When seafloor disappears in the subduction zones

Plate tectonics and evolution of subduction zones

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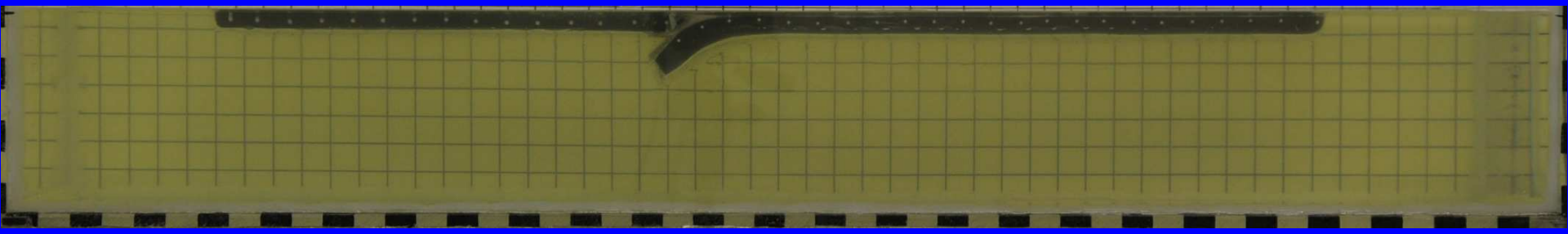
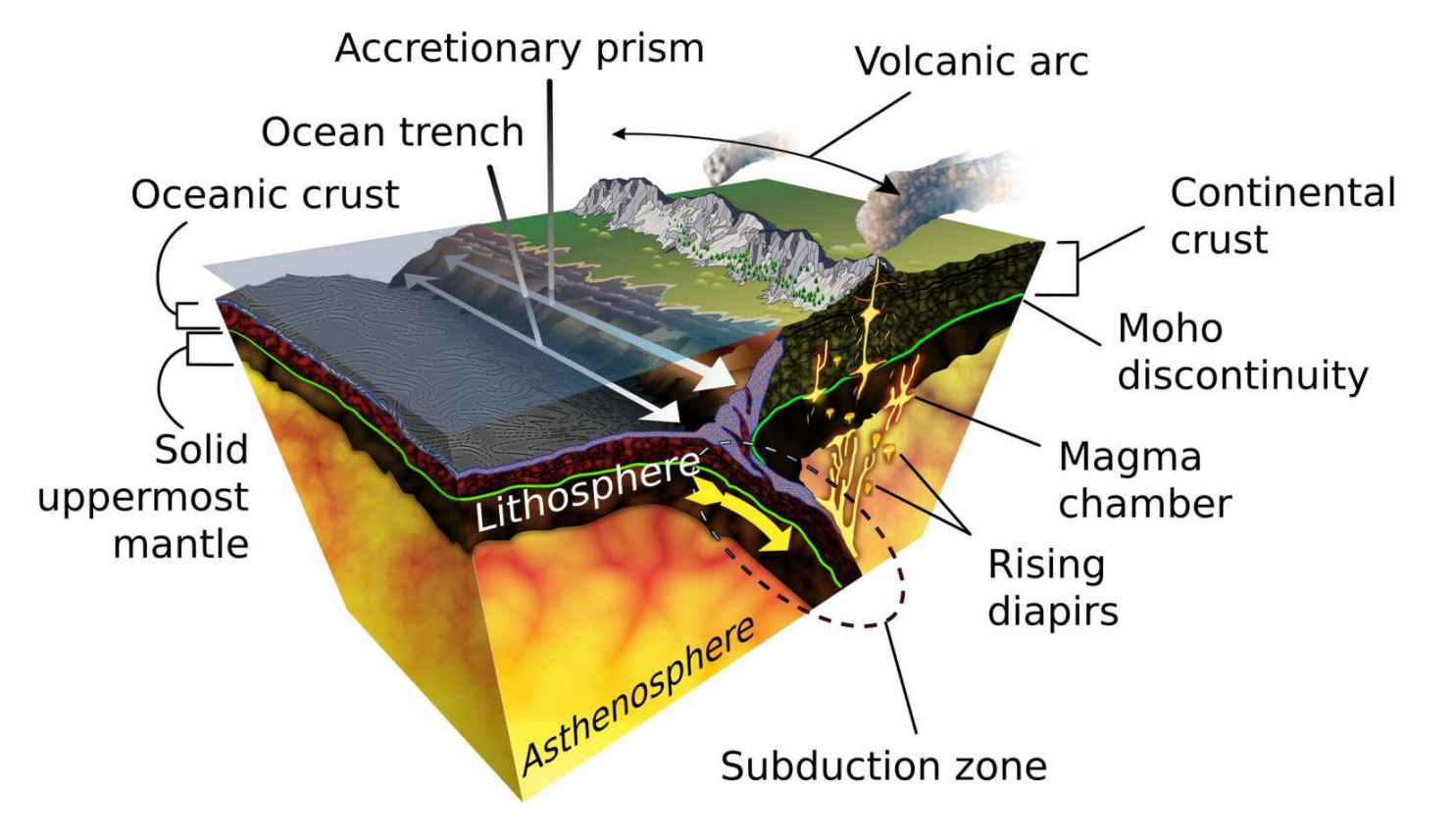
Plate Tectonics Planet

Subduction



Subduction Zone



Timeline

1906

Otto Ampferer
Crustal compression
“verschluckungszone”

1922

Herbert Turner
Deep earthquakes

1928

Kiyoo Wadati
Deep earthquakes plan
connection with volcanoes

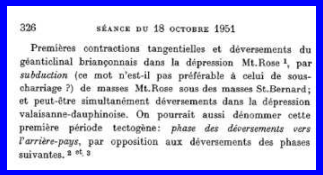
1930

Vening Meinesz
Gravity measurements

1946

Hugo Benioff
Deep quakes; downwarping
of oceanic blocks

1951

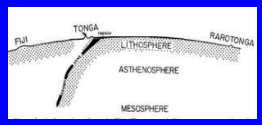


Amstutz
First time term
subduction

1961

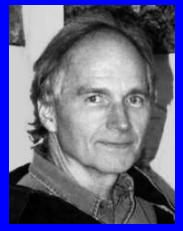
Harry Hess
Seafloor has to be
consumed

1967



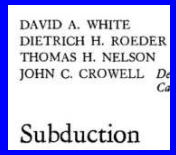
Oliver and Isacks
Bending of the
lithosphere

