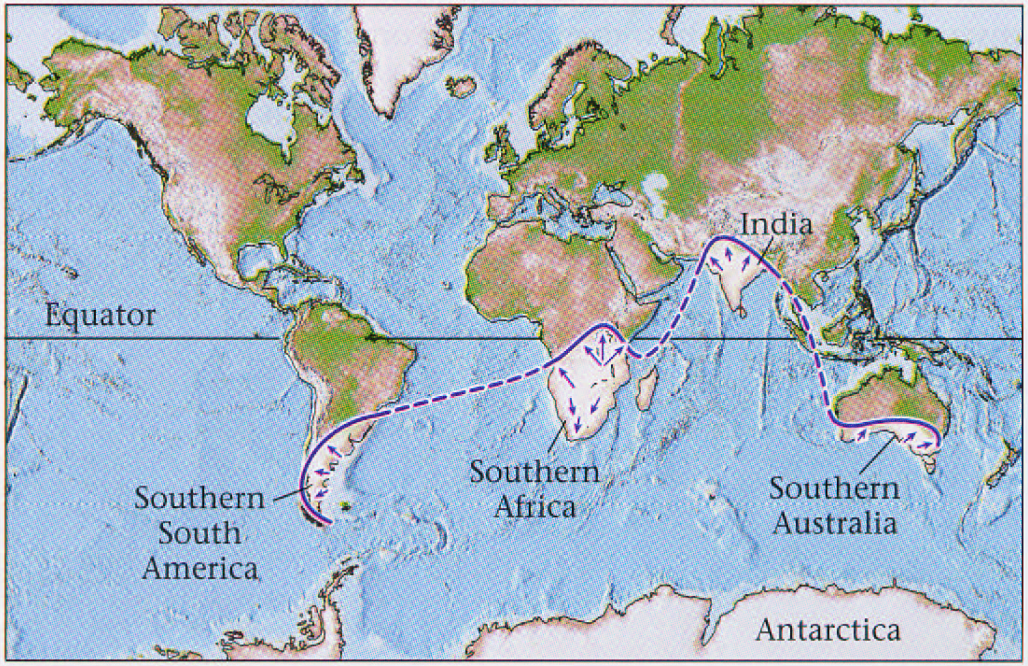
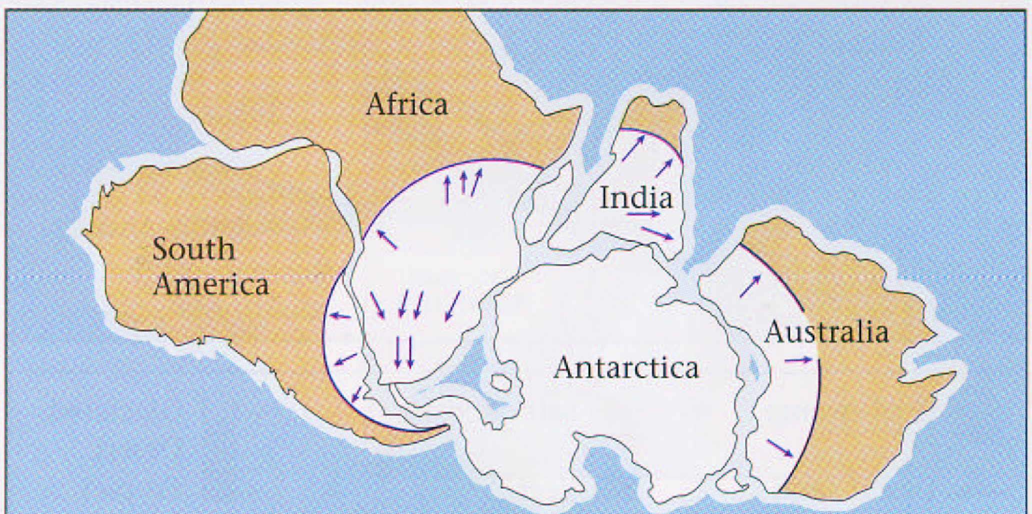


FIGURE 2.2. Wegener's original continental assembly, Pangea, appropriate for the end of the Paleozoic Era, about 250–200 million years ago (simplified after Dietz and Holden 1970). Tethys was the ocean between southern continents and Asia

Areas with Permo-Carboniferous Glaciation



(a)

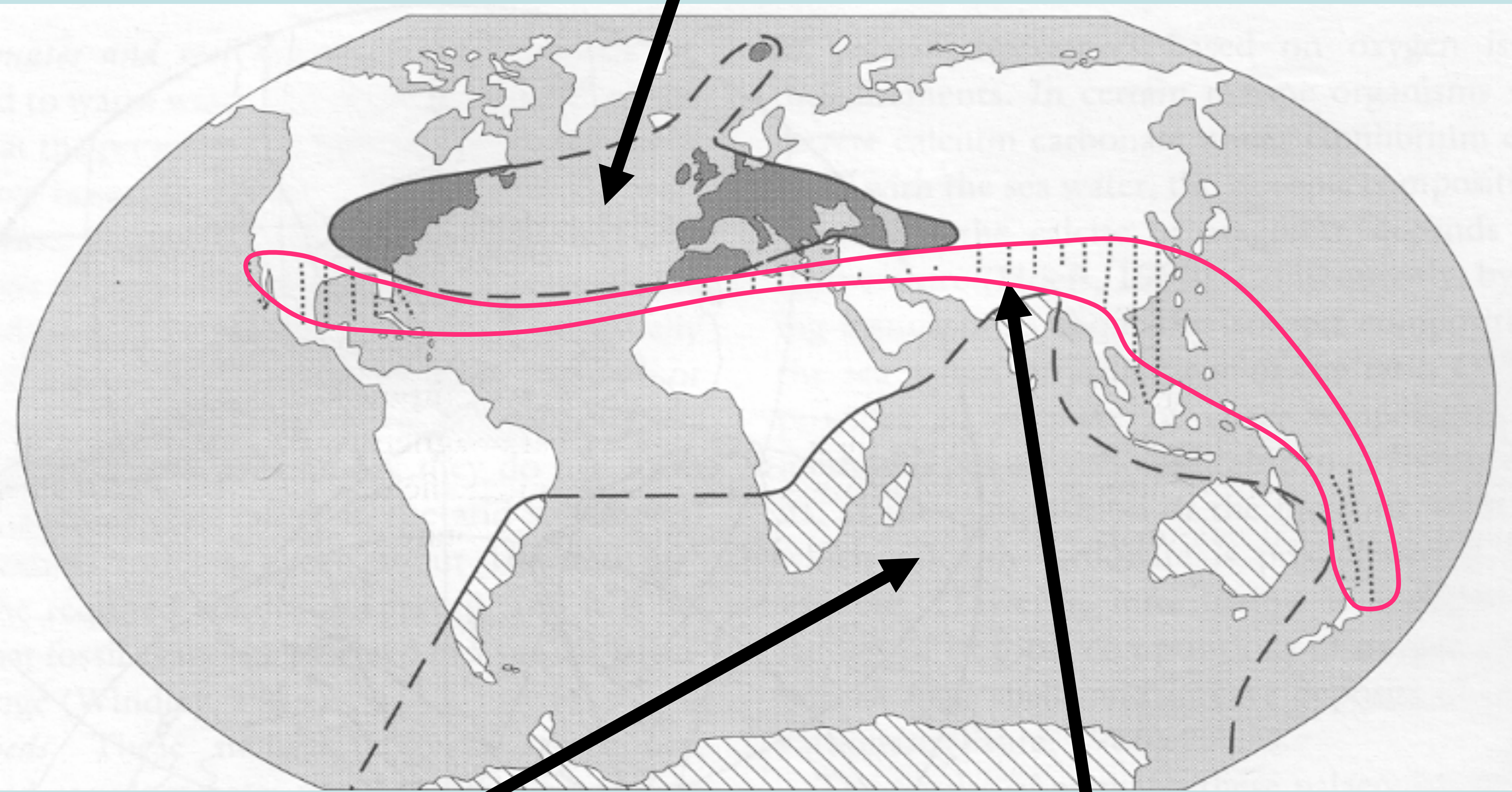


Type of observations used by Wegener:

Glacial striations point toward sources "offshore". Only made sense in a reconstruction that closed continents

Had more uniform fauna and fewer species before breakup, more diverse fauna and more species after breakup -

Tropical Laurasian flora with many species of identical reef-forming corals

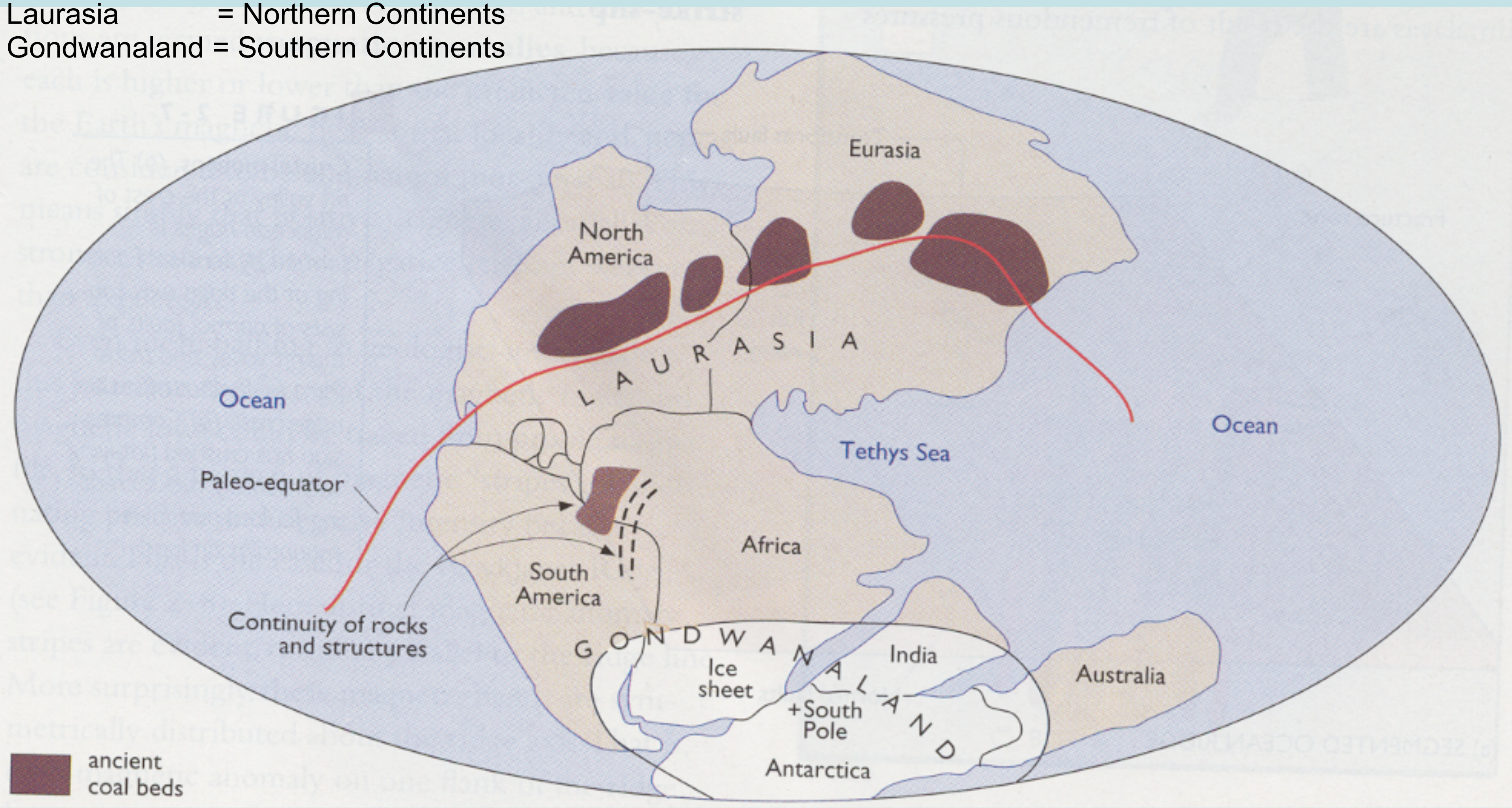


Polar Gondwanan flora

Tethyan marine plankton

Pangaea 200-300 million years ago

Laurasia = Northern Continents
Gondwanaland = Southern Continents



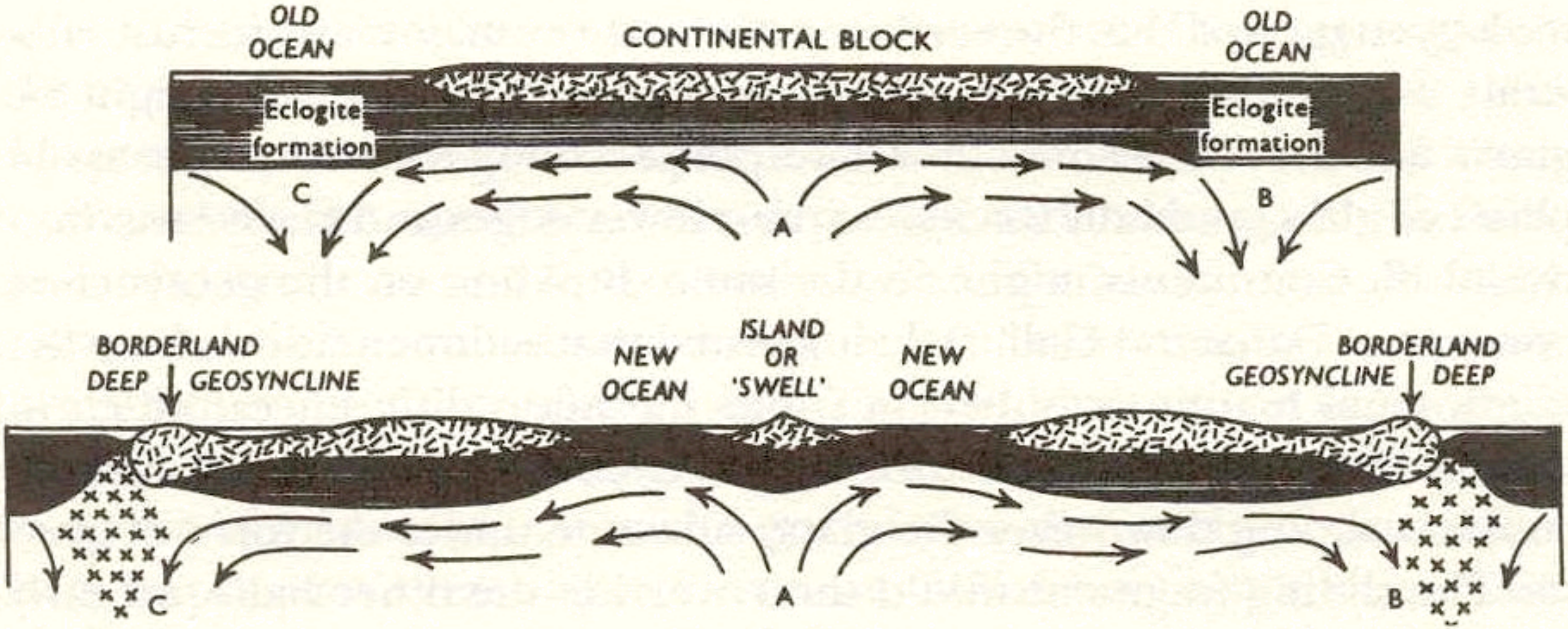
Coal beds and glacial deposits defined paleo-equator and paleo-poles of Pangaea

The main problem with the ideas proposed in the early 1900’s was the lack of a suitable mechanism.

