Afterthoughts of a witness

Xavier Le Pichon
Collège de France, Paris
June 25 2018

The horses of Lake Ladoga of Curzio Malaparte

- **In the sixties, Earth Sciences were in a super cooled state.** Anything could lead to the solidification of the new paradigm any time, anywhere. Striking proofs of the existence of this supercooled state was the independent proposal of the corolary *Sea Floor Spreading (SFS) = Magnetic Anomalies* by Fred Vine and Lawrence Morley in 1963 and of the Earth spherical plate kinematics in 1967 by Jason Morgan and Dan Mc Kenzie.

The context of my “Sea Floor Spreading and Continental Drift” paper

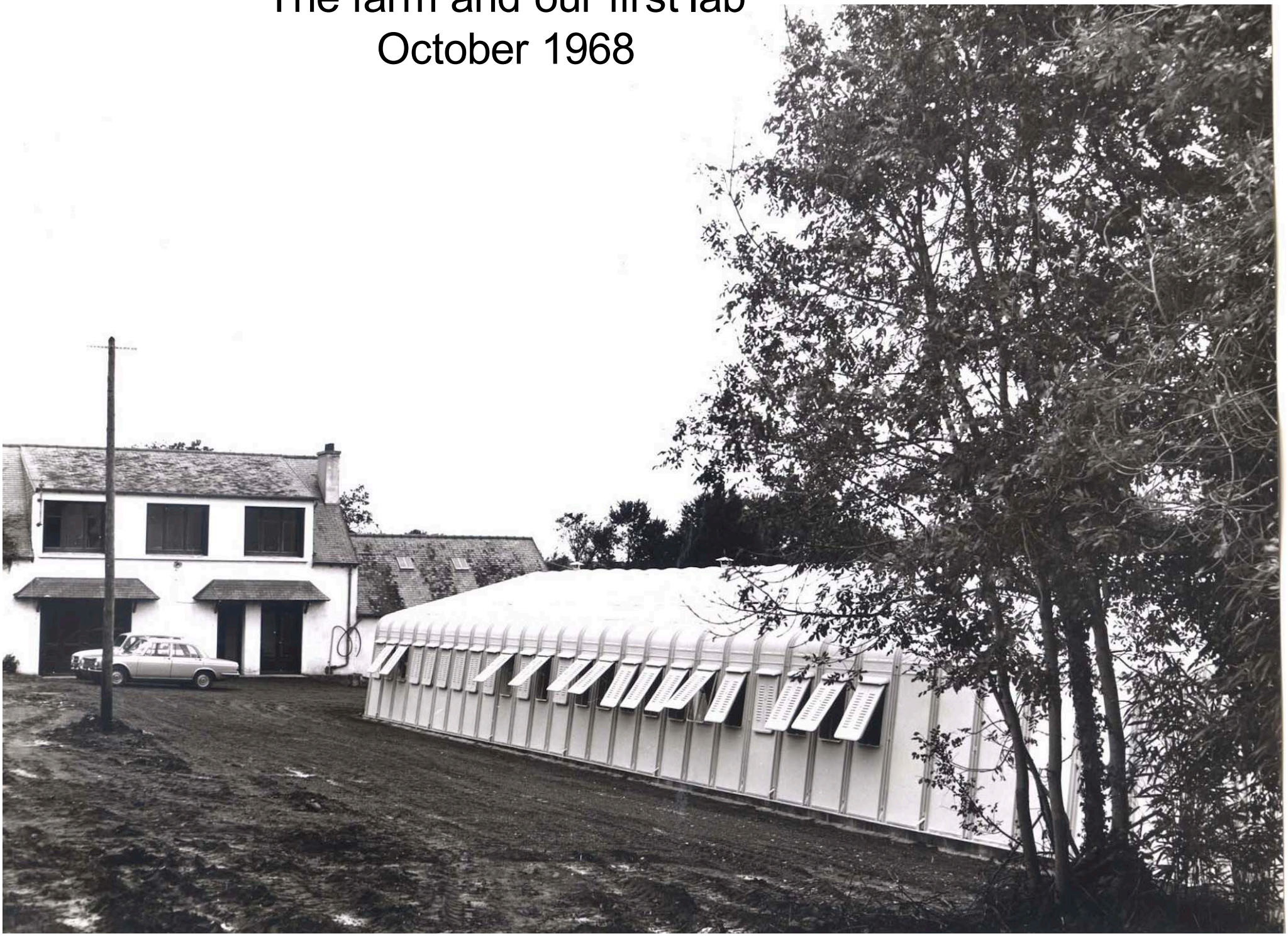
By June 1967, I was already negociating my return to France. I wrote this paper knowing that I would be gone at the end of the year and would not have the possibility to exploit the new paths I was opening.

The IPGP having rejected my offer to join it (Roland Schlich already occupied marine geophysics), I received an offer of the president of CNEXO to be his scientific advisor for Earth Sciences. He accepted my condition to create in the future Centre Océanologique de Brest a mutidisciplinary research department that I would start with the biologist Lucien Laubier.

My ambition: a French Lamont.

Centre Océanologique de Bretagne 2018

The farm and our first lab
October 1968



Walter Sullivan New York Times May 5 1968

Science

Tracing the Drift of the Continents Over Millions of Years

The mapping of what seems to be identical magnetic "time-tables" on the floor of the world's three great oceans has emboldened scientists to construct a schedule of past continental rupture and drift. So extensive now is the magnetic mapping that scientists from Columbia University's Lamont Geological Observatory are able to ascribe ages to more than half the Pacific Basin.

A French scientist, who until recently was working with the Lamont group, has redrawn the maps of the world for various epochs back to 70 million years ago. From the magnetic timetables he concludes that, at that time, Australia was close to Antarctica, India was detached from Asia and the Atlantic Ocean was almost as narrow as the "Atlantic River" displayed in some airline ads.

Rotational Motion

A major implication of the timetables is that much of the continental motion was rotational. For many years some geophysicists — until recently a minority—believed that the continents, like great barges of light, granitic rock, plowed slowly through the heavy underlying rock of the earth's interior. However, doubts were raised as to what could push the continents in this manner. Rotational motion presumably would require less energy.

According to the Lamont team, Africa, India, Australia, Antarctica, and the Americas were a single land mass as recently as 120 million years ago. The breaking away of Africa from India, Australia and Antarctica began at what is now the eastern tip of Africa and propagated down the East Coast toward the Cape of Good Hope. By 100 million years ago the separation of the continents was complete.

The changing latitudes of these various land masses relative to the magnetic poles have been determined from the magnetism frozen into lava flows and other rocks formed at various times in their history.

Mountains Created

It appears that Africa, during the break-up period, remained in the same latitude. Antarctica drifted south toward its present position at the South Pole. India drifted north until its collision with Asia formed the world's highest mountains — the Himalayas. Africa rotated clockwise, compressing the Mediterranean to its present size and crumpling Southern Europe to form the Alps. The Americas drifted westward, opening up the Atlantic.

From the motions of the sea floor deduced from earthquake data the Lamont scientists concluded that the spreading of the sea floor thought to account for these movements is active today.

The Lamont group has reported its findings in a series of articles submitted to the Journal of Geophysical Research. The basic data were described in the March 15 issue, as well as a preliminary interpretation of its significance. In the June 15 issue, Dr. Xavier Le Pichon of France, who worked with the Lamont group, will further interpret the continental movements.

The Lamont group included Dr. James R. Heirtzler, who now heads the Hudson Laboratories of Columbia University at Dobbs Ferry, N. Y. Other contributors were G. O. Dickson, E. M. Herron and W. C. Pitman 3d.

Their work is based on the hypothesis that hot, soft rock is welling upward into the mid-ocean ridges and spreading across the ocean floors from both sides of these ridges. As the rock cools it becomes imprinted with the magnetism of the earth in existence at that time.

It is now well established that at irregular intervals, ranging from 30,000 years to more than 2 million years, the polarity of the earth's magnetism flips over. These magnetic reversals are recorded in the newly forming rock on the ocean floors. Hence the oceans are paved with ribbons of rock laid down, alternately, when the earth's magnetism was aligned as of today or of reversed polarity.

These reversals can be detected magnetically by ship. Researchers from Lamont and other oceanographic institutions have now charted these magnetic patterns across extensive portions of the Atlantic, Pacific and Indian Oceans, identifying the ridges that are currently active.

One of these parallels the northwest coast of the United States a short distance off shore. The material spreading from this ridge has laid down magnetic patterns that can be traced westward for 2,000 miles, representing a record extending perhaps 80 million years into the past.

Magnetic Reversals

In the opposite direction, the pattern vanishes under North America. There, presumably, this activity is related in some way to the formation of the western mountains and the volcanic eruptions of that region.

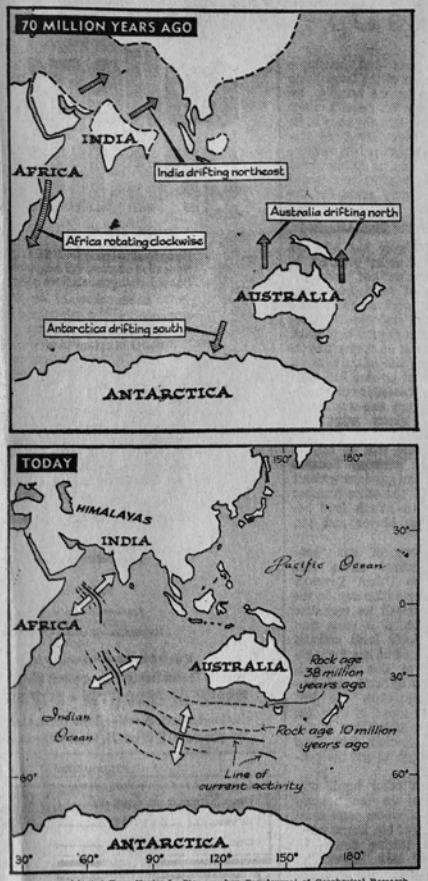
The timetable of continental movements is derived from the timetable of magnetic reversals. For the last 5 million to 10 million years the magnetic reversals have been determined from rocks on land whose ages can be calculated by radioactive analysis. The earlier reversals have been deduced from the seafloor pattern. The accuracy of this earlier timetable depends on the assumption that the spreading rate has been constant. However, there are indications that this has not always been the case.

Nevertheless, the researchers have found that the magnetic patterns flanking ridges in all three oceans are the same, much as the trees from a particular valley, having experienced the same succession of dry and wet years, display the same sequence of broad and narrow tree rings.

The magnetic charts predict the age of the rock at any point where the patterns are evident. Next month, a newly built ship, the Glomar Challenger, will drill into the floor of the Gulf of Mexico as the first step in an ambitious project to sink some 50 holes into the floors of the Atlantic and Pacific. The program is called JOIDES for "Joint Oceanographic Institutions for Deep Earth Sampling." The goal is to drill holes 2,500 feet deep under 20,000 feet of water, sampling the sediments and the rock beneath.

This may confirm the timetables of sea floor spreading, but it is unlikely to crush the resistance of some geophysicists to the idea that such activity is pushing the continents hither and yon.

—WALTER SULLIVAN



Adapted From Xavier Le Pic hon For Journal of Geophysical Research

SHIFTING LAND MASSES: Some 70 million years ago, Australia was close to Antarctica and India was floating alongside Africa, according to Dr. Xavier Le Pichon of France. He based his studies on a timetable of rock formation indicated by magnetic surveys of the ocean floor. The outflow of material from mid-ocean ridges pushed Australia northward and shoved India against Asia, producing the Himalayan folds.

Does a man's lifespan depend on the region in which he lives? A Government study released last week suggests that it very well may.

In the study, which analyzed death rates among middle-aged white men throughout the United States, certain areas on the East Coast were found to have the highest death rates and regions west of the Mississippi the lowest.

In some regions, men between 45 and 64 ran twice the risk of dying as those in low death-rate regions, according to the study, which was conducted by the National Center for Chronic Disease Control, a division of the Public Health Service.

The death rate in Scranton and Wilkes-Barre, Pa., for example, was about 2,100 for every 100,000 persons. This was nearly twice the rate in south central Nebraska, the region with one of the lowest death rates in the nation.

Further studies are being conducted to determine the causes of these geographical differences in death rates.

Quartier Latin Mai 1968

My exclusive source for the Sea Floor Spreading paper was Jason Morgan extended outline (Late April 1967) of his communication on April 19 1967 at the AGU "Rises, trenches, great faults and crustal blocks".

His message:
It is easy to quantify
the relative motions of plates
on the spherical Earth
and it works.

I dropped everything to
quantify the motions of plates.

But none of my usual coworkers were interested in joining me. They did not consider this a priority.

Note that this was also true of all those who listened to Morgan's talk and of the nine scientists (in addition to myself) who received the extended outline.

The concept was too new
to be adopted universally right away.

