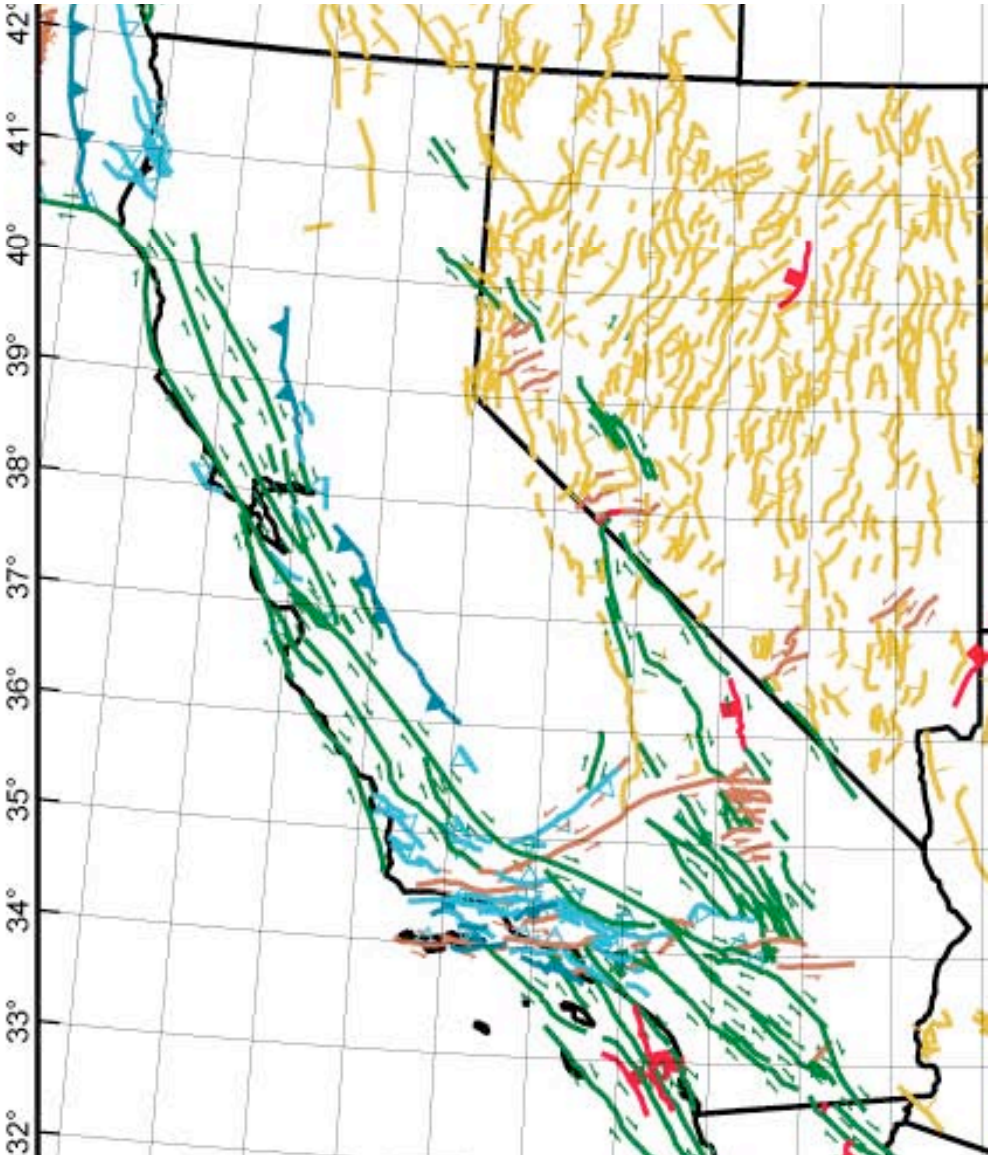
EESC 2200
The Solid Earth System

Plate tectonics - 2

15 Sep 08

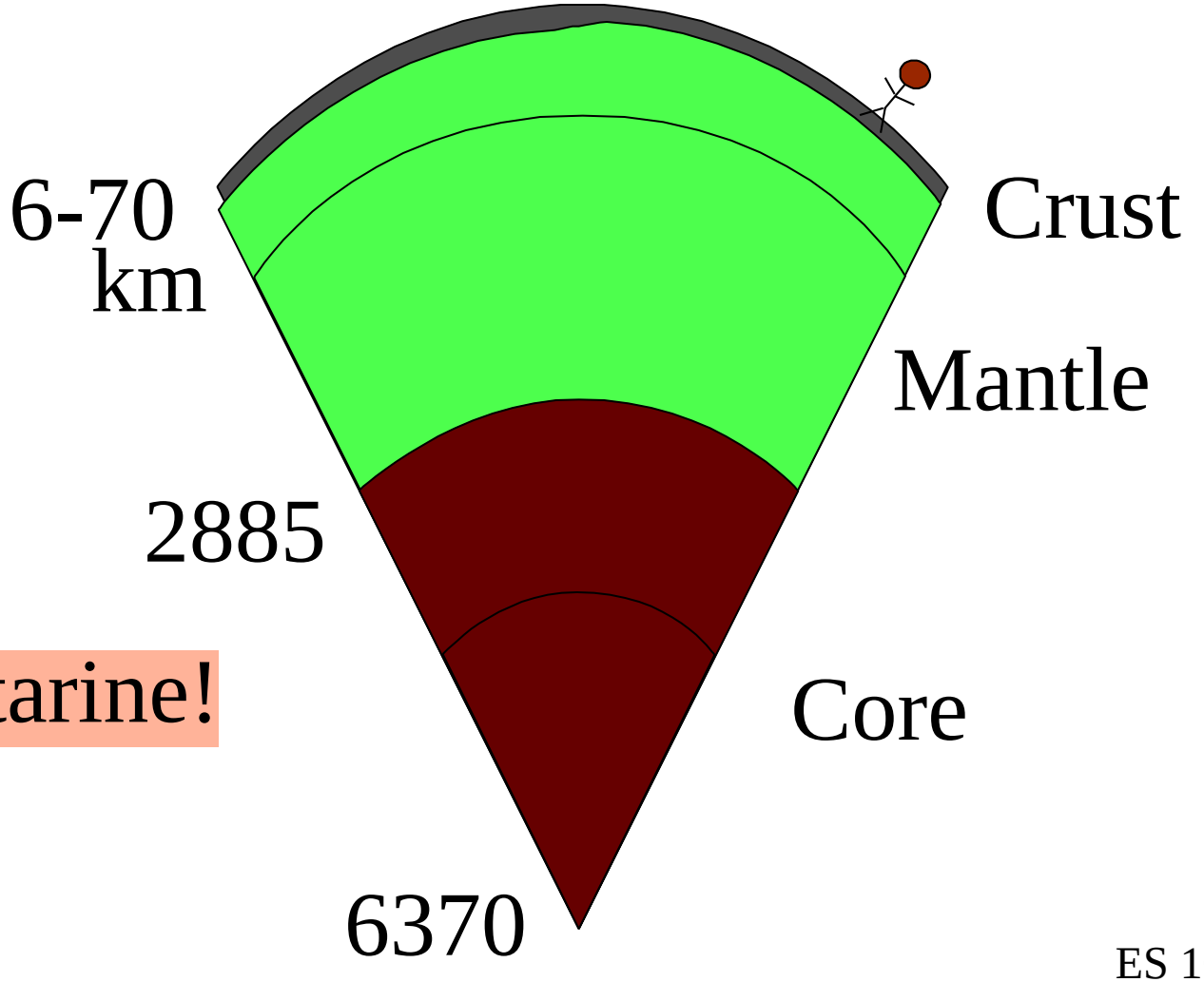
Subduction Zones

Transform Faults



Review

Compositional Layering (Chemical)



The Nectarine!

Compositional Layering
vs.
Mechanical Layering

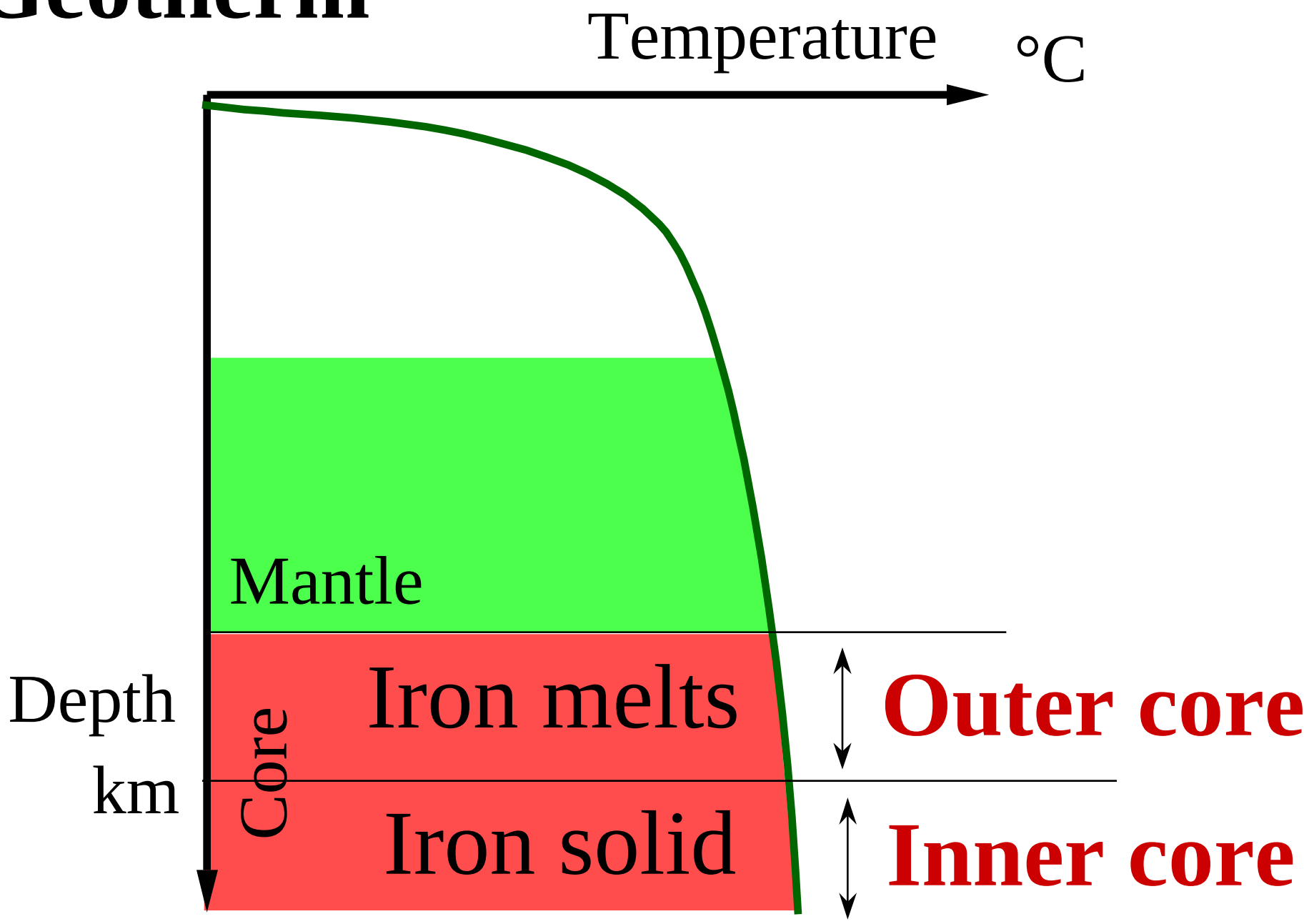
How Strong or Weak?

