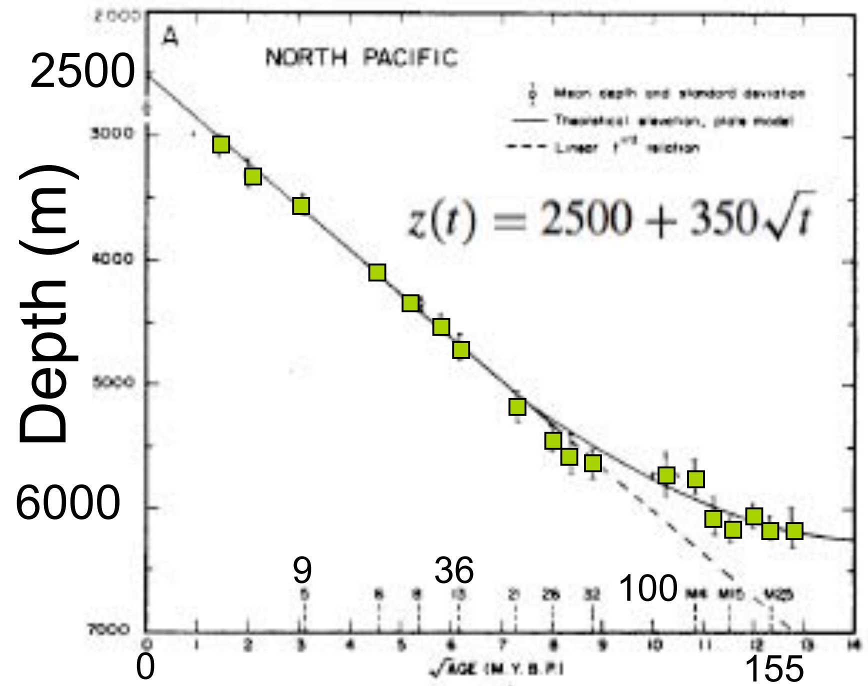
EESC 2200
The Solid Earth System

Plate tectonics - 3

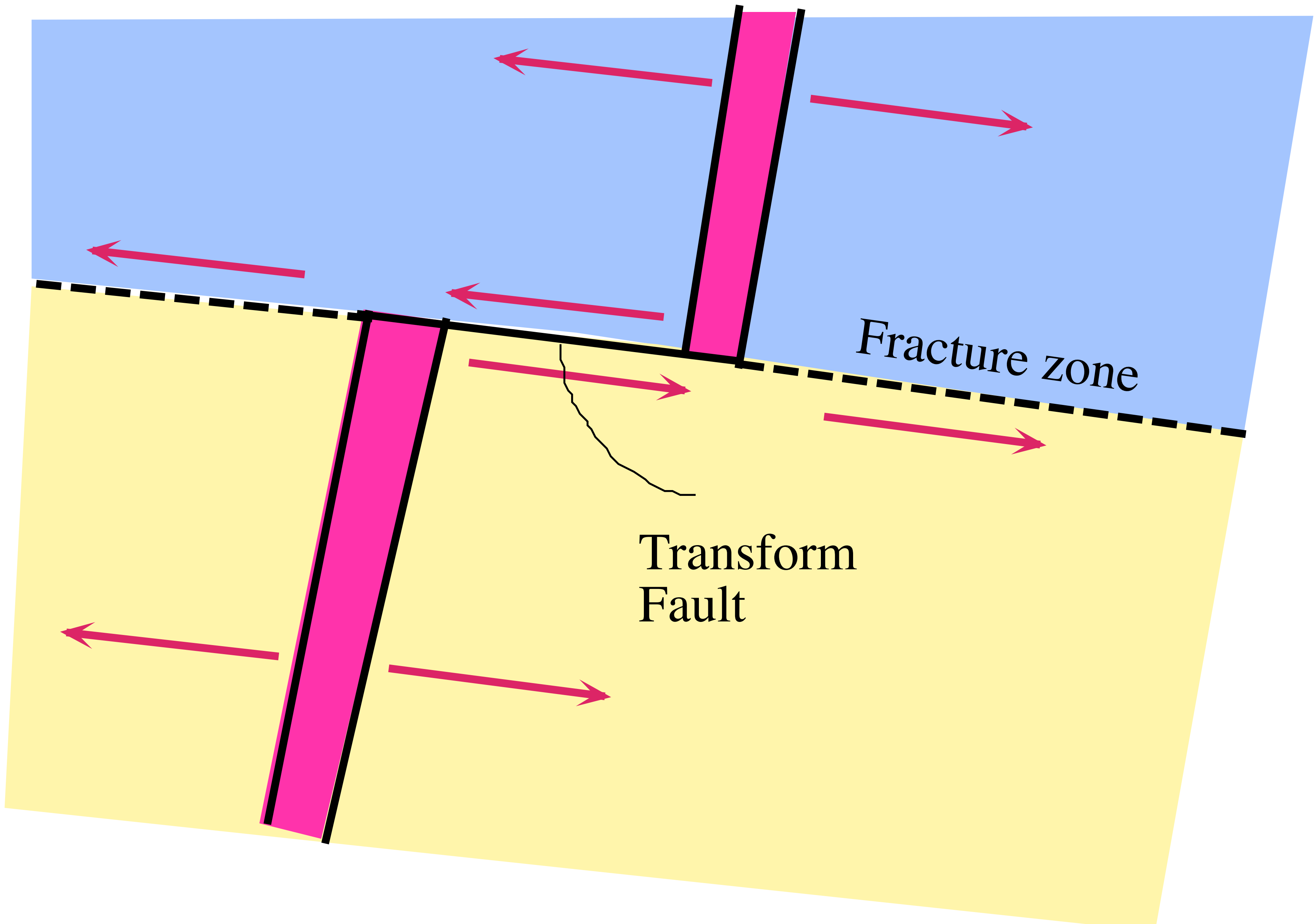
17 Sep 08

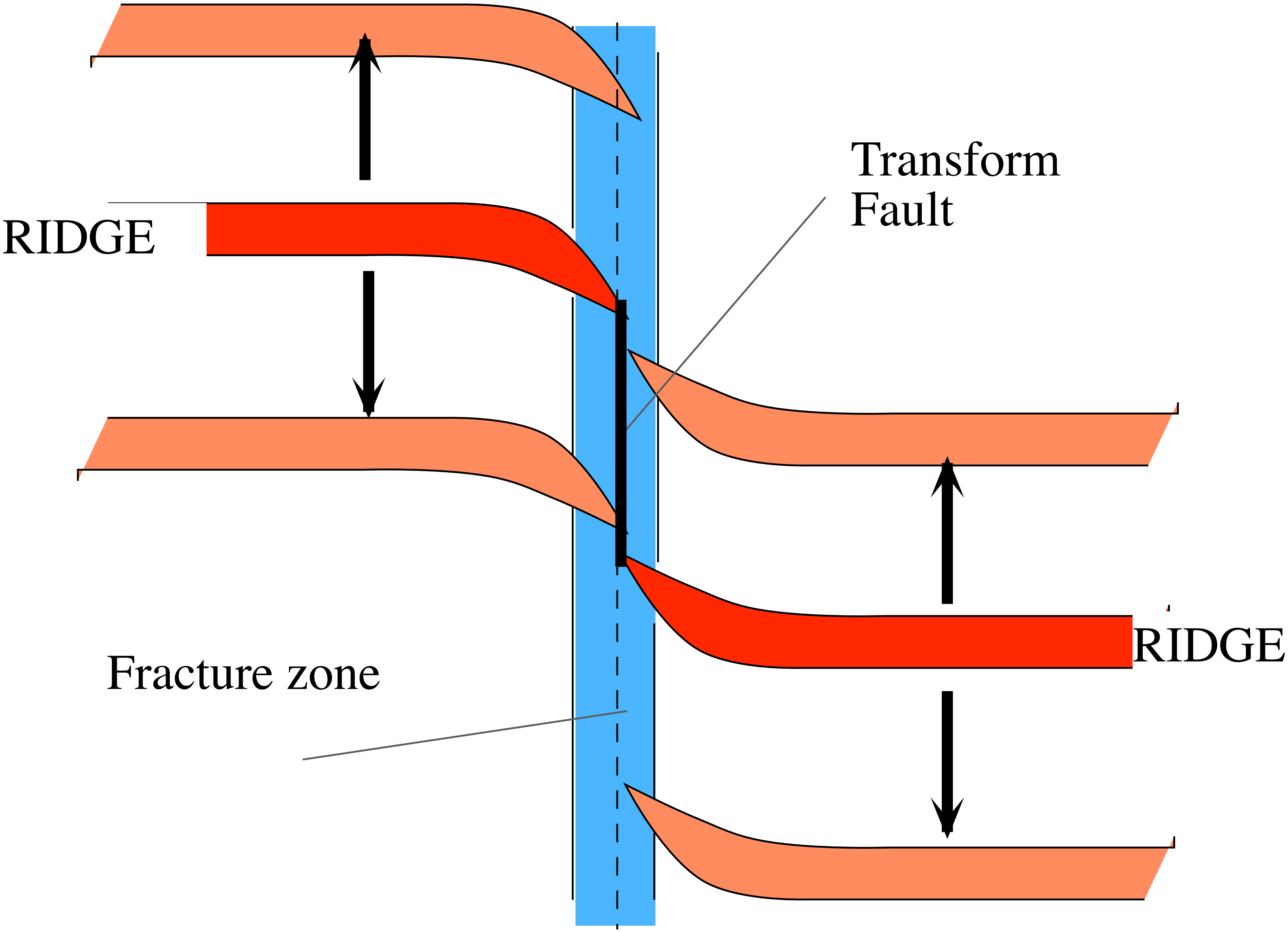
Hot Spots
Magnetic Reversals
Isostasy
Continental Tectonics



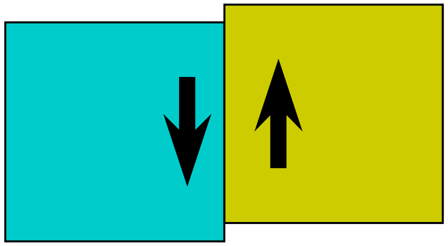
Homework 1:
Due Monday

Review:

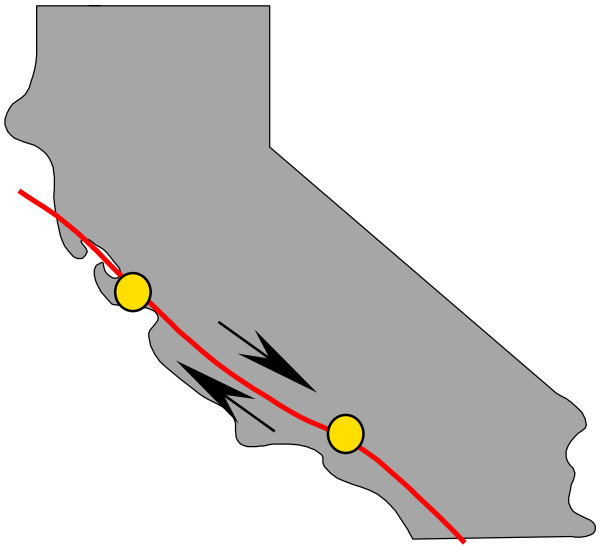




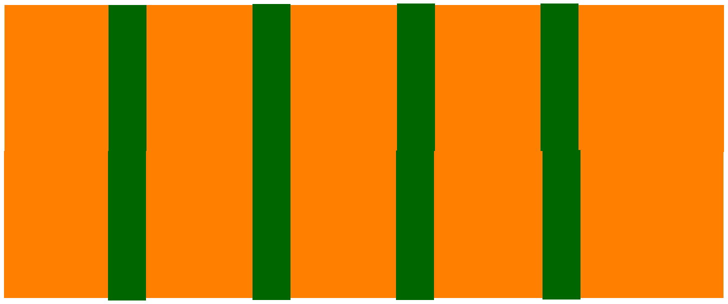
Pitman Fracture Zone Fly-by



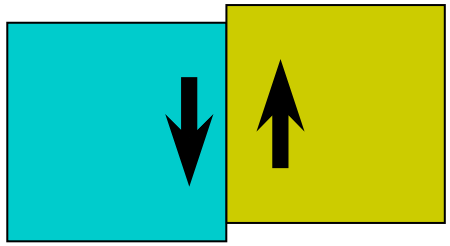
- **Transform**



- San Andreas Fault

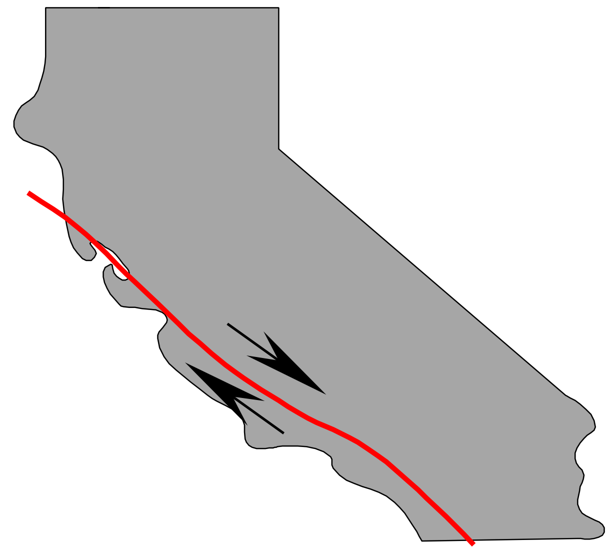


- Big Earthquakes, No Volcanoes
- Offsets

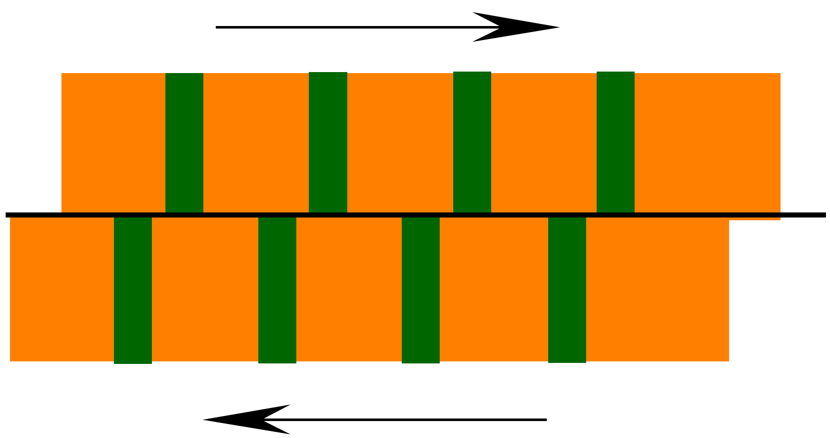


- **Transform**

- San Andreas Fault

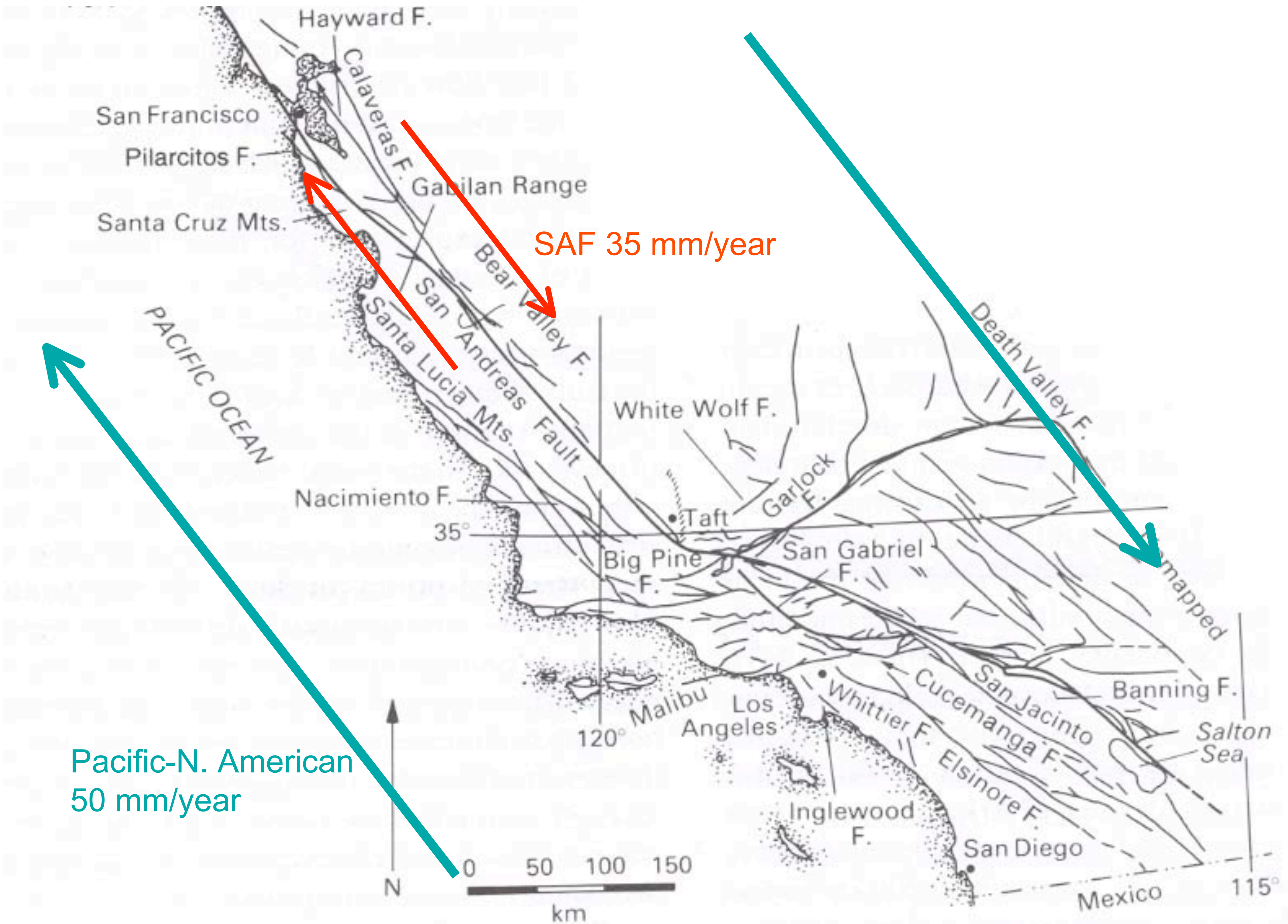


right lateral



- Big Earthquakes,
  No Volcanoes
- Offsets

slides-general


Hayward F.
Calaveras F.
San Francisco
Pilarcitos F.
Gabilan Range
Santa Cruz Mts.
SAF 35 mm/year
Bear Valley F.
San Andreas Fault
Santa Lucia Mts.
PACIFIC OCEAN
Death Valley F.
White Wolf F.
Garlock F.
Nacimiento F.
Taft
35°
Big Pine F.
San Gabriel F.
unmapped
Banning F.
San Jacinto
Cucemanga F.
Whittier F.
Elsinore F.
Salton Sea
Malibu
Los Angeles
120°
Inglewood F.
San Diego
Mexico
115°
N
0 50 100 150
km
Pacific-N. American
50 mm/year

1906 Earthquake
Magnitude 7.8

6 meters
of slip on a
fault 500 km
long

earthquake cycle

Fault at boundary between plates is “locked”

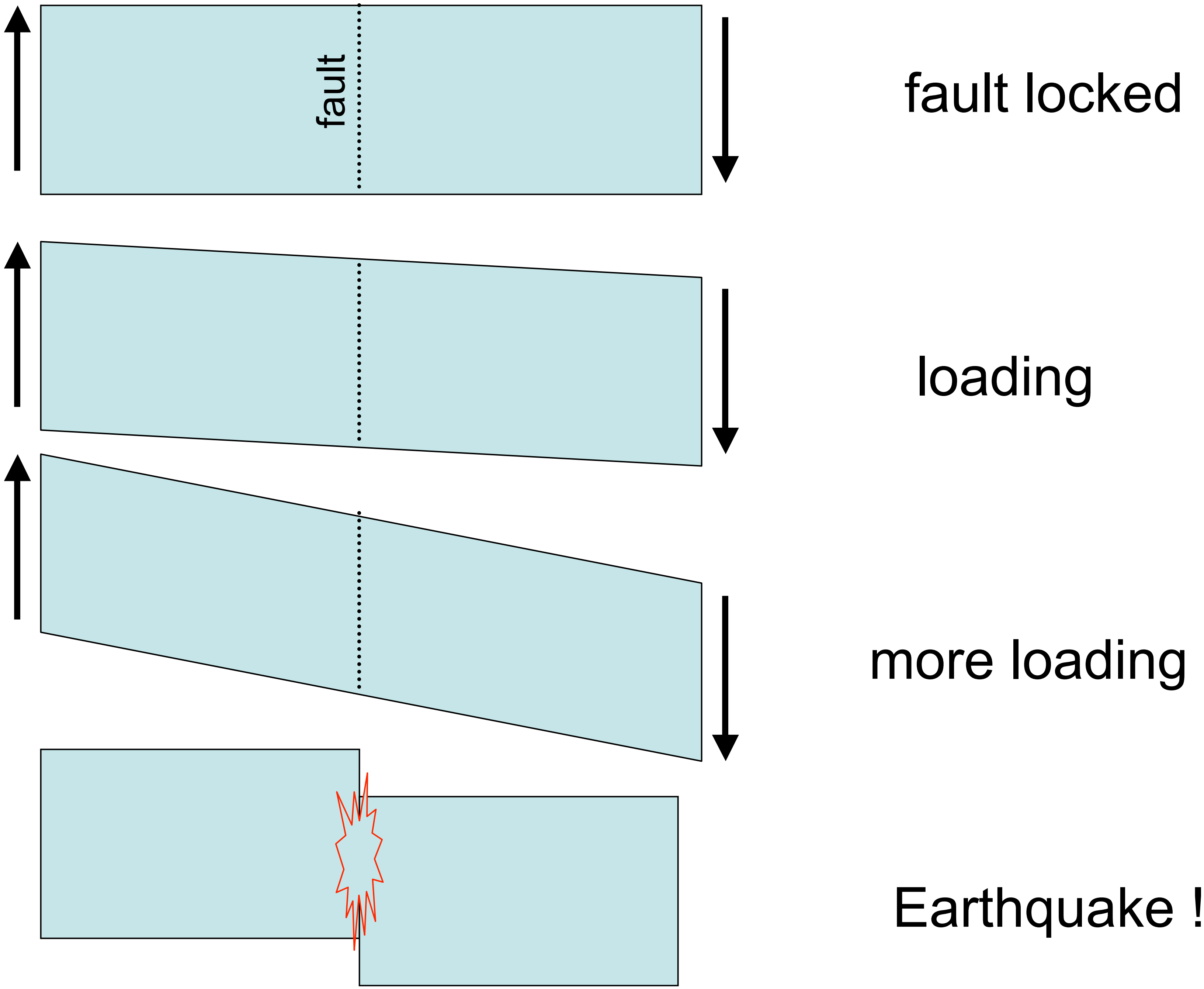
Stress builds up on fault as plates move

Stress exceeds strength of fault

Fault suddenly slips in an earthquake

Plate boundary moves

Fault locks again


fault
fault locked
loading
more loading
Earthquake !

Earthquake Repeat Time
Mean time interval between large earthquakes on a particular fault

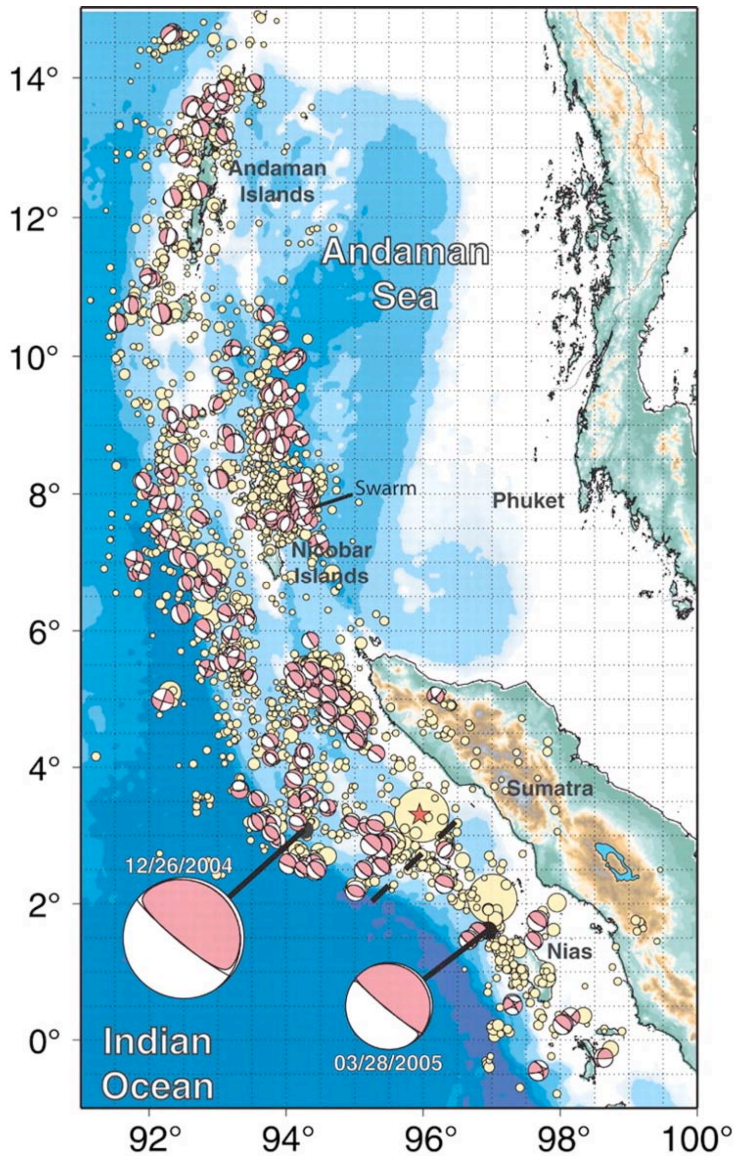
For San Andread
6 meters = 6000 mm

6000 mm / 35 mm/year
= 170 years

170 years of plate motion was released by this earthquake

Basis for believing that
The repeat time for
Such earthquakes is
About 200 years.