Wegener’s idea was that the continents somehow “plowed” through the mantle. He had both an equatorward force (Polfluchtkraft or pole-flight) and an East-West force perhaps due to centripetal or tidal forces. Physicists like Harold Jeffreys demonstrated that the forces that Wegener proposed were too weak to push continents and cause the formation of mountains.

Wegener had some continents moving very fast - 1 to 10 m/yr; Norway and Greenland separated in 2 Ma.

Mantle convection as a driving mechanism



Arthur Holmes' model of continental drift driven by mantle convection currents, from Holmes (1929), Radioactivity and earth movements, *Transactions of the Geological Society of Glasgow* 18: 579 (1929), used by permission of the Geological Society of Glasgow.

Not too far from today's mantle convection models …
but … had basalt beneath continents, no new crust at ridges, ridges = upwelling of convection cells.

The South African geologist Alexander DuToit demonstrated the remarkable continuity in the bedrock of Africa and South America in reconstructions in the 1920’s. He was a strong supporter of Wegener. He wrote “Our wandering continents” in 1937.

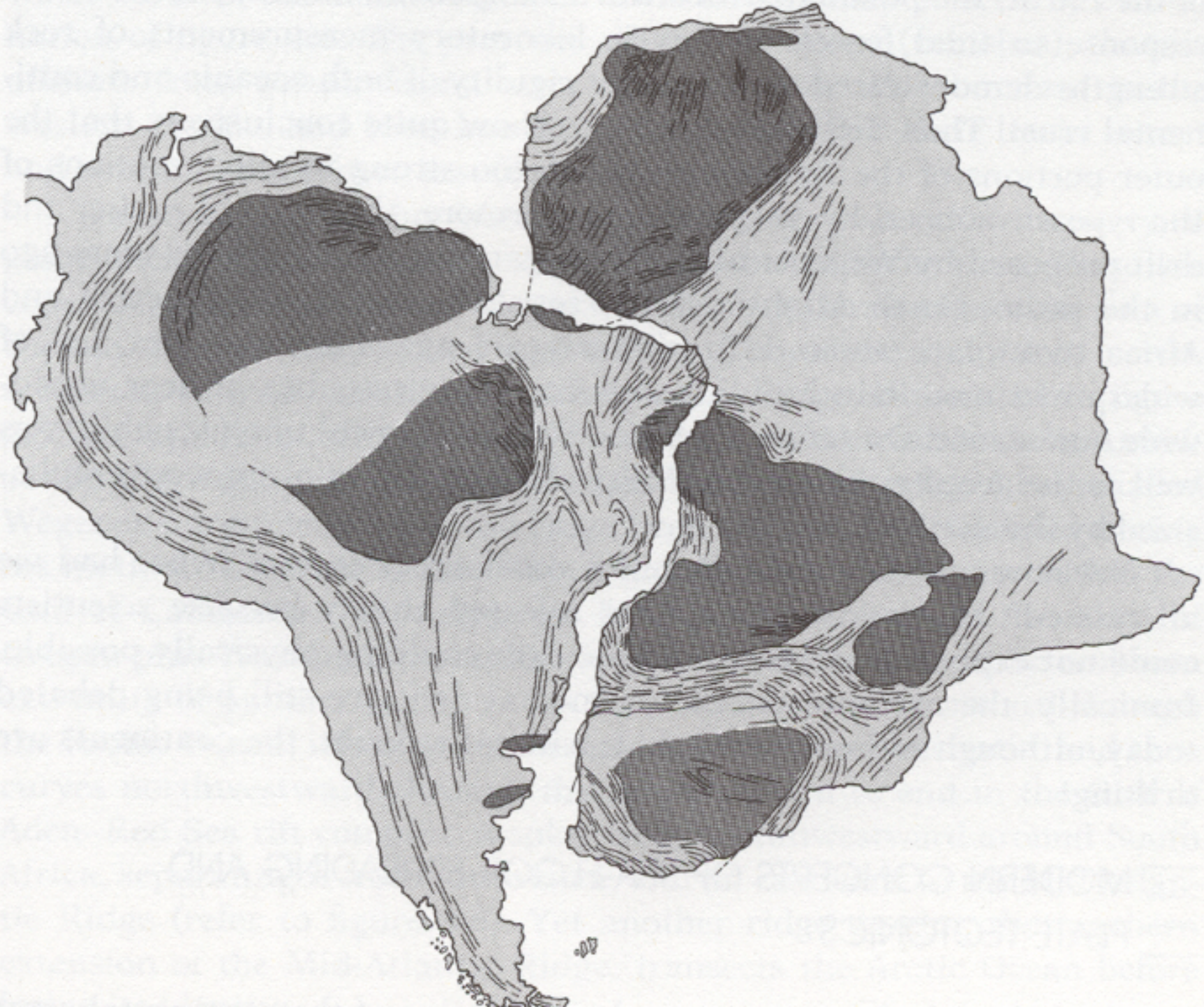
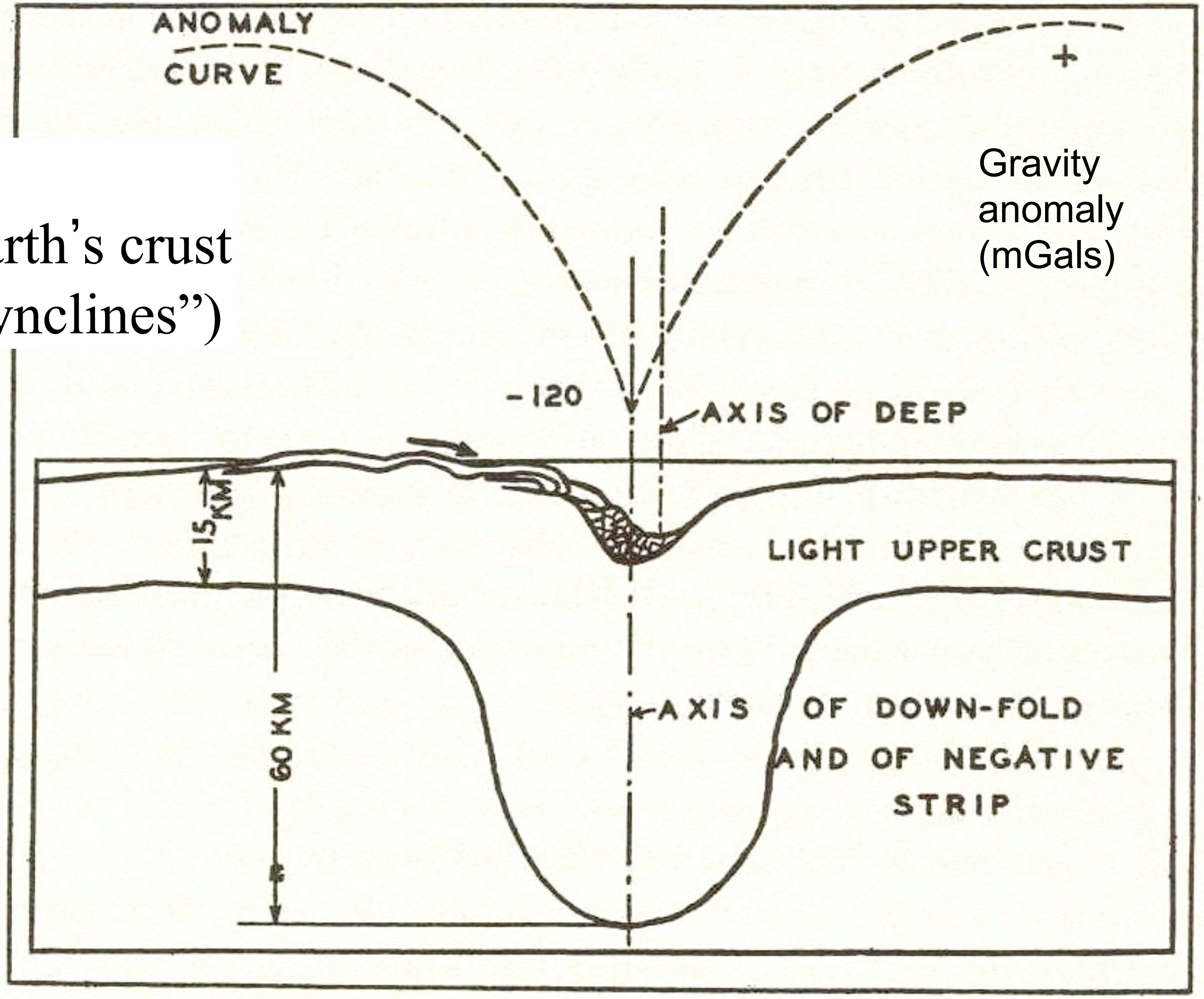


FIGURE 2.4. Geological belts truncated at the present margins of the South Atlantic Ocean. Dark areas are early Precambrian cratons, lineated patterns show the trends of late Precambrian and younger mountain belts (after Hurley 1968).

Hess' tectogene: Downbuckle in Earth's crust ("Theory of Geocynclines")

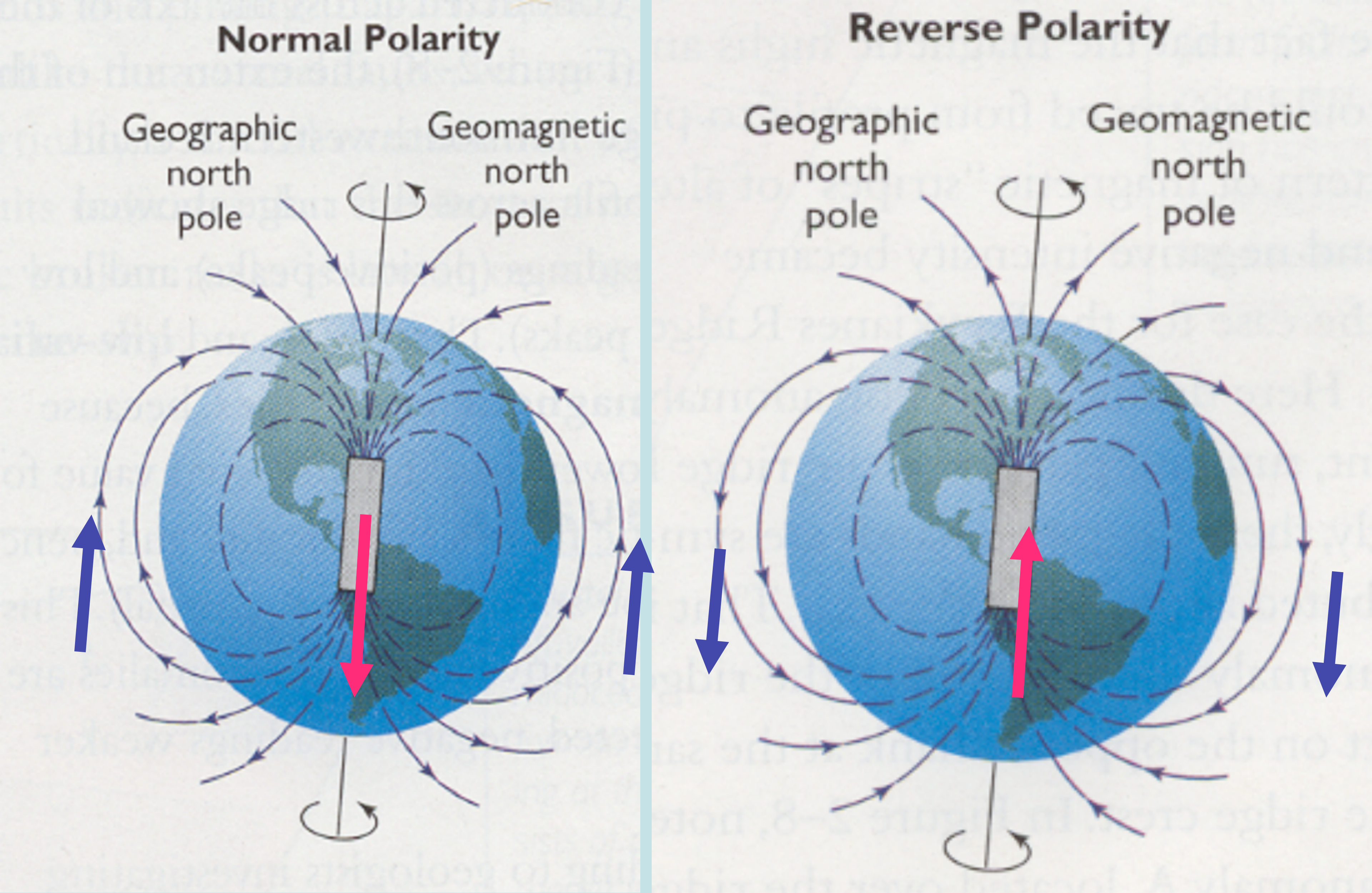
1930's: Entering era of geophysical constraints: gravity measurements at sea

Hess later went on to propose sea floor spreading in 1962



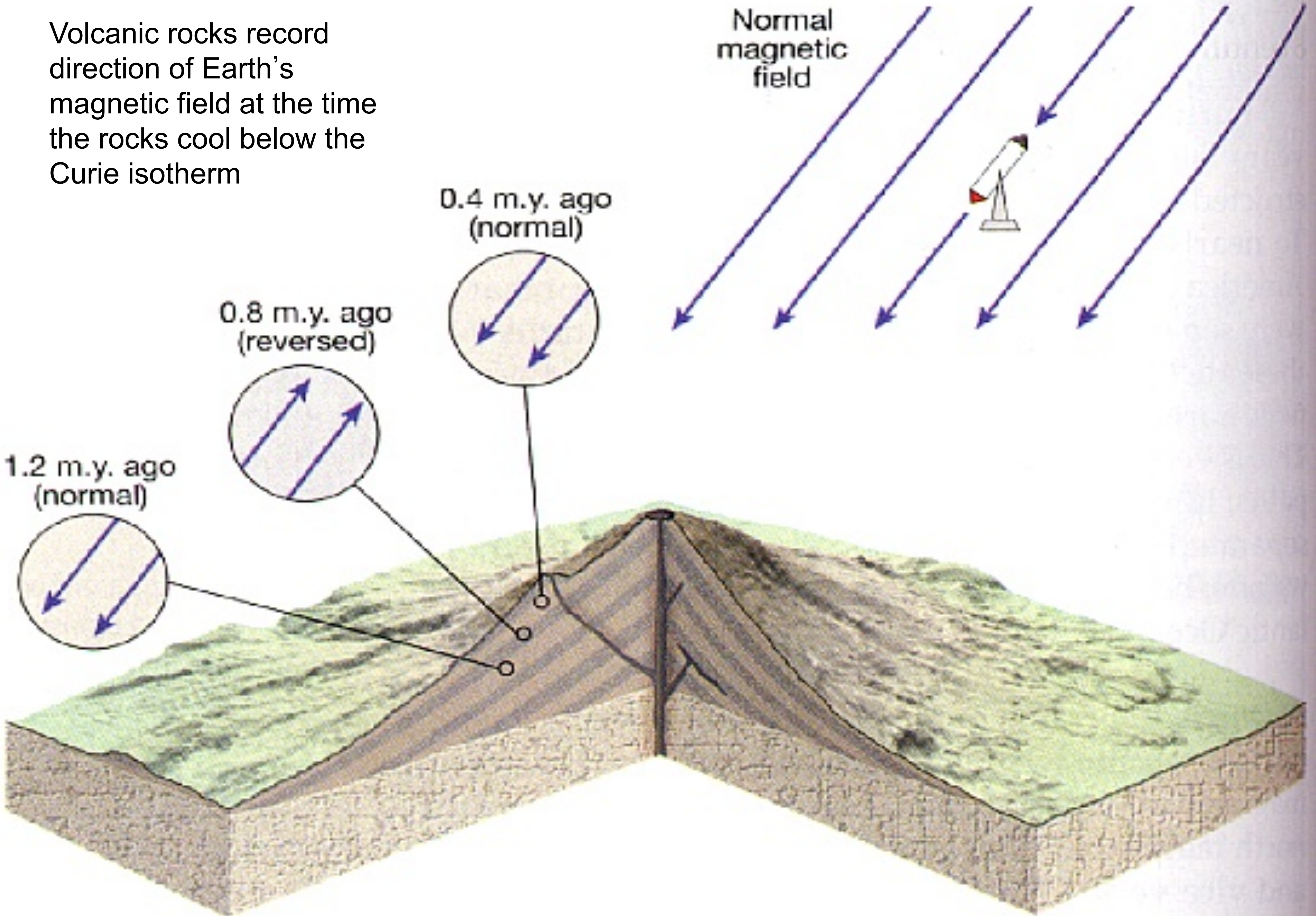
Gravity anomaly (mGals)

Harry Hess' tectogene concept explaining the origins of ocean deeps associated with negative gravity anomalies, from Hess (1933), Interpretation of geological and geophysical observations, in *The Navy–Princeton Gravity Expedition to the West Indies in 1932*, edited by R. M. Field. Washington, D.C., U.S. Government Printing Office, p. 30.