Seven months of solitary work
from May to November 1967:

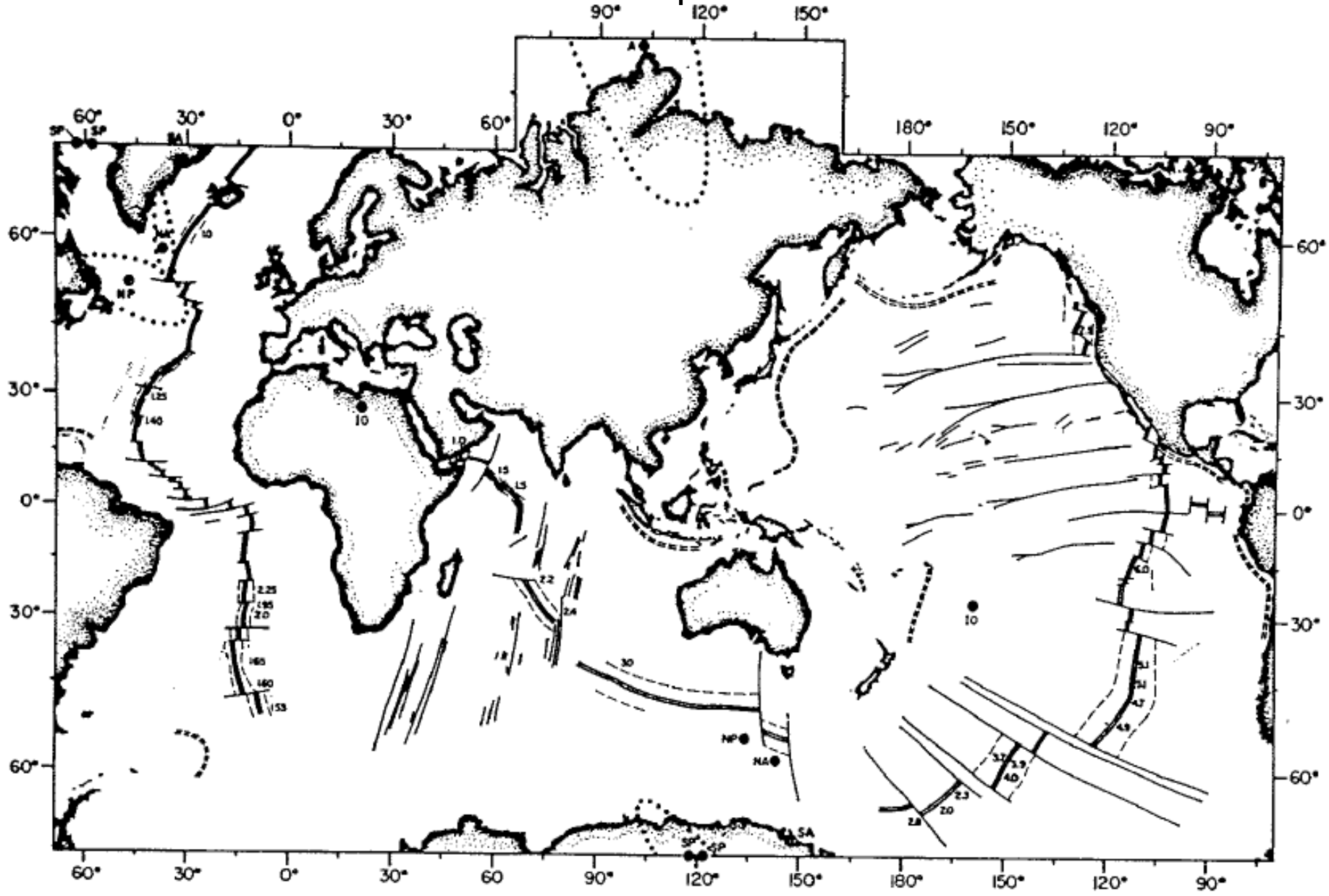
I opened three new directions knowing that I would not be able to exploit them.

1: quantification of five openings of oceans, June and July, ***first demonstration of the absence of Earth expansion***

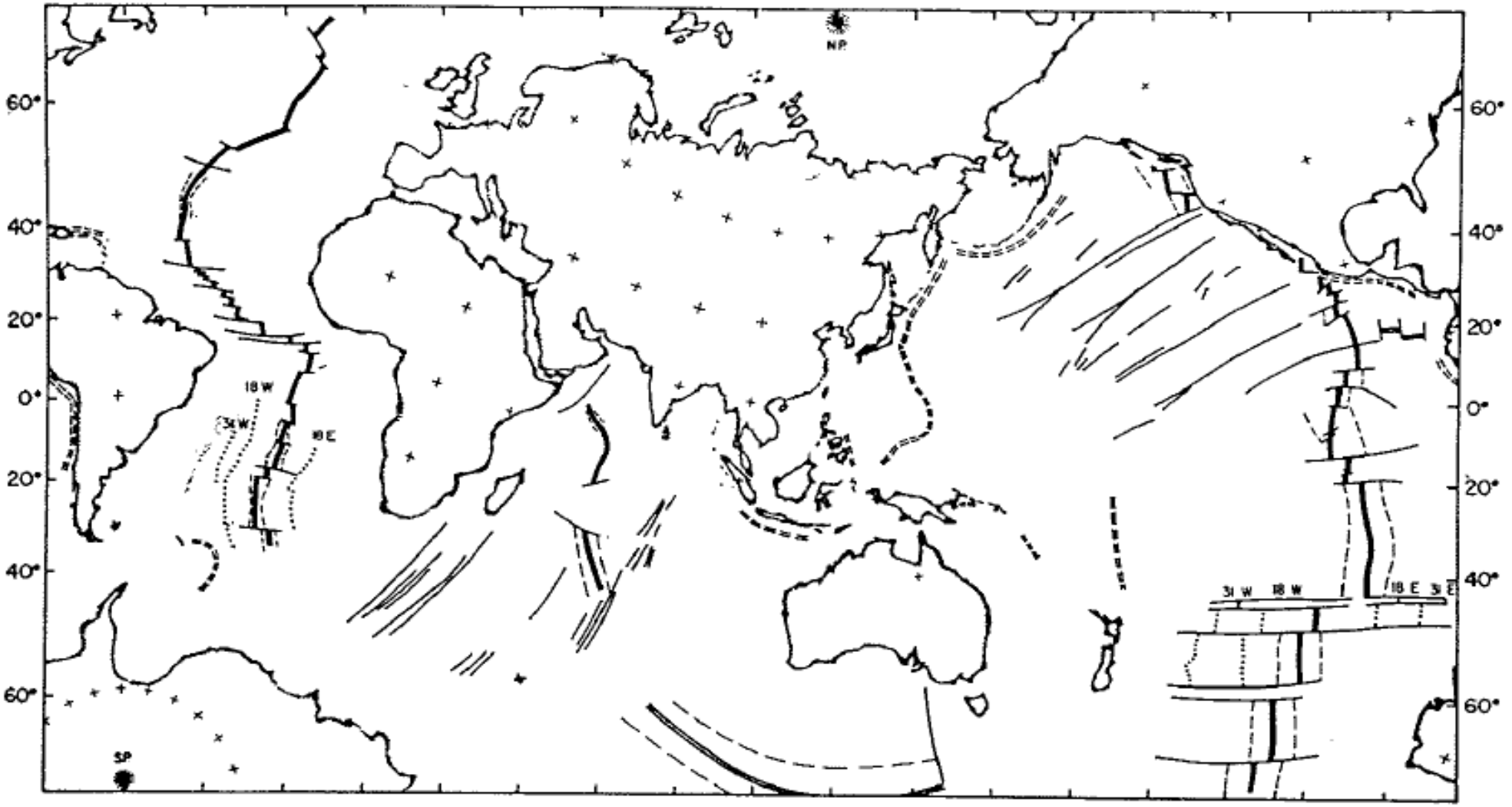
2: closure of Earth plates circuit, August and September, ***first global model***

3: ***first finite reconstructions*** based on magnetic anomalies, October

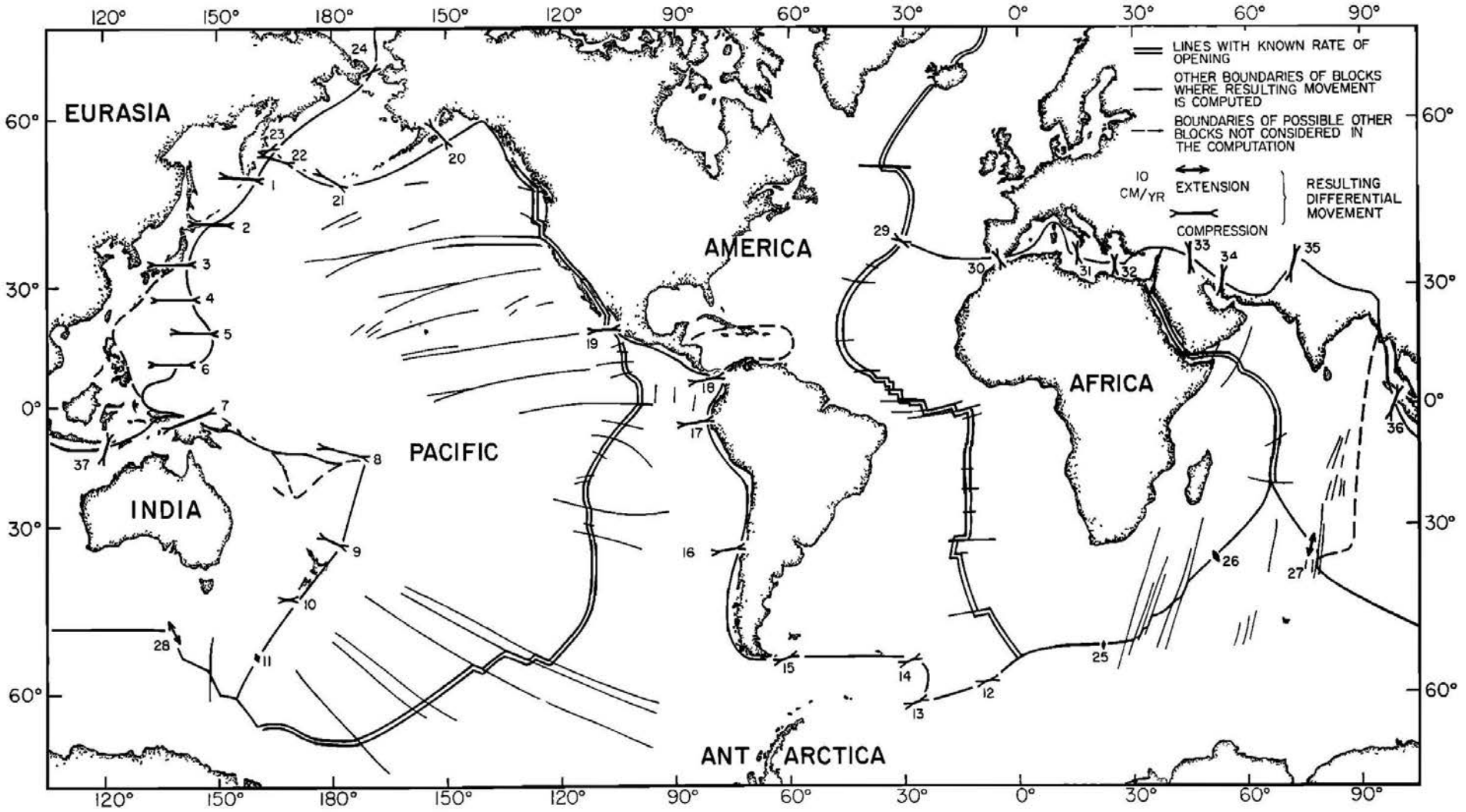
Data for six plates model



1 No Earth Expansion



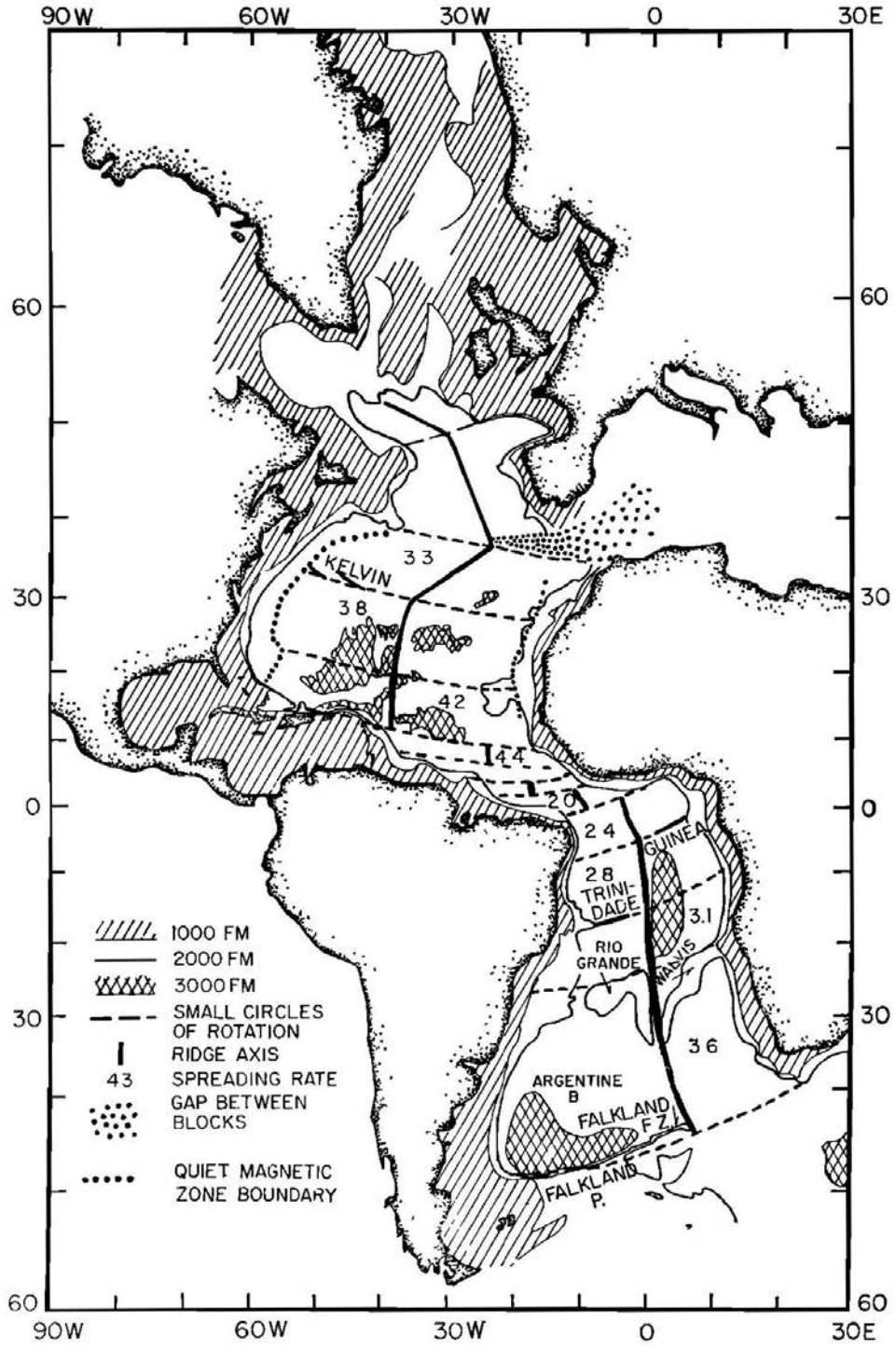
2. First global kinematic model



Does the minimum number of plates necessary to obtain global kinematic closure have a sense?