Aftershocks of Sumatra Dec 2004

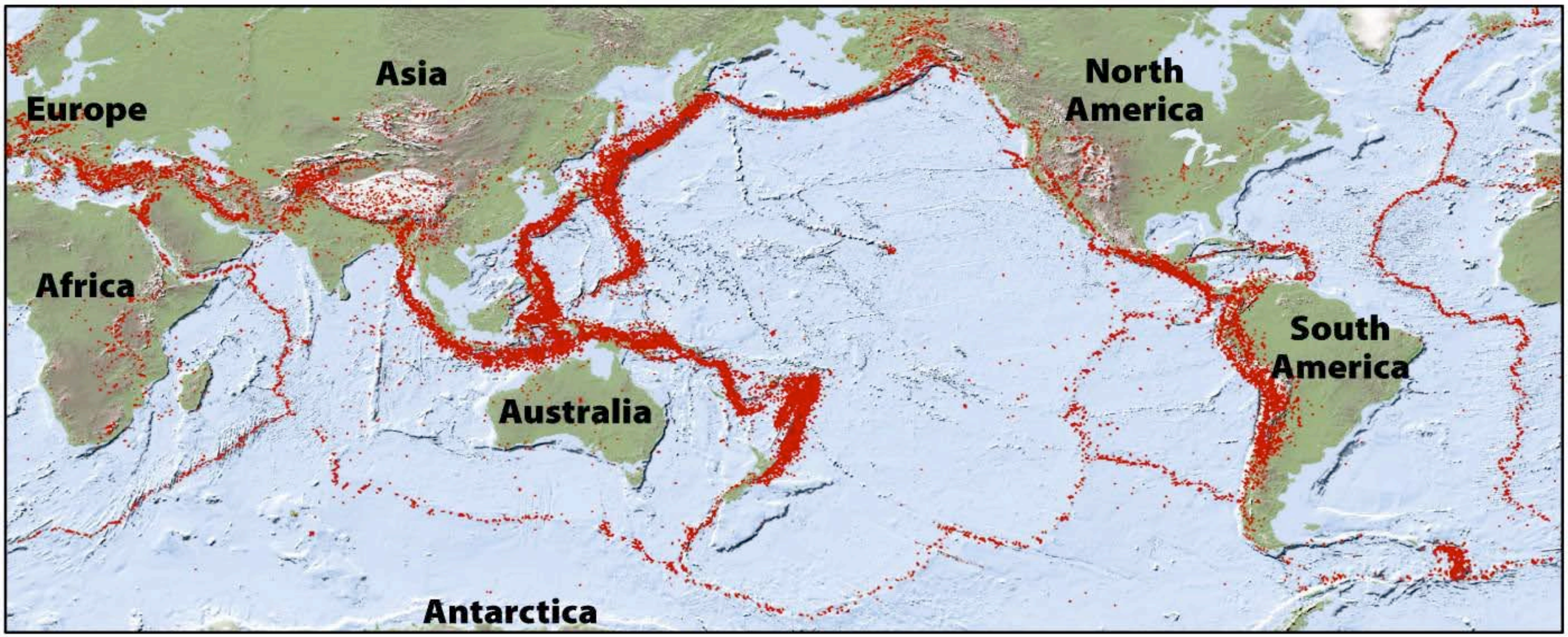


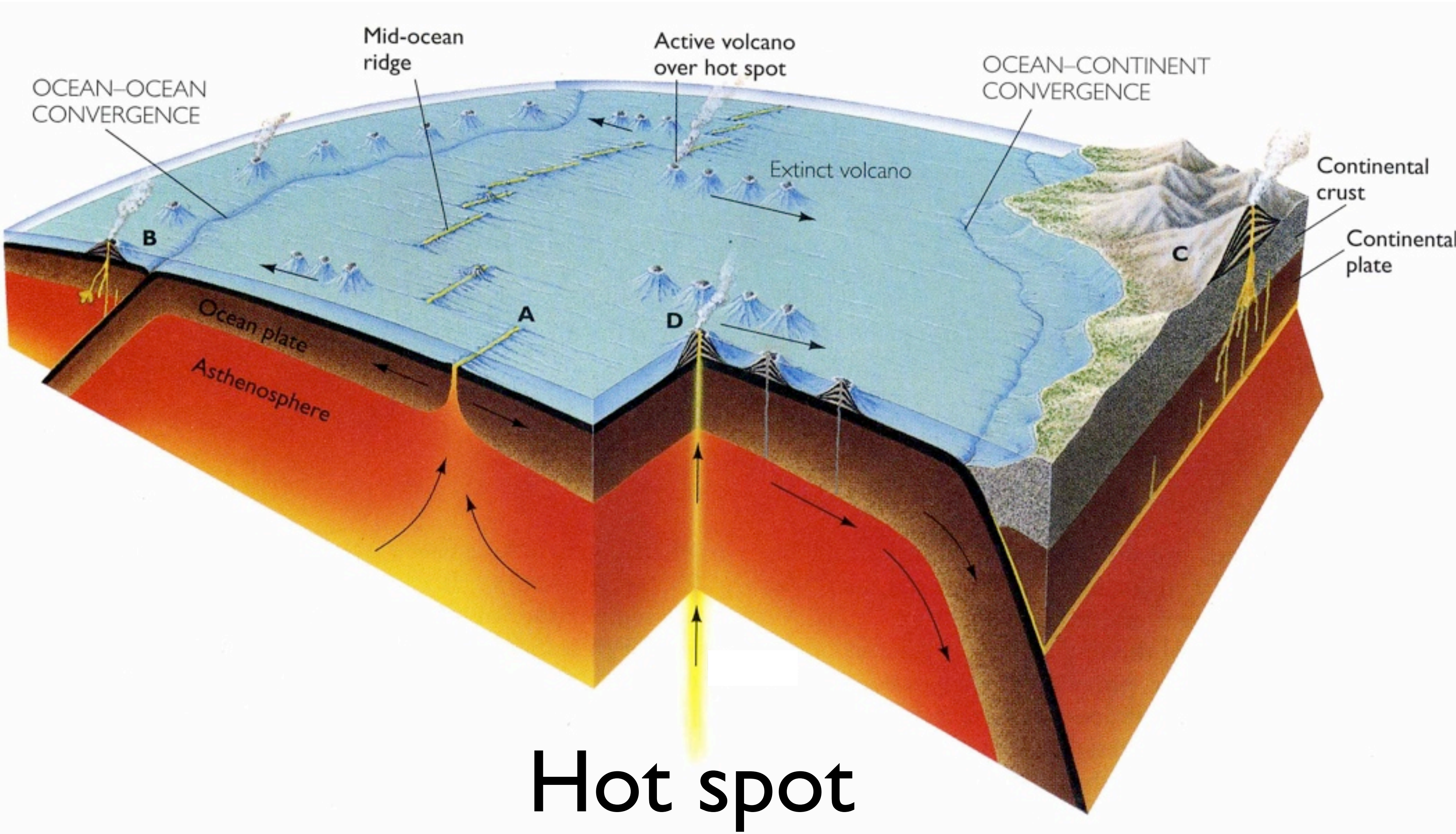
Lay et al, Science (2005)

Fig. 2. Map showing aftershock locations for the first 13 weeks after the 26 December 2004 earthquake from the NEIC (yellow dots, with radii proportional to seismic magnitude). Moment-tensor solutions from the Harvard CMT catalog (21) are shown for the 26 December 2004 and 28 March 2005 mainshocks (large solutions at bottom, with associated centroid locations) and aftershocks. Star indicates the epicenter for the 2004 rupture obtained by the NEIC. Dashed line shows the boundary between the aftershock zones for the two events.

Plate Boundaries

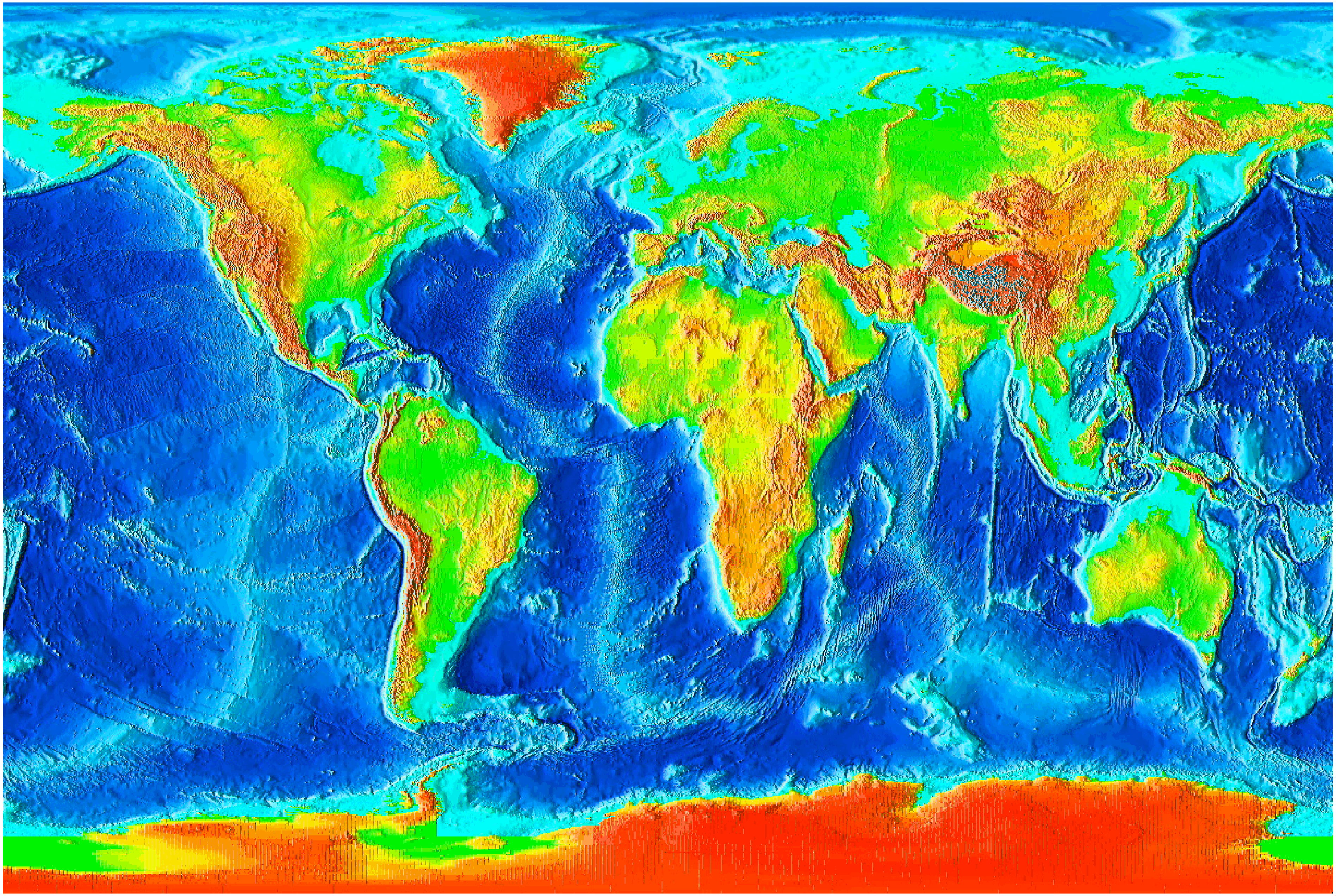
- Locations on Earth where tectonic plates meet.
  - Identified by concentrations of earthquakes.
  - Associated with many other dynamic phenomena.
- Plate interiors are almost earthquake-free.

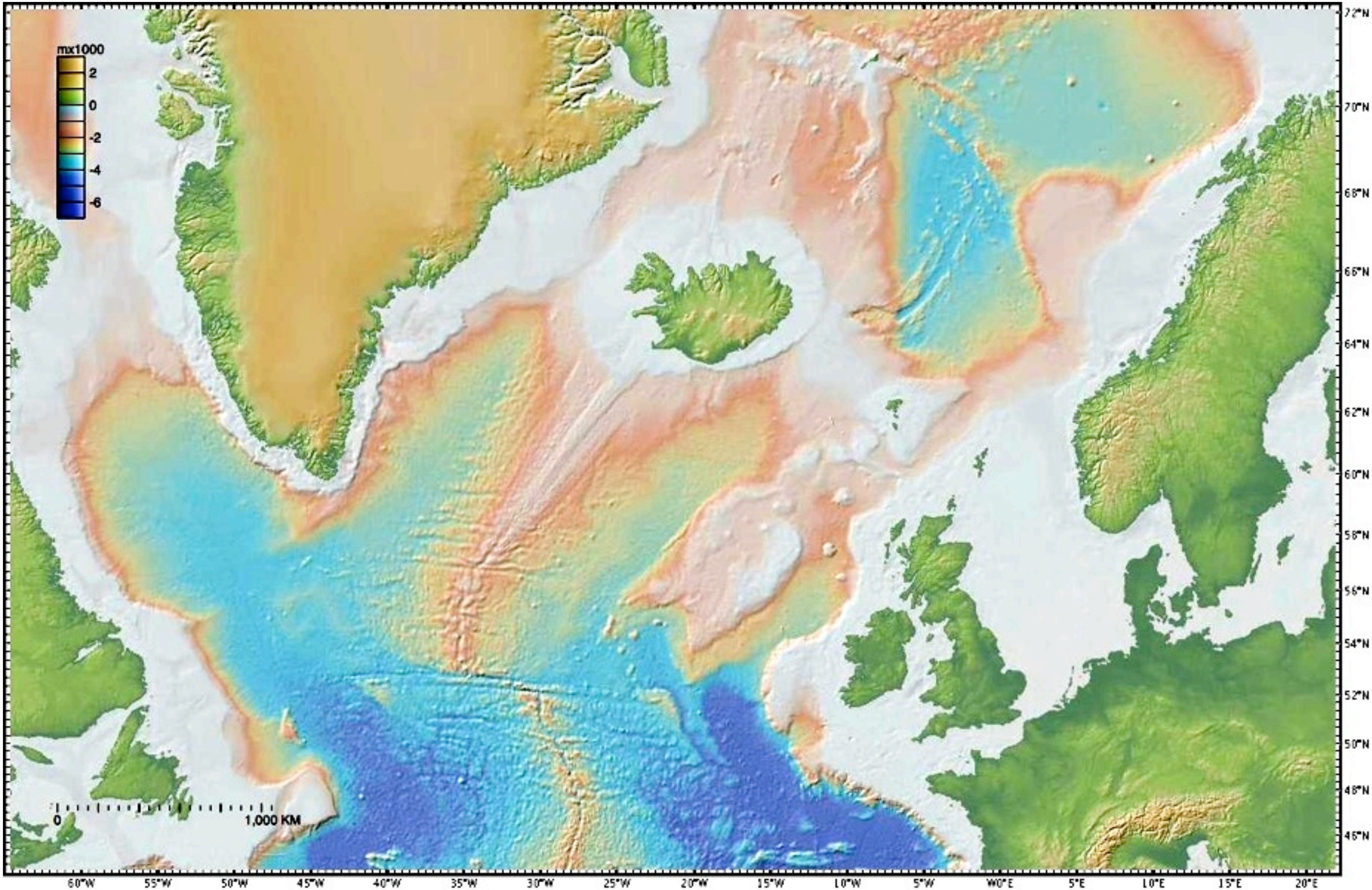


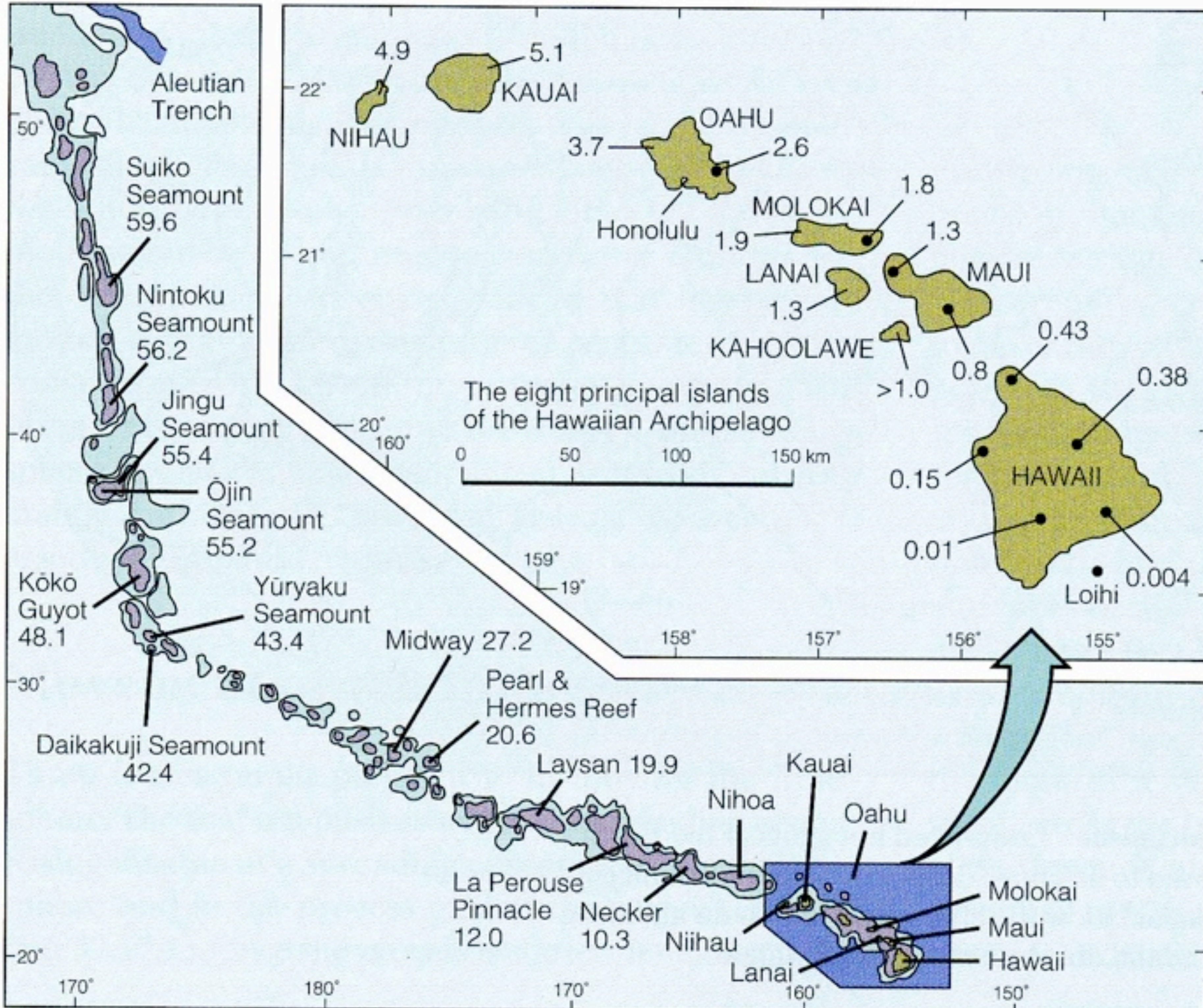

Mid-ocean ridge
Active volcano over hot spot
OCEAN–OCEAN CONVERGENCE
OCEAN–CONTINENT CONVERGENCE
Extinct volcano
Continental crust
Continental plate
B
C
A
D
Ocean plate
Asthenosphere

Hot spot

Hot Spots - independent of plates

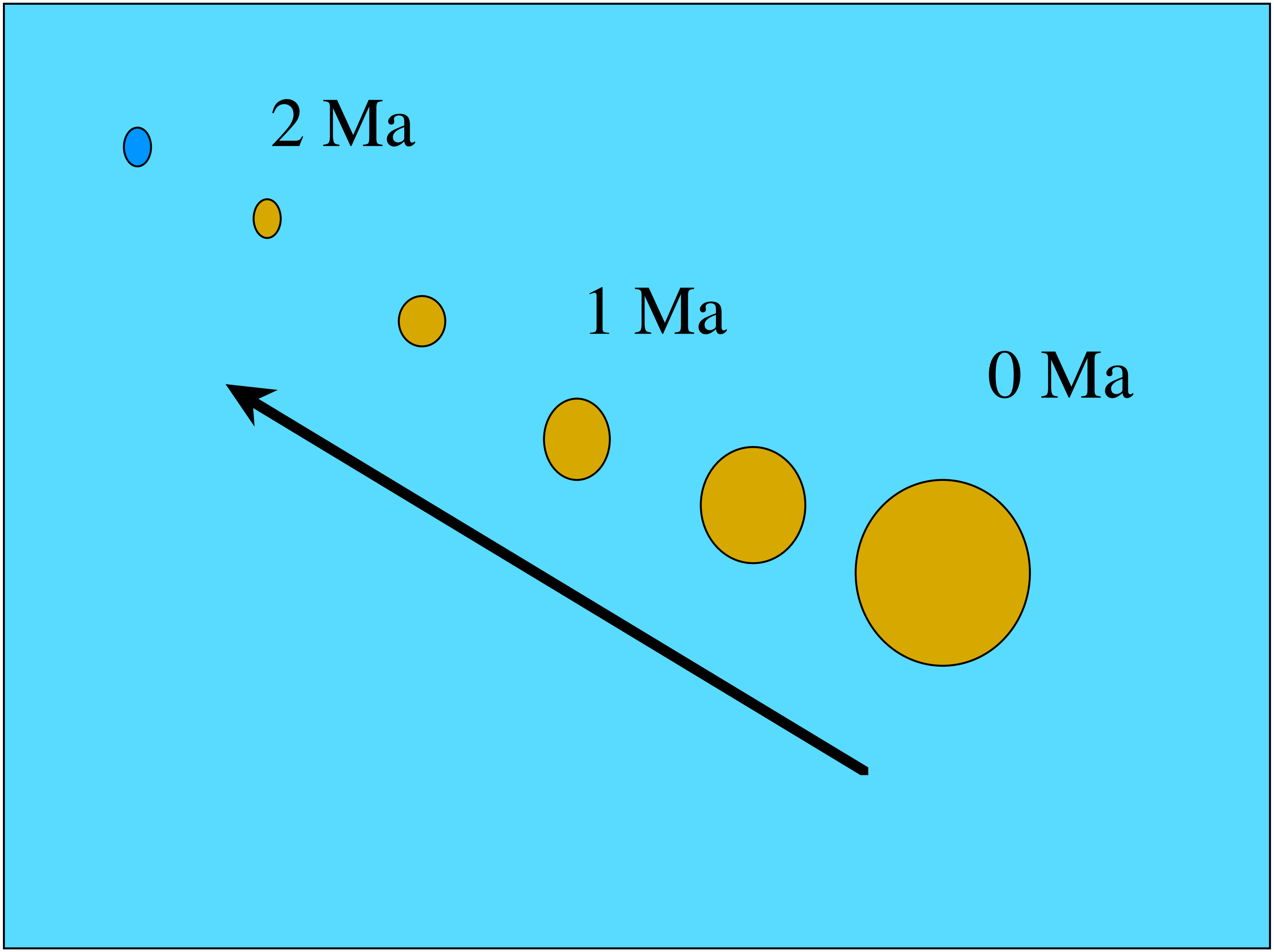



mx1000
2
0
-2
-4
-6
0
1,000 KM
72°N
70°N
68°N
66°N
64°N
62°N
60°N
58°N
56°N
54°N
52°N
50°N
48°N
46°N
60°W
55°W
50°W
45°W
40°W
35°W
30°W
25°W
20°W
15°W
10°W
5°W
W0°E
5°E
10°E
15°E
20°E

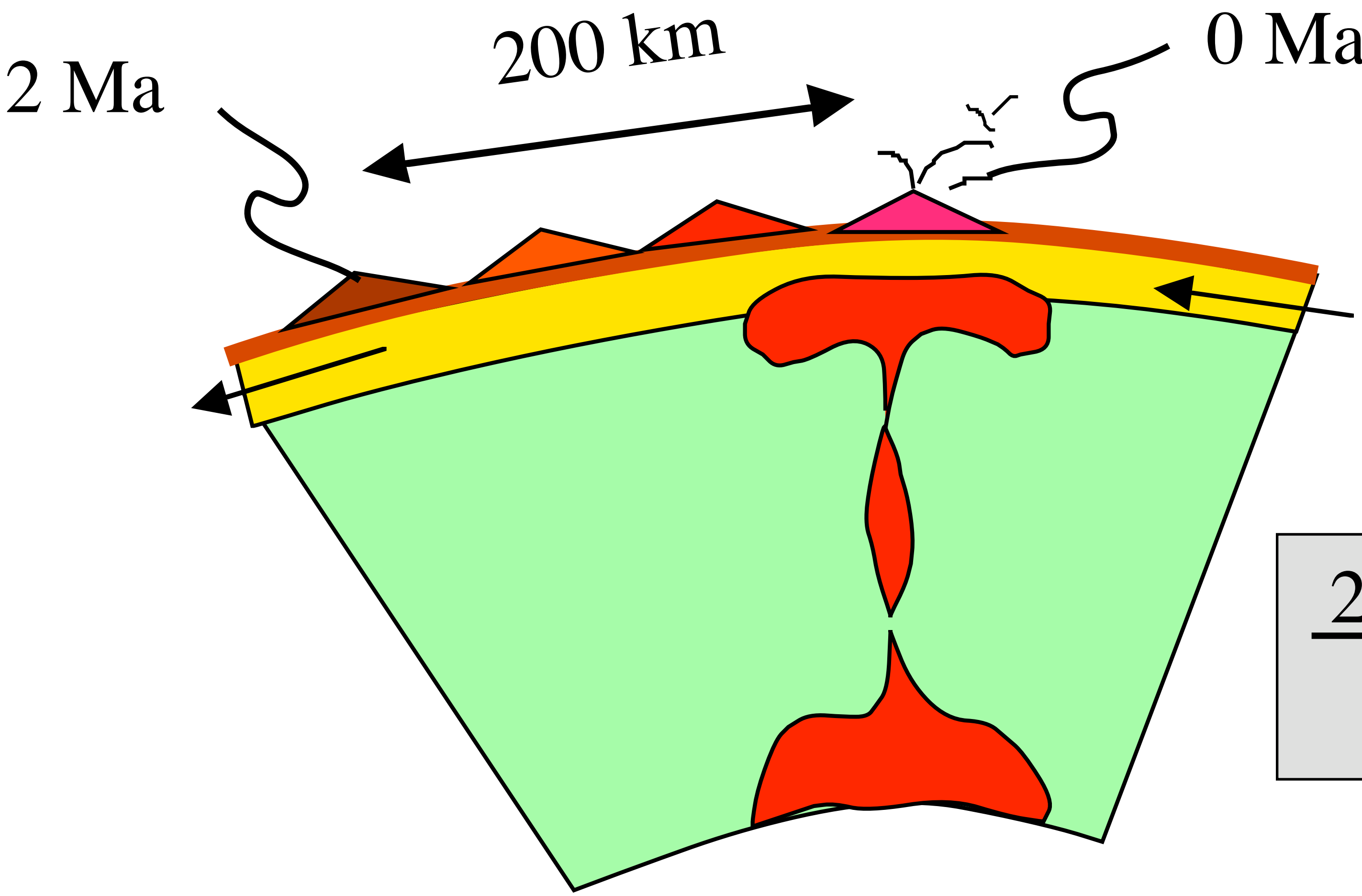


Aleutian Trench
Suiko Seamount 59.6
Nintoku Seamount 56.2
Jingu Seamount 55.4
Ōjin Seamount 55.2
Kōkō Guyot 48.1
Yūryaku Seamount 43.4
Daikakuji Seamount 42.4
Midway 27.2
Pearl & Hermes Reef 20.6
Laysan 19.9
La Perouse Pinnacle 12.0
Necker 10.3
Nihoa
Kauai
Oahu
Niihau
Molokai
Maui
Lanai
Hawaii
NIHAU
4.9
KAUAI
5.1
OAHU
3.7
2.6
Honolulu
MOLOKAI
1.9
1.8
LANAI
1.3
MAUI
1.3
0.8
KAHOOLAWE
>1.0
HAWAII
0.43
0.38
0.15
0.01
0.004
Loihi
The eight principal islands of the Hawaiian Archipelago
0 50 100 150 km
22°
21°
20°
19°
160°
159°
158°
157°
156°
155°
50°
40°
30°
20°
170°
180°
170°
160°
150°