1969

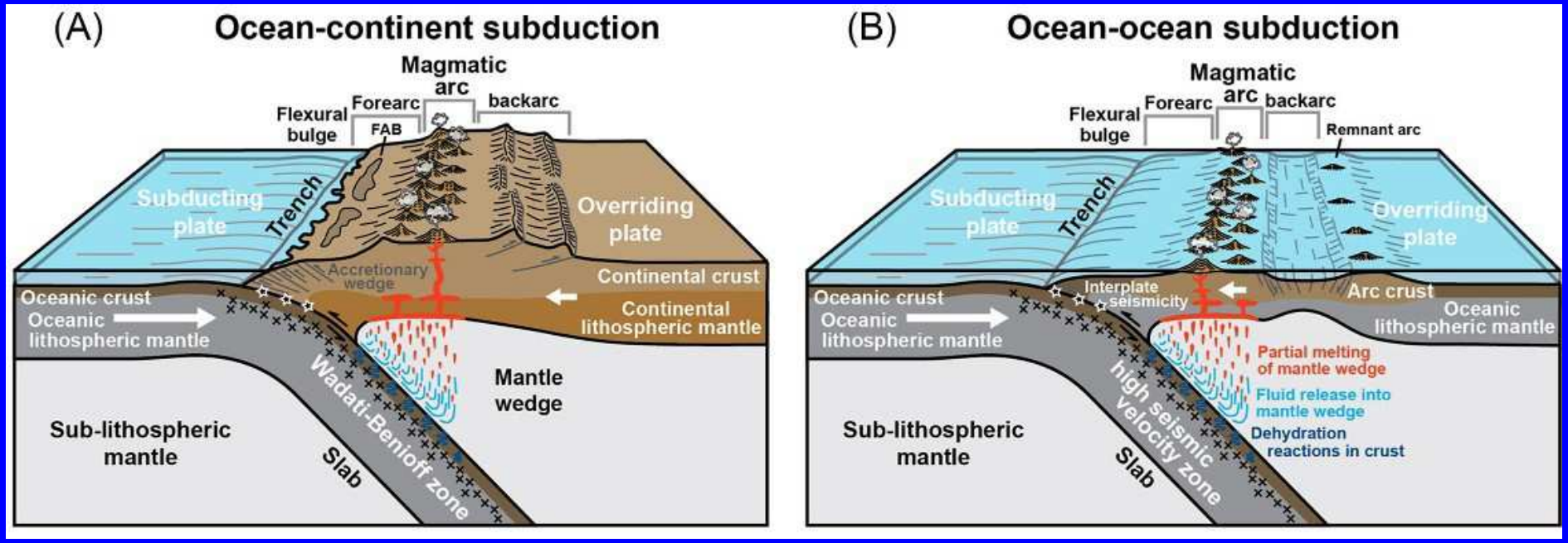


Isacks and Molnar
Downgoing slabs pull plates

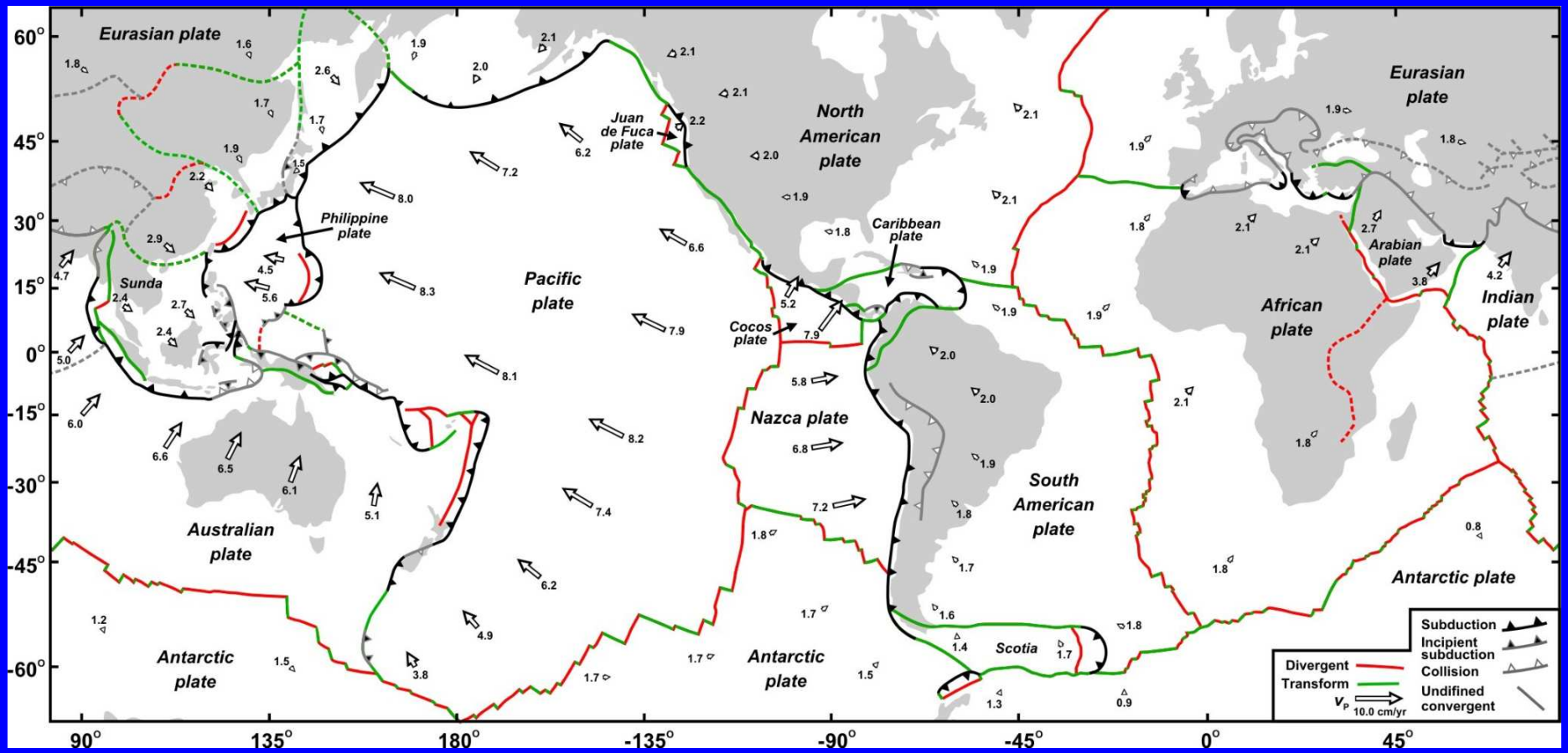
1970



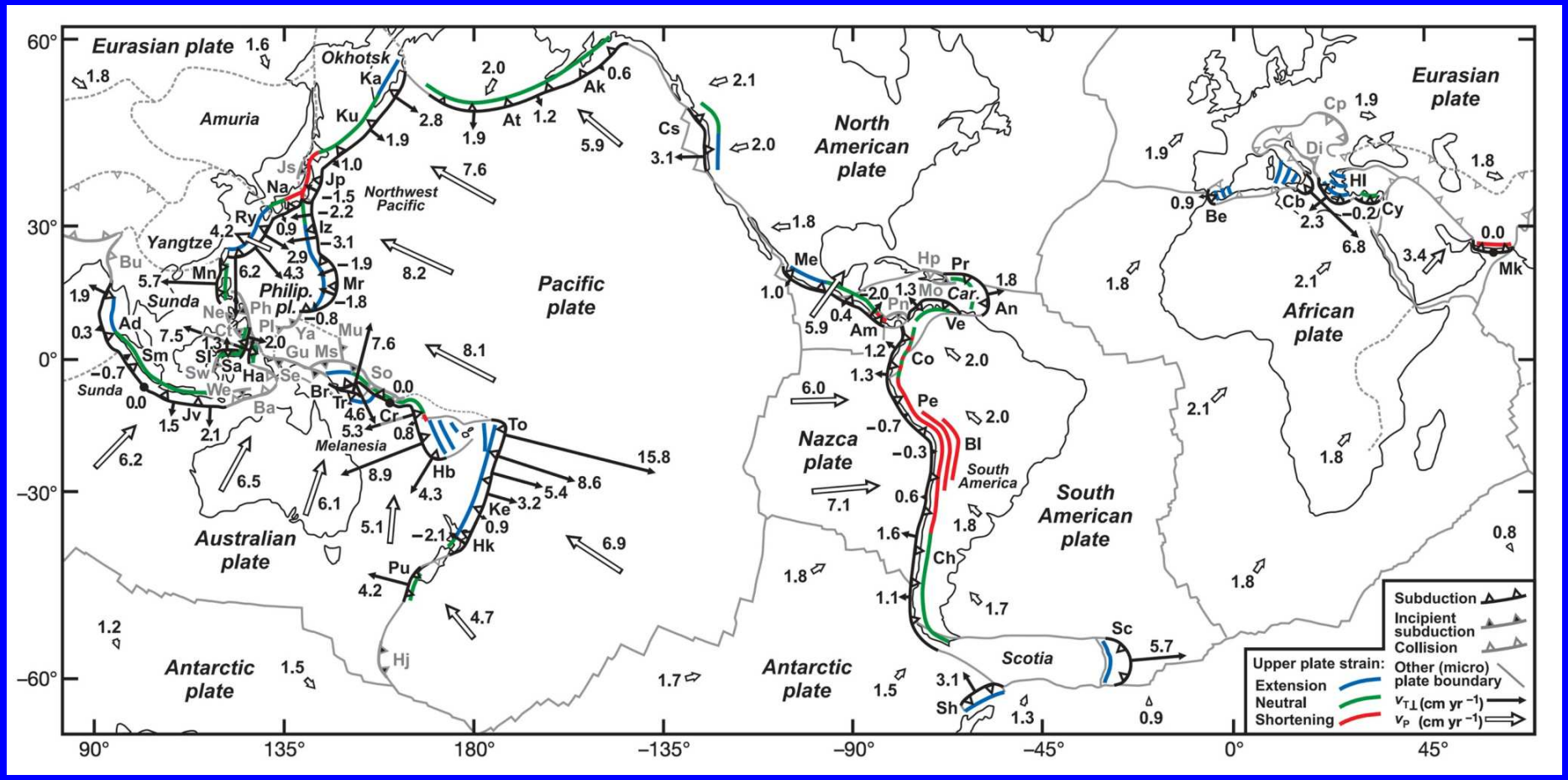
What is a subduction zone?



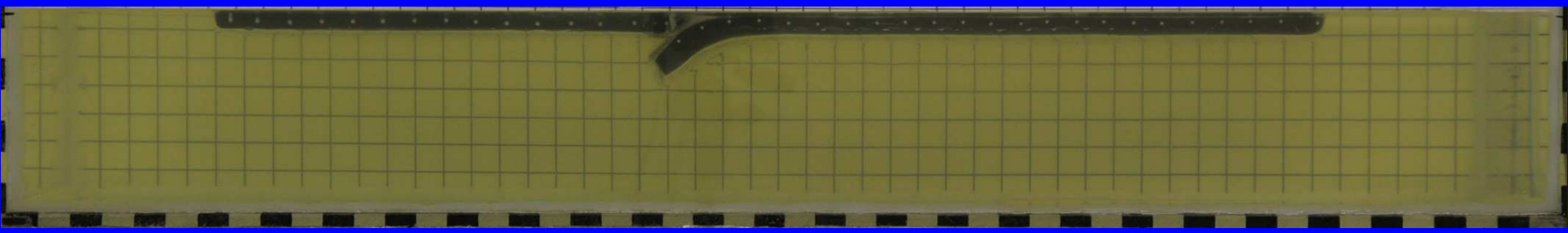
Where?

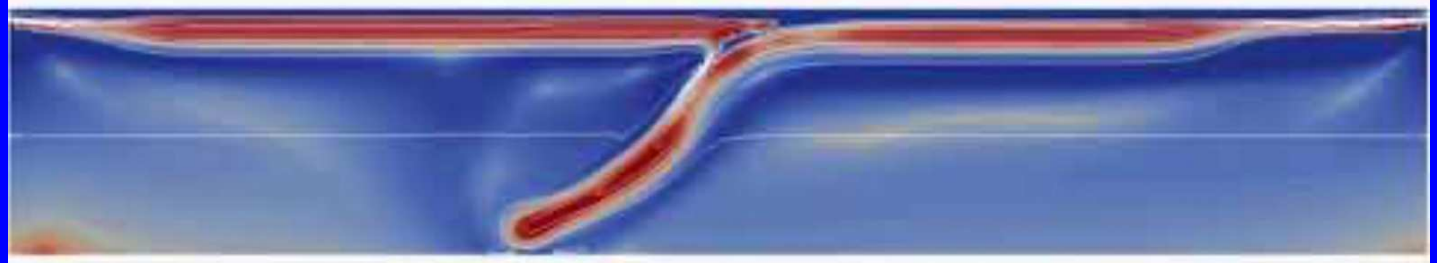

Eurasian plate
North American plate
Pacific plate
Philippine plate
Sunda
Juan de Fuca plate
Caribbean plate
Cocos plate
Nazca plate
South American plate
Australian plate
Antarctic plate
Scotia
African plate
Arabian plate
Indian plate
Subduction
Incipient subduction
Collision
Undifined convergent
Divergent
Transform
v_p 10.0 cm/yr
60°
45°
30°
15°
0°
-15°
-30°
-45°
-60°
90°
135°
180°
-135°
-90°
-45°
0°
45°

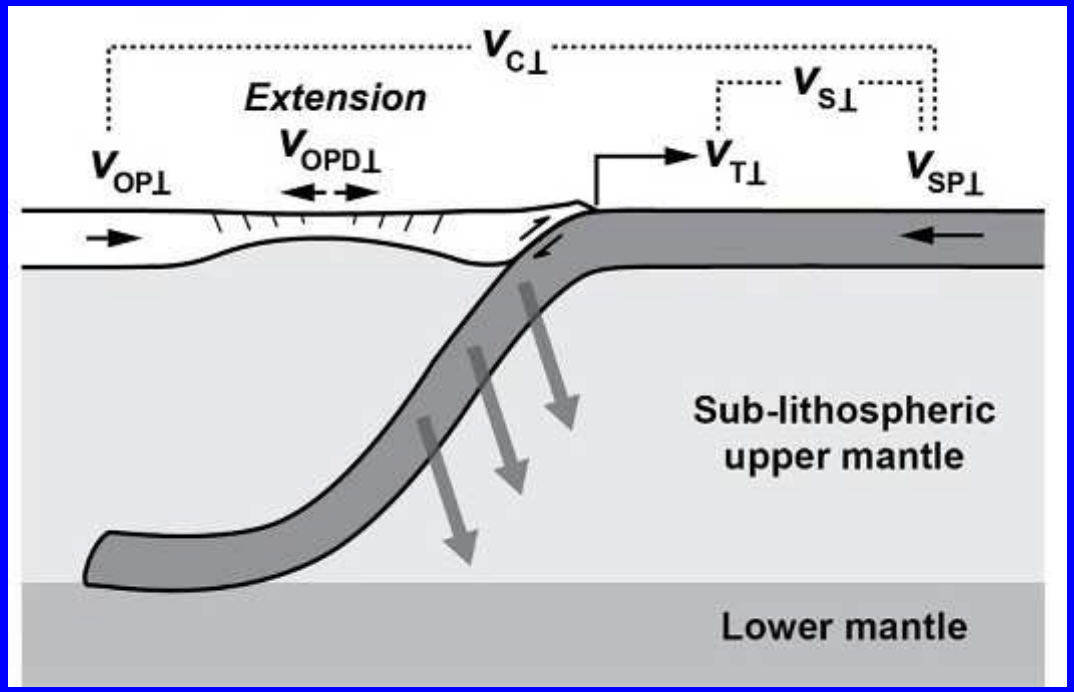
They move!

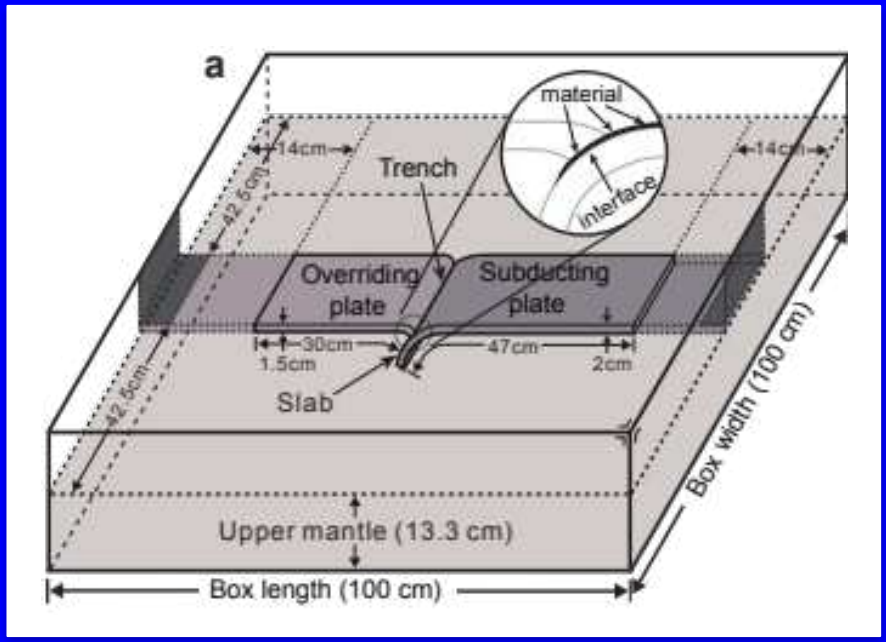

Eurasian plate
Okhotsk
Amuria
Northwest Pacific
Yangtze
Philip. pl.
Sunda
Pacific plate
North American plate
Nazca plate
South America
South American plate
Australian plate
Melanesia
Antarctic plate
Scotia
African plate
Eurasian plate
Subduction
Incipient subduction
Collision
Other (micro) plate boundary
Upper plate strain:
Extension
Neutral
Shortening
$v_{T\perp}$ (cm yr^{-1})
v_P (cm yr^{-1})
60°
30°
0°
−30°
−60°
90°
135°
180°
−135°
−90°
−45°
0°
45°

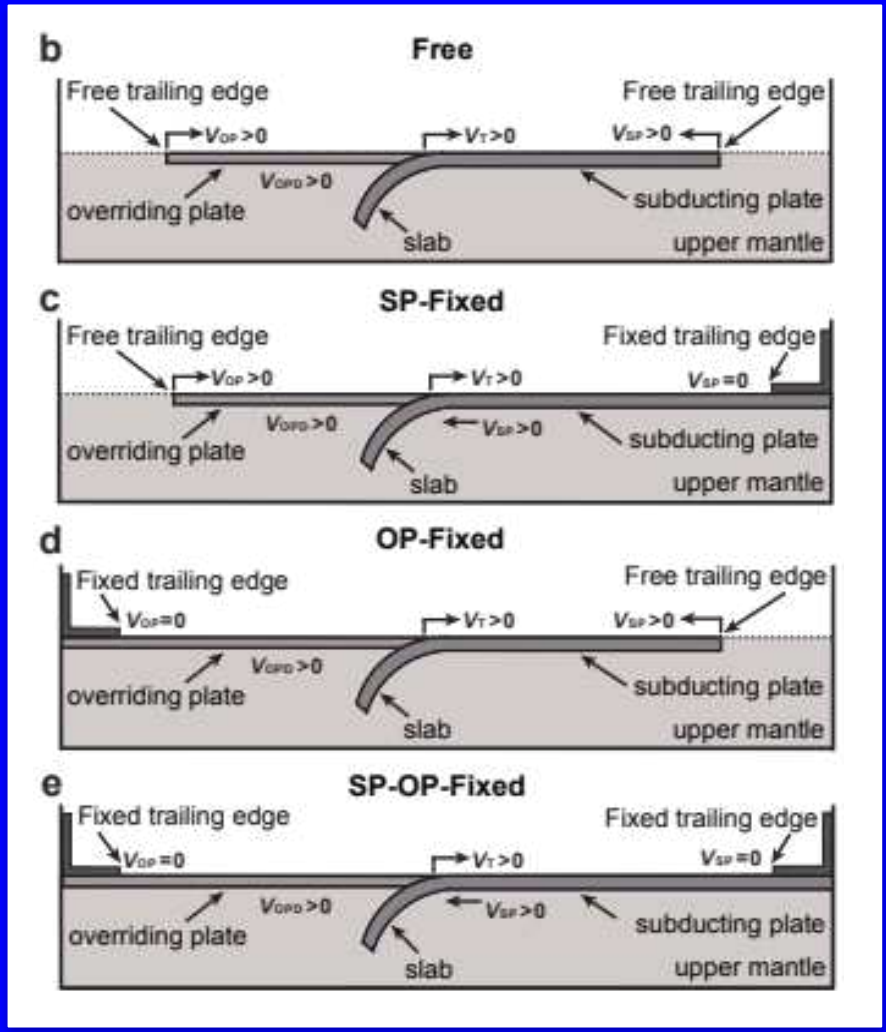
How they work?