Seven main plates cover 94% of the Earth. They reflect the dominant wavelength of convection. Mallard et al. (2016, Nature) have shown that this number of 6-7 is governed by the value of the elastic limit of the lithosphere (150 MPa).

3. First finite reconstructions based on magnetic anomalies Reconstruction at anomaly 31 (70 Ma)



Why did I fail to adopt sea floor spreading in our heat flow research in 1965 (Langseth, Le Pichon and Ewing, 1966)?

Jean Francheteau and I both believed that the model presented in the 1966 paper, written by Langseth, yourself and Ewing, provided the spark that set off the whole Plate Tectonic revolution.

John Sclater, March 9 2018

Langseth, Le Pichon, Ewing, 1966

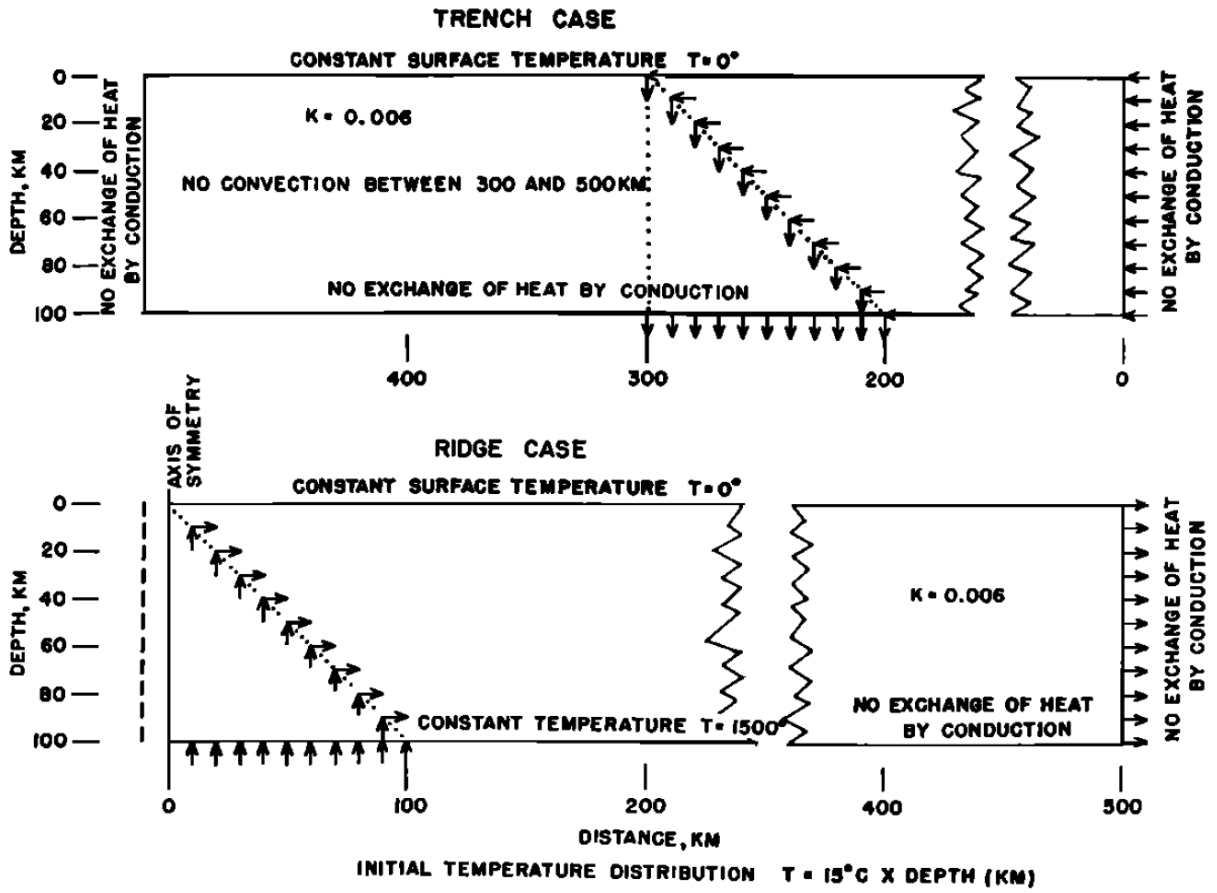


Fig. 15. Models used for numerical computations of distribution of temperature in the case of rising and sinking convection currents reaching the sea floor.

In SFS, the crest of the ridge always reaches the same height (provided that V> 0.5 cm/yr,) whereas the slopes of the flank depend on the velocity.(Langseth et al. 1966)

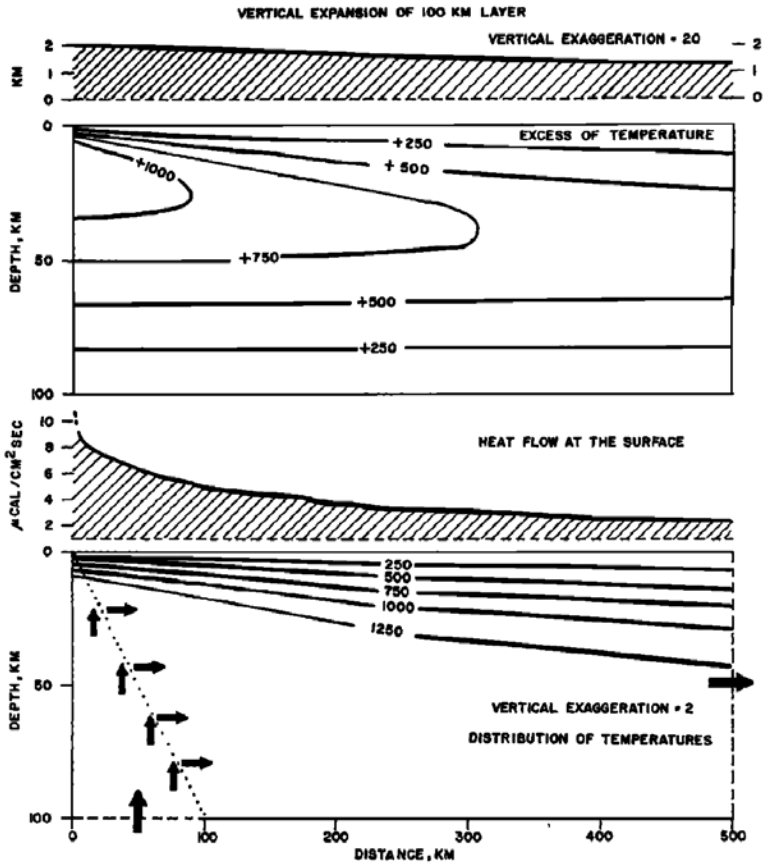


Fig. 16. Distribution of temperatures and heat flow over the ridge for a rate of spreading of 2 cm/yr. *Bottom:* The distribution of temperatures with depth versus distance from the axis of the ridge, with the corresponding heat flow. *Top:* The excess of temperature over the equilibrium temperature in the absence of convection currents and the corresponding vertical expansion.

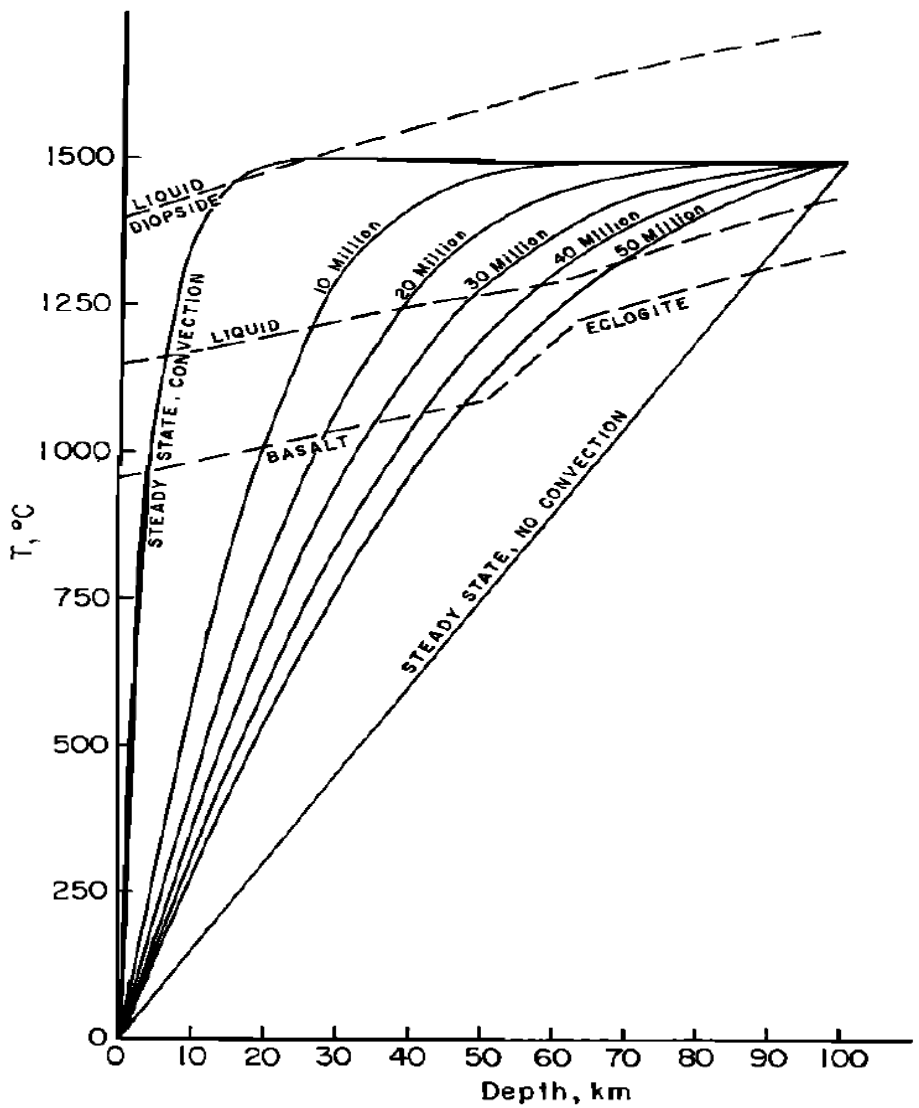


Fig. 18. Distribution of temperatures near the axis of the ridge for a rate of spreading of 2 cm/yr and evolution of temperatures with time after convection ceases (in m.y.). The melting curves of basalt and diopside are also shown.

One should record near zero HF landward of trench… No other mechanism than SFS can produce such a low HF (Langseth et al., 1966)