Hot spot records plate motion



Hot spot records plate motion

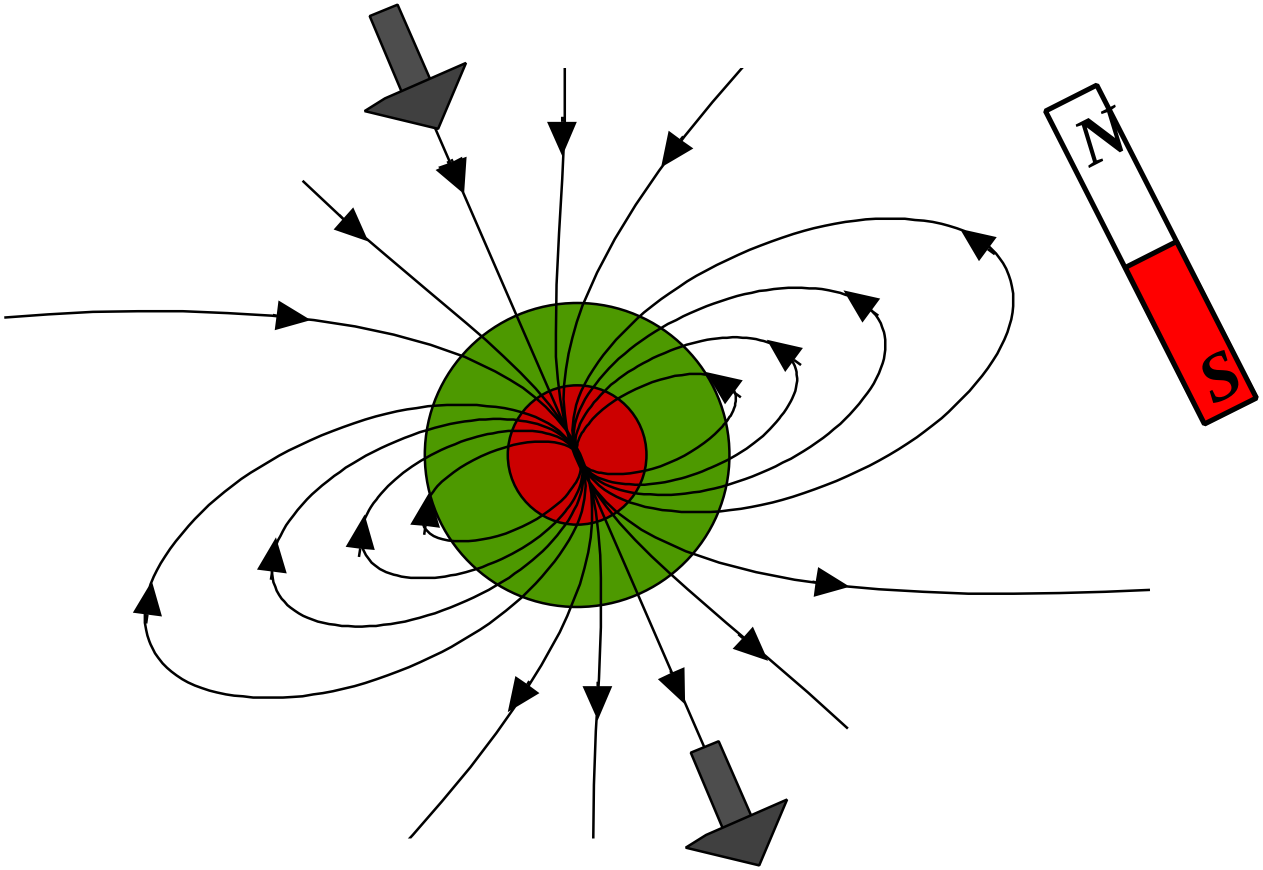


$$\frac{200\text{ km}}{2\text{ Ma}} = 10\text{ cm/}$$

Hot spot demo

The Earth's Magnetic Field

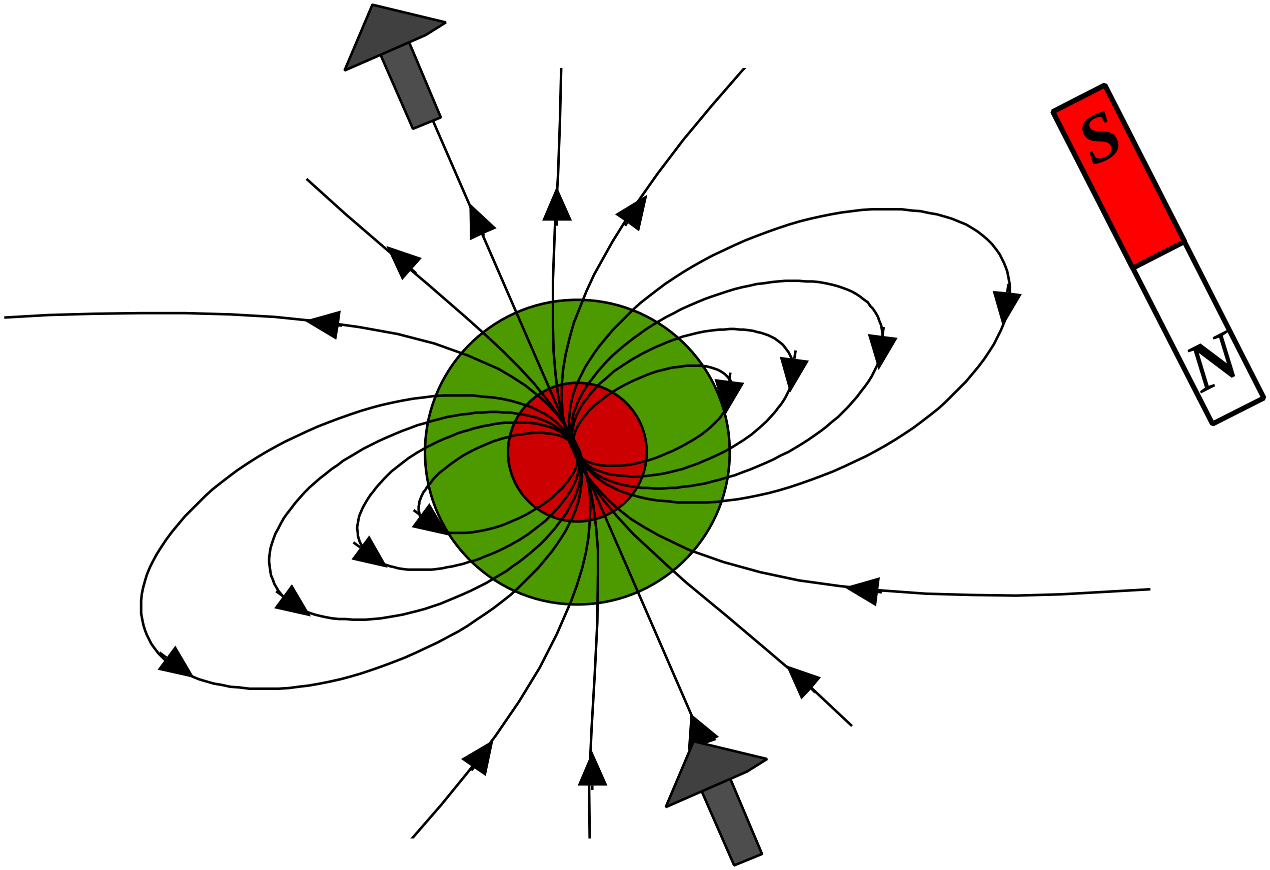
-- generated in core



Magnets line up with North magnetic pole

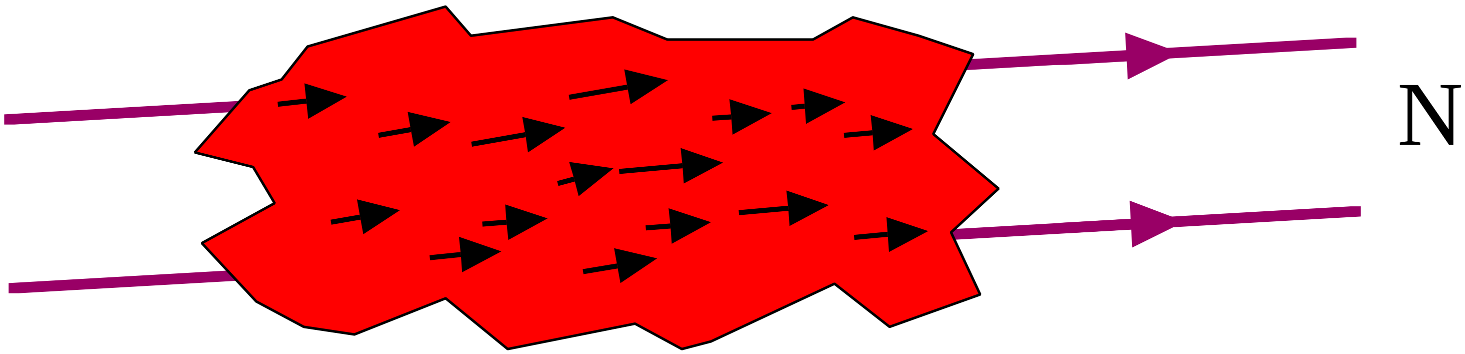
The Earth's Magnetic Field

REVERSES sometimes



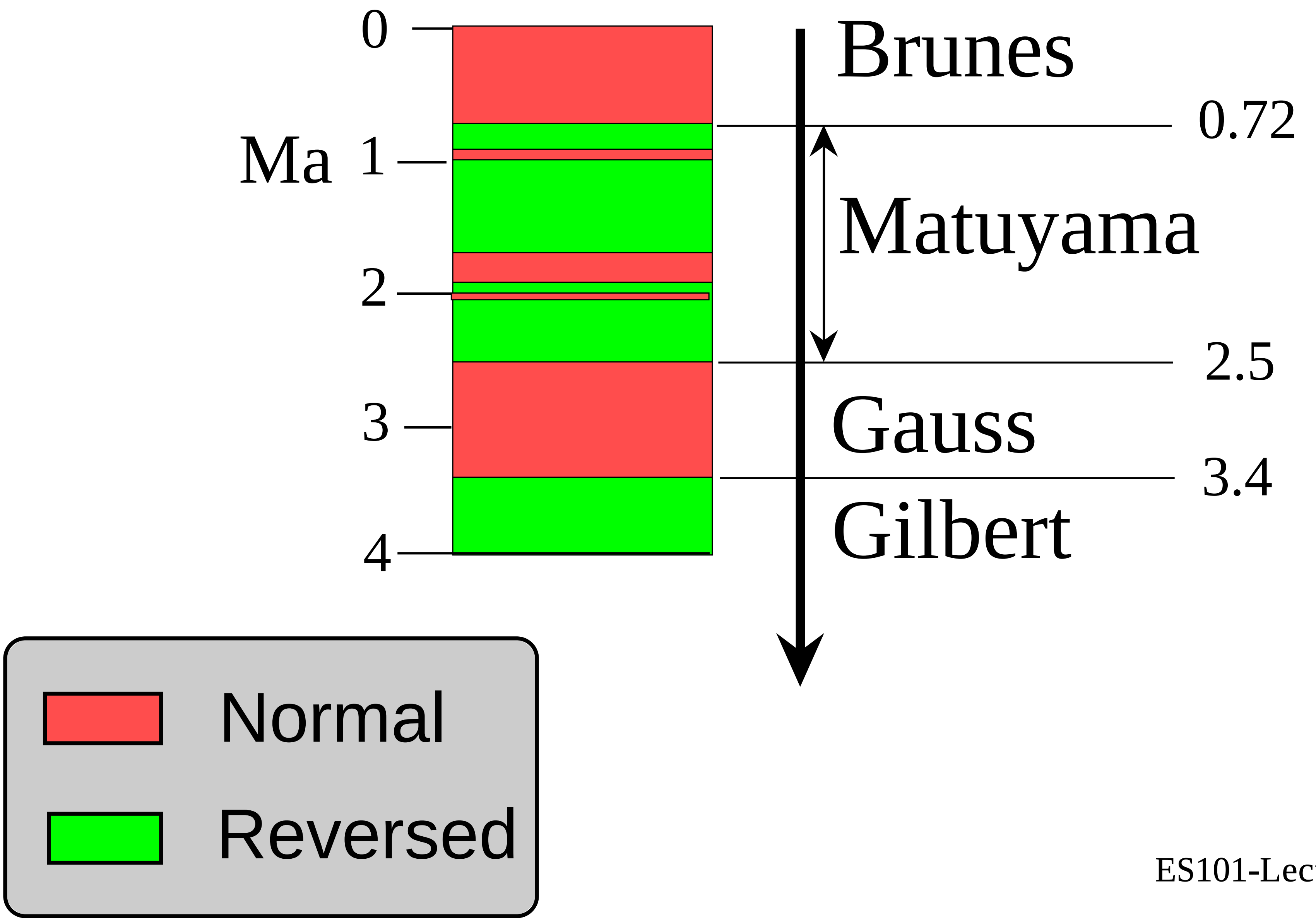
Rock Magnetism

Some minerals (magnetite) can be magnetized



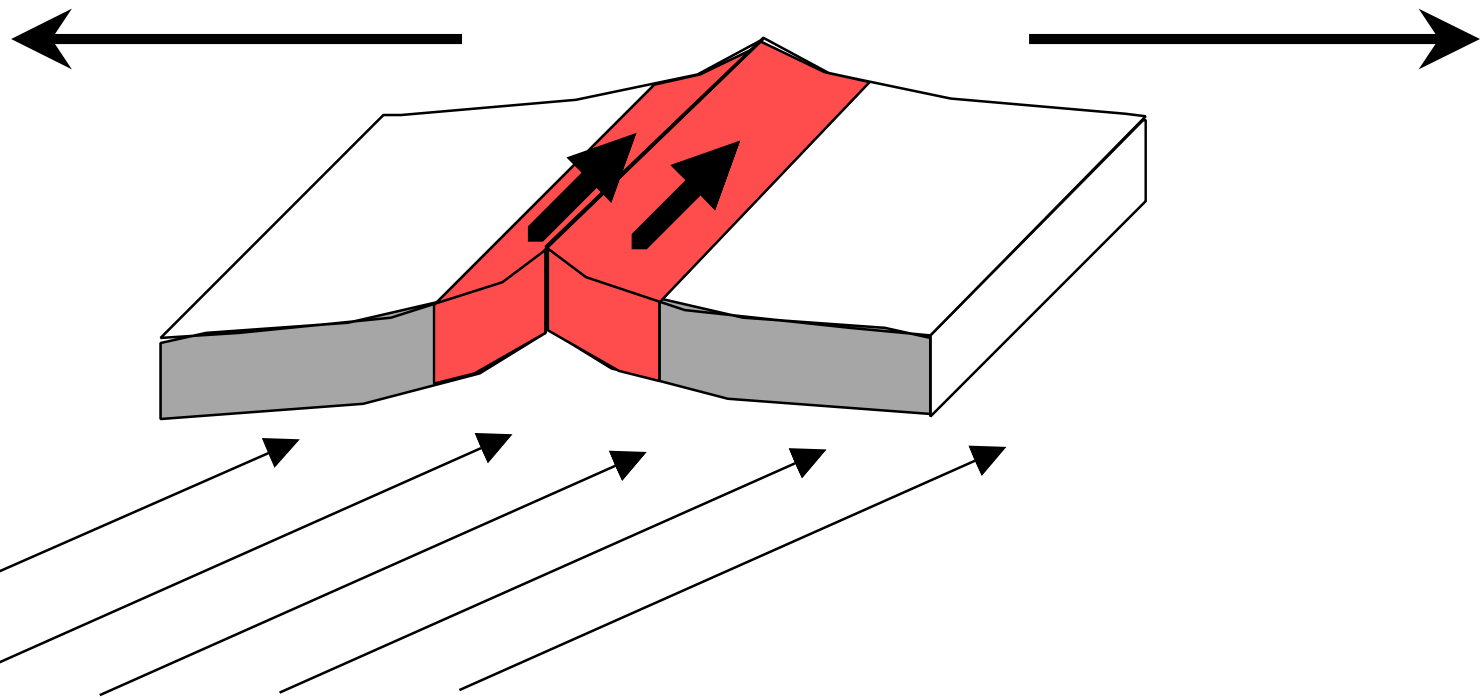
As magmas cool, magnetite crystals orient and point to north pole

Magnetic Reversal Time Scale



Basalt crust

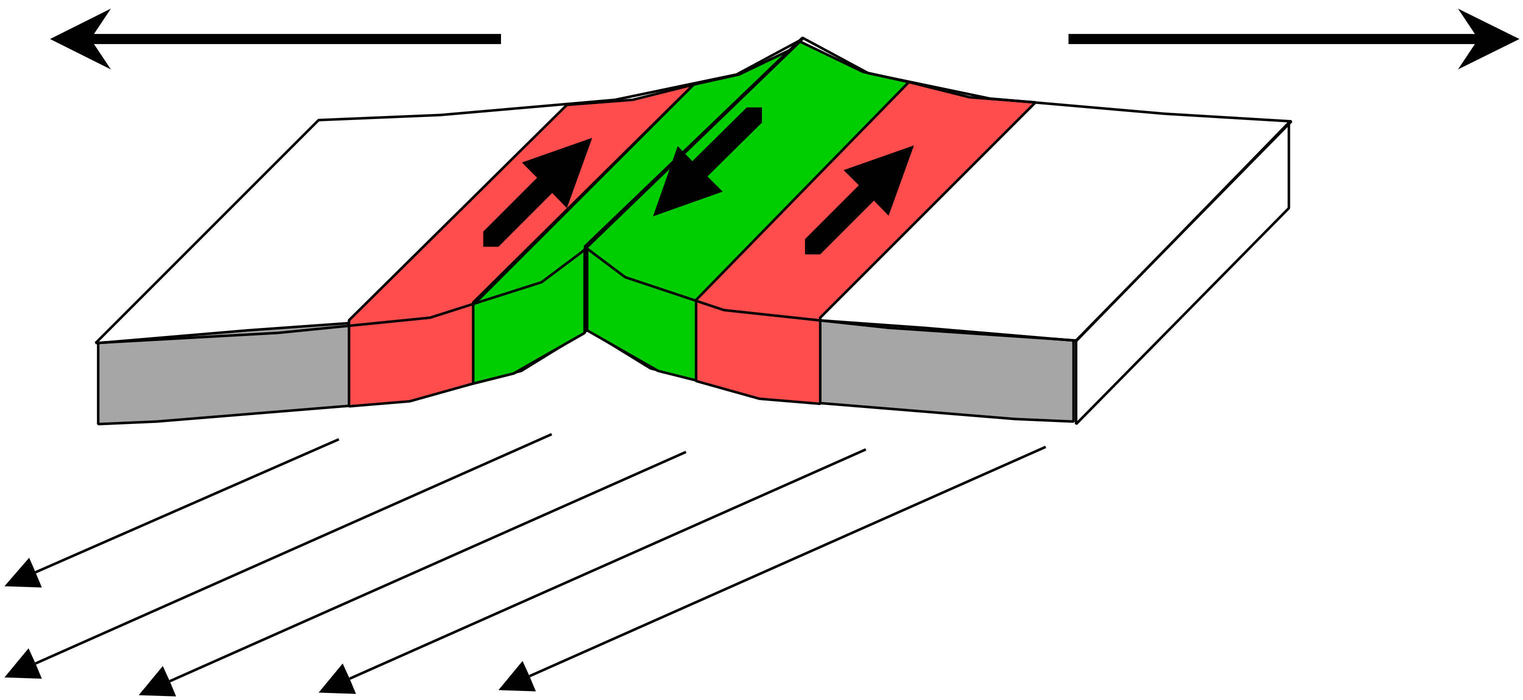
Forms at Ridge, cools, freezes Mag. Field



Plates Spread, New Basalt Crust Forms

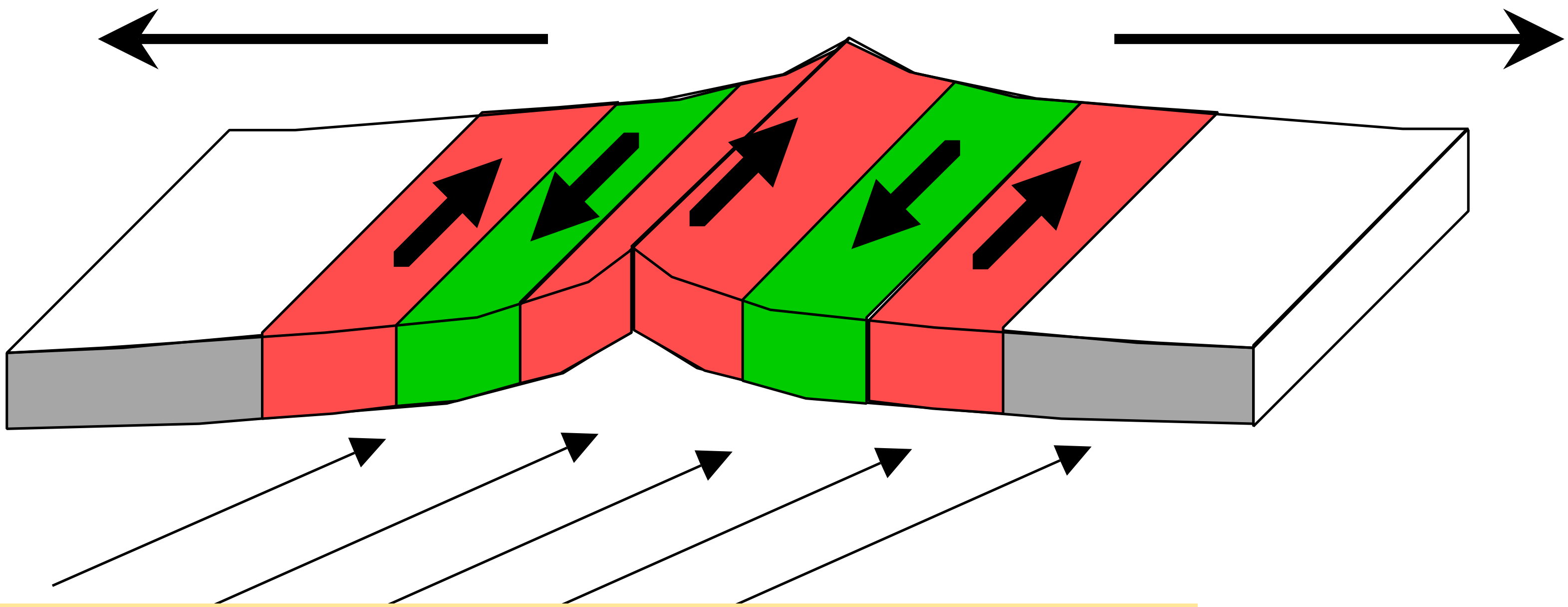
animation

Magnetic Field Flips "recorded"



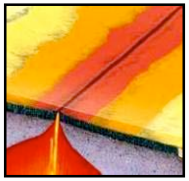
... leaving magnetic "stripes" on sea floor

Stripes are
• parallel to ridge • youngest at ridge



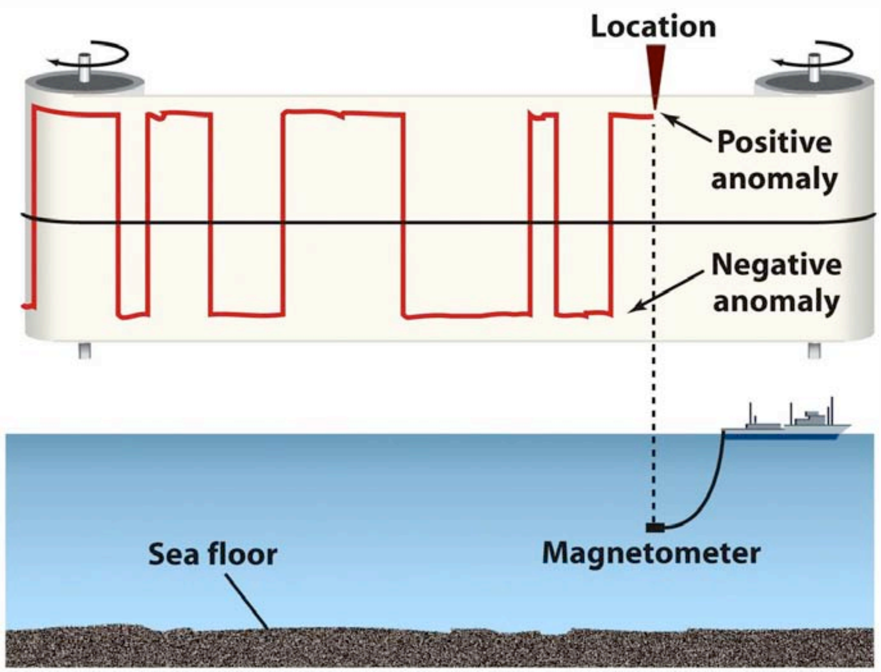
Vine-Mathews (1963):
Magnetic stripes give ages

