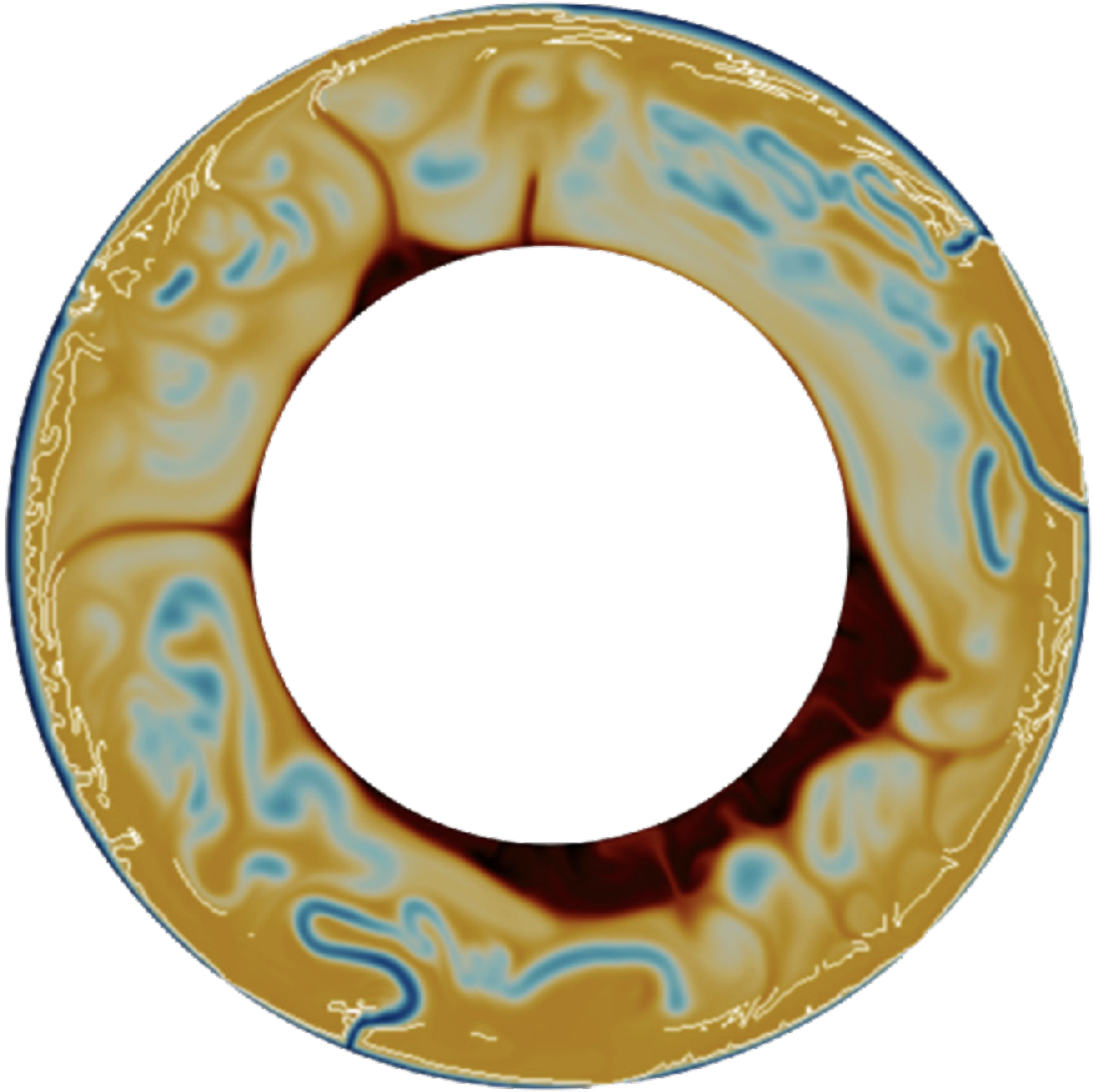
Plate Tectonics

EAS-2600

Fall 2024



L3. August 27th

Ch. 2 – Plate Tectonics

Learning Objectives

2.1 Identify the largest tectonic plates and delineate their boundaries on a global map.

2.2 Summarize how geologists of the 1960s used seafloor spreading to explain Wegener's continental drift.

2.3 Based on observations of relative motions and geological activity, determine whether the edge of a tectonic plate is acting as part of a divergent, convergent, or transform-fault boundary.

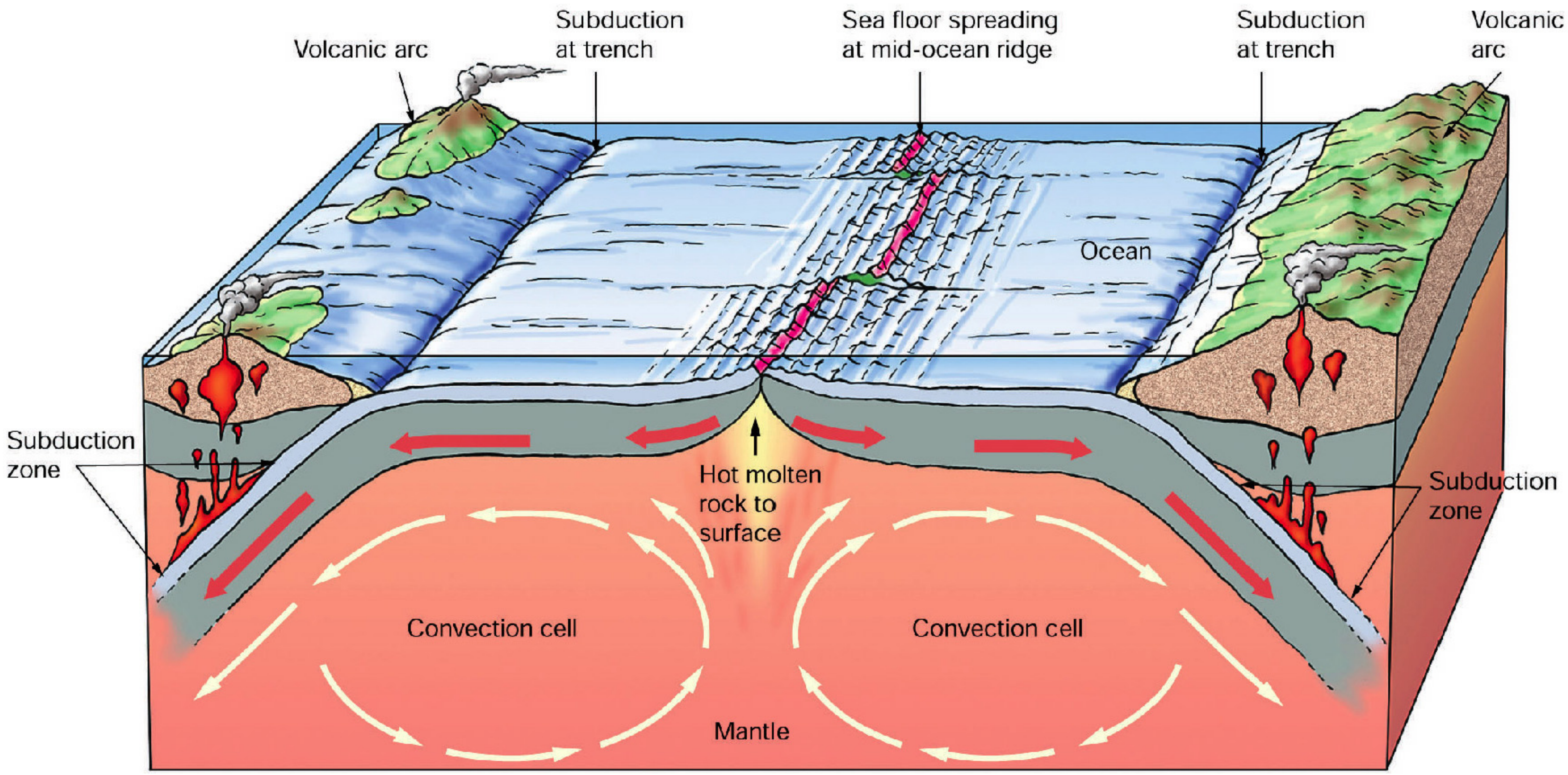
2.4 Explain how magnetic anomalies recorded by ships at sea are used to estimate the age of the seafloor and the rate of seafloor spreading.

2.5 Reconstruct the supercontinent of Pangaea by running continental drift backwards over the past 200 million years.

2.6 Describe how the oceanic plates participate in mantle convection.

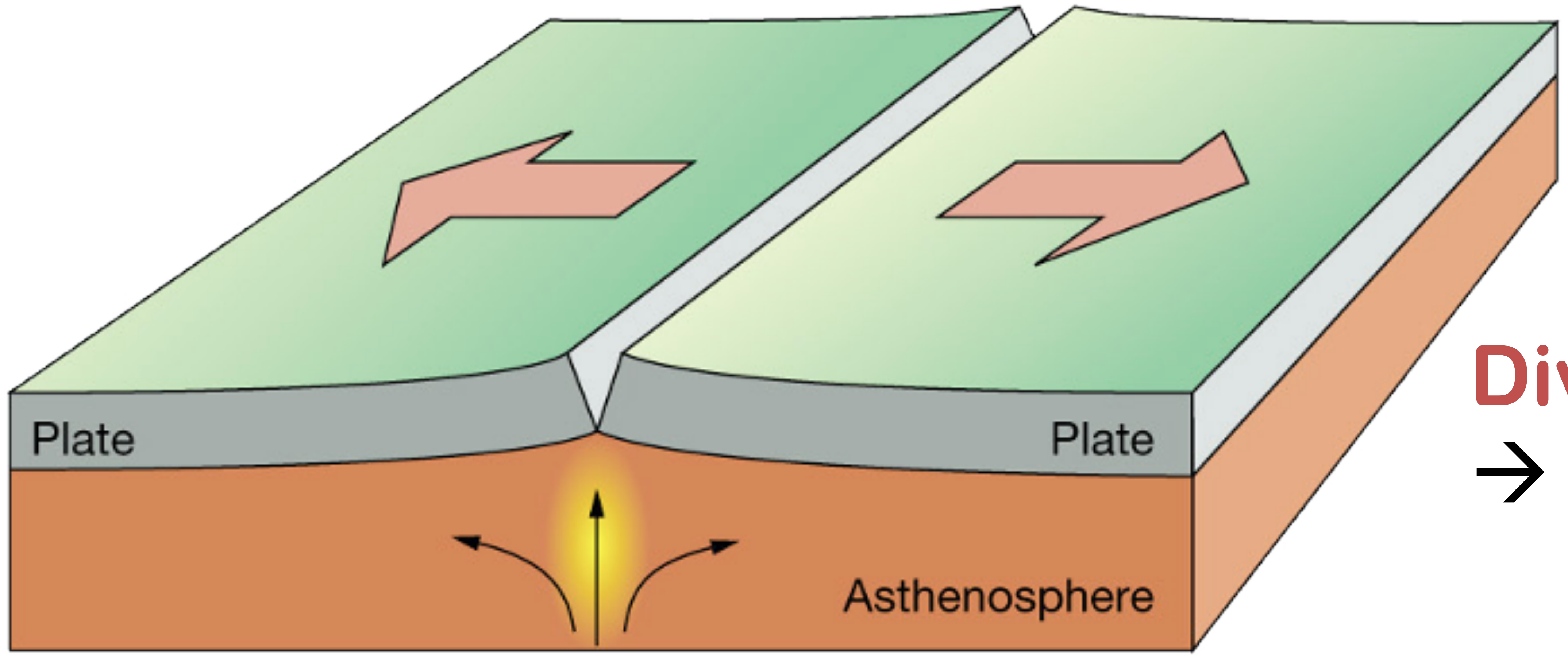
Recap

Plate tectonics revolution



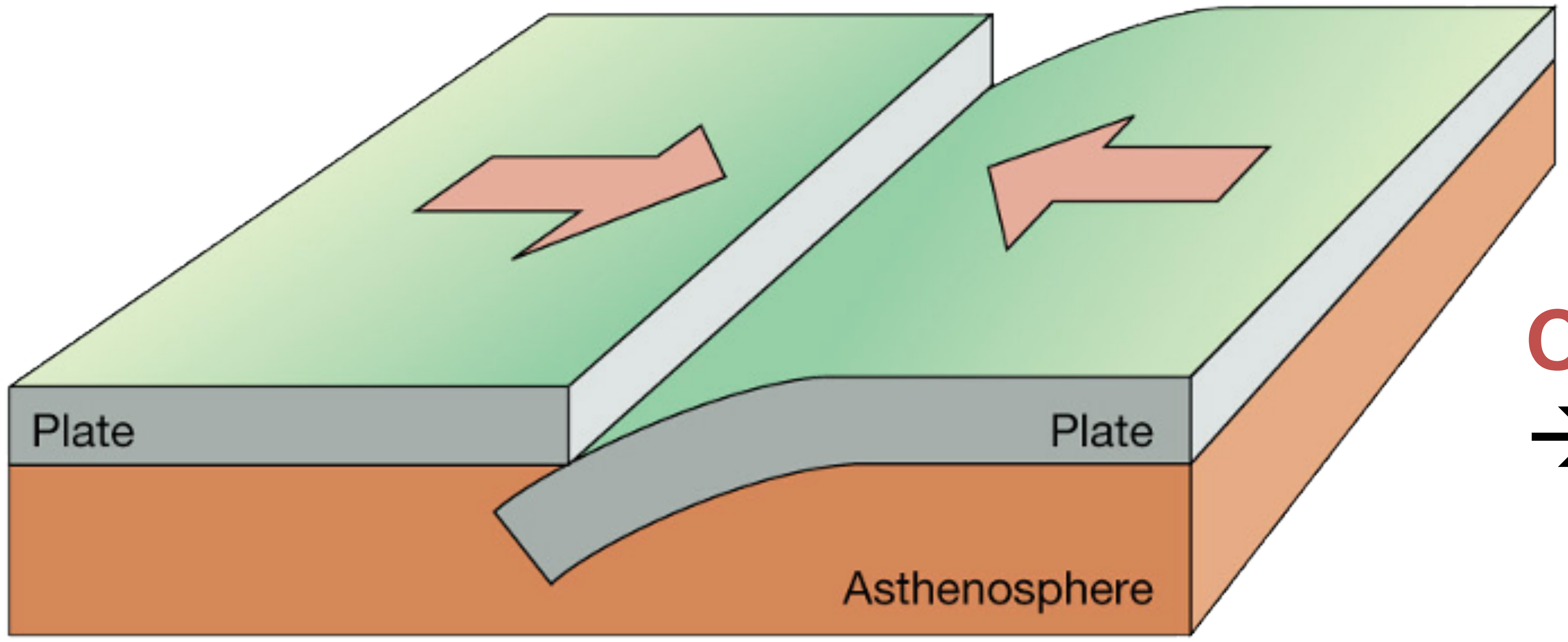
- ➡ New seafloor is created at mid-ocean ridges
- ➡ Old seafloor is recycled into mantle at subduction zone trenches
- ➡ Mantle convection is a key driving force of plate tectonics

Types of plate boundaries



(a)

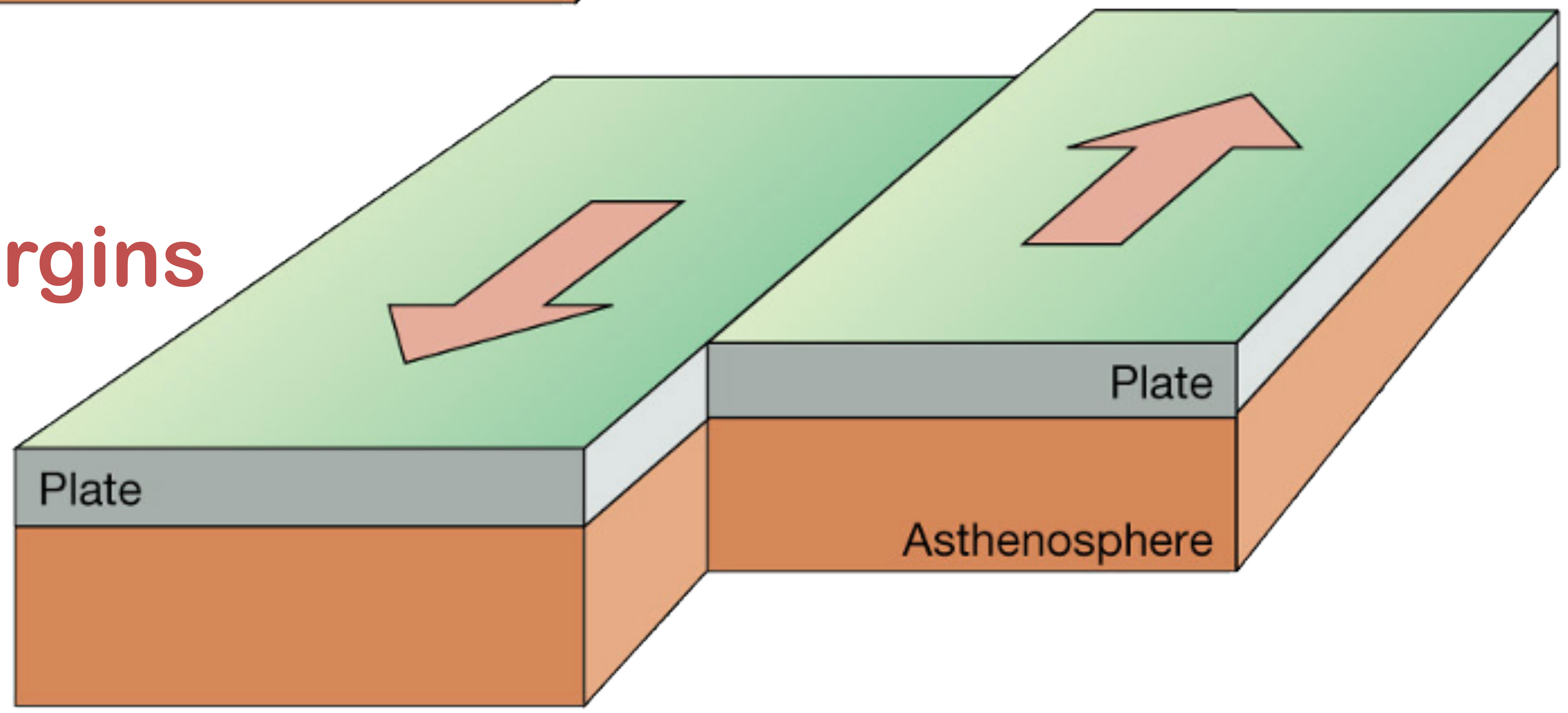
Divergent or Constructive margins
→ Mid-ocean ridges



(b)

Convergent or Destructive margins
→ Subduction zones

Conservative or Transform margins
→ Transform faults



(c)

DIVERGENT BOUNDARIES

Oceanic Spreading Center

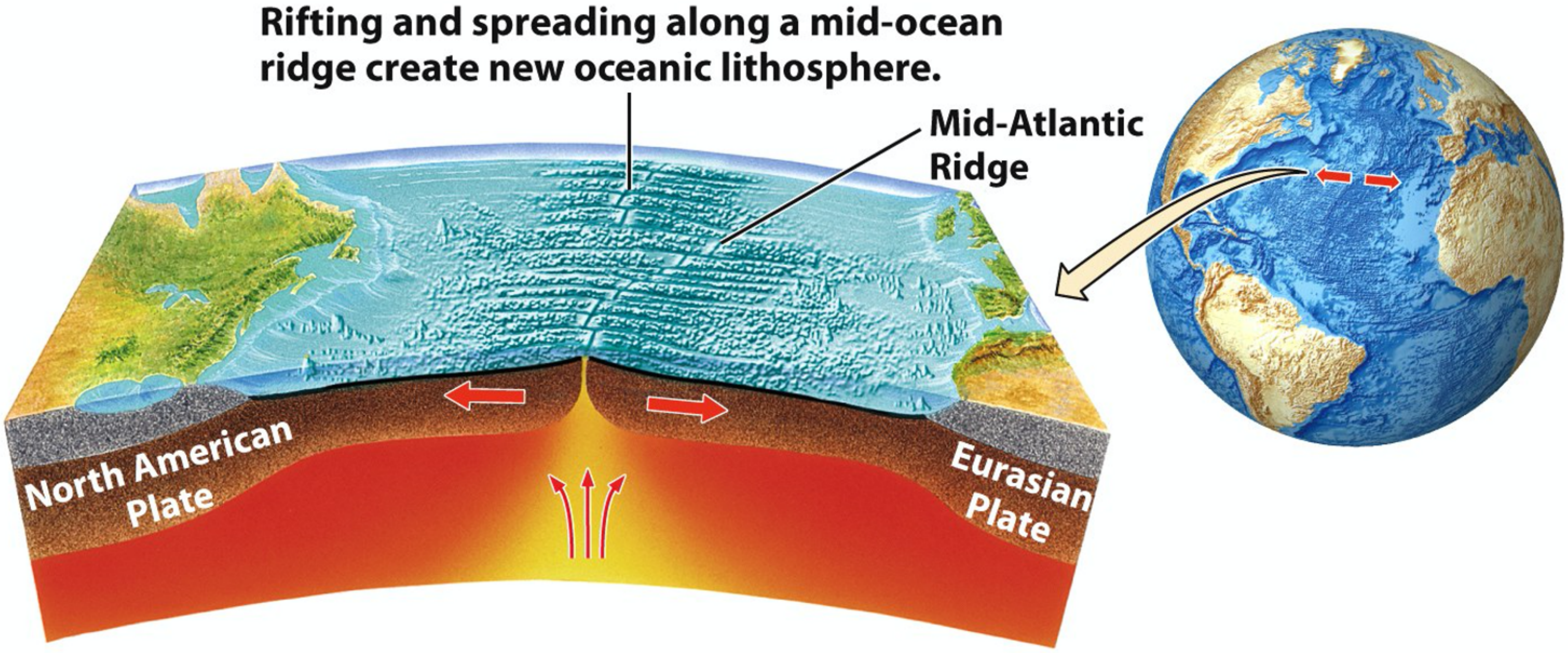


Figure 2.8a

- Volcanism is present
- Only shallow focus earthquakes
- Mid-Atlantic Ridge is “textbook example”

- These boundaries wind through all the oceans – at ~60,000 km long, it is the largest scale linear geologic feature on Earth.