Temperature weakens

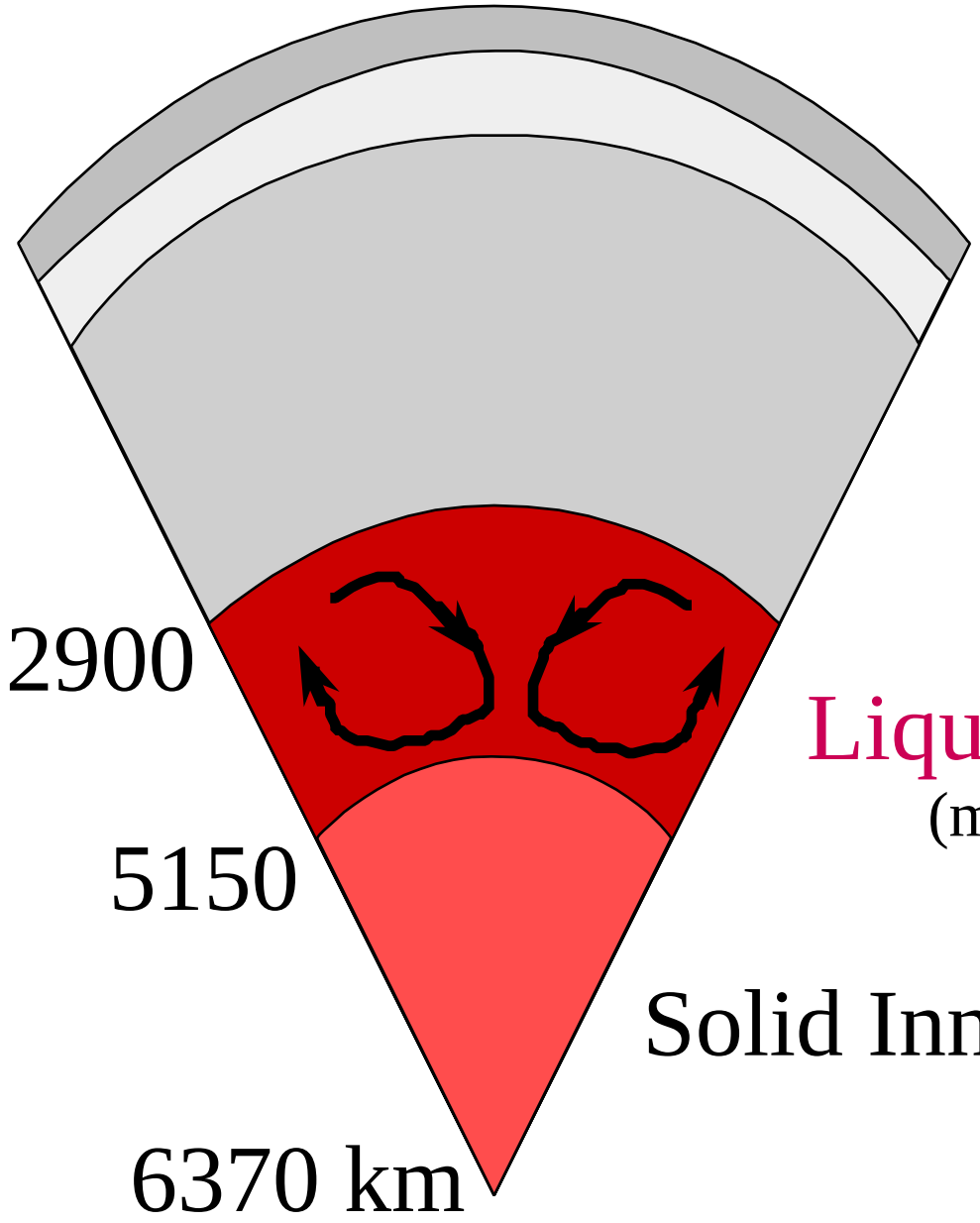
Pressure strengthens

BOTH Increase into the Earth

Geotherm

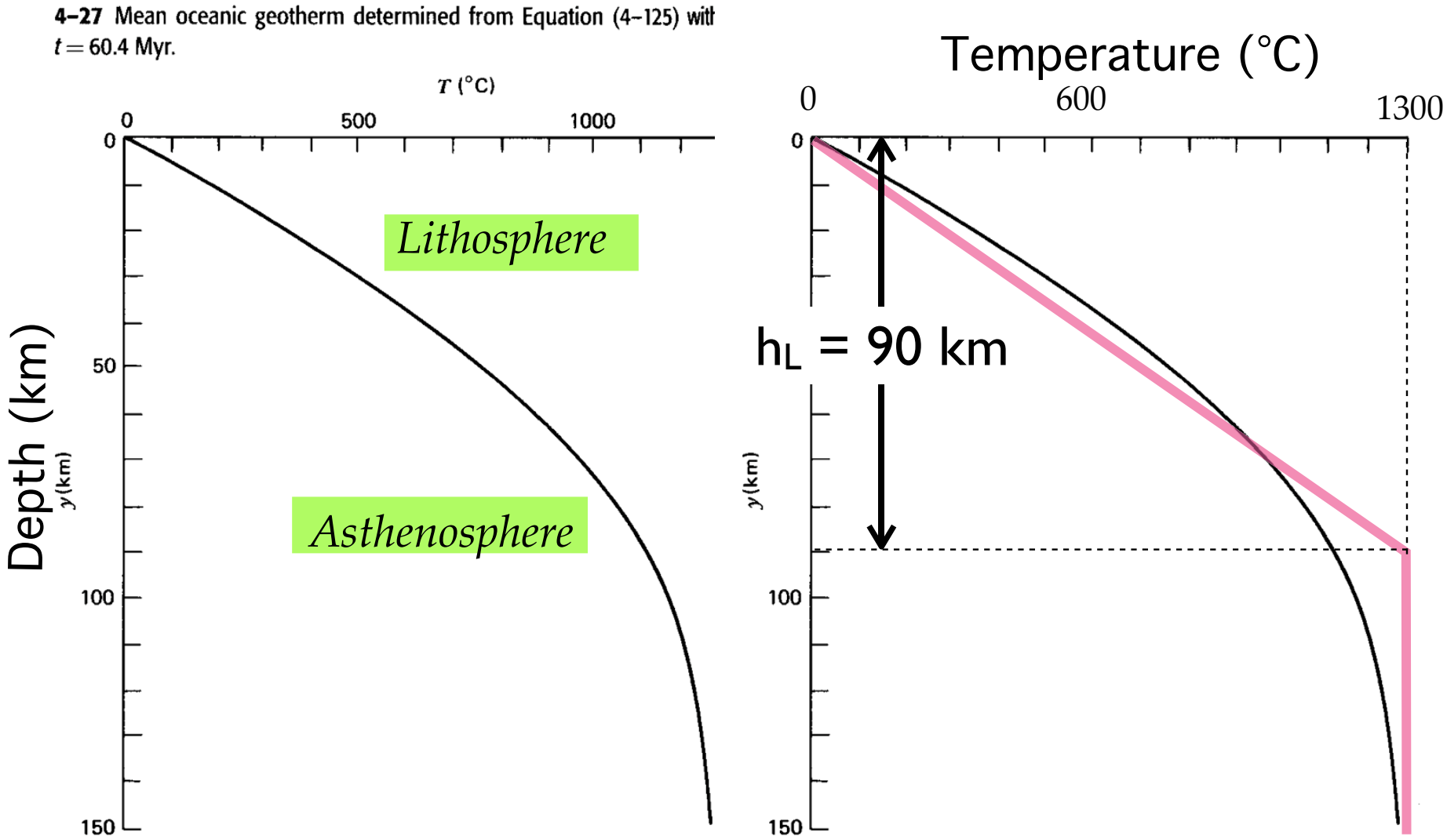

Temperature
°C
Mantle
Depth
km
Core
Iron melts
Outer core
Iron solid
Inner core

Mechanical Layering



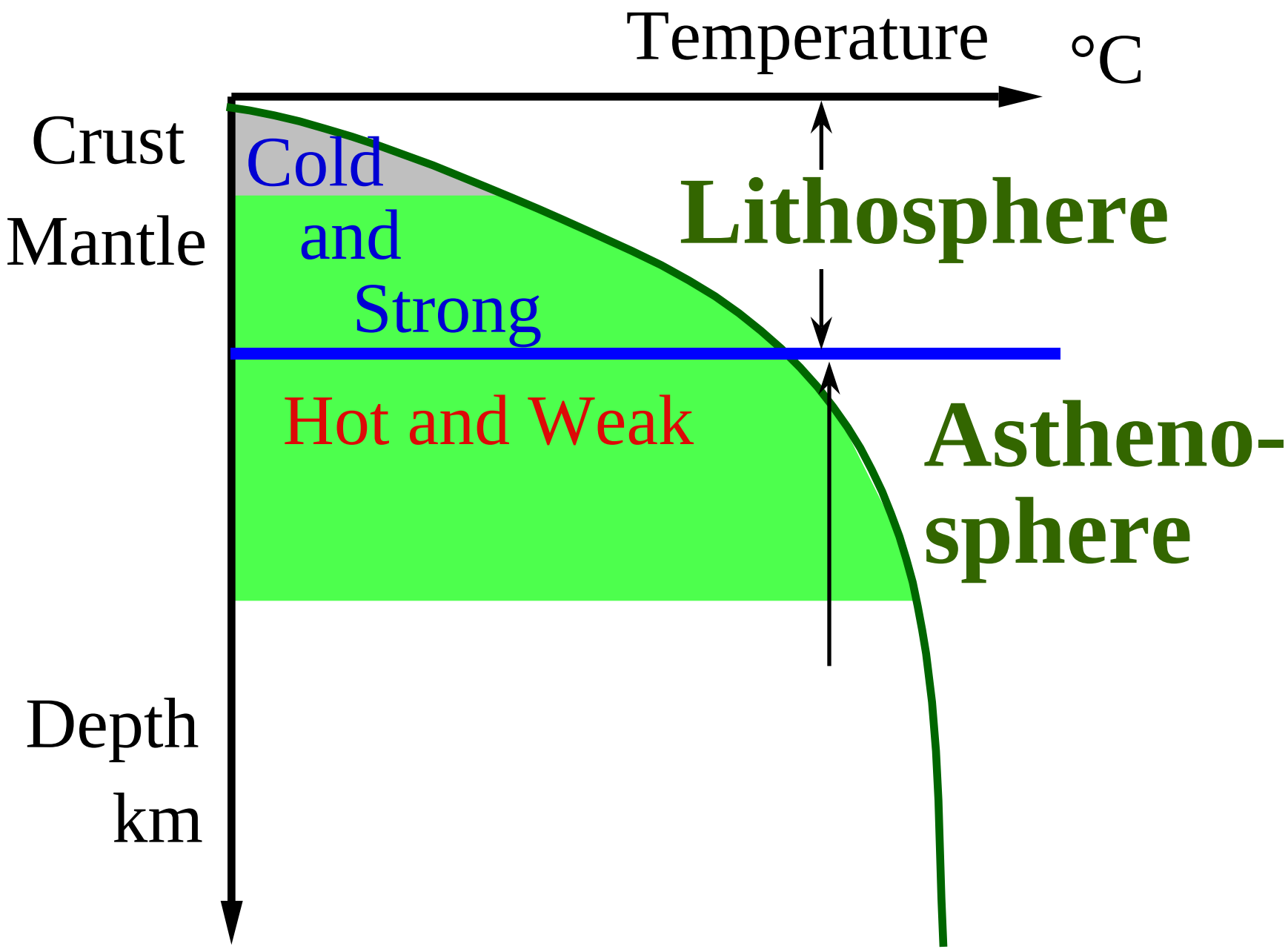
Liquid Outer Core
(magnetic field)

Solid Inner Core

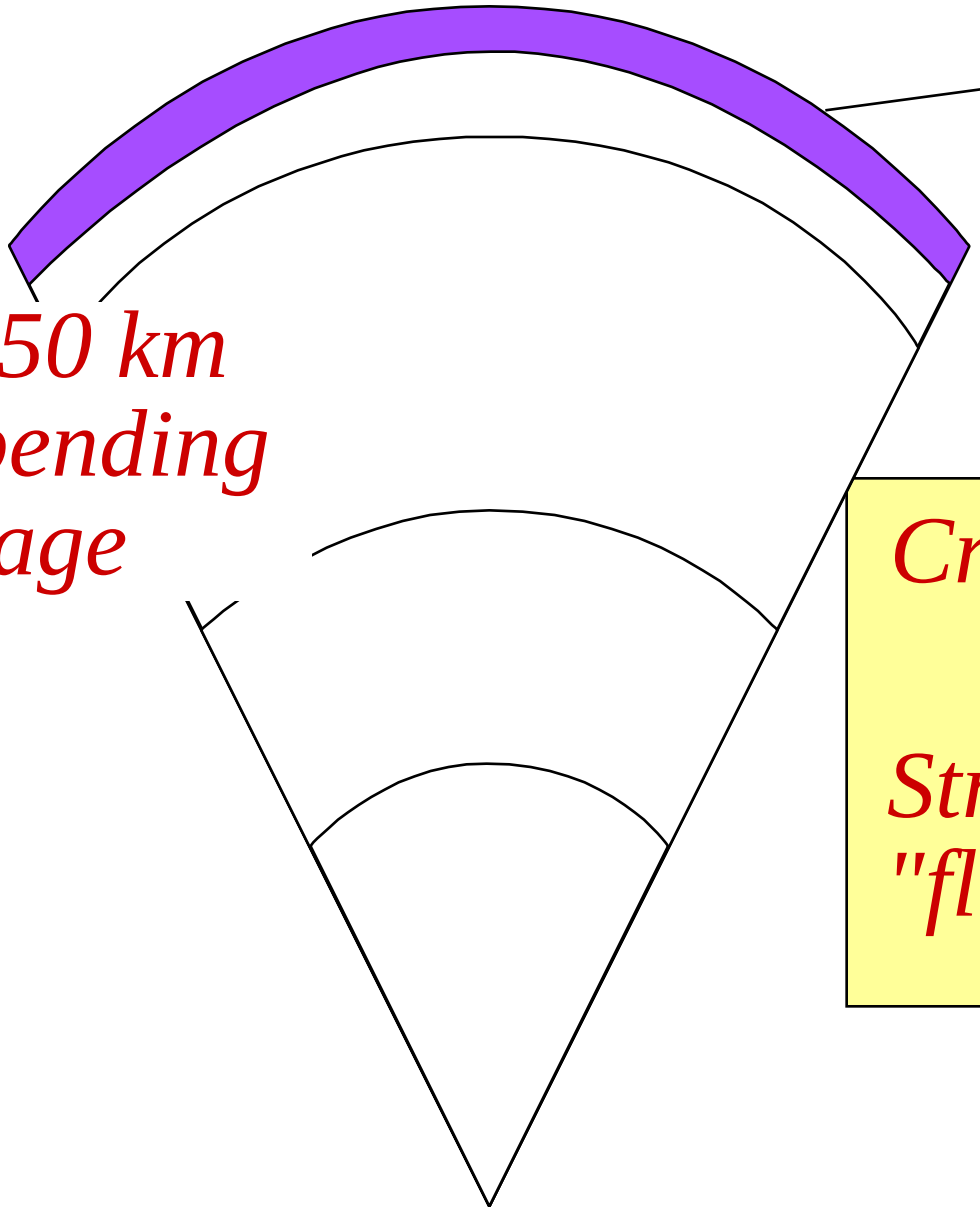


Turcotte & Schubert, 2002

Geotherm


Temperature
°C
Crust
Mantle
Cold
and
Strong
Lithosphere
Hot and Weak
Astheno-
sphere
Depth
km

Mechanical Layering



Lithosphere

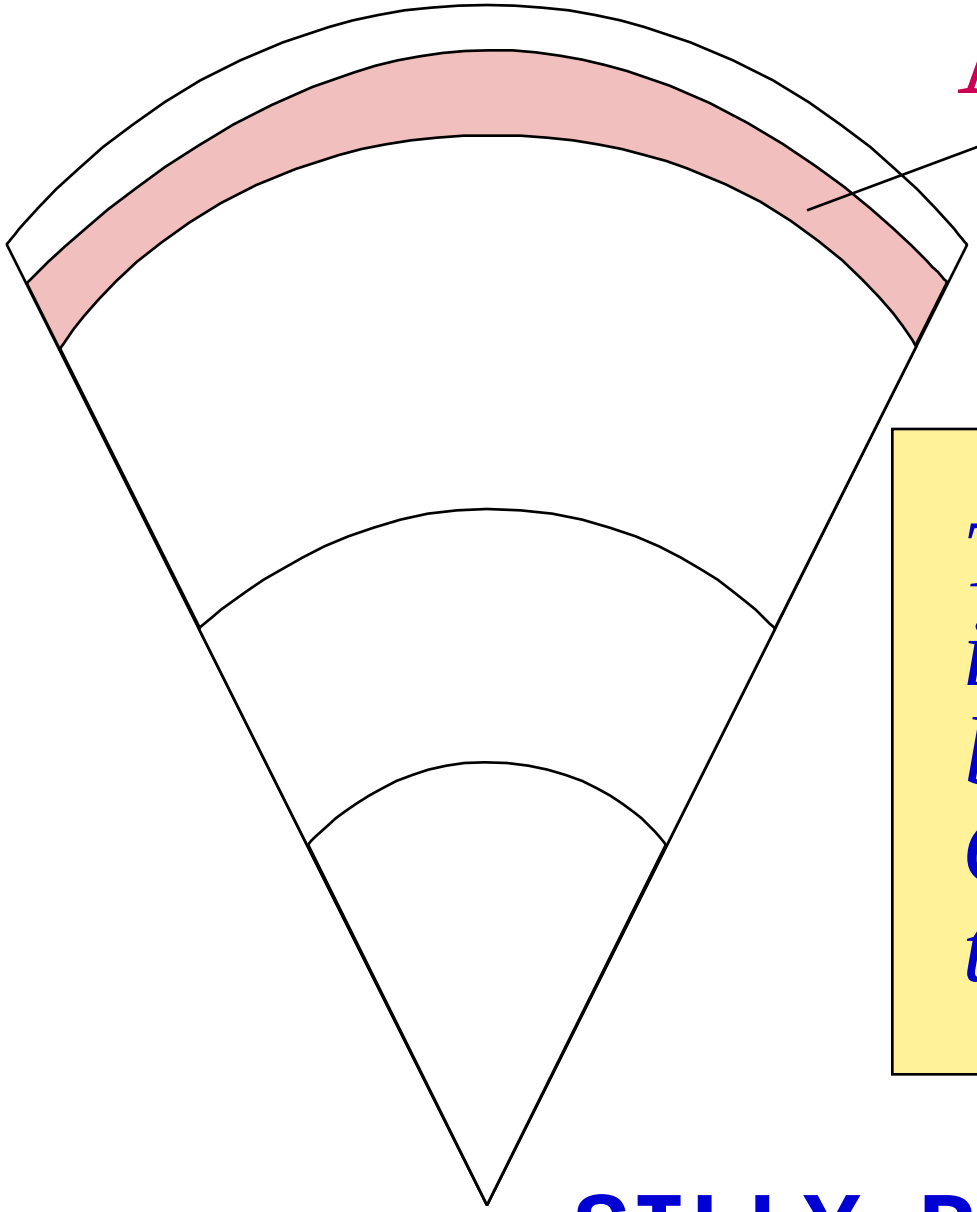
The "Plate"

0-250 km depending on age

Crust + some mantle

Strong, rigid shell -- "floats"

Mechanical Layering



Asthenosphere

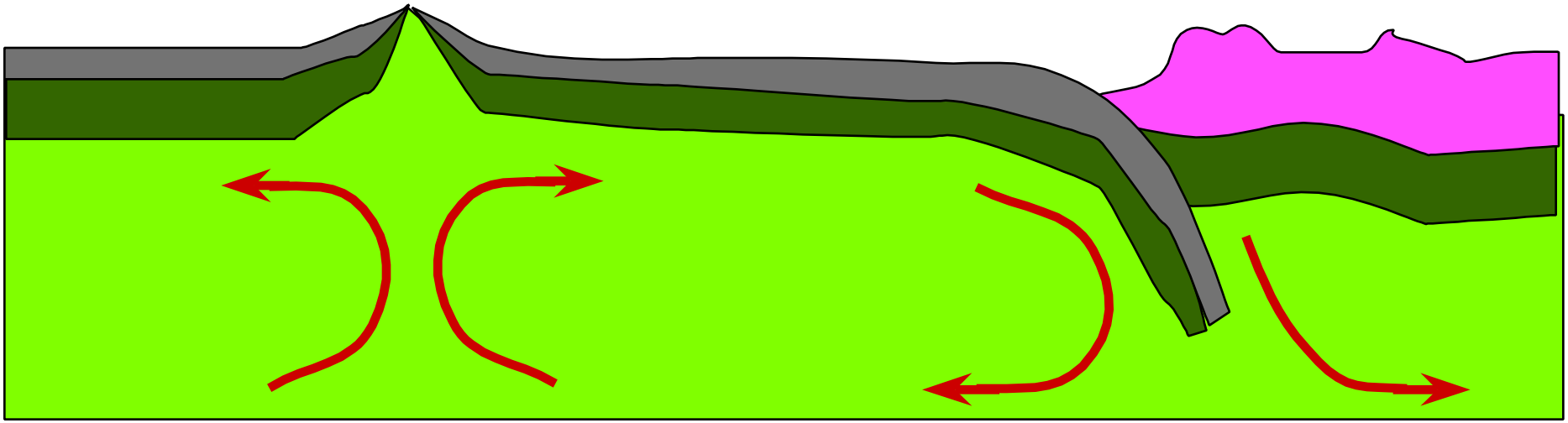
The asthenosphere is mostly solid, but it flows at Geological time scales (Ma)

SILLY PUTTY

Convection in Mantle/Asthenosphere

-- The driving force for movement at Earth's Surface

-> Plate Tectonics



Because Mantle is HOT!

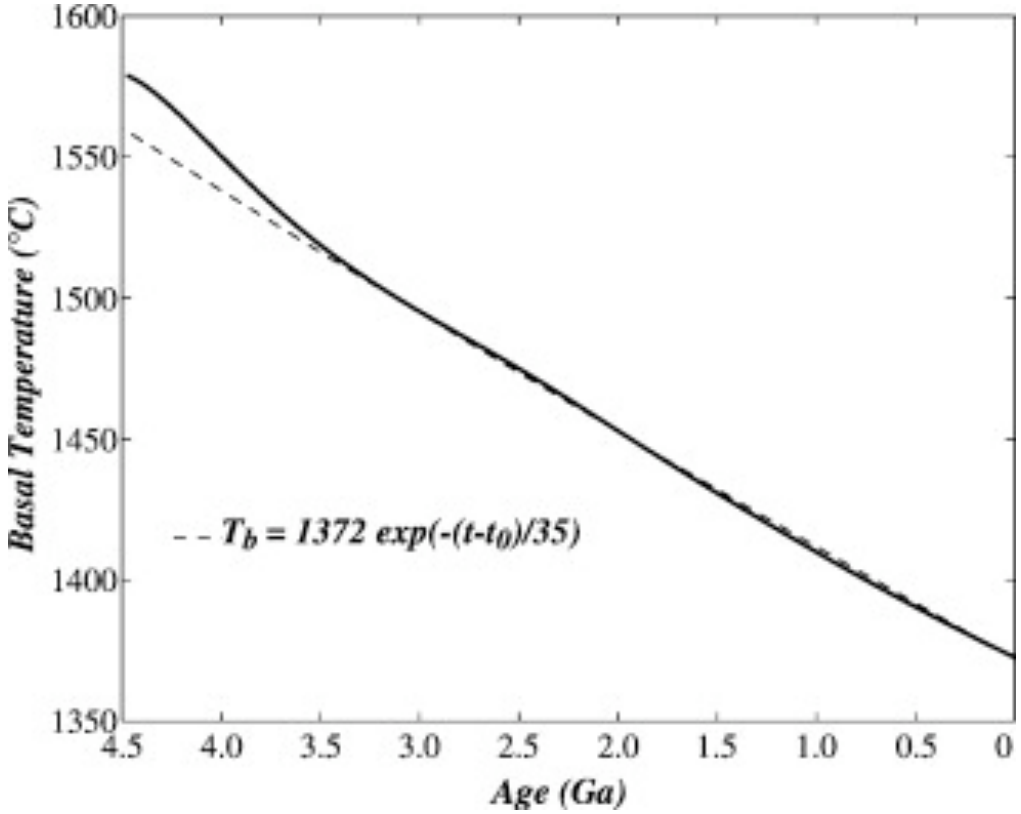
Density

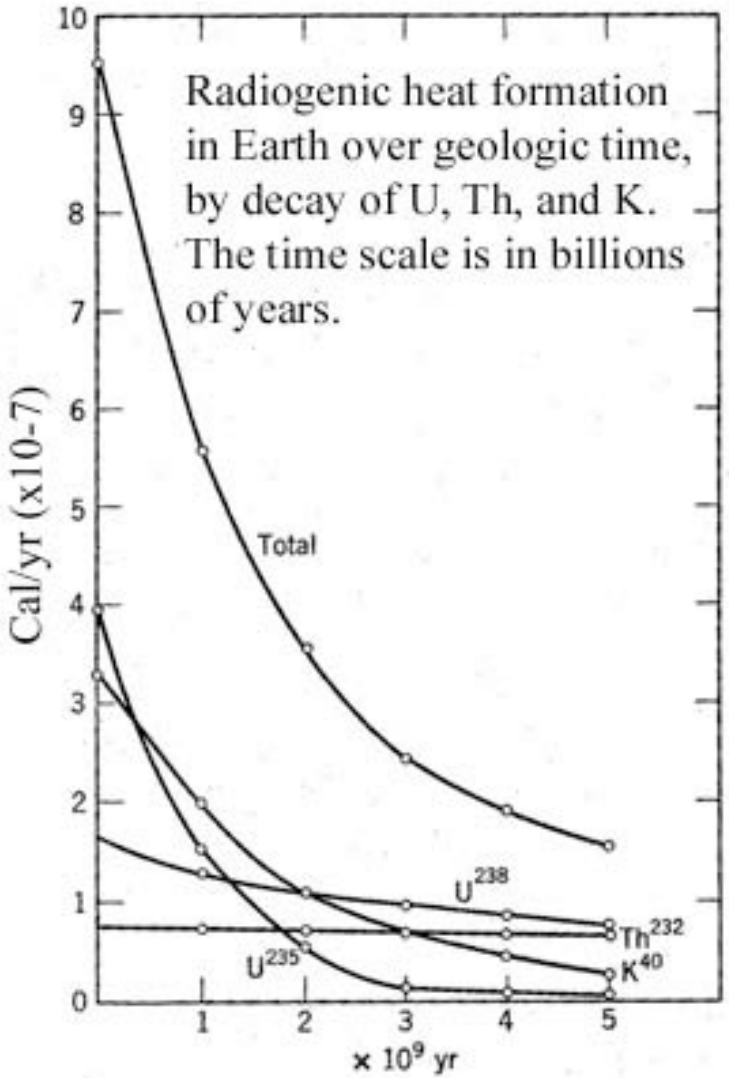
Why is the Earth Hot?