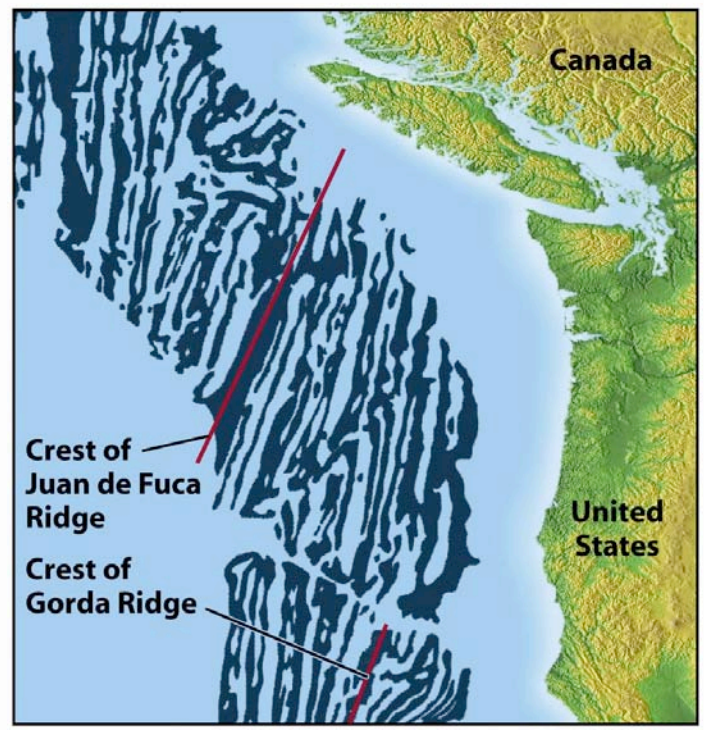
A Plate Tectonic strip chart



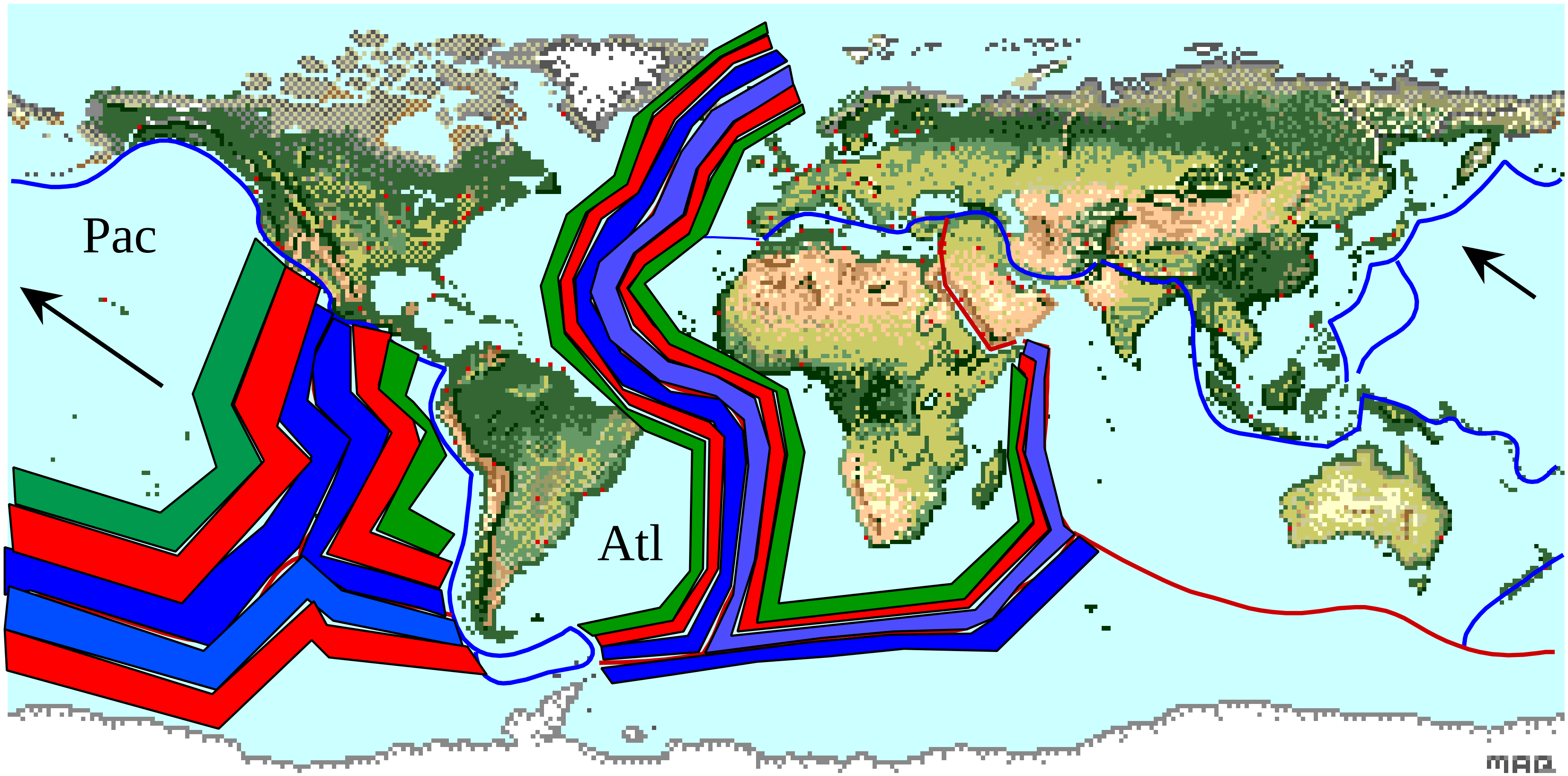
Magnetic Anomalies

- Towed magnetometers measure ocean crust.
- Magnetism oscillates perpendicular to the MOR.
- These variations are + and - magnetic anomalies.
- Anomalies are linear belts that parallel MOR.



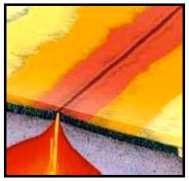


Magnetic Stripes "Date" the Seafloor



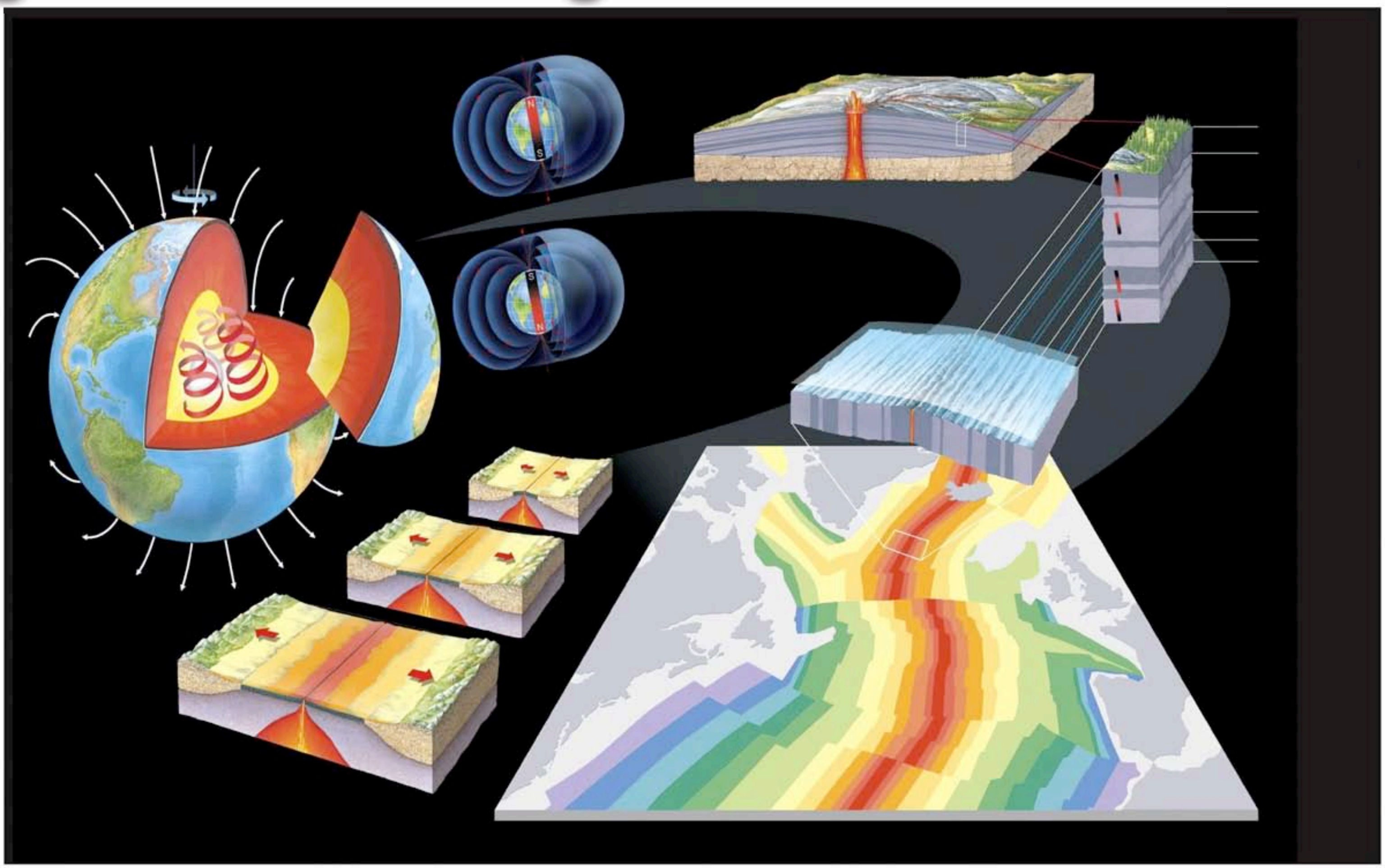
Global

Atlantic animation



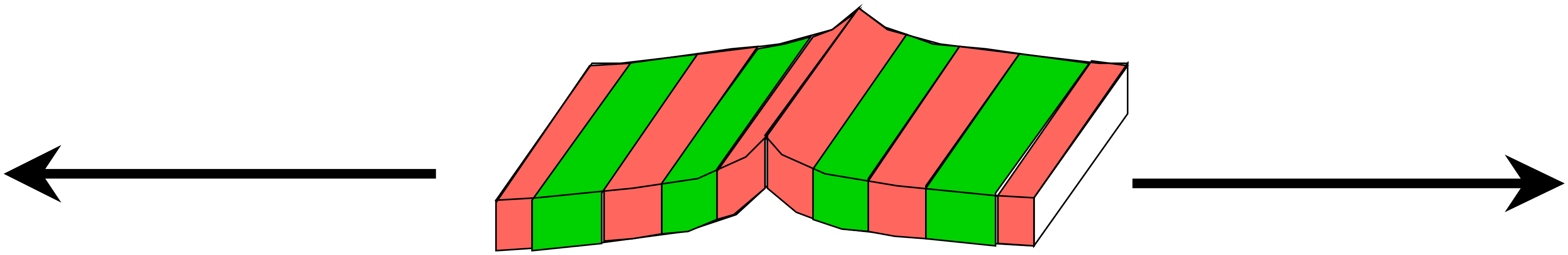
Sea-Floor Spreading

- Ages increase away from the MOR.
- Ages are “mirror images” across the MOR.

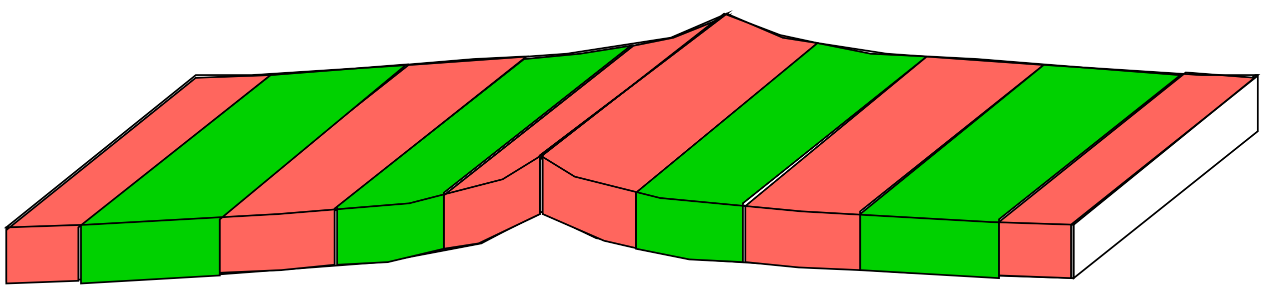


Spreading Rates vary from 3 to 16 cm/yr

Slow spreading: Atlantic

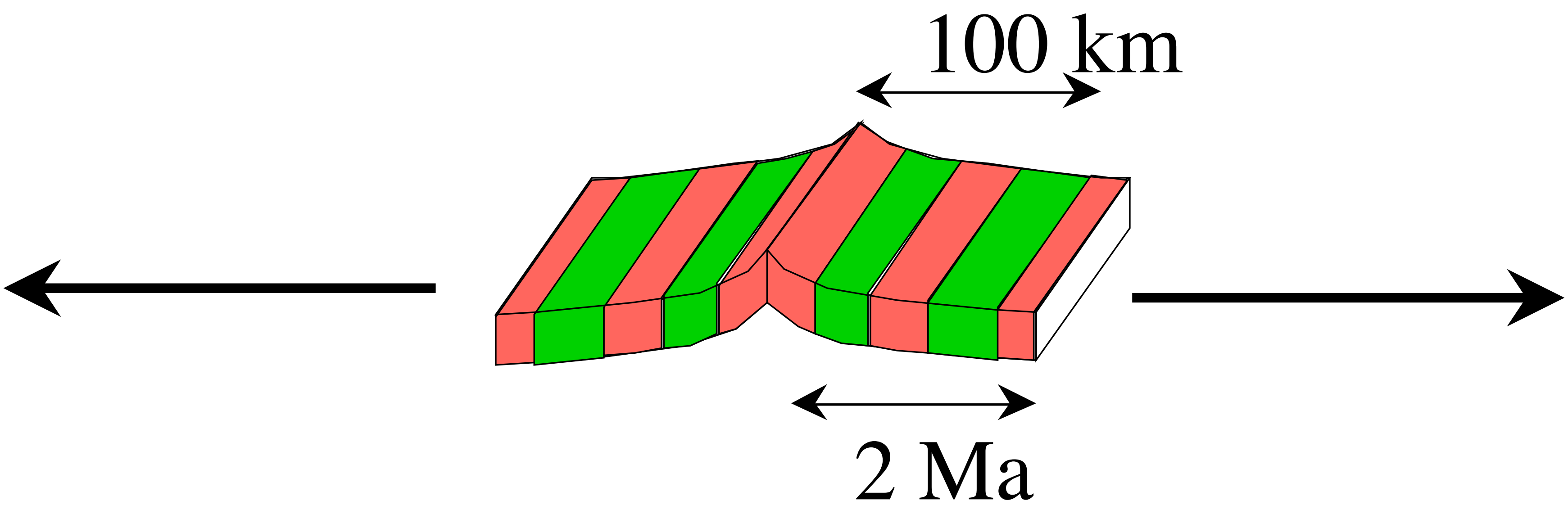


Fast spreading: East Pacific Rise



how do we know?

Magnetic Stripes!



= 100 km per 2 Ma = 50 km/Ma

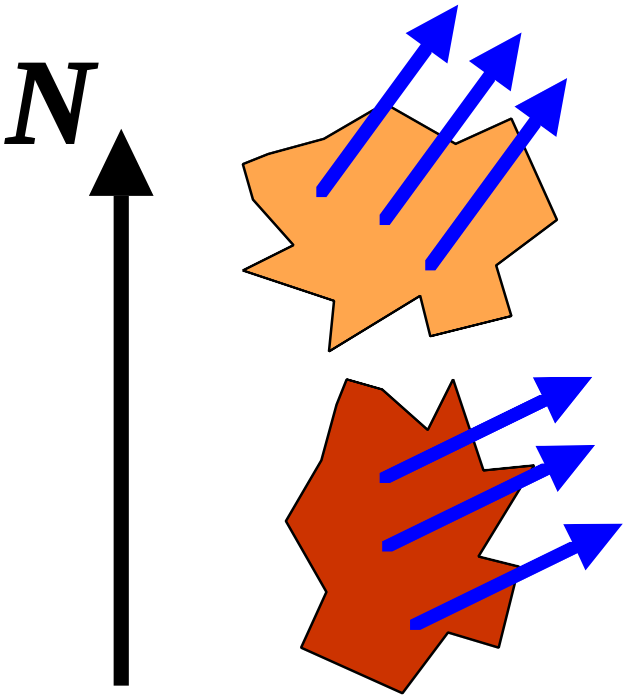
= 5 cm/yr

half-spreading rate; full = 10 cm/yr

Paleomagnetism:
Evidence for continental drift

Some rocks retain magnetic field at formation

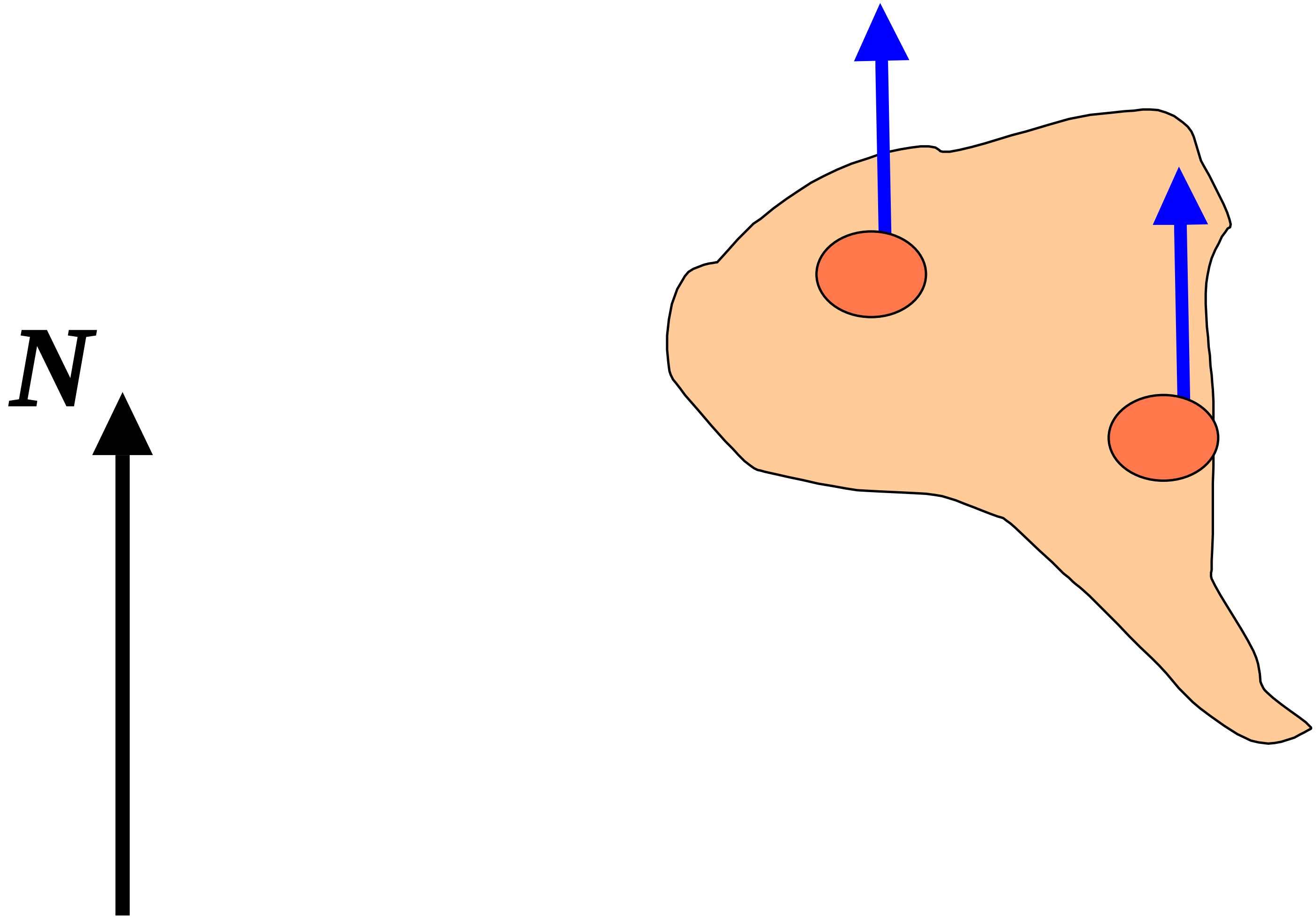
(cooling, sedimentation, ...)



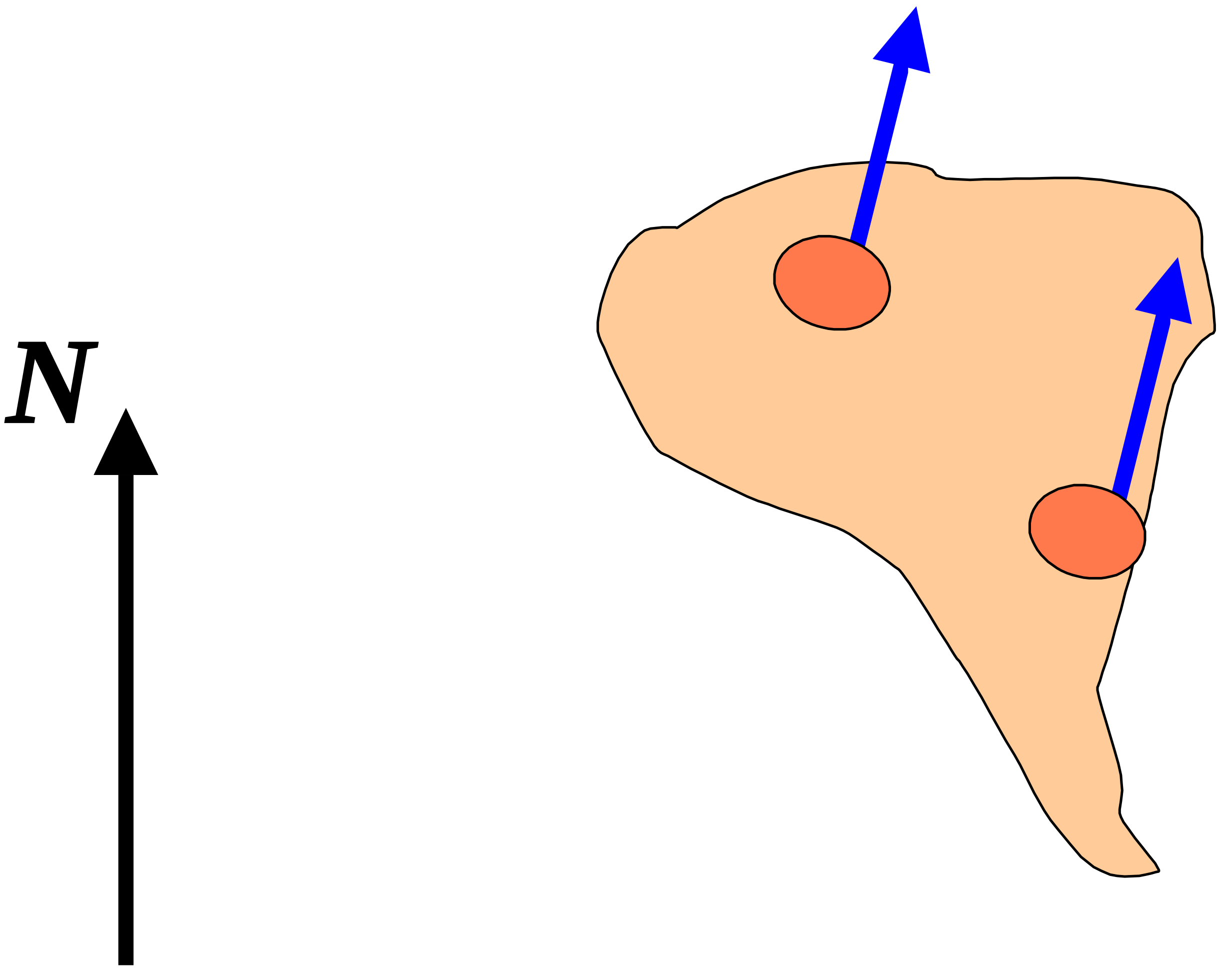
Old rocks: field does not point to North pole

why not?