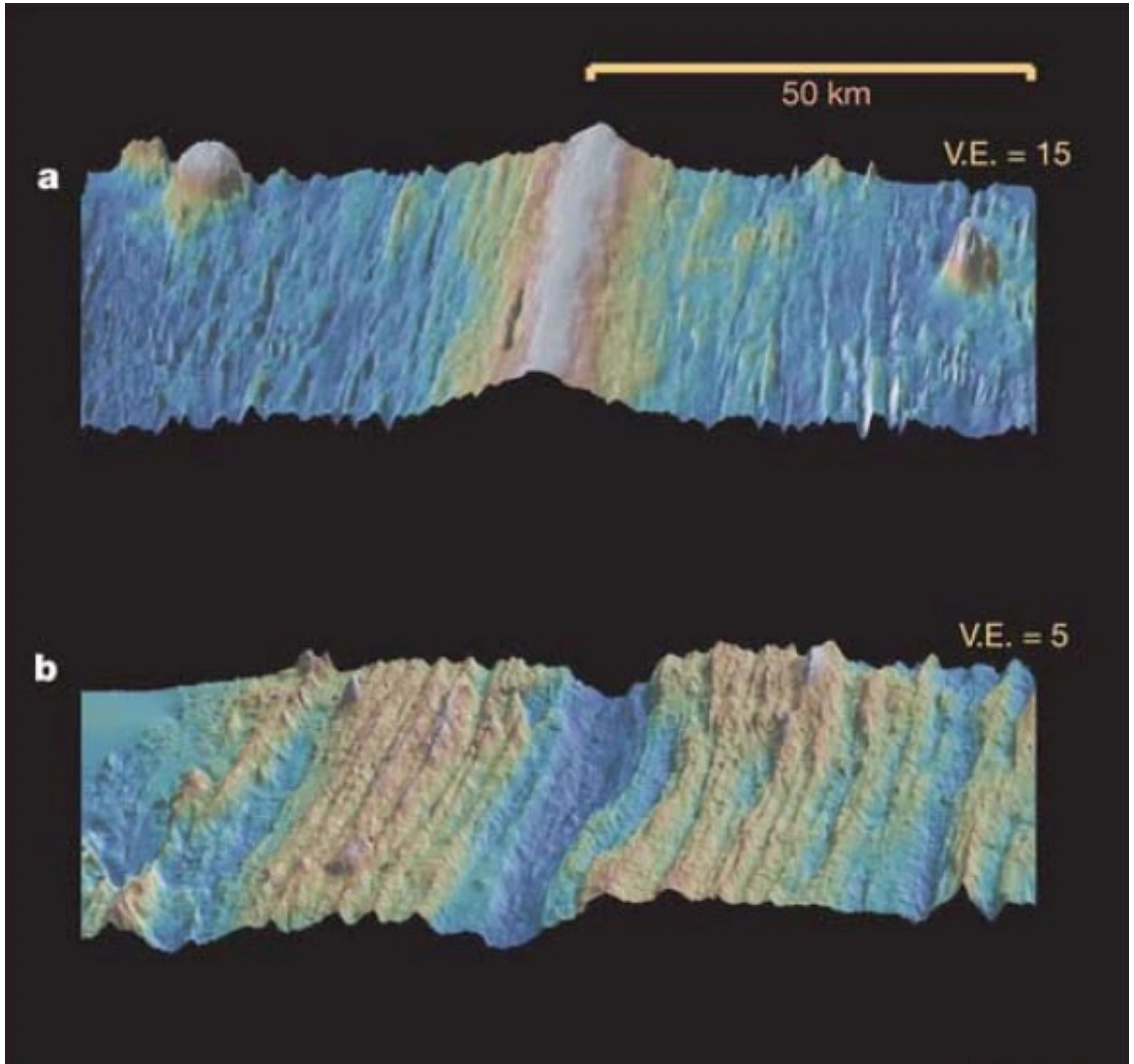
How to form a new ocean basin

From incipient rifting to seafloor spreading

The chicken or the egg? An important question for scientists today:

When forming a new divergent plate boundary, does a plate get pulled apart from above or pushed apart from below?

Divergent Boundaries



a. fast-spreading mid-ocean ridge

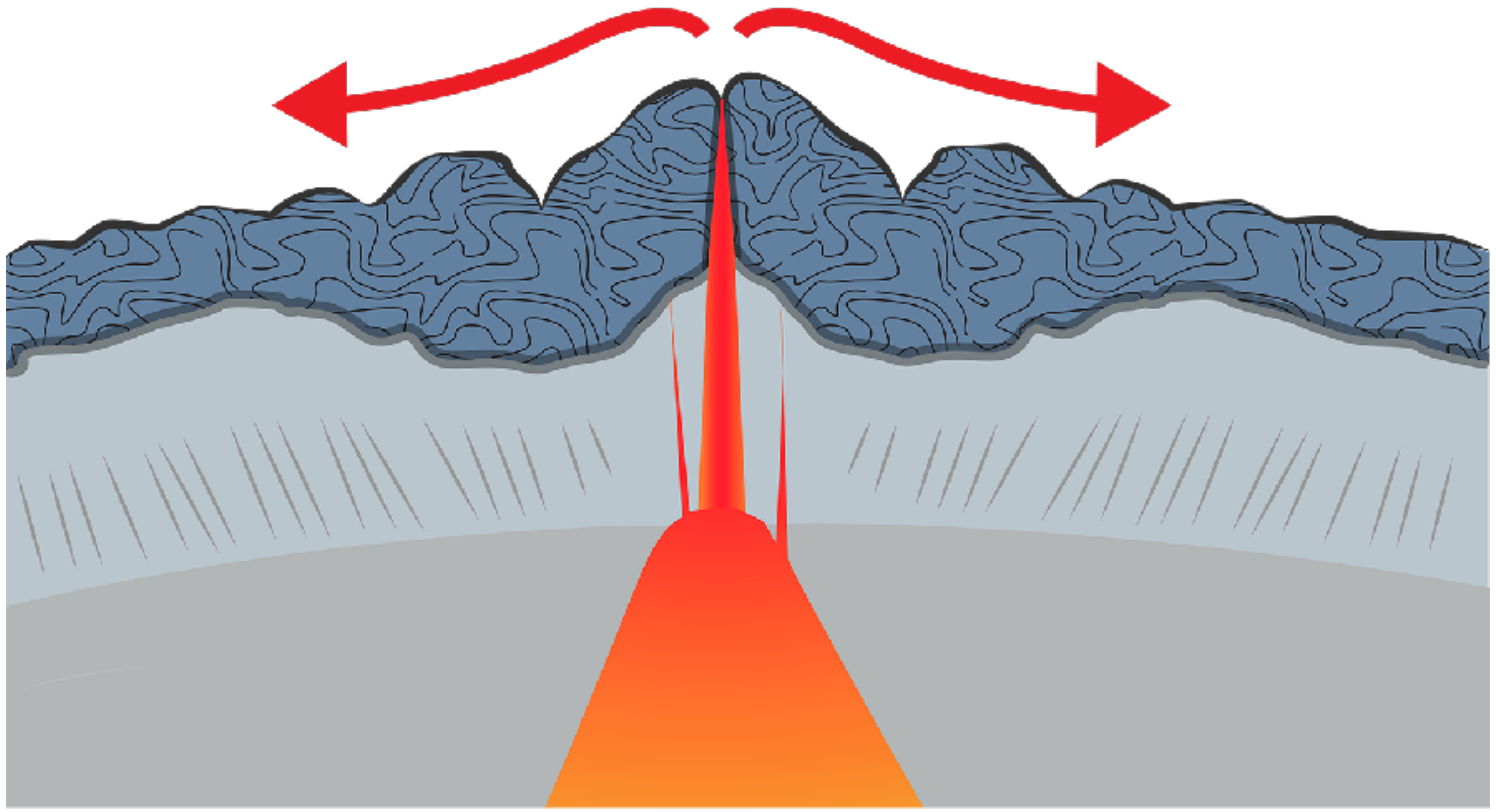
Fast spreading is characterized by a topographic ridge at the center, while slow spreading has a narrow valley at the center.

b. slow-spreading mid-ocean ridge

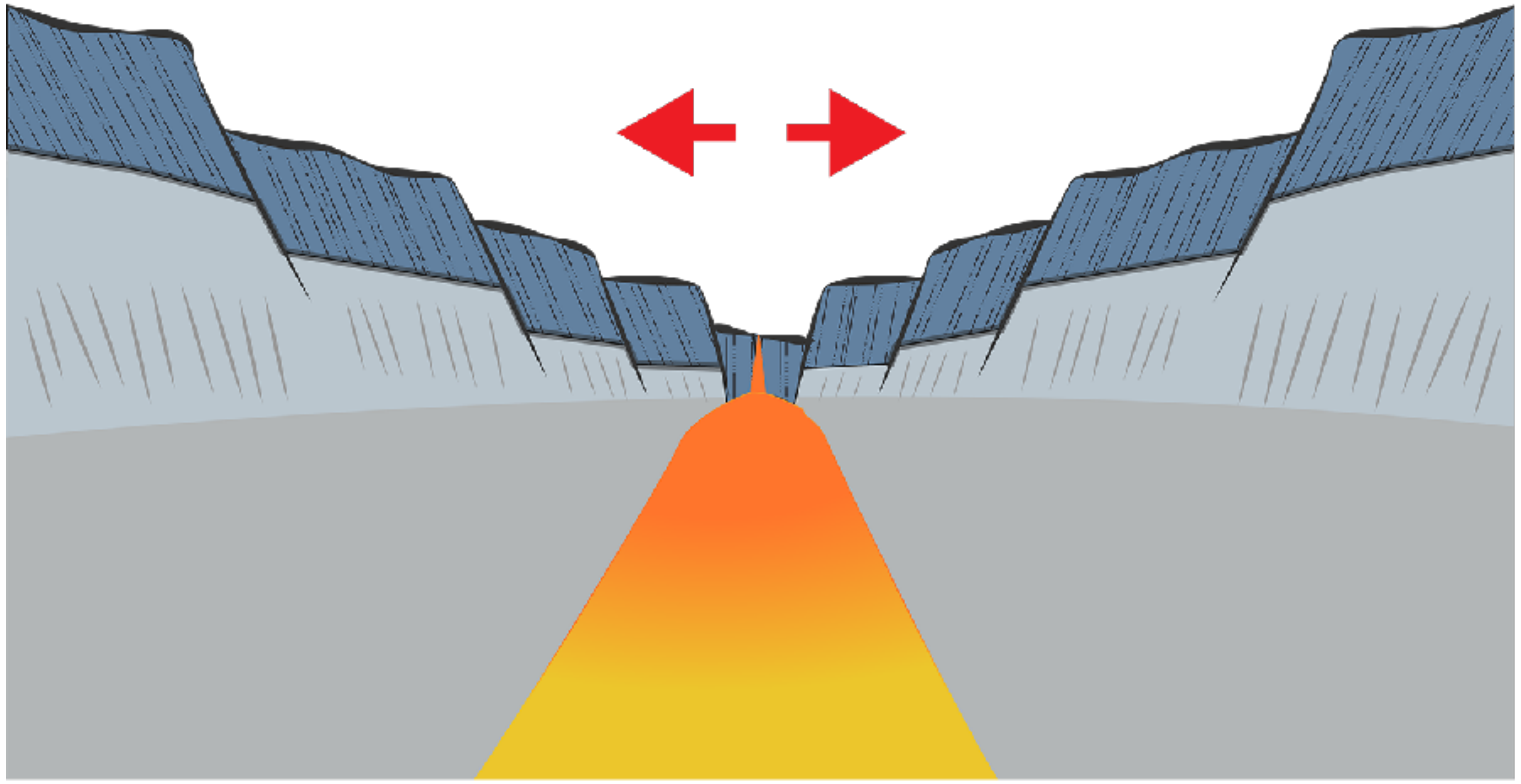
This illustrates the V-shaped valley that Marie Tharp discovered at the Mid-Atlantic Ridge, a slow spreading center

Divergent Boundaries

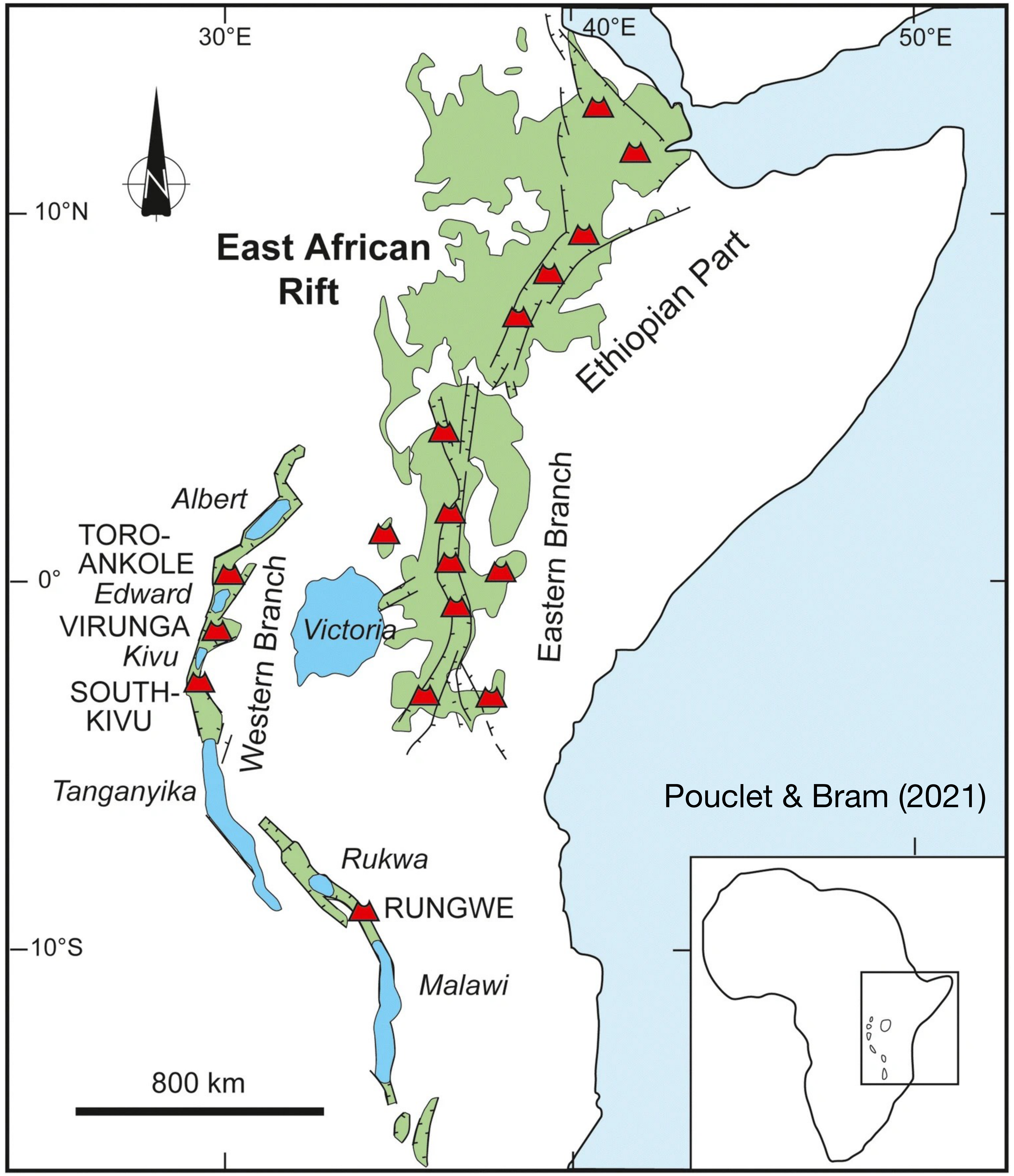
fast-spreading mid-ocean ridge



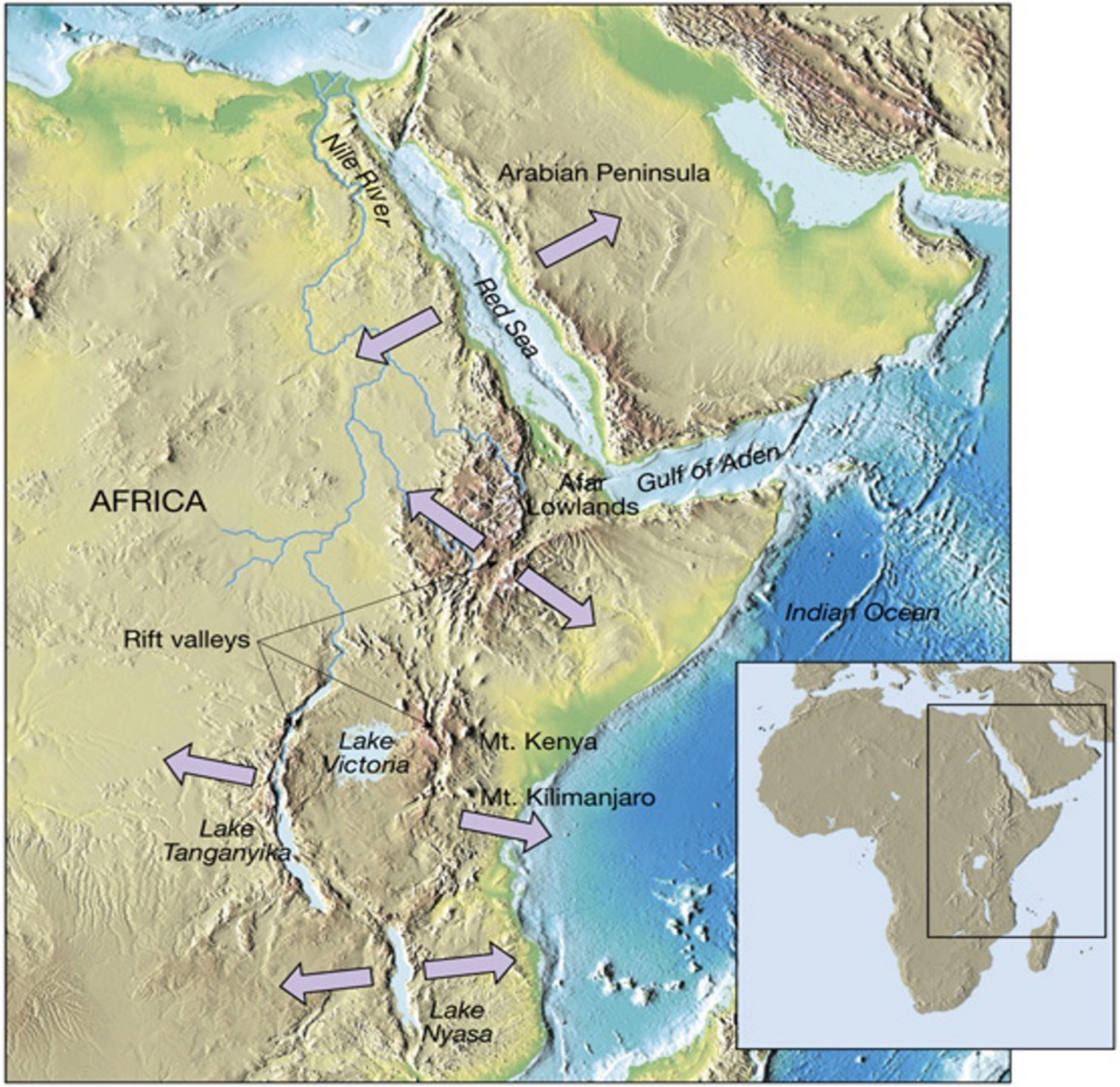
slow-spreading mid-ocean ridge
& continental rifting



Continental Rifting: East African Rift



Pouclet & Bram (2021)



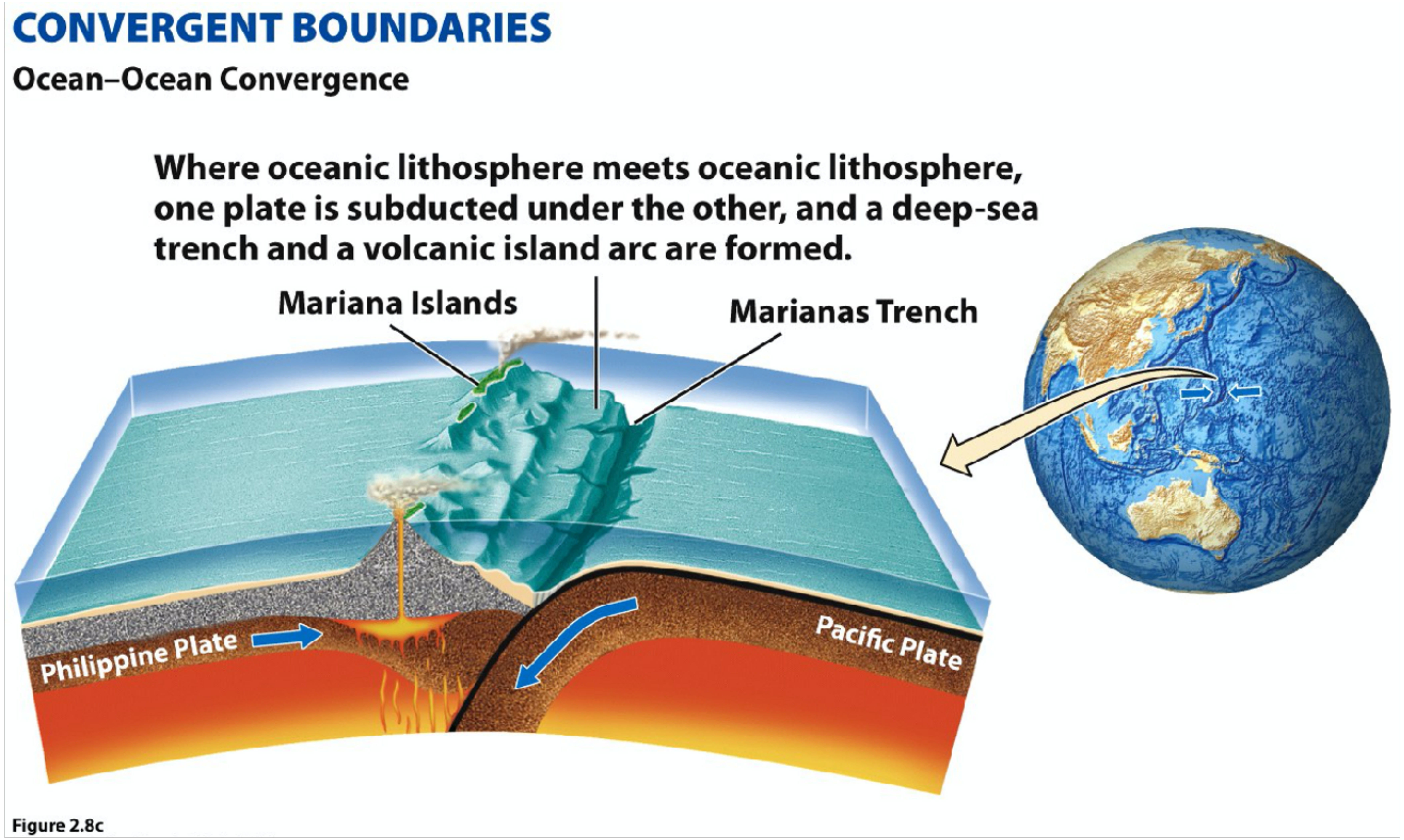


Figure 2.8c

- Subducting crust is destroyed
- Produces deep oceanic trenches
- Chain of volcanic islands (aka, 'island arc') found on overriding plate
- Shallow to deep focus earthquakes

CONVERGENT BOUNDARIES

Ocean–Continent Convergence

When oceanic lithosphere meets continental lithosphere, the oceanic lithosphere is subducted, and a volcanic mountain belt is formed at the continental margin.