Why is the Earth's Interior Hot?

Radioactivity

Original heat (gravitational)





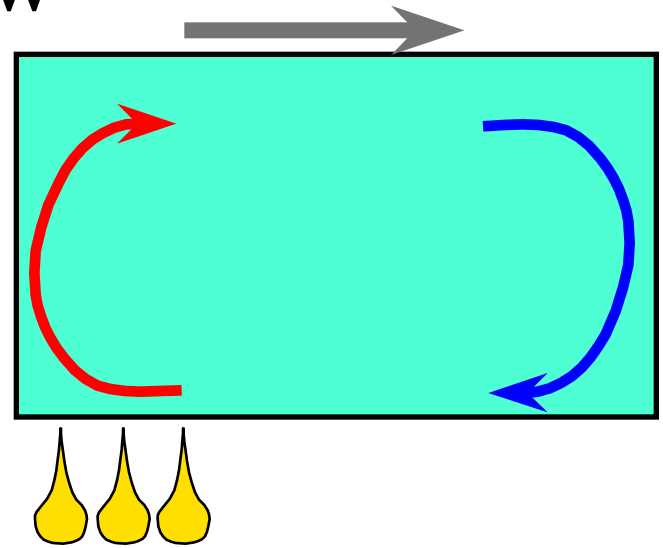
Consequences of a Hot Earth

- Dense material sinks, light float

DIFFERENTIATION

- Some parts weak -- flow

CONVECTION

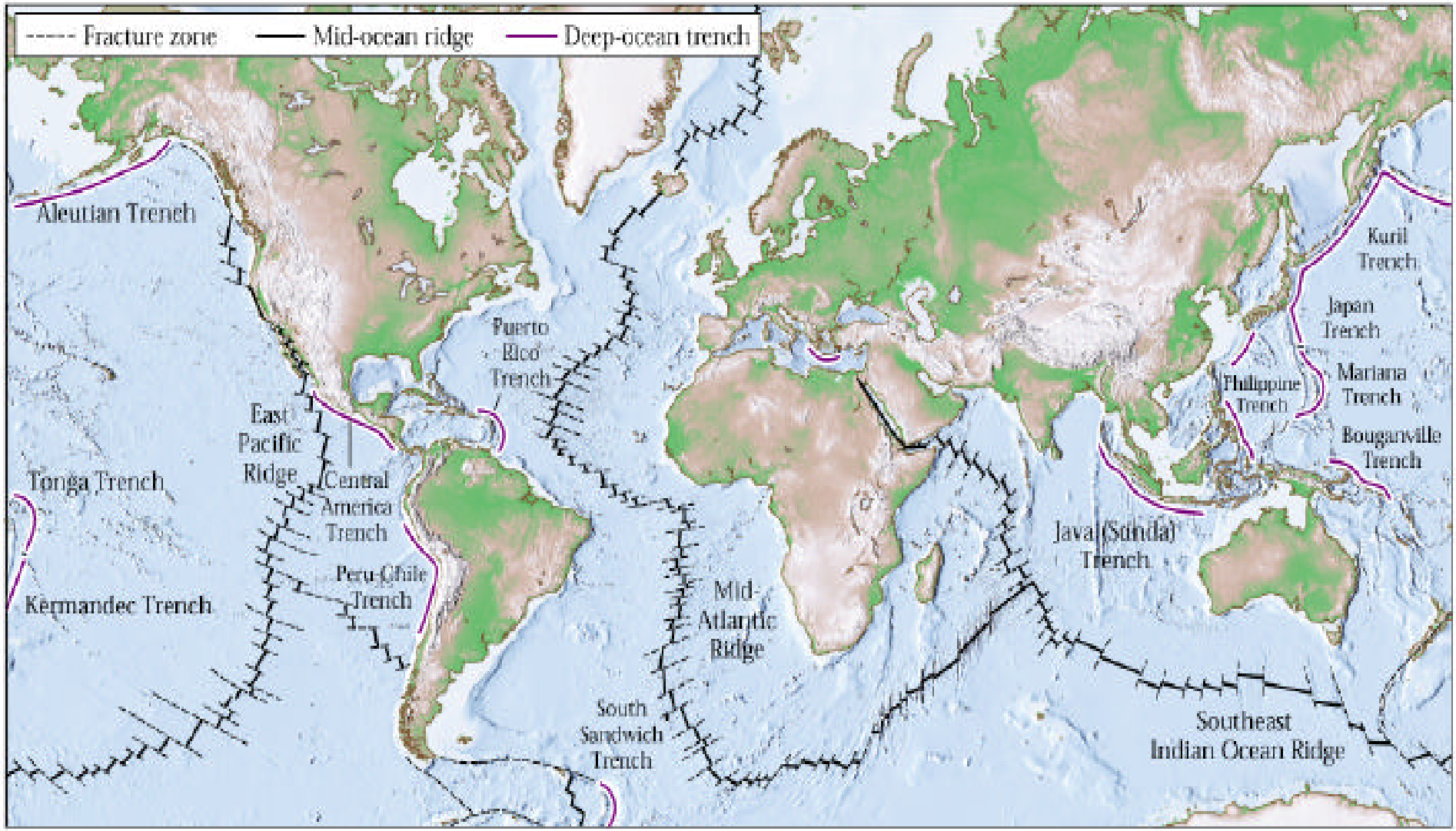


Consequence of Convection....

Plate Tectonics

Large plates move over the Earth surface

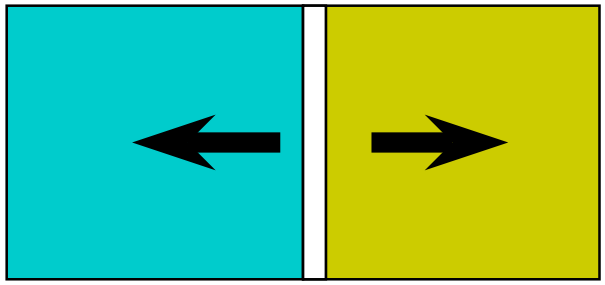
Rates: 5 - 120 mm/yr


Fracture zone
Mid-ocean ridge
Deep-ocean trench
Aleutian Trench
Puerto Rico Trench
East Pacific Ridge
Central America Trench
Peru-Chile Trench
Tonga Trench
Kermandec Trench
Mid-Atlantic Ridge
South Sandwich Trench
Java (Sunda) Trench
Philippine Trench
Kuril Trench
Japan Trench
Mariana Trench
Bougainville Trench
Southeast Indian Ocean Ridge

At Boundaries, Plates...

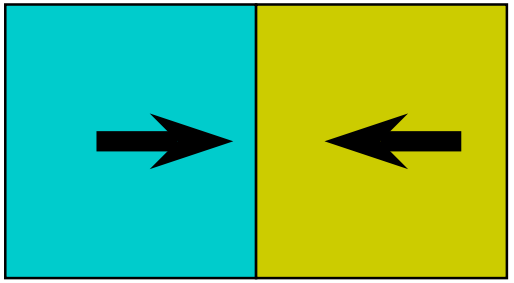
1. Divergent

Spread Apart



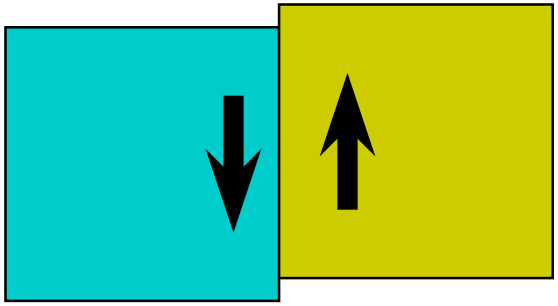
2. Convergent

Collide



3. Transform

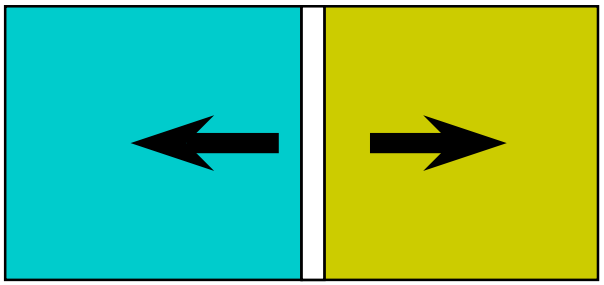
Slide by



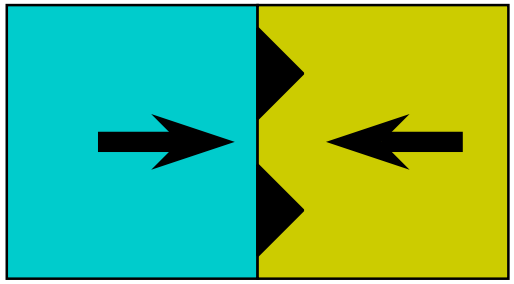
Animations

At Boundaries, Plates...