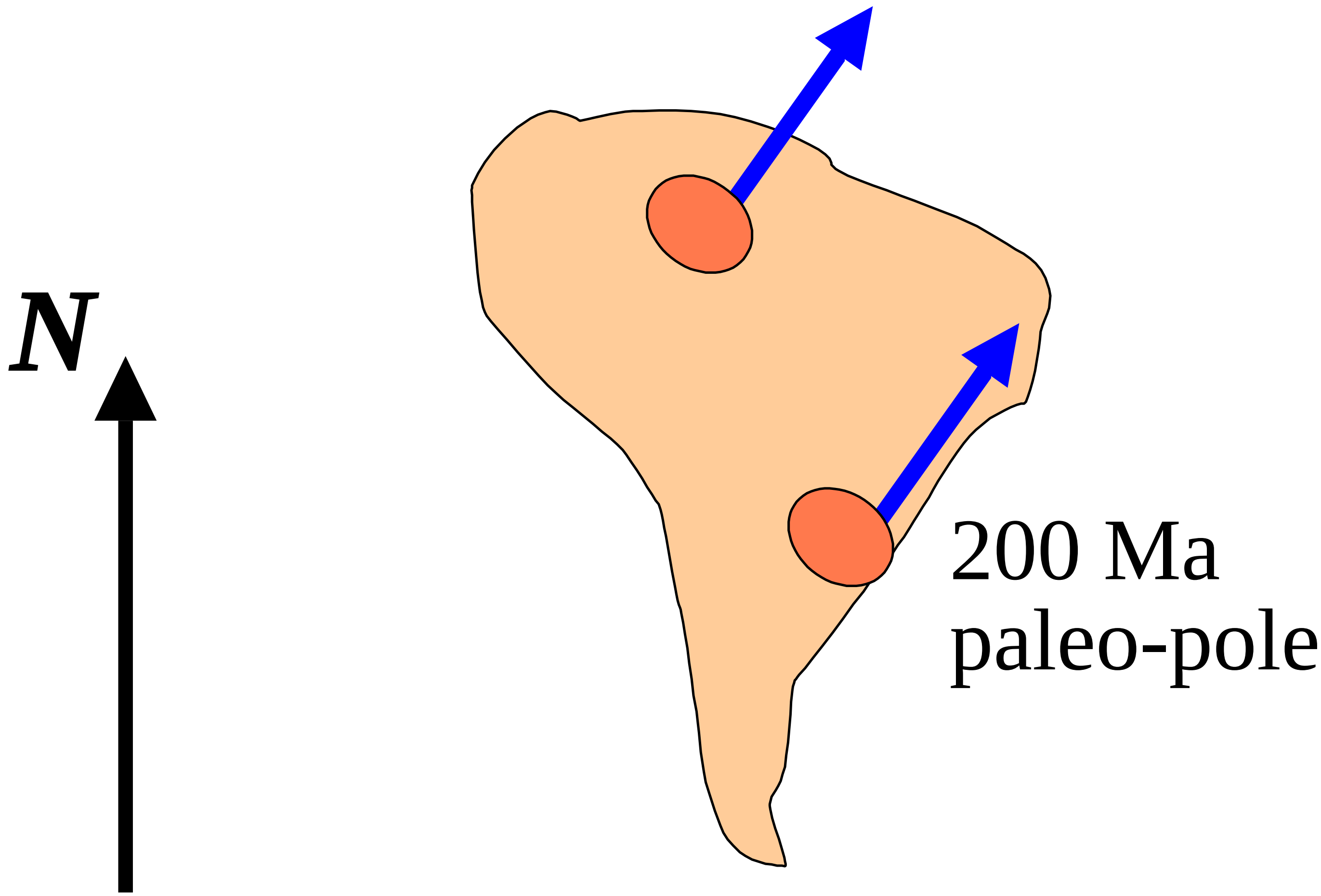
200 Ma



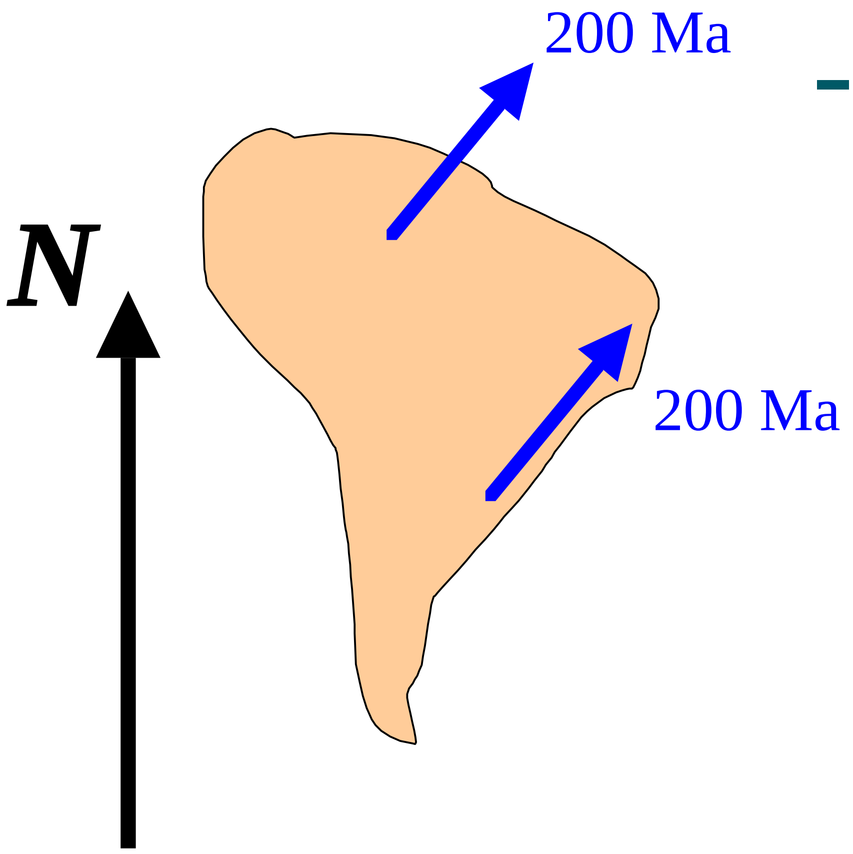
100 Ma



Today



"paleo-pole"



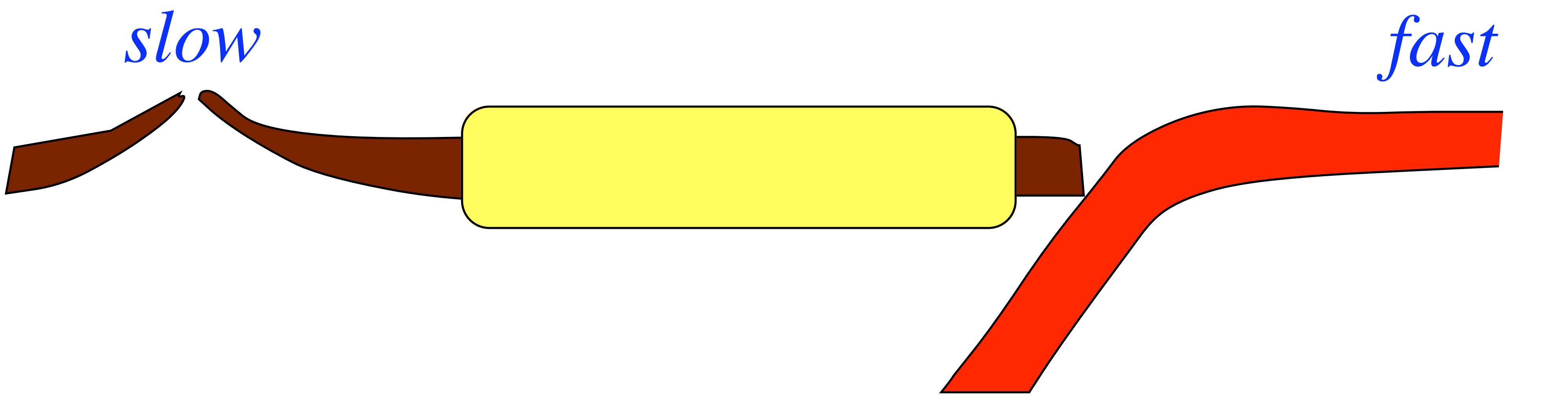
--> Plates moved!

-> A method for reconstructing continental drift

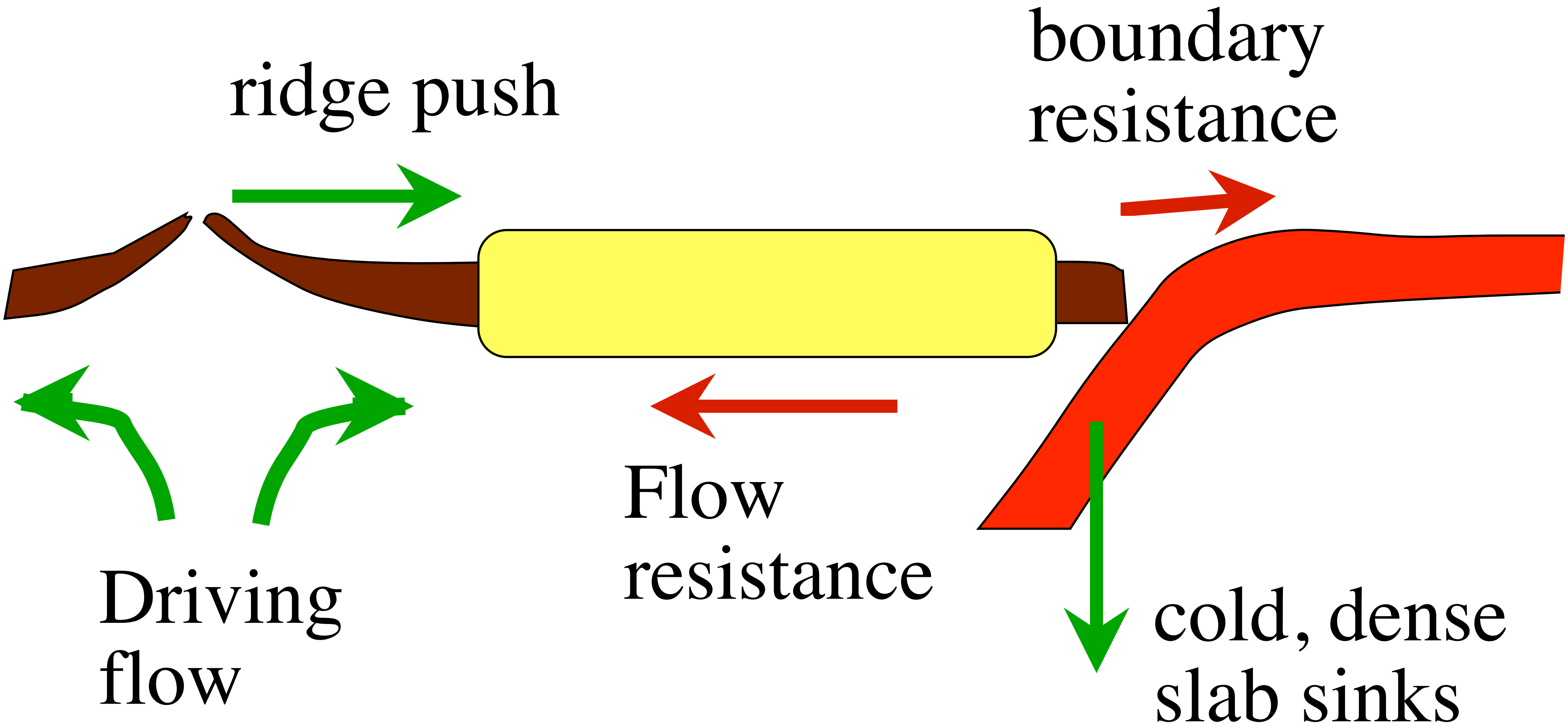
Why are some slow, some fast?

Plates with slabs are fast
(Pacific, Nazca)

Plates with continents are slow
(Africa, Eurasia, Americas)



What are possible Driving Forces?

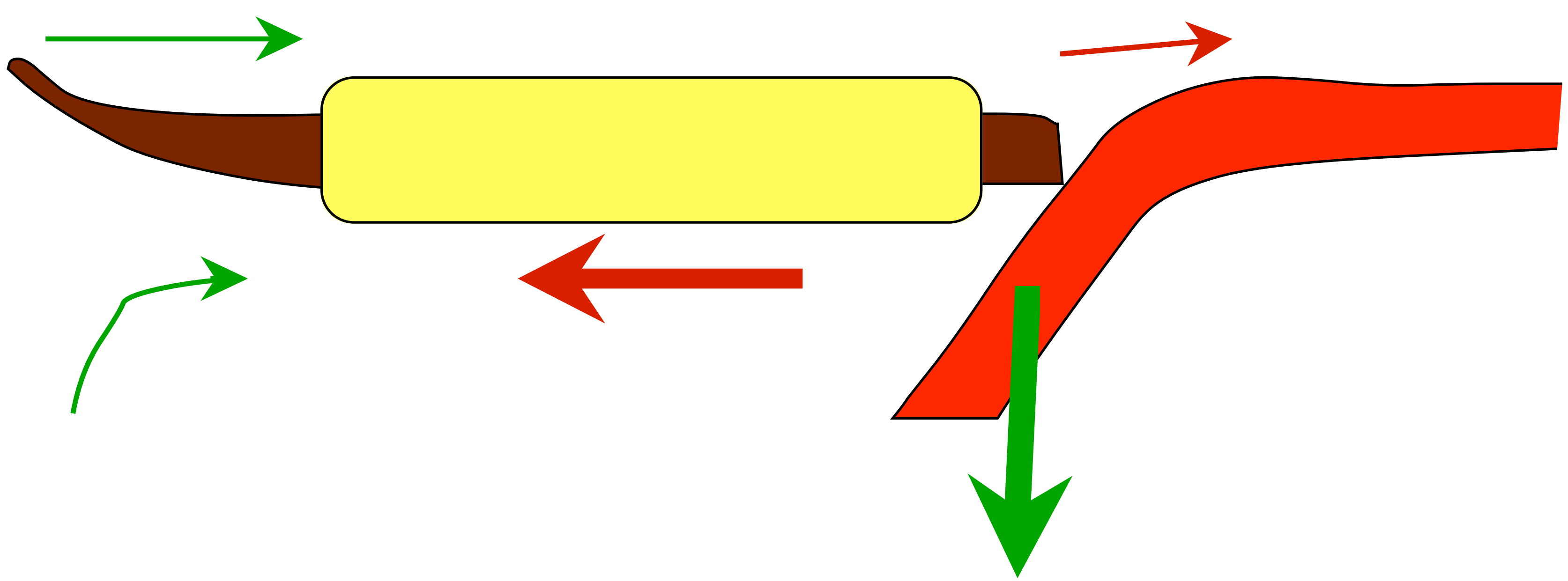


plates with slabs are fast:

dense slab drives motion

plate with continents are slow:

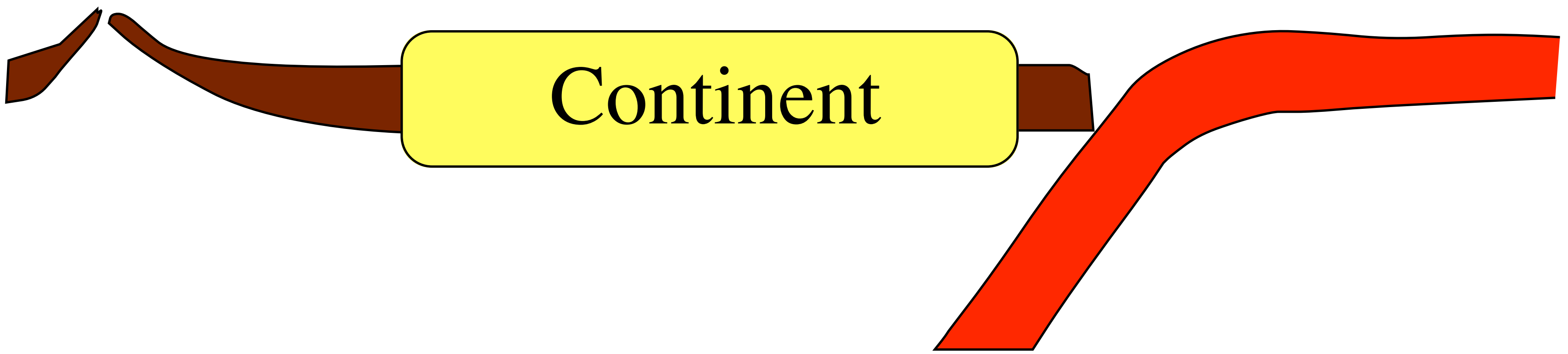
continents resist flow



Continental Tectonics

continent = a passenger

bump and grind



oldest oceanic crust = 170 Ma

oldest continental crust = ??

FIGURE 25.11. Deflection of a plumb bob by a pyramid on a plain.

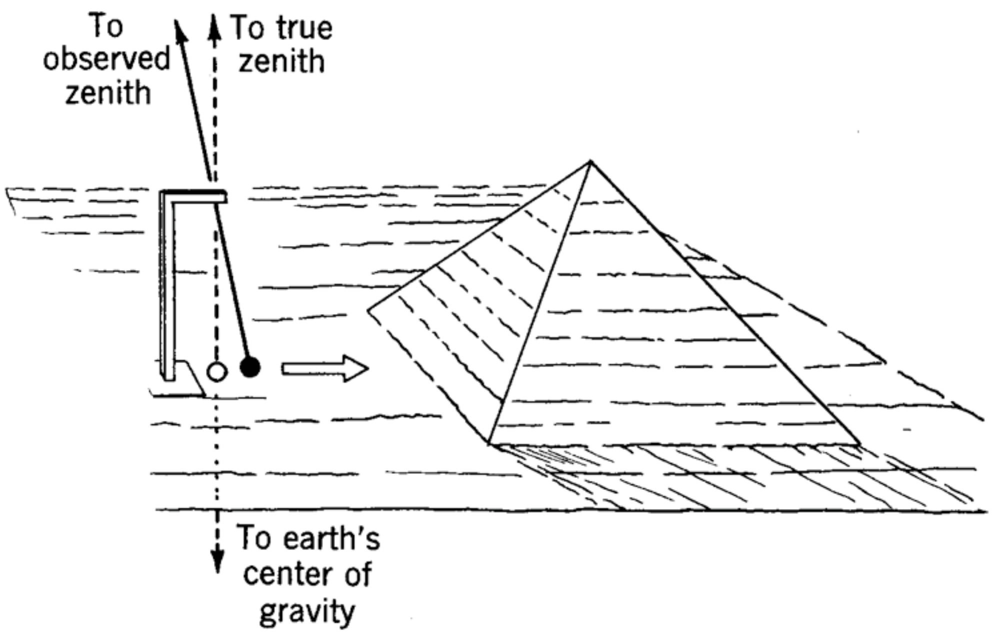


FIGURE 25.12. Attraction of The Himalaya for a plumb bob on the Gangetic plain is not as great as might be expected for so large a mountain mass.

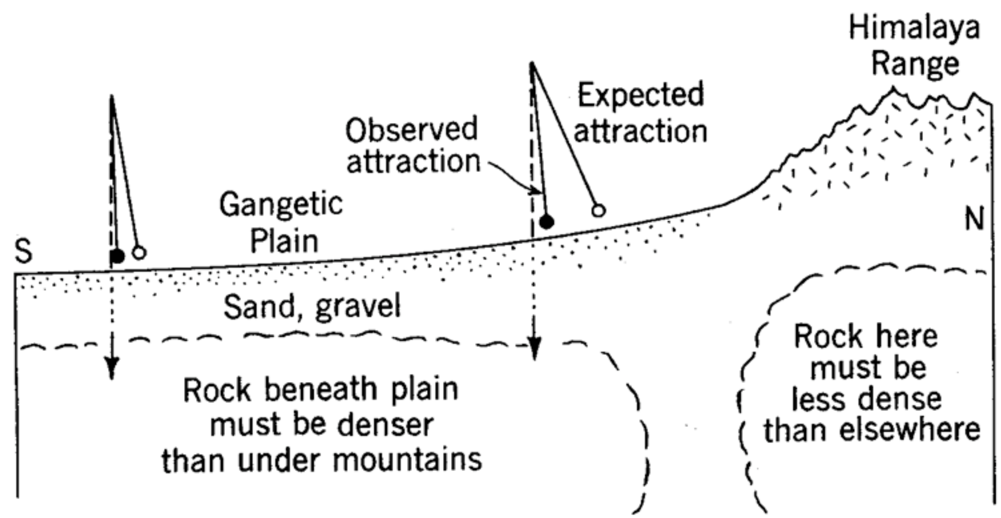


FIGURE 25.13. The Airy hypothesis of mountain roots is suggested by the equilibrium positions of blocks of the same density.

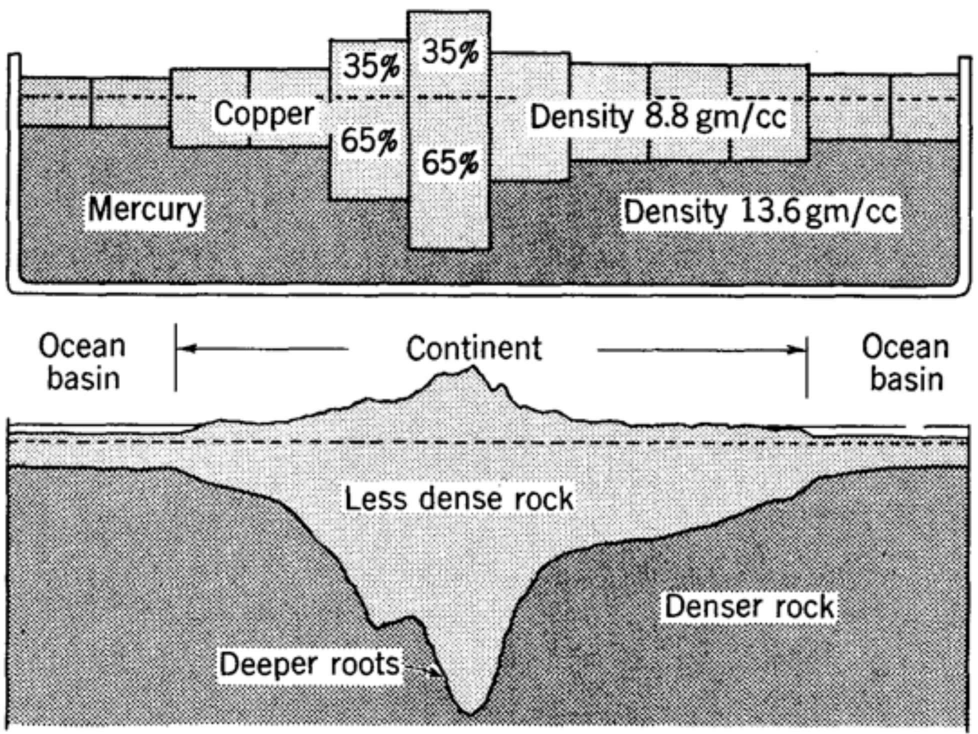


FIGURE 25.14. According to the Pratt hypothesis, crustal elements have different densities.

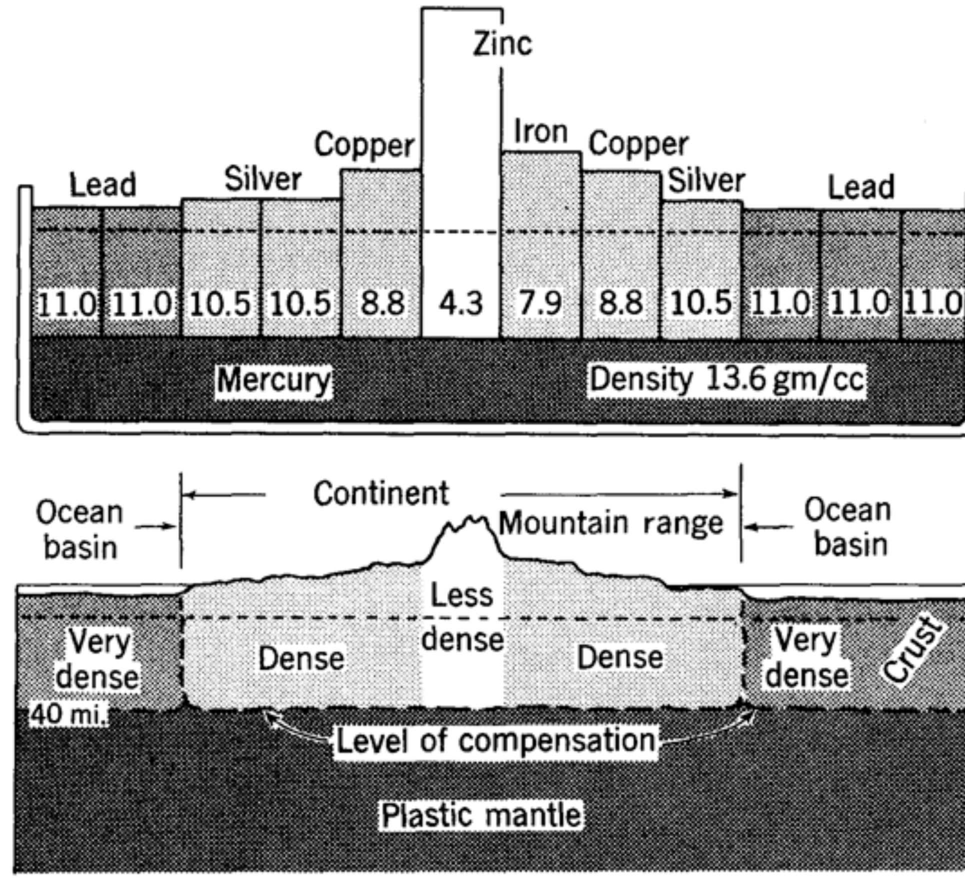
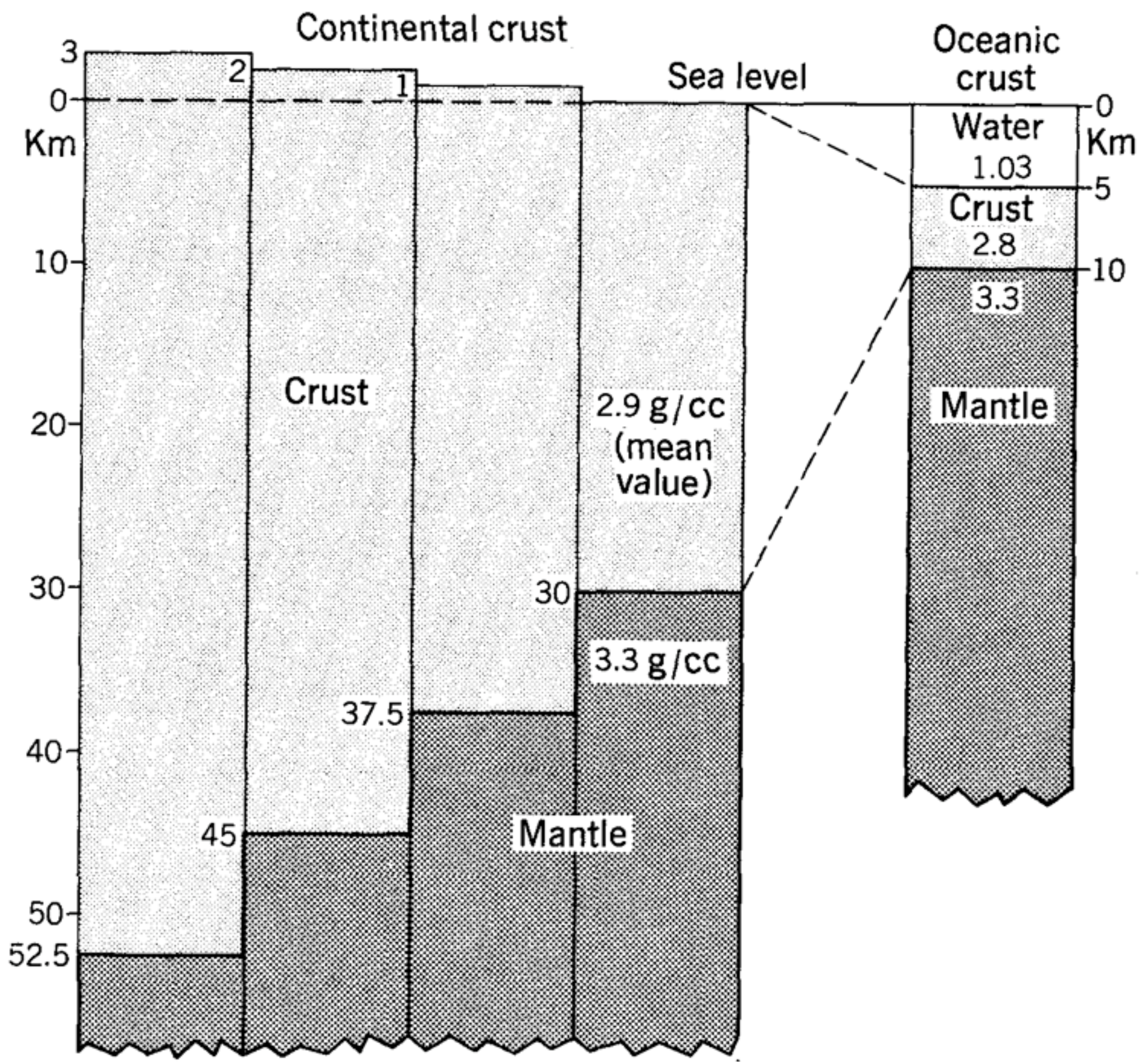


FIGURE 25.16. Simplified Airy isostatic model of crust. [Based on parameters suggested by G. P. Woollard (1966), *The Earth Beneath the Continents, Geophysical Monograph 10,* Washington, D.C., Amer. Geophys. Union, p. 563.]