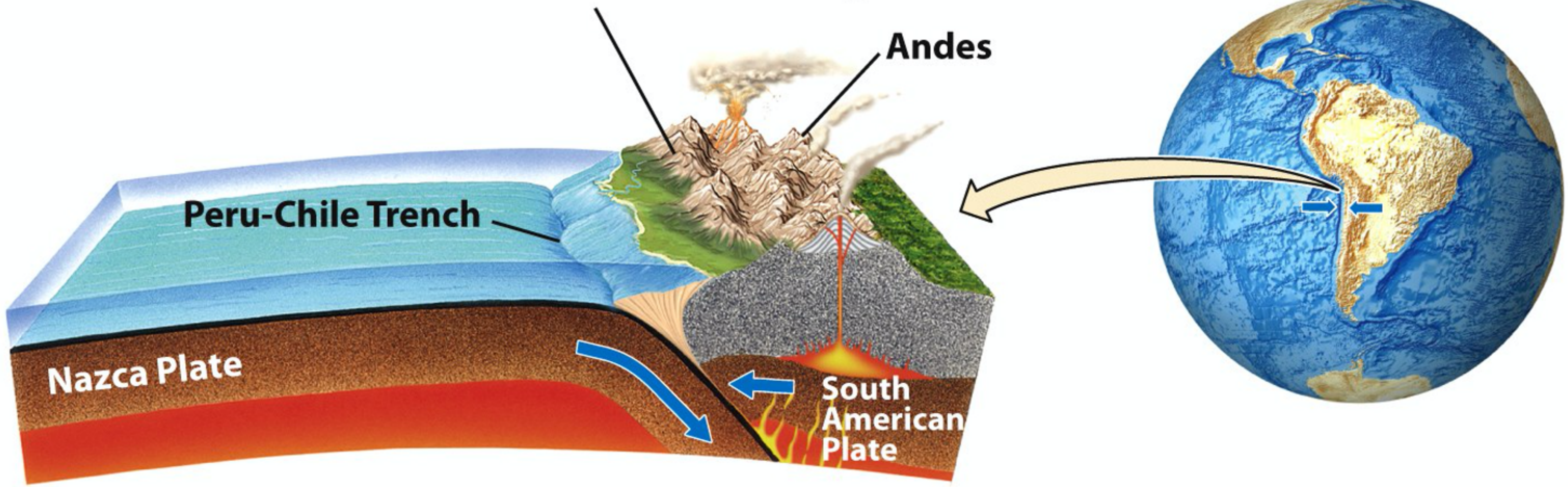


Figure 2.8d

- Subducting crust is destroyed
- Ocean trench adjacent to continent
- Chain of volcanic mountains (‘volcanic arc’) located on continent
- Oceanic plate is always the one that is subducting
- Shallow to deep focus earthquakes

CONVERGENT BOUNDARIES

Continent–Continent Convergence

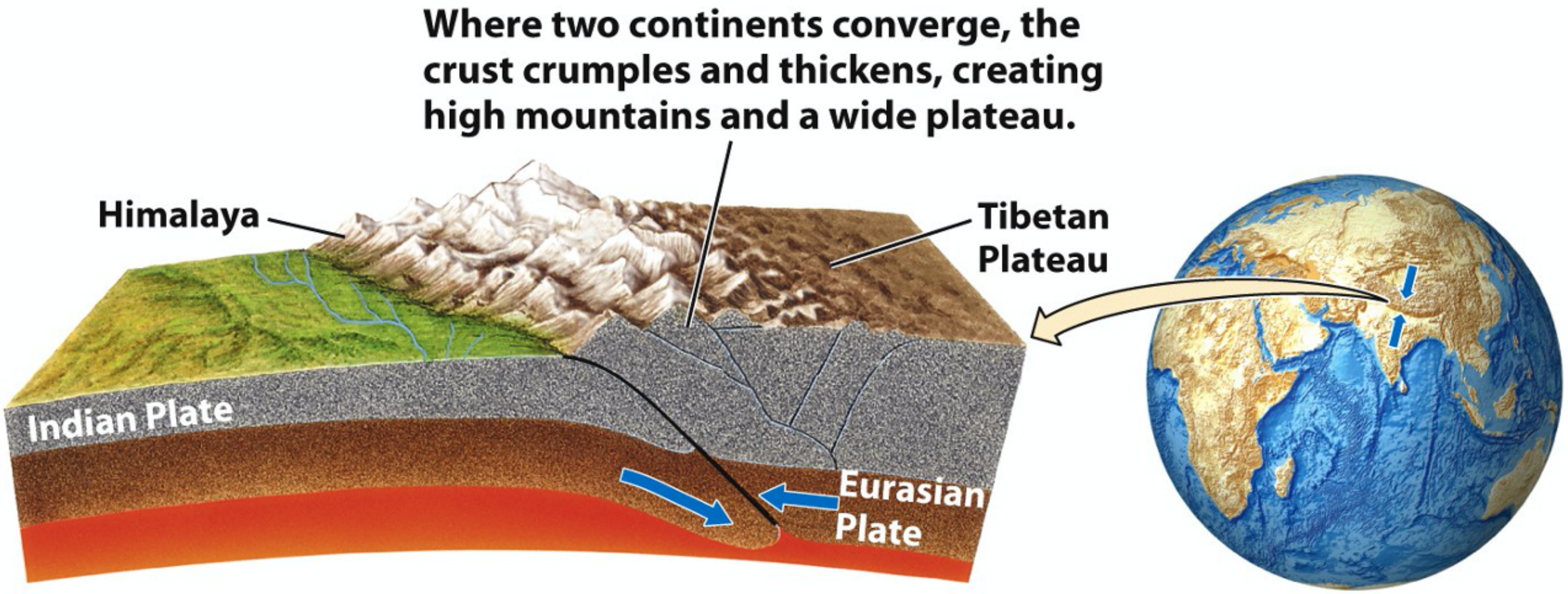


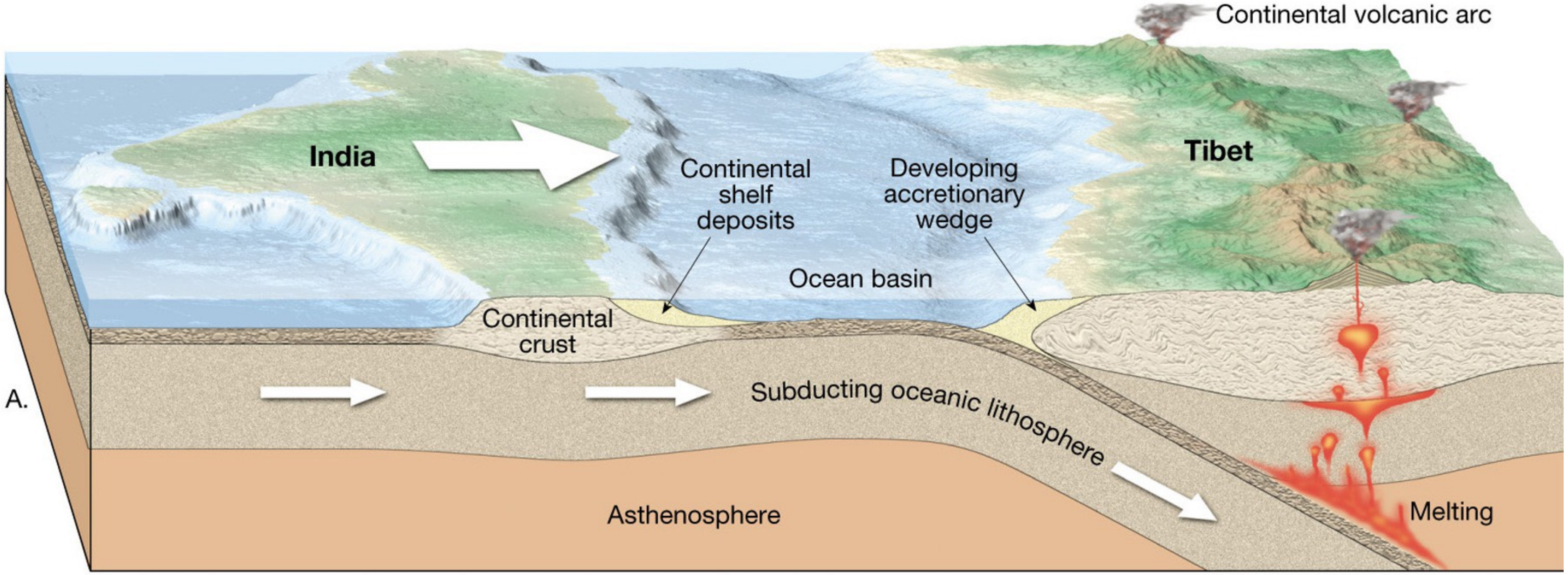
Figure 2.8e

- Crust is thickened — same density on both plates, which limits subduction
- Produces large mountain ranges but no volcanism
- Shallow to intermediate focus earthquakes

How to close an ocean basin

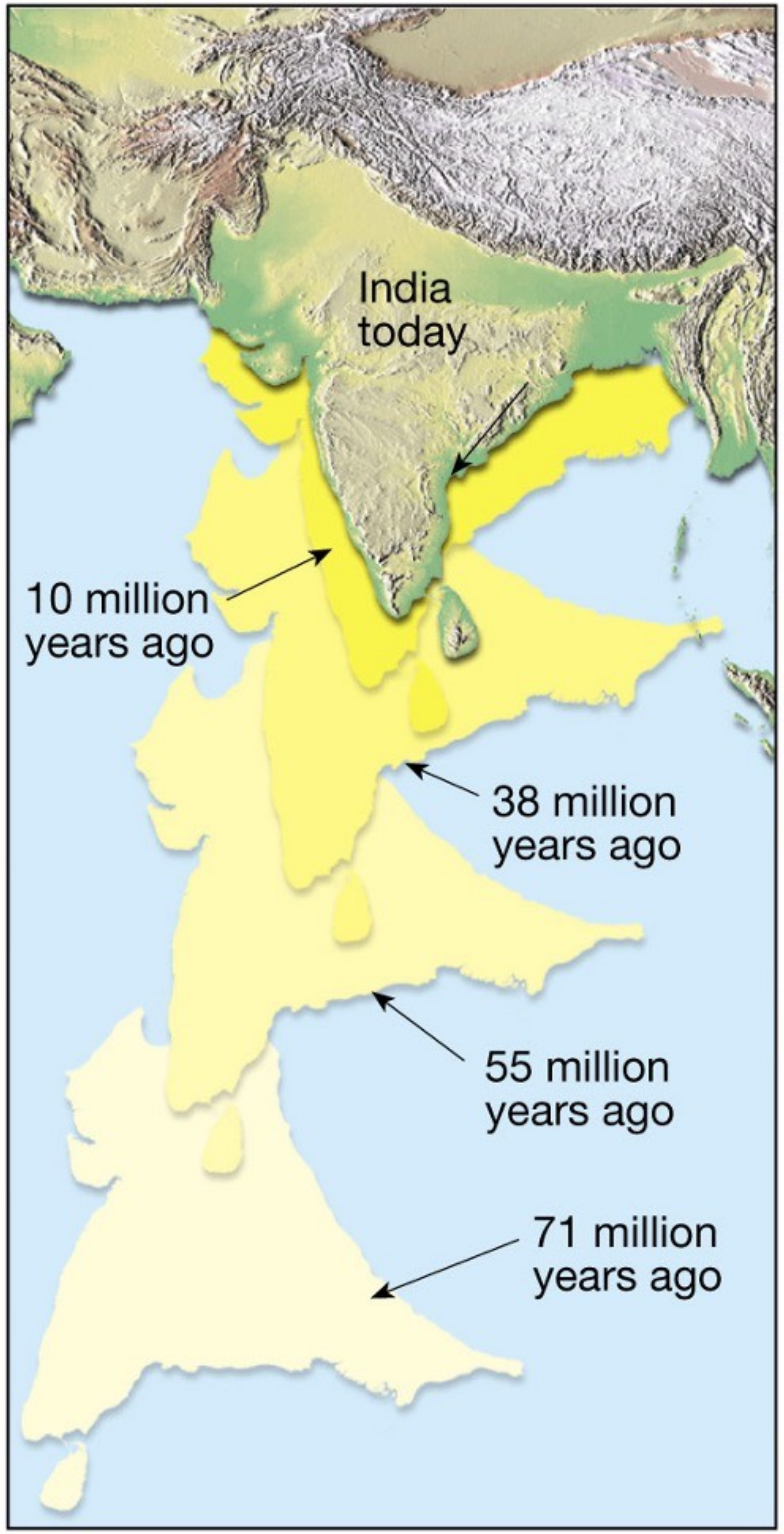
From continental-oceanic to continental-continental collision

A.



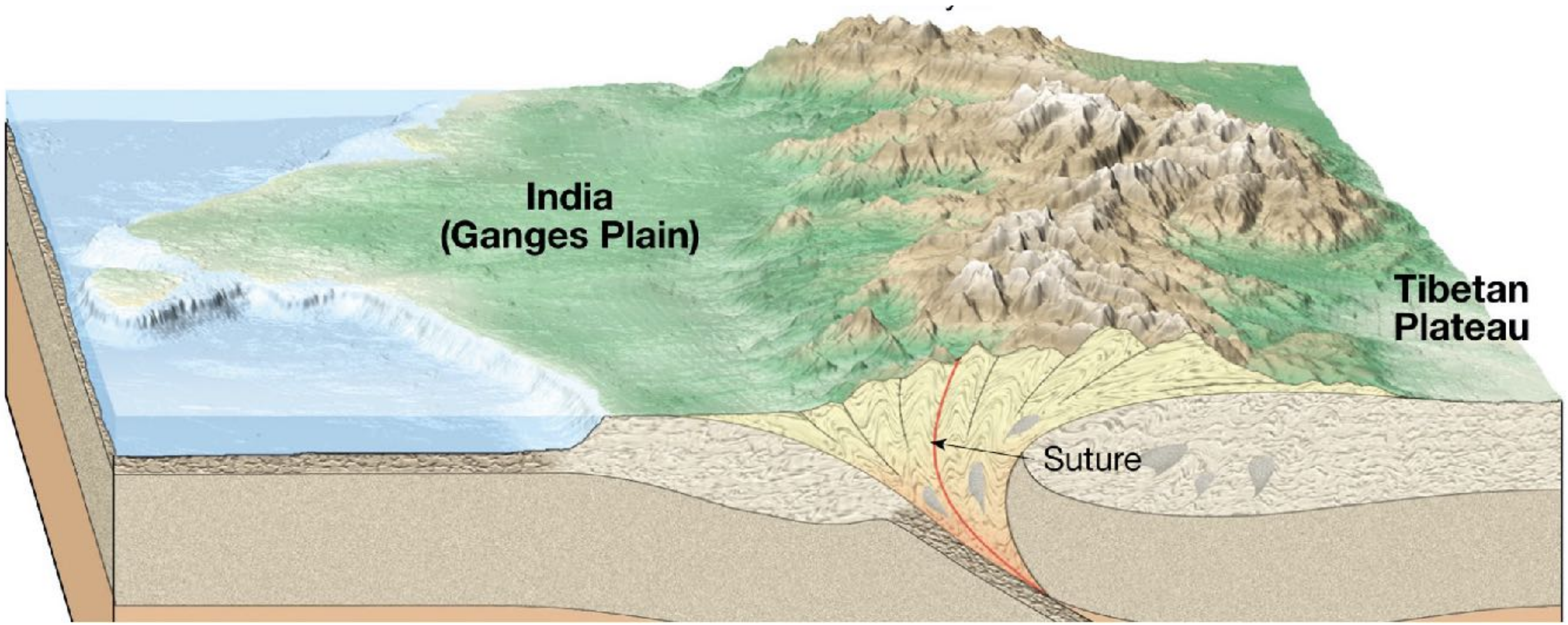
Before collision of India and Asia produced the Himalayas

B.