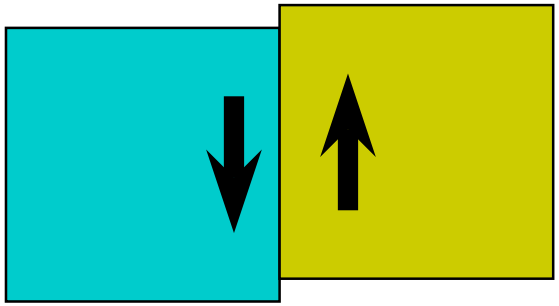
- **Divergent**
  Middle of Atlantic



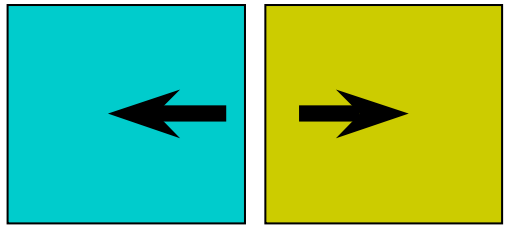
- **Convergent**
  Aleutians



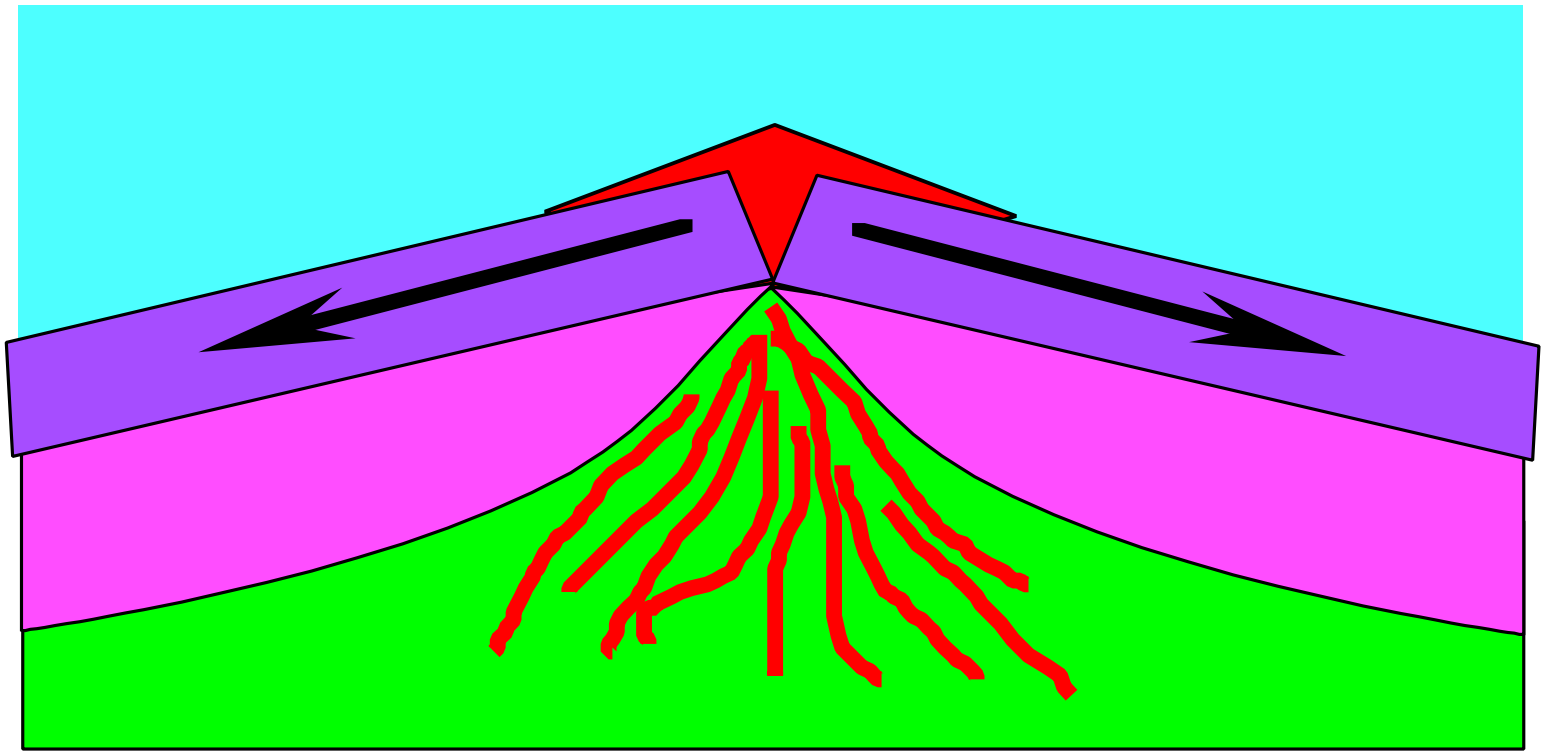
- **Tranform**
  San Andreas Fault



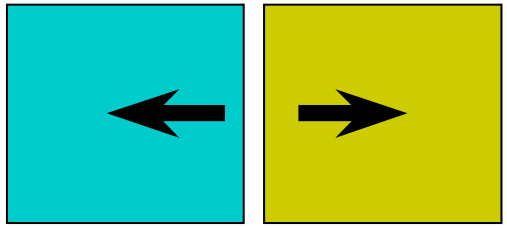
- **Divergent**



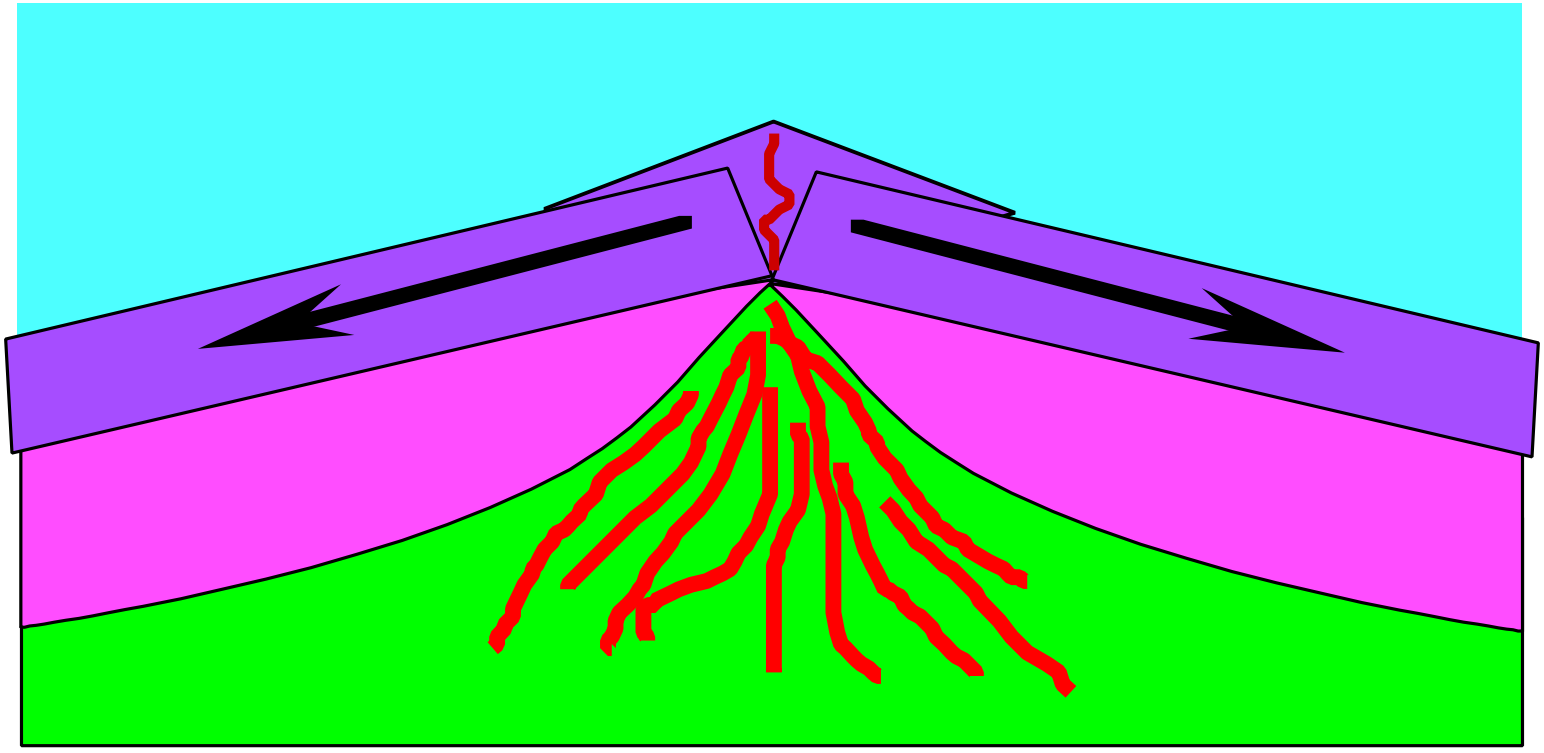
Mid-Ocean Ridge



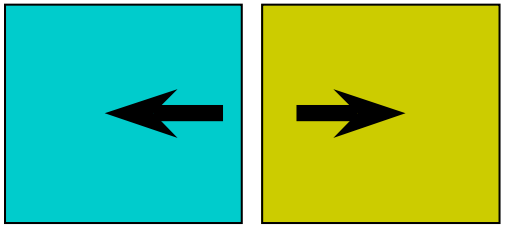
- **Divergent**



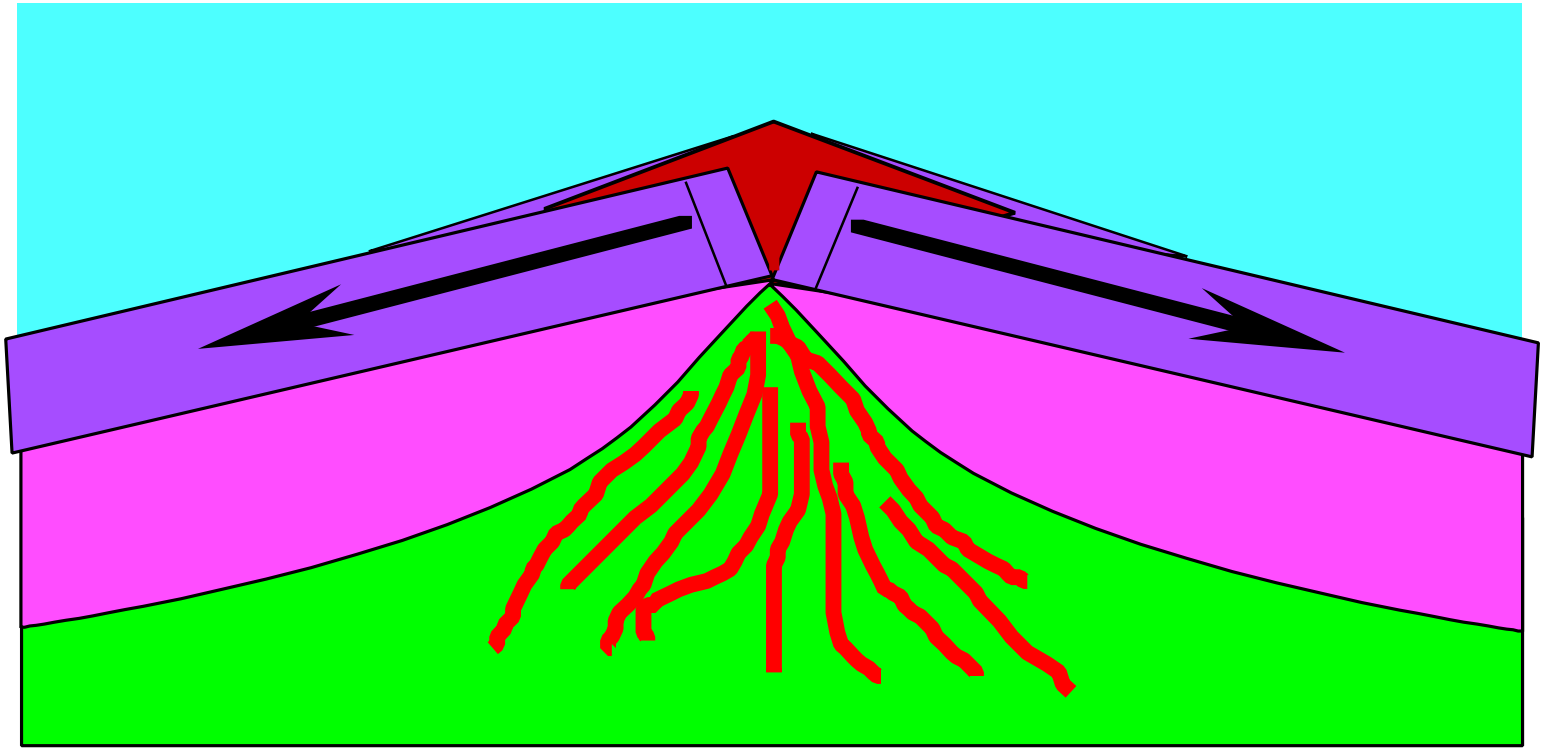
Mid-Ocean Ridge



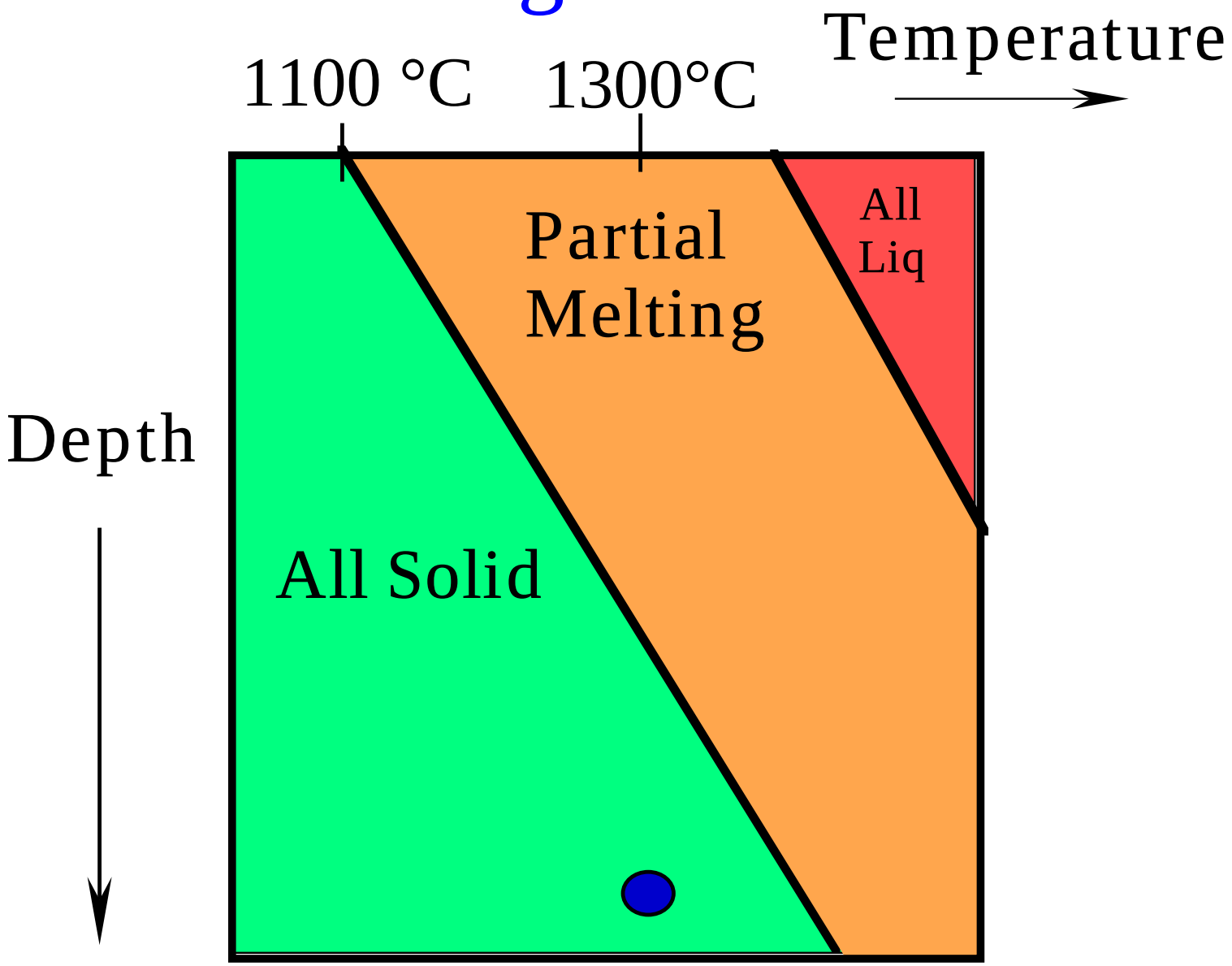
- **Divergent**



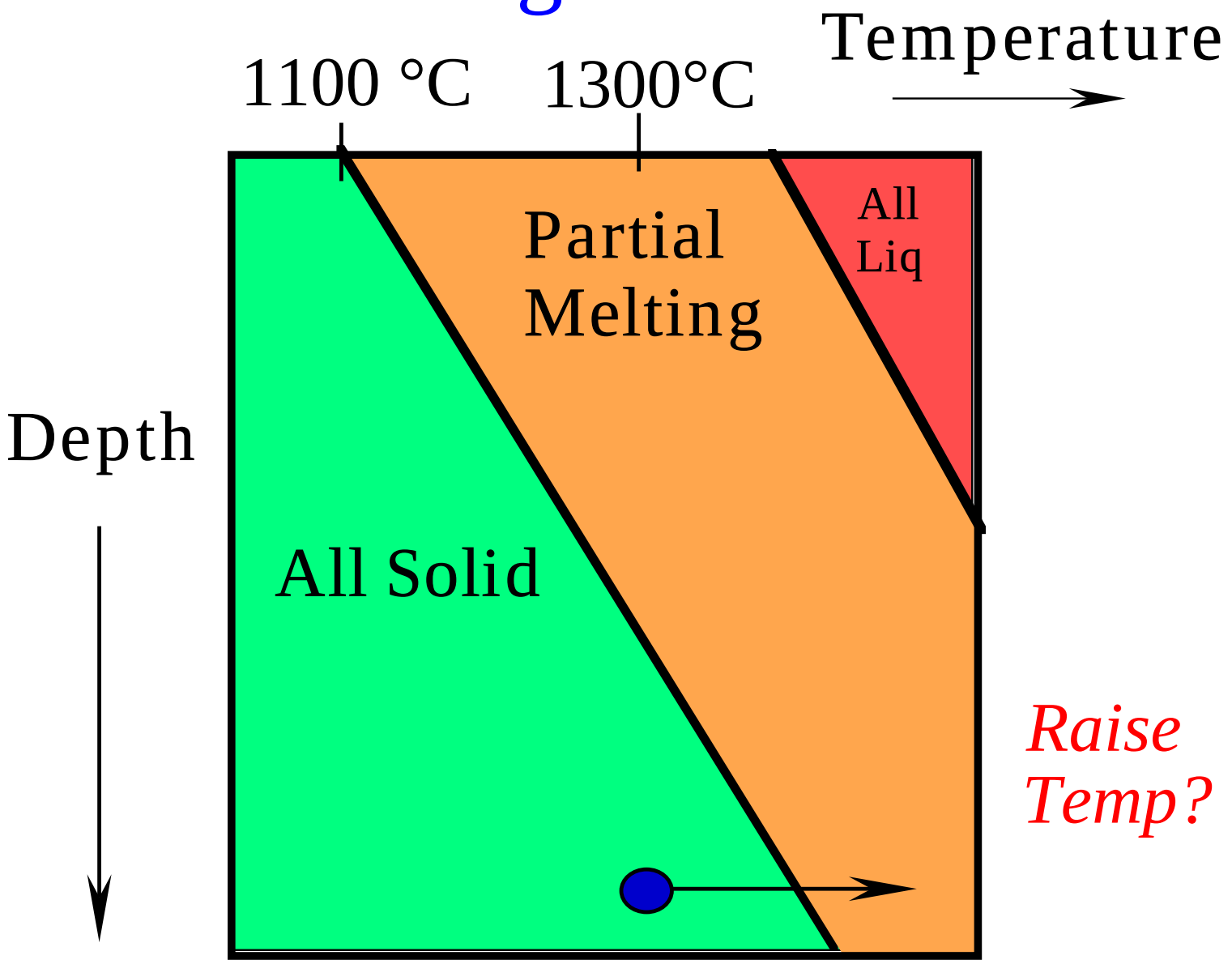
Mid-Ocean Ridge



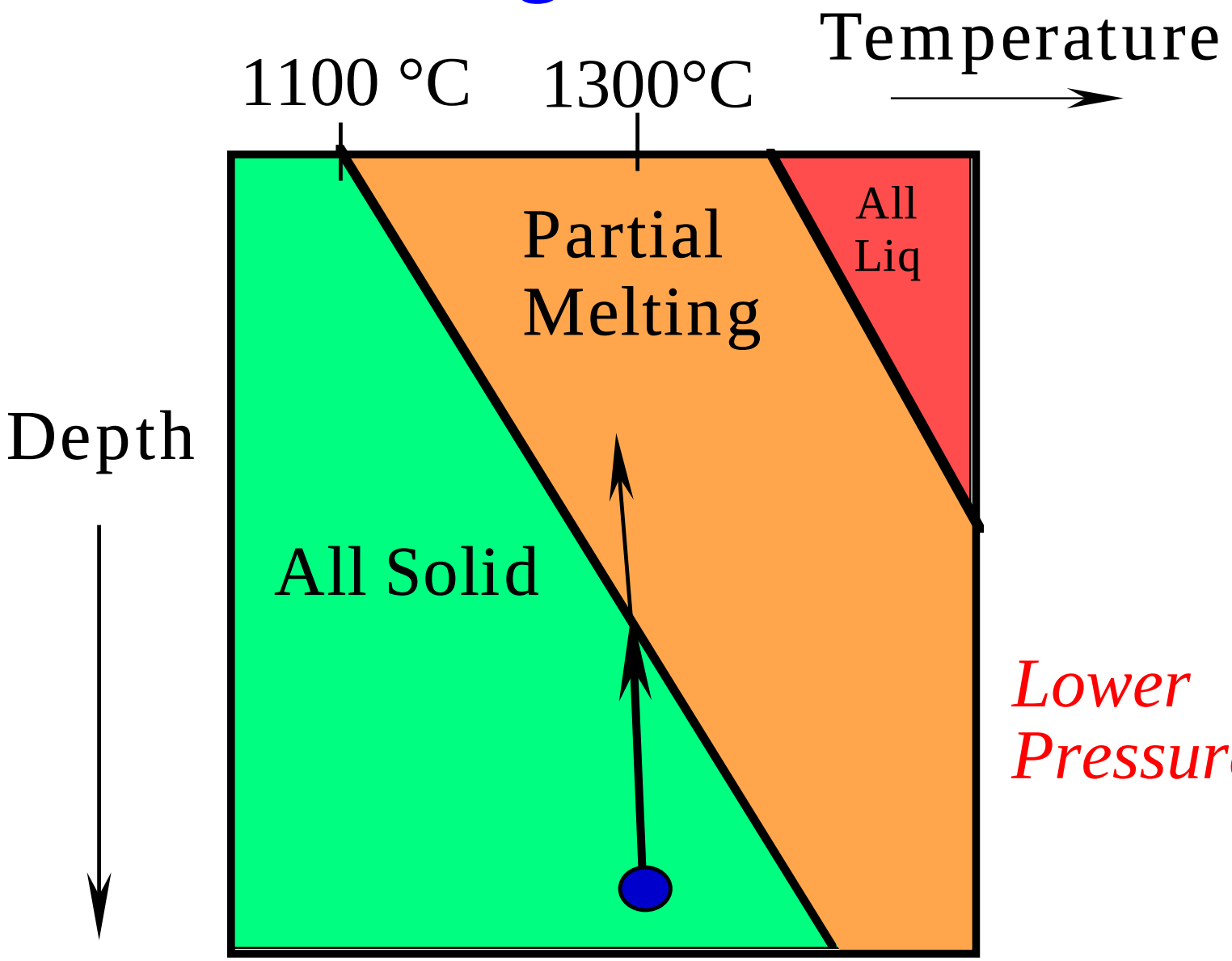
Mantle Melting



Mantle Melting

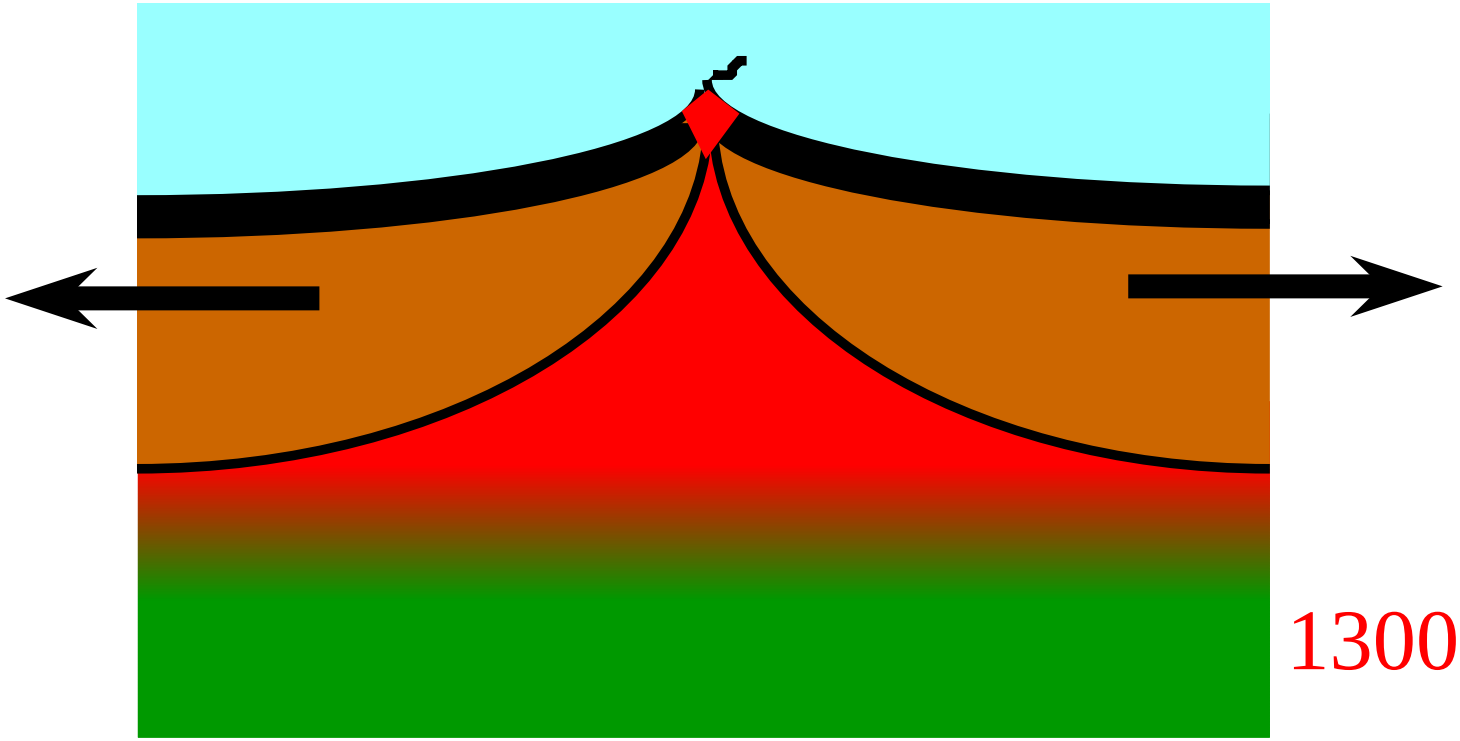


Mantle Melting

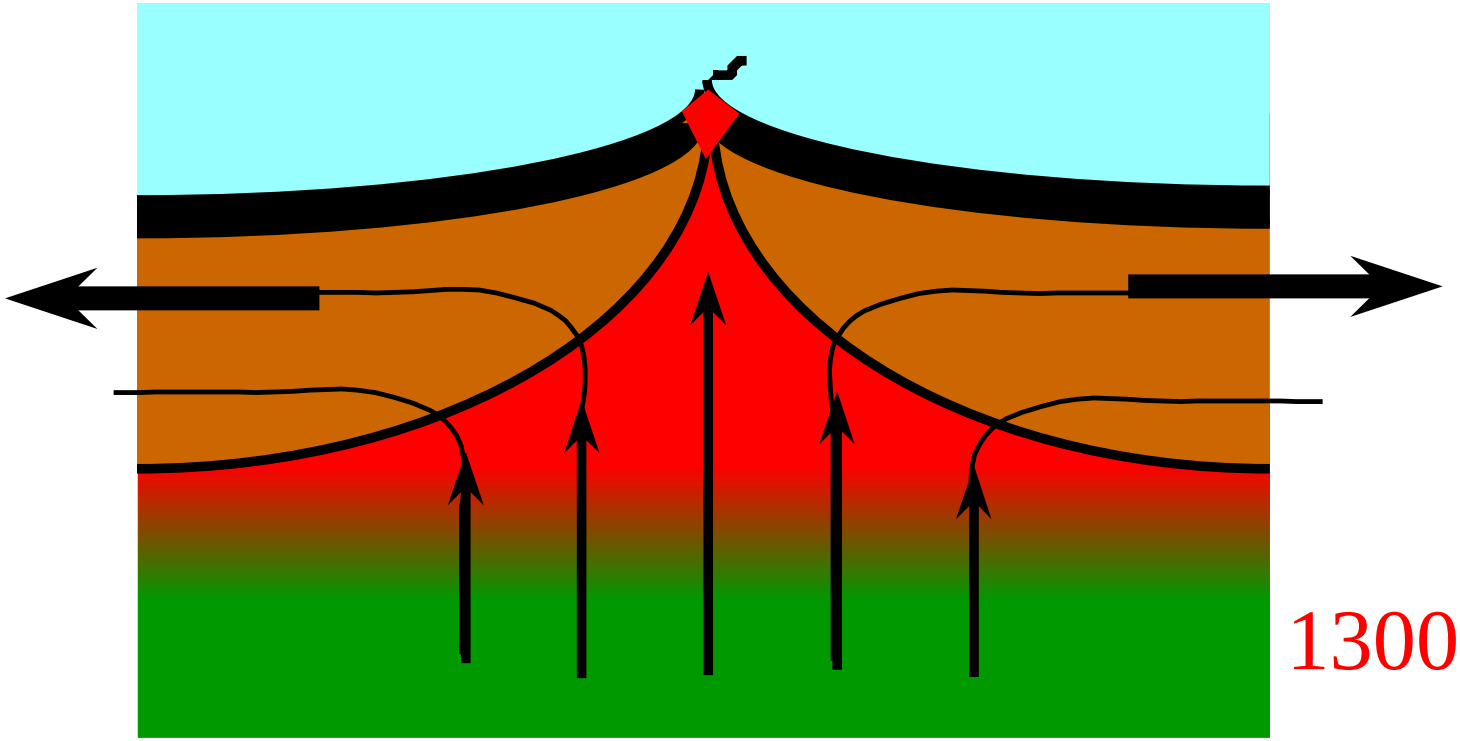


Ridges: plate spreading

mantle below?