Density, buoyancy, and isostasy

- Crust is less dense than mantle
- Lithospheric mantle is colder and denser than asthenospheric mantle
- As the lithosphere is rafted away from the ridge axis, it thickens and the seafloor deepens because of isostasy

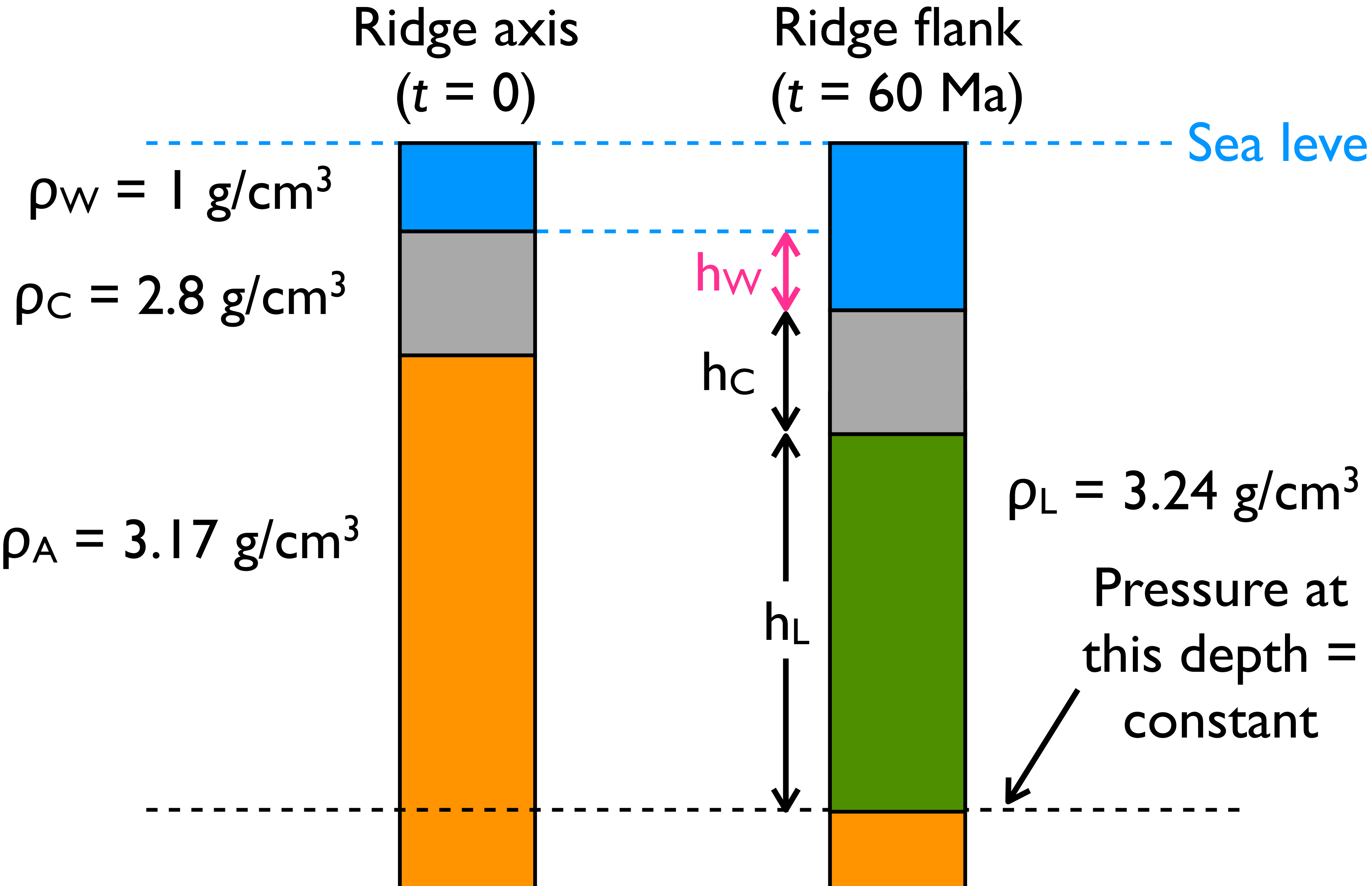
Density and temperature

- Coefficient of thermal expansion α

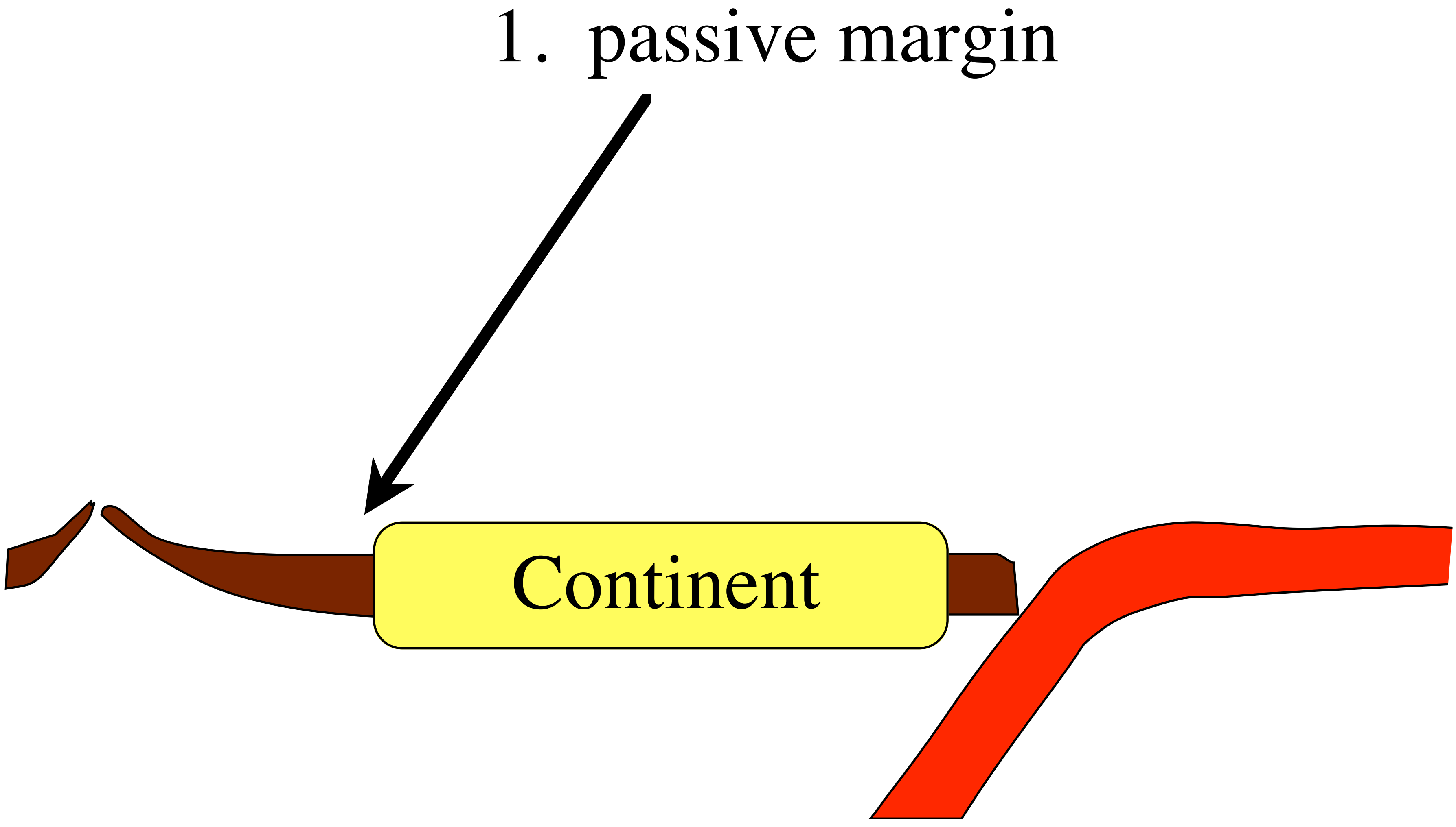
$$\rho = \rho_0 \, (1 - \alpha T)$$

- For mantle rocks, $\alpha = 3 \times 10^{-5}$
- Density of mantle rocks ρ_0 at low T: 3.3 g/cm^3
- Density of mantle asthenosphere ρ_A (T = 1300°C): 3.17 g/cm^3
- Average density of mantle lithosphere ρ_L: 3.24 g/cm^3

Cooling lithosphere



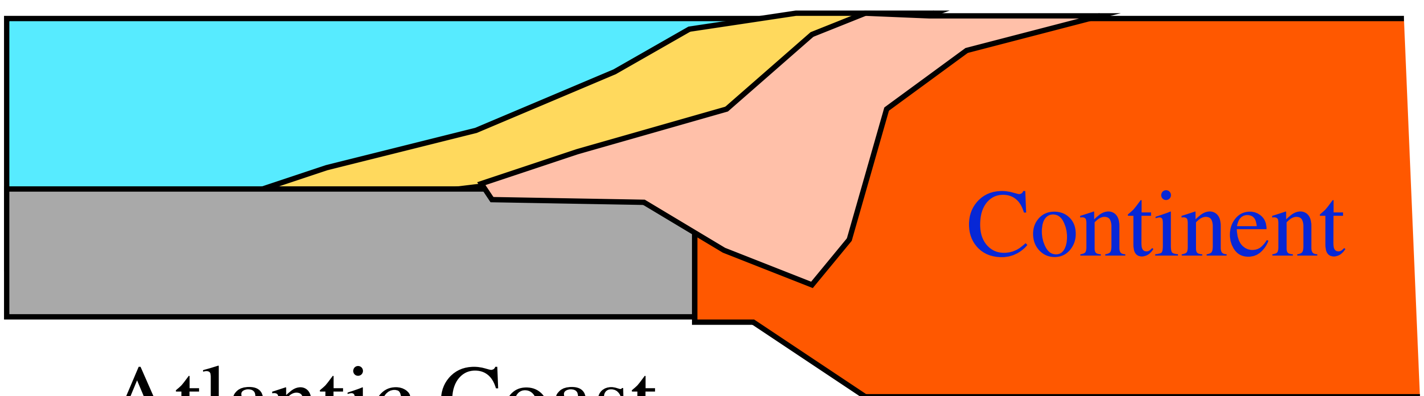
Continental Margins



Passive Margins: NOT a plate boundary

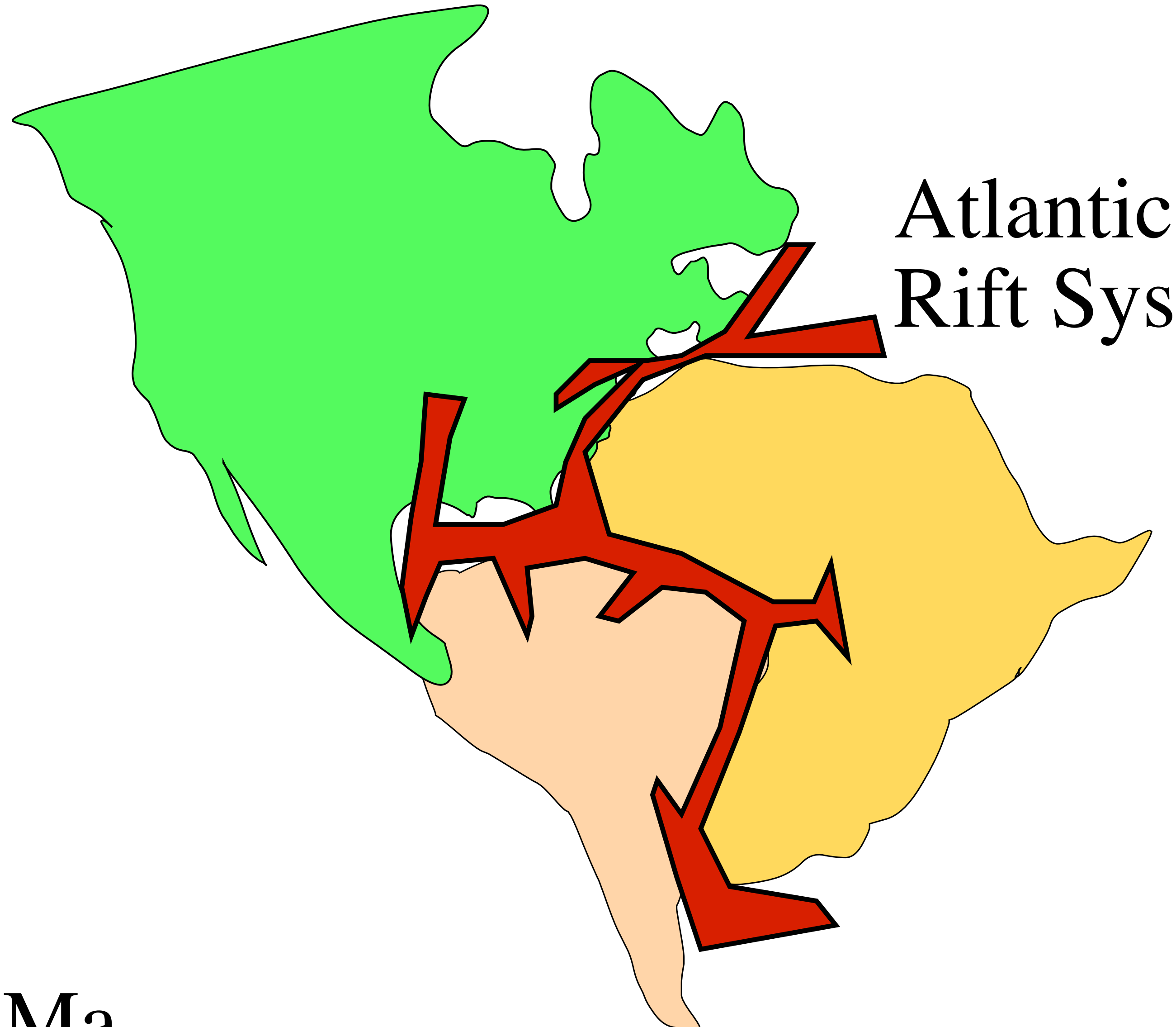
- Can hold high volumes of sediment (up to 15 km thick!!)

Passive Margin sediments



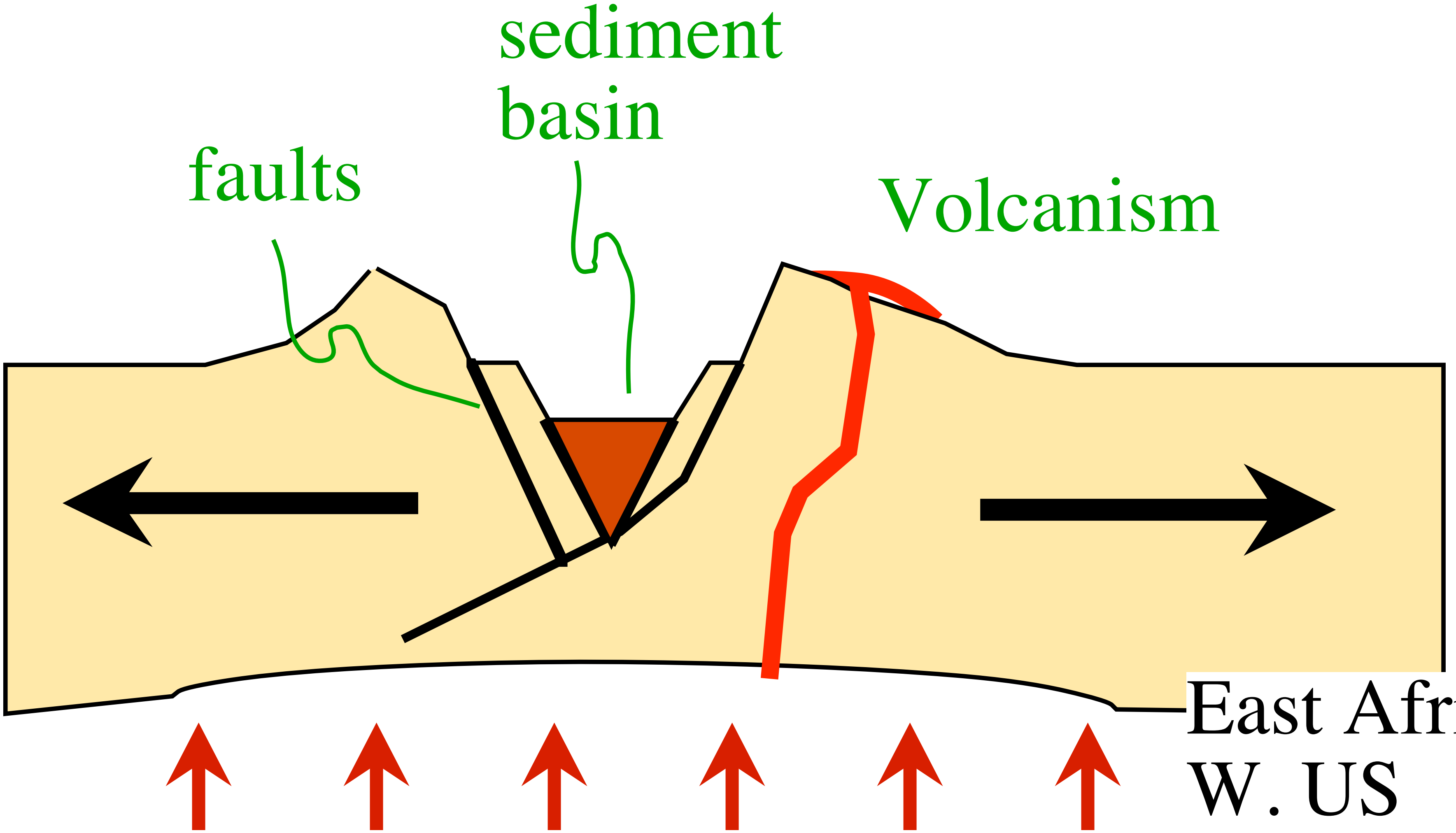
Atlantic Coast

Passive Margins are created by Rifting

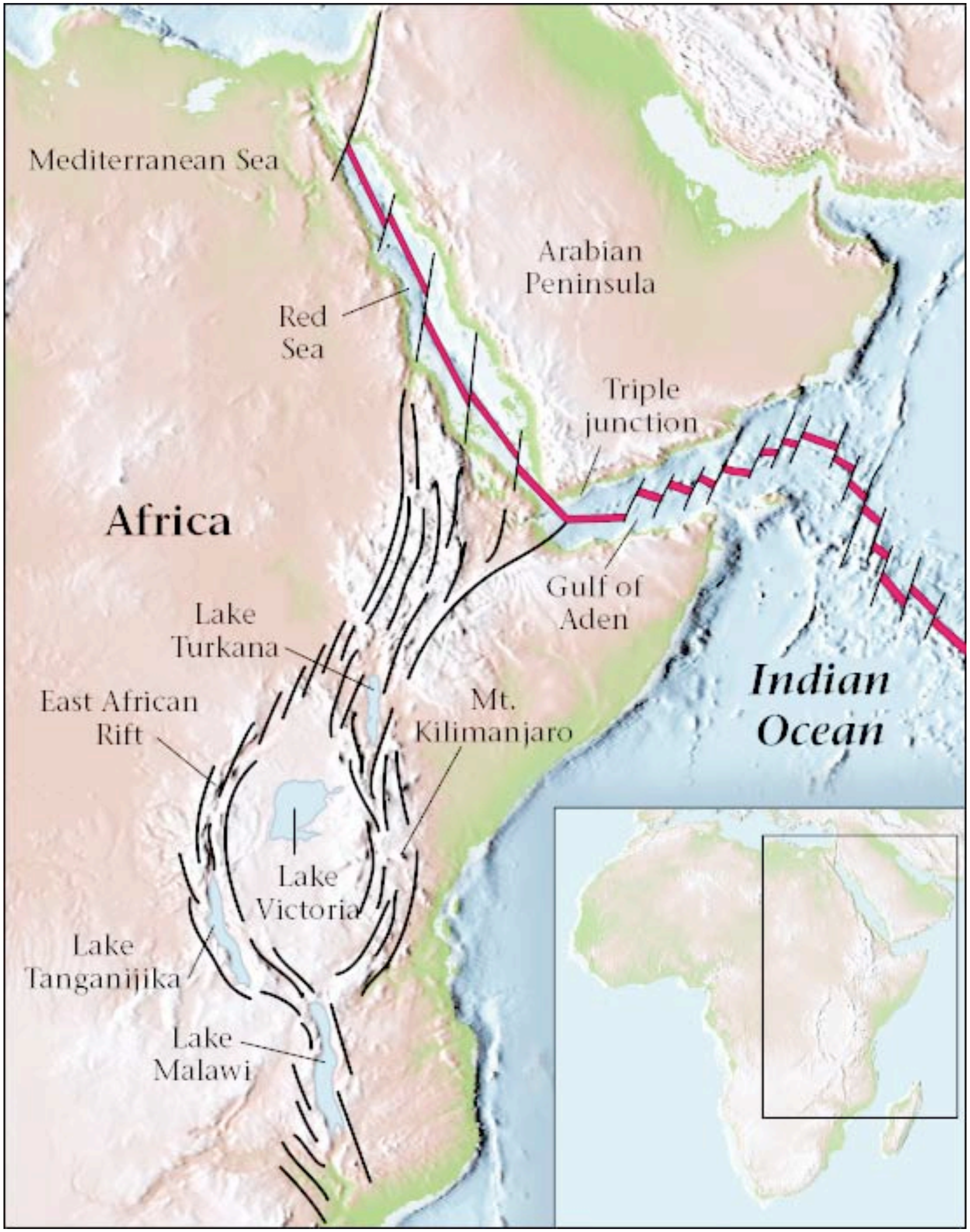


~ 225 Ma

Continental Rifting



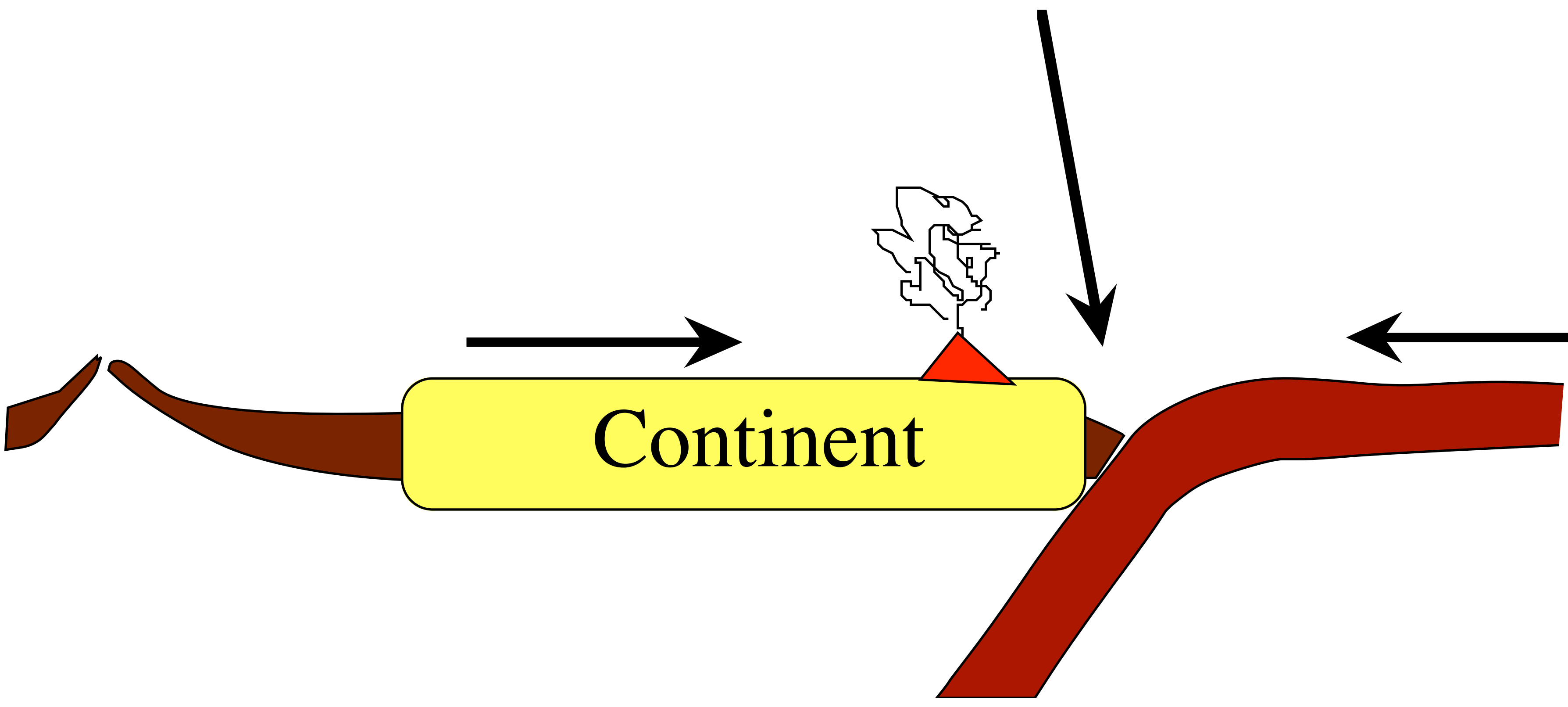
East Africa
W. US

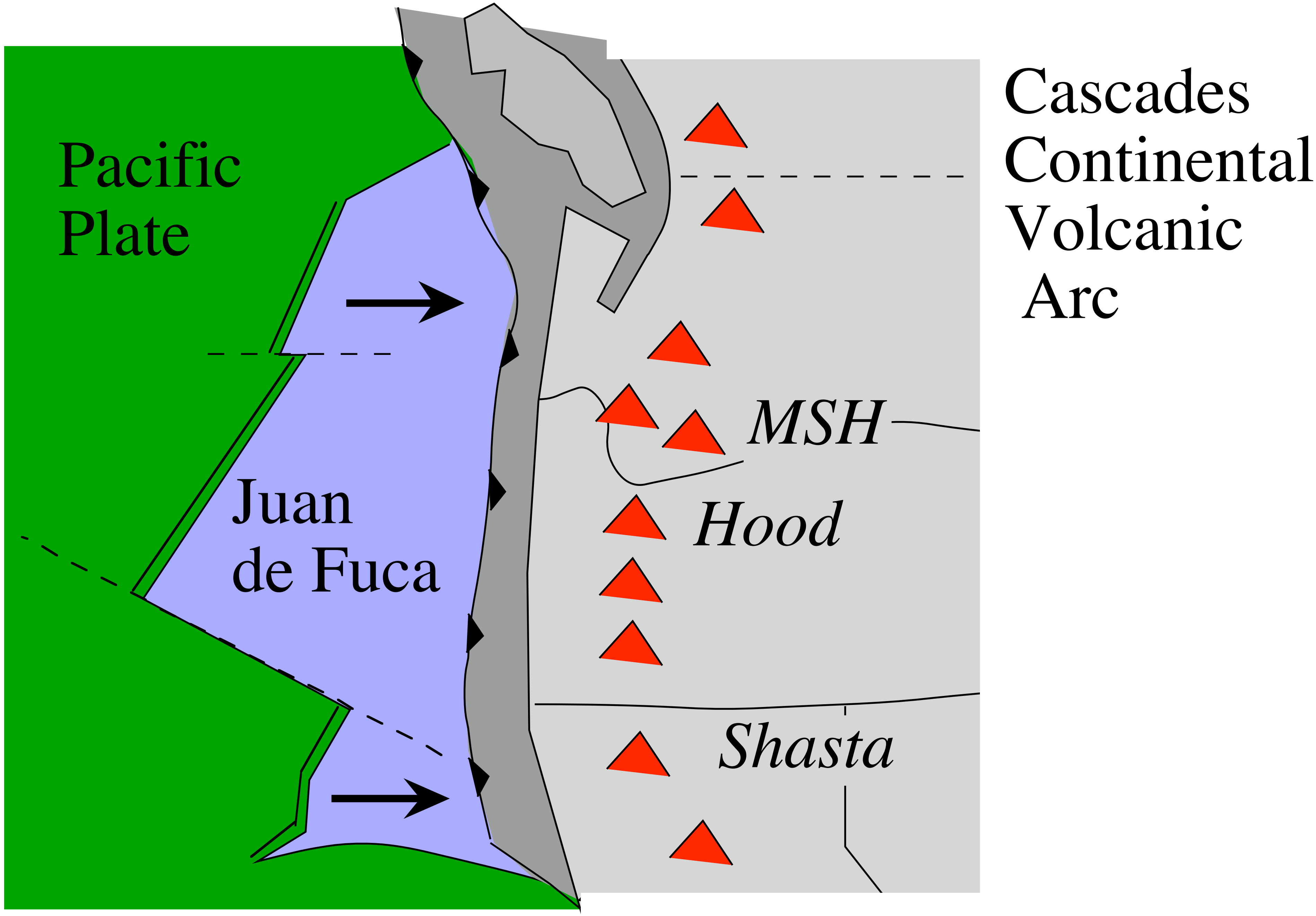


Mediterranean Sea
Arabian
Peninsula
Red
Sea
Triple
junction
Africa
Gulf of
Aden
Lake
Turkana
East African
Rift
Mt.
Kilimanjaro
Indian
Ocean
Lake
Victoria
Lake
Tanganijika
Lake
Malawi