Convincing data from paleomagnestism, beginning in1950's
It wasn't until 1947 that Blackett showed that field was generated by earth's core and not a property of spinning masses as some thought

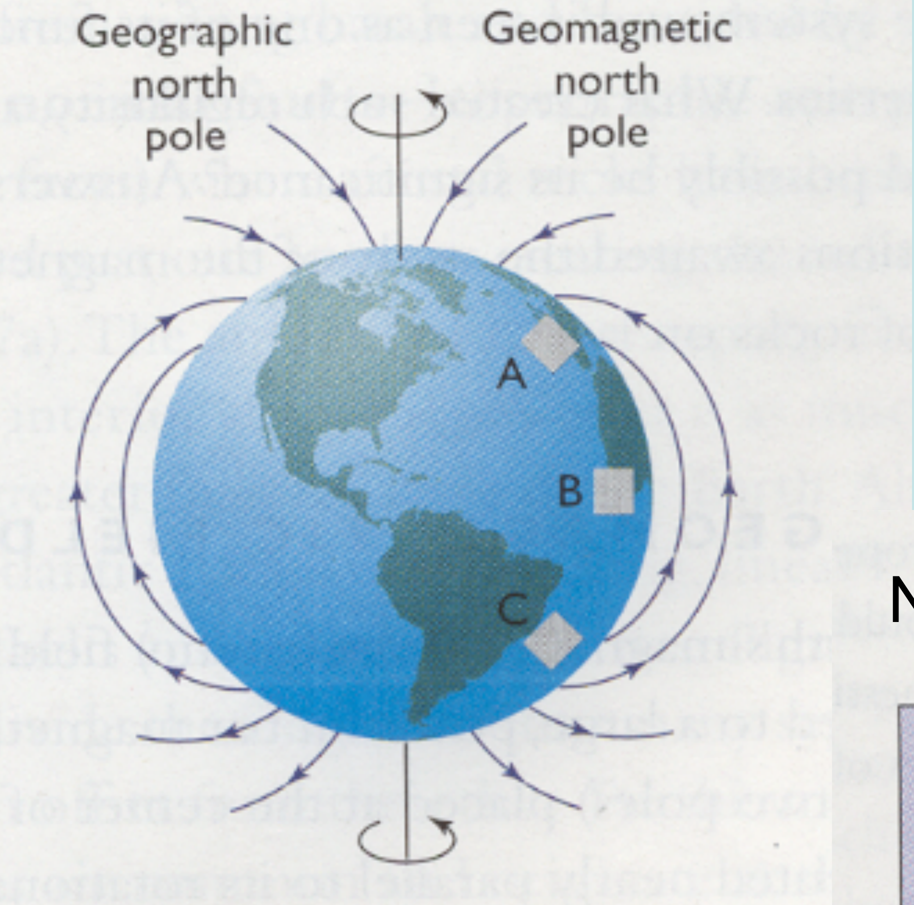
Volcanic rocks record direction of Earth's magnetic field at the time the rocks cool below the Curie isotherm



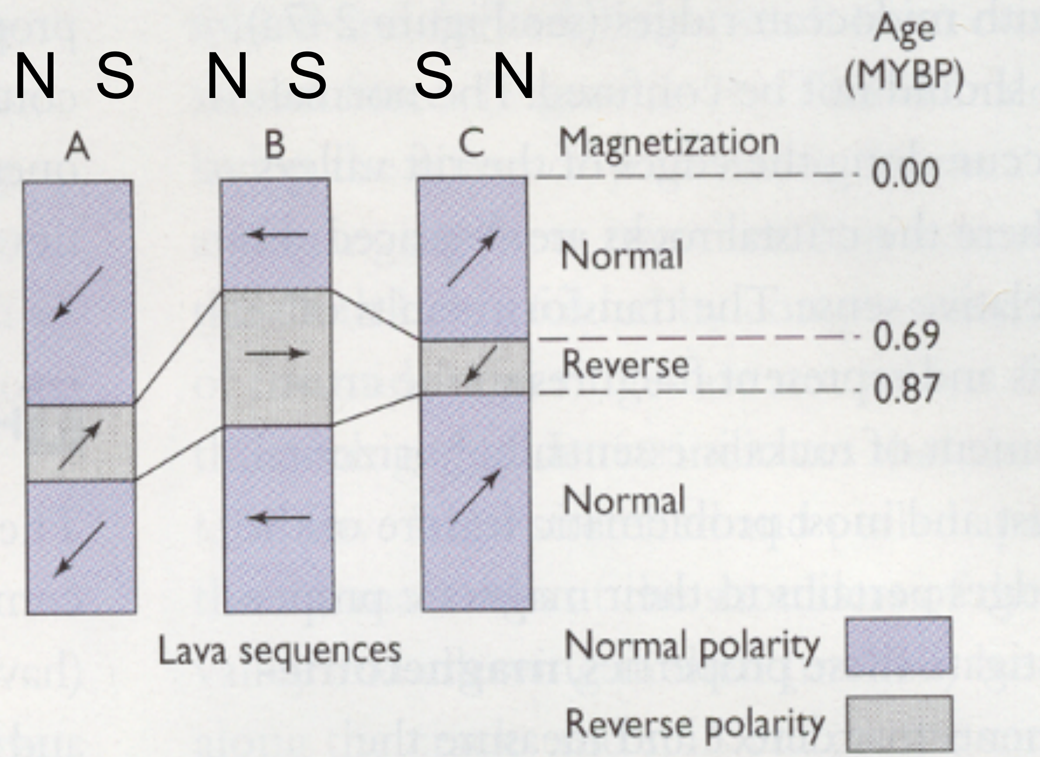
How paleomagnetism works:

• Determine when field reversed by studying polarity of rocks of similar ages

2) Study where continents drifted by comparing observed inclinations to predicted inclinations



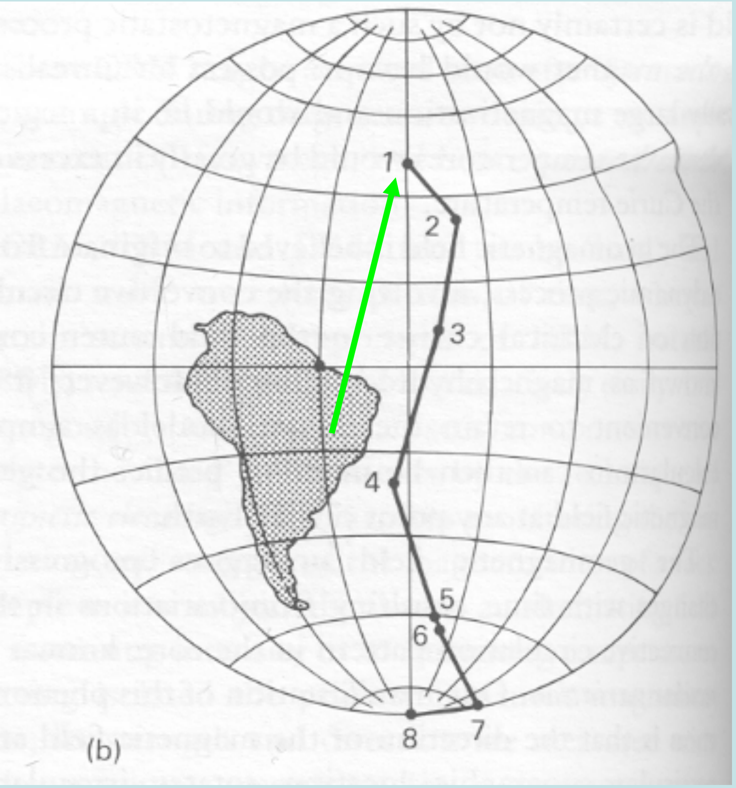
(a) MAGNETIZATION OF LAVAS

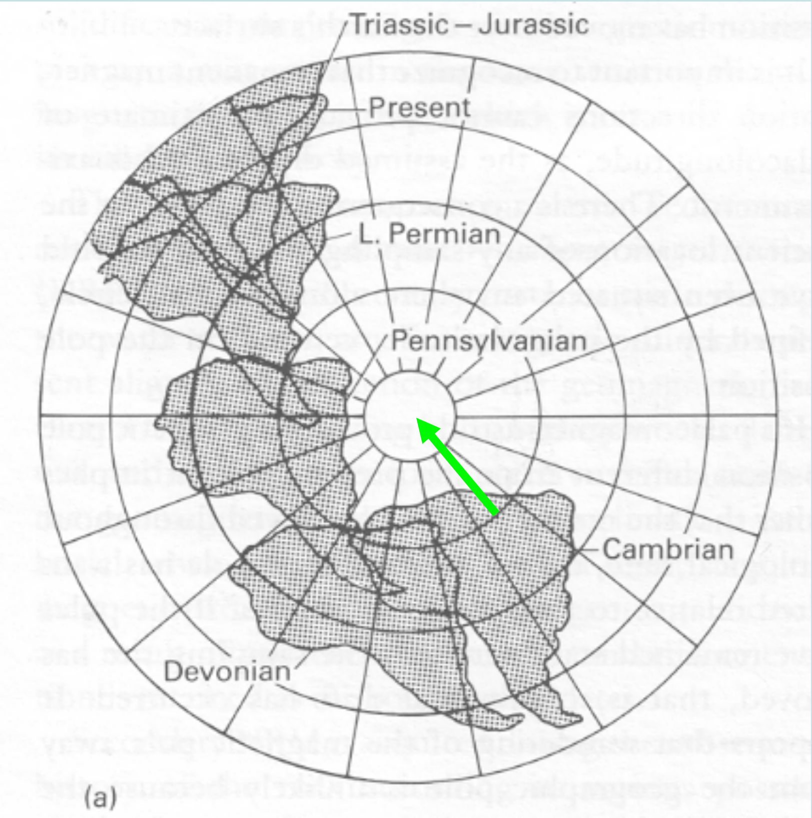


(Note that column C has to be S to N for mag directions to make sense; a textbook mistake)

Displaying paleomagnetic data assuming fixed continent and wandering pole path. Apparent Polar Wandering (APW) paths

Displaying paleomagnetic data assuming fixed pole and shifting continents





Measure inc and dec at a site and, assuming a dipole field, plot where paleomag pole was relative to that site

Here are plotting South magnetic pole

Of course what is really happening is that plate is drifting relative to spin axis

In the 1950's paleomagnetists constructed Apparent Polar Wandering paths for North America and Eurasia

… and found that they were different!

But, if you moved the continents back together, the paths fell on top of each other.

The paleomagnetists became strong advocates of continental drift

But in the 1950's – most people weren't buying the paleomagnetists story. Too many assumptions. It took more data

Conclusive evidence came from the study of the ocean floor in the 1950's and 60's

The 1950's was a period of rapid progress in mapping the ocean floor. Heezen, Tharp and Doc Ewing at Lamont Observatory mapped the globe encircling mid-ocean ridge system. Marie Tharp discovered a rift valley along the axis.