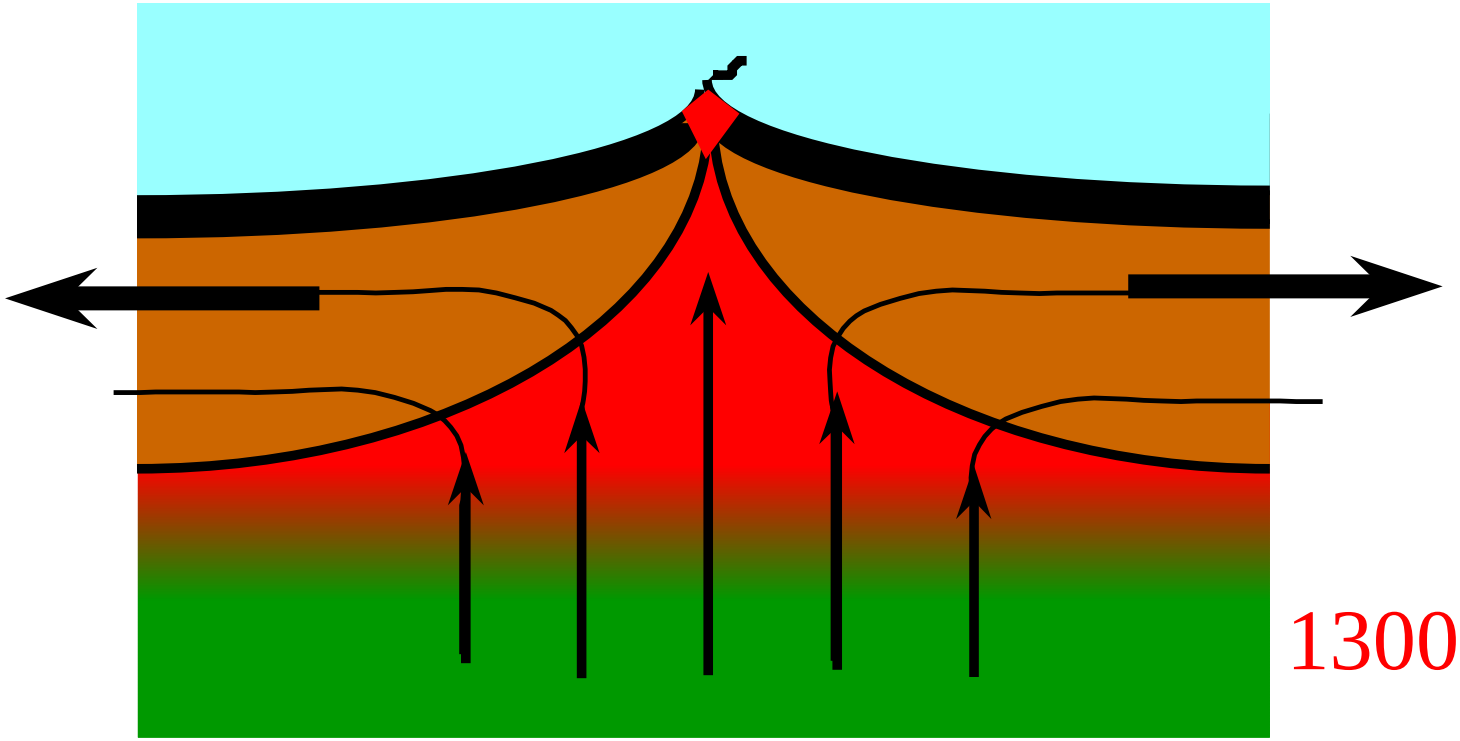
Ridges:



Ridges:

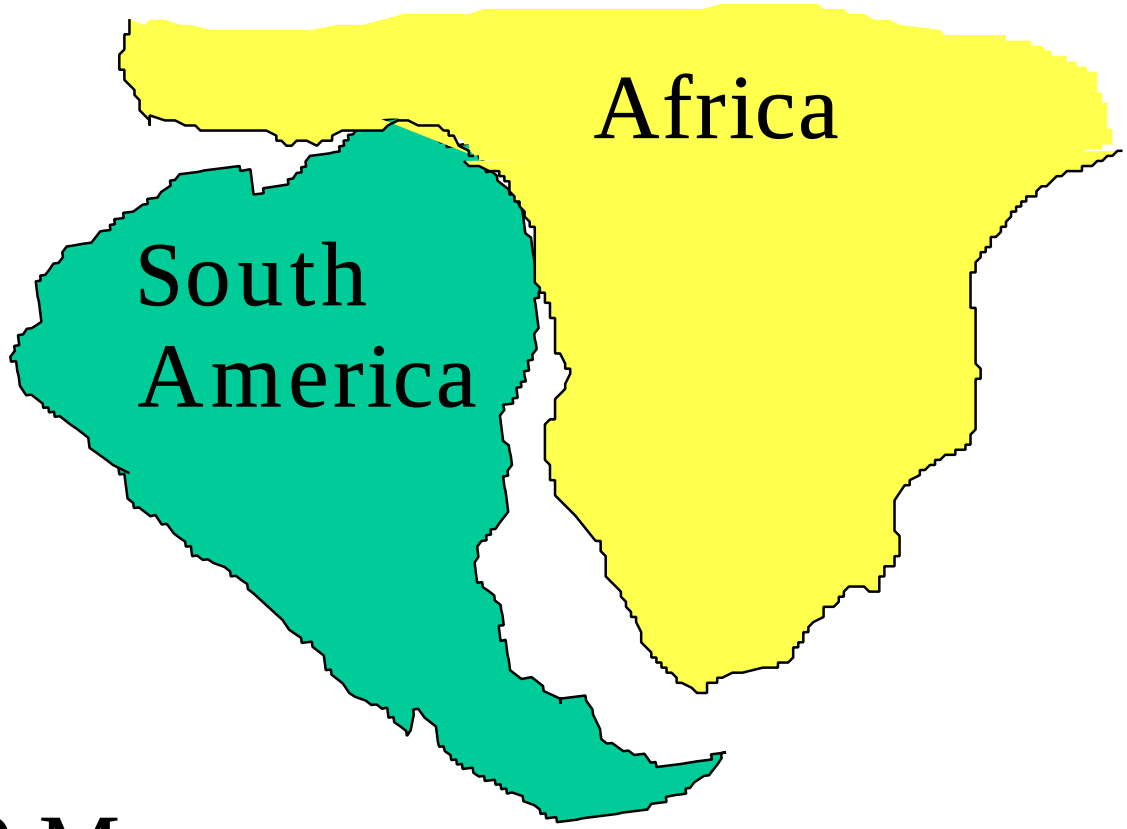
Mantle undergoes **decompression melting**

--->>> **Basalts** (dry)



basalt = mantle melt ("blood of the Earth")