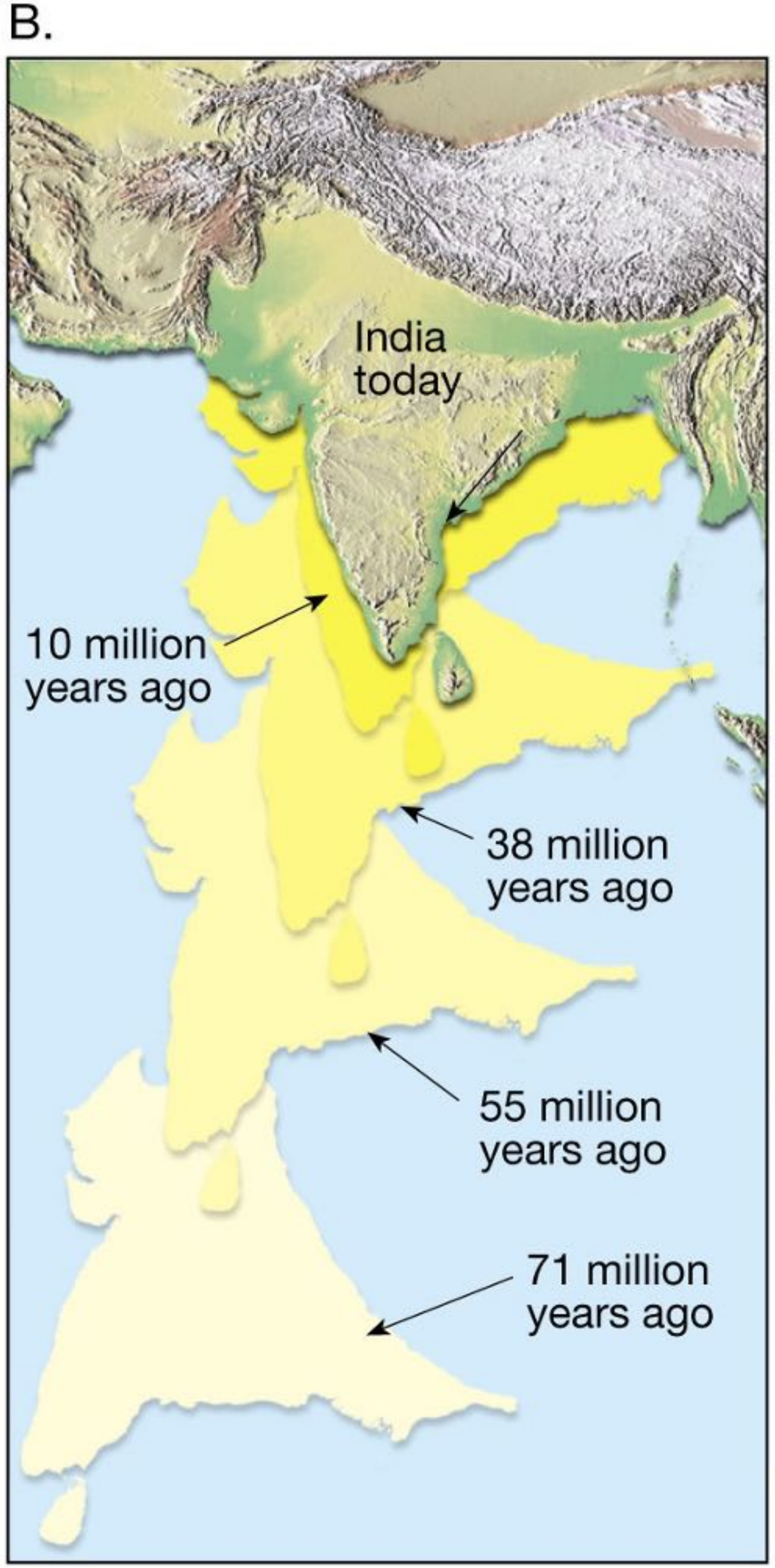


How to close an ocean basin

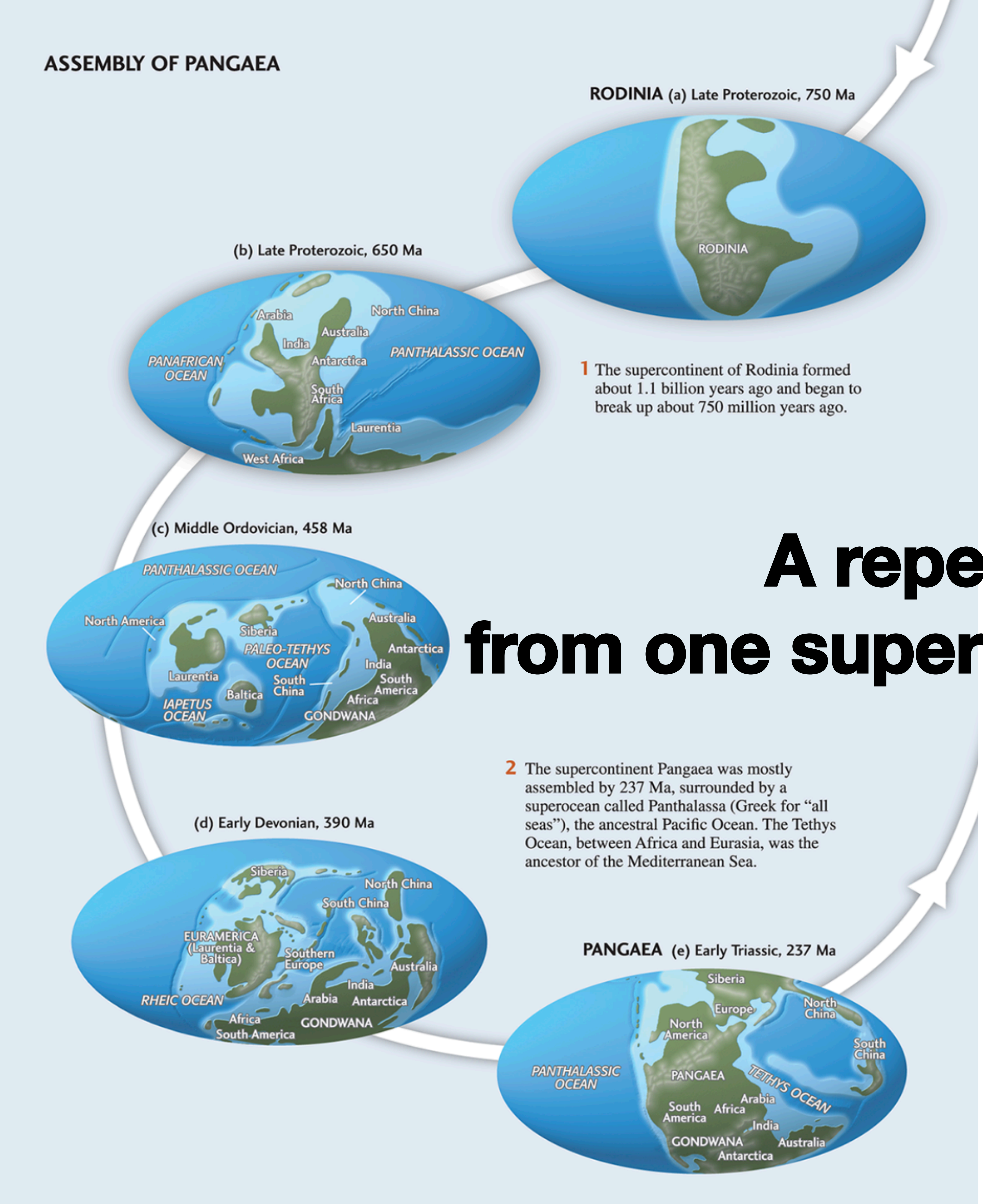
From continental-oceanic to continental-continental collision

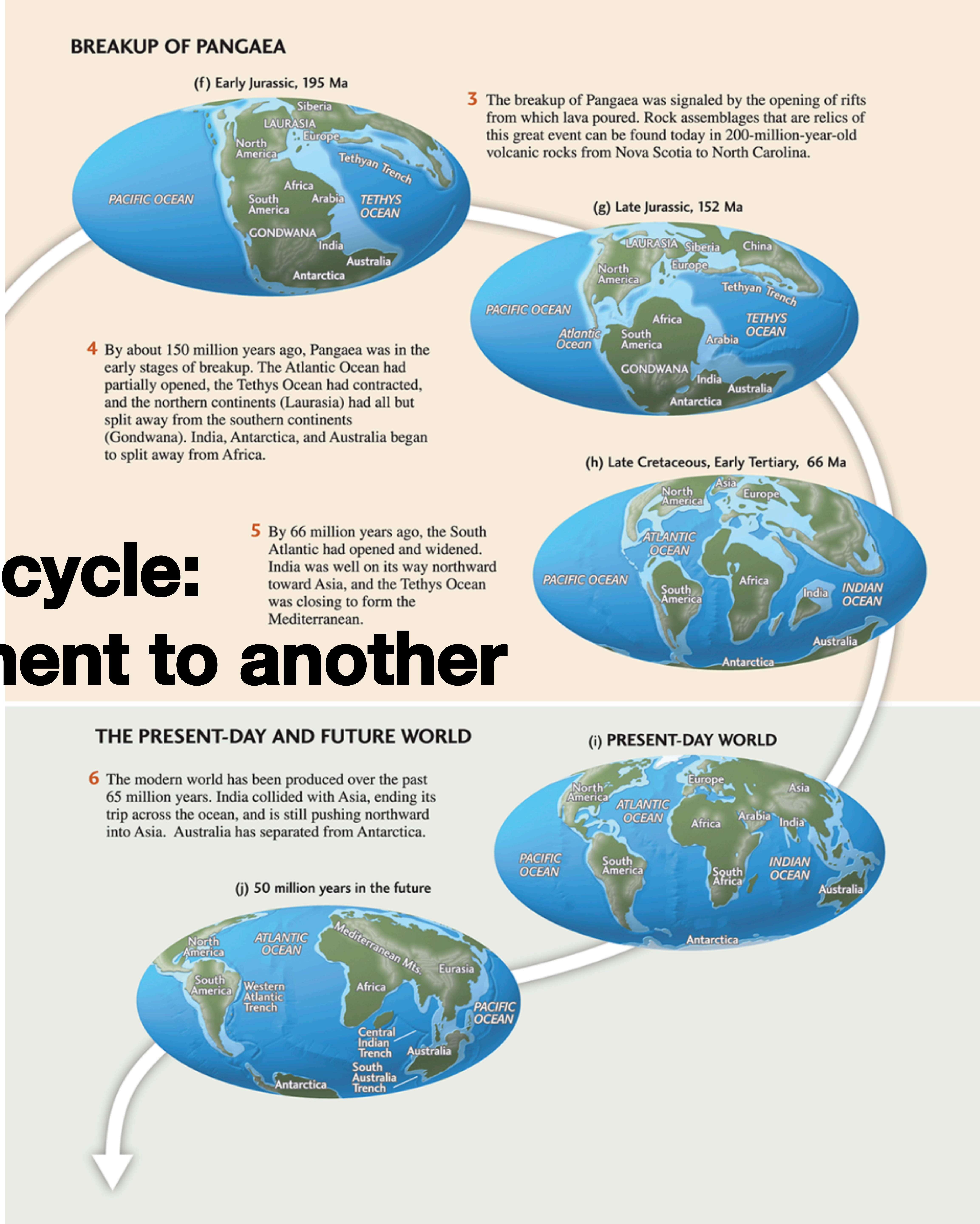


After collision of India and Asia produced the Himalayas (*present day*)

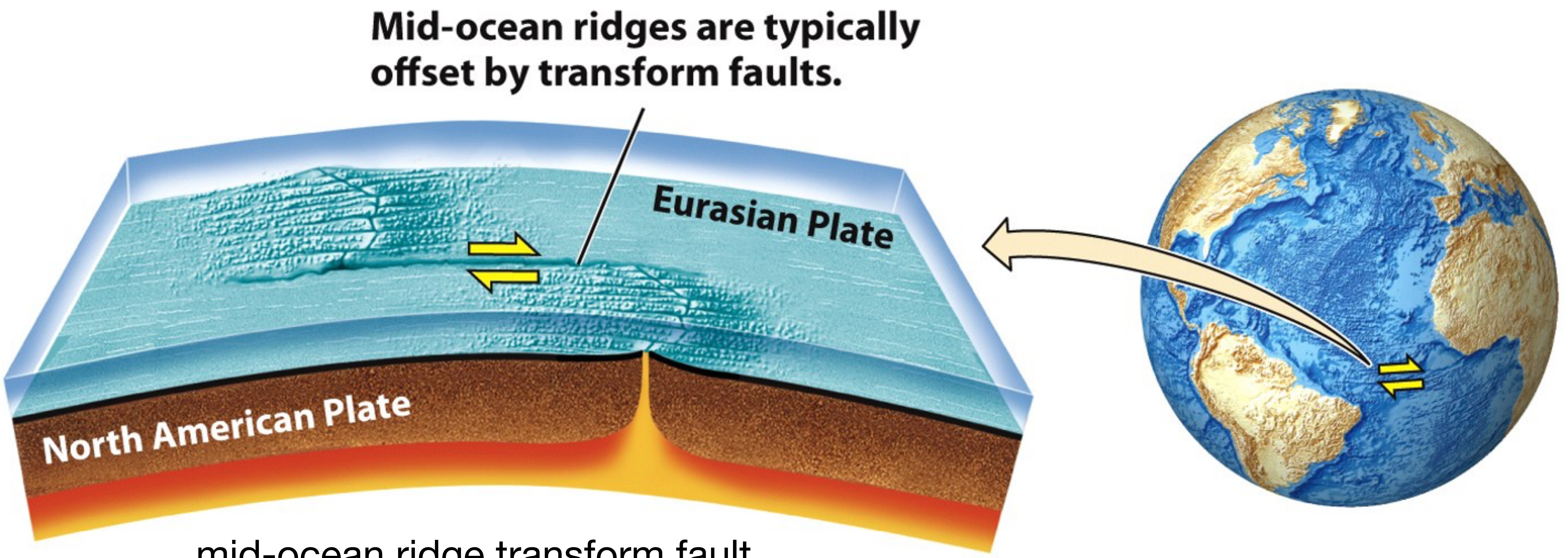


A repeating cycle: from one supercontinent to another





Transform-fault boundaries



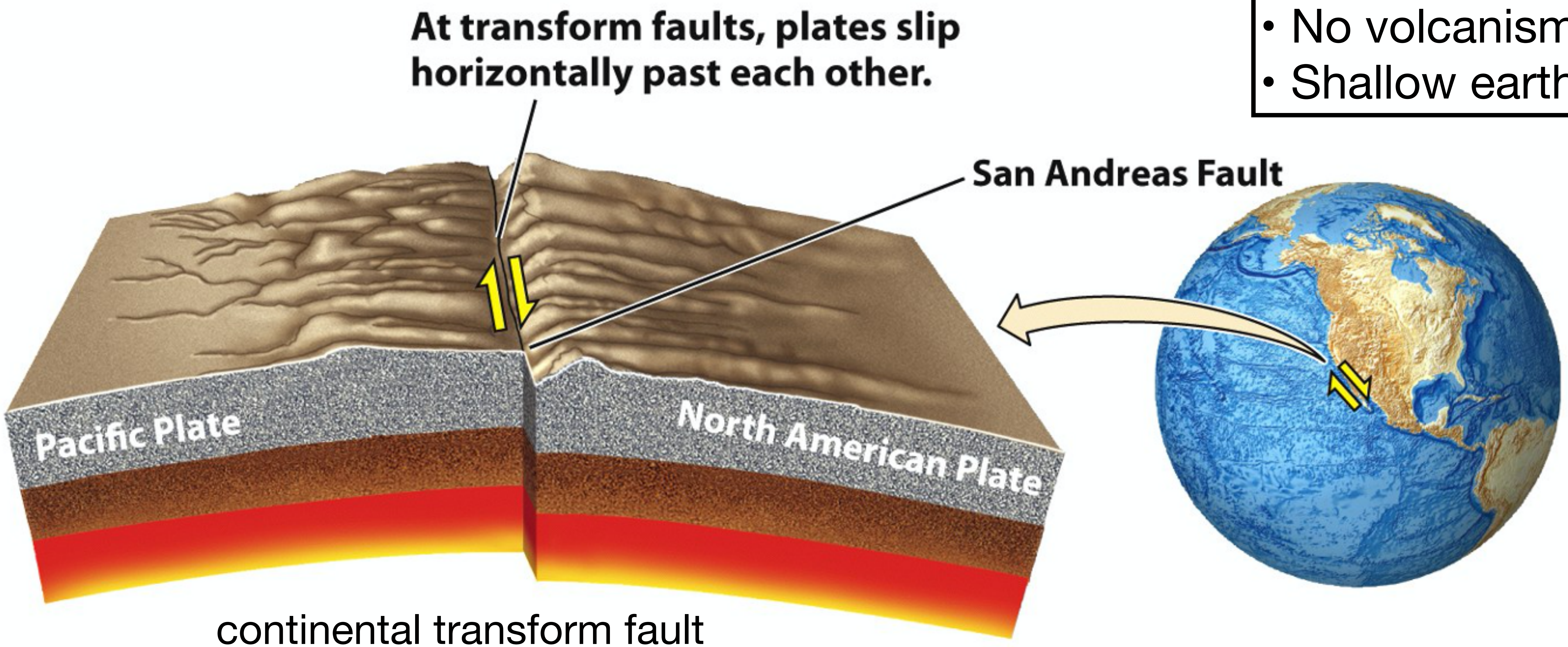
mid-ocean ridge transform fault

Figure 2.8g

- Transform-fault plate boundaries — most are in the ocean
- Above image shows transform faults connecting segments of a divergent boundary
  - shallow focus earthquakes only
  - no volcanism along these segments

Transform-fault boundaries

- No volcanism
- Shallow earthquakes

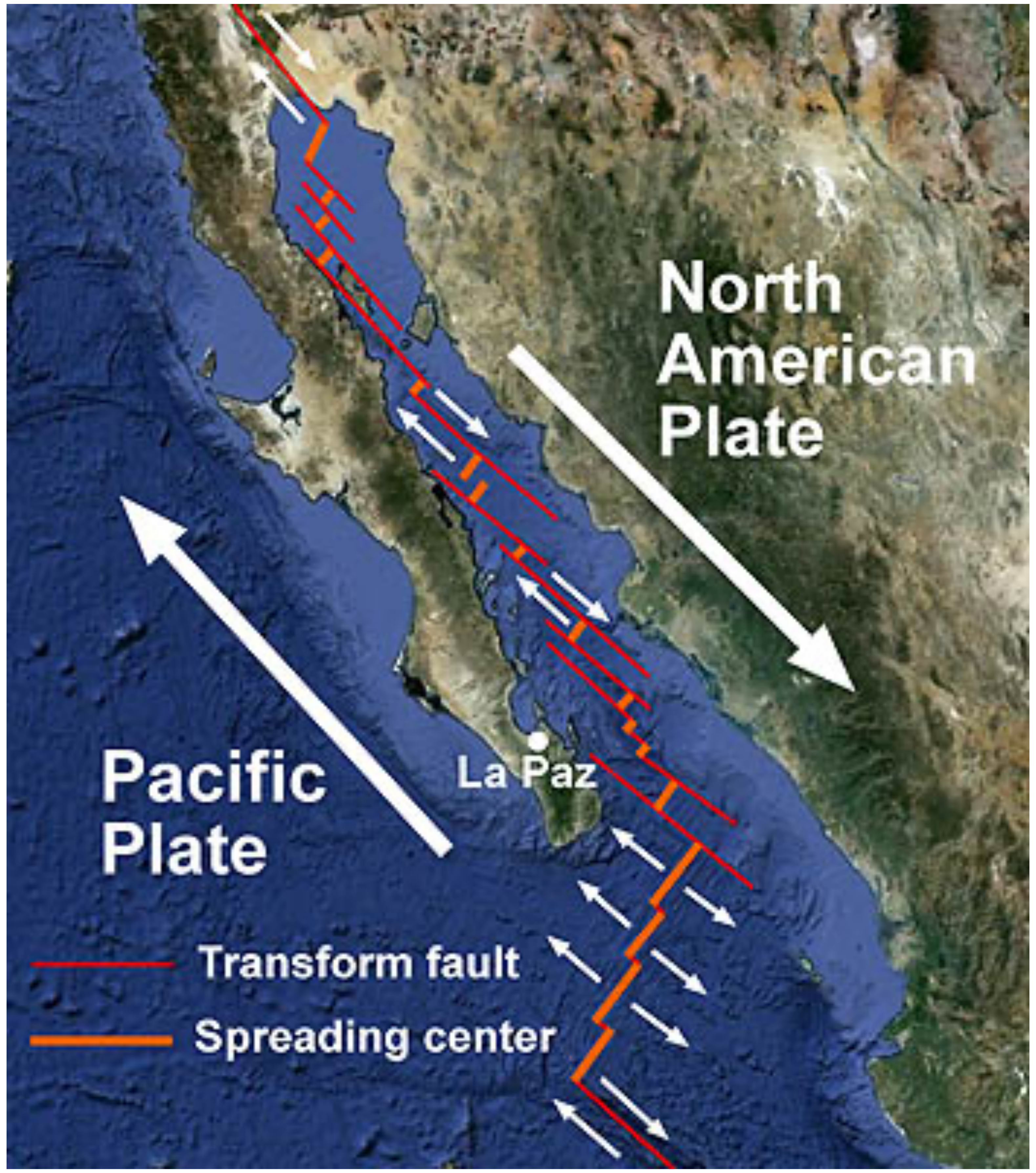


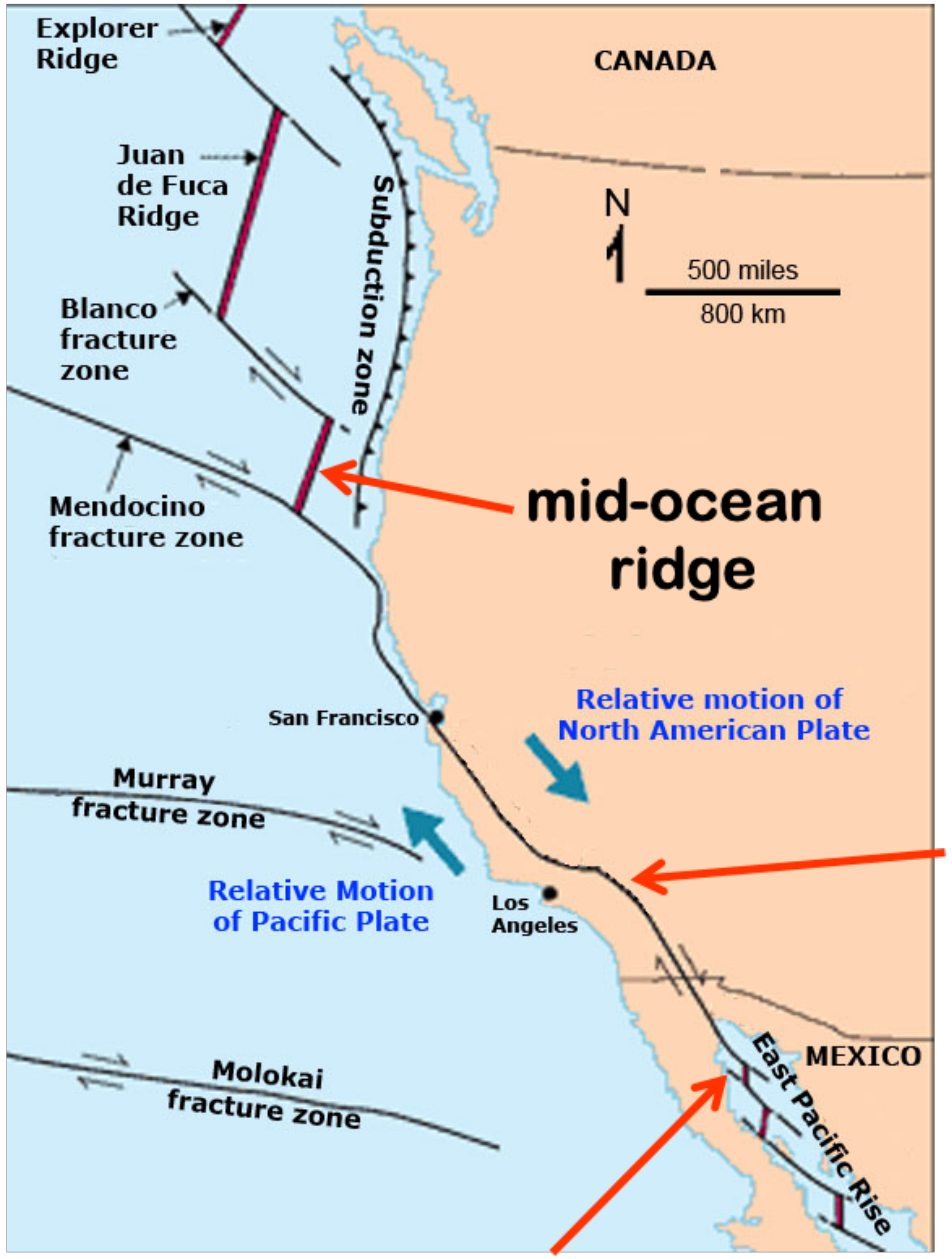
continental transform fault

Figure 2.8f

- Crust is not created or destroyed (hence “conservative” margin)
- Plates slide past one another with shearing motion
- San Andreas Fault is a good example of a Transform Plate Boundary
    - continent-continent boundary
    - separates the Pacific plate from the North American plate