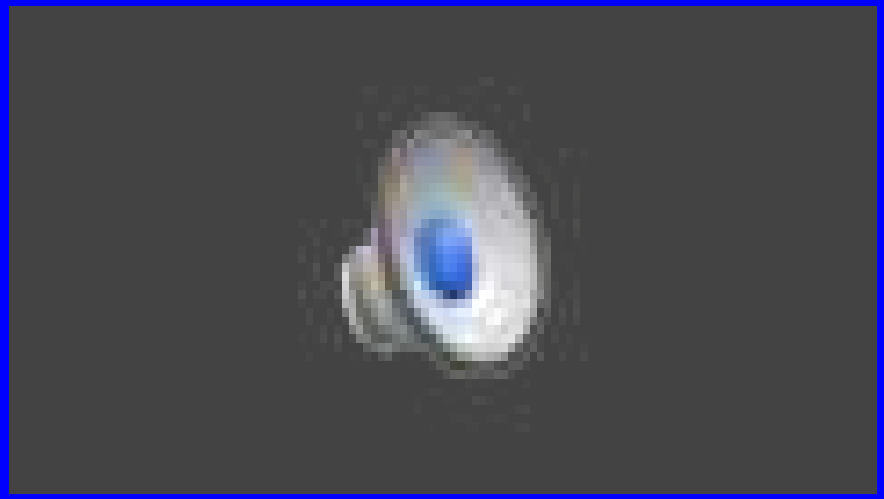

$V_{C\perp}$
Extension
$V_{S\perp}$
$V_{OP\perp}$
$V_{OPD\perp}$
$V_{T\perp}$
$V_{SP\perp}$
Sub-lithospheric
upper mantle
Lower mantle



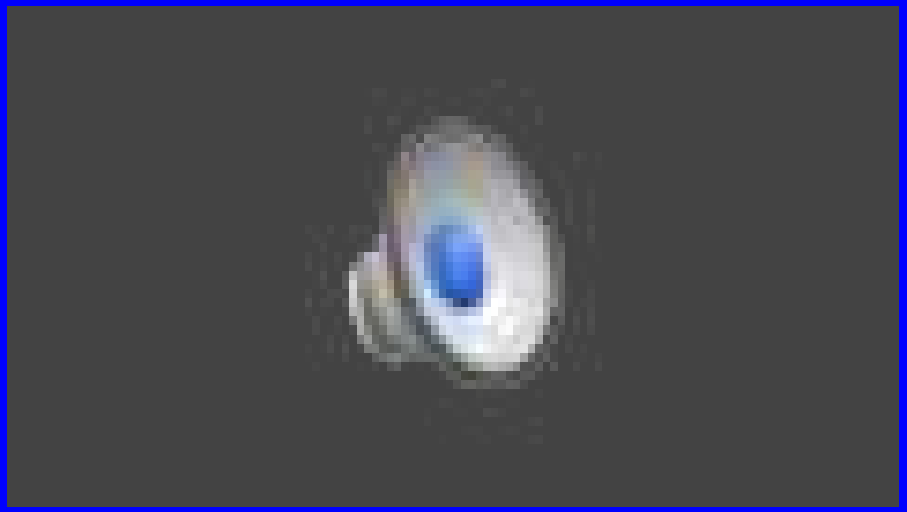


Chen et al. (2015, G-Cubed)