Marie Tharp & Bruce Heezen

Recognition of a global mid-ocean ridge system; with a rift valley

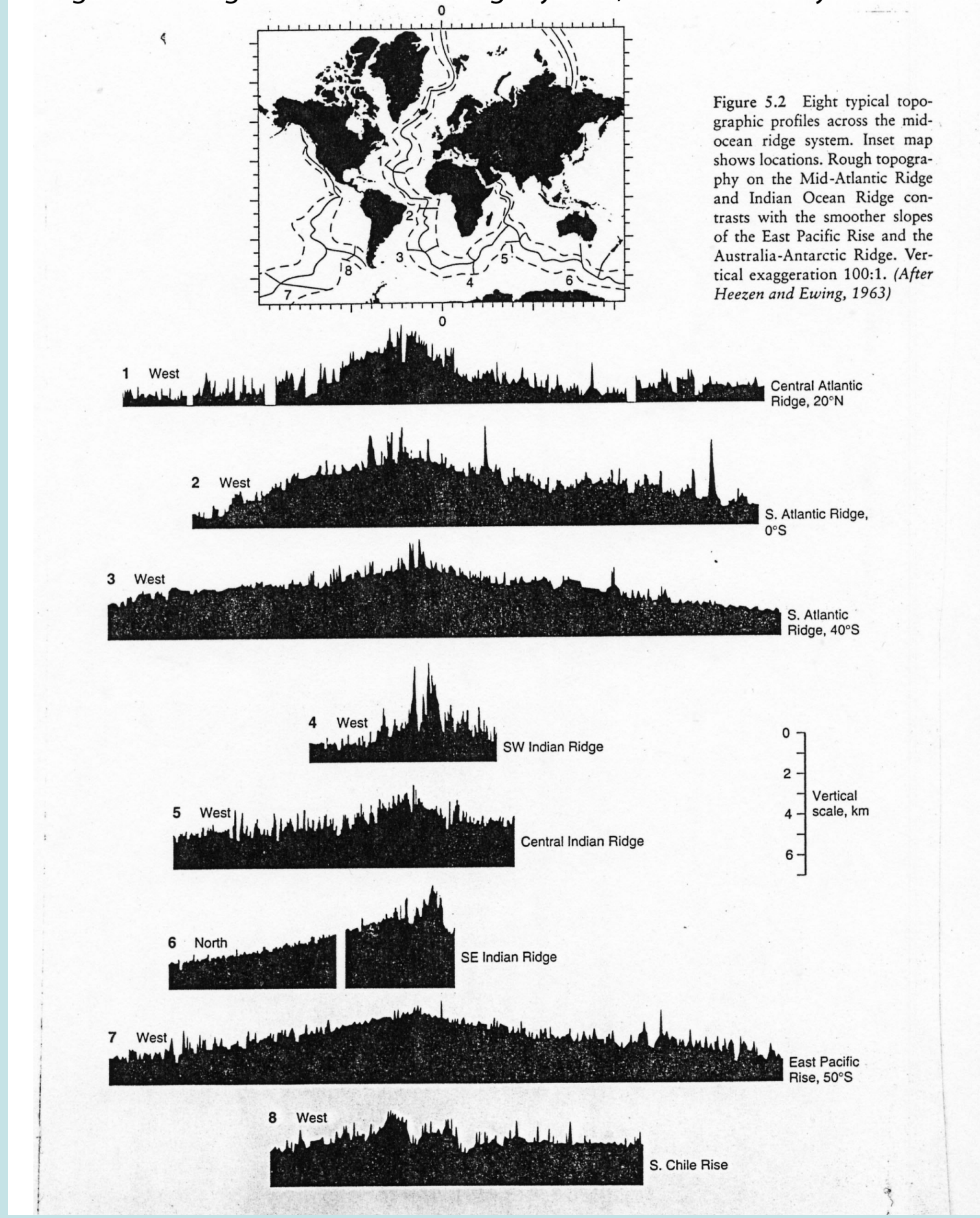
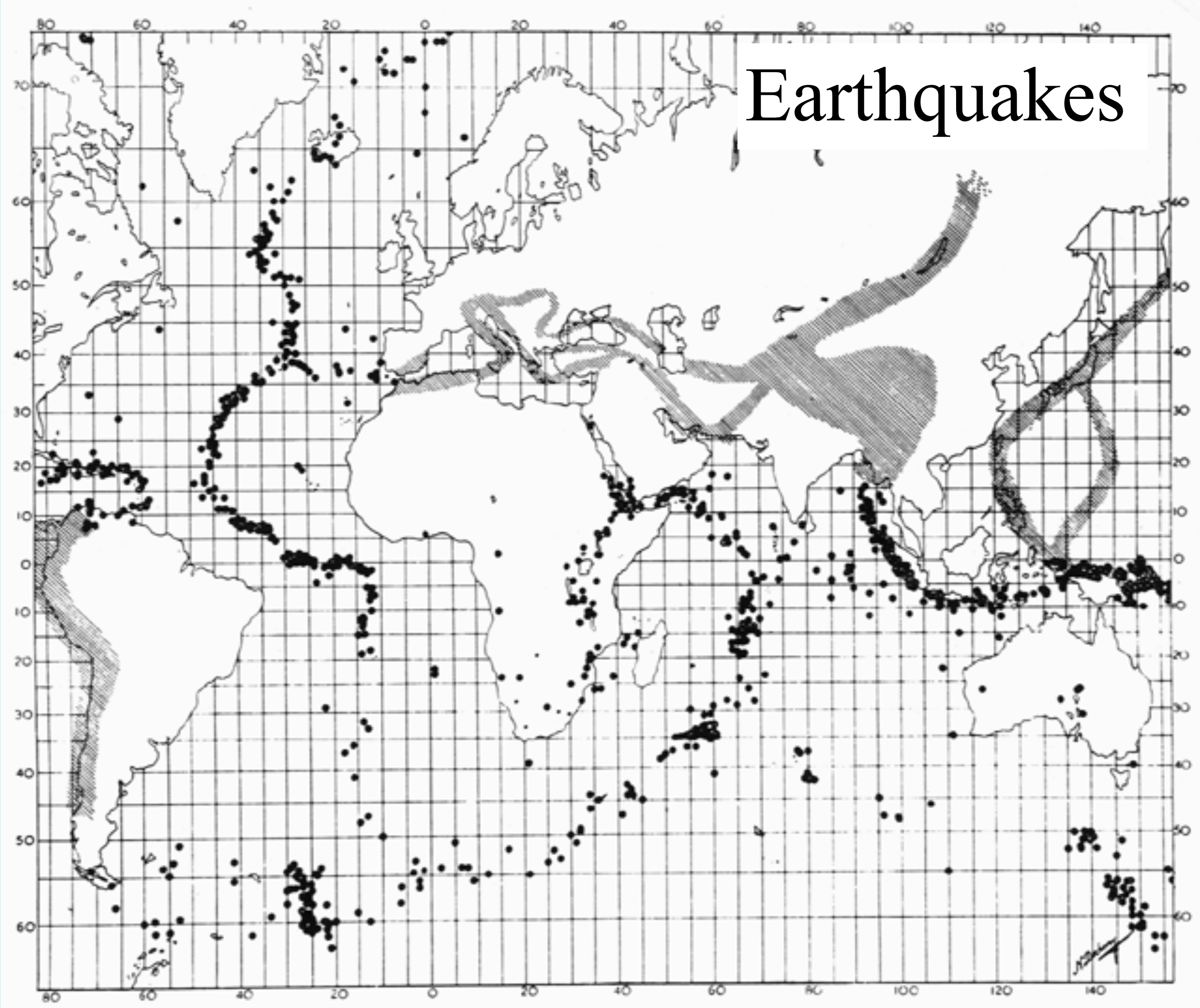


Figure 5.2 Eight typical topographic profiles across the mid-ocean ridge system. Inset map shows locations. Rough topography on the Mid-Atlantic Ridge and Indian Ocean Ridge contrasts with the smoother slopes of the East Pacific Rise and the Australia-Antarctic Ridge. Vertical exaggeration 100:1. *(After Heezen and Ewing, 1963)*

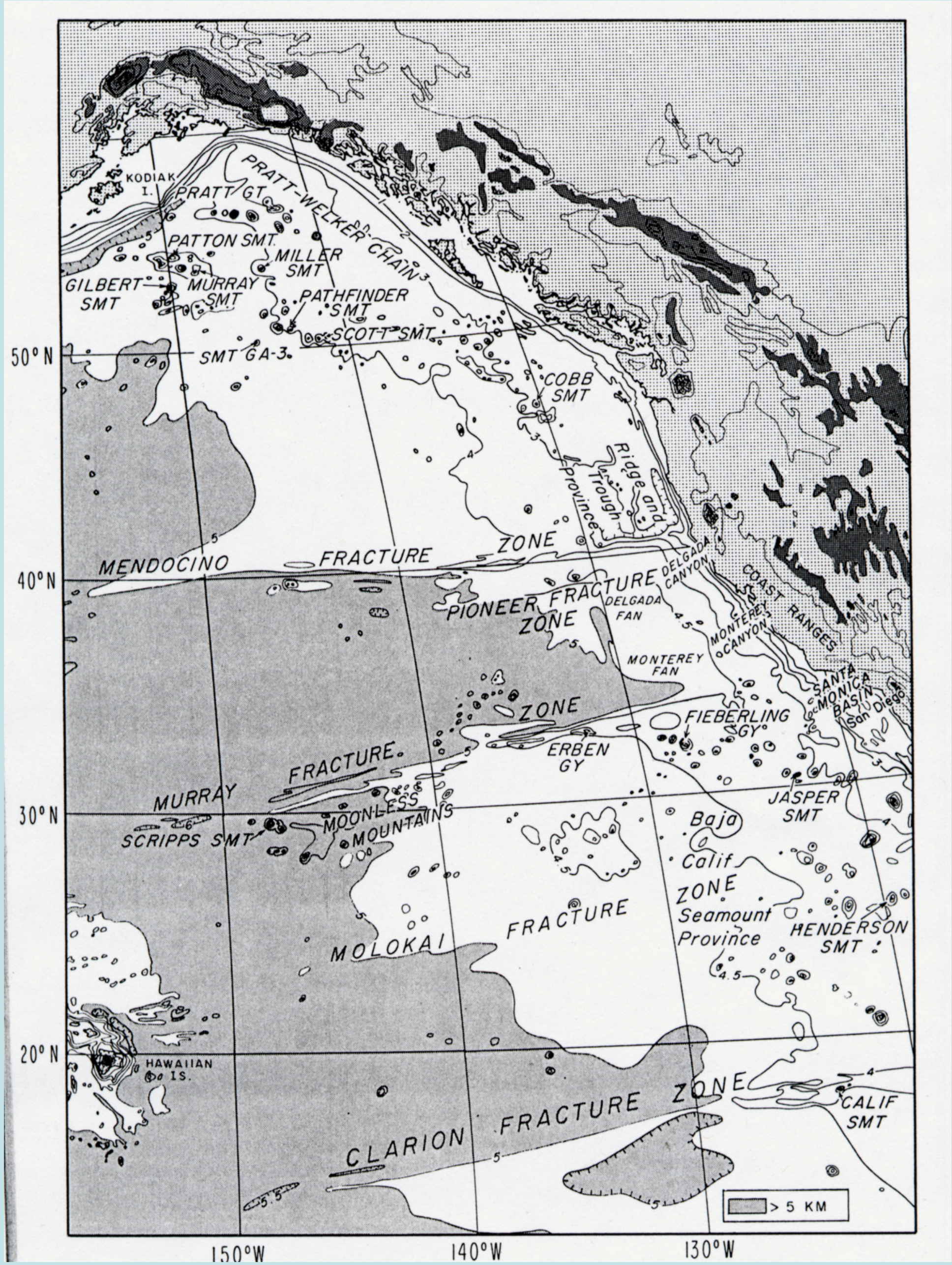


Linked rift valley with seismicity, indicating it was an active tectonic feature

In 1954, French seismologist J.P. Rothé published this map showing the concentration of **earthquakes** along the zones indicated by dots and cross-hatched areas. (Reproduced with permission of the Royal Society of London.)

Heezen thought the globe encircling mid-ocean rift valley supported the expanding Earth hypothesis of Warren Carey (1956). Ewing thought the axis was very old.

Heezen and Tharp map, from early 1970’s

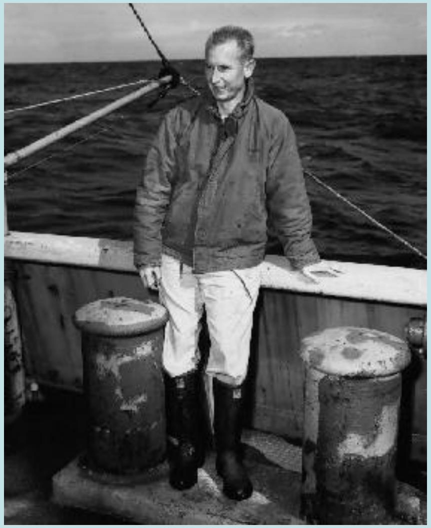


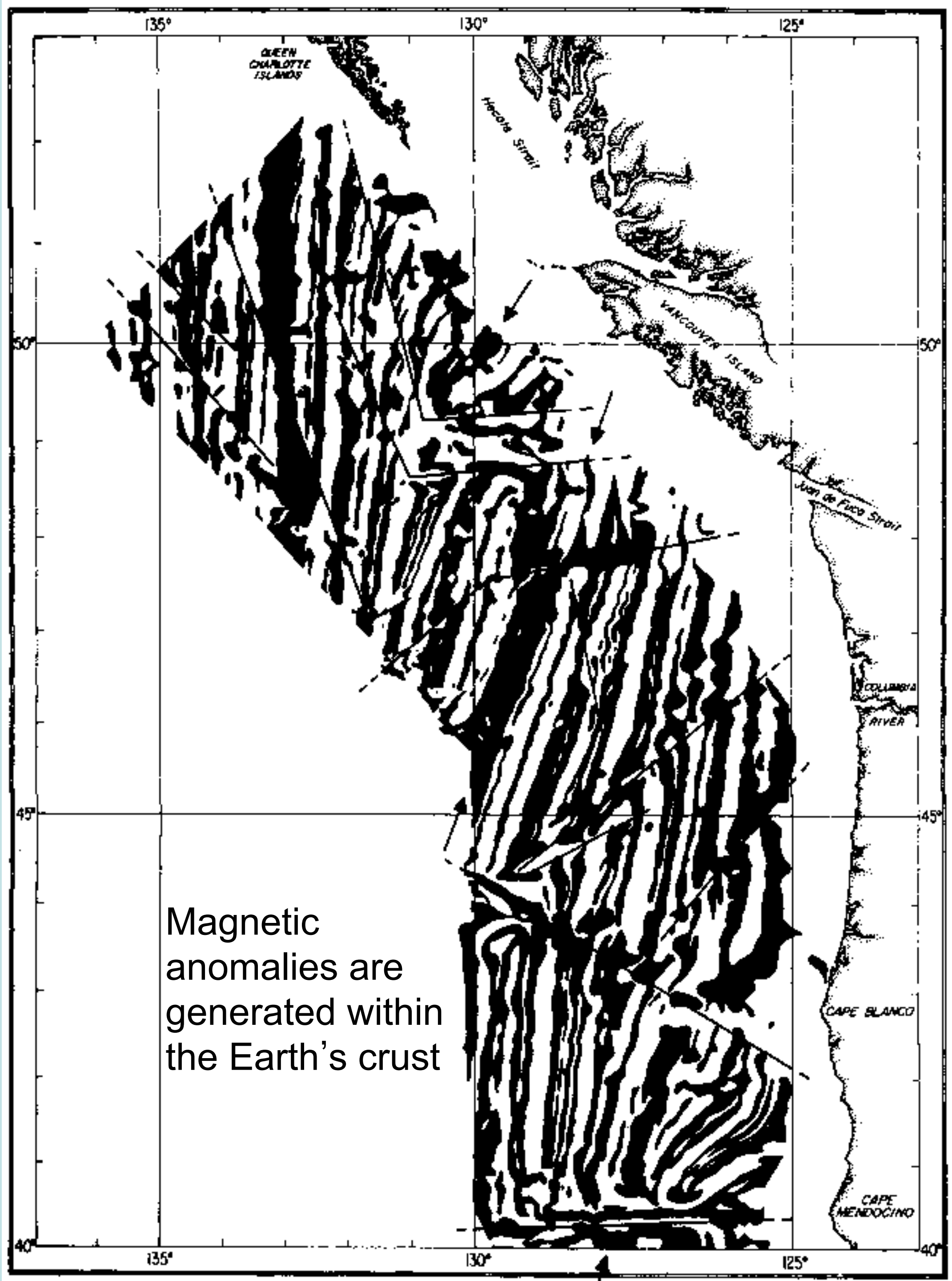
(Menard, 1964)

The expanding earth hypothesis didn't work so well in the Pacific …

Mapping of the seafloor in the Pacific revealed remarkably long and straight bathymetric escarpments. Their origin was also a puzzle.

The northeast quadrant of Bill Menard's bathymetric map of the Pacific basin.





Magnetic anomalies are generated within the Earth's crust

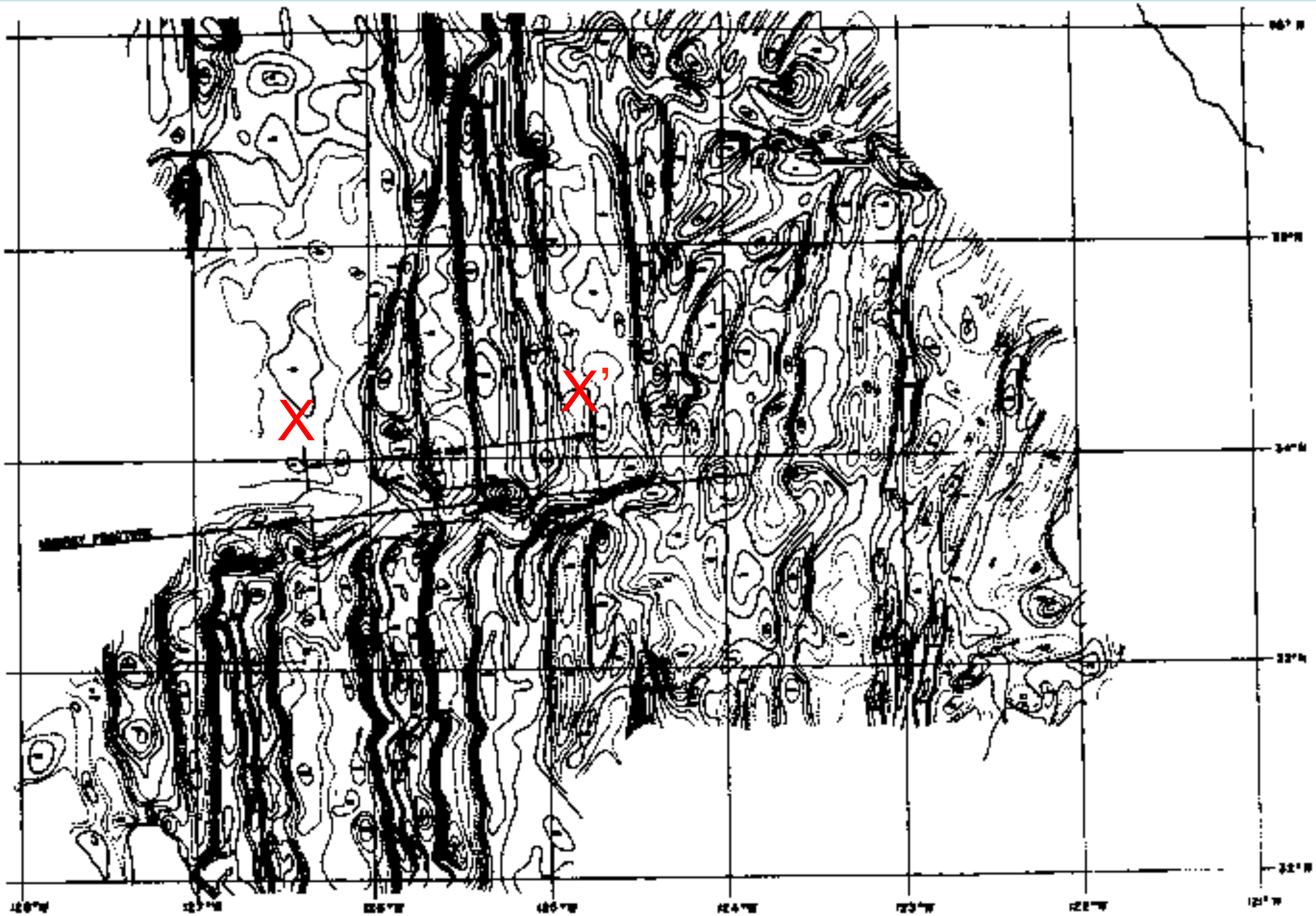
Magnetic Anomalies

positive

negative

The 1950's also saw the development of magnetometers and the mapping of lineated magnetic anomalies over the ocean floor.