Continental Margins

2. convergent margin

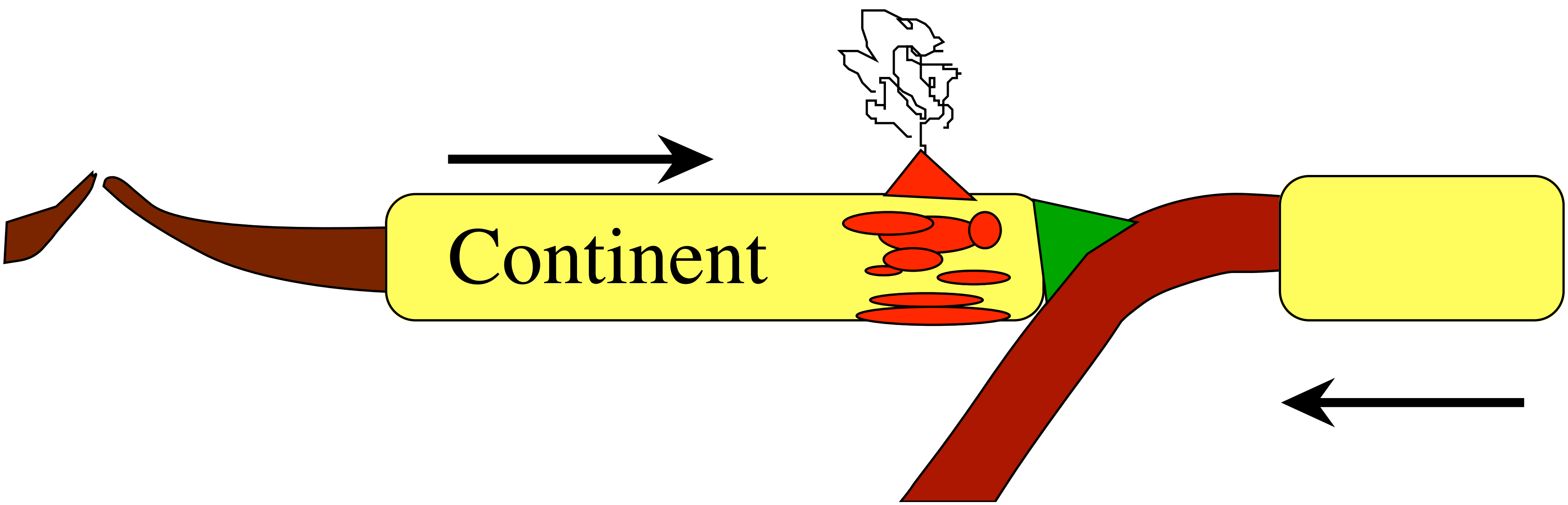




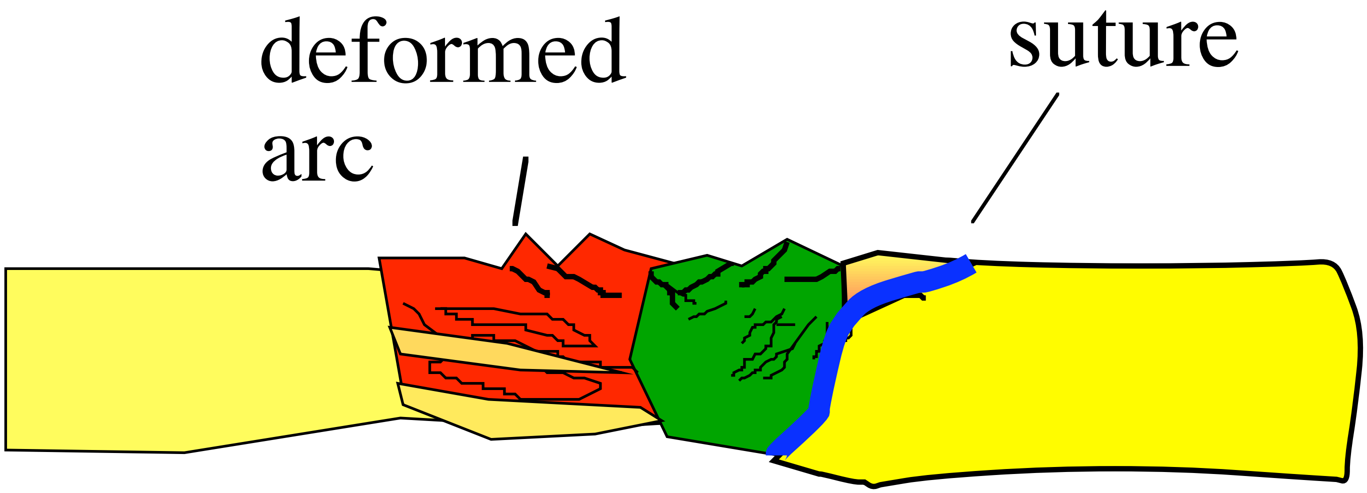
Pacific Plate
Juan de Fuca
Cascades Continental Volcanic Arc
MSH
Hood
Shasta

Continental Margins

3. collision margin

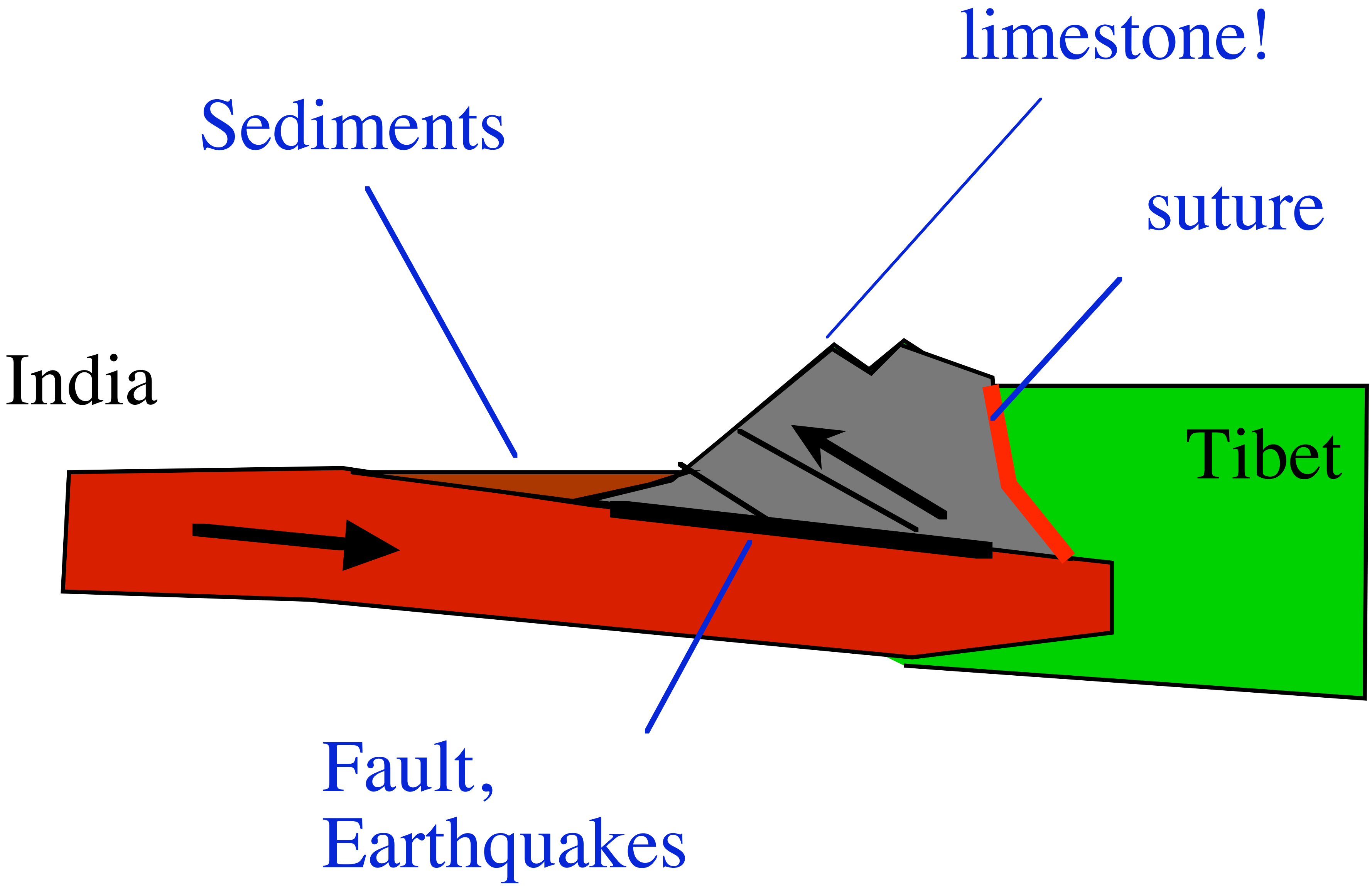


Parts of the Collision

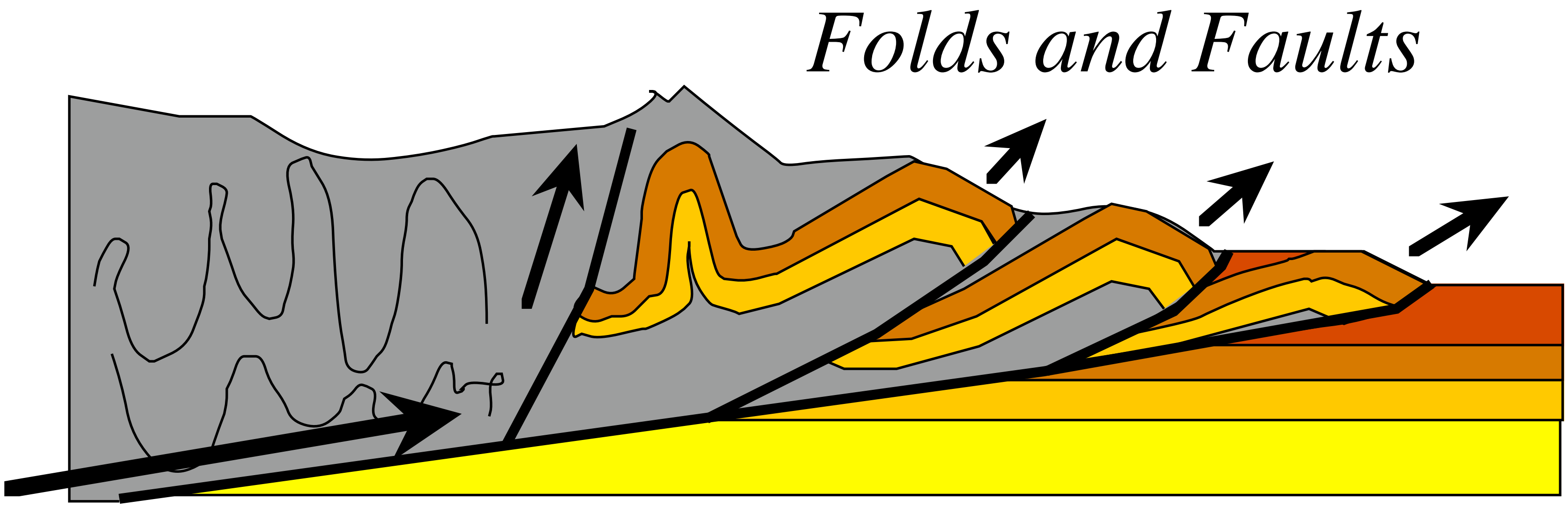


Orogeny = Mountain Building

Himalayan Orogeny

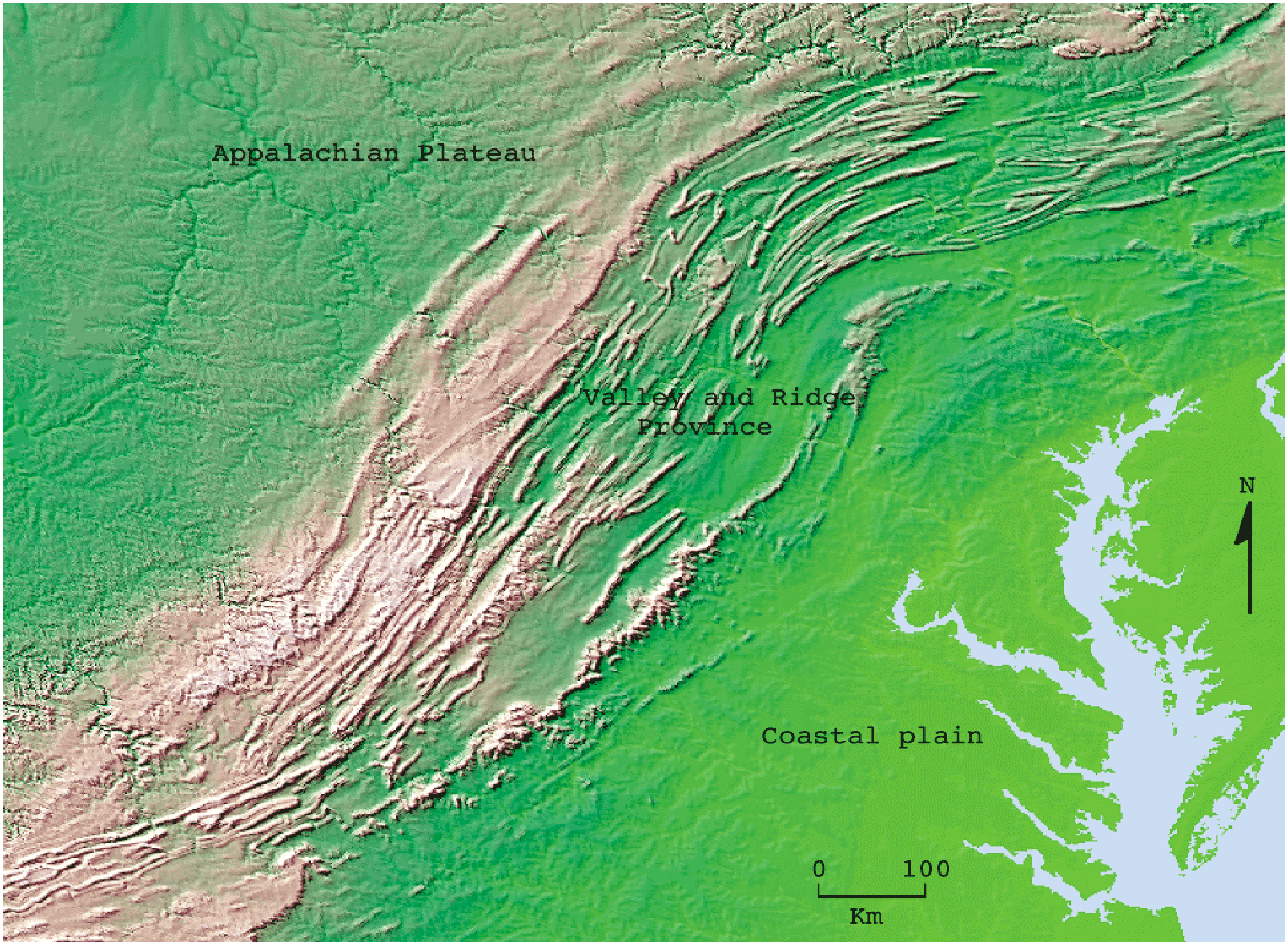


Mountain Belts

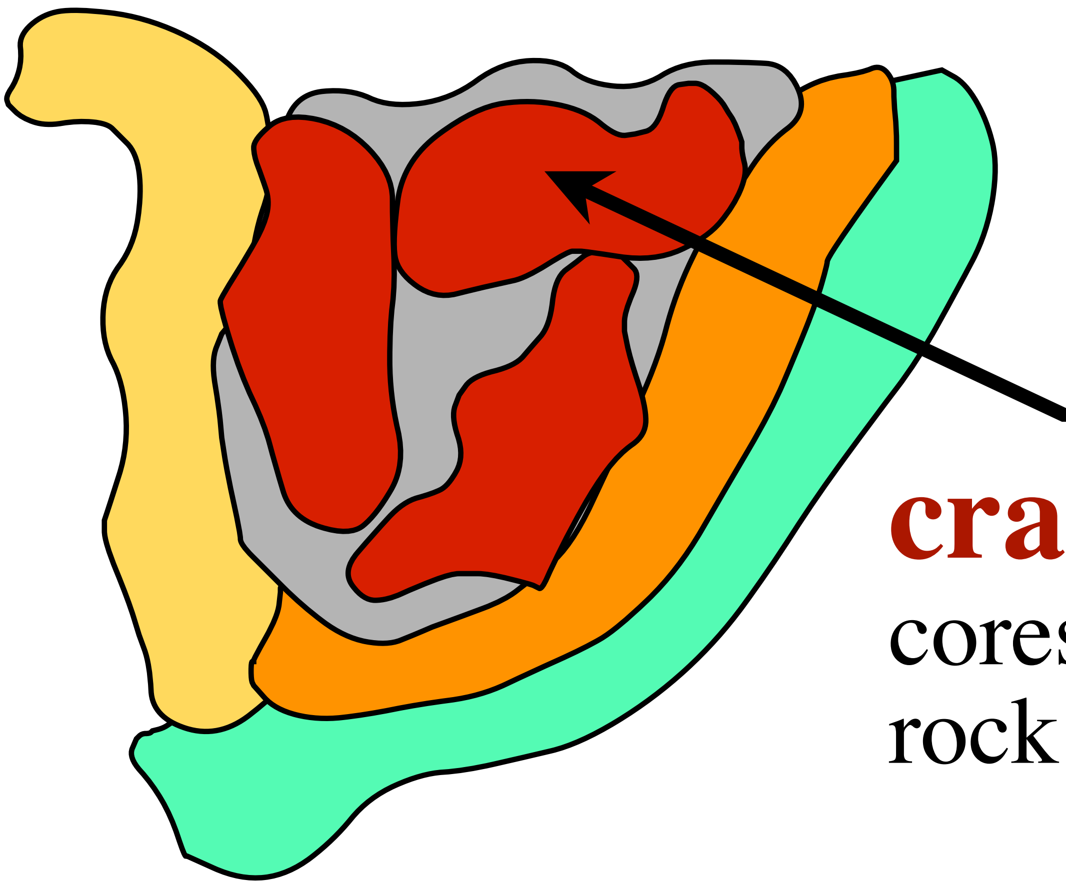


Appalachian Orogenies

Valley and Ridge Province



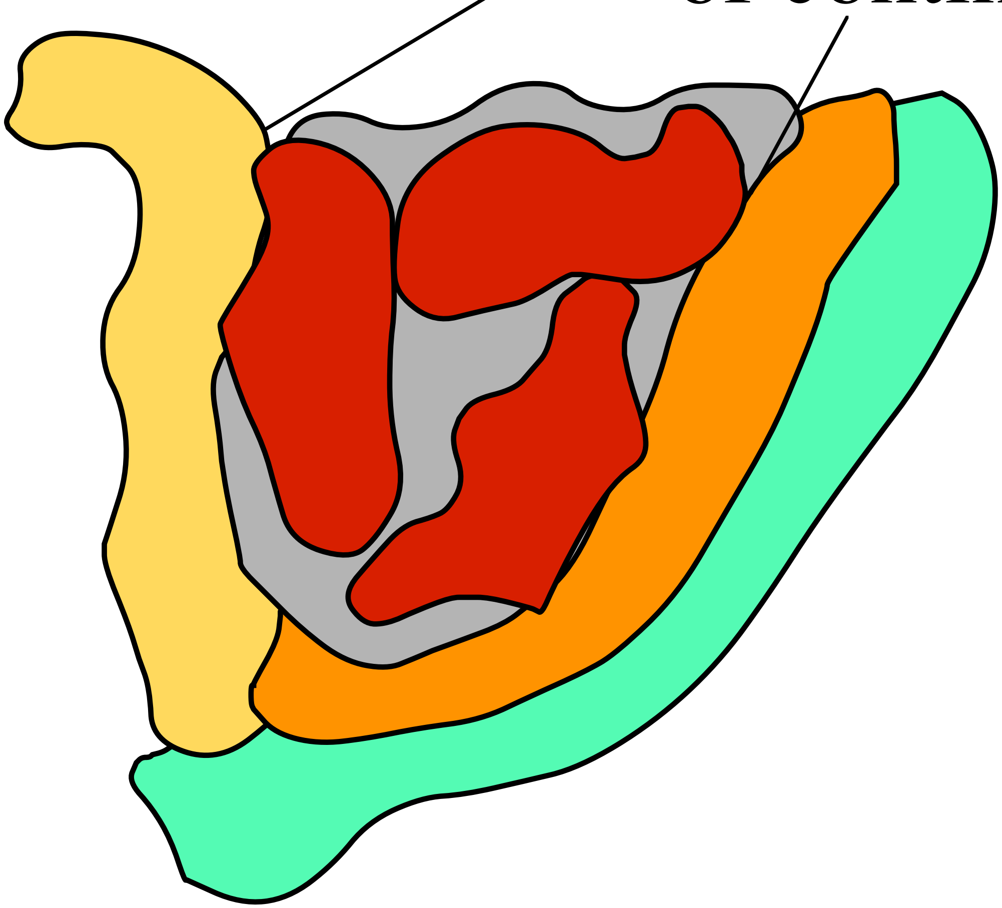
Continents built outward...



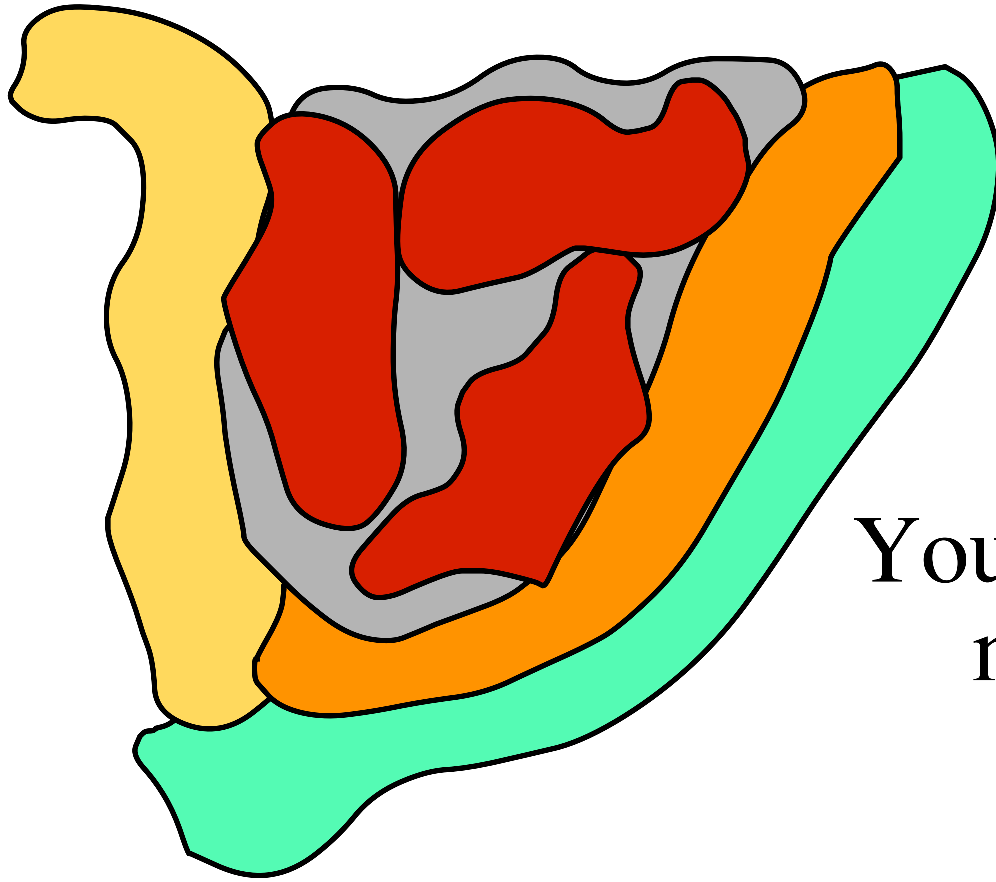
cratons: old cores of ancient rock

Continents built outward...