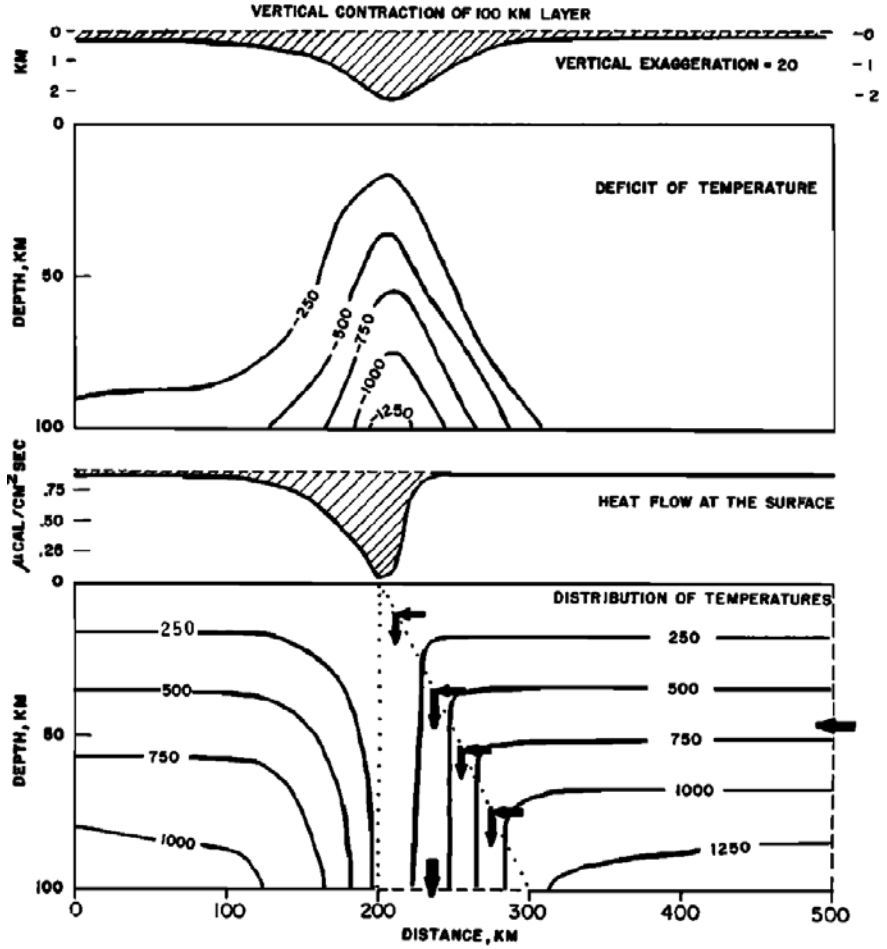


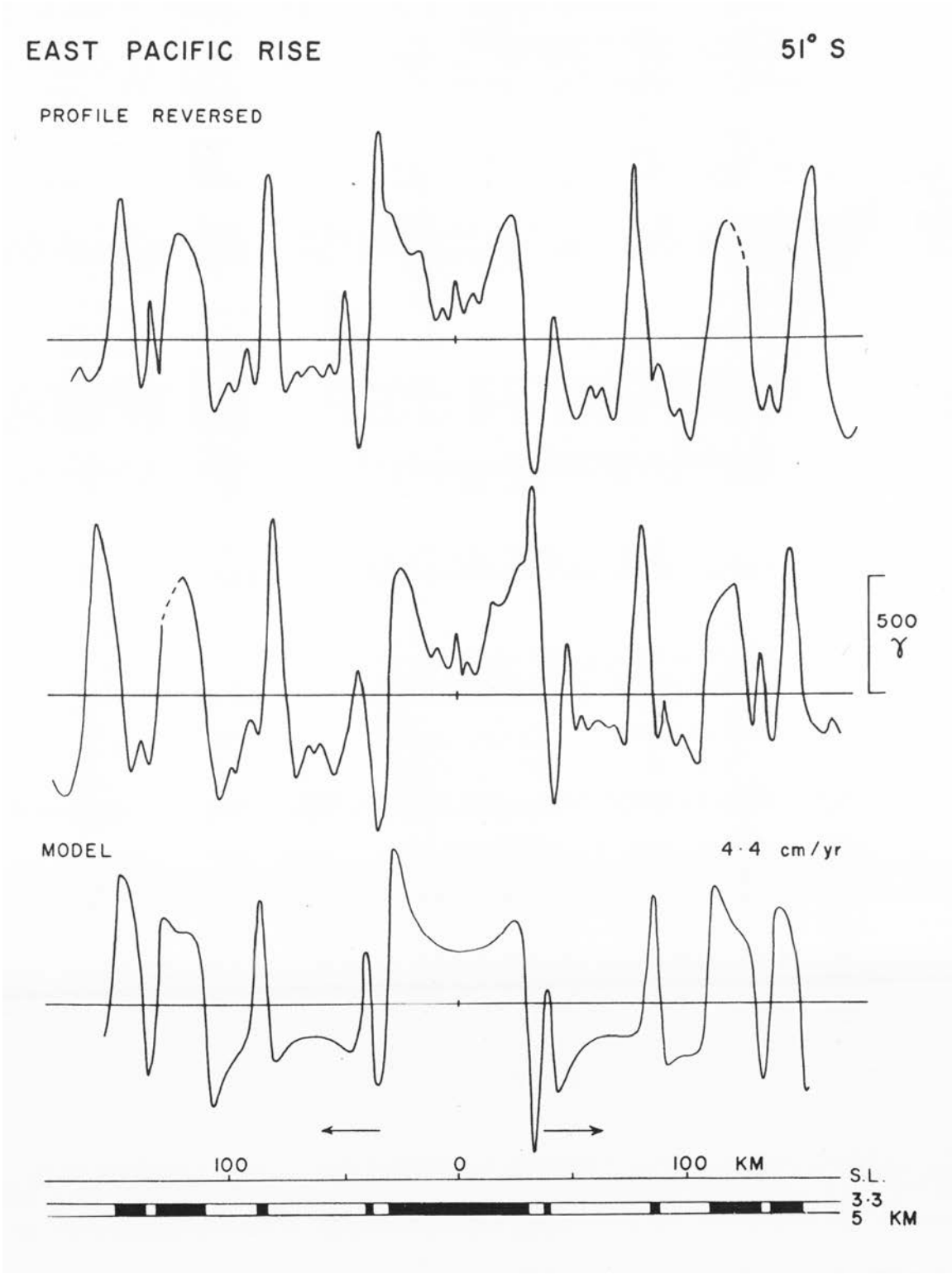
Fig. 20. Trench case. Spreading rate of 1 cm/yr.

My model indicated that SFS failed the energy test

- Average HF expected for 1 cm/yr over 1000 km width ***3.1*** for 1 cm/yr vs ***1.6*** measured for MAR and ***2.5*** for EPR.
- We consequently rejected the model in favor of a convection one
- Dan McKenzie one year later divided by three the temperature of the asthenosphere (550°C instead of 1500°C for us) and obtained the proper heat flow.

Crisis: my conversion to sea-floor spreading

I defended this conclusion during my thesis in France in early 1966 to discover at my return in Lamont on April 26 1966 the magic profile of Pitman. Sea-floor spreading imposed itself to me. Yet I did not know why the energy test failed.



After Pitman (1966)

The theory of Plate Tectonics

After January 1968, I was cut out from all Lamont data and my priority was building this new oceanographic lab. Consequently, I first turned to Plate Tectonics theory with Jean Francheteau and Jean Bonnin. This resulted in the publication of our book “Plate Tectonics” published in 1973.

“I find it virtually impossible to find fault with this book.”
Fred Vine

The book was a manifest about Plate Tectonics that would then guide my research:

1 kinematics in the North Atlantic Ocean 1969-1970
2 accreting plate boundaries with FAMOUS 1973-1974
3 consuming plate boundaries with HEAT (1979) and Kaiko (1983-1984)
4 continental tectonics especially within Greece and Turkey starting in 1979

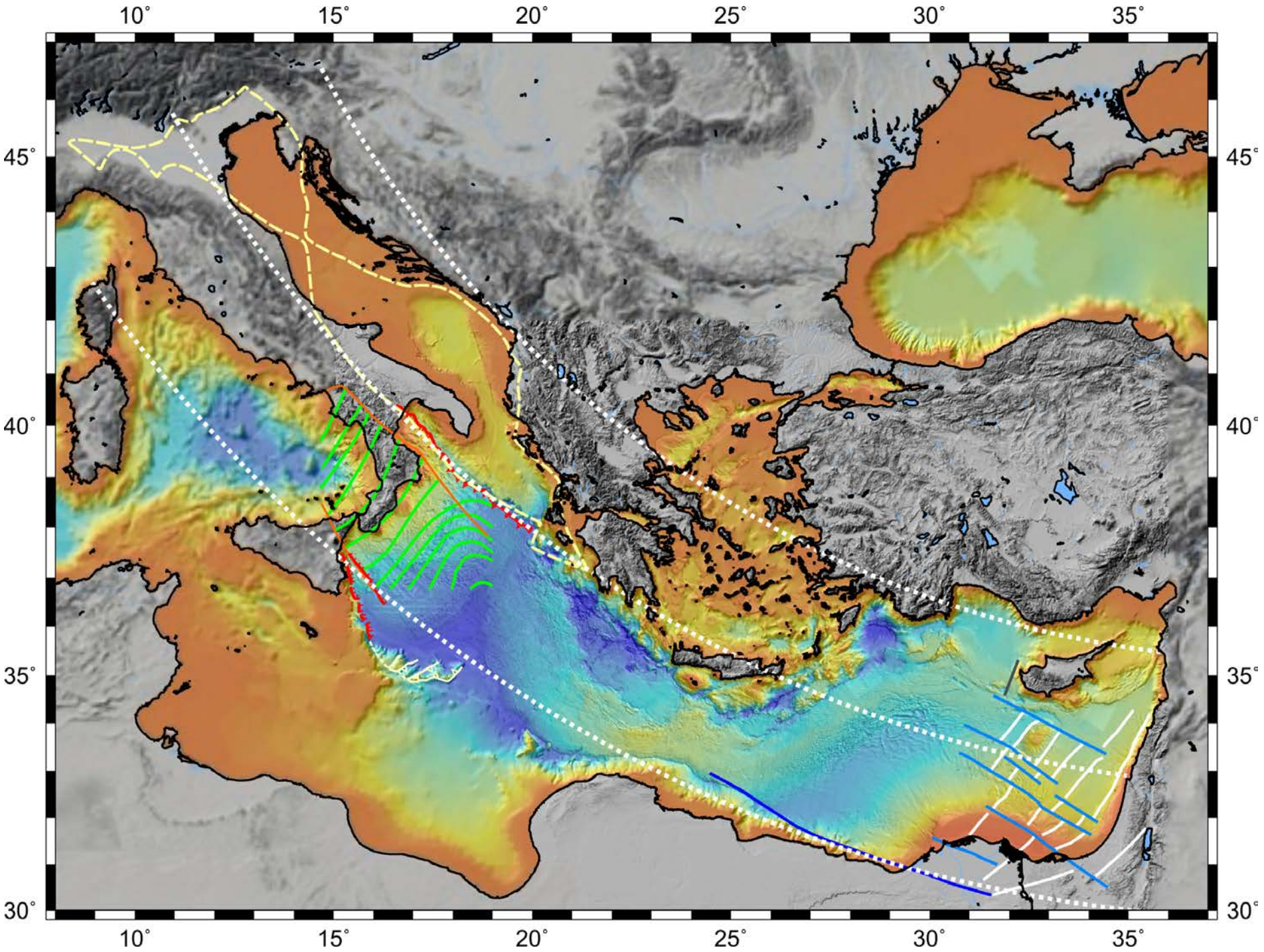
Plate Tectonics and Pangea

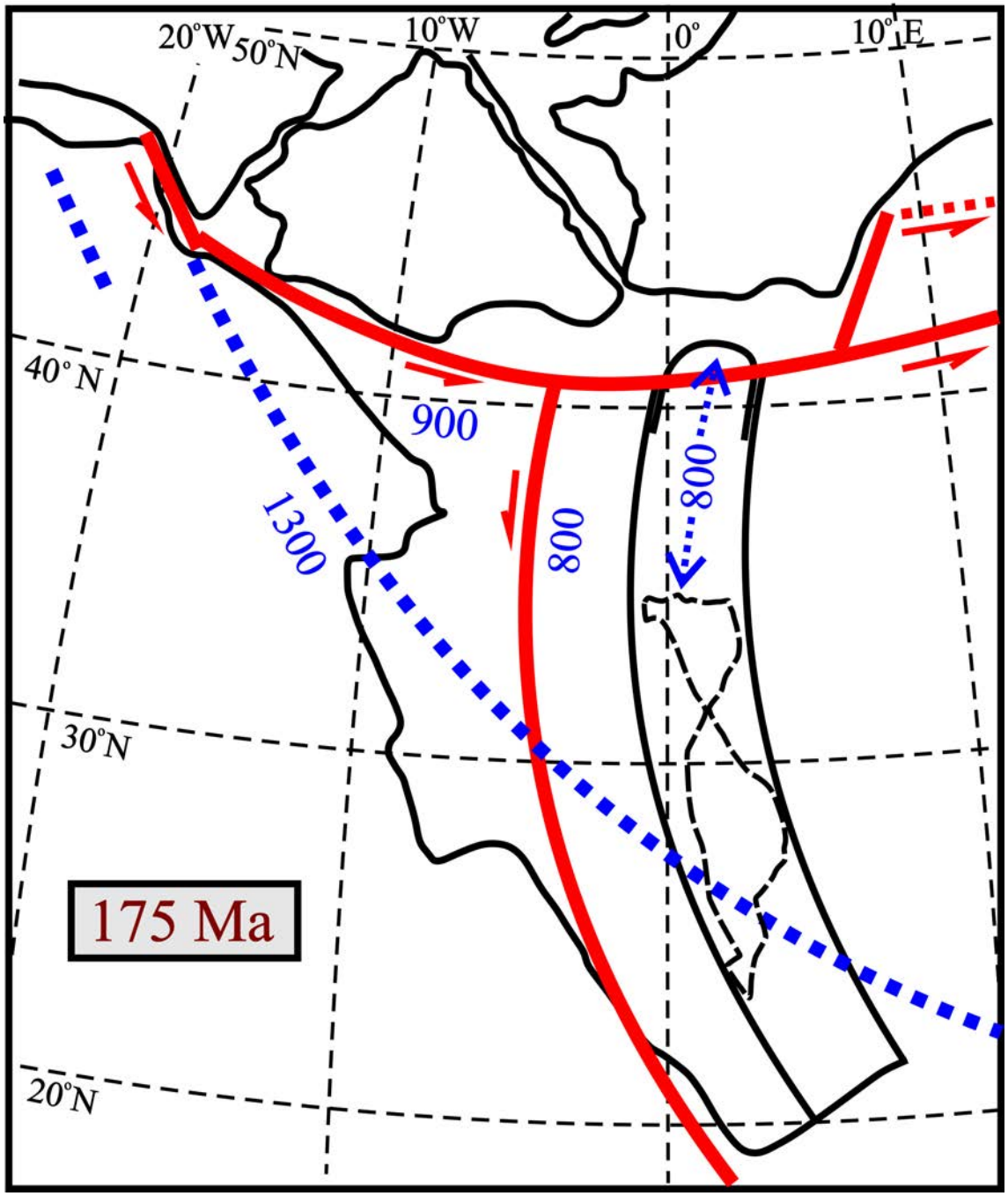
Did Plate Tectonics change from Pangea to Present?