From Raff and Mason, 1961, Bull GSA

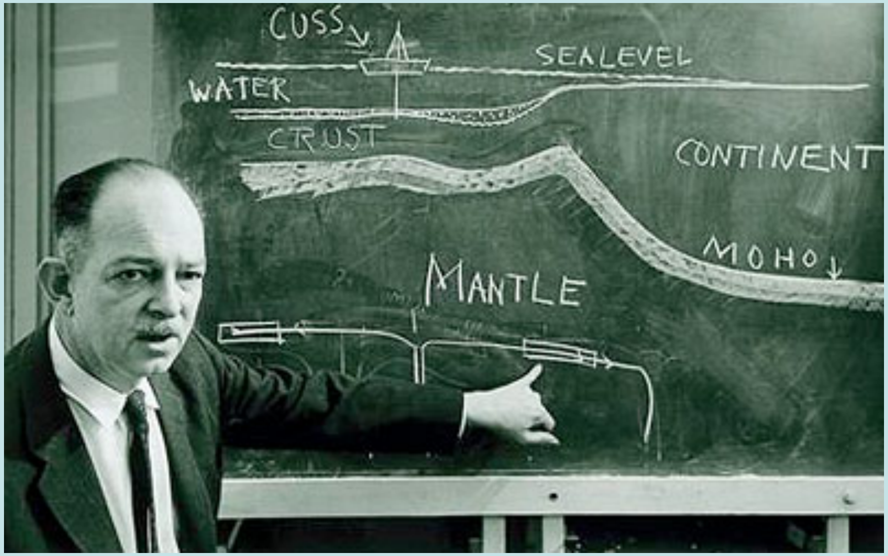


Initial results of the *Pioneer* survey of rock magnetism off the west coast of North America, after three months' operation. The distinctly linear pattern in the south-west corner of the map area, where we started, persuaded us to continue with the survey. (From Mason, 1958, Figure 2.)

Magnetic anomalies indicated that there were huge offsets on the faults;

See offset marked on figure

but origin of anomalies was unknown



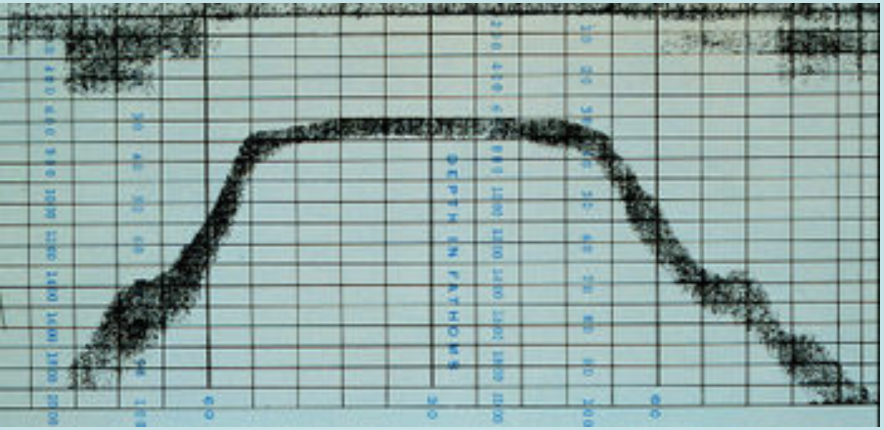
Harry Hess's amazing paper - "History of Ocean Basins" (1962)

Proposed idea of sea-floor spreading

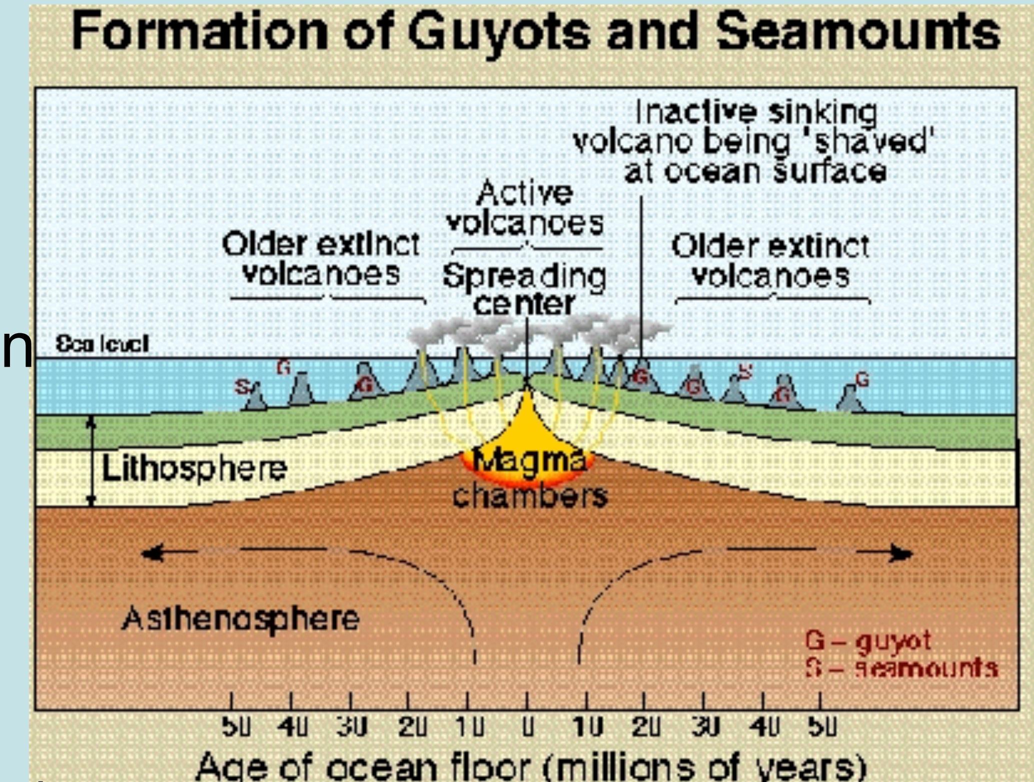
Based on very little data; he called it "an essay in geopoetry"

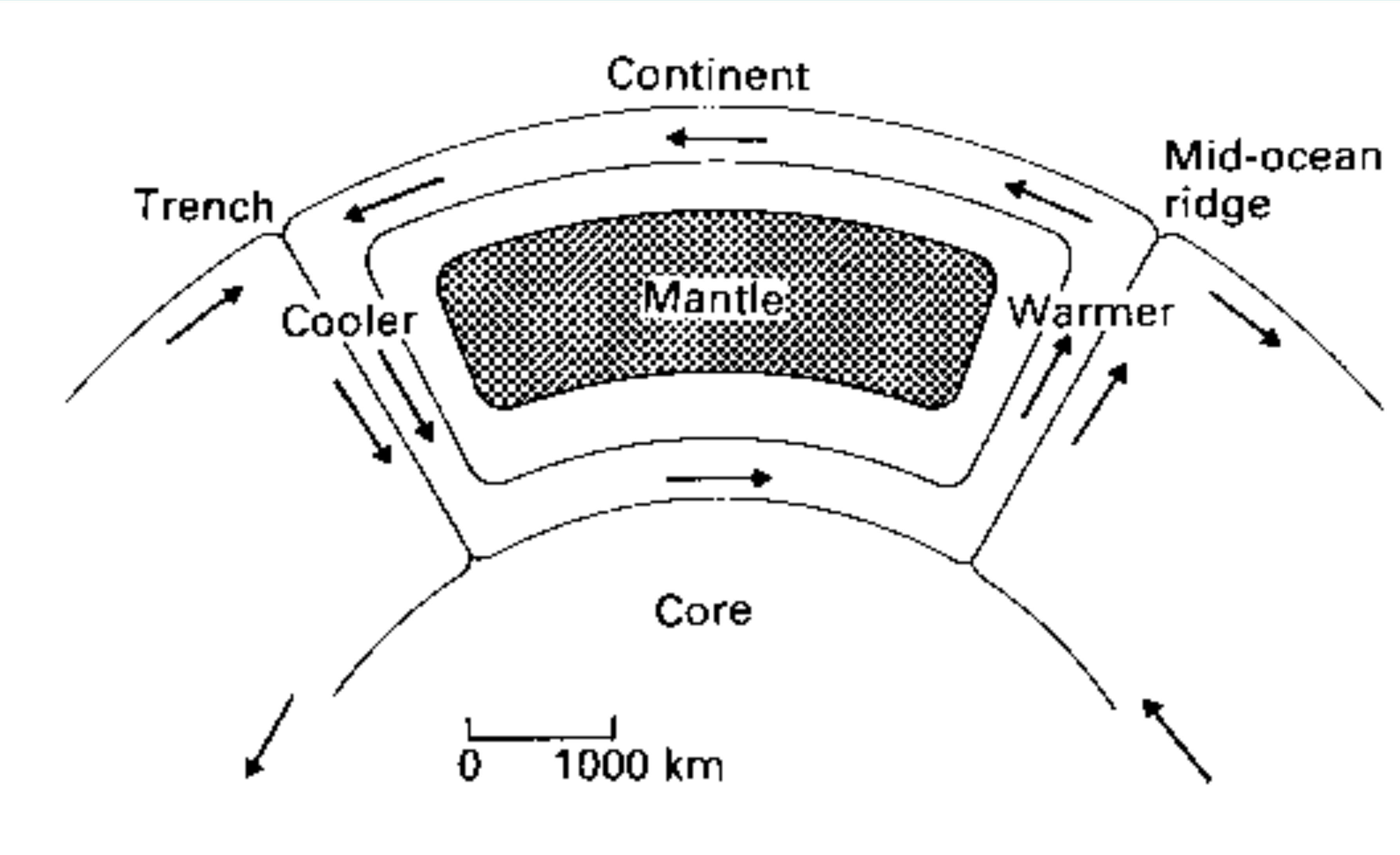
- Mantle is convecting at rate of 1 cm/yr
- Mid-ocean ridges are ephemeral features having a life of 200 to 300 Ma
- The whole ocean floor is virtually swept clean every 300 - 400 Ma
- Continents are carried passively on the mantle
- Leading edges are strongly deformed.

Depth sounder record across a flat-topped Pacific seamount

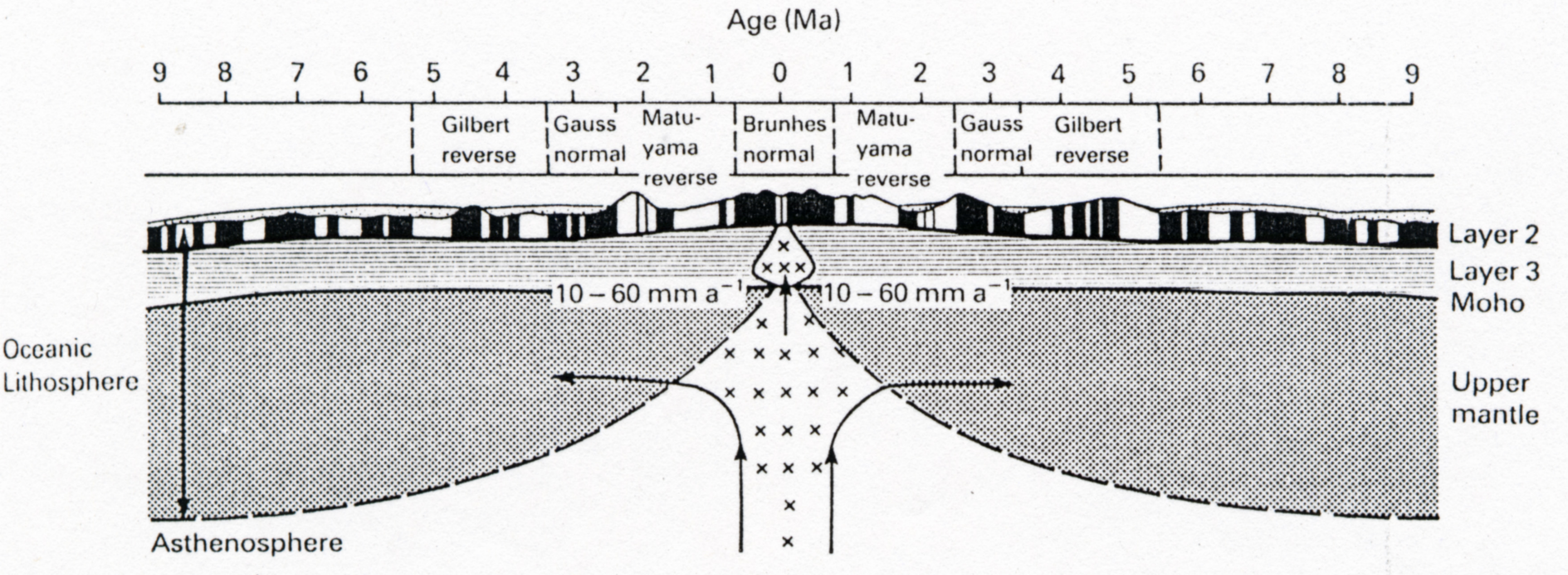


During WWII, Hess had commanded a transport ship in the Pacific and had become fascinated by flat-topped seamounts. He called them guyots, after the flat-roofed Guyot Hall at Princeton, and connected them with the aging/ cooling of the ocean crust.