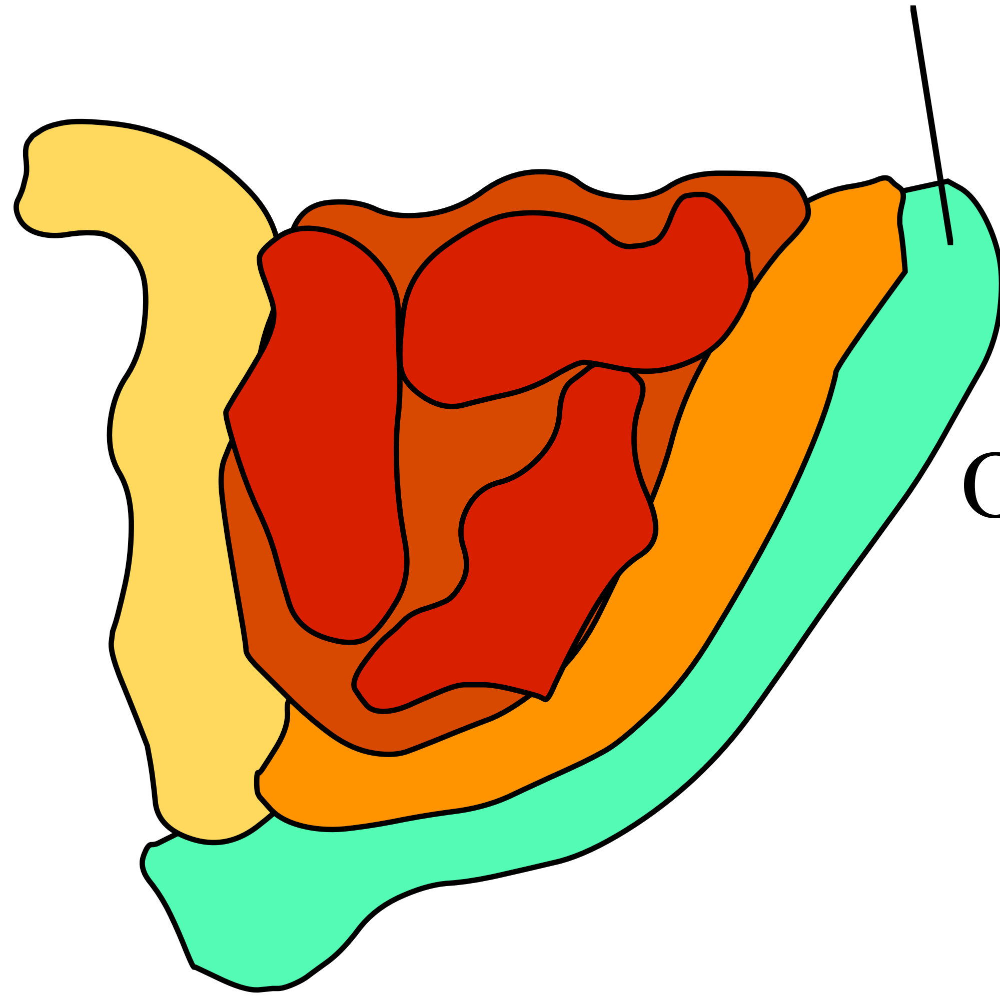
shield: The stable center of continent



Continents built outward...



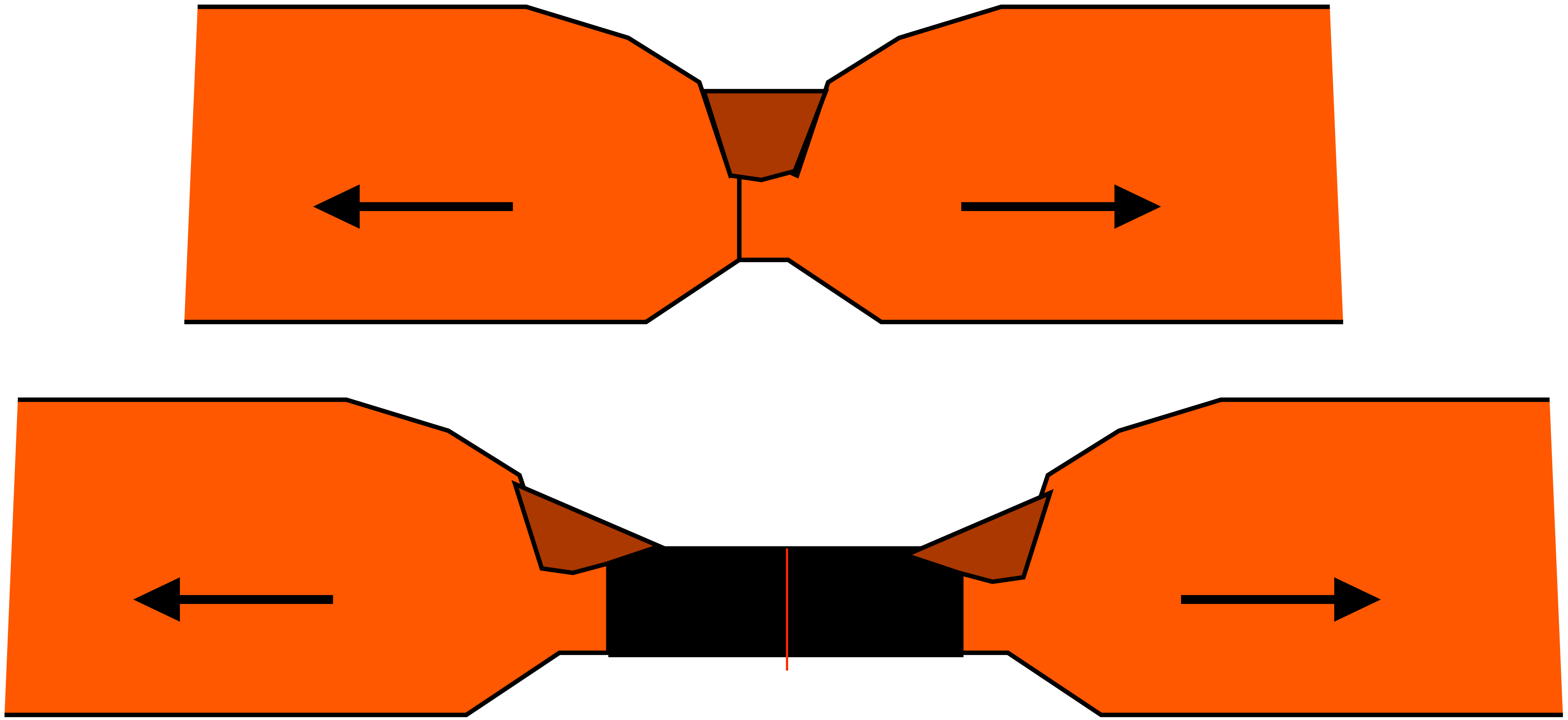
passive margins:



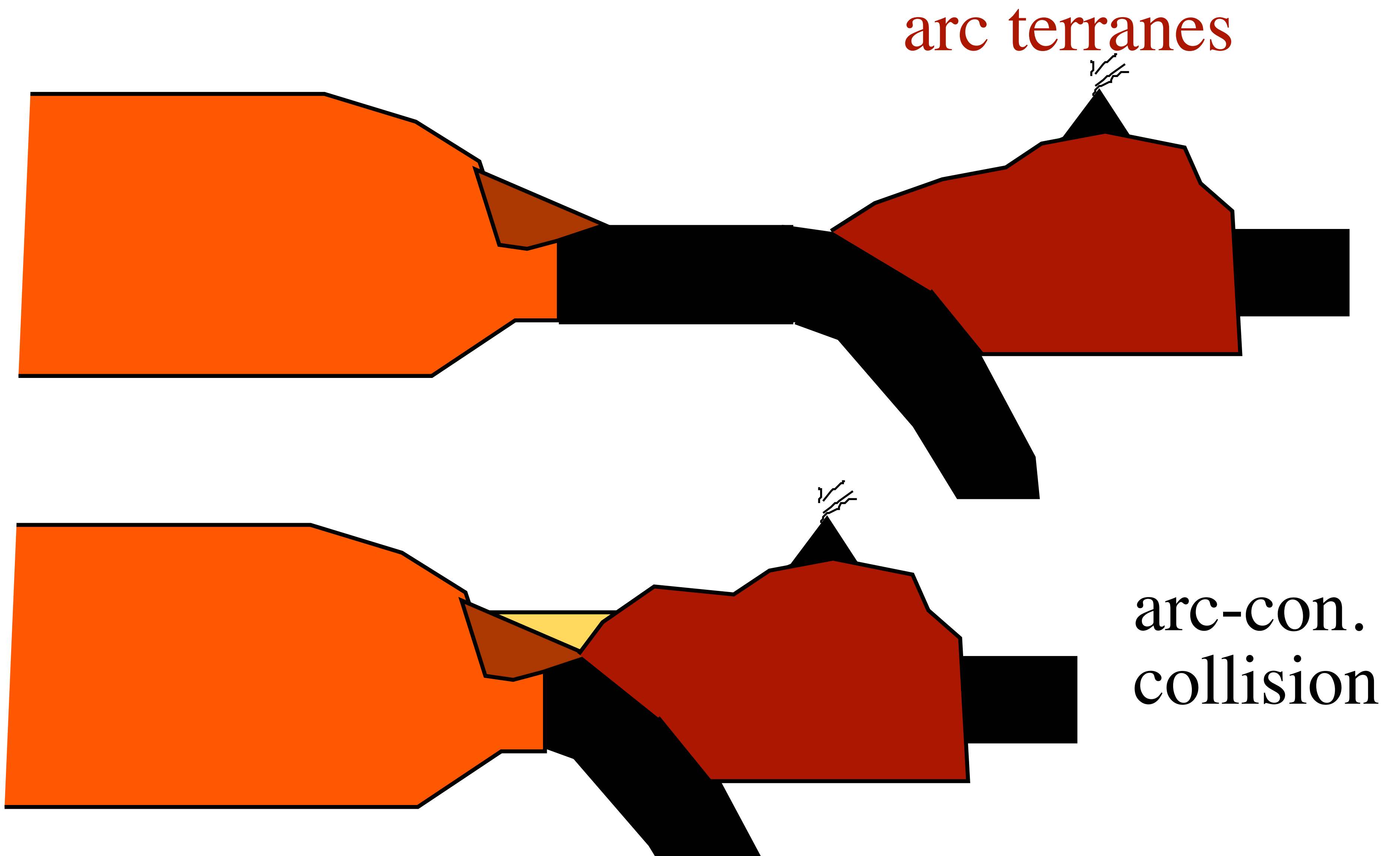
Old Rifting sites...

Passive and active margins: the Wilson Cycle

Rifting leads to Ocean Basin formation (Red Sea, Atlantic)

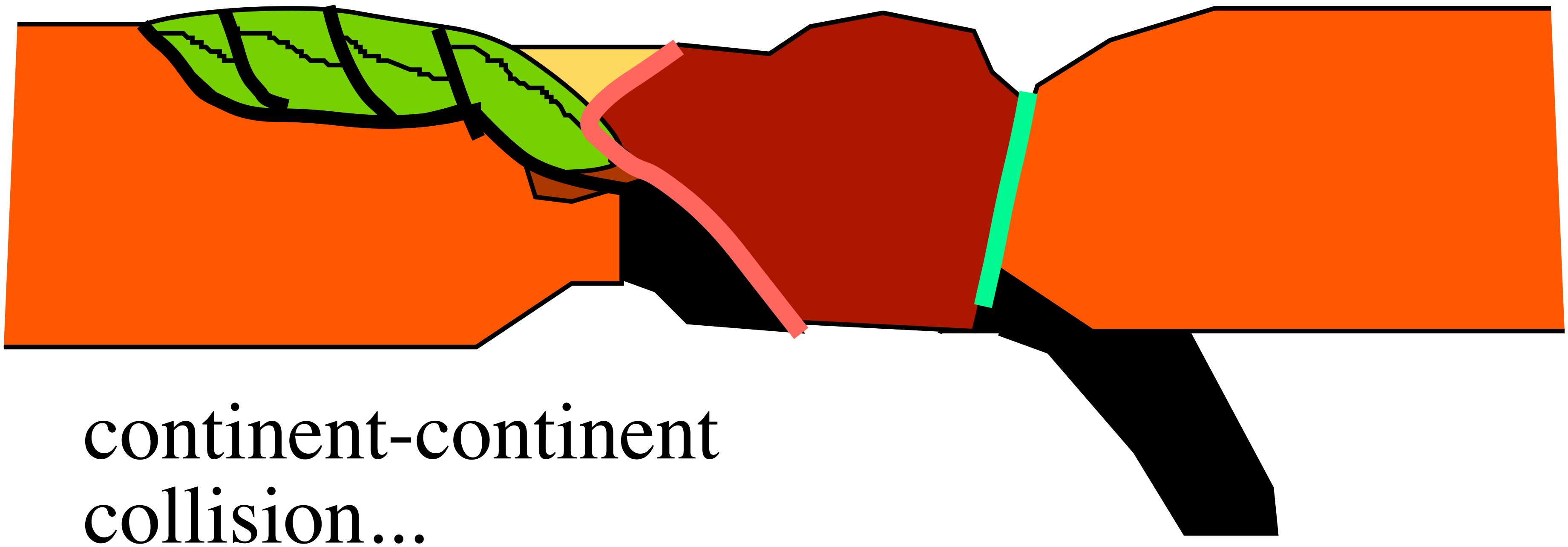


...later, plates converge and subduct ocean...



Finally, continents collide..

Orogeny!

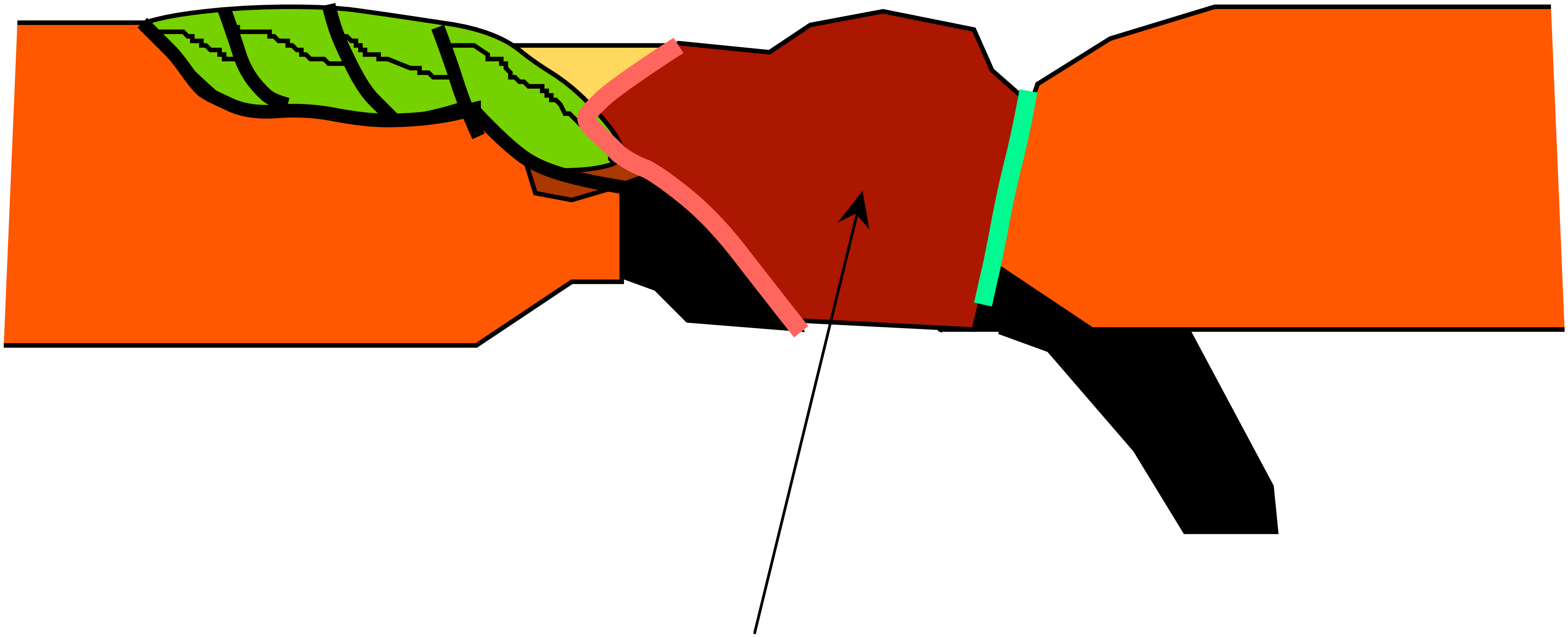


continent-continent collision...

..later Rifting event can start process over

The Wilson Cycle

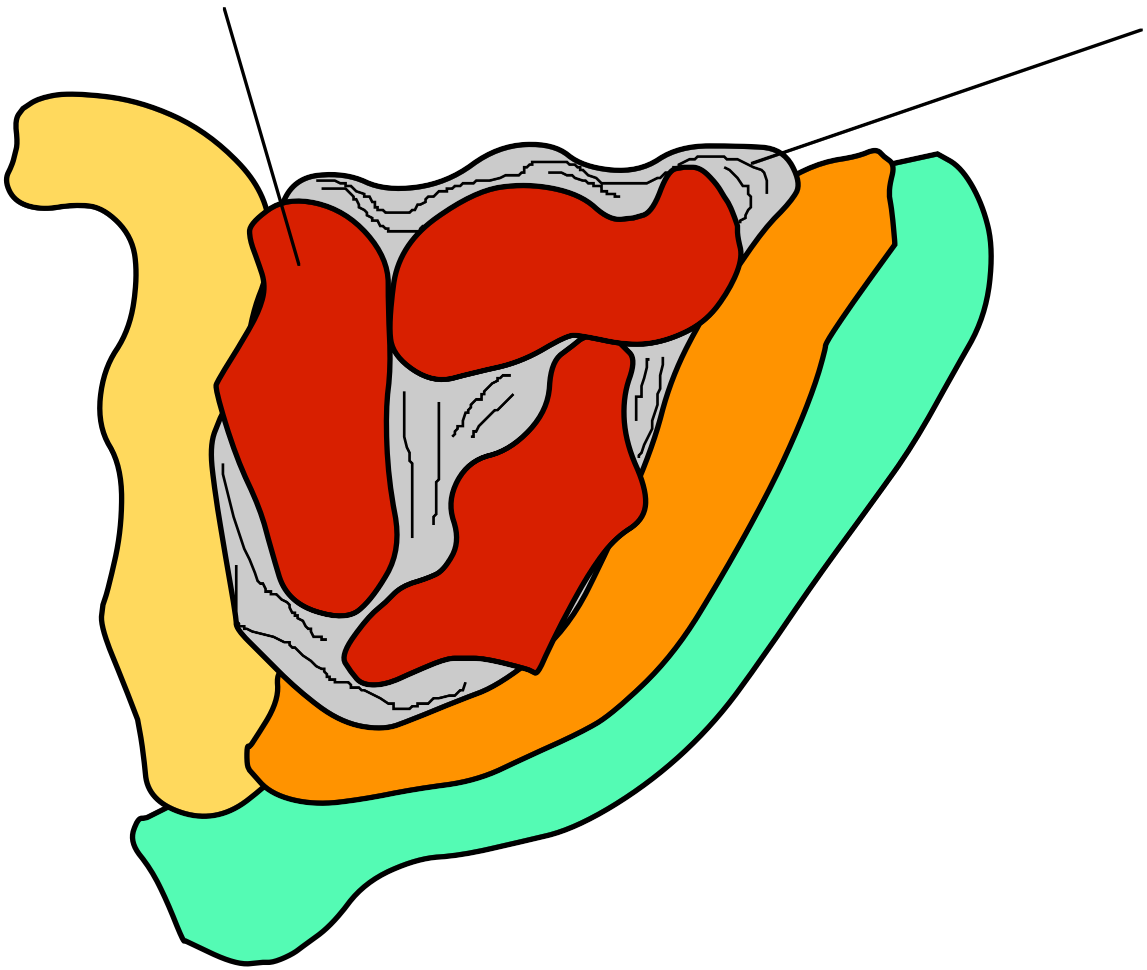
Net Growth of Continents:



Accretion of volcanic arcs!!

Arcs = new crust, born from the mantle

Cratons



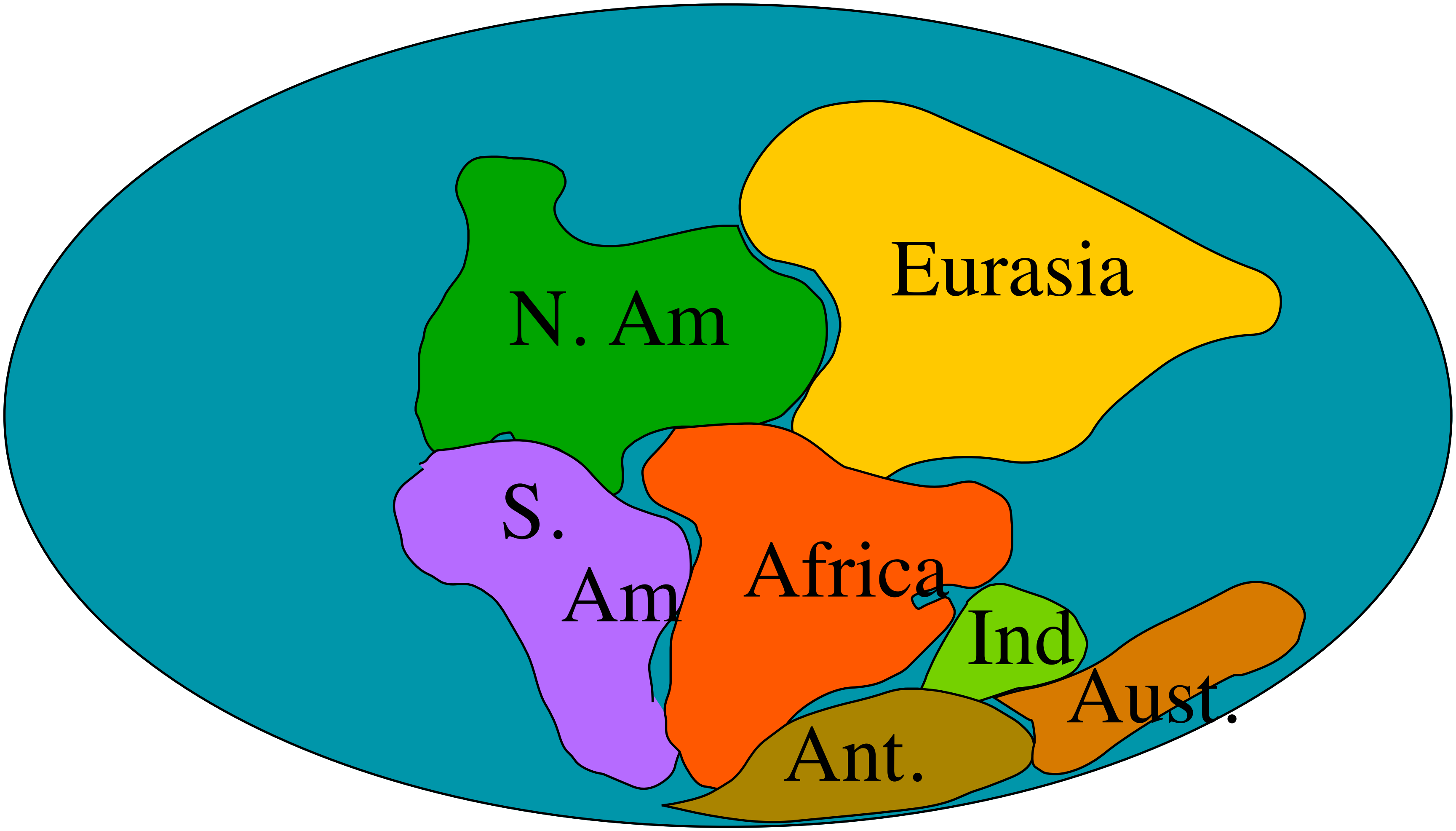
(accreted arcs)

orogenic
belts

OLD
MOUNTAIN
BELTS

the seams
between cratons

200 Ma: Pangaea



Supercontinent!

200 Ma: Pangaea

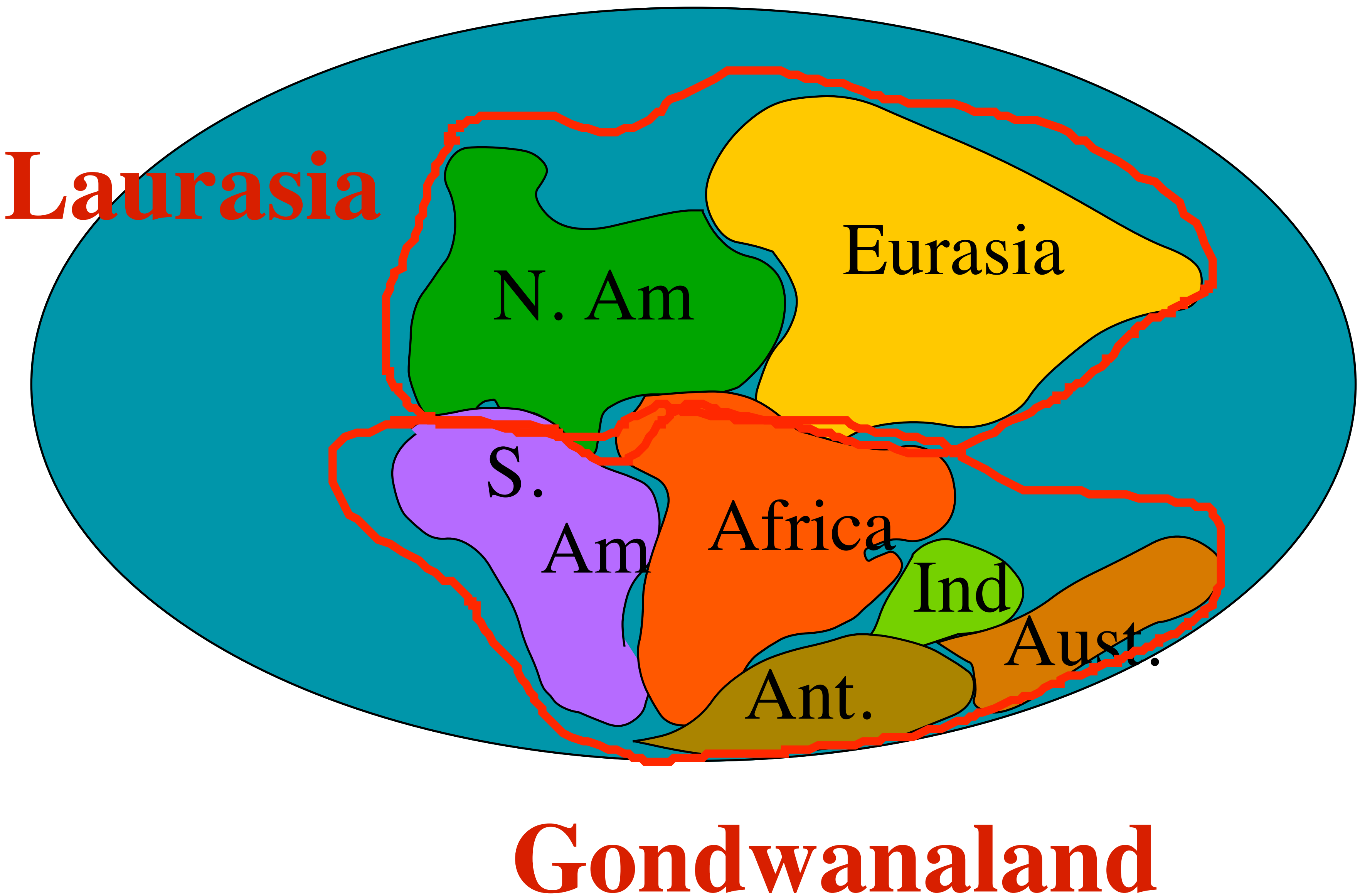


plate recon demo