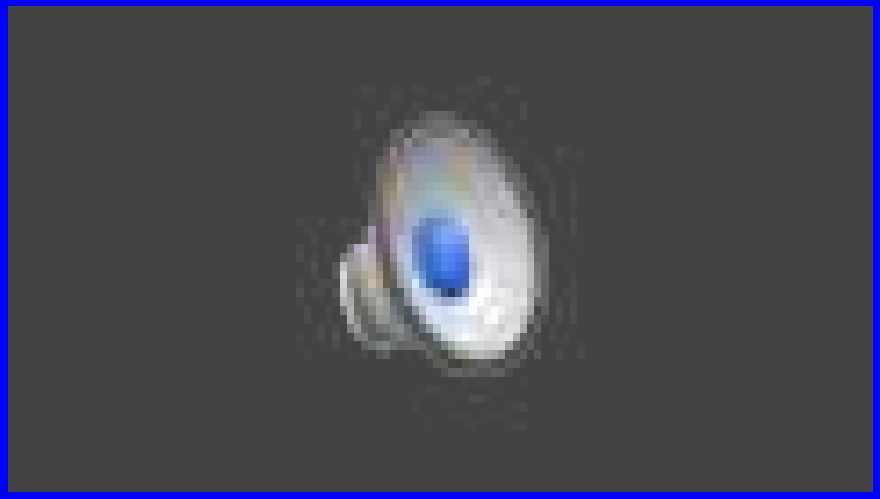
OP – SP Free



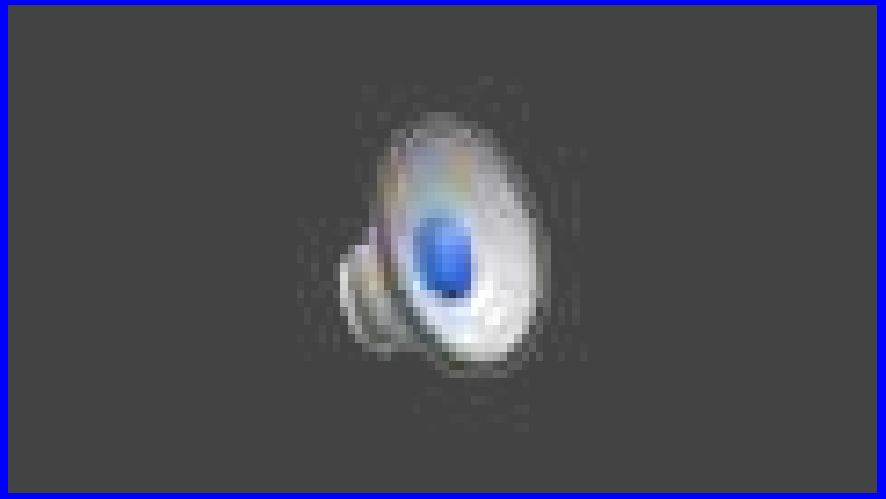
SP Fixed



OP Fixed

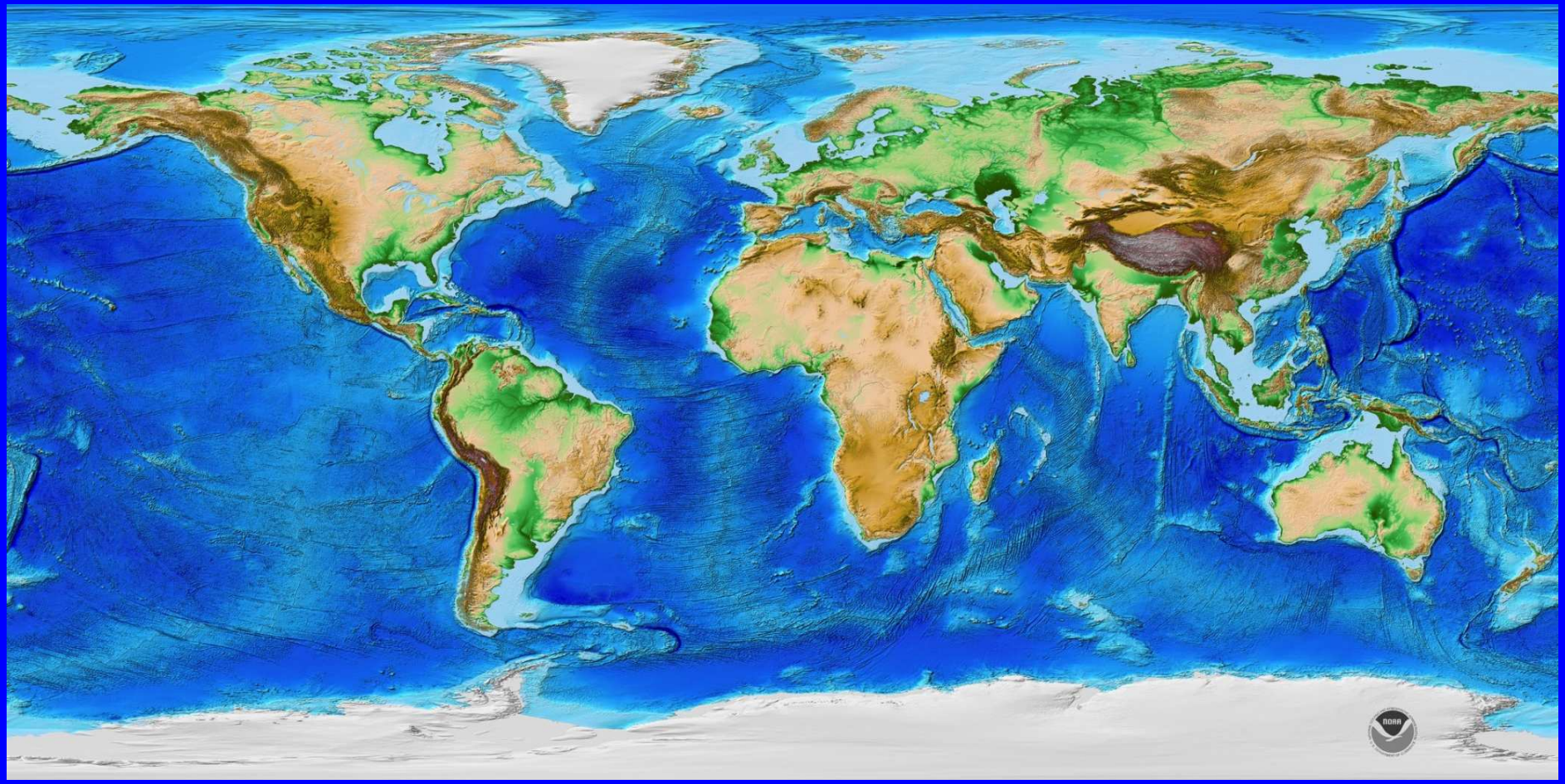


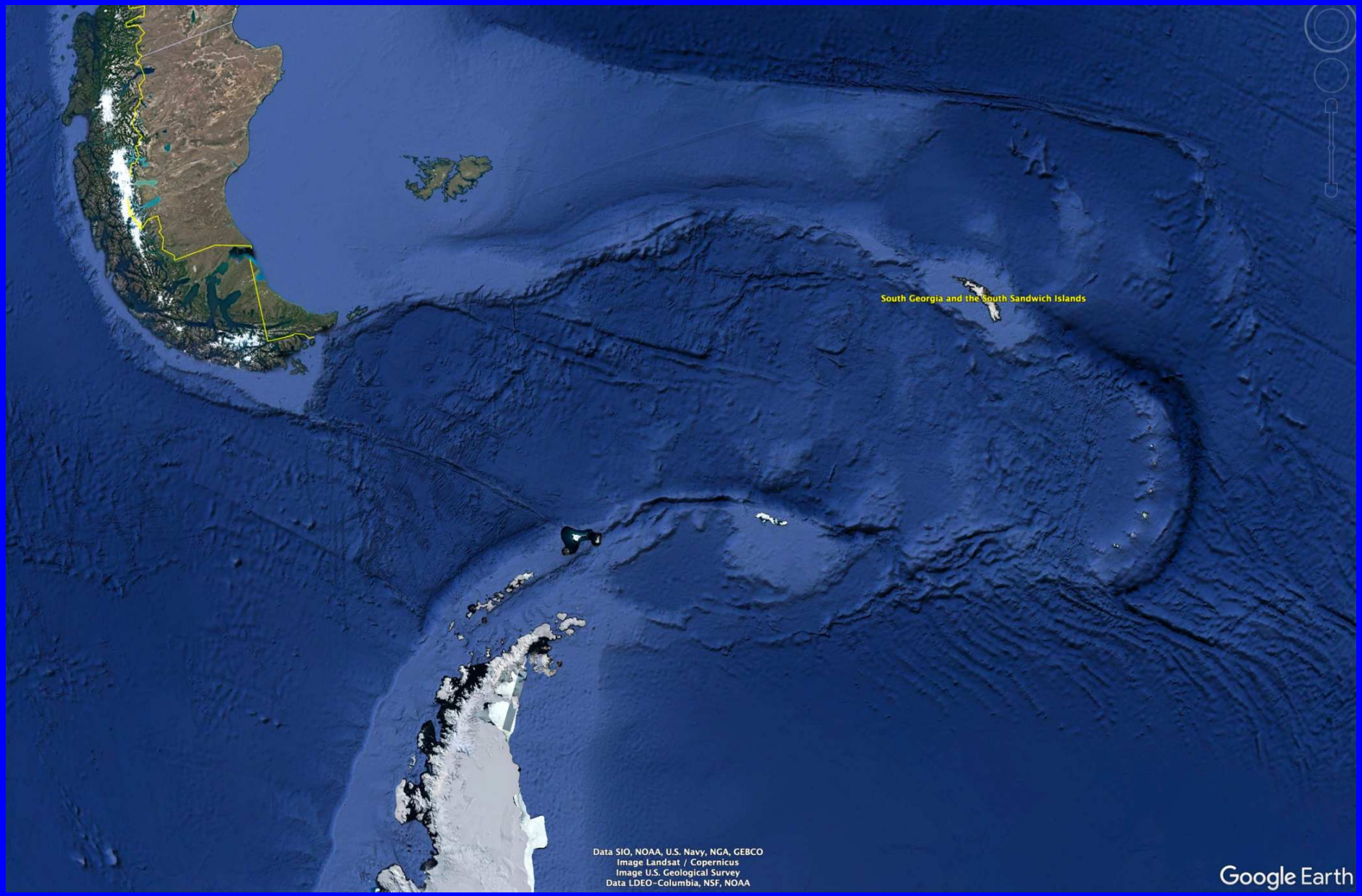
SP - OP Fixed

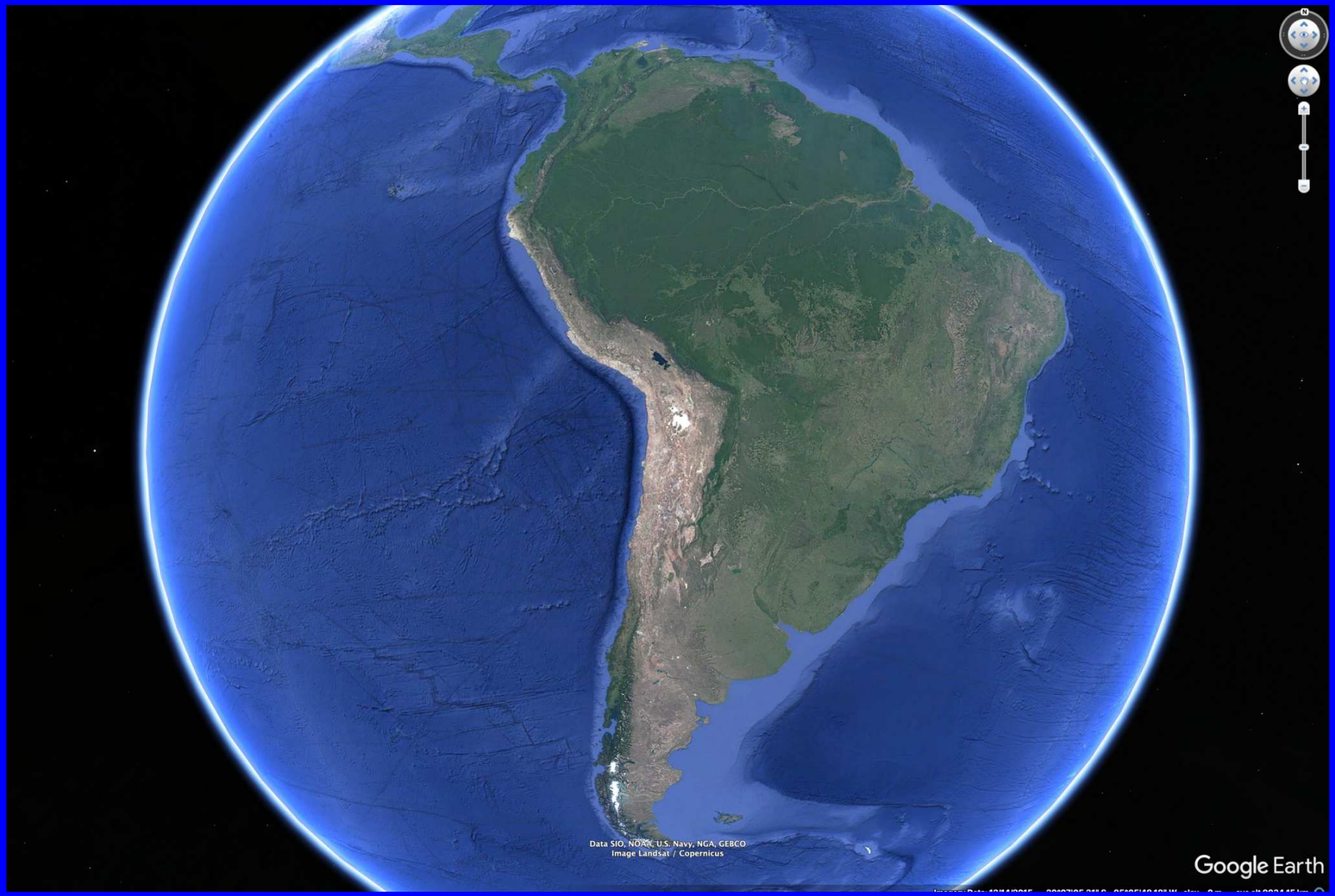


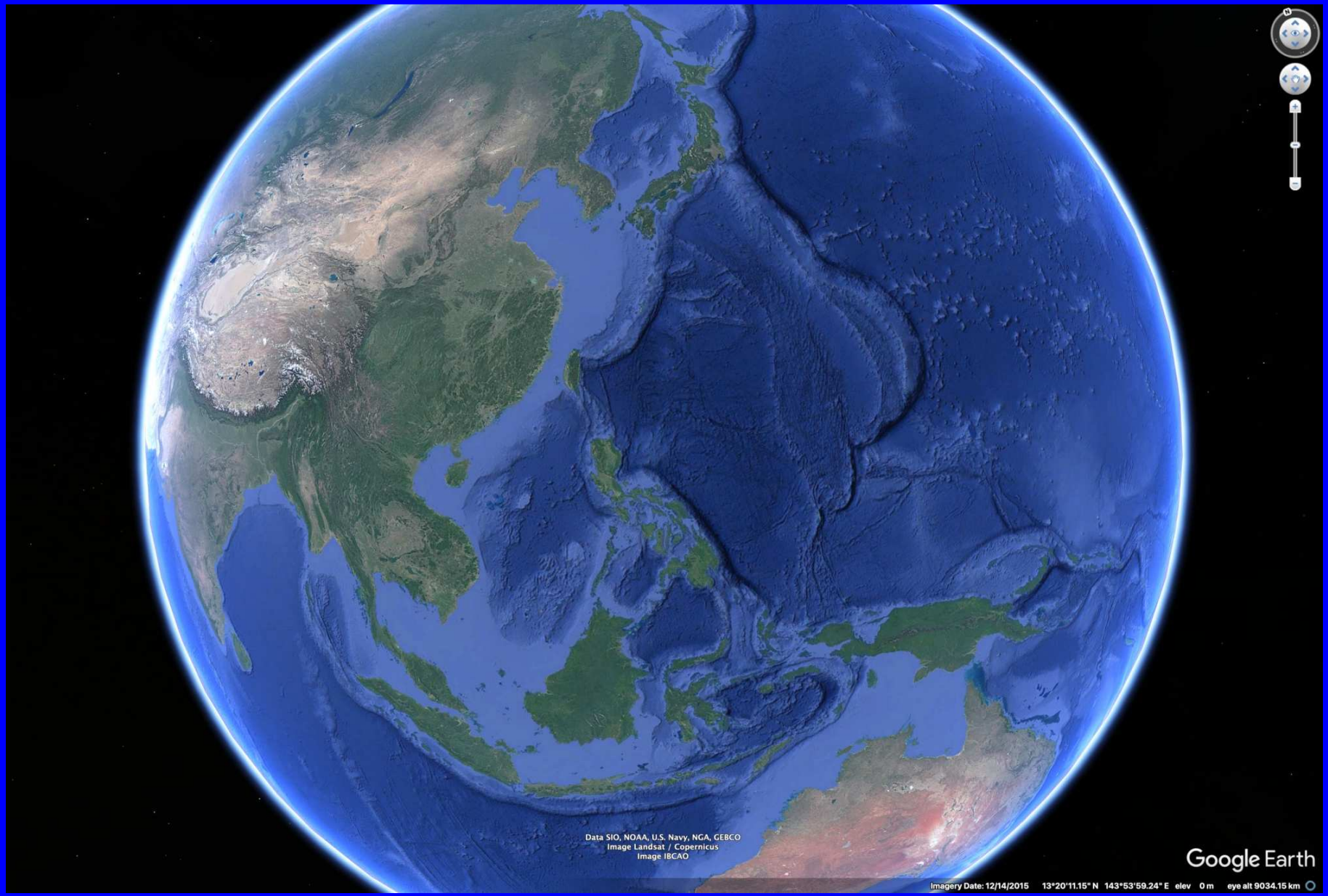
Chen et al. (2015, G-Cubed)

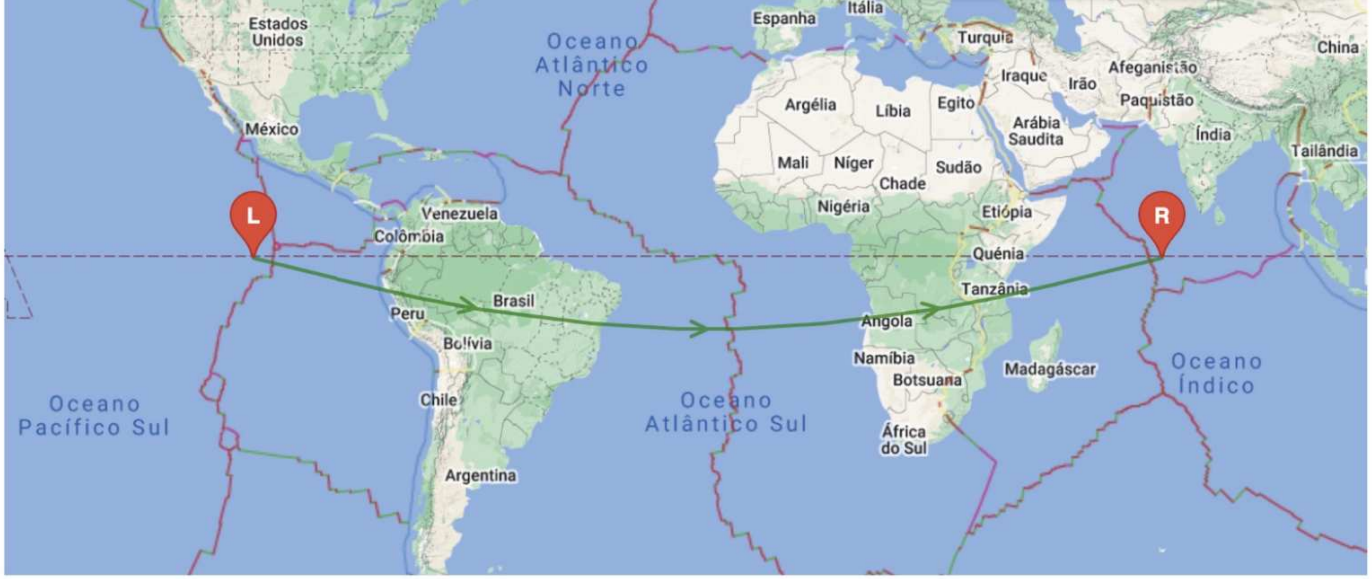
How they look like?