All three plate boundaries



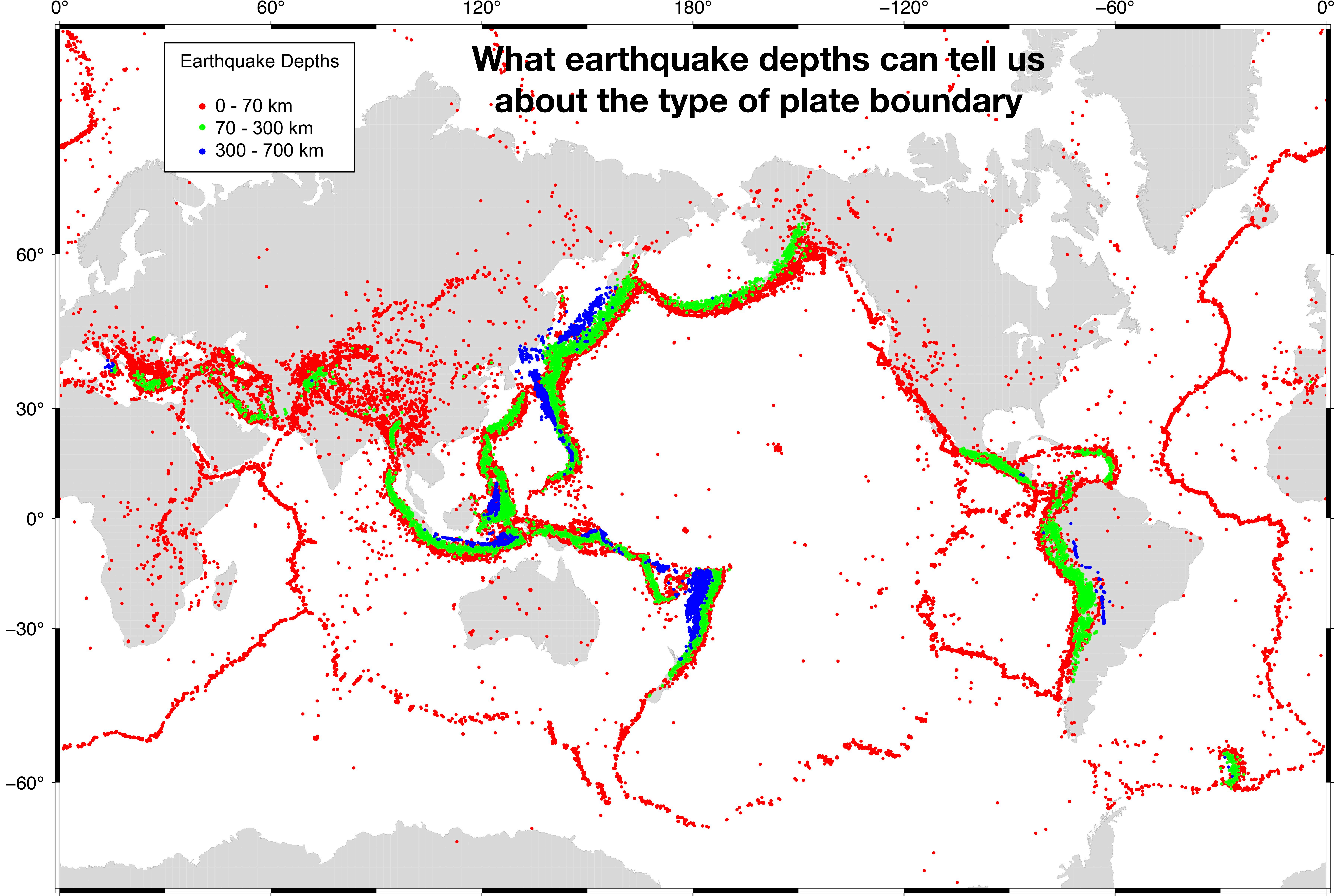


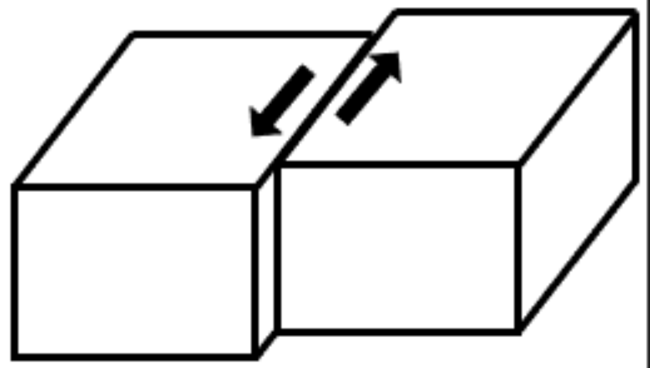
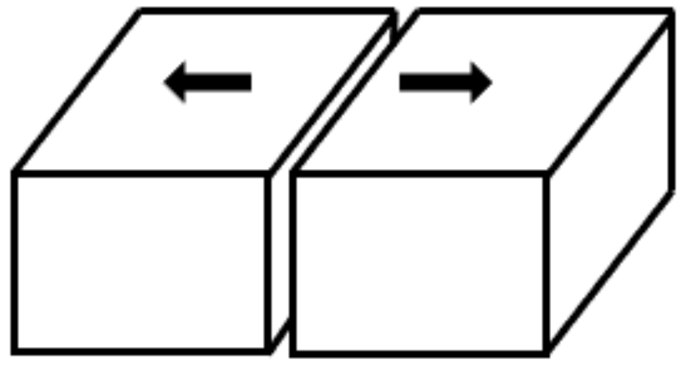
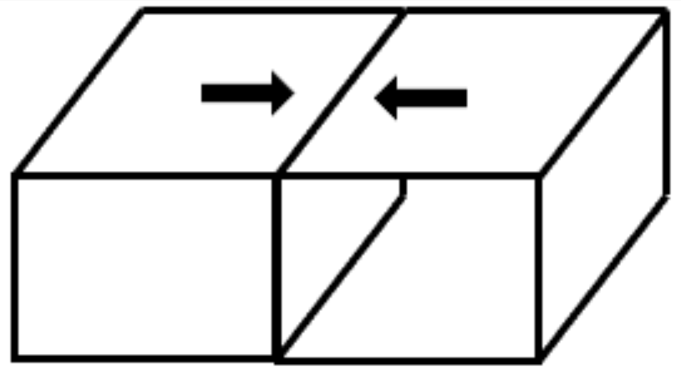
San Andreas fault

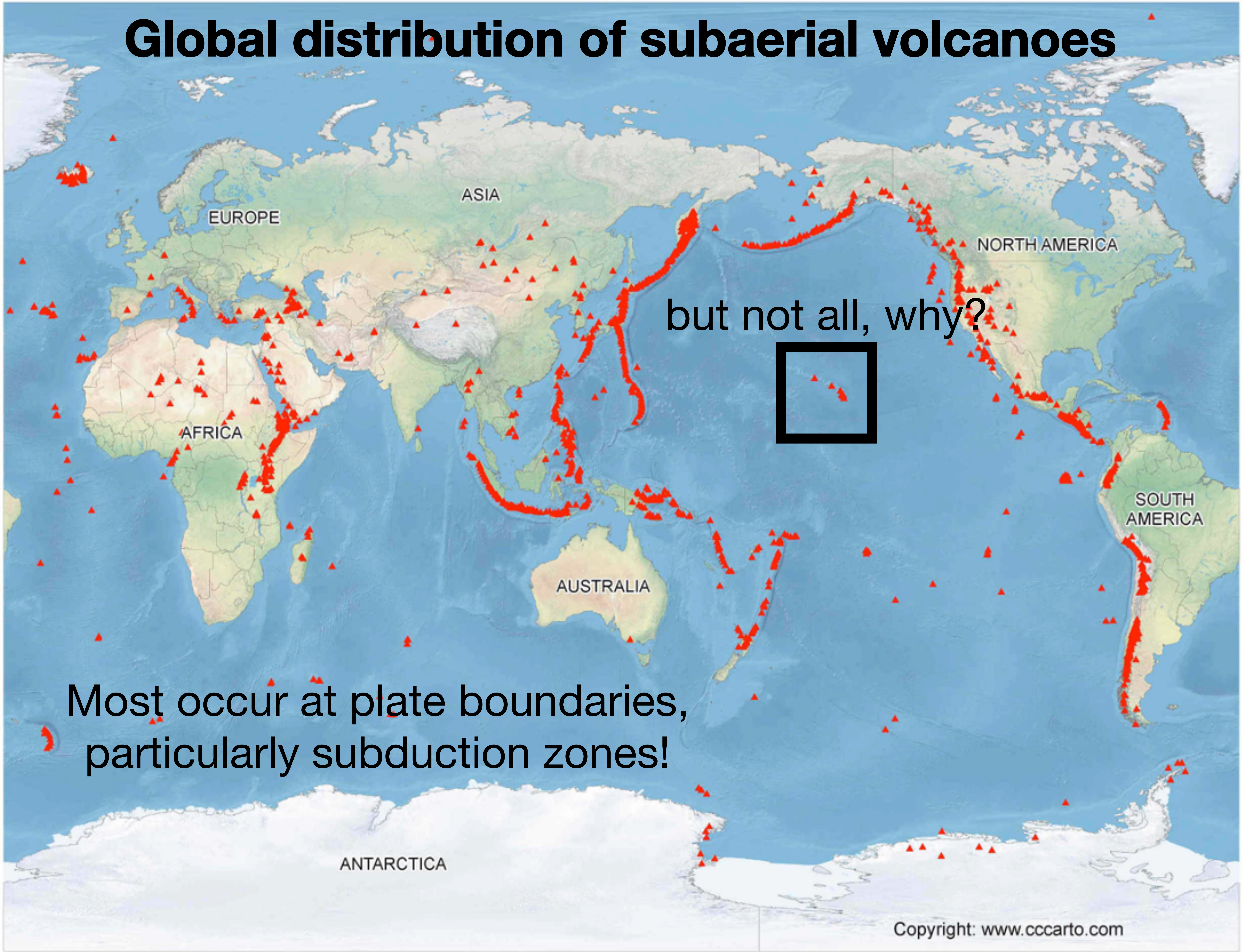
mid-ocean ridge

Global distribution of earthquakes

What earthquake depths can tell us about the type of plate boundary

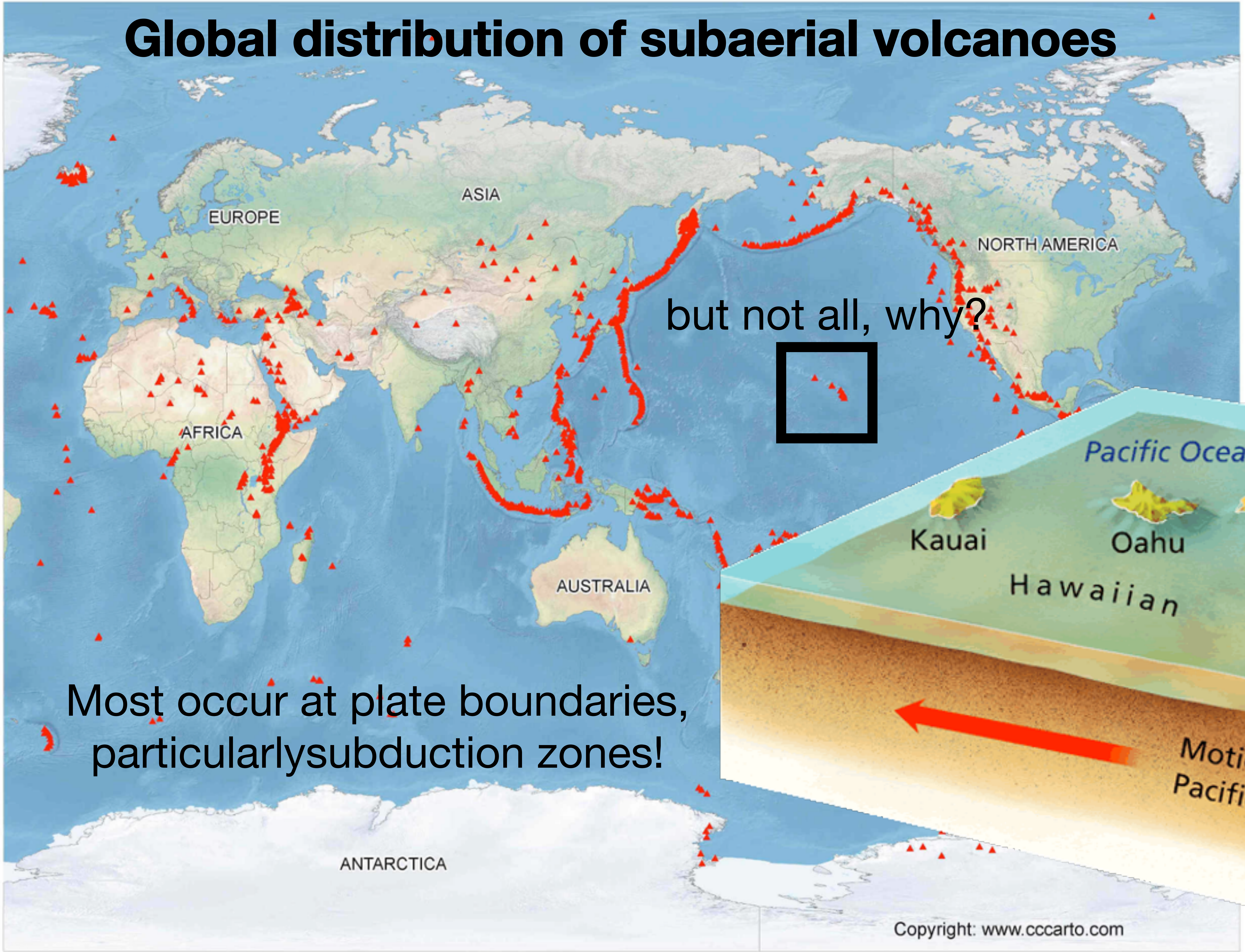


			Convergent	
	Transform	**Divergent**	**Collision**	**Subduction**
Motion				
Crust	Preserved	Created	Preserved	Destroyed
Mountains	None	Yes	Yes (highest)	Yes
Earthquakes	Shallow	Shallow	Shallow-Moderate	Shallow-Deep
Volcanism	None	Yes	None	Yes
Example	San Andreas Fault	Mid Atlantic Ridge	Himalaya Mountains	Andes Mountains
Additional Information	Connects Ridge Segments	Youngest Crust on Earth	Tallest Mountains	Deep Trenches



Where are volcanoes formed?

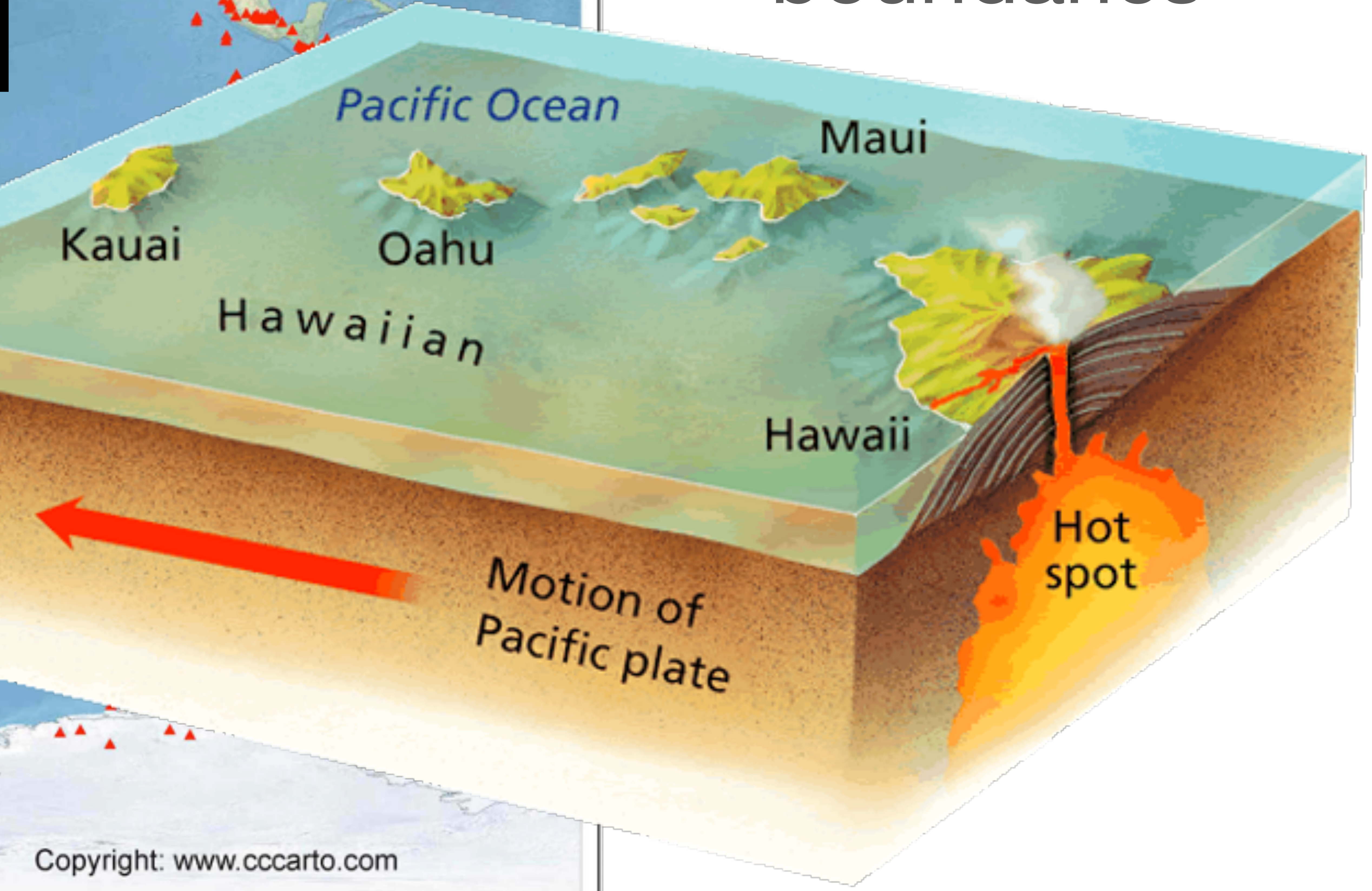
Global distribution of subaerial volcanoes

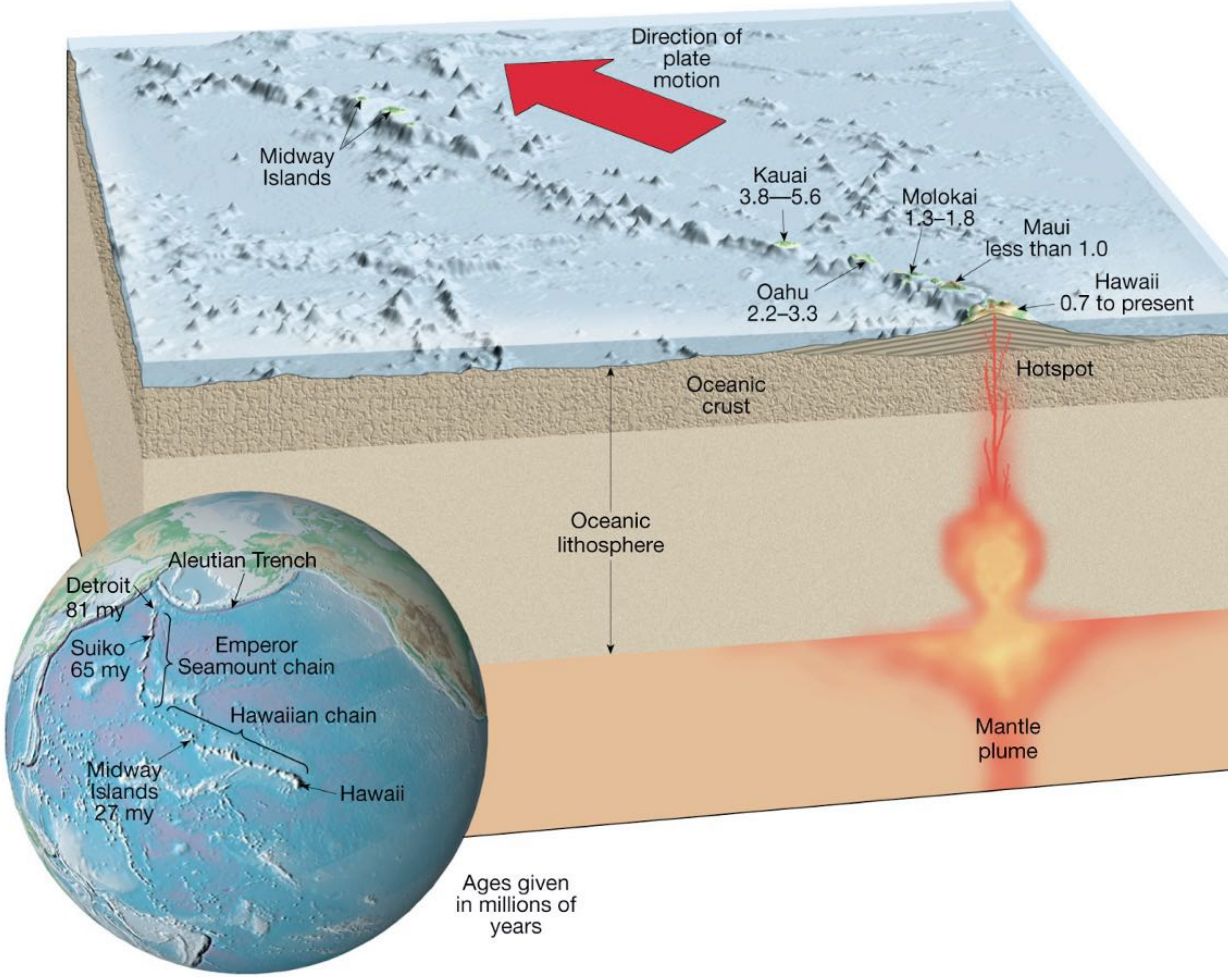


but not all, why?