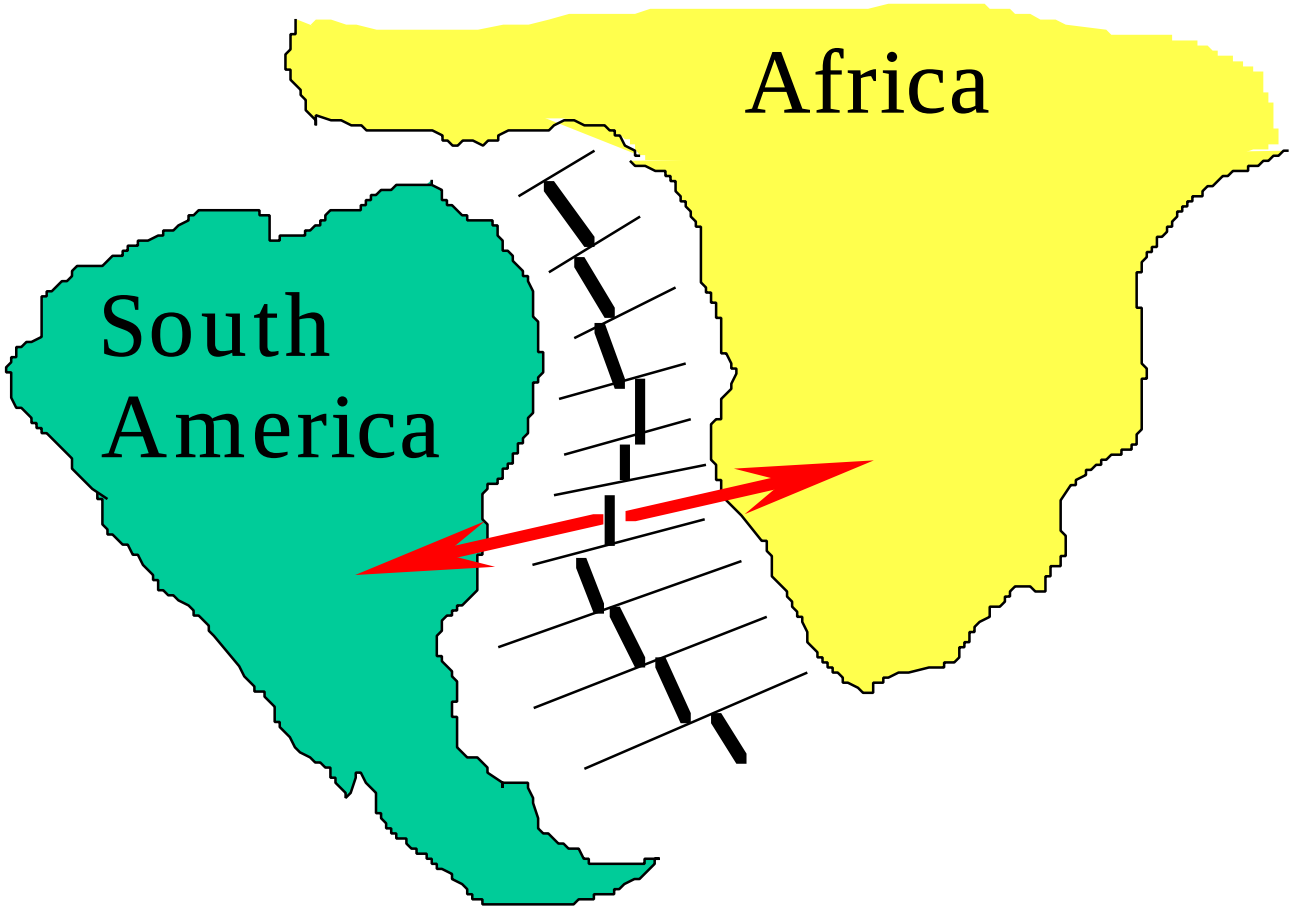
Continental Break-Up



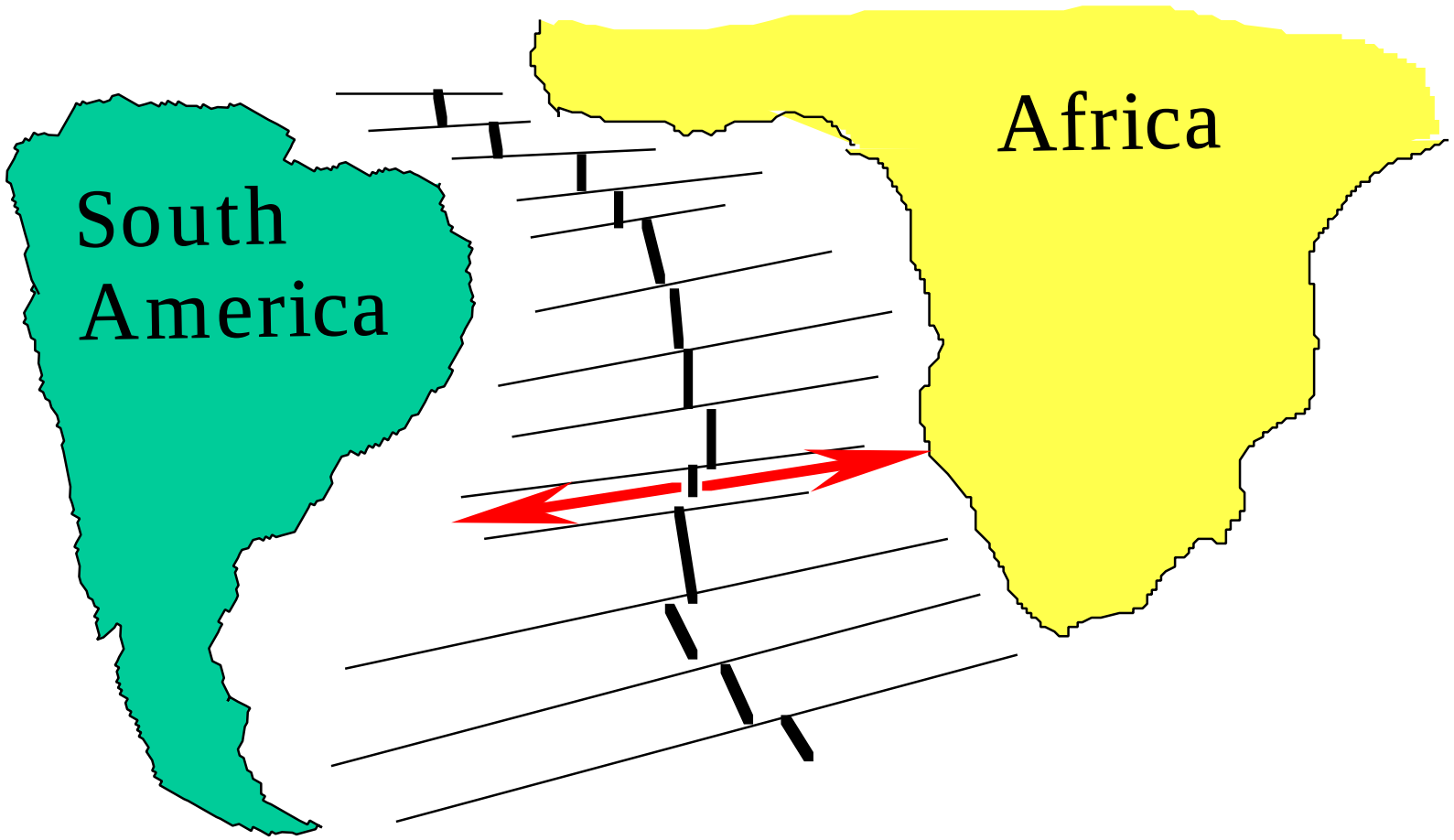
140-110 Ma

Late Jur-Early Cret

Continental Break-Up

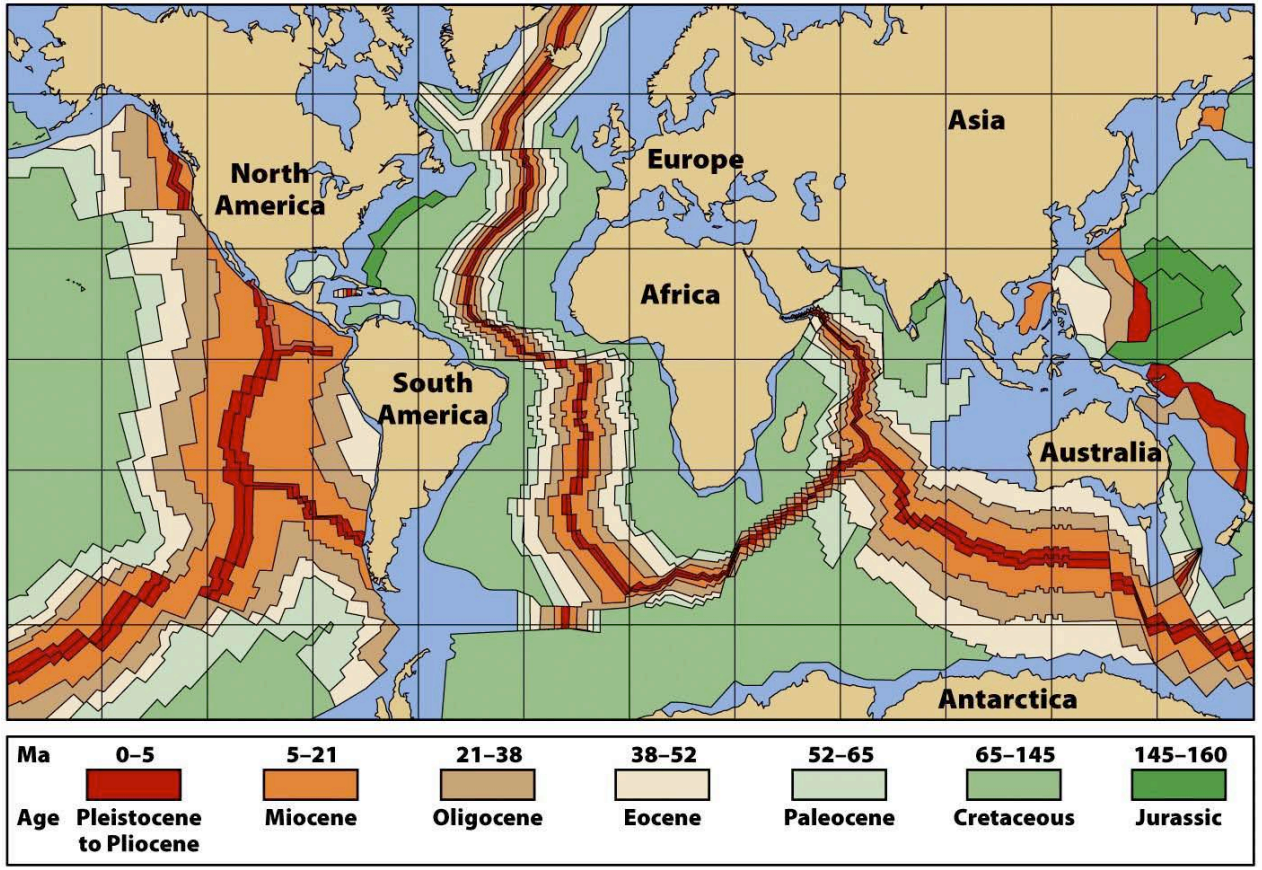


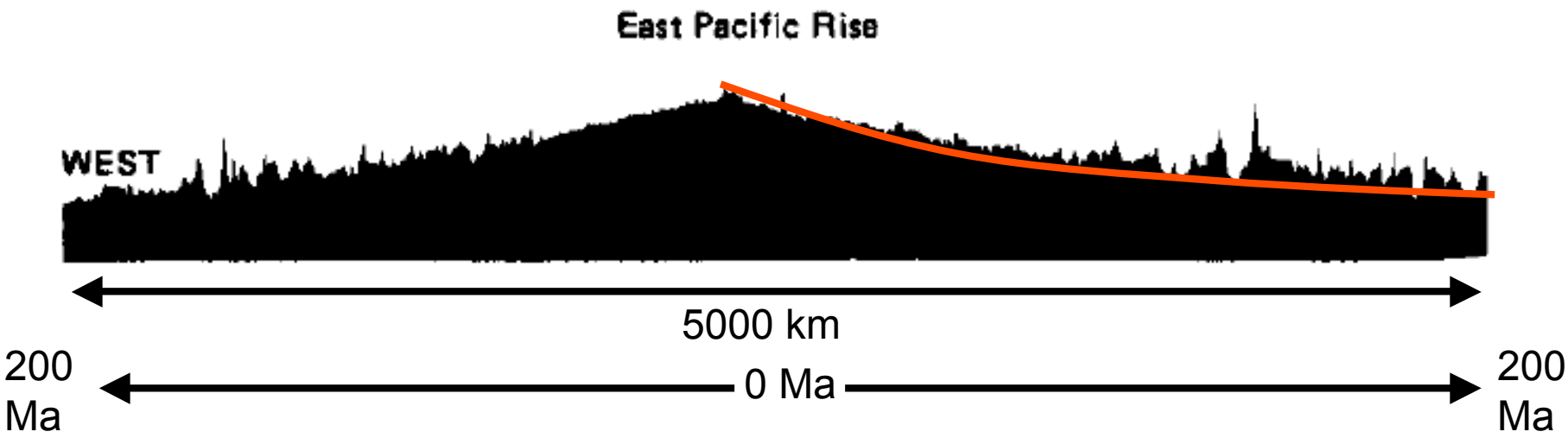
Continental Break-Up



Ocean Crustal Age

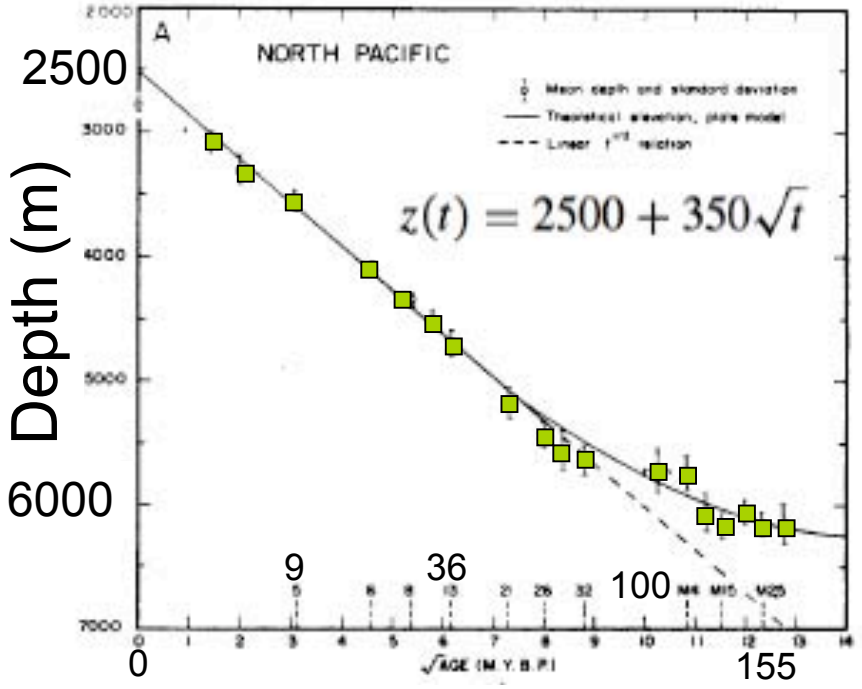
- Oceanic crust spreads away from the ridge axis.
  - New crust is closer to the ridge; older crust farther away.
  - Oldest oceanic crust is found at the far edge of the basin.



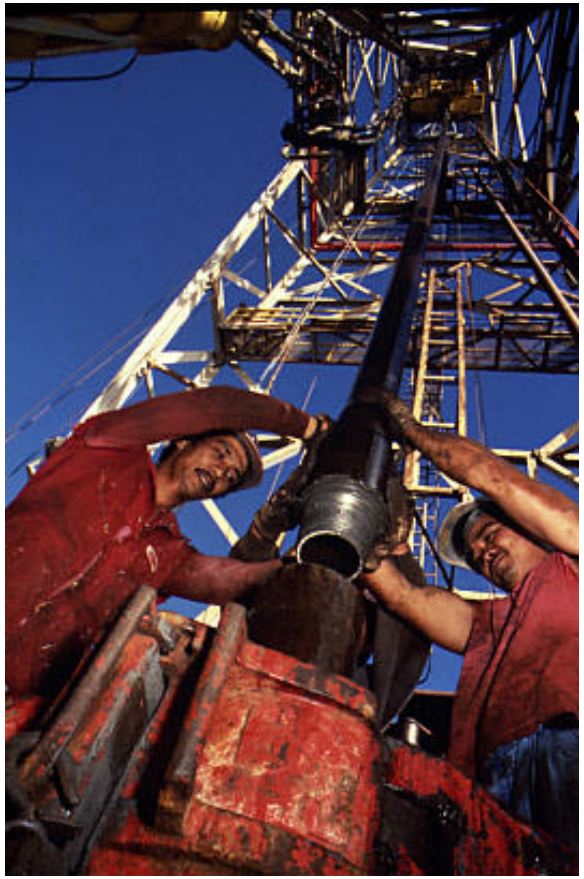


Depth-Age Relationship

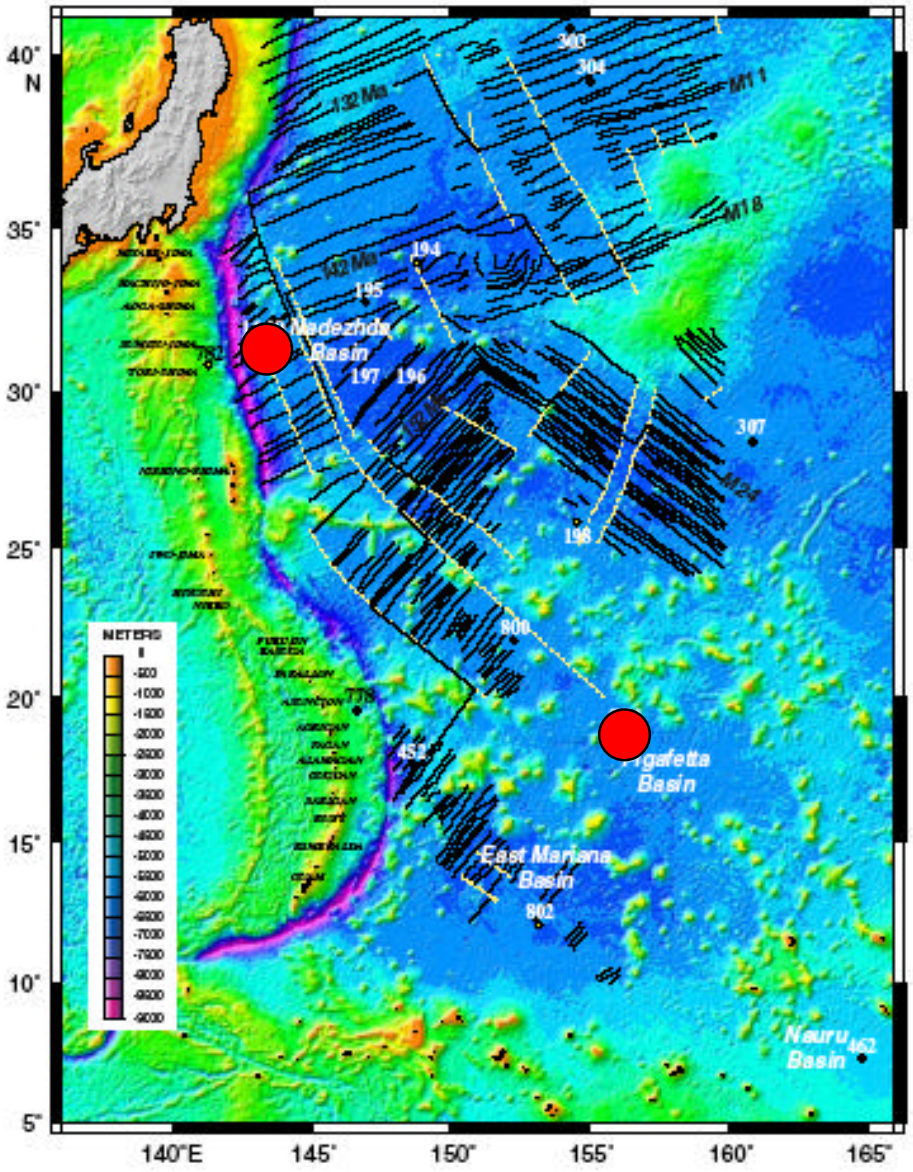
If you know the age of a patch of sea floor, you can predict its depth to amazing accuracy!



Drilling Sedimentary Input to Subduction Zones



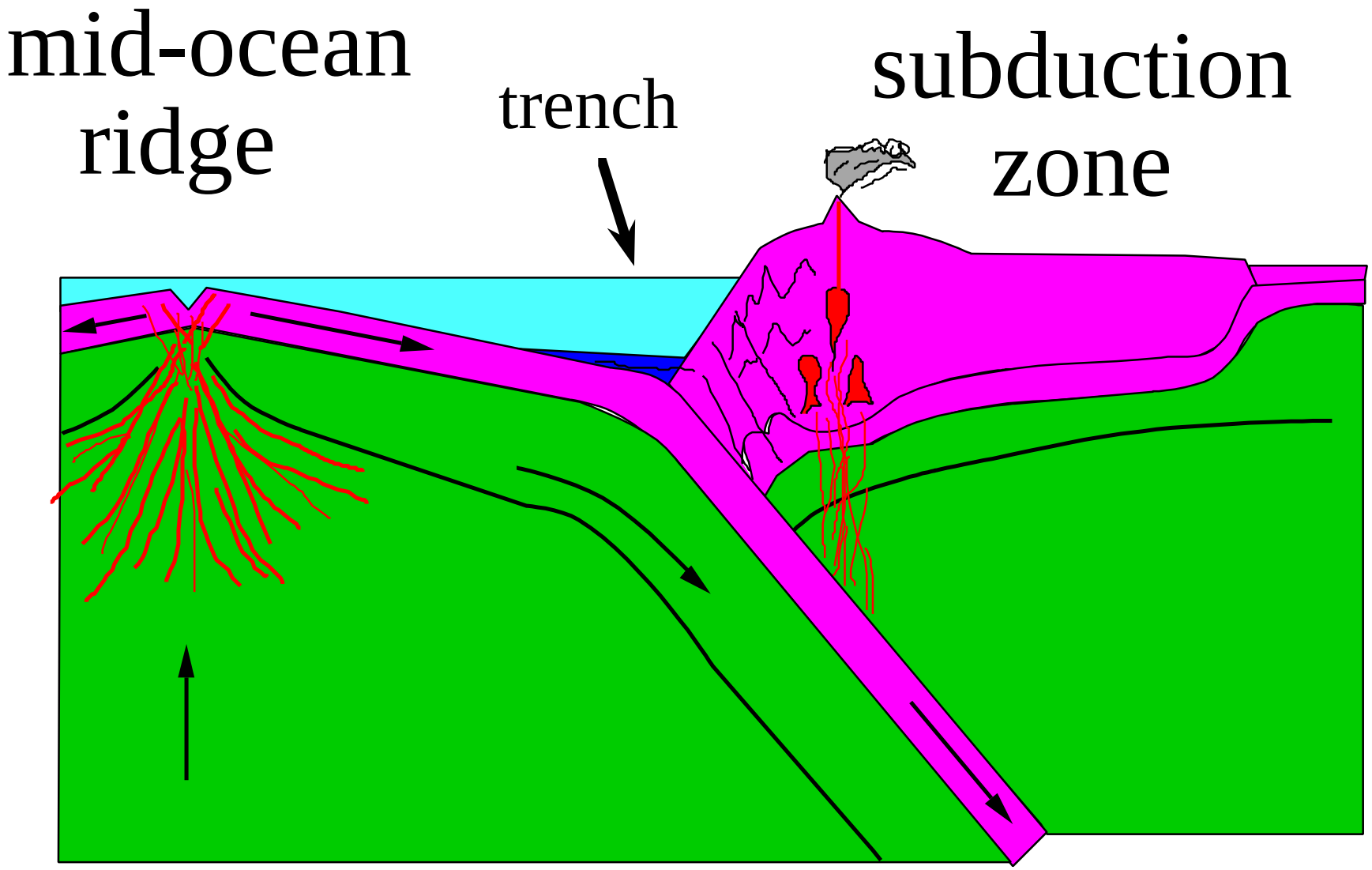
Sediment & Oceanic Crust Cores



ODP Leg 185

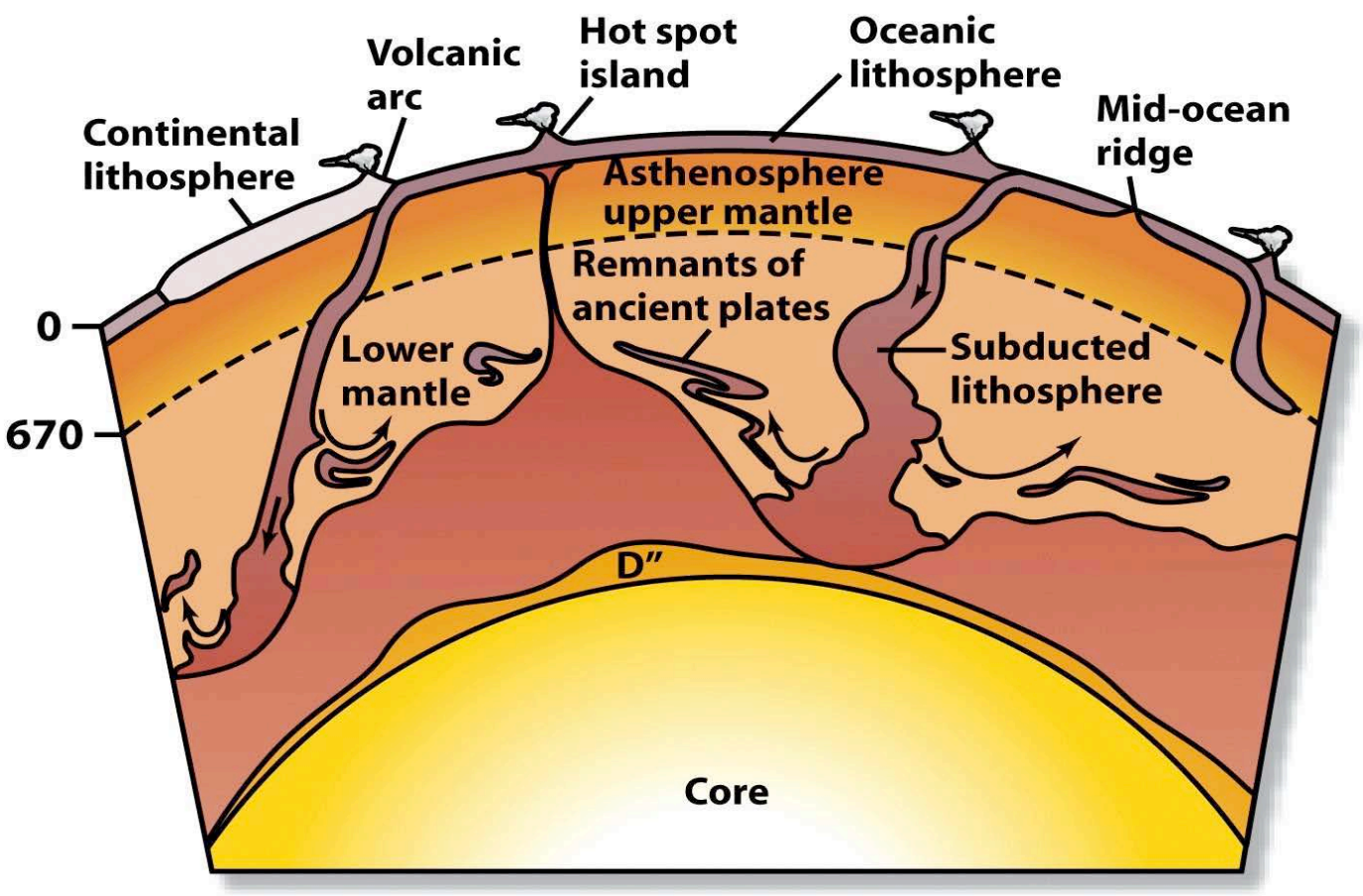
Drilling oldest crust in Pacific

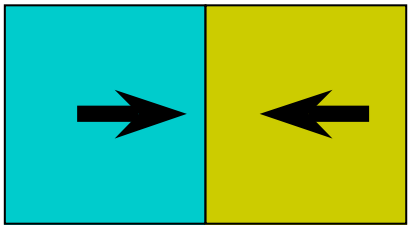

Anatahan, Marianas
2004


mid-ocean ridge
trench
subduction zone

Fate of Subducted Plates?