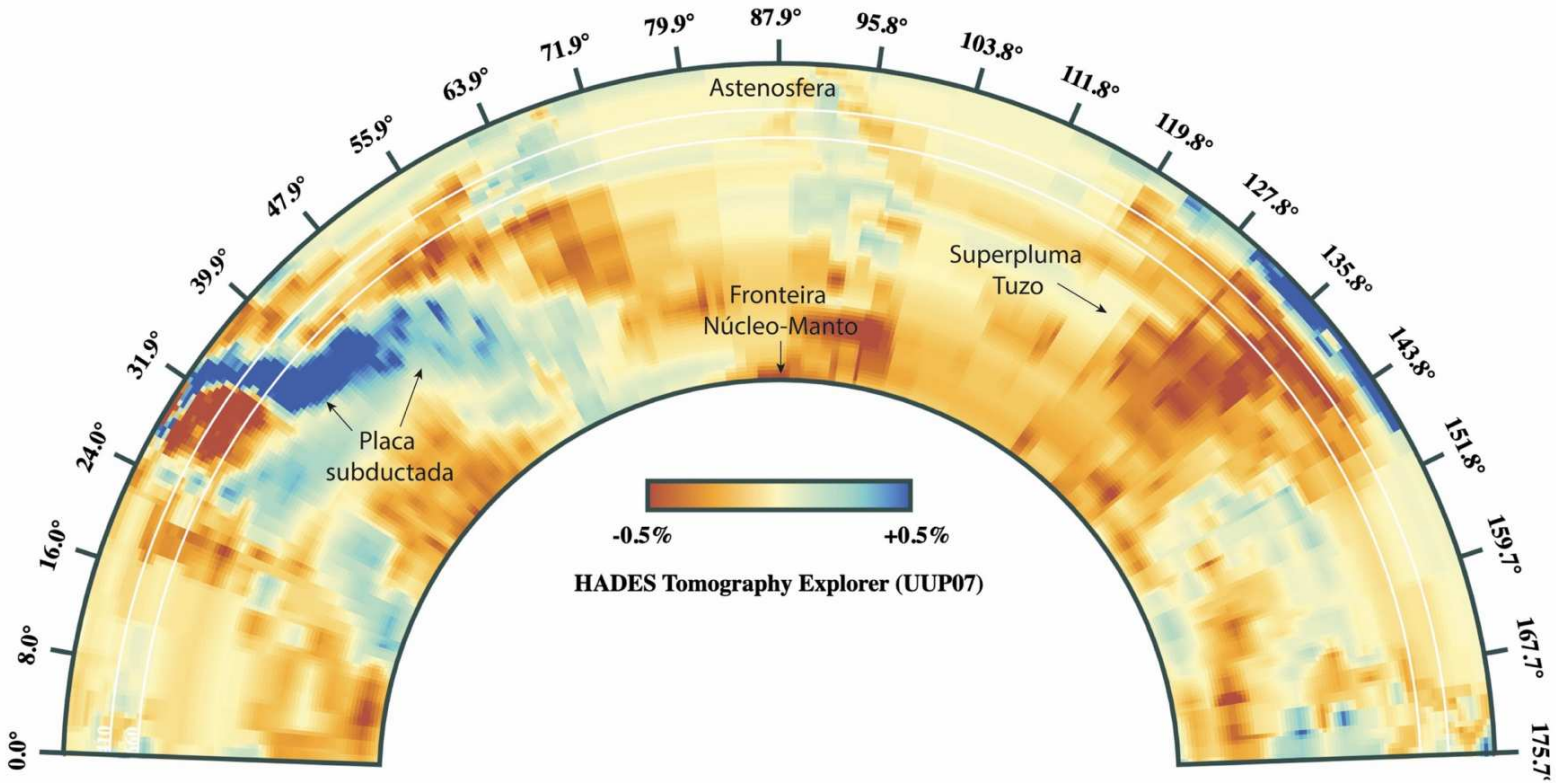


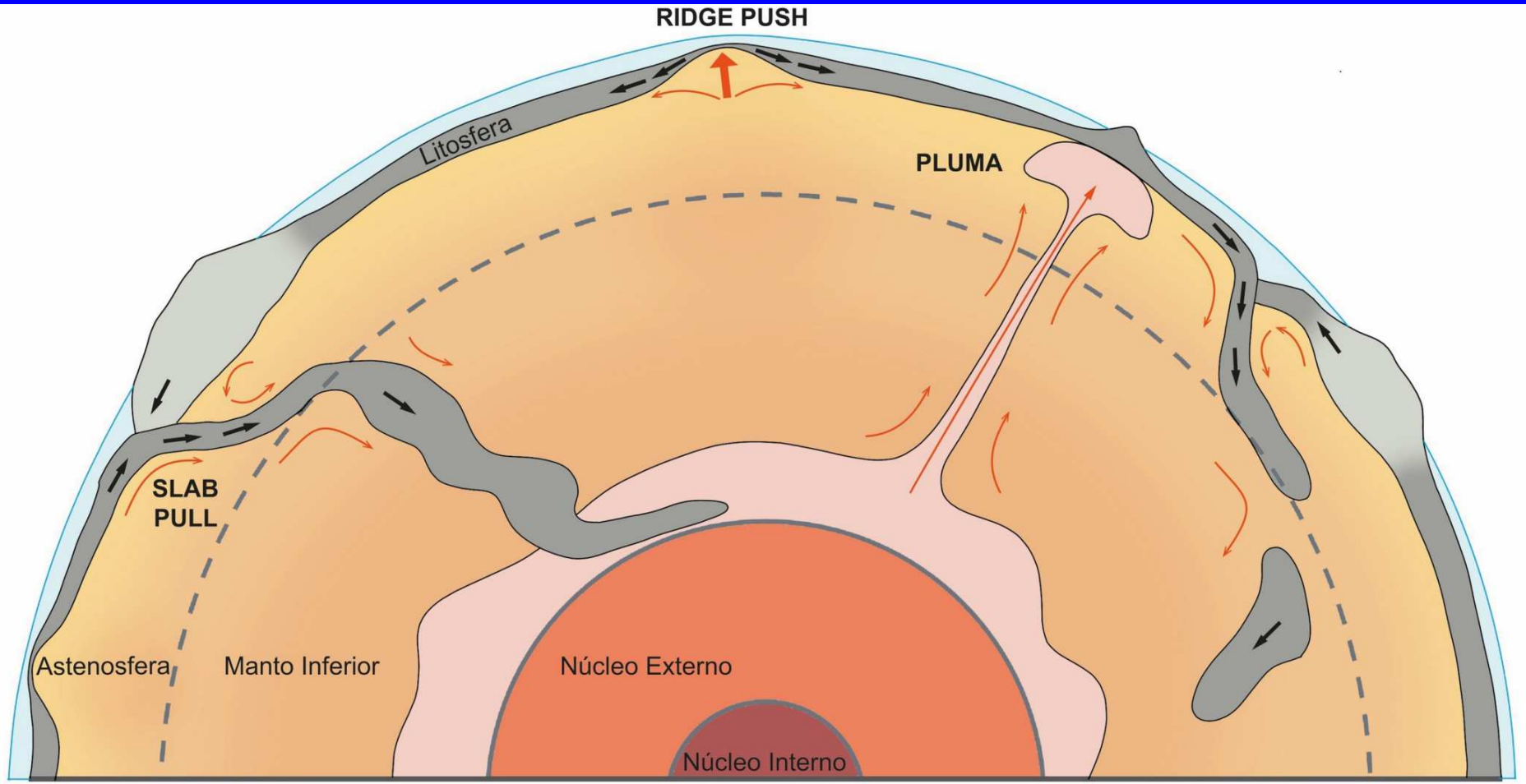

South Georgia and the South Sandwich Islands
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat / Copernicus
Image U.S. Geological Survey
Data LDEO-Columbia, NSF, NOAA
Google Earth

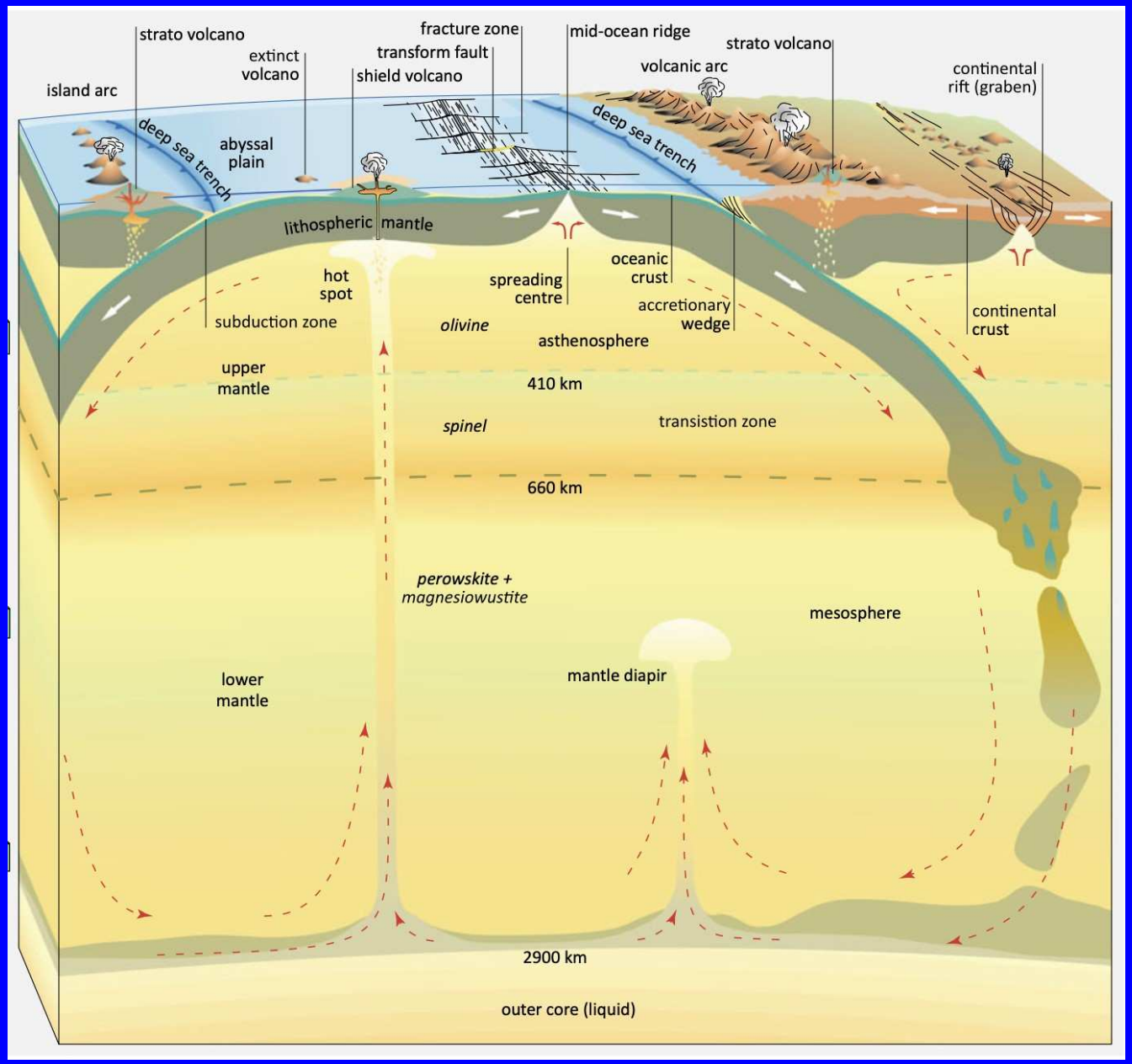

Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat / Copernicus
Google Earth


Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat / Copernicus
Image IBCAO
Google Earth
Imagery Date: 12/14/2015 13°20'11.15" N 143°53'59.24" E elev 0 m eye alt 9034.15 km

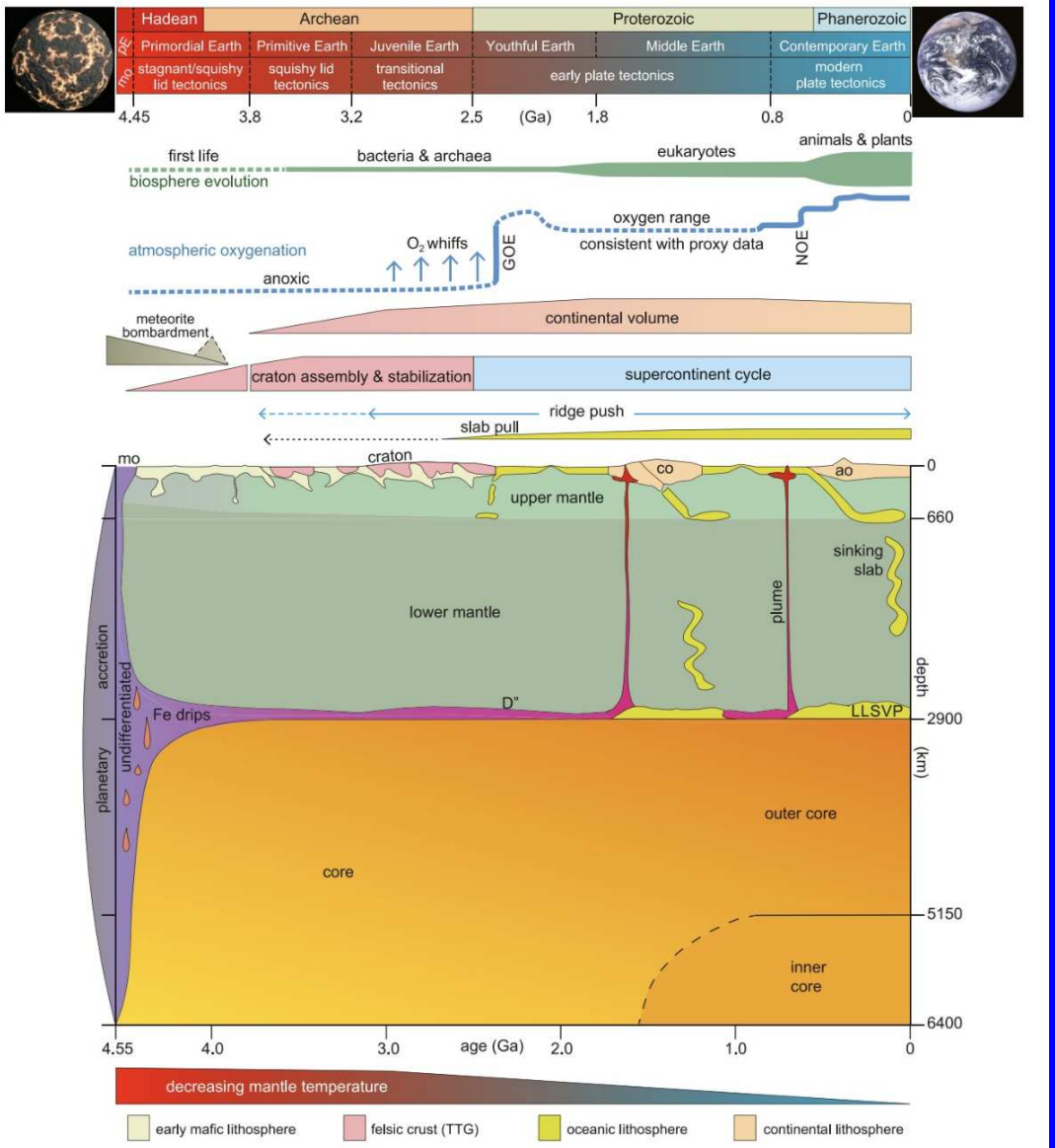

L
R
Oceano Atlântico Norte
Oceano Pacífico Sul
Oceano Atlântico Sul
Oceano Índico
Estados Unidos
México
Venezuela
Colômbia
Brasil
Peru
Bolívia
Chile
Argentina
Espanha
Itália
Turquia
Iraque
Irão
Afeganistão
Paquistão
China
Índia
Tailândia
Arábia Saudita
Egito
Líbia
Argélia
Mali
Níger
Sudão
Chade
Nigéria
Etiópia
Quénia
Tanzânia
Angola
Namíbia
Botsuana
Madagáscar
África do Sul


Astenosfera
Superpluma Tuzo
Fronteira Núcleo-Manto
Placa subductada
-0.5%
+0.5%
HADES Tomography Explorer (UUP07)
0.0°
8.0°
16.0°
24.0°
31.9°
39.9°
47.9°
55.9°
63.9°
71.9°
79.9°
87.9°
95.8°
103.8°
111.8°
119.8°
127.8°
135.8°
143.8°
151.8°
159.7°
167.7°
175.7°


RIDGE PUSH
Litosfera
PLUMA
SLAB
PULL
Astenosfera
Manto Inferior
Núcleo Externo
Núcleo Interno