The concept of sea floor spreading (after Hess, 1962)



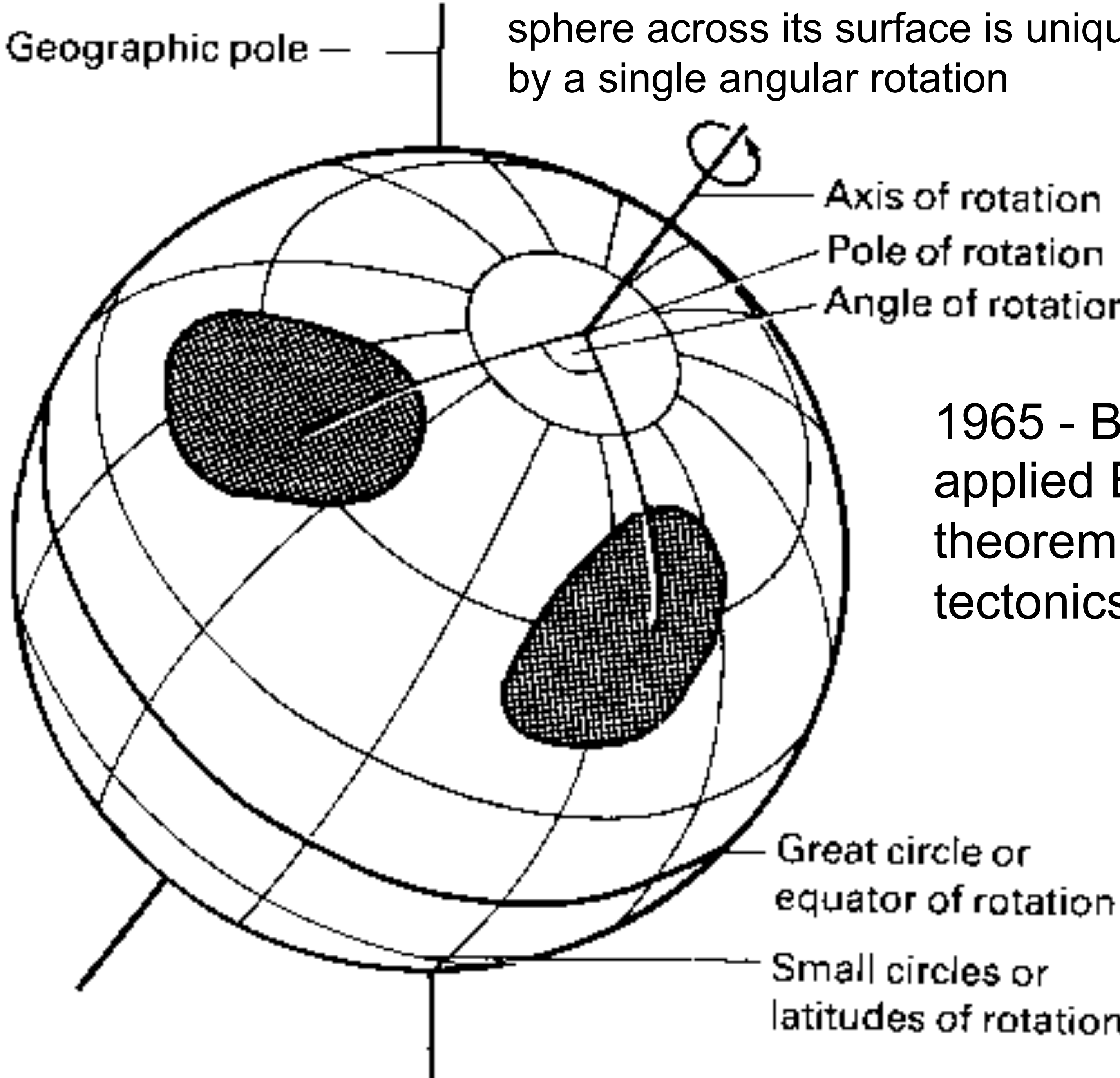
Fred Vine and Drum Matthews (1963):

Linear marine magnetic anomalies represent reversals of the magnetic field recorded at the ridge axis by new oceanic crust as it cools down.

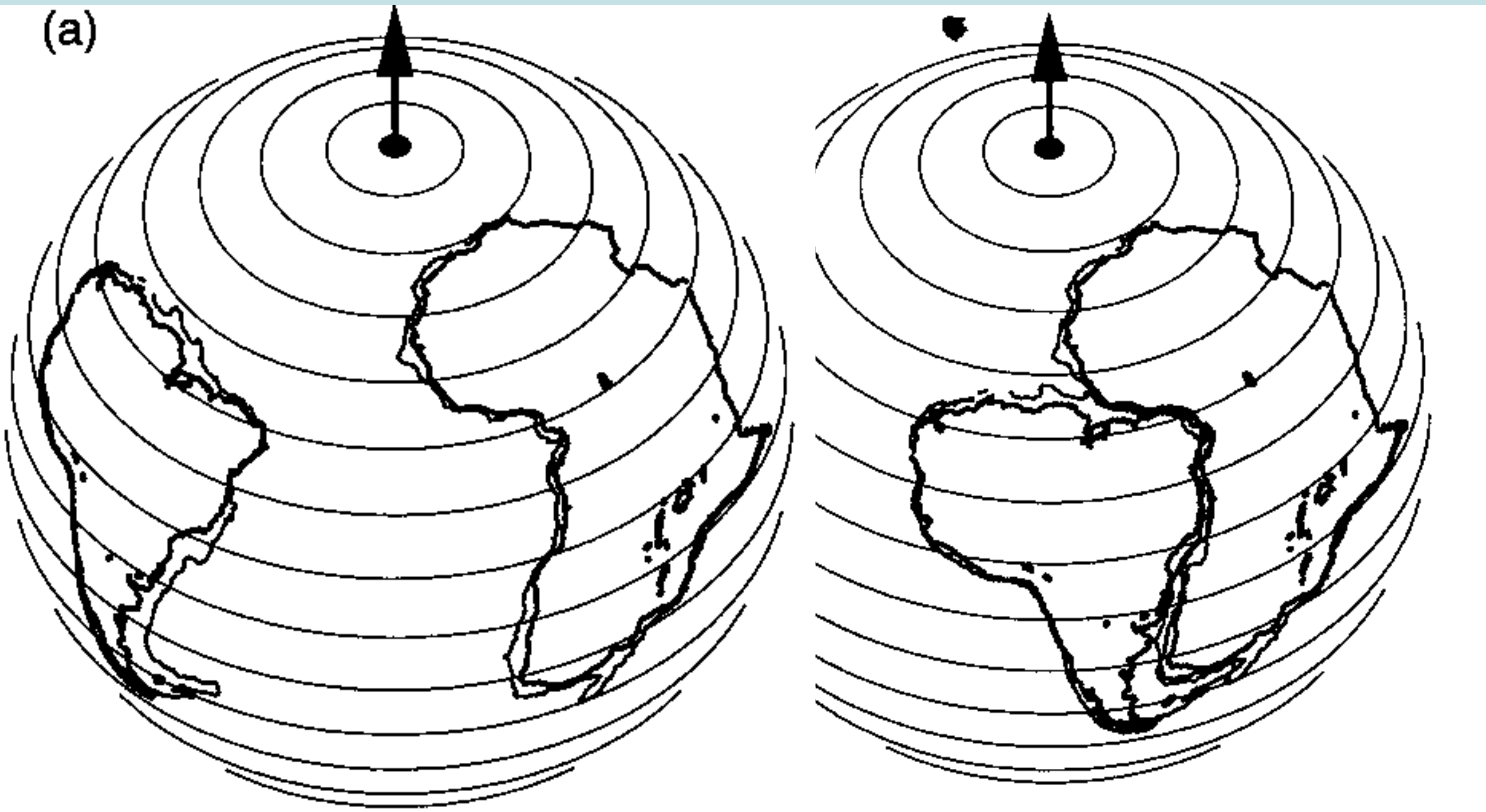
Magnetic stripes provide a way of dating the ocean floor and tracking the motion of the plates.

Vine was a first year grad student.

Euler's Theorem: movement of a portion of a sphere across its surface is uniquely defined by a single angular rotation



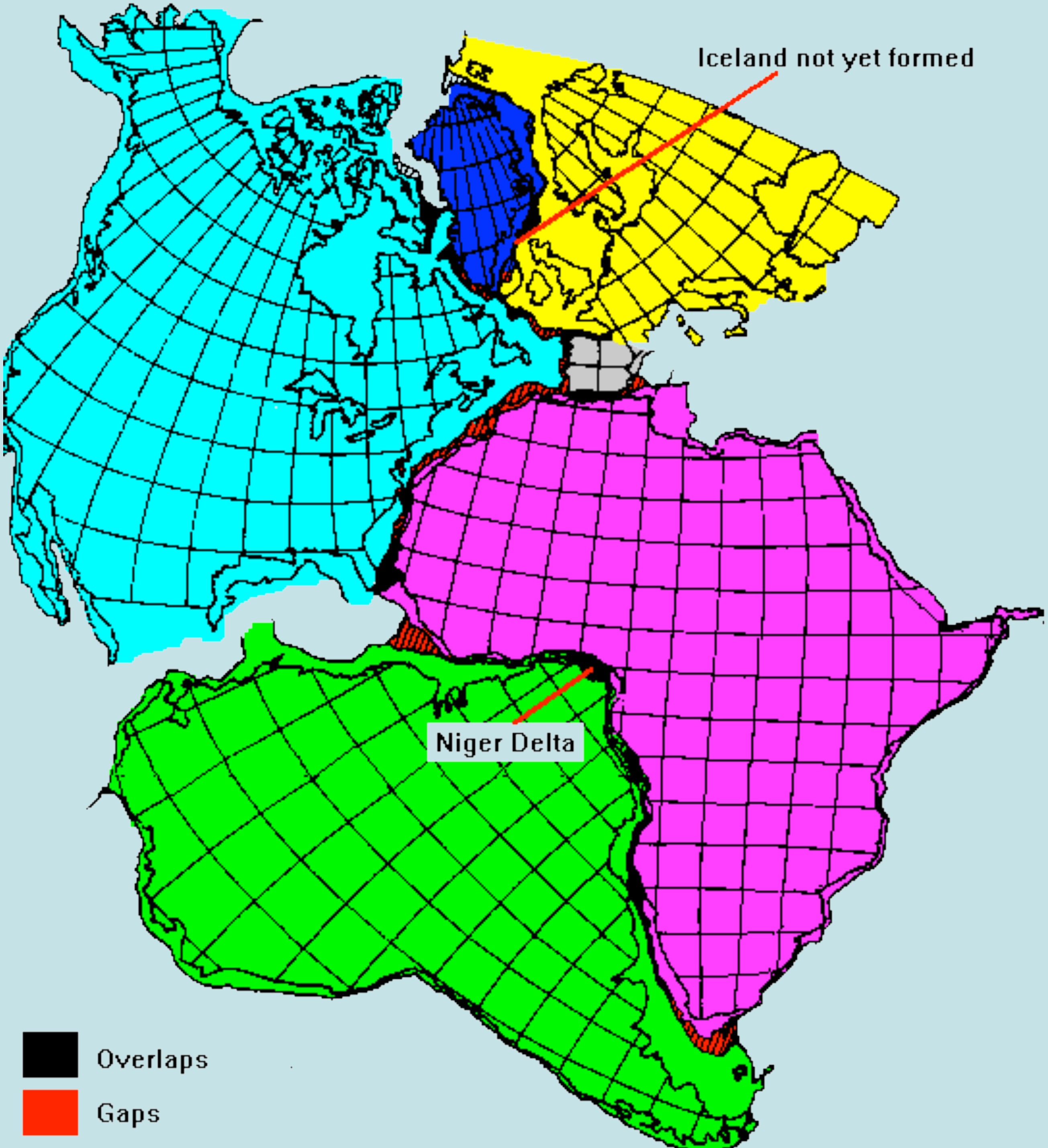
1965 - Bullard applied Euler's theorem to plate tectonics



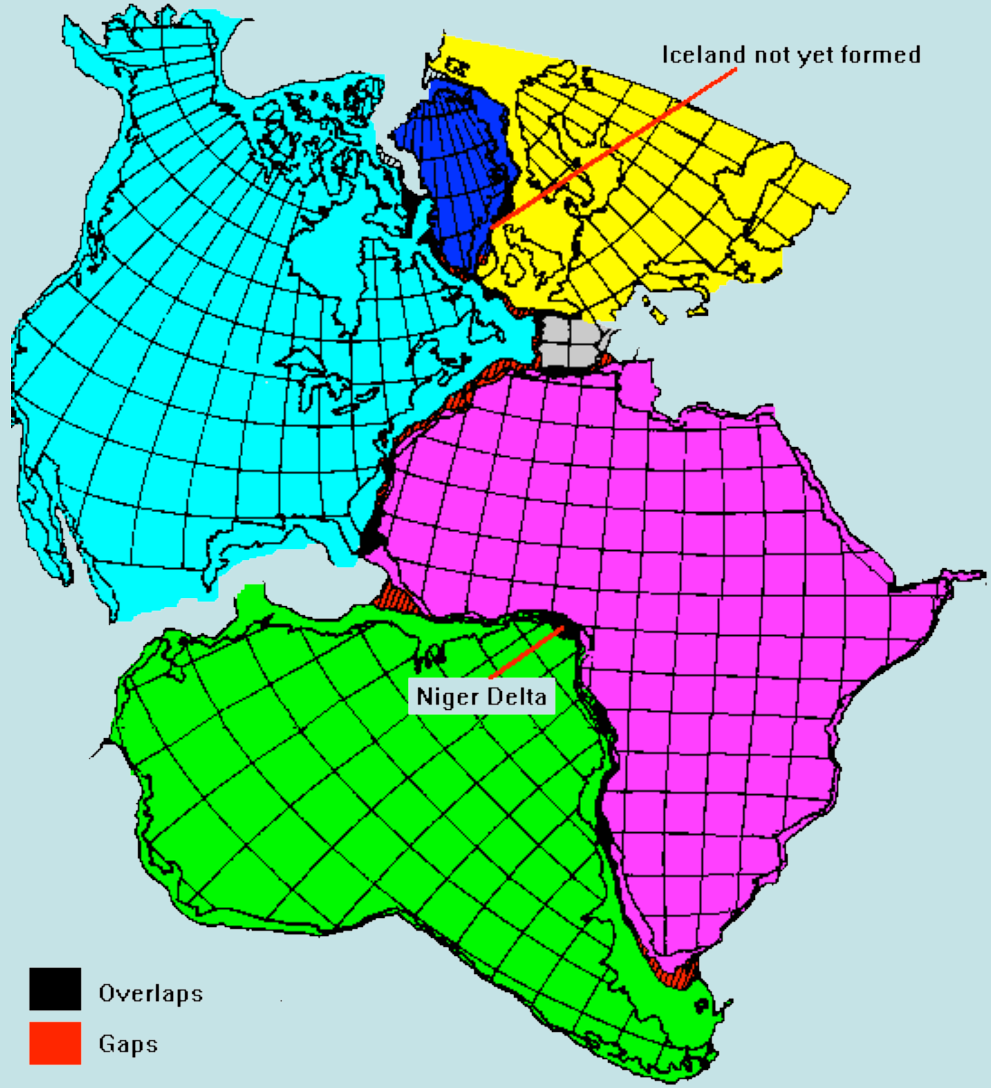
These plots show lines of latitude about the Euler pole (not the spin axis). The Euler pole that closes up South America and Africa is in the Central Atlantic

Computer generated “best-fit” reconstructions by Bullard et al. (1965) convinced many of the rigidity of plates and the reality of continental drift.