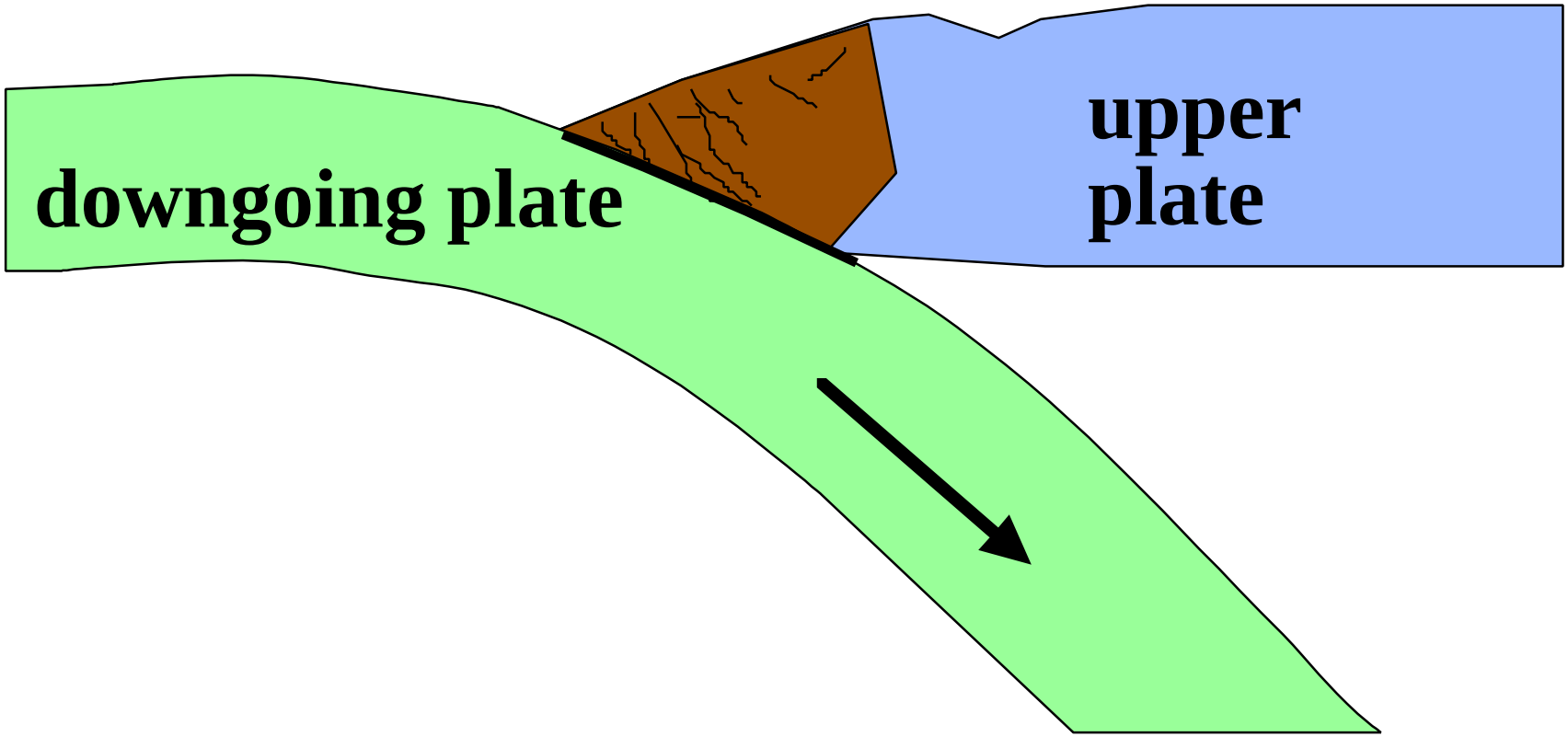
- Plate descent continues past the earthquake limit.
- The lower mantle may be a "plate graveyard."





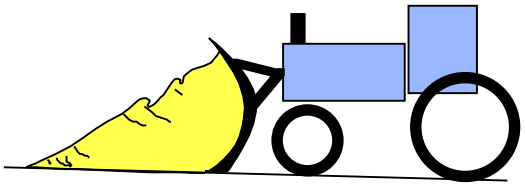
- **Convergent**

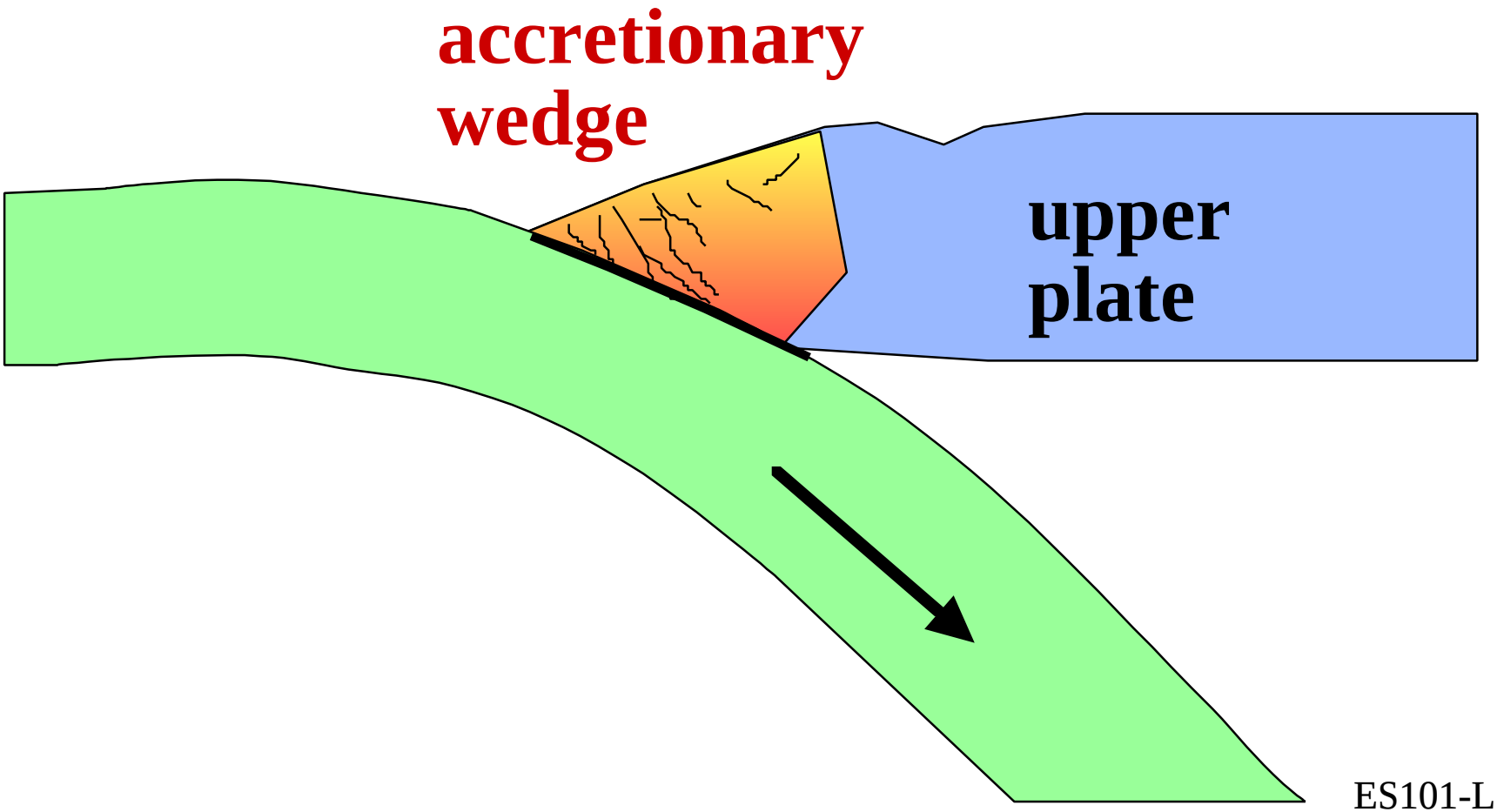
Subduction



Subduction Zones

Upper plate like "bulldozer" scraping sediments

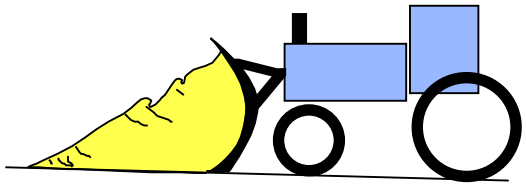




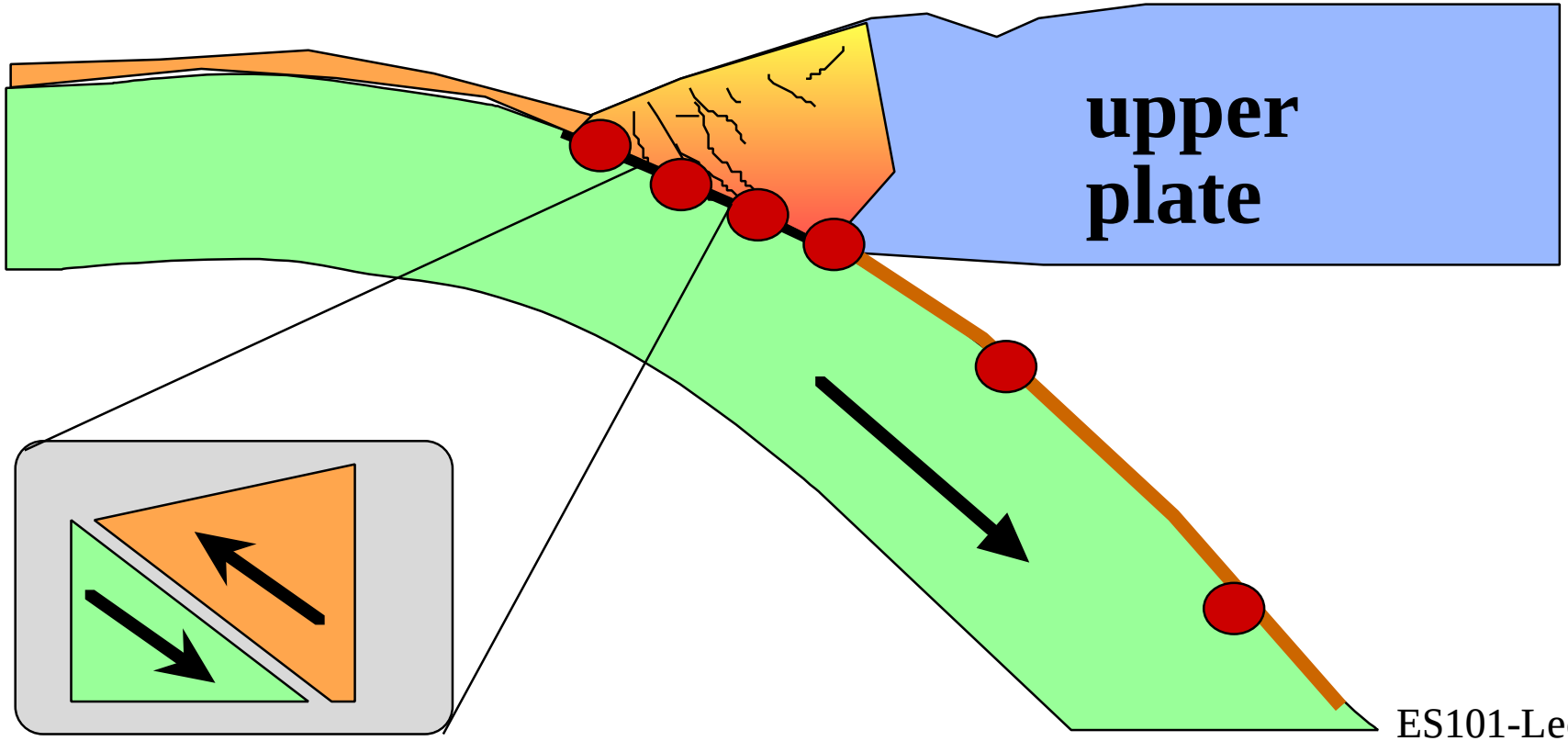
Convergent Boundaries

- **Accretionary prisms – Deformed sediment wedges.**
  - **Sediments scraped off subducting plates are smeared and welded onto the overriding plates.**
  - **These contorted sediments can be pushed above sea.**
    - **Washington's Olympic Peninsula.**
    - **Taiwan.**

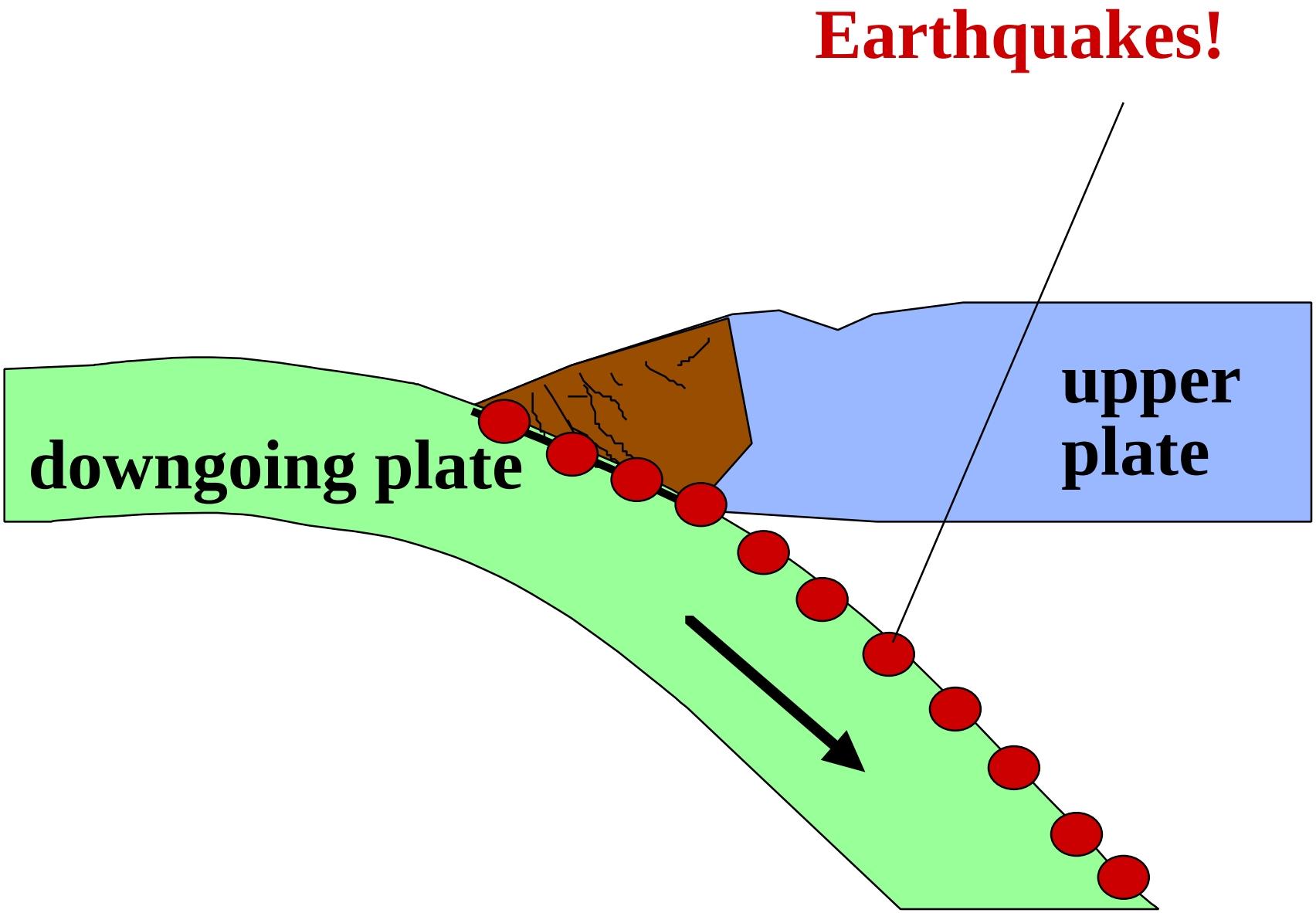
Subduction Zones

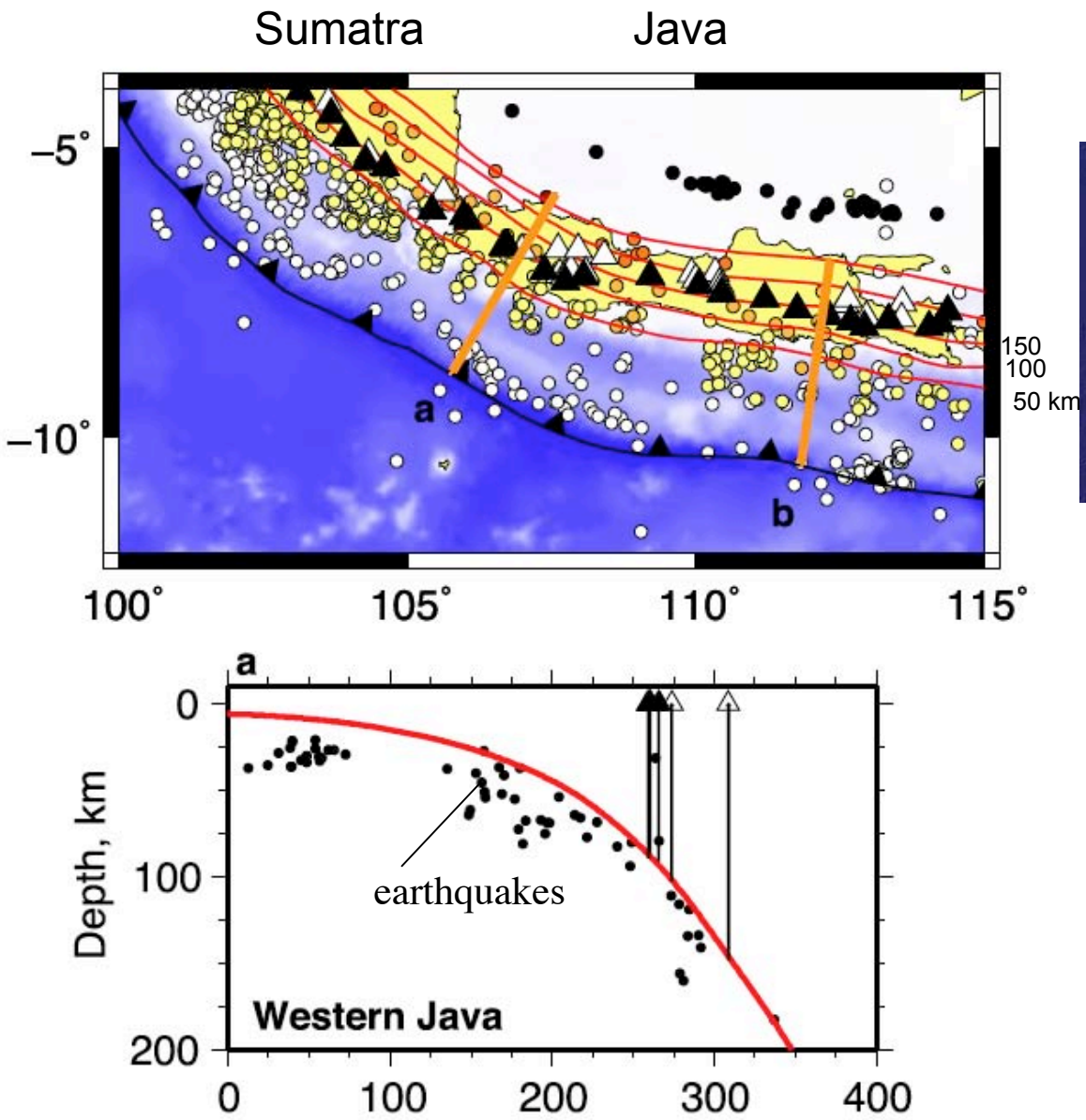


Earthquakes!