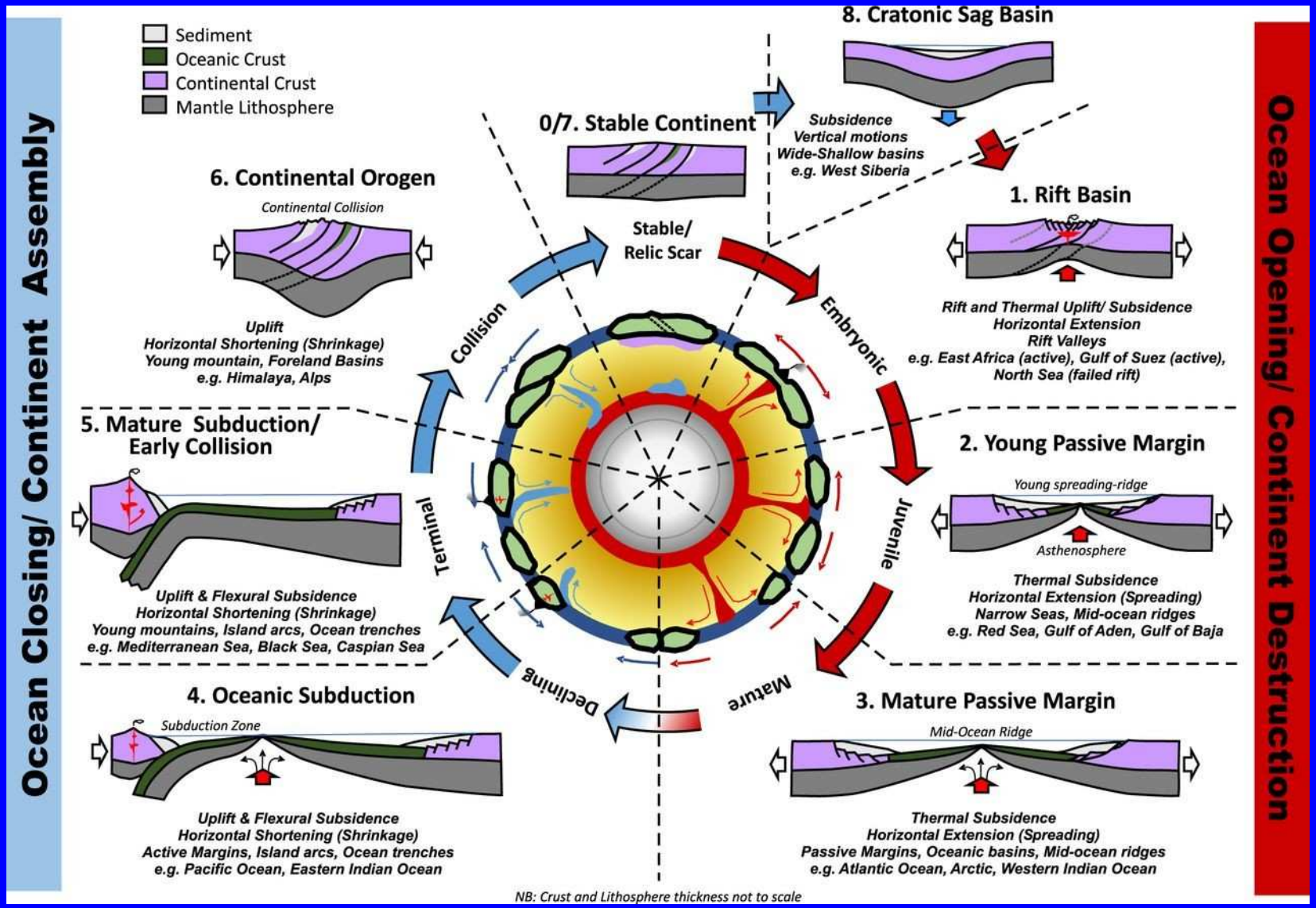

strato volcano
extinct volcano
island arc
deep sea trench
abyssal plain
fracture zone
transform fault
shield volcano
mid-ocean ridge
deep sea trench
volcanic arc
strato volcano
continental rift (graben)
lithospheric mantle
hot spot
spreading centre
oceanic crust
accretionary wedge
continental crust
subduction zone
olivine
asthenosphere
upper mantle
410 km
spinel
transition zone
660 km
perowskite + magnesiowustite
mesosphere
lower mantle
mantle diapir
2900 km
outer core (liquid)

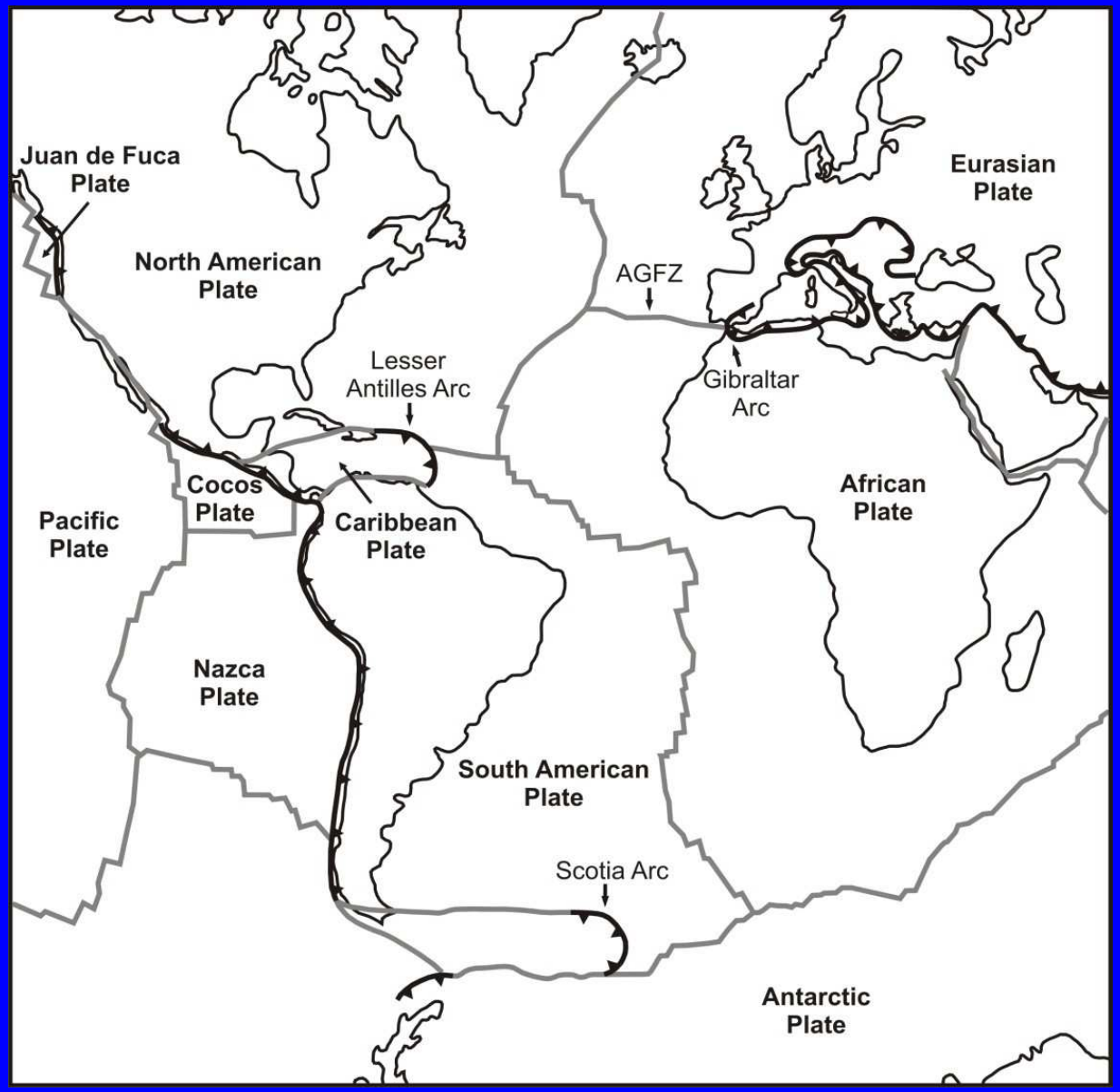
When did they start?



Cawood et al. (2022)

How do they start?




Juan de Fuca Plate
North American Plate
Eurasian Plate
AGFZ
Lesser Antilles Arc
Gibraltar Arc
Cocos Plate
Pacific Plate
Caribbean Plate
African Plate
Nazca Plate
South American Plate
Scotia Arc
Antarctic Plate

Relevance

HOW PLATES MOVE

Additional evidence of mantle dynamics from sources such as seismic tomography have allowed us to develop our understanding better of the mechanisms that move plates. It seems, rather than being carried along passively like rafts on huge convection cells in the mantle, that the plates themselves appear to be the main cause of the convection system of our planet – mantle convection not only *includes* the plates, but is primarily *driven by* them.

The loss of heat from the lithosphere over time causes it eventually to become cold and dense enough to have **negative buoyancy.** This allows it to sink into the warmer and more ductile asthenosphere. This drags the surface plates by **slab pull**, which appears to be the main force responsible for plate movement. This, in turn, creates tension forces elsewhere on the plate (such as then Mid-Atlantic Ridge), thinning it and causing **passive convectional upwelling** of the hotter mantle rock in response to the movement of the plates above (the convection seems to be an *induced* upwelling). This forms the ridge which slides away laterally as it cools, pushing the plates apart by **ridge push** and contributing to the process of slab pull to move the plates. The solid but ductile rock of the asthenosphere does flow, but the movements there seem to be mostly induced movements by the movements of the plates (kind of like how a paddle pushes water around it as it moves through the water.

SLAB PULL

A. Negative buoyancy of plate → subduction

i. Cooling of oceanic plate over time

ii. Inc temperature as the plate subducts → metamorphism

↓ ↓

increased density of the plate → **SUBDUCTION**

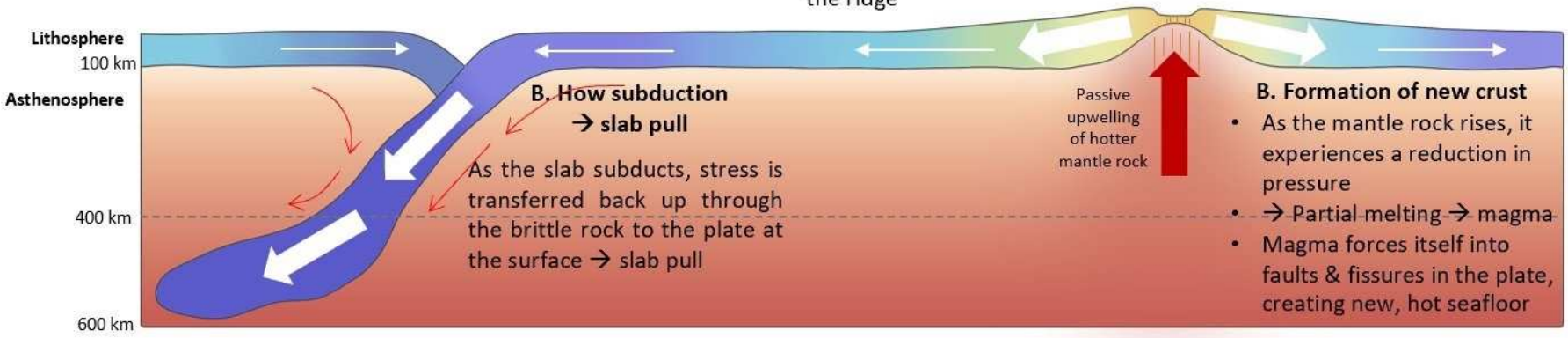
RIDGE PUSH

A. How the ridge is formed

- Tension forces → plate thins
- Hotter mantle rock upwells passively to fill the cavity
- This heats the plate → positive buoyancy → uplifts the ridge

C. Ridge push

- As the new seafloor cools over time, it becomes more dense and slides away laterally down slope
- This pushes the plates apart by ridge push