Here: fit of 500 fathom isobath

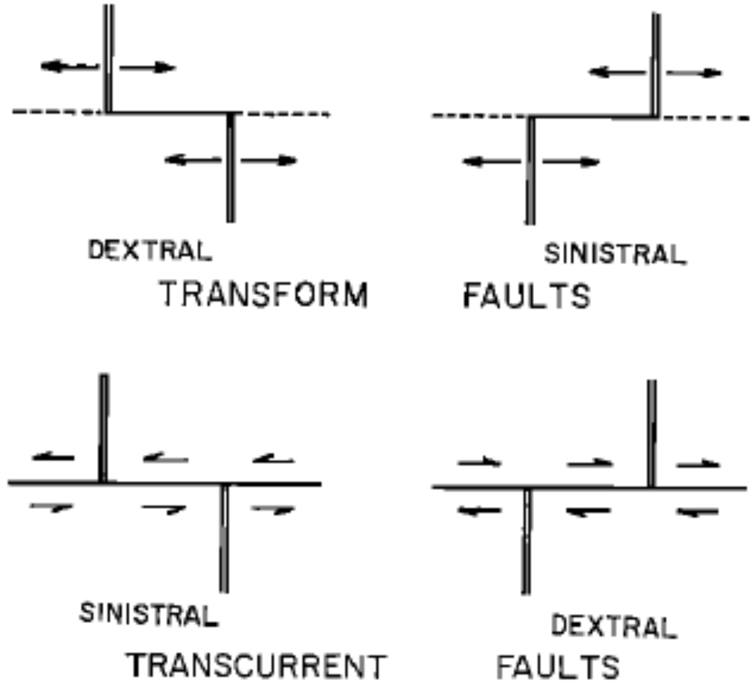


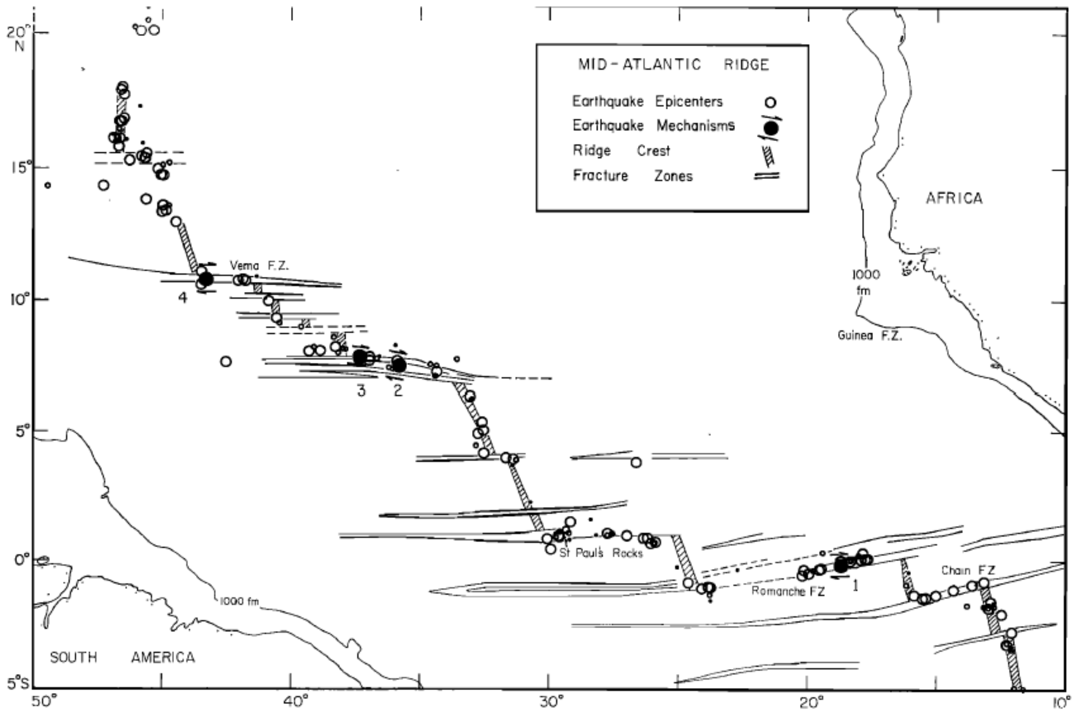
Wegener, 1915

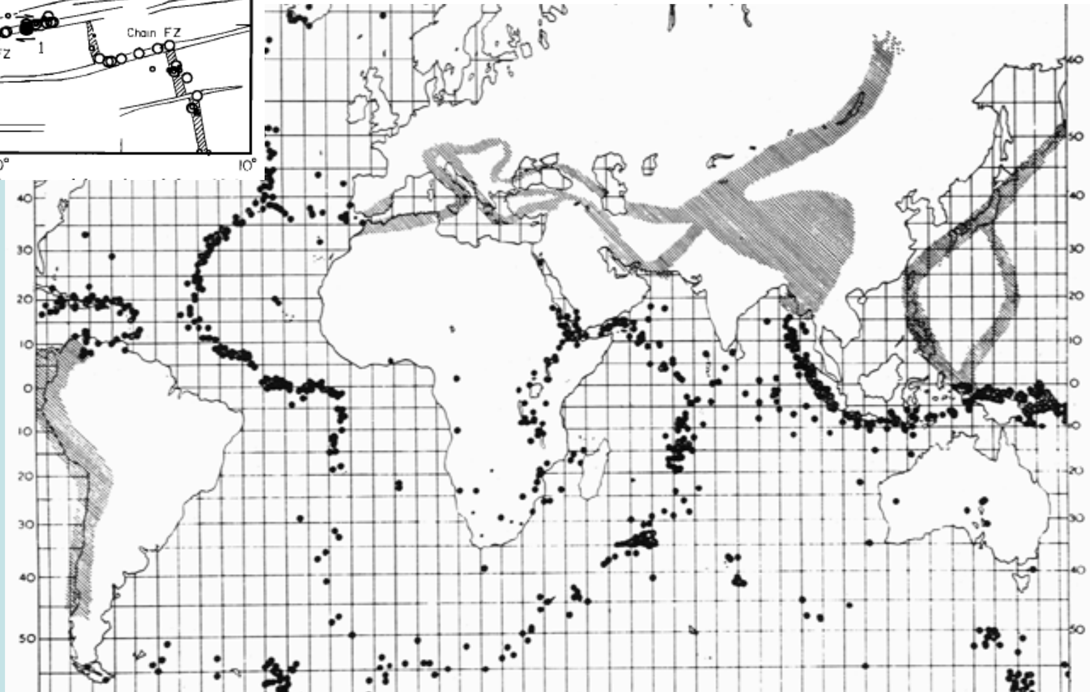


Bullard et al.,1965

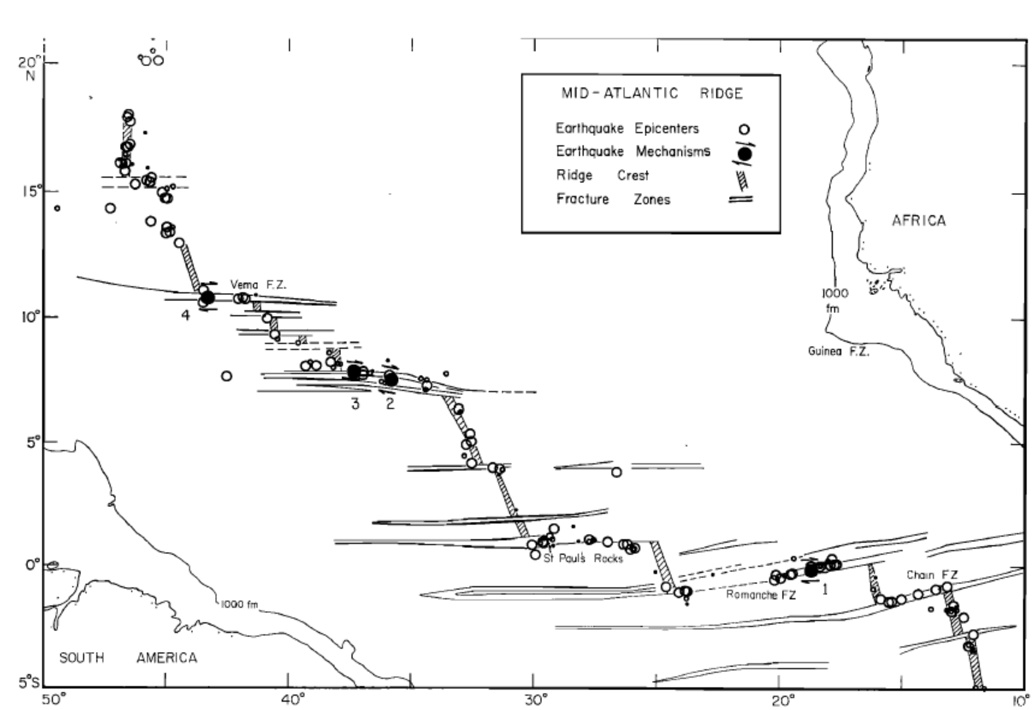
Transform Faults

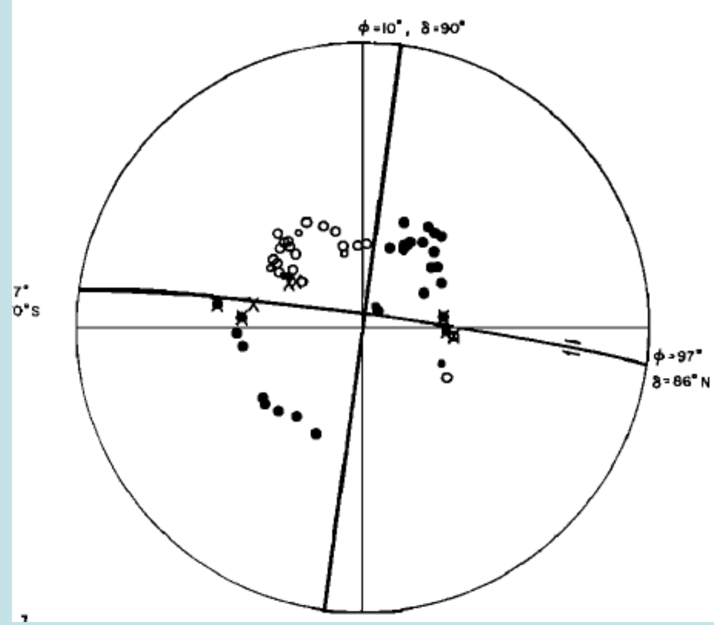




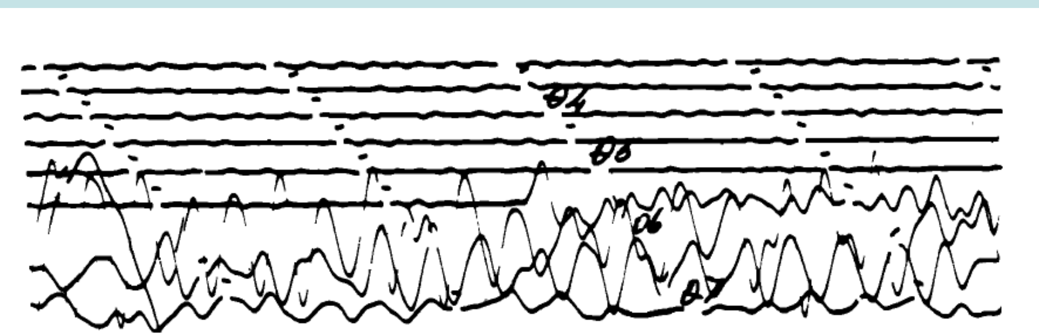


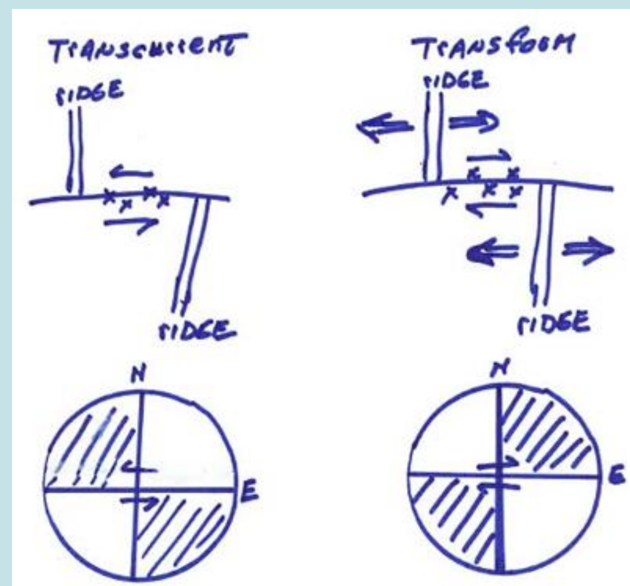
J. Tuzo Wilson (1965)





Focal mechanisms; fault plane solutions

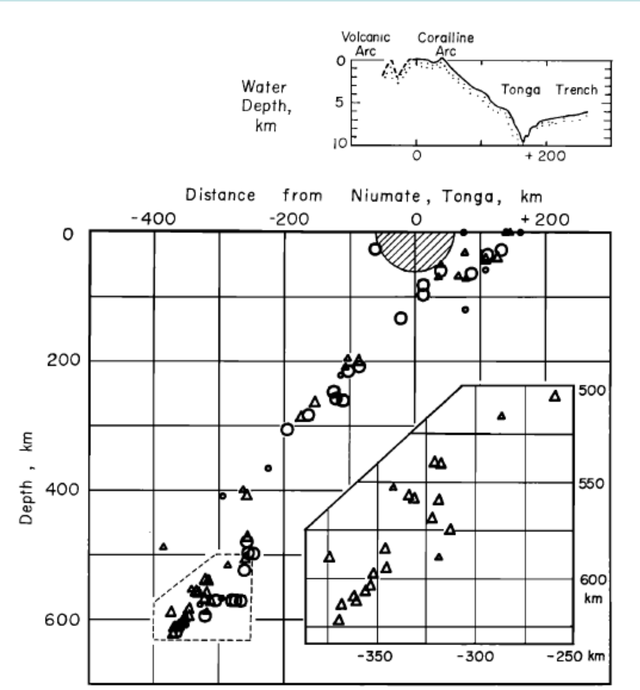


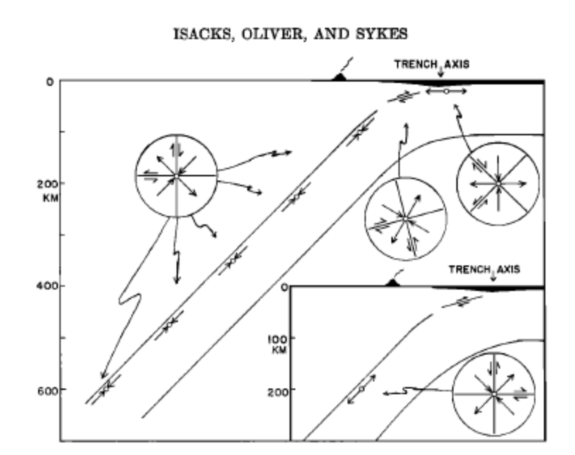


The seismologists verify Wilson's transform fault hypothesis;
World wide seismic network

Lynn Sykes (1967)

Imaging the subducting slab





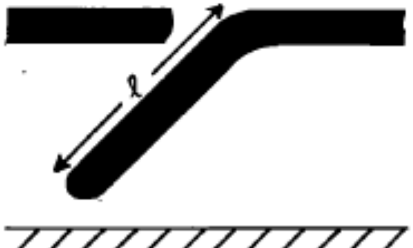


Fig. 14a. Length l is a measure of the amount of underthrusting during the most recent period of sea-floor spreading.

Fig. 14b. Lithosphere is deformed along its lower edge as it encounters a more resistant layer (the mesosphere).

Fig. 14c. Length of seismic zone is the product of rate of underthrusting and time constant for assimilation of slab by upper mantle.