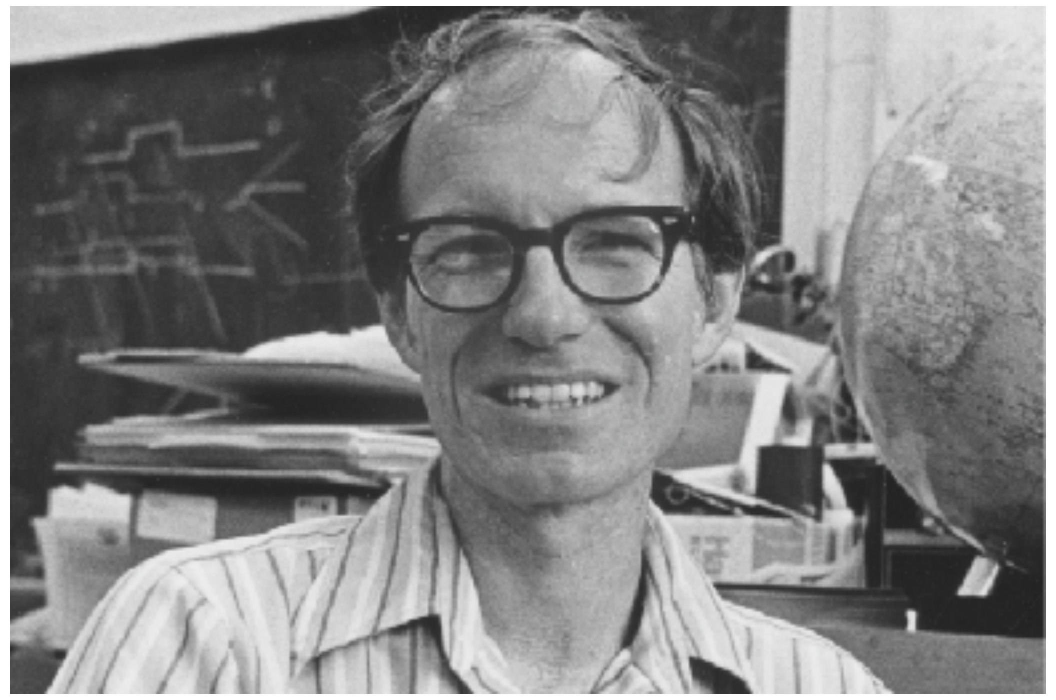
Most occur at plate boundaries, particularlysubduction zones!

Volcanoes like the Hawaiian and Yellowstone ones are not associated with tectonic boundaries



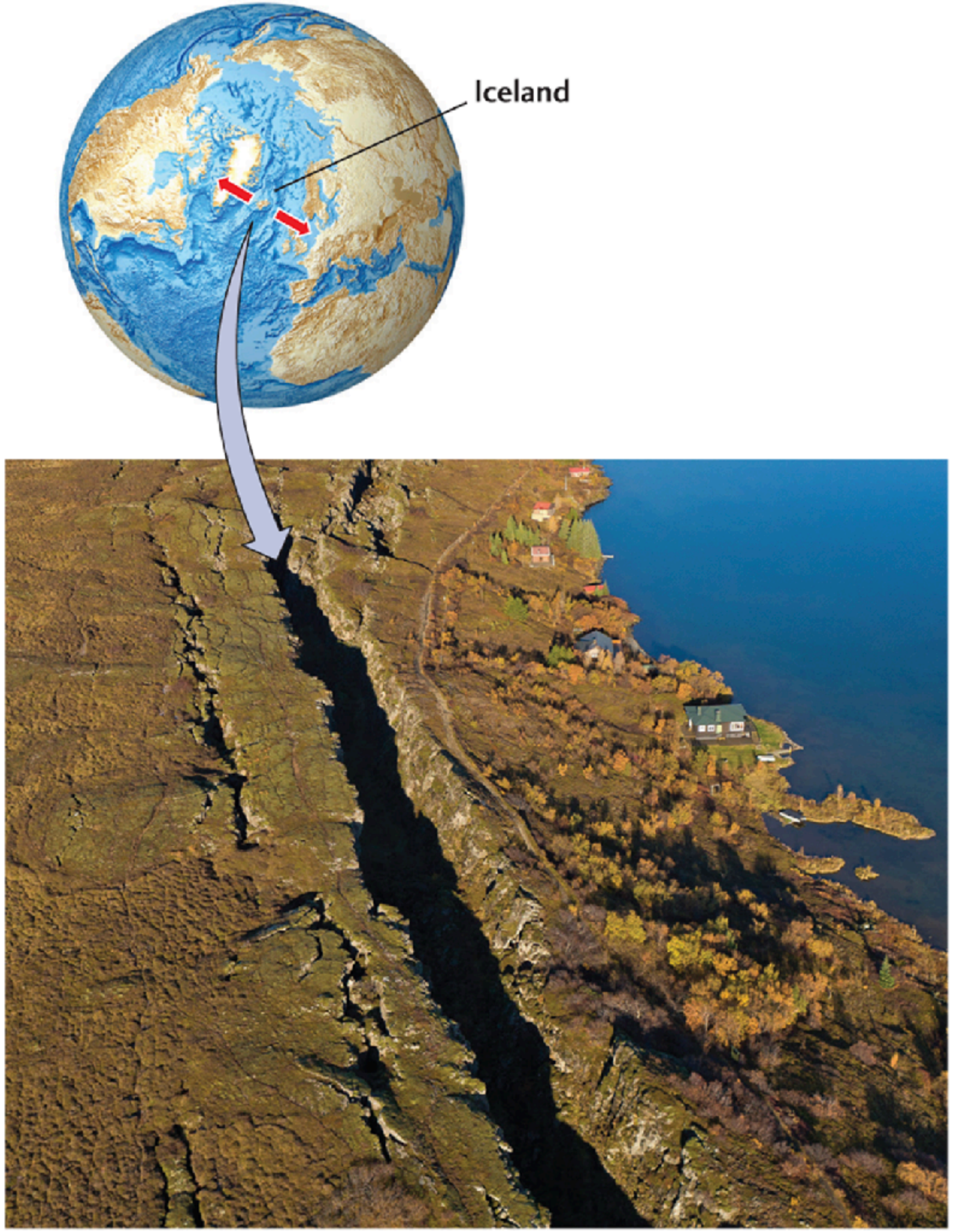


Hot spots are stationary magma sources deep in the earth. The plate moves over them leaving a trail of volcanoes.



LINK

Plume hypothesis was proposed by W. Jason Morgan, a Georgia Tech alumnus who recently passed away

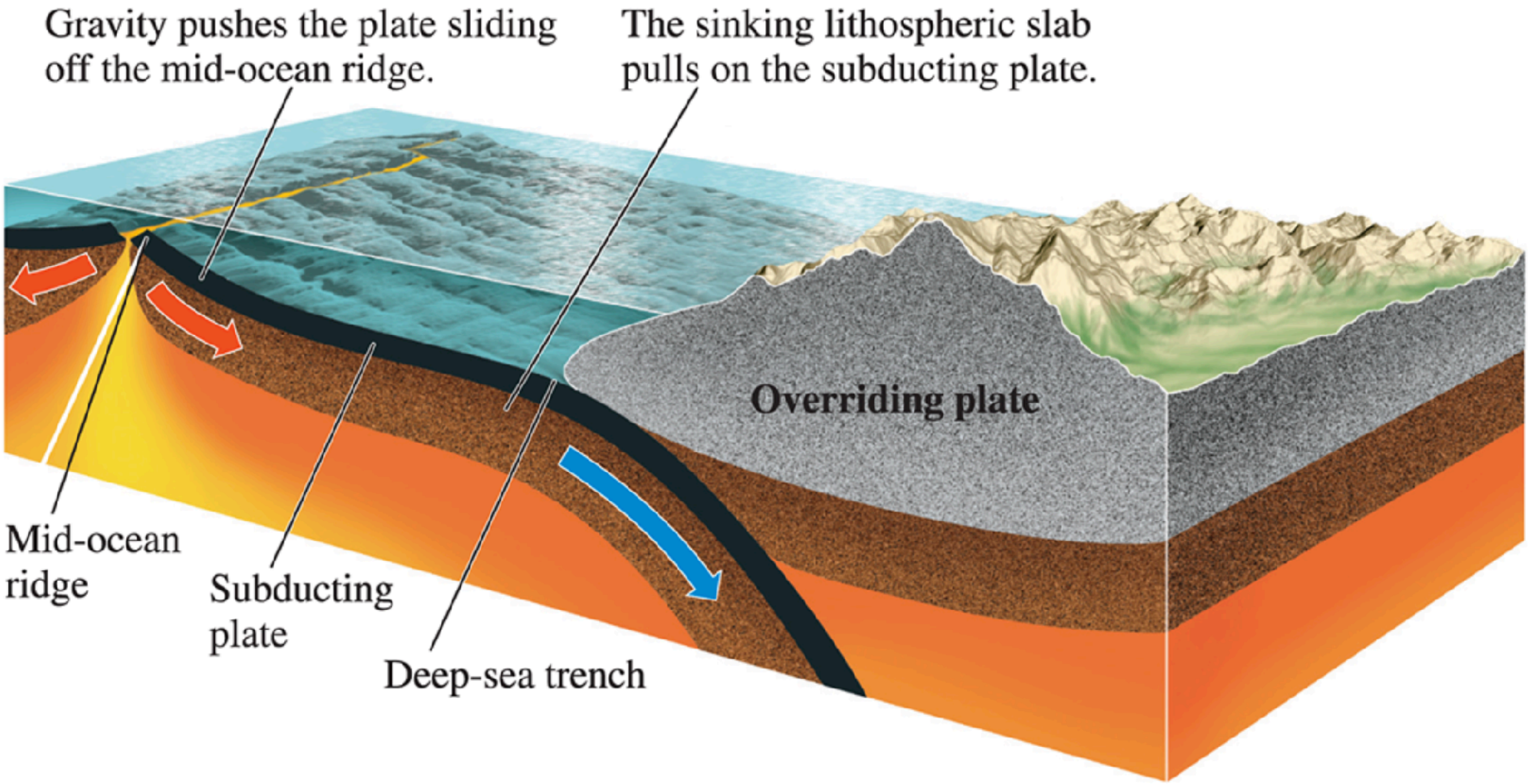


Grotzinger/Jordan, *Understanding Earth*, 8e, © 2020 W. H. Freeman and Company
Ragnar Th. Sigurdsson © Arctic Images/Alamy.

Iceland:

Hot spot beneath a mid-ocean ridge?

From Ridge to Trench



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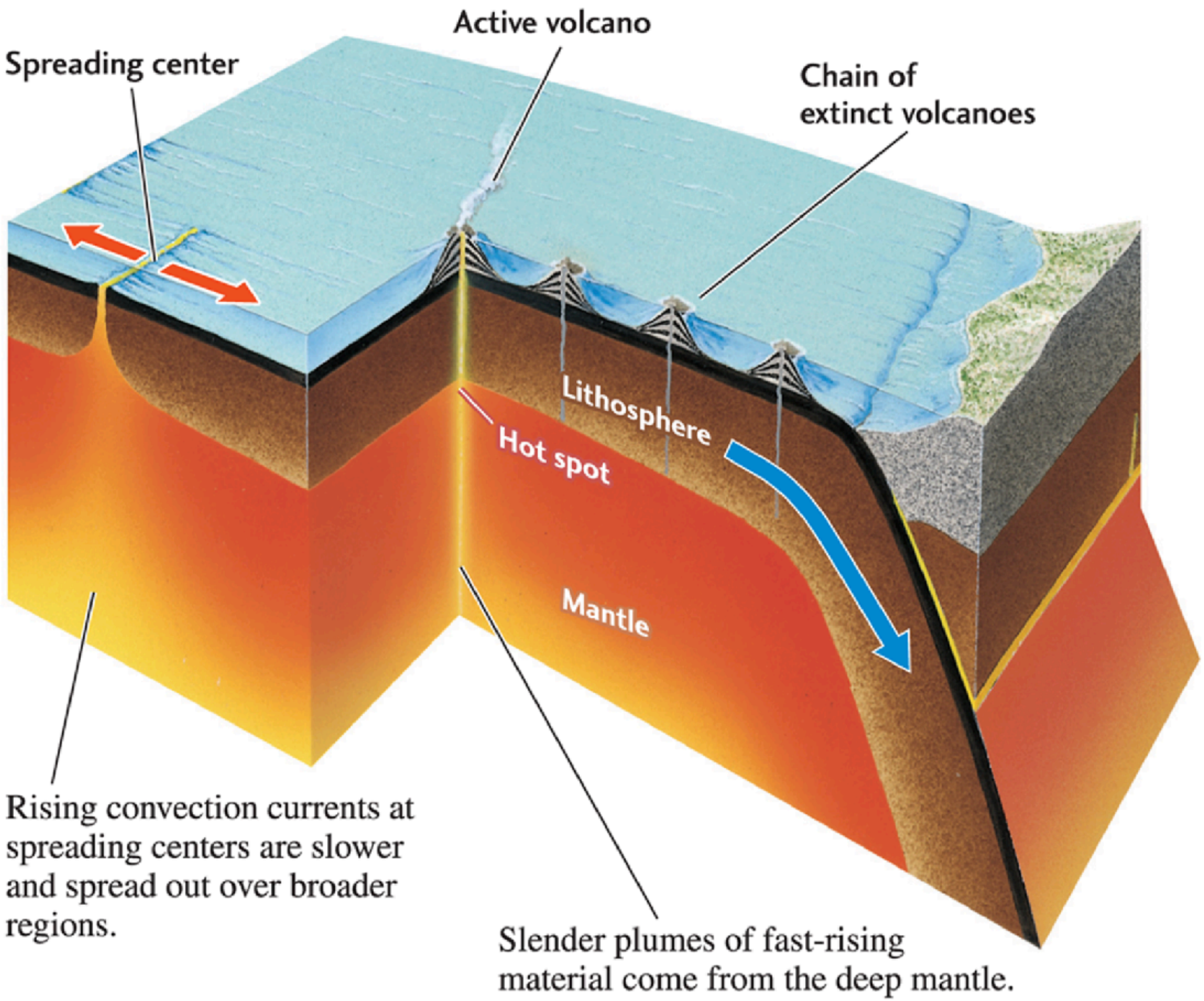
From Ridge to Trench



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Style of Mantle Convection

Grotzinger/Jordan, *Understanding Earth*, 8e, © 2020 W. H. Freeman and Company

Seismic observations support whole mantle convection

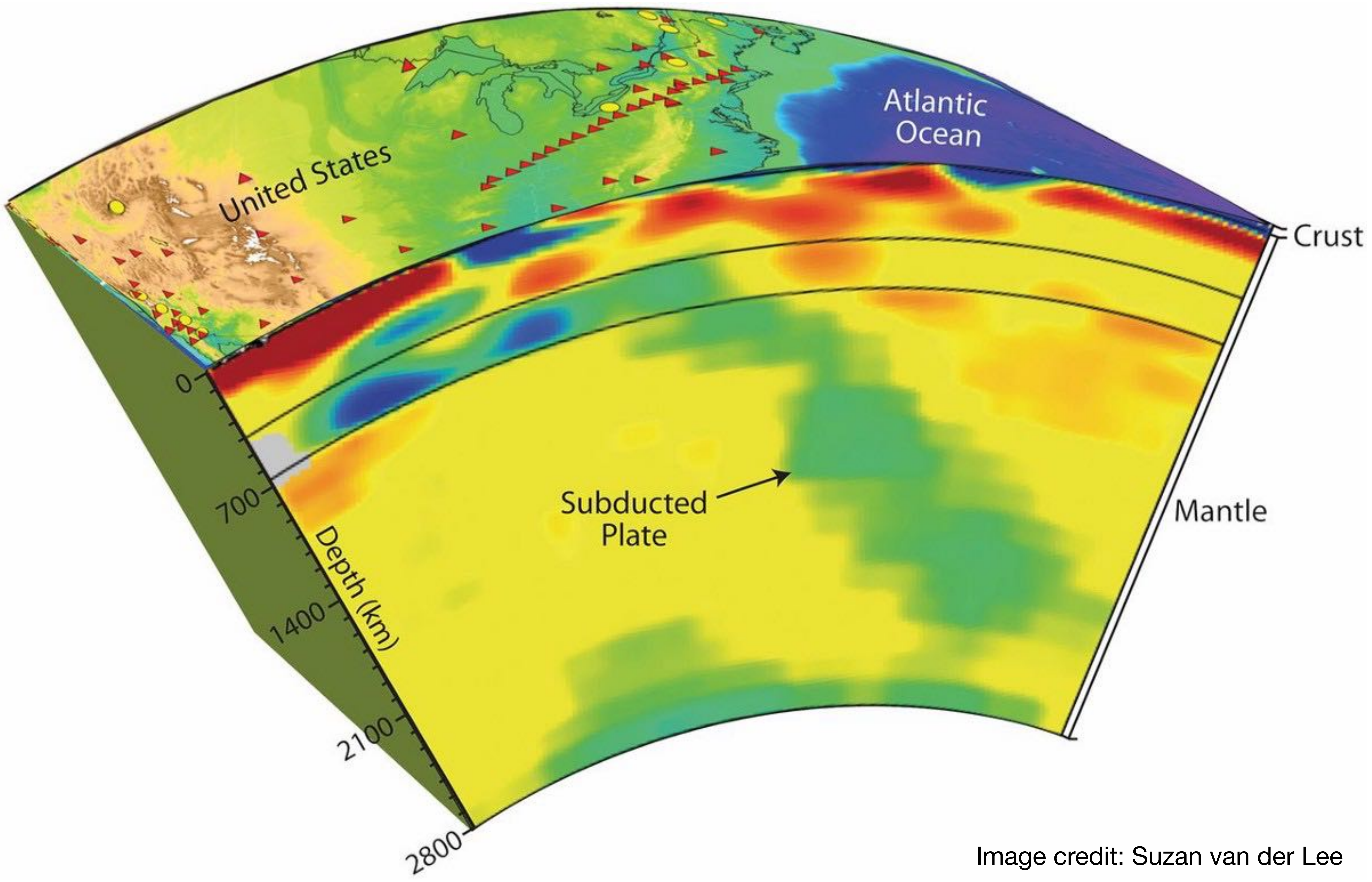
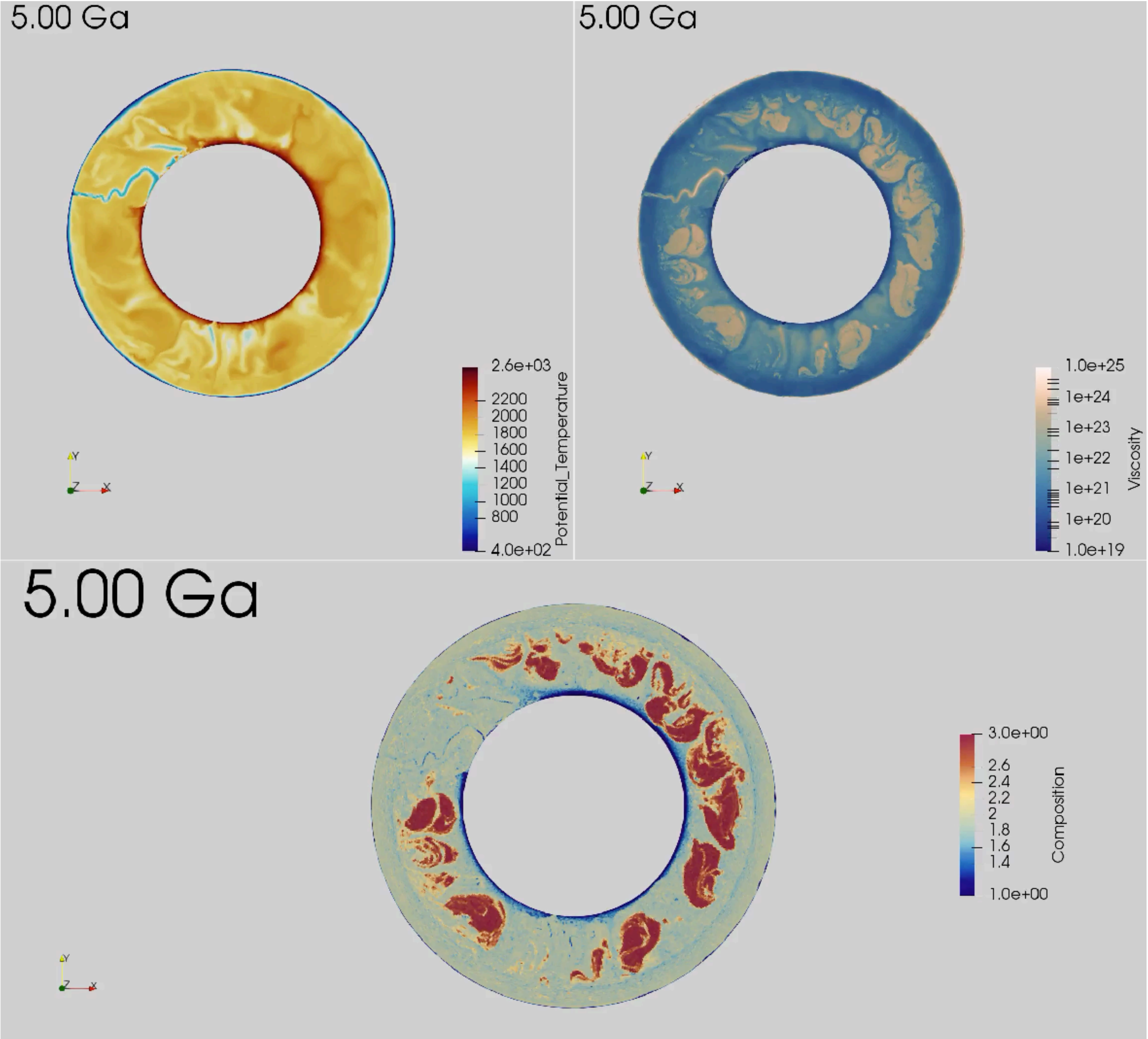


Image credit: Suzan van der Lee



How well mixed is the mantle?