Seismicity

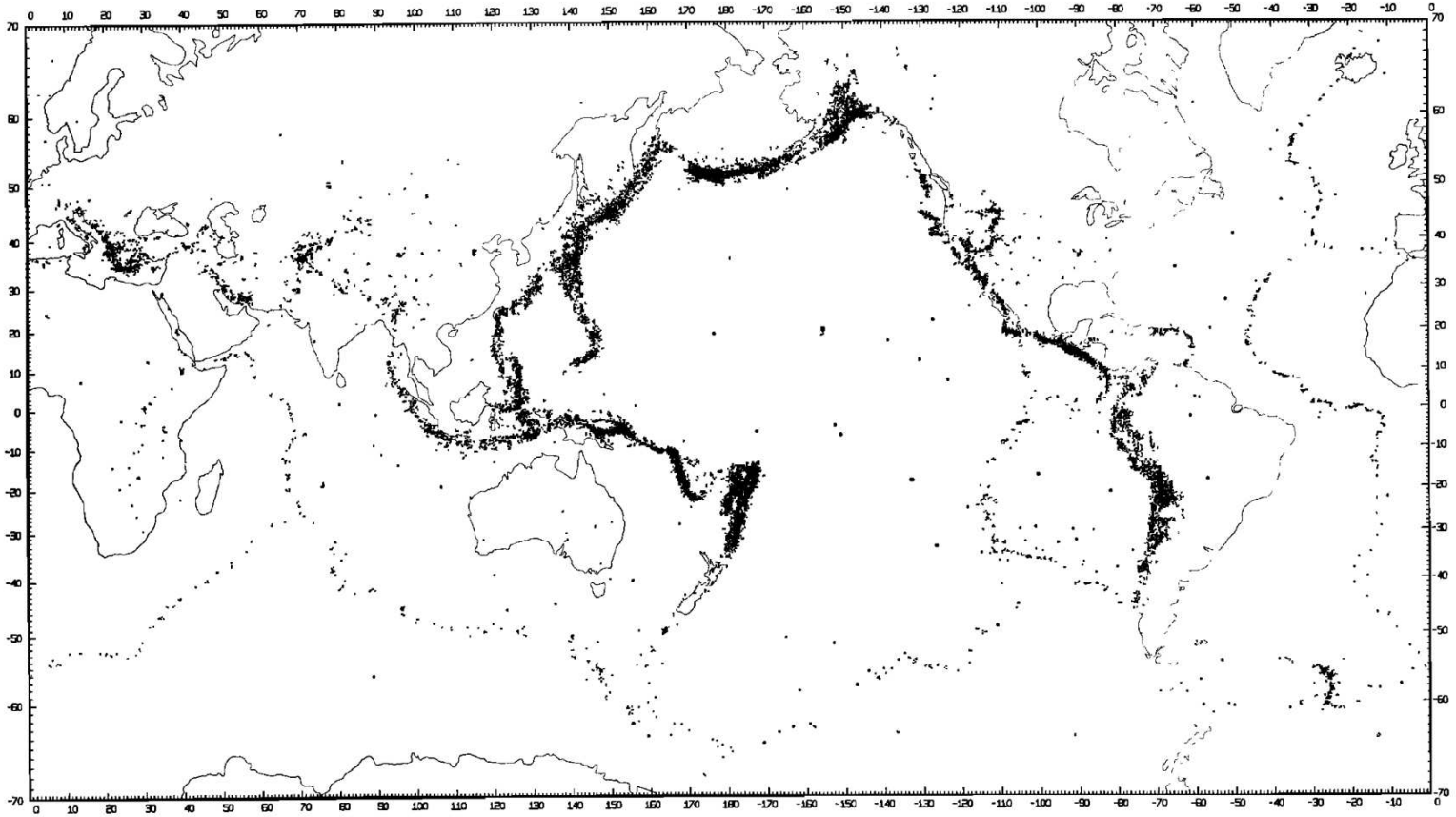
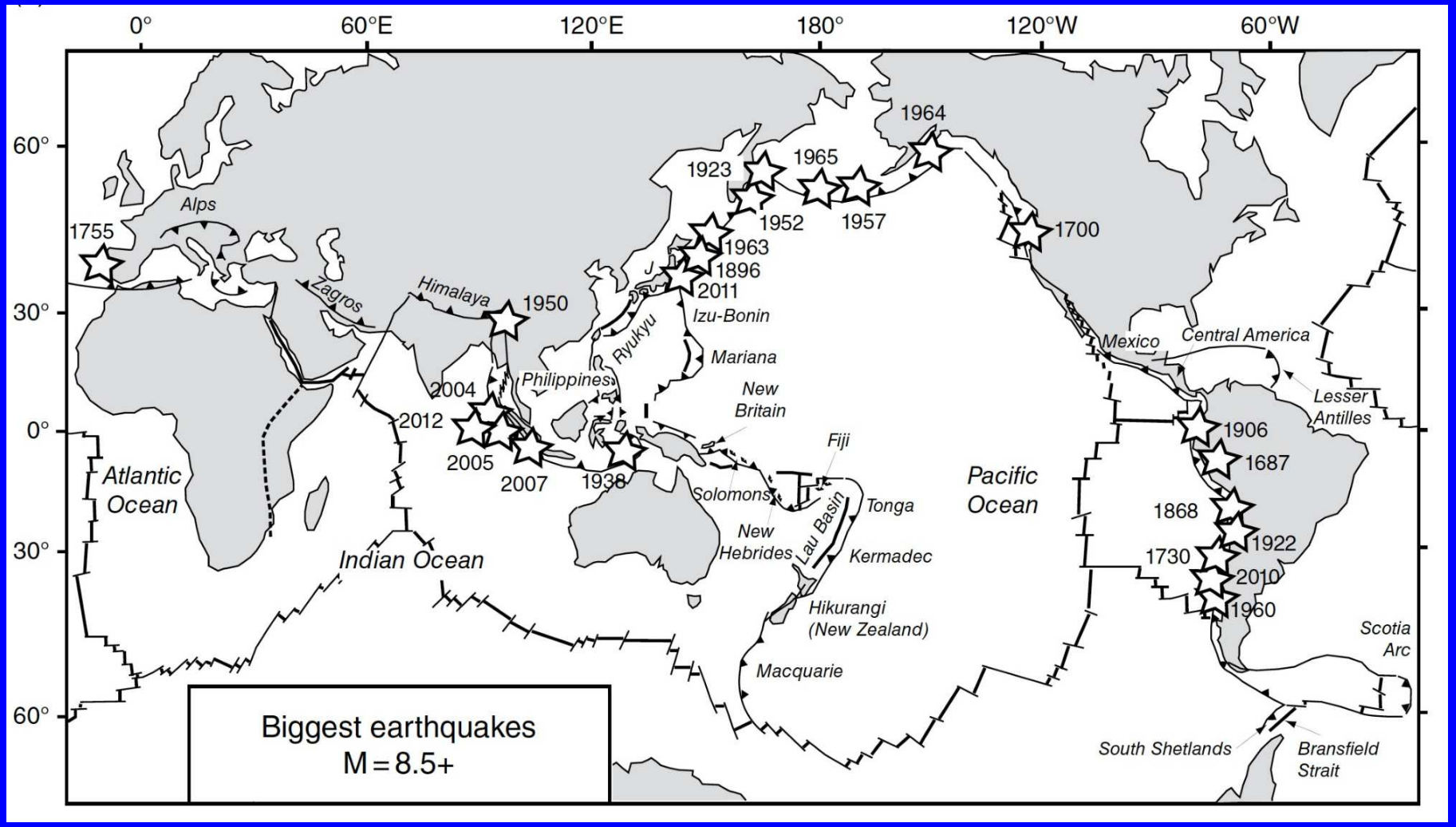


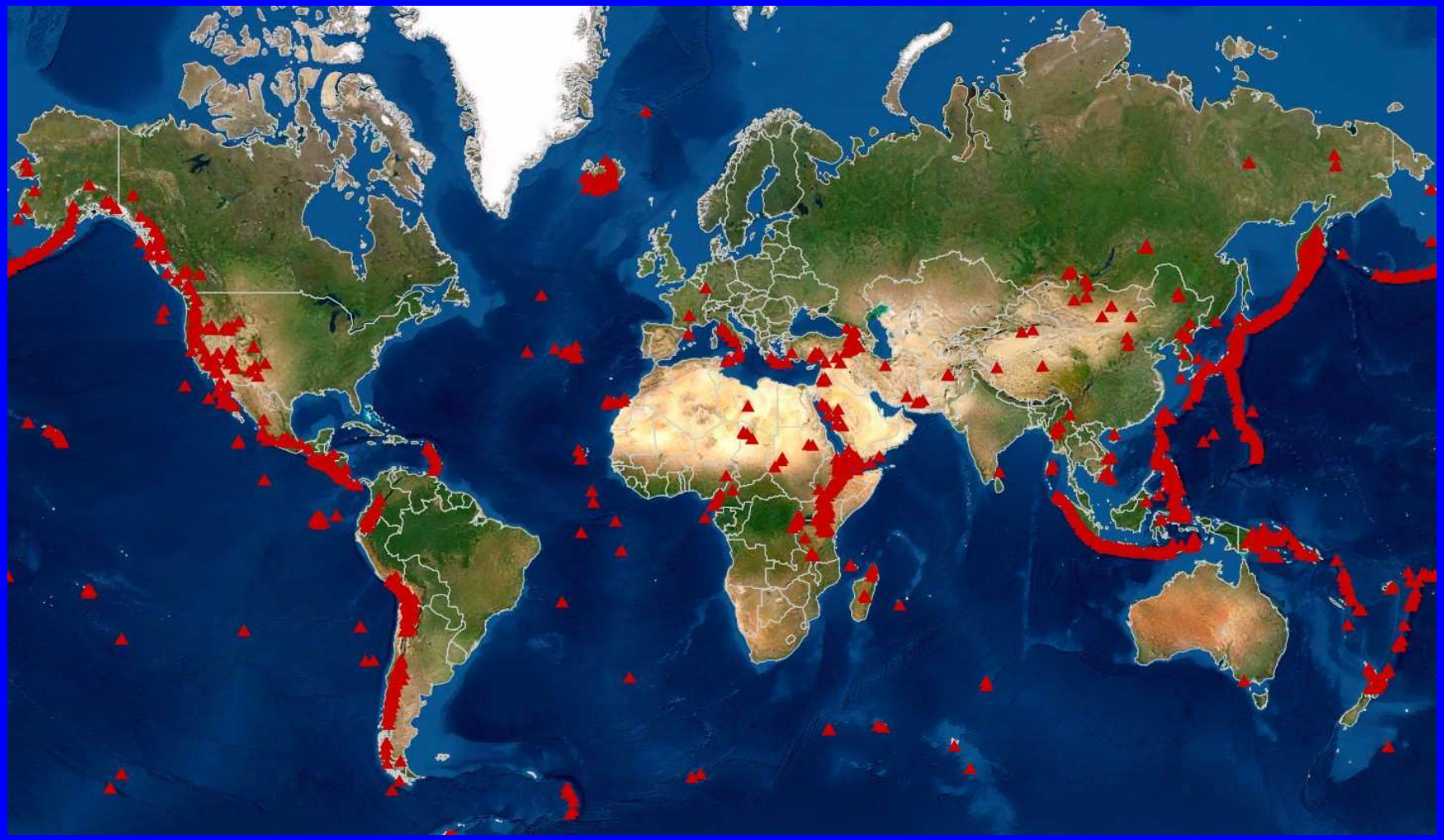
Fig. 15. Worldwide distribution of all earthquake epicenters for the period 1961 through 1967 as reported by U. S. Coast and Geodetic Survey [after *Barazangi and Dorman*, 1968]. Note continuous narrow major seismic belts that outline aseismic blocks; very narrow, sometimes steplike pattern of belts of only moderate activity along zones of spreading; broader very active belts along zones of convergence; diffuse pattern of moderate activity in certain continental zones.

Major earthquakes

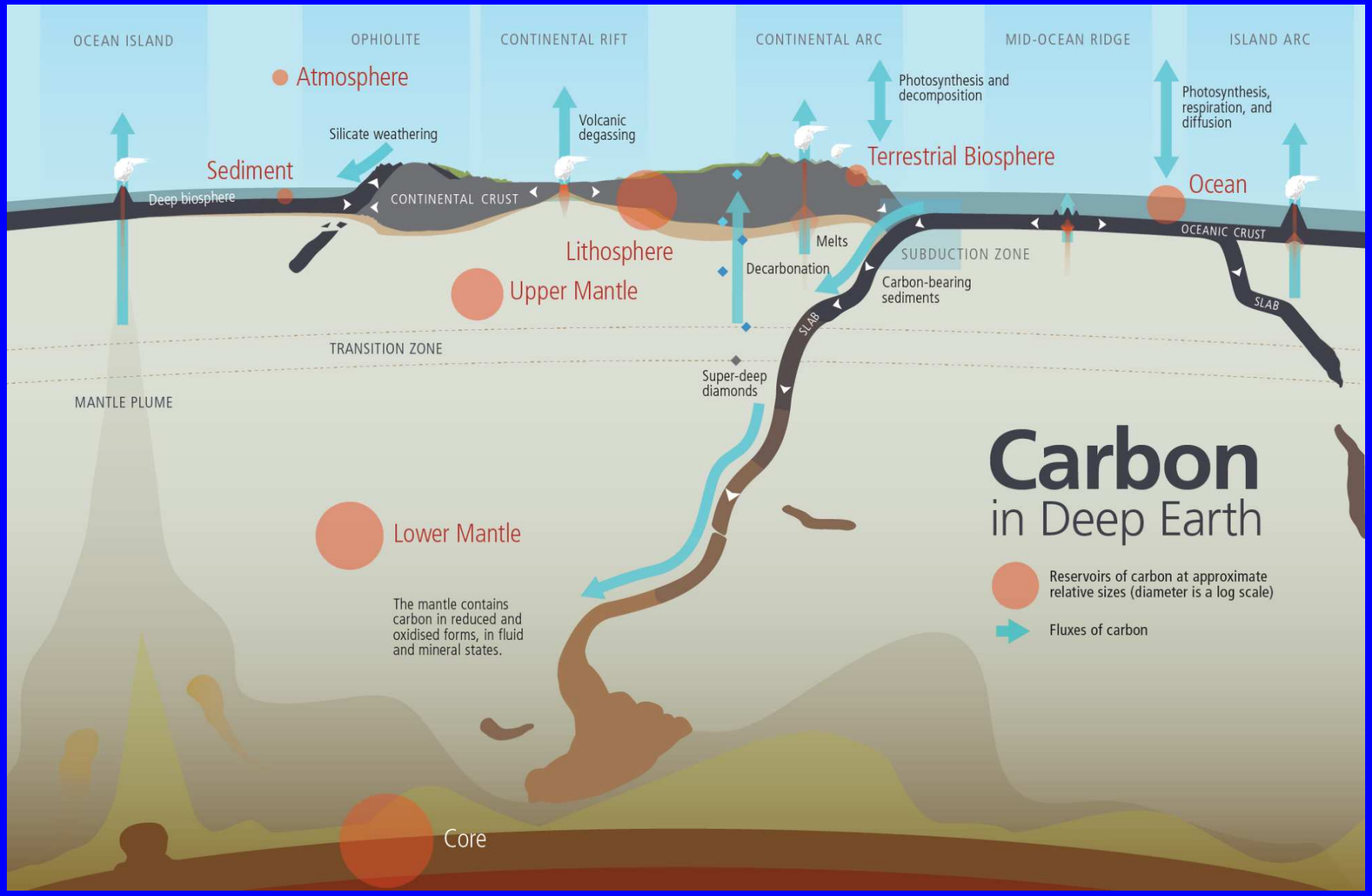


Cawood et al. (2022)