Isacks, Oliver and Sykes (1968)

Forces acting on plates

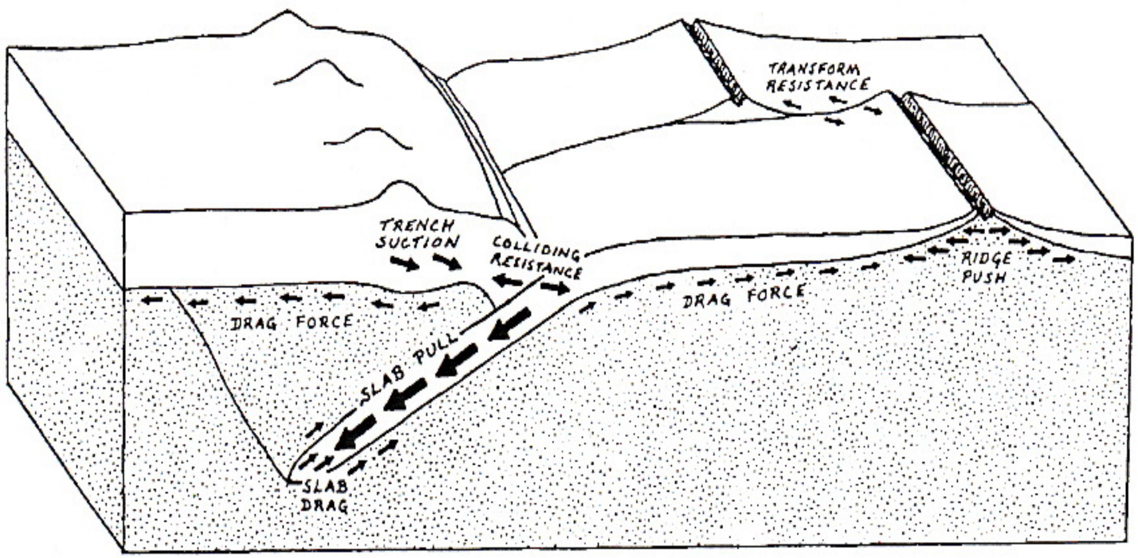


Figure 10-6.
Forces acting on plates.

Cox & Hart

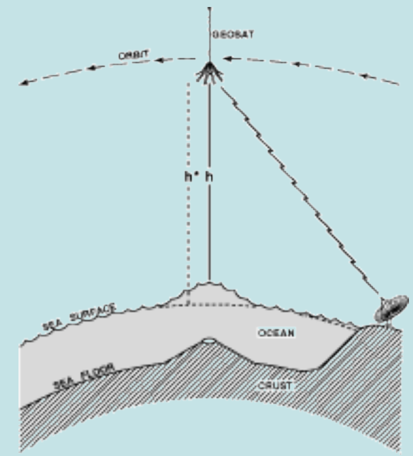
By the mid-1970's plate tectonics ruled supreme

Driving Forces:

Slab Pull
Ridge push
Mantle Drag
Continental Drag
Slab Drag
Trench suction
Transform fault resistance

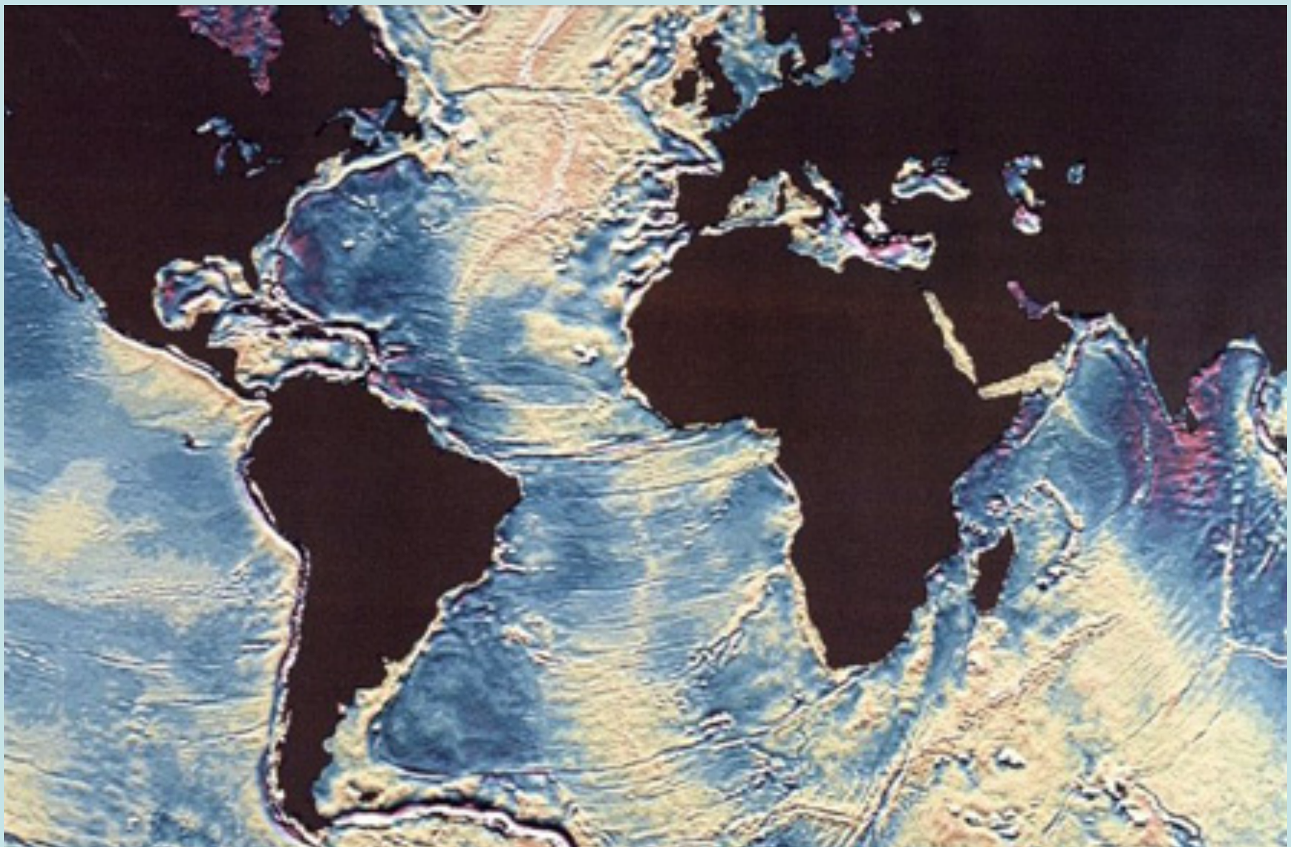
Satellite radar altimetry observations, starting in the early 1980’s, revolutionized the mapping of features on the ocean floor.

For the first time, fracture zones could be accurately mapped in remote areas of the oceans.

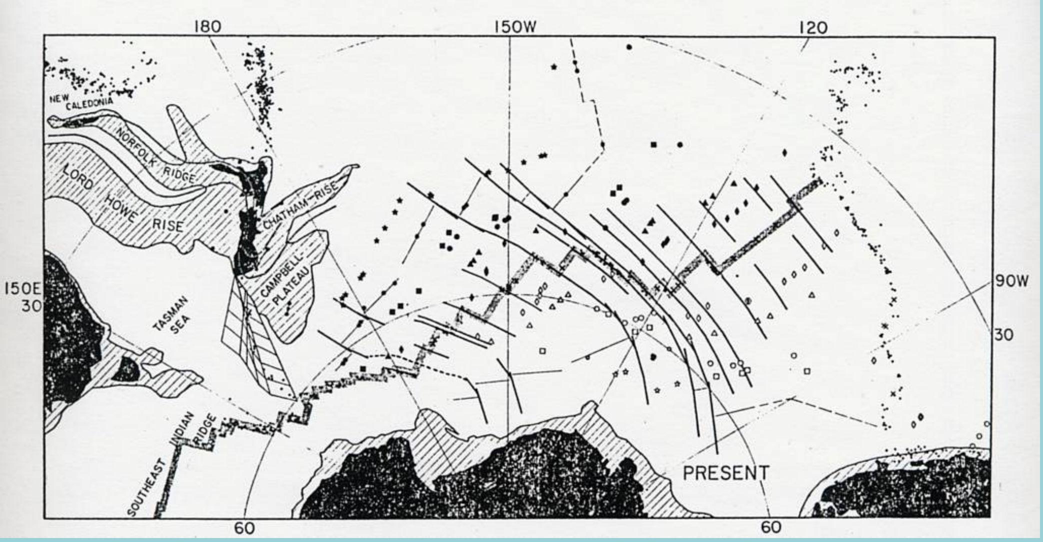


Measure distance from satellite to sea sea surface to a few cm’s.

Water piles up over seamounts and ridges, is lower over trenches



Bill Haxby’s 1985 gravity map based on Seasat

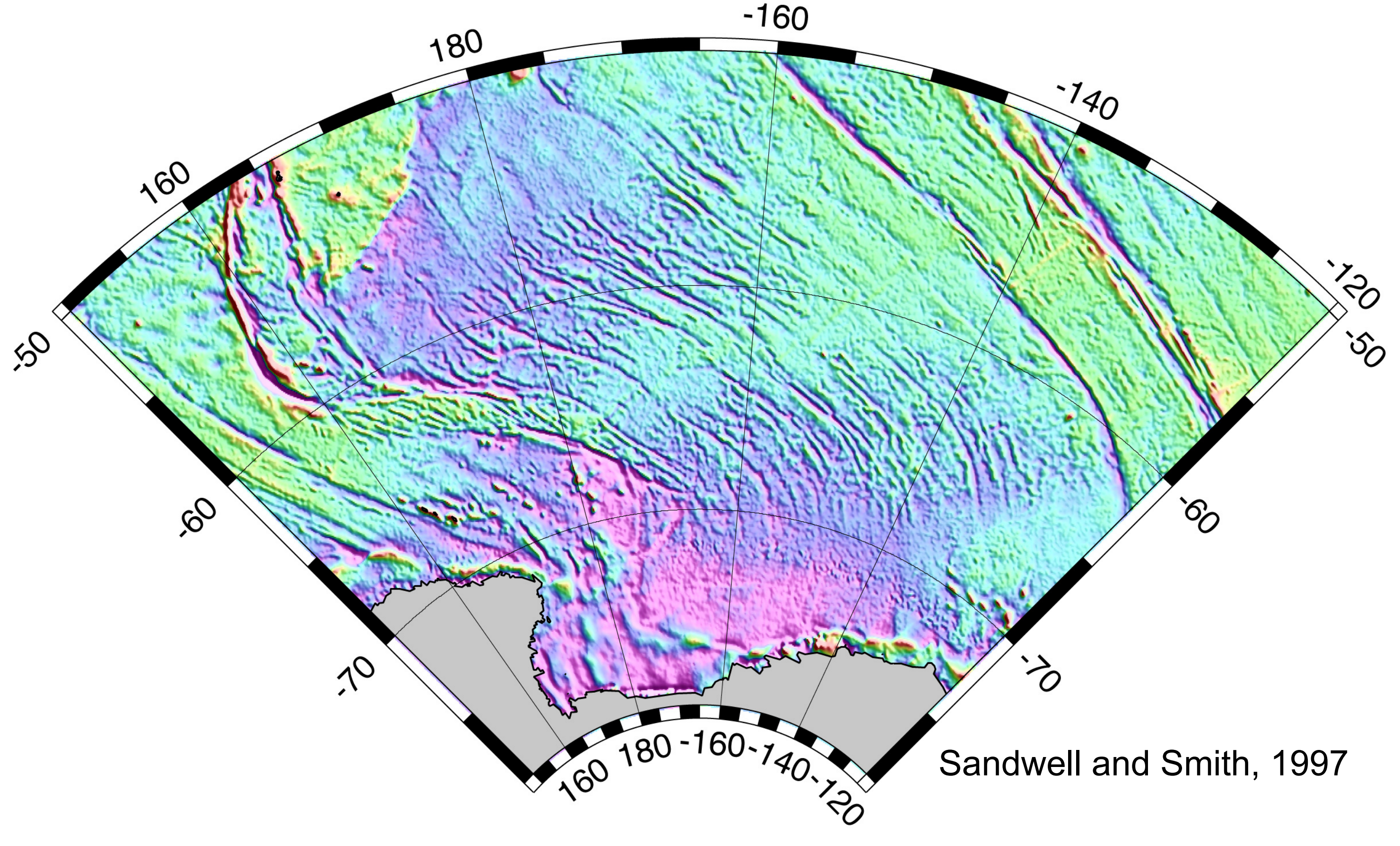


Map based on shipboard data - 1975

Newer satellite data were even better … Geosat

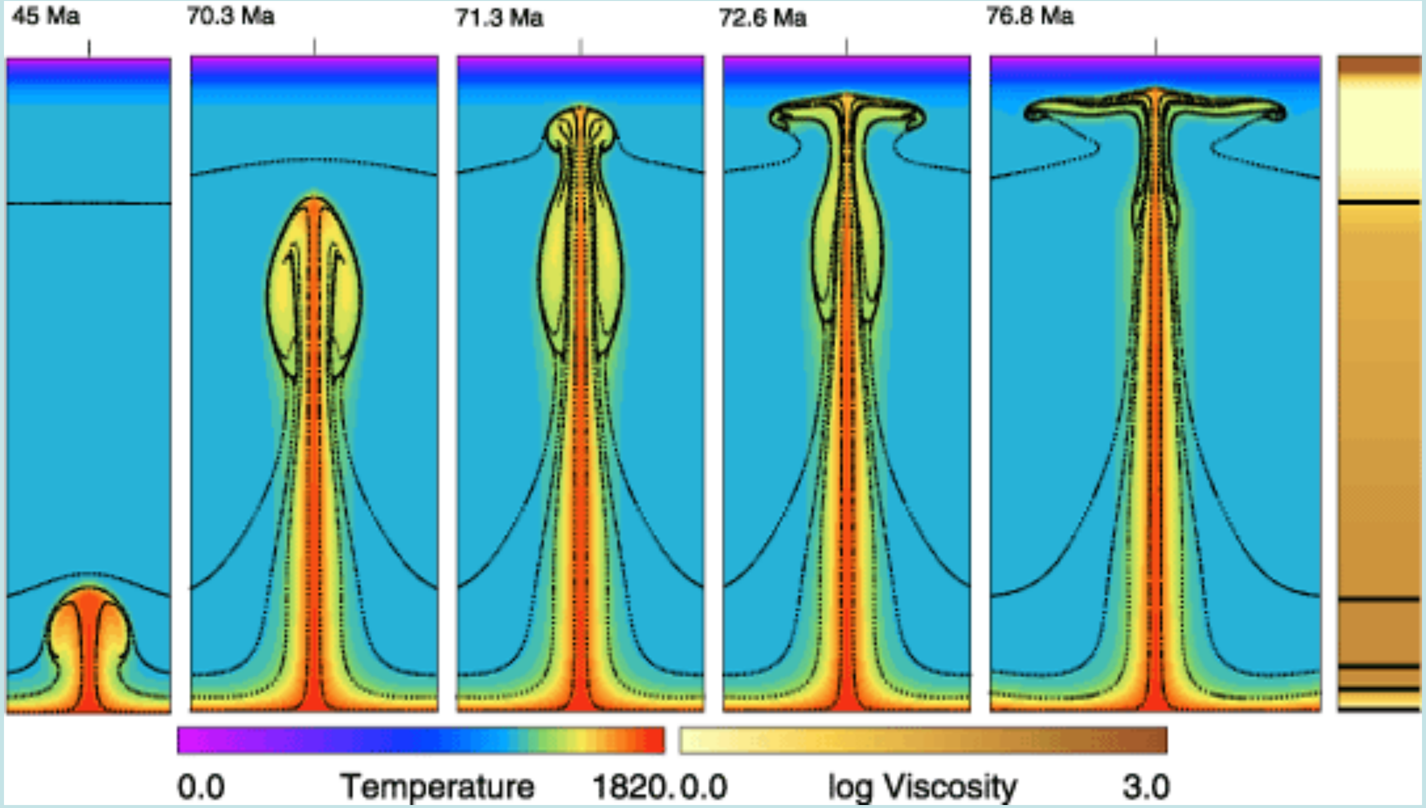
Driven by military …

The fracture zones on the Pacific-Antarctic ridge can be followed towards Antarctica with twists and turns that are not easily resolvable with shipboard data



Sandwell and Smith, 1997

Now, geophysicists are modeling the dynamics of mantle convection. Plumes “drift’ in the mantle wind; plumeheads smash into the undersides of plates.



G. Davies