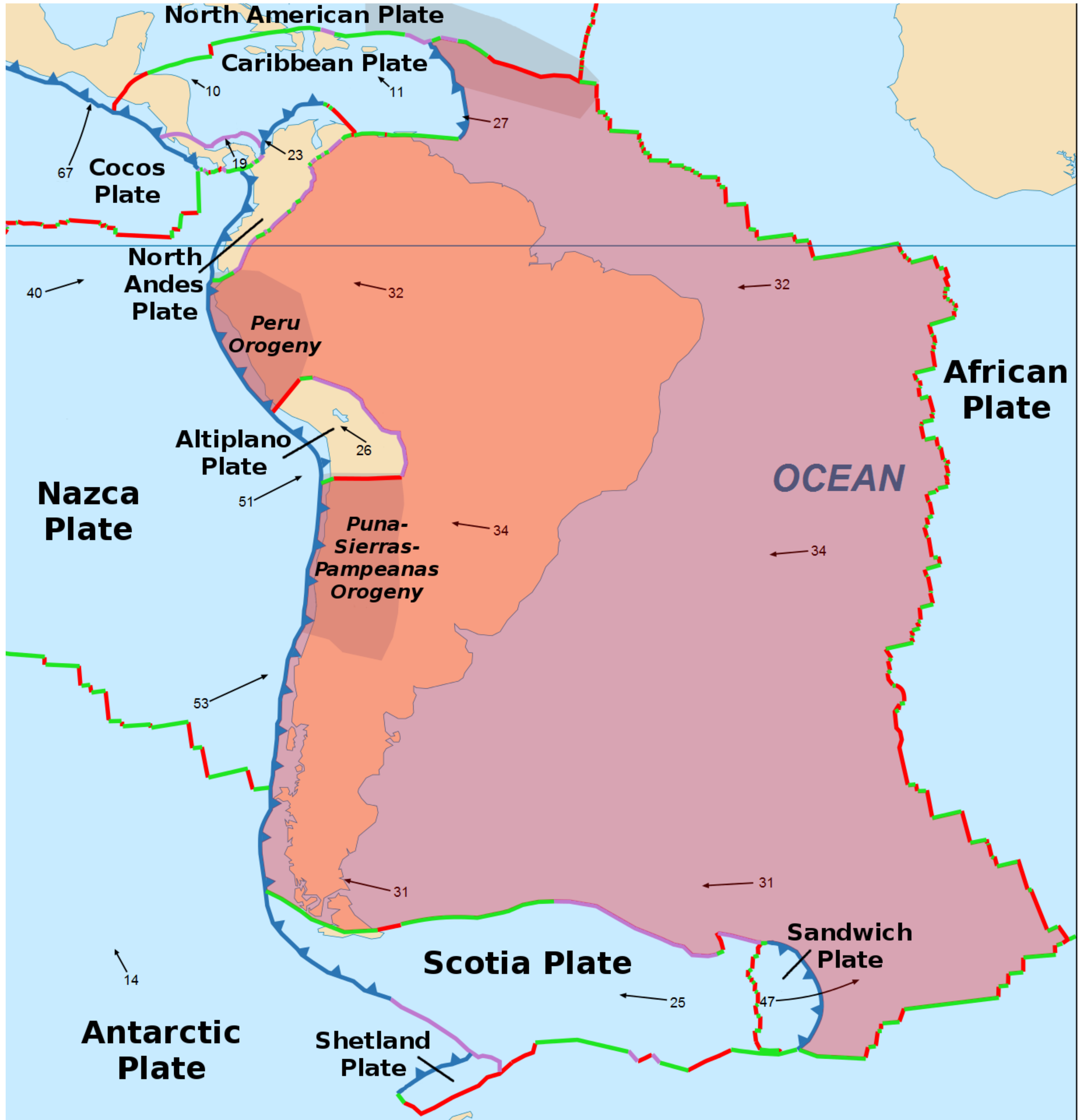
Marble Cake Mantle

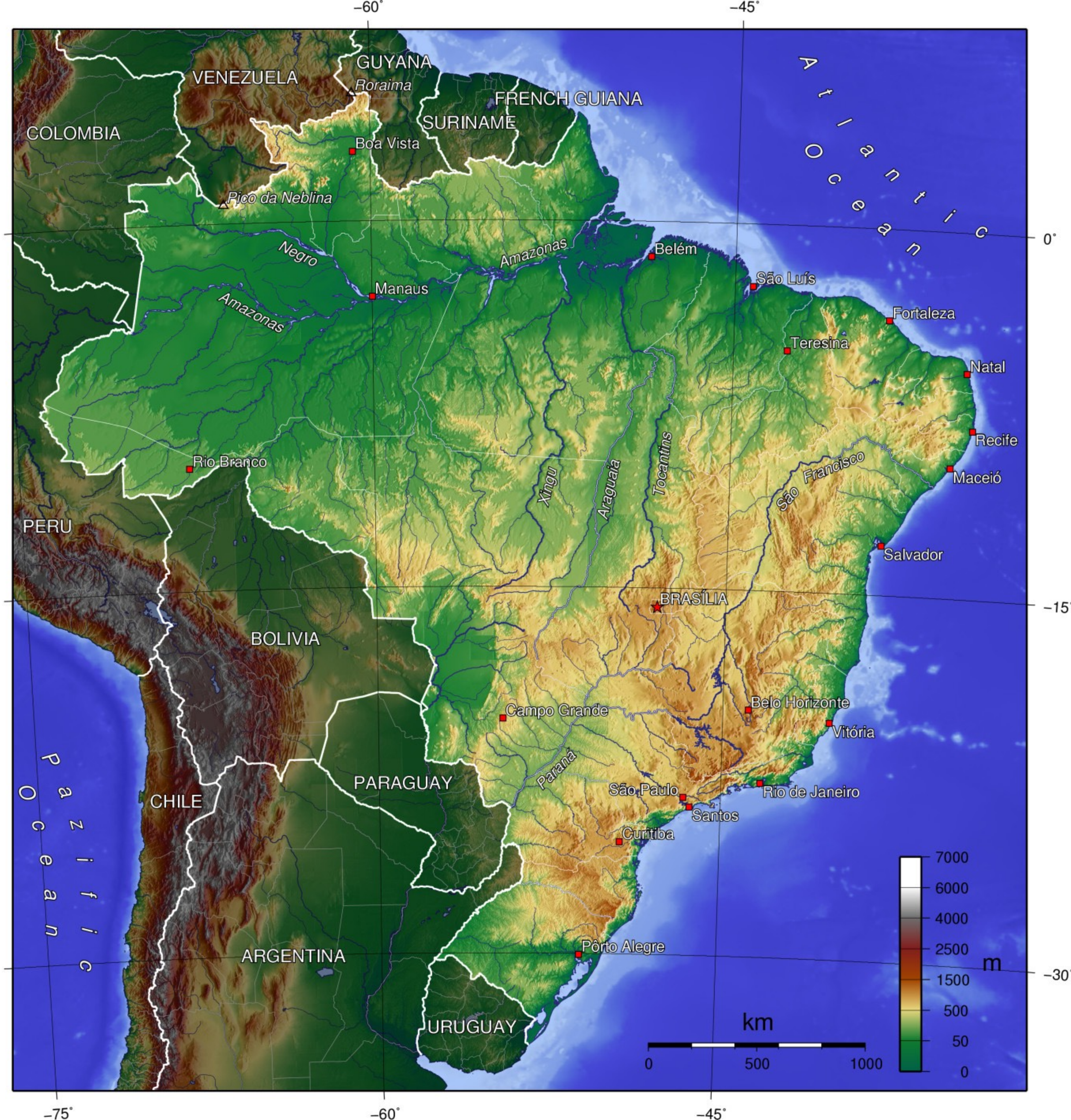
Proposed style of present-day mantle heterogeneity

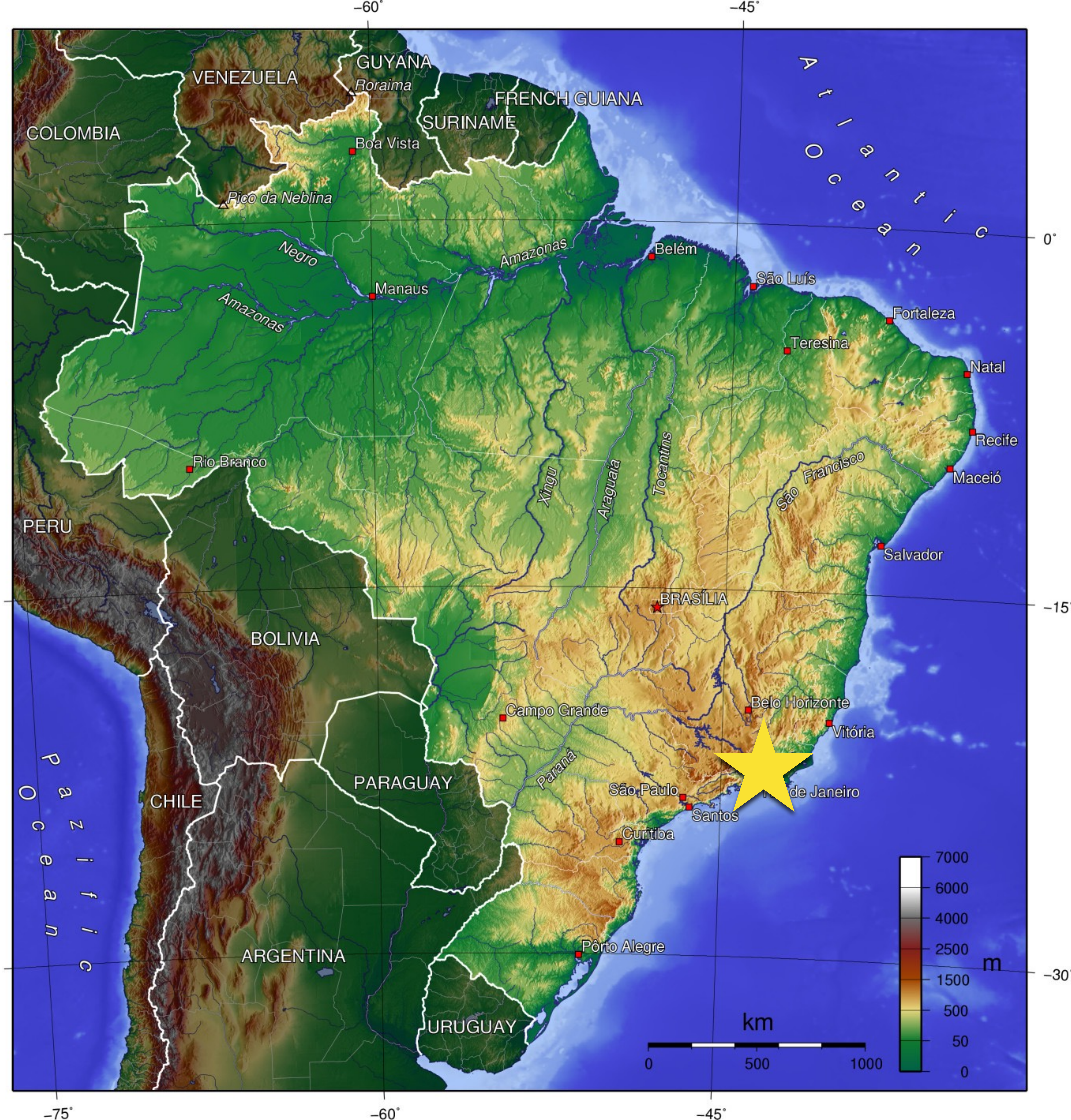
from Gülcher et al. (2021)

But wait…

How do we explain regions of high elevation far away from plate boundaries?





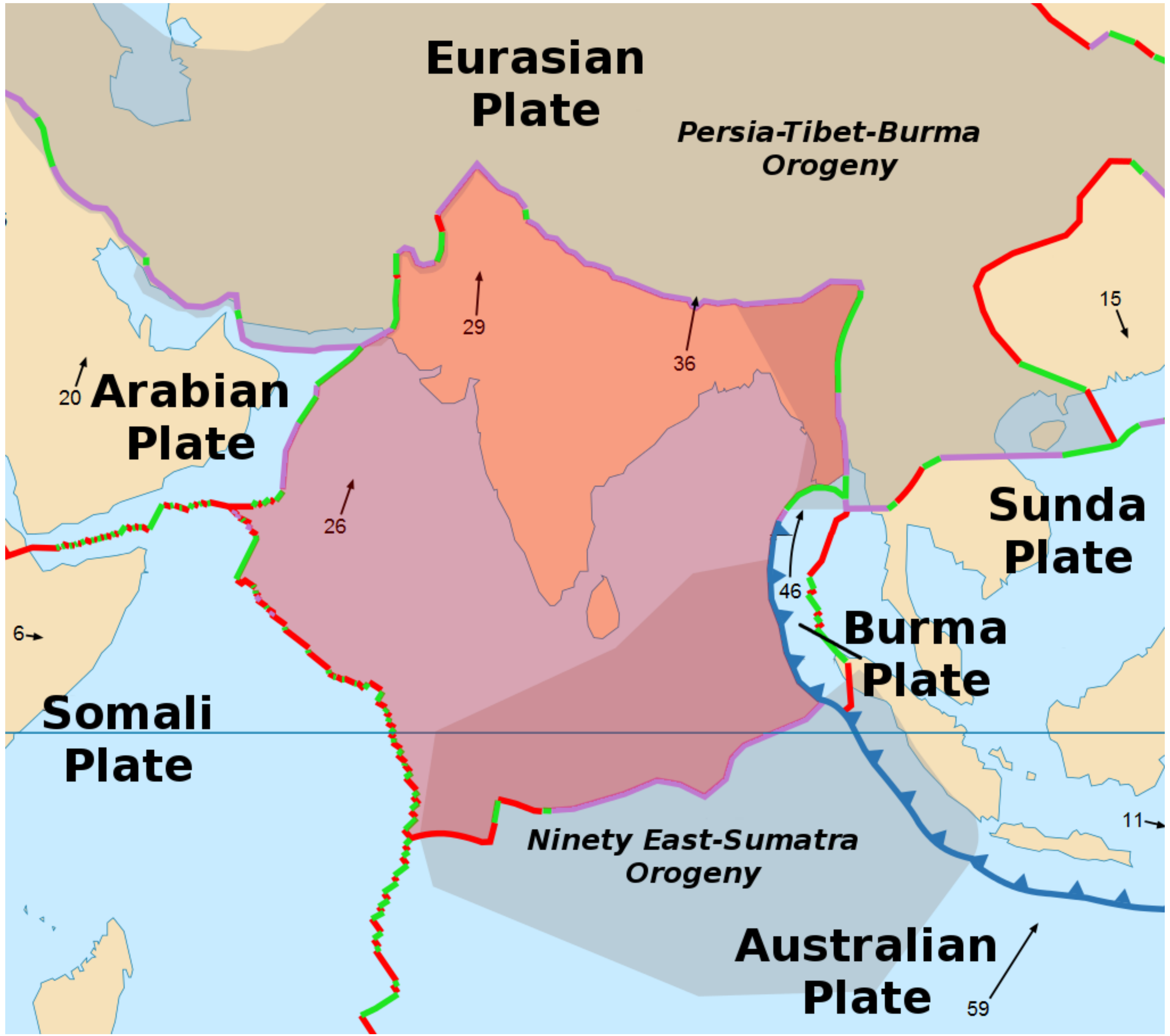


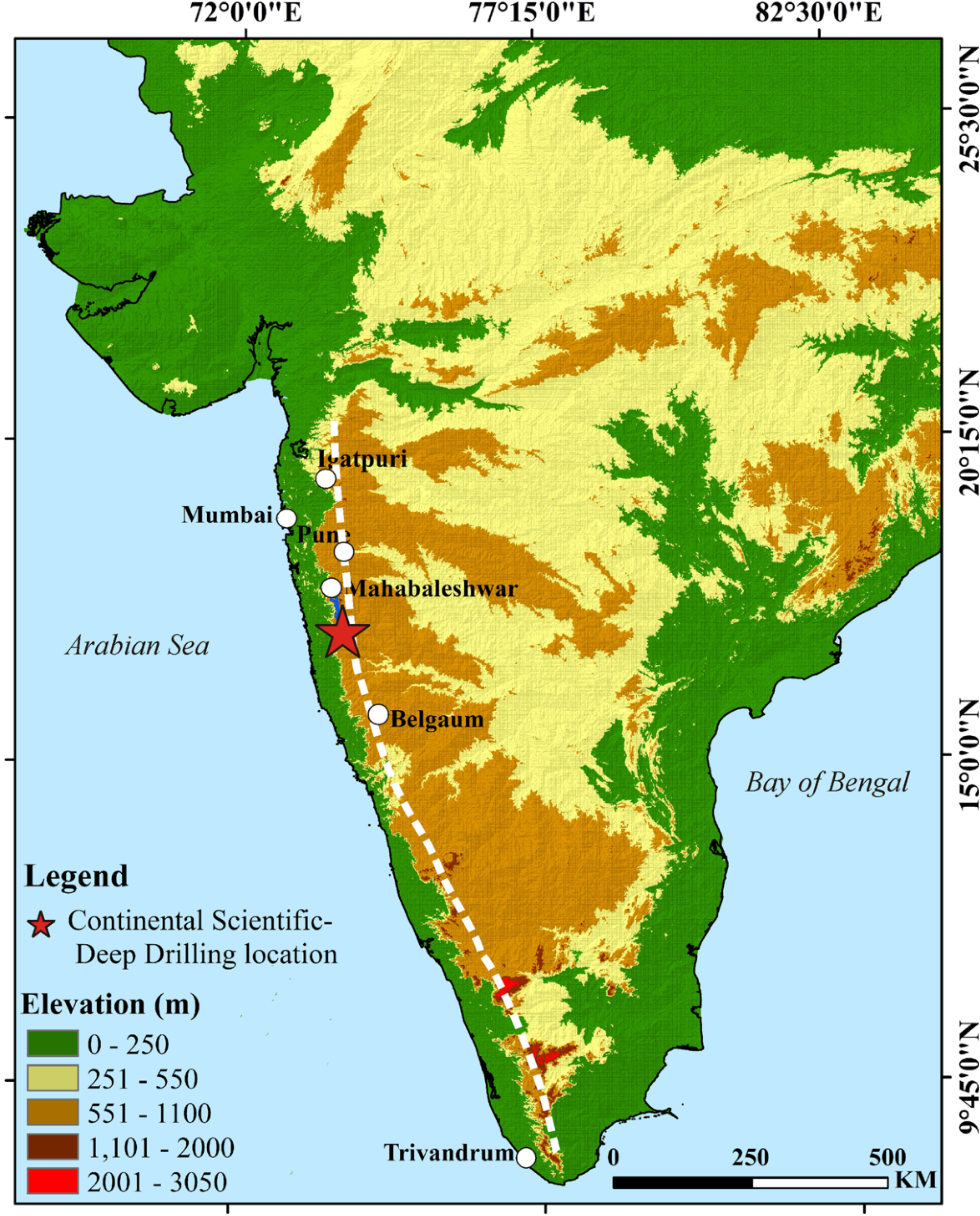
-60°
-45°
-75°
-60°
-45°
0°
-15°
-30°
VENEZUELA
GUYANA
Roraima
FRENCH GUIANA
SURINAME
COLOMBIA
Boa Vista
Pico da Neblina
Atlantic Ocean
Negro
Amazonas
Belém
São Luís
Manaus
Amazonas
Fortaleza
Teresina
Natal
Recife
Rio Branco
Maceió
São Francisco
Xingu
Araguaia
Tocantins
PERU
Salvador
BRASÍLIA
BOLIVIA
Belo Horizonte
Campo Grande
Vitória
Paraná
Pazific Ocean
PARAGUAY
CHILE
São Paulo
de Janeiro
Santos
Curitiba
7000
6000
4000
2500
1500
500
50
0
m
Porto Alegre
ARGENTINA
km
0
500
1000
URUGUAY

map from Radhakrishna et al. (2019)

But wait…

How do we explain regions of high elevation far away from plate boundaries?