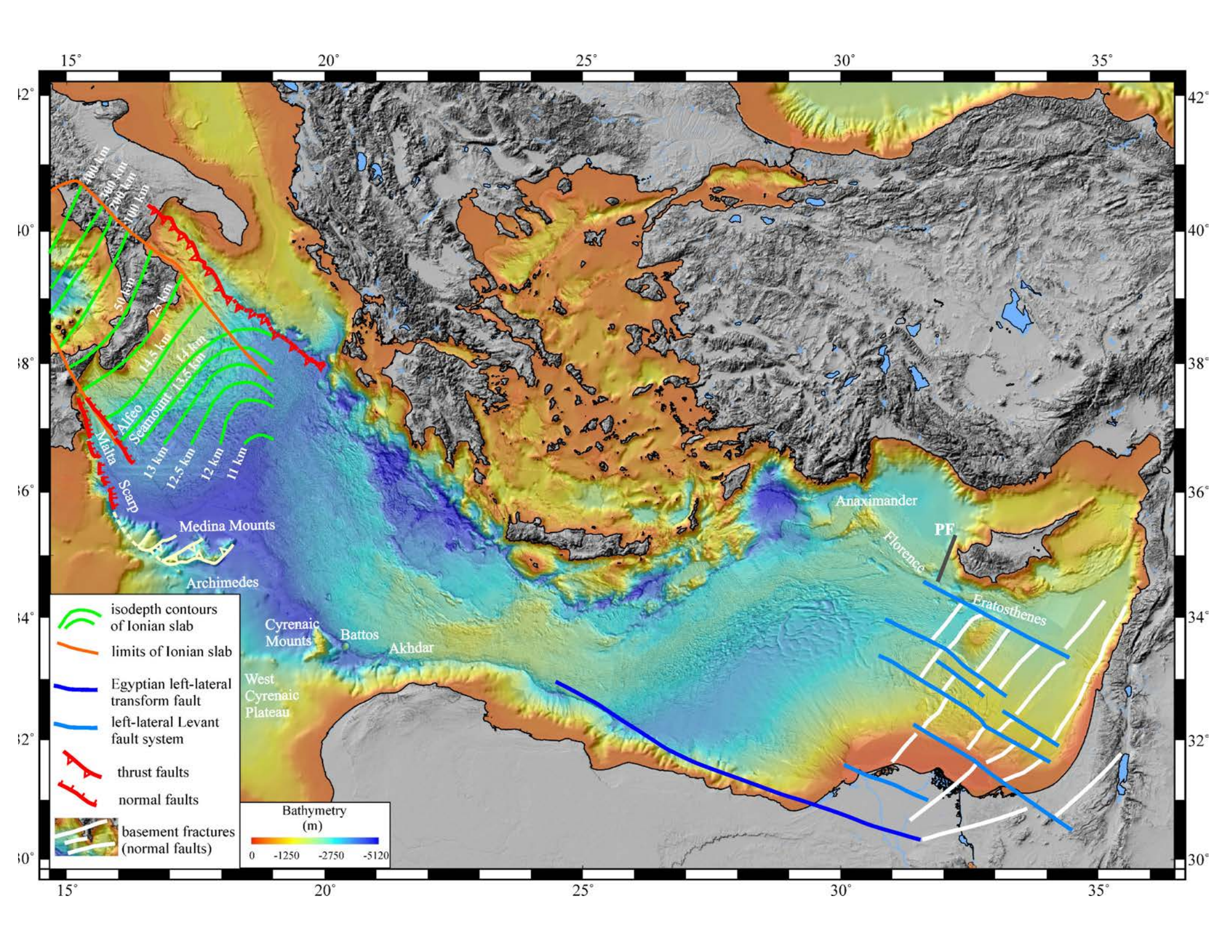
Reflection coming out from a paper submitted to Canadian Journal of Earth Sciences

A new approach to the opening of the Eastern Mediterranean Sea

Xavier Le Pichon, Celal Sengor and Caner Imren


10°
15°
20°
25°
30°
35°
45°
40°
35°
30°


20°W
50°N
10°W
0°
10°E
40°N
30°N
20°N
900
800
800
1300
175 Ma


15°
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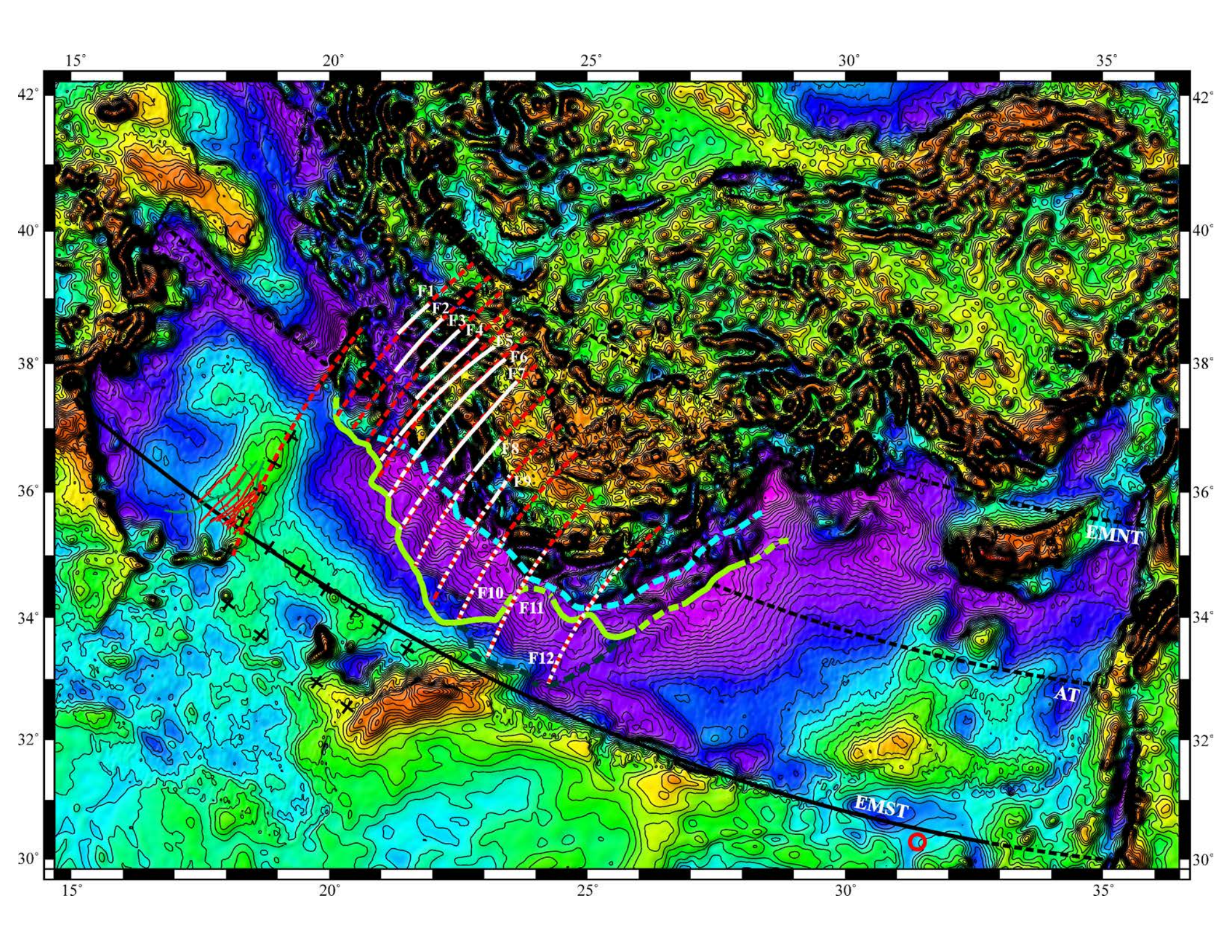
35°
42°
40°
38°
36°
34°
32°
30°
1000 km
800 km
600 km
400 km
200 km
100 km
50 km
25 km
14.5 km
14 km
13.5 km
13 km
12.5 km
12 km
11 km
Alfeo Seamount
Malta Scarp
Medina Mounts
Archimedes
Cyrenaic Mounts
Battos
Akhdar
West Cyrenaic Plateau
Anaximander
PF
Florence
Eratosthenes
isodepth contours of Ionian slab
limits of Ionian slab
Egyptian left-lateral transform fault
left-lateral Levant fault system
thrust faults
normal faults
basement fractures (normal faults)
Bathymetry (m)
0
-1250
-2750
-5120


15°
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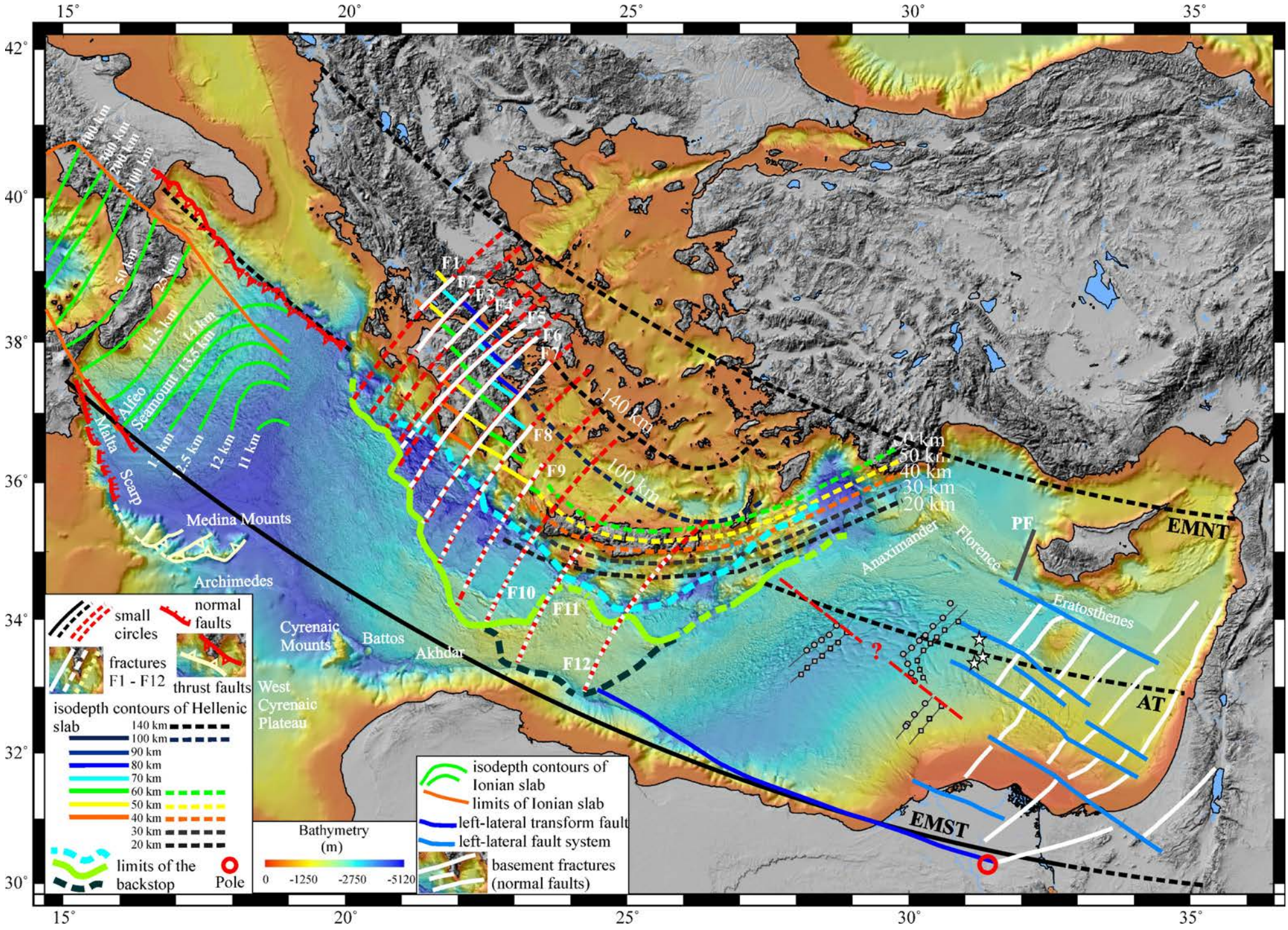
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F1
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F3
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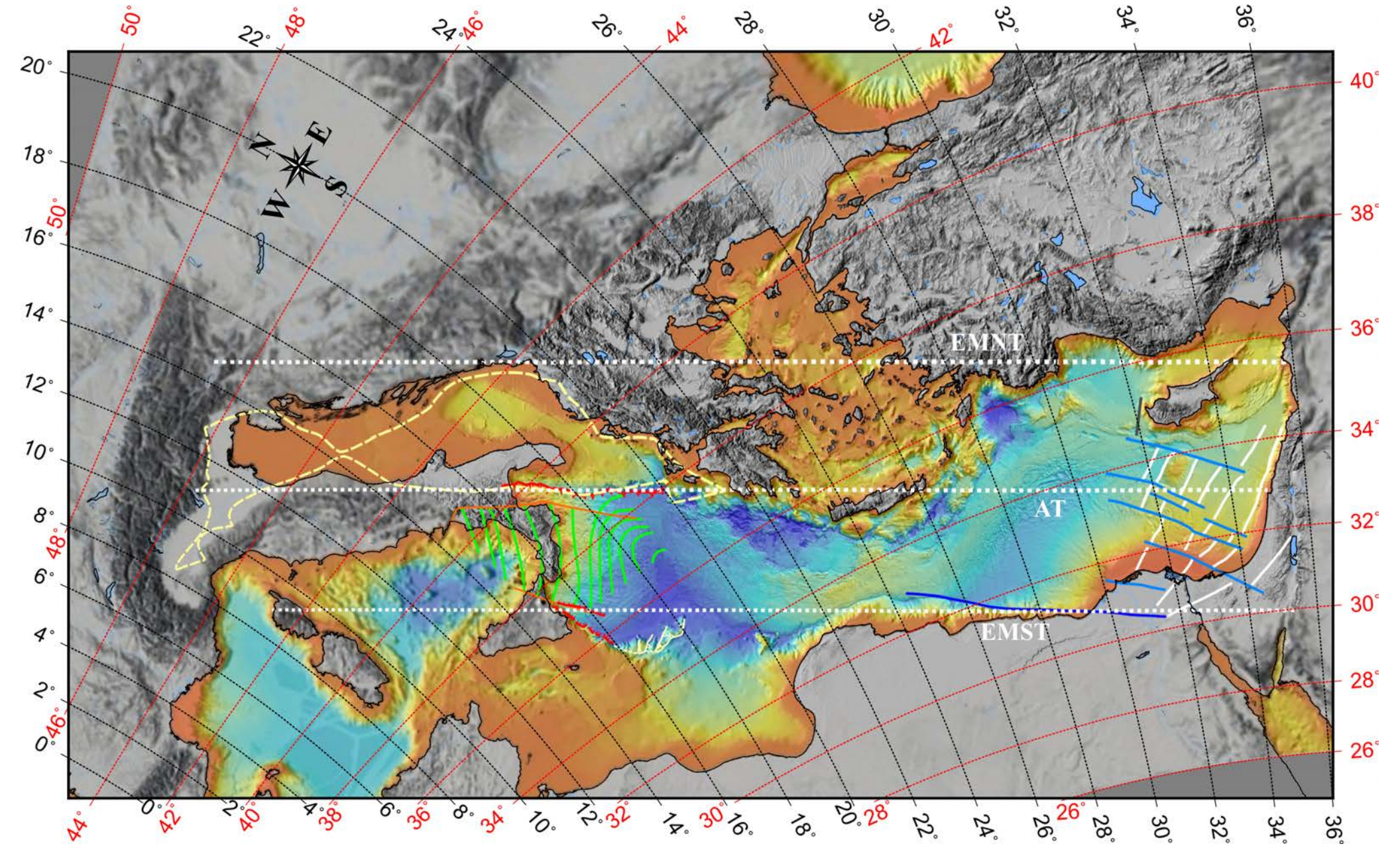
F6
F7
F8
F9
F10
F11
F12
140 km
100 km
50 km
40 km
30 km
20 km
Malta Scarp
Alfeo Seamount
Medina Mounts
Archimedes
Cyrenaic Mounts
Battos
Akhdar
West Cyrenaic Plateau
Anaximander
Florence
PF
EMNT
Eratosthenes
AT
EMST
small circles
normal faults
fractures F1 - F12
thrust faults
isodepth contours of Hellenic slab
limits of the backstop
Pole
Bathymetry (m)
0
-1250
-2750
-5120
isodepth contours of Ionian slab
limits of Ionian slab
left-lateral transform fault
left-lateral fault system
basement fractures (normal faults)