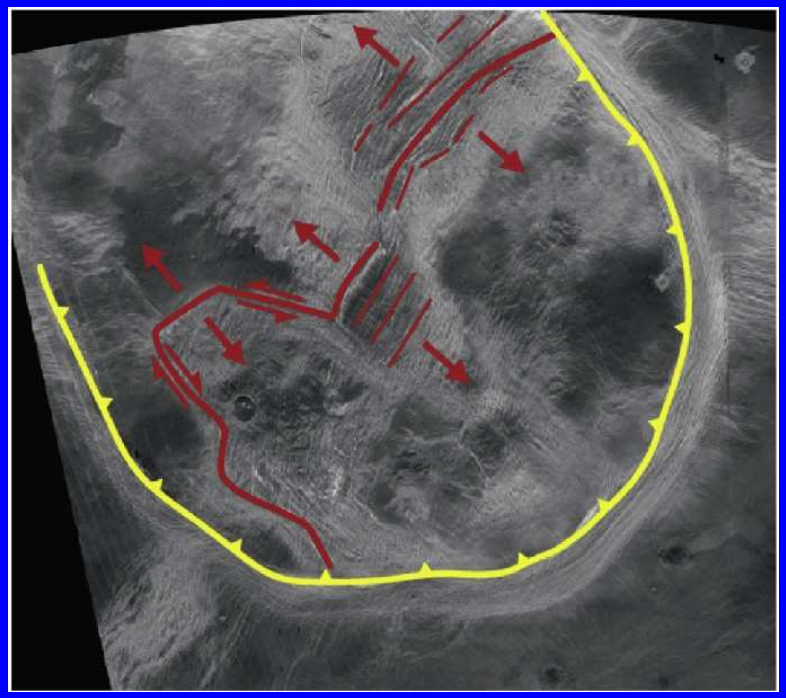
Volcanoes



Deep Carbon Cycle



Planetary subduction zones

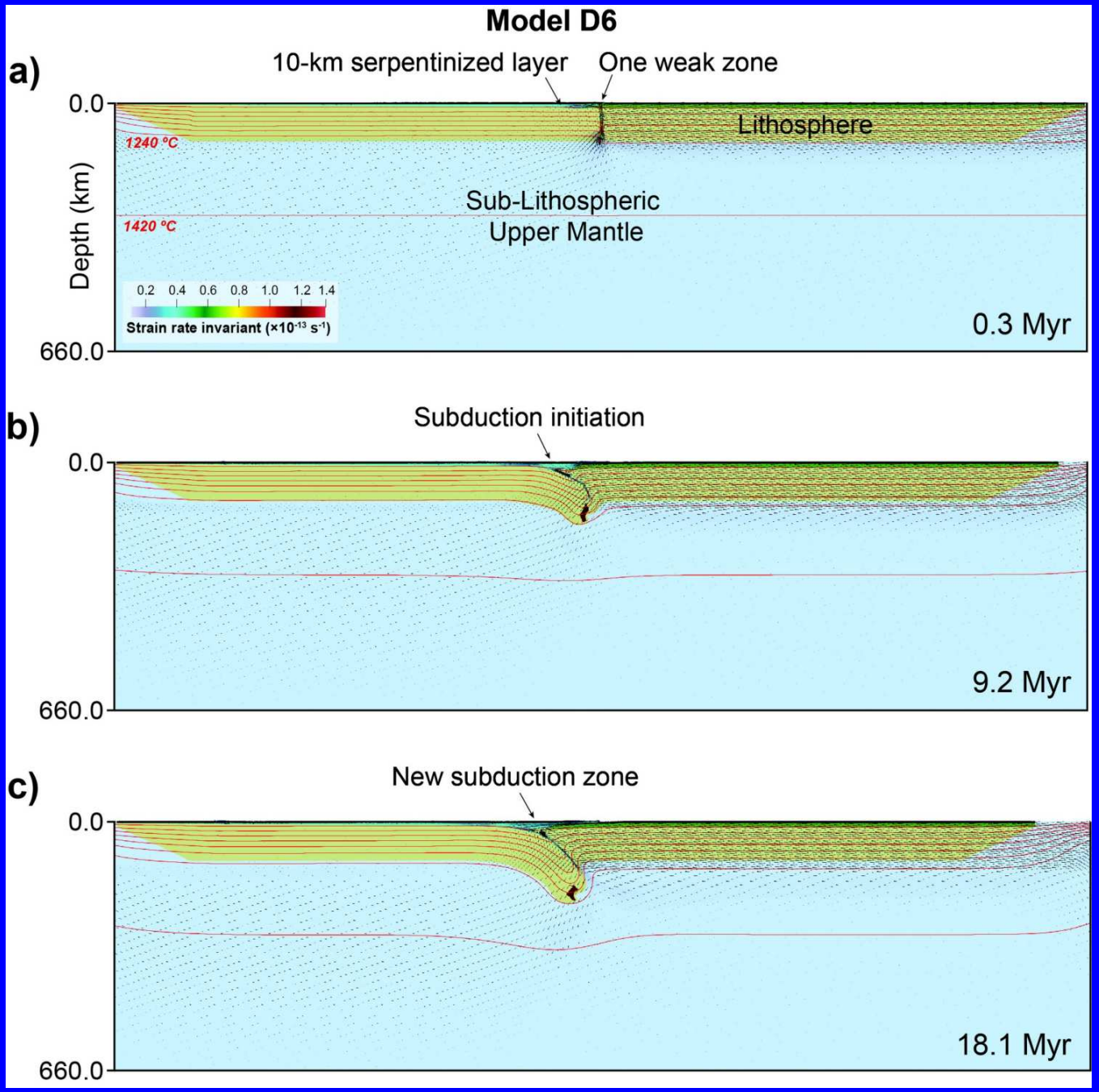


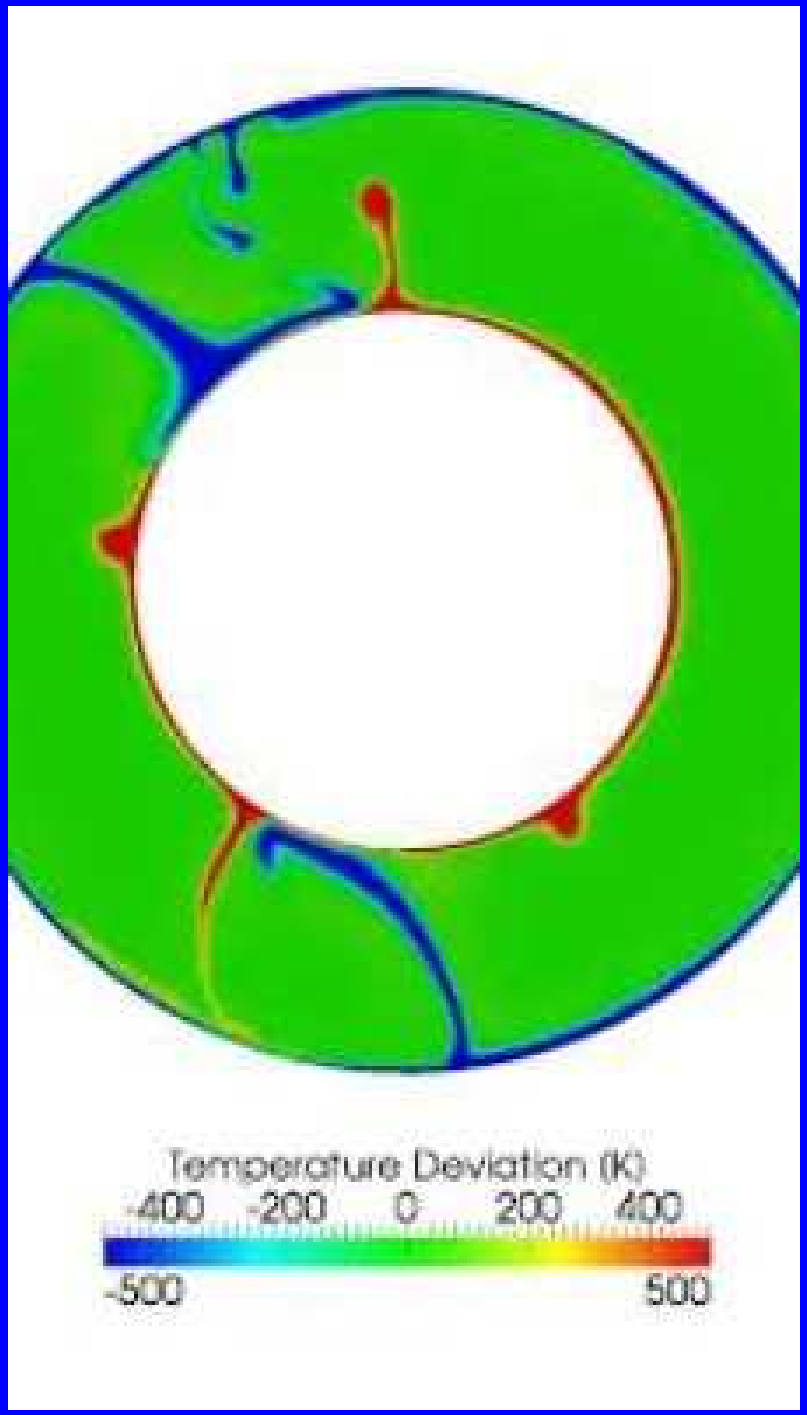
Mints et al. (2019)

Some misconception about subduction zones

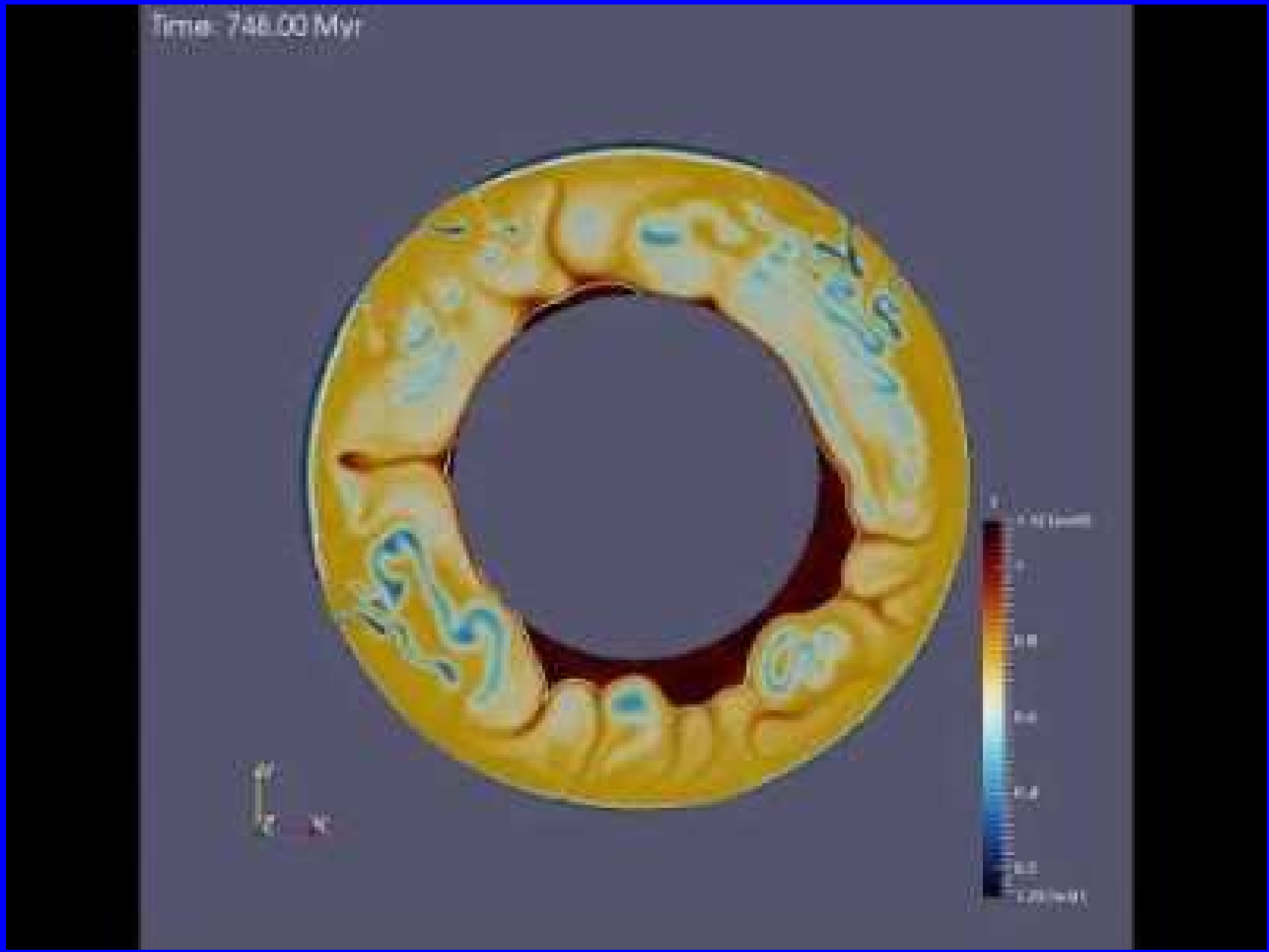
- Subduction is driven by the density difference between plates
- It is always the denser plate that sinks
- Plates are destroyed at subduction zones
- Subduction zones are compressive plate boundaries

Thank you!


Model D6
a)
10-km serpentinized layer
One weak zone
0.0
Depth (km)
660.0
1240 °C
1420 °C
Lithosphere
Sub-Lithospheric
Upper Mantle
0.2 0.4 0.6 0.8 1.0 1.2 1.4
Strain rate invariant (×10-13 s-1)
0.3 Myr
b)
Subduction initiation
0.0
660.0
9.2 Myr
c)
New subduction zone
0.0
660.0
18.1 Myr



Aspect


Time: 746.00 Myr