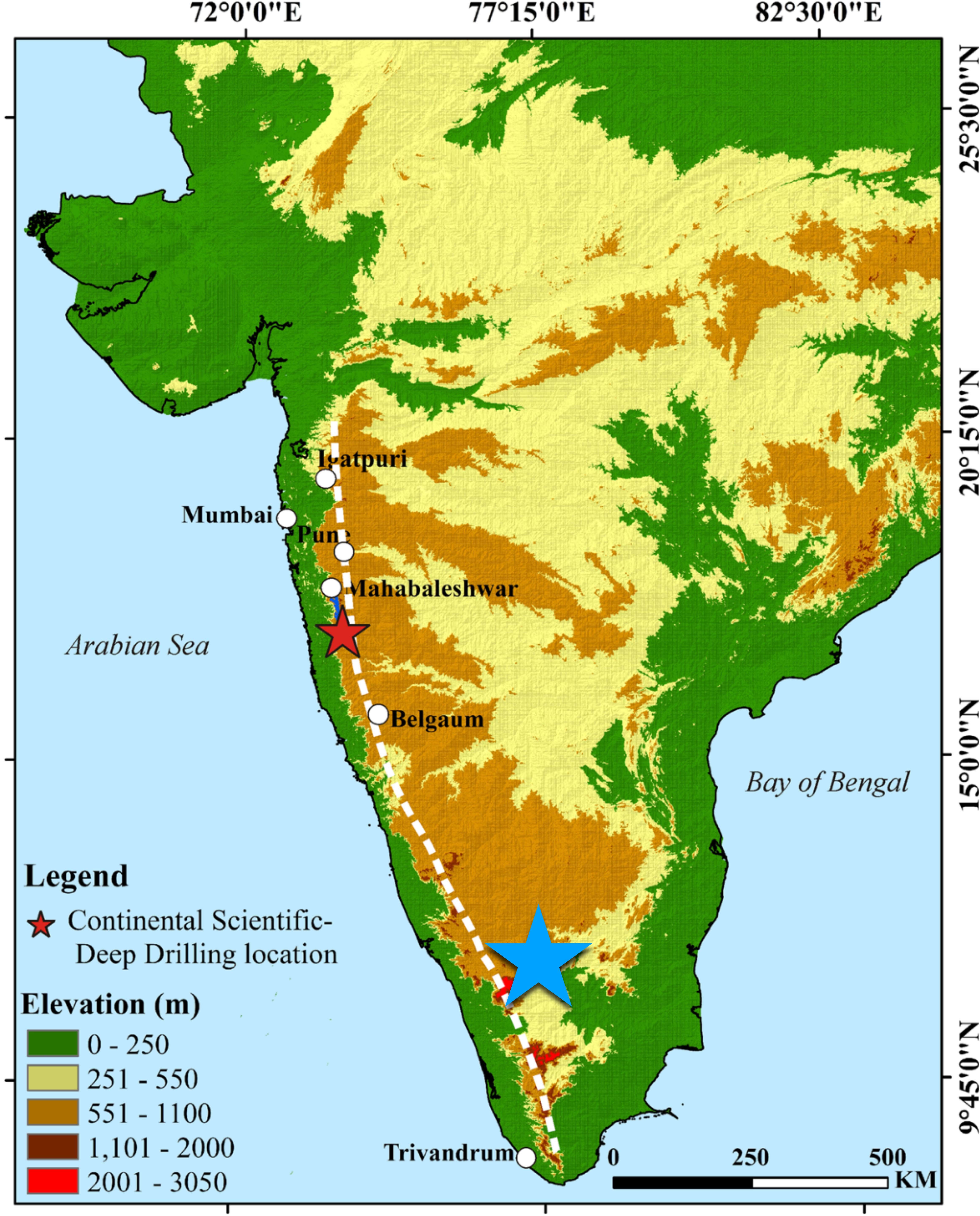




map from Radhakrishna et al. (2019)

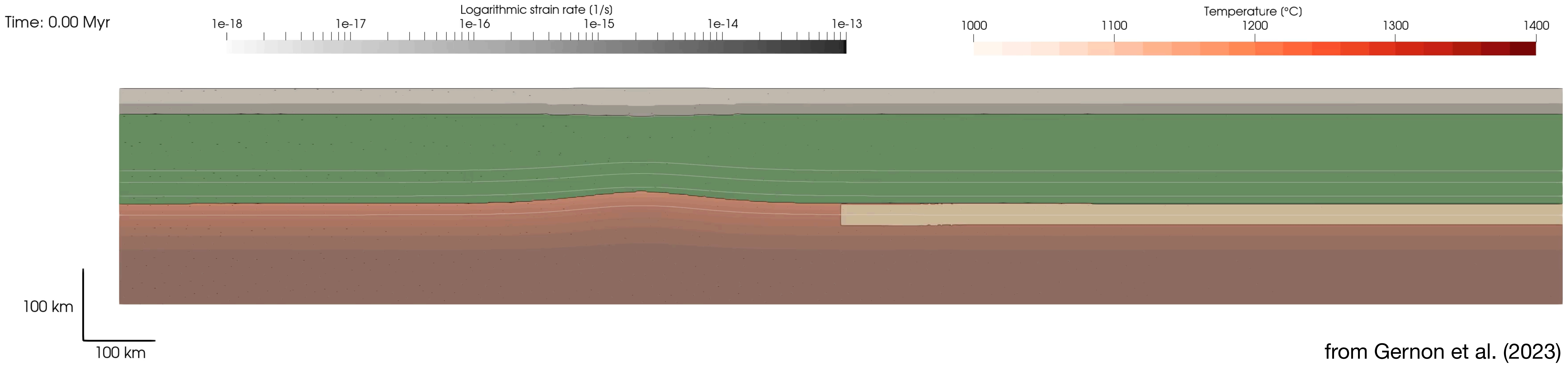
But wait…

How do we explain regions of high elevation far away from plate boundaries?



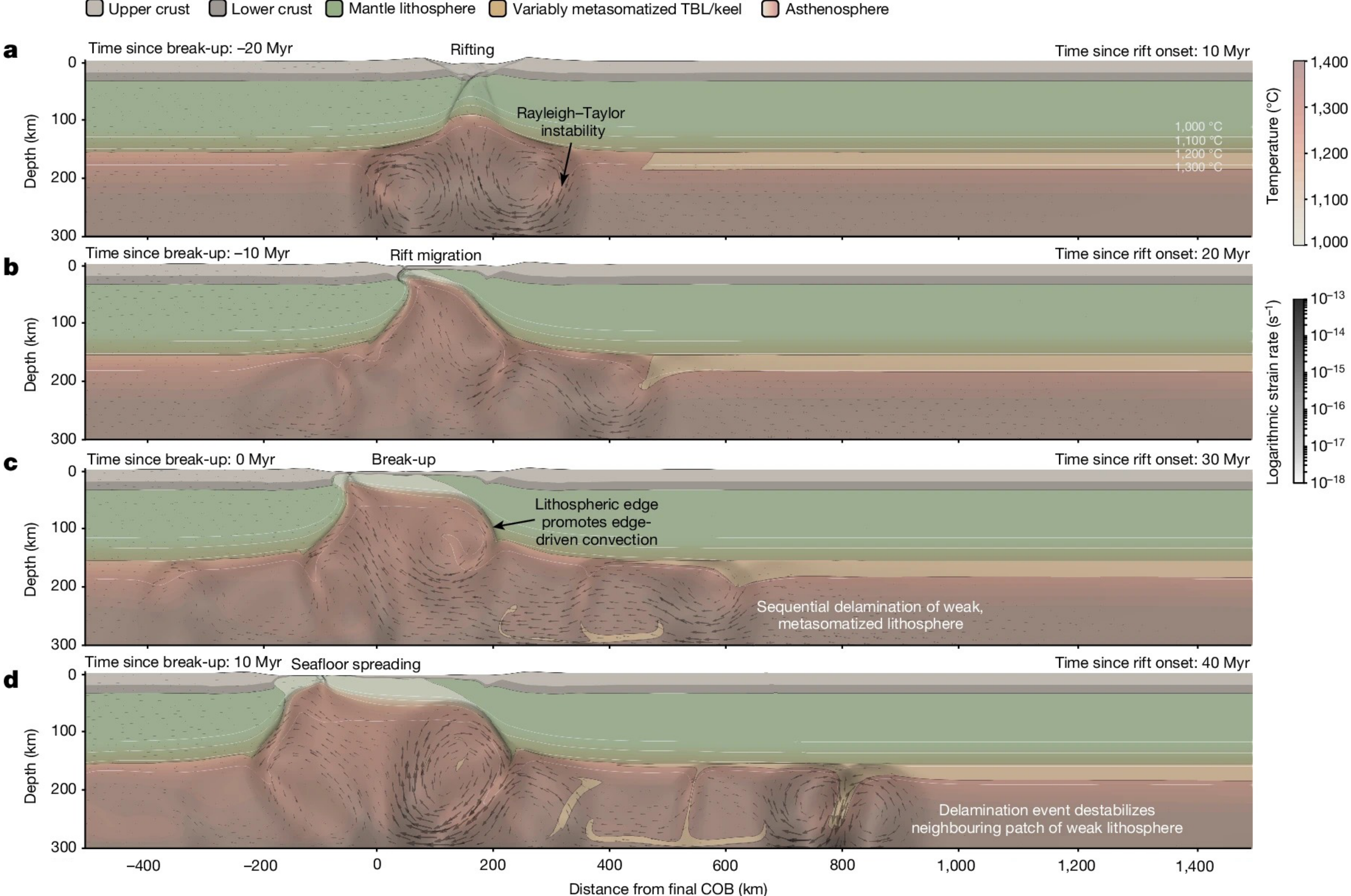
A new theory was published earlier this month

Rift initiation generates mantle waves…

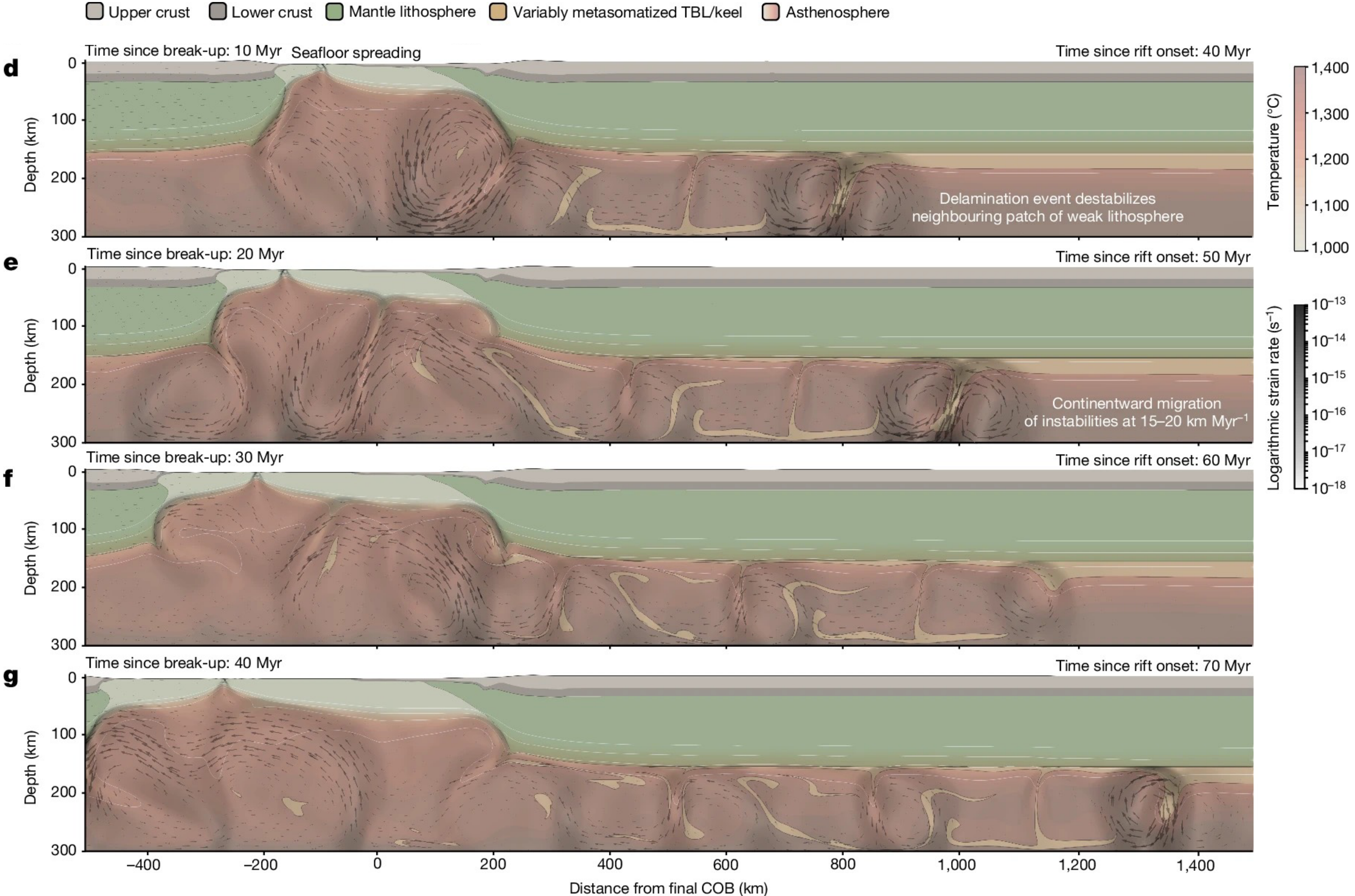


from Gernon et al. (2023)

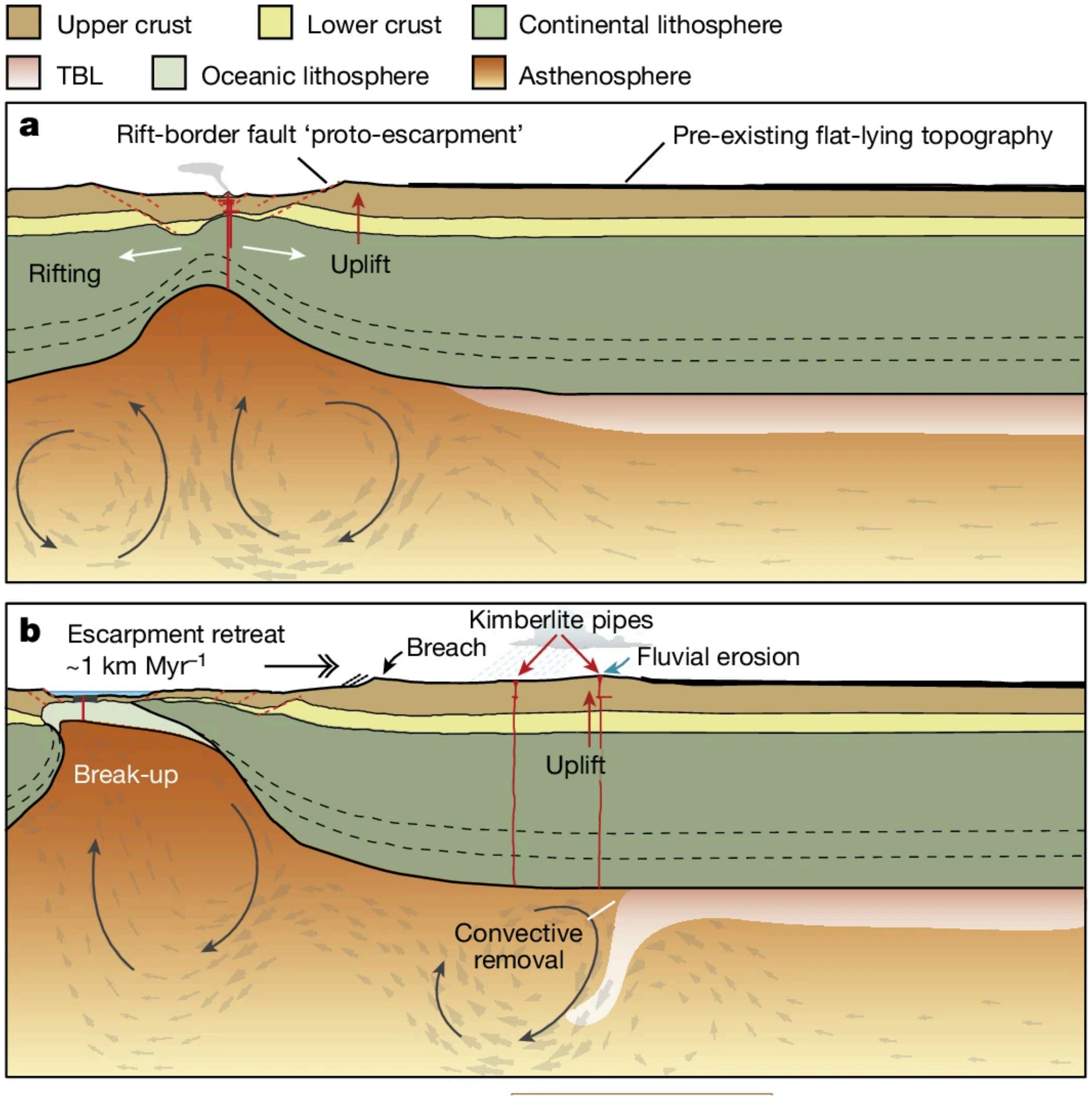
…which are responsible for surface uplift



Upper crust
Lower crust
Mantle lithosphere
Variably metasomatized TBL/keel
Asthenosphere
a
Time since break-up: –20 Myr
Rifting
Time since rift onset: 10 Myr
Rayleigh–Taylor instability
1,000 °C
1,100 °C
1,200 °C
1,300 °C
b
Time since break-up: –10 Myr
Rift migration
Time since rift onset: 20 Myr
c
Time since break-up: 0 Myr
Break-up
Time since rift onset: 30 Myr
Lithospheric edge promotes edge-driven convection
Sequential delamination of weak, metasomatized lithosphere
d
Time since break-up: 10 Myr
Seafloor spreading
Time since rift onset: 40 Myr
Delamination event destabilizes neighbouring patch of weak lithosphere
Depth (km)
0
100
200
300
Distance from final COB (km)
-400
-200
0
200
400
600
800
1,000
1,200
1,400
Temperature (°C)
1,400
1,300
1,200
1,100
1,000
Logarithmic strain rate (s^{-1})
10^{-13}
10^{-14}
10^{-15}
10^{-16}
10^{-17}
10^{-18}



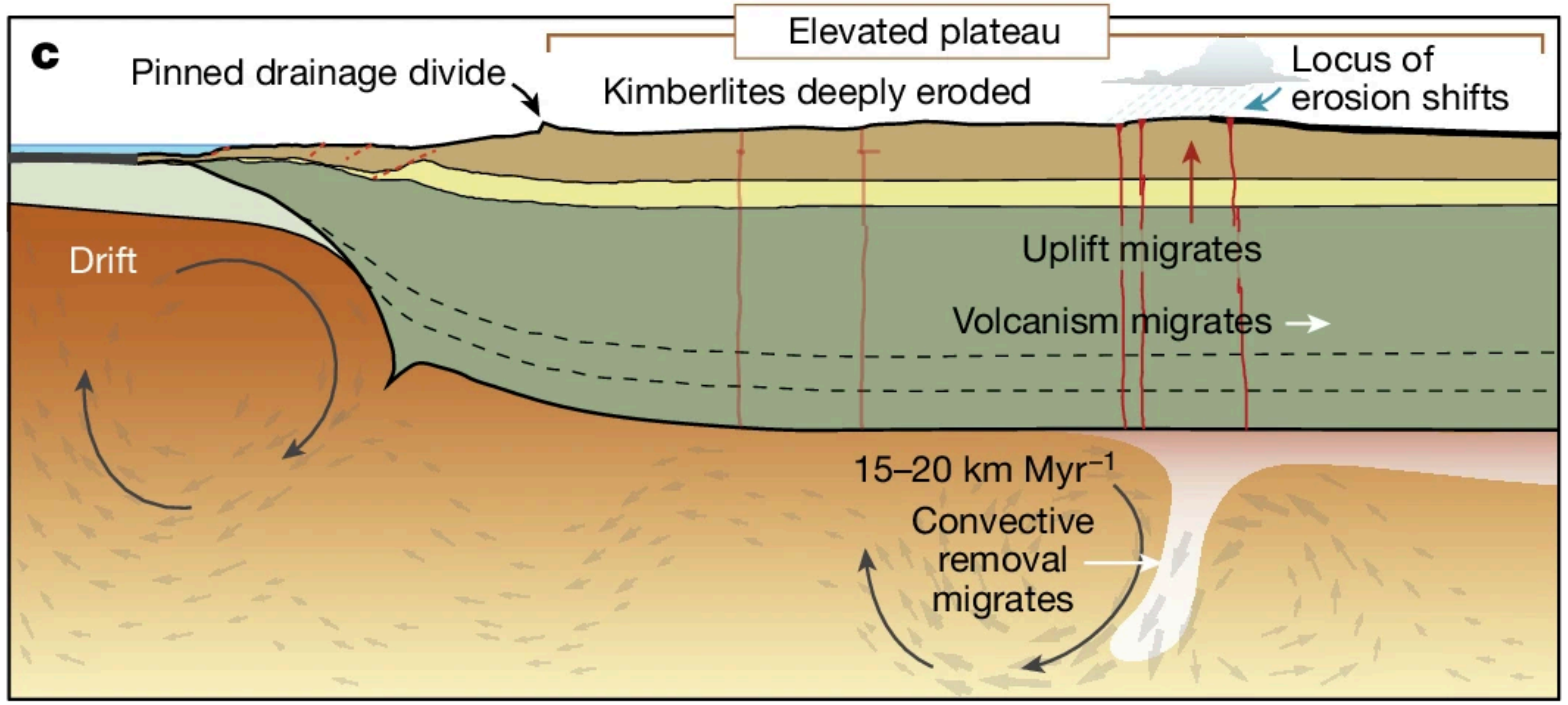
Upper crust
Lower crust
Mantle lithosphere
Variably metasomatized TBL/keel
Asthenosphere
d
Time since break-up: 10 Myr
Seafloor spreading
Time since rift onset: 40 Myr
Delamination event destabilizes neighbouring patch of weak lithosphere
e
Time since break-up: 20 Myr
Time since rift onset: 50 Myr
Continentward migration of instabilities at 15–20 km Myr^{-1}
f
Time since break-up: 30 Myr
Time since rift onset: 60 Myr
g
Time since break-up: 40 Myr
Time since rift onset: 70 Myr
Depth (km)
0
100
200
300
Distance from final COB (km)
−400
−200
0
200
400
600
800
1,000
1,200
1,400
Temperature (°C)
1,000
1,100
1,200
1,300
1,400
Logarithmic strain rate (s^{-1})
10^{-18}
10^{-17}
10^{-16}
10^{-15}
10^{-14}
10^{-13}



An article about this new result will be the topic of your first written report.

Look for Canvas announcement tomorrow. Due Fri Sep. 6th

from Gernon et al. (2024)



First quiz this Friday Aug 30th. Will be announced on Canvas later today.

Covers mostly Ch 2, a few questions from Ch 1

Next two lectures [Aug 29 & Sep 3]: Minerals (Ch. 3)