EMNT
AT
EMST
N
E
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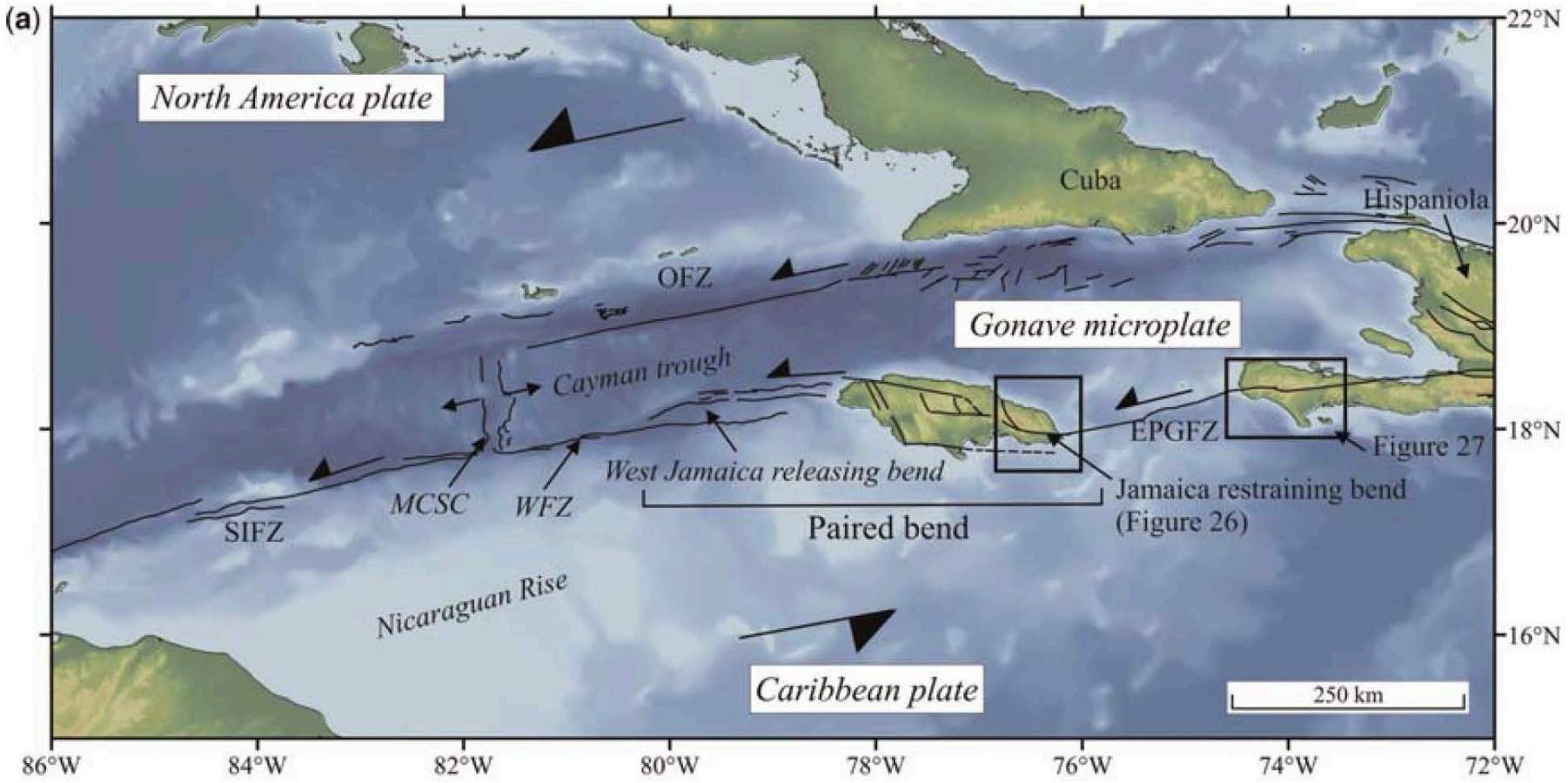
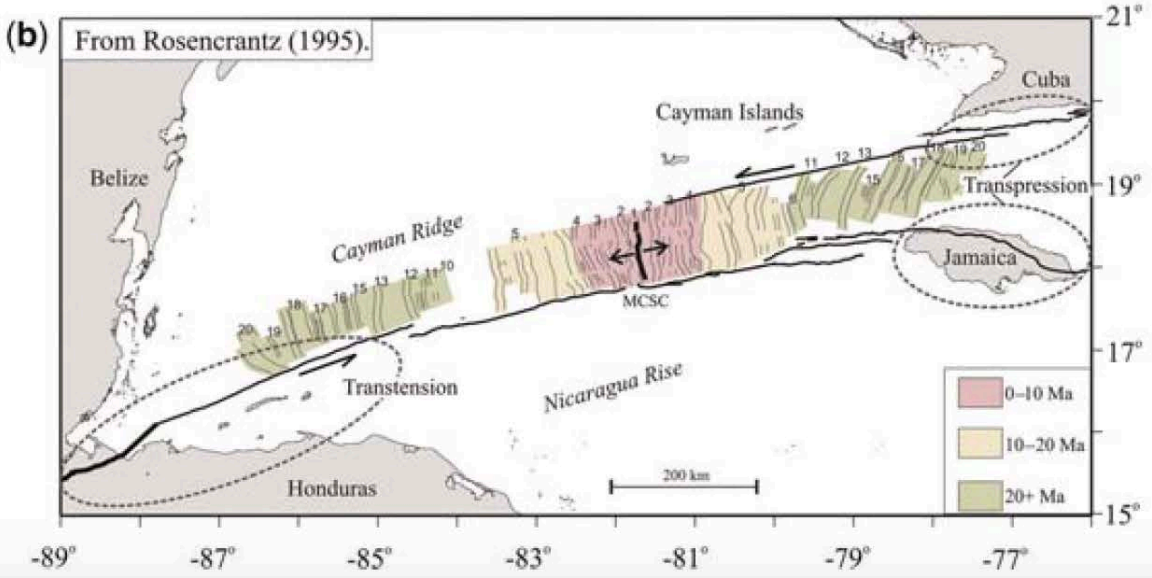
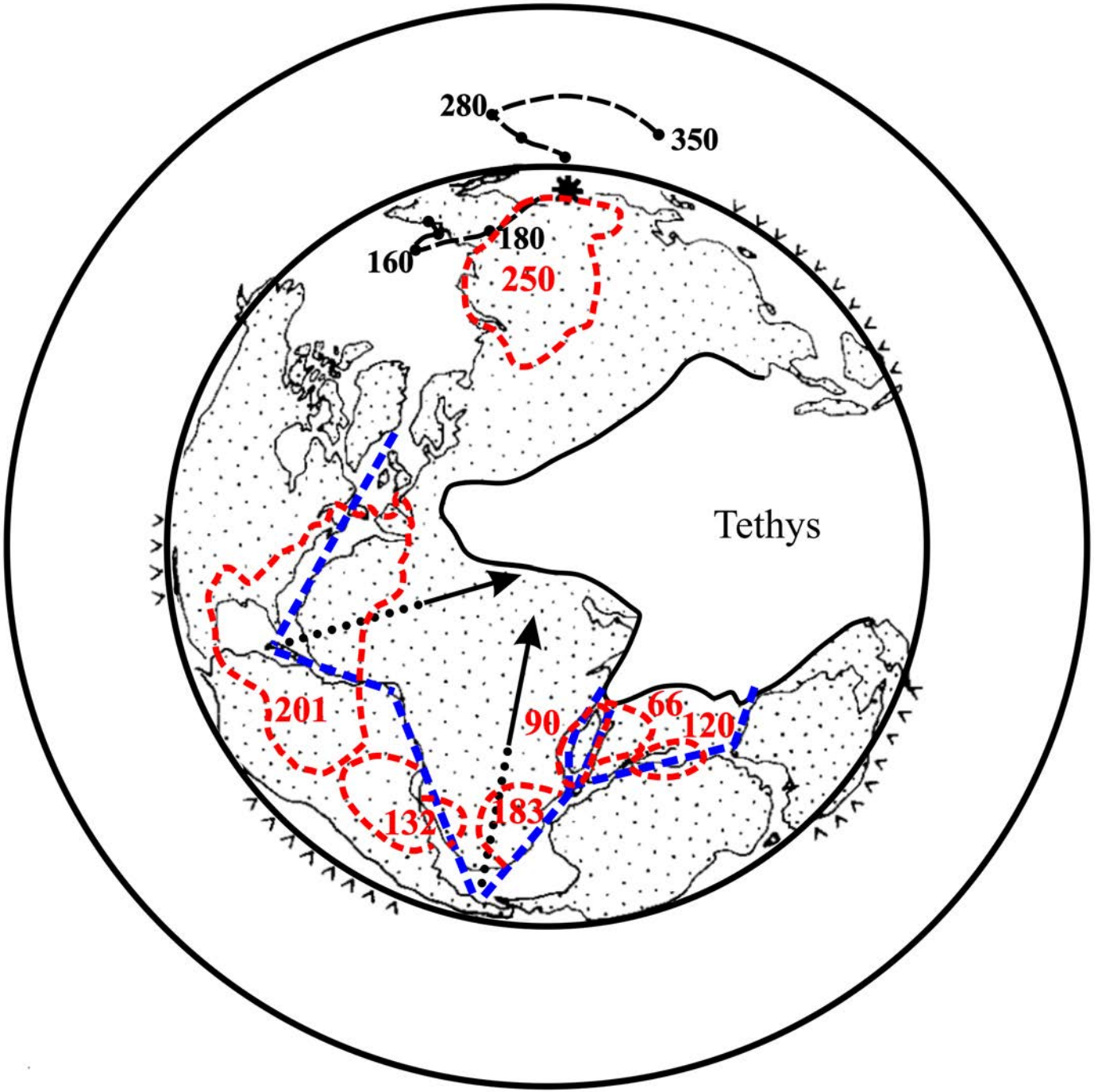
W


(a)
North America plate
Cuba
Hispaniola
OFZ
Gonave microplate
Cayman trough
EPGFZ
Figure 27
West Jamaica releasing bend
Jamaica restraining bend
(Figure 26)
MCSC
WFZ
SIFZ
Paired bend
Nicaraguan Rise
Caribbean plate
250 km
22°N
20°N
18°N
16°N
86°W
84°W
82°W
80°W
78°W
76°W
74°W
72°W

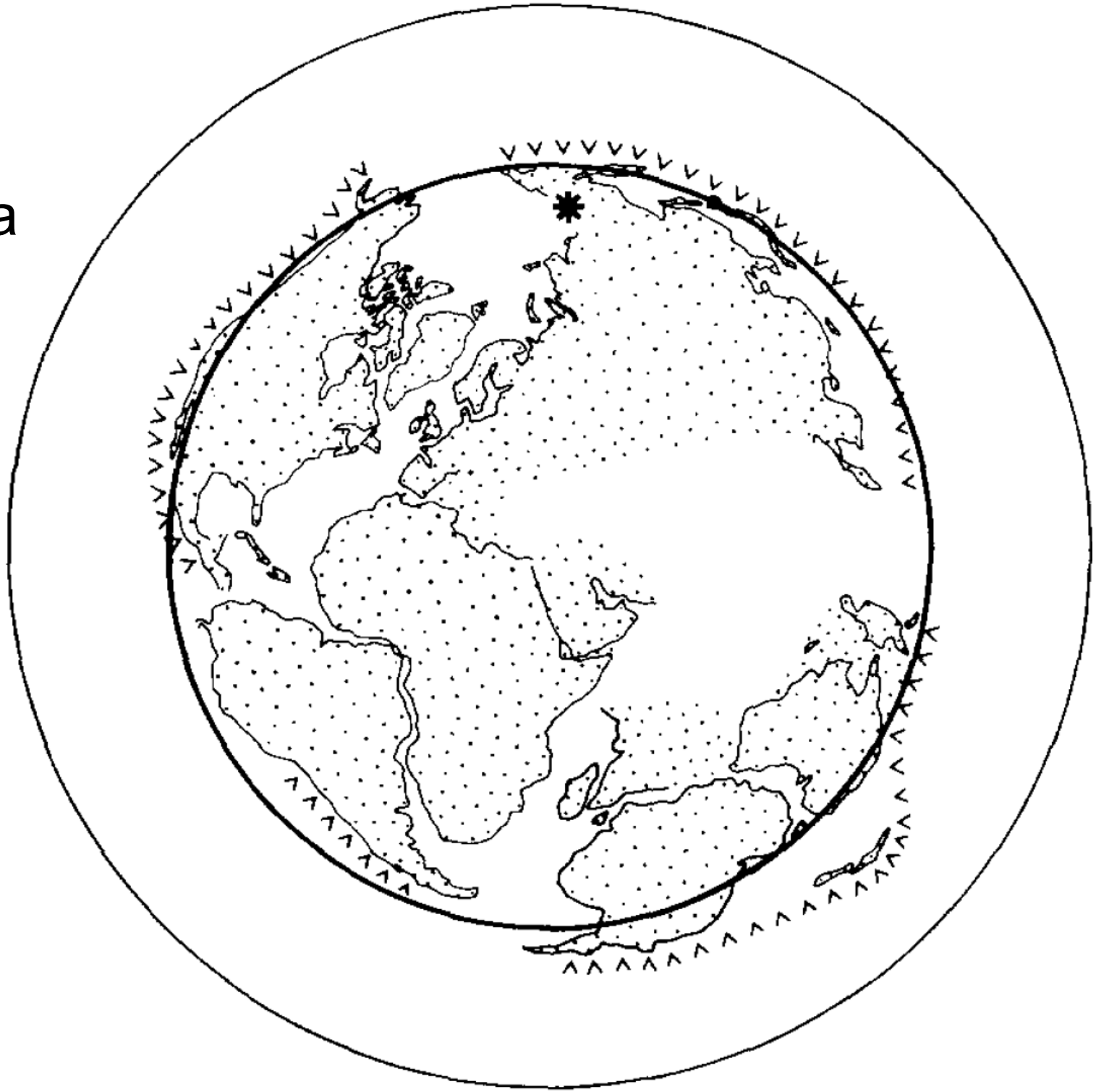

(b)
From Rosencrantz (1995).
Cuba
Cayman Islands
Belize
Transpression
Cayman Ridge
Jamaica
MCSC
Transtension
Nicaragua Rise
Honduras
200 km
0–10 Ma
10–20 Ma
20+ Ma
21°
19°
17°
15°
-89°
-87°
-85°
-83°
-81°
-79°
-77°

Pangea and flood basalts

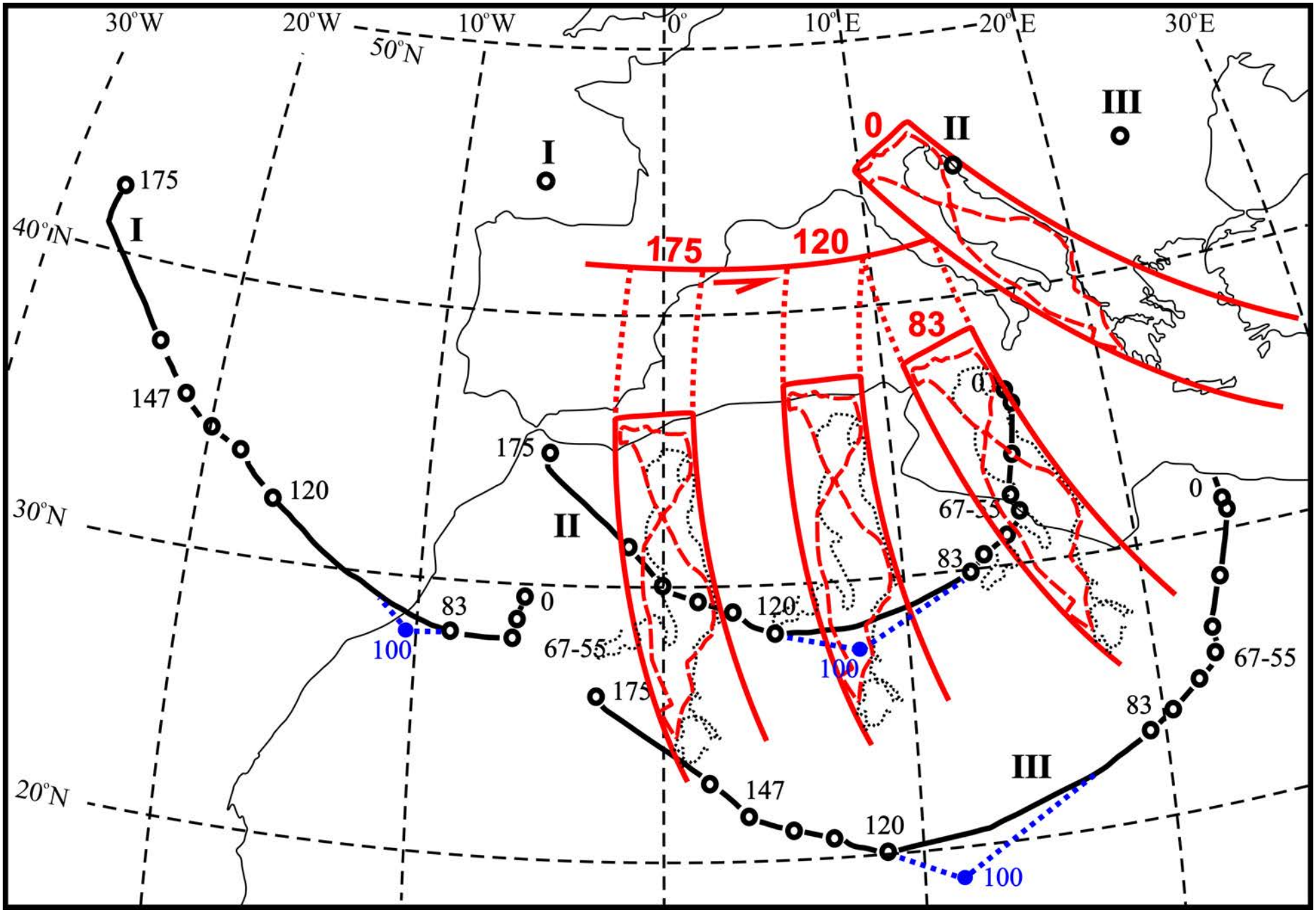
Modified from Le Pichon and Huchon 1984



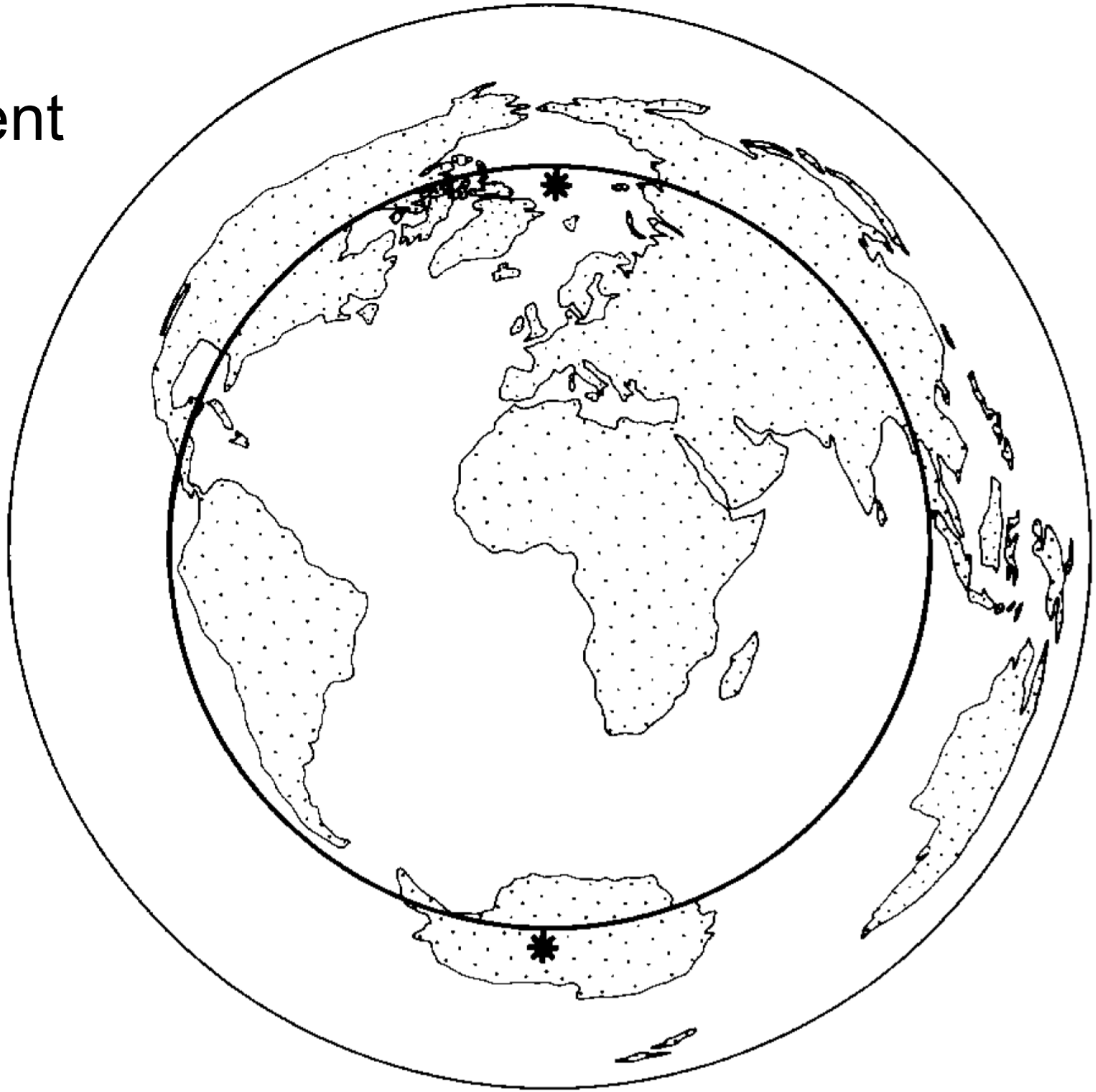
125 Ma



Kinematics of Africa/Eurasia from Rosenbaum et al. (2002)

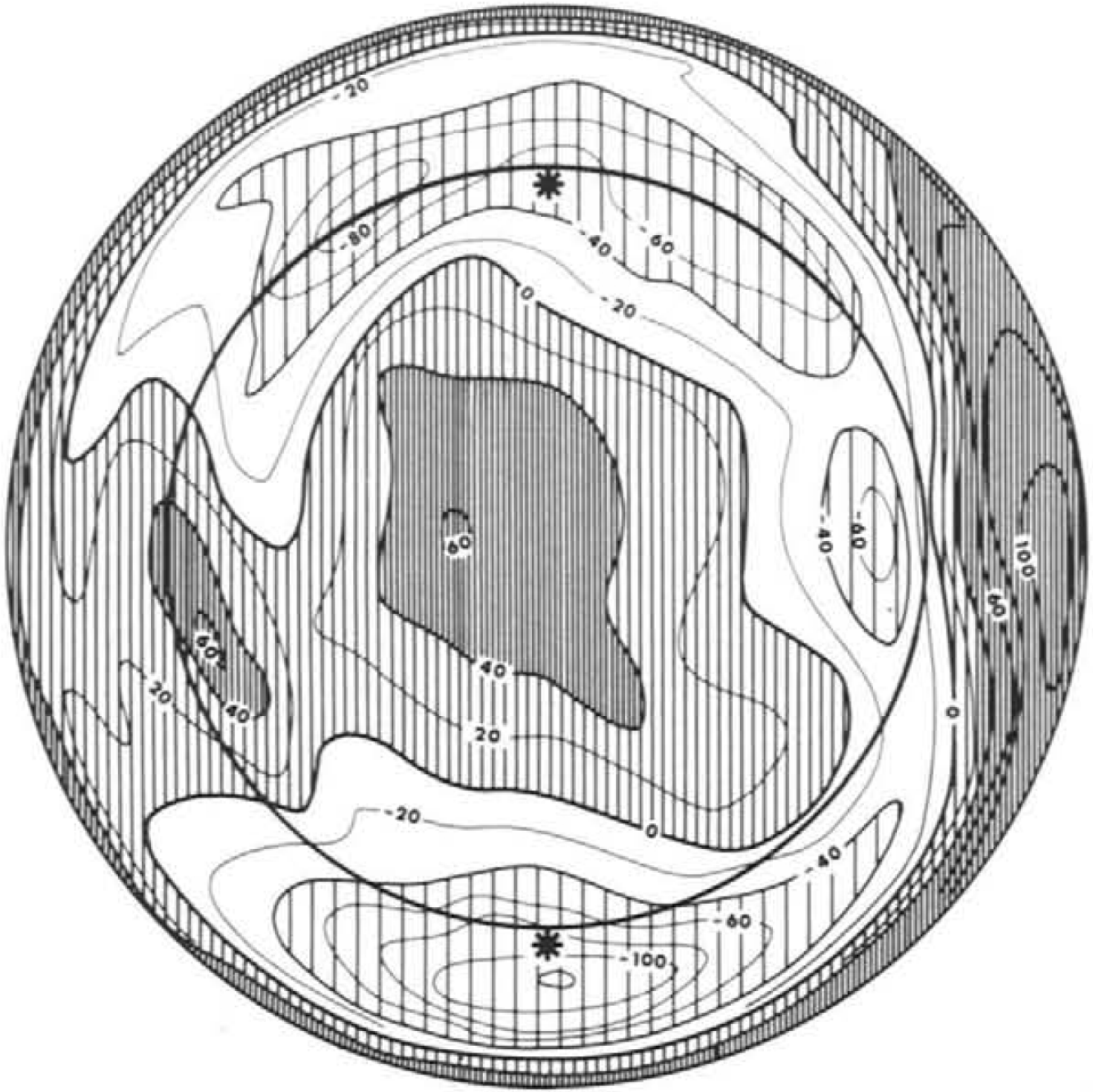


Present

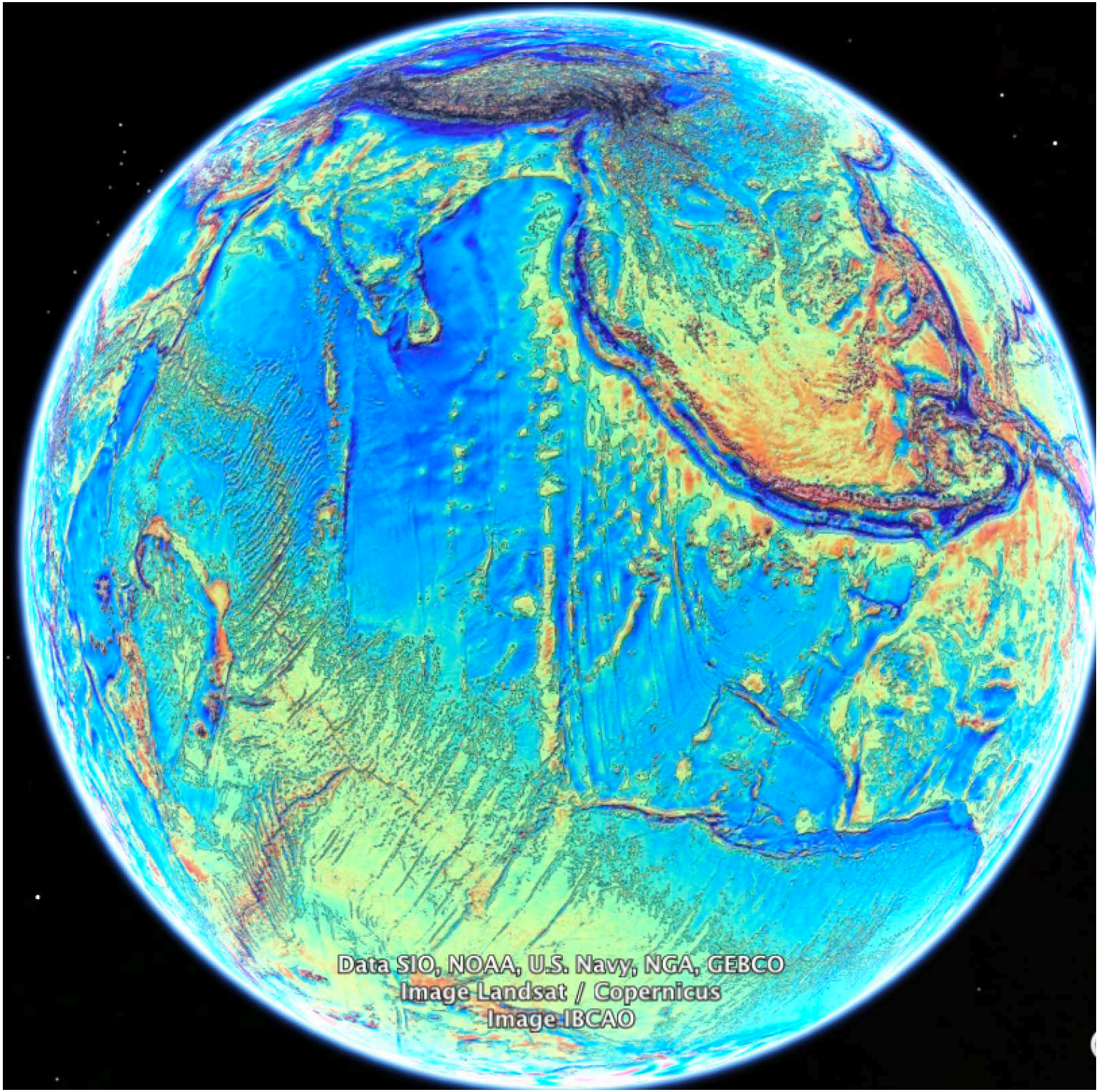


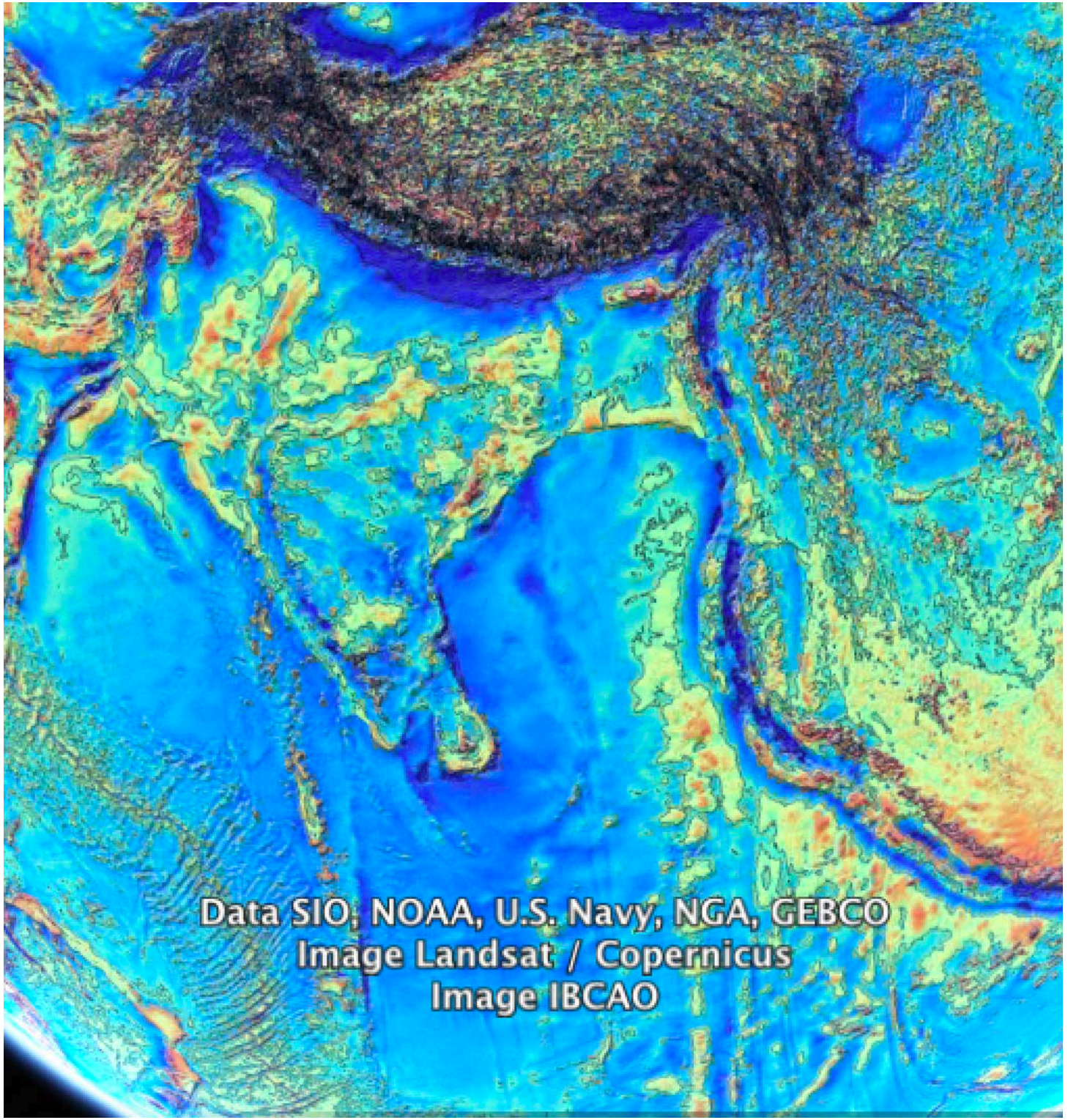
Geoid

Le Pichon and
Huchon 1984

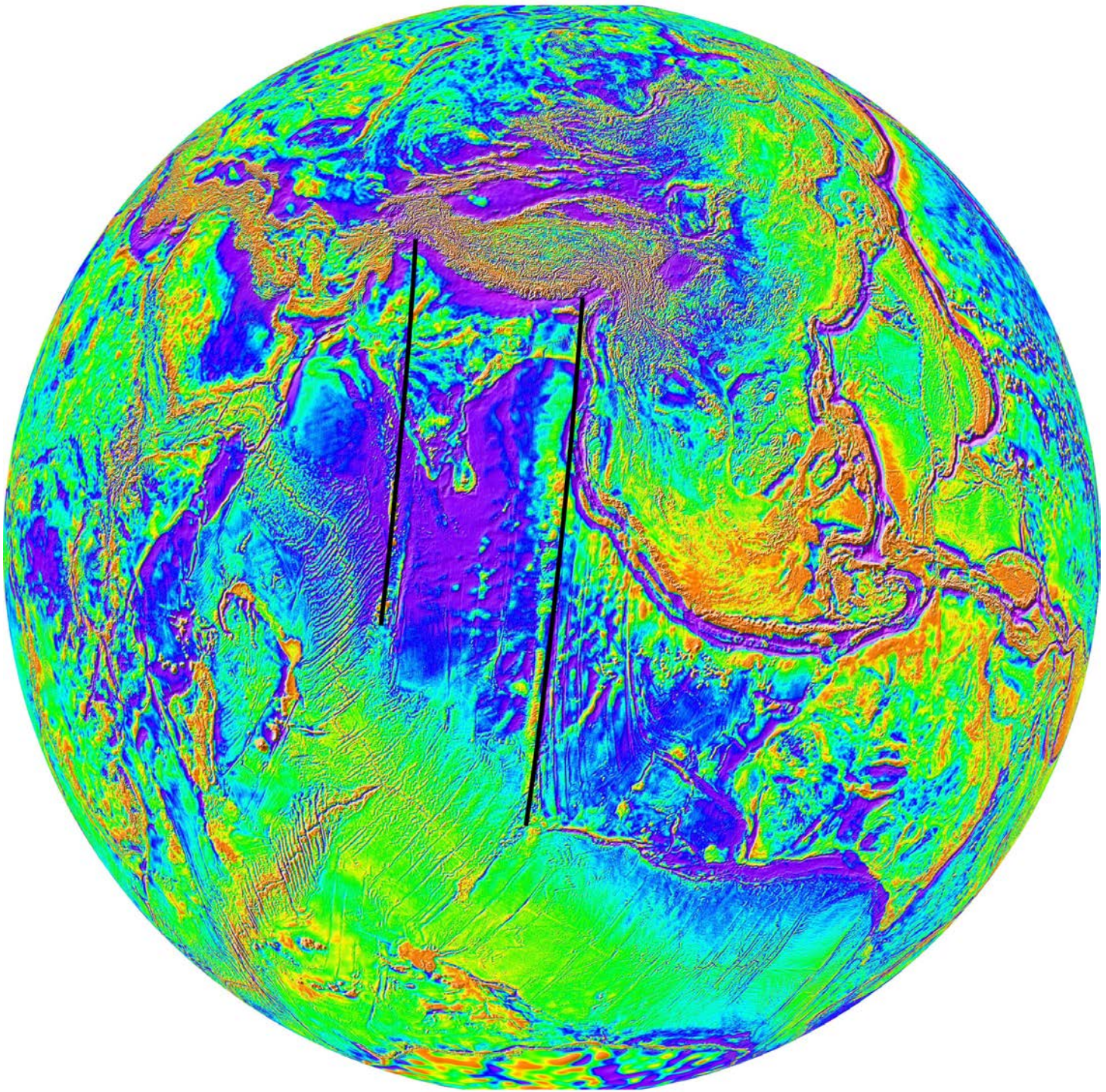


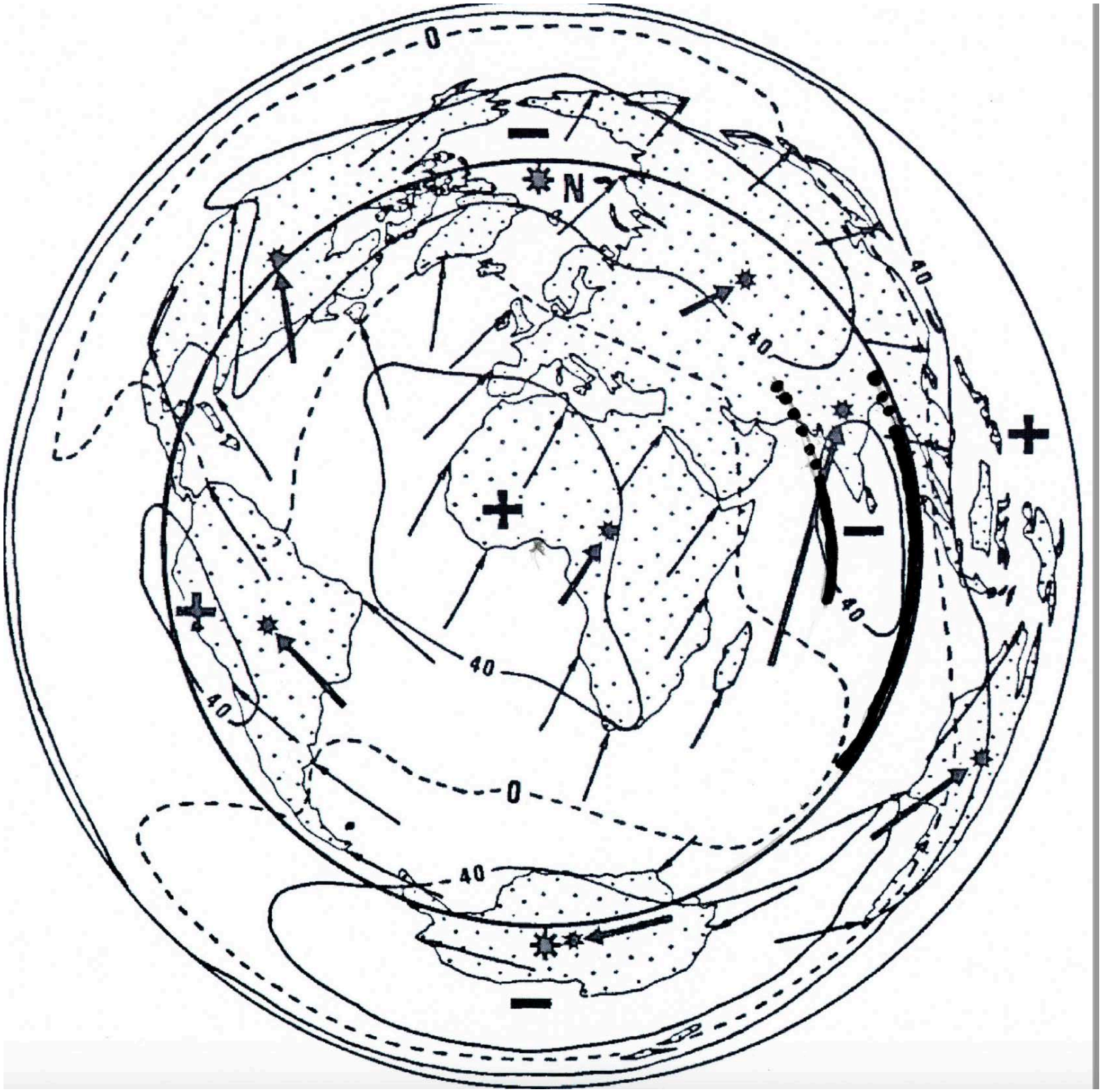
Gravity
Indian Ocean




Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat / Copernicus
Image IBCAO

Chagos and 90°E ridges circles about geoid pole 6°N, 4°E Radius, 69° and 87°

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Pangea and flood basalts

Modified from Le Pichon and Huchon 1984