Subduction Zones

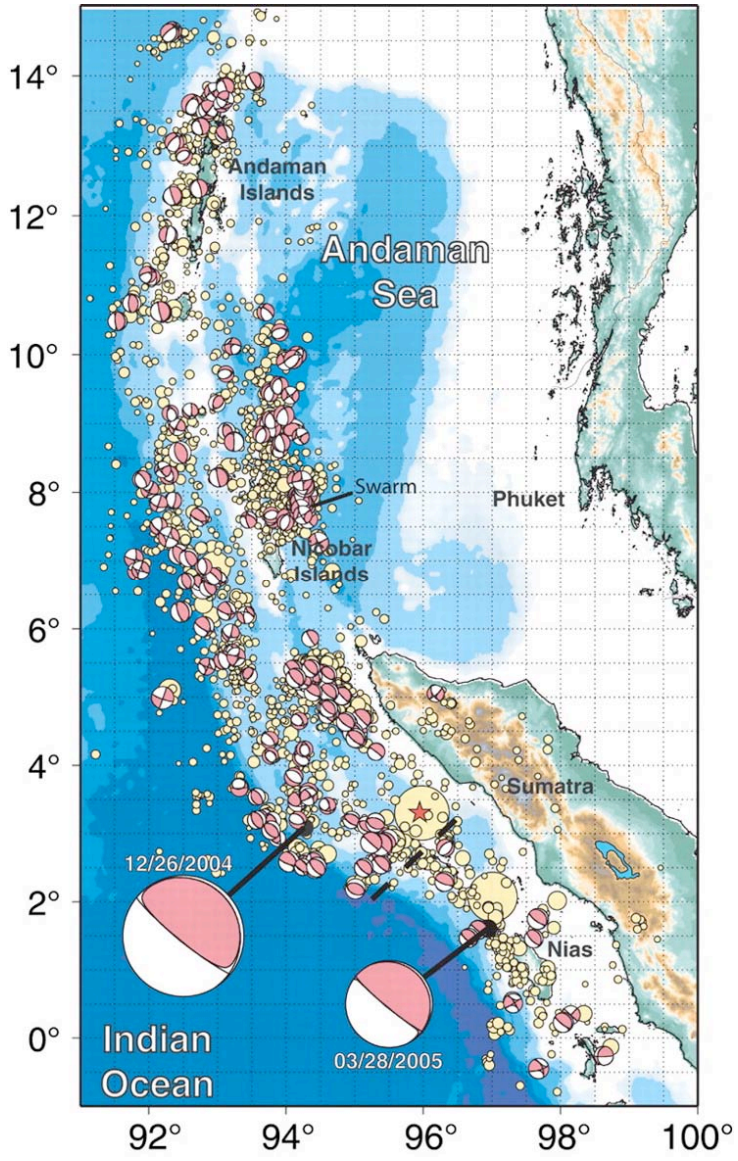




Wadati-Benioff Zone

Earthquakes define
Subducting plate surface

Syracuse & Abers (2006) G3

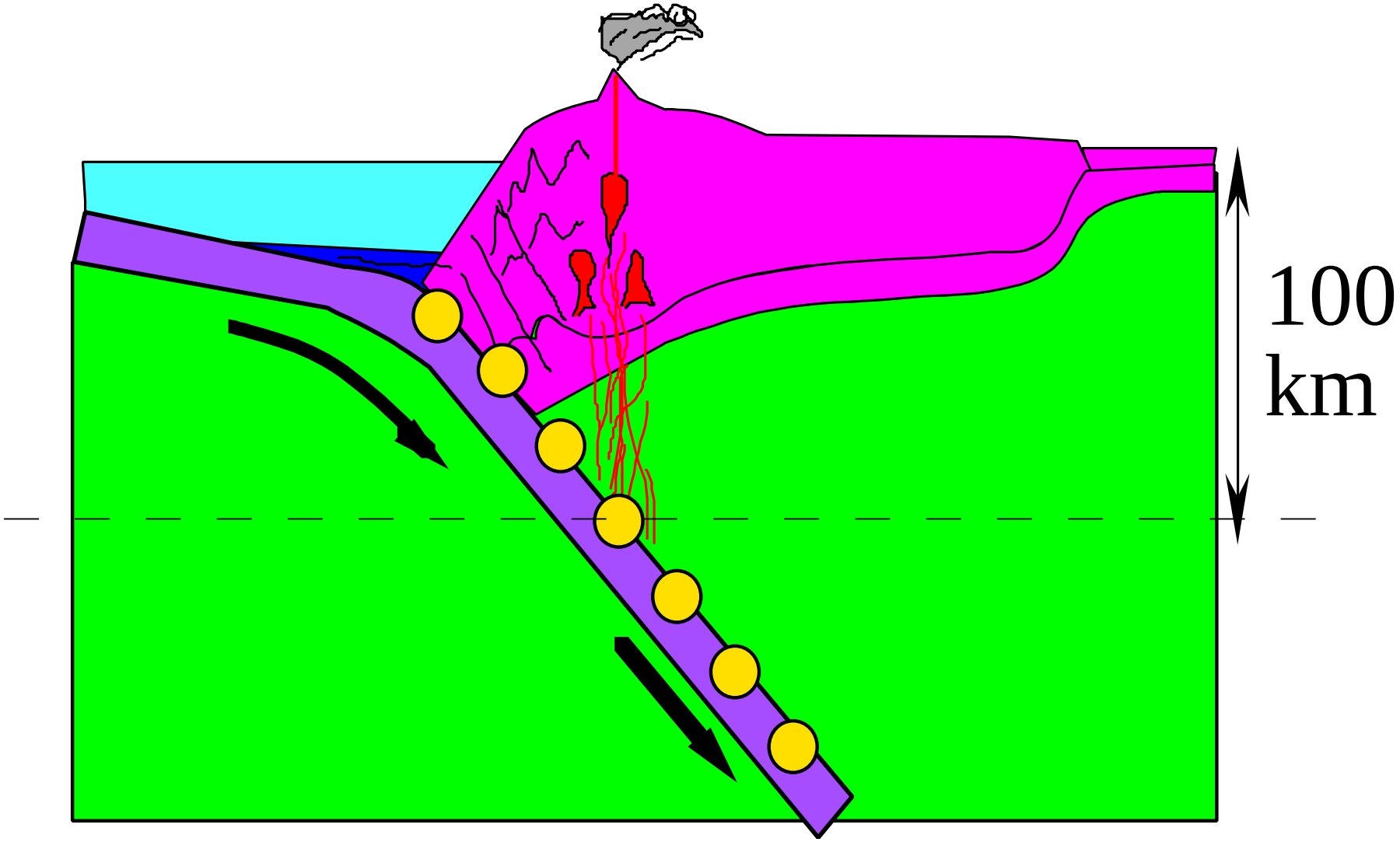


Lay et al, Science (2005)

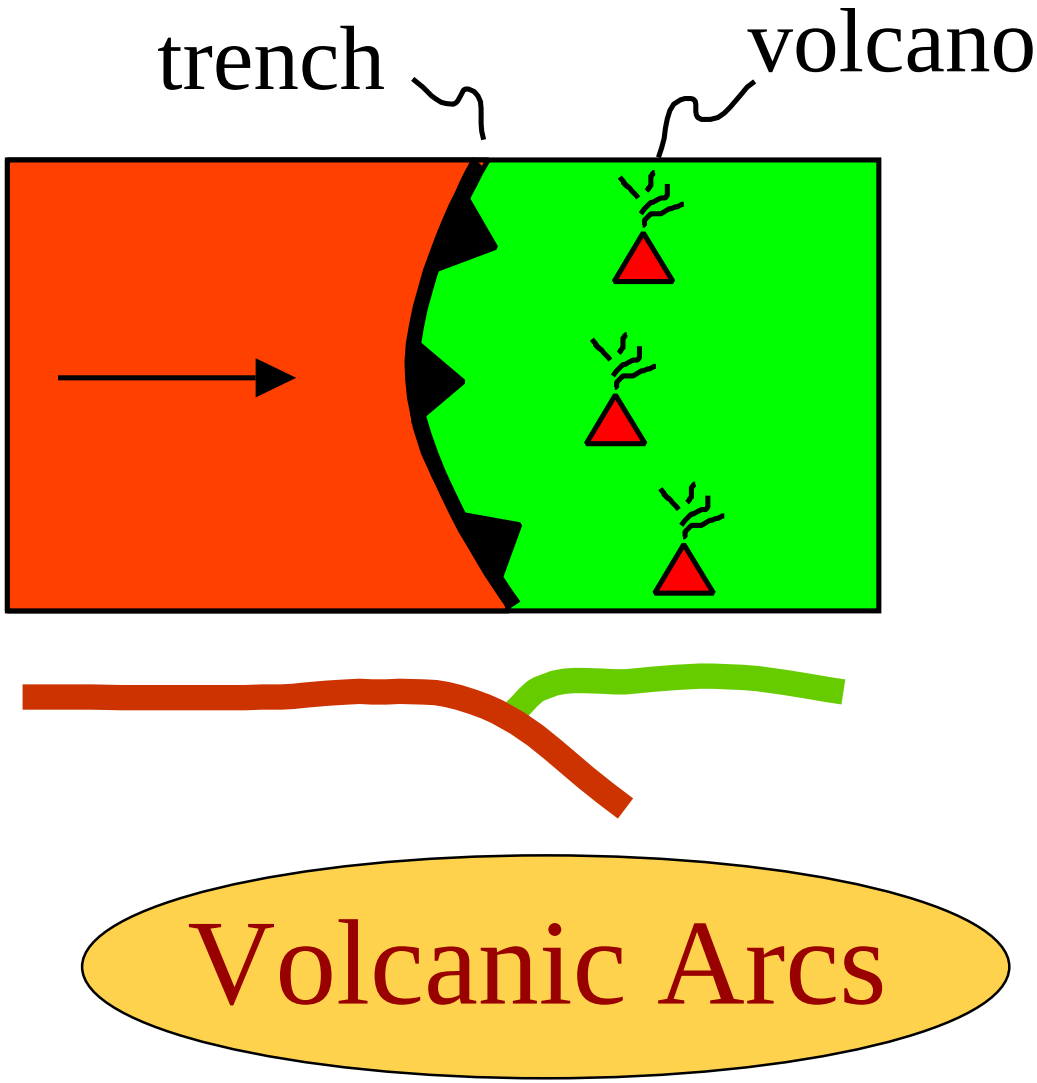
Aftershocks of Sumatra Dec 2004

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.

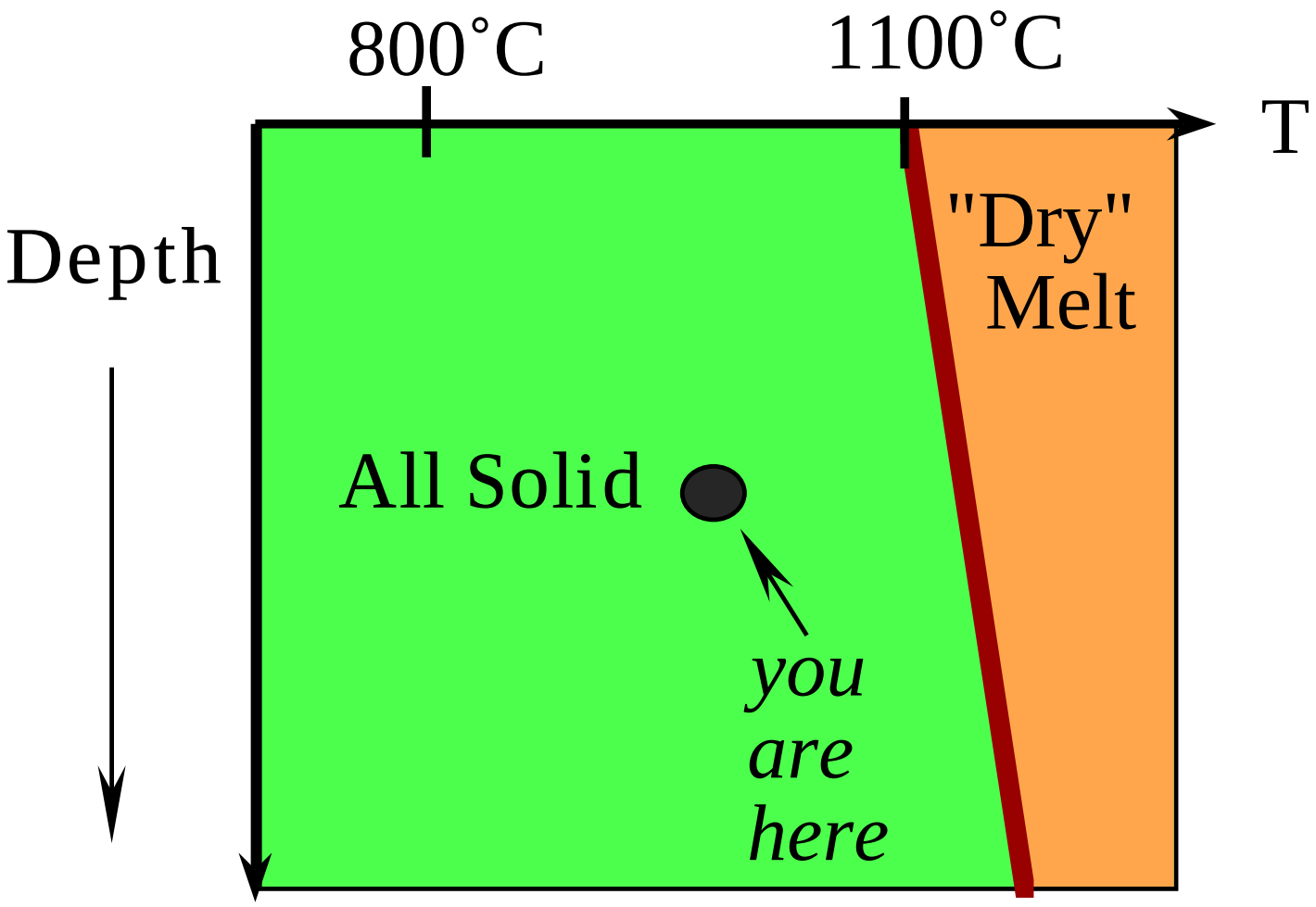
Subduction Volcanism



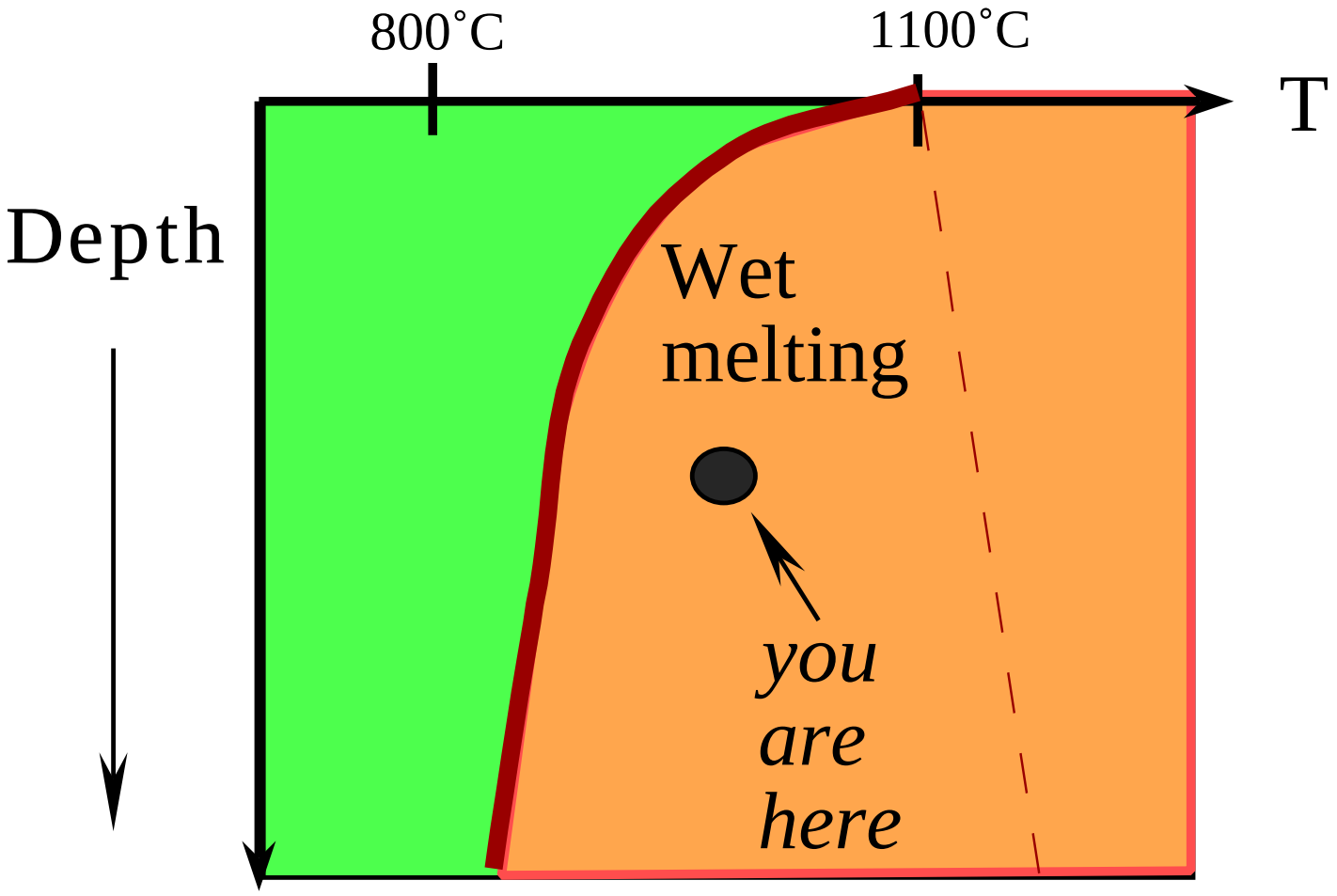
Most subduction zones are **arcuate** on maps



H_2O -- Lowers Melting Point



H_2O -- Lowers Melting Point



Two Ways that the Mantle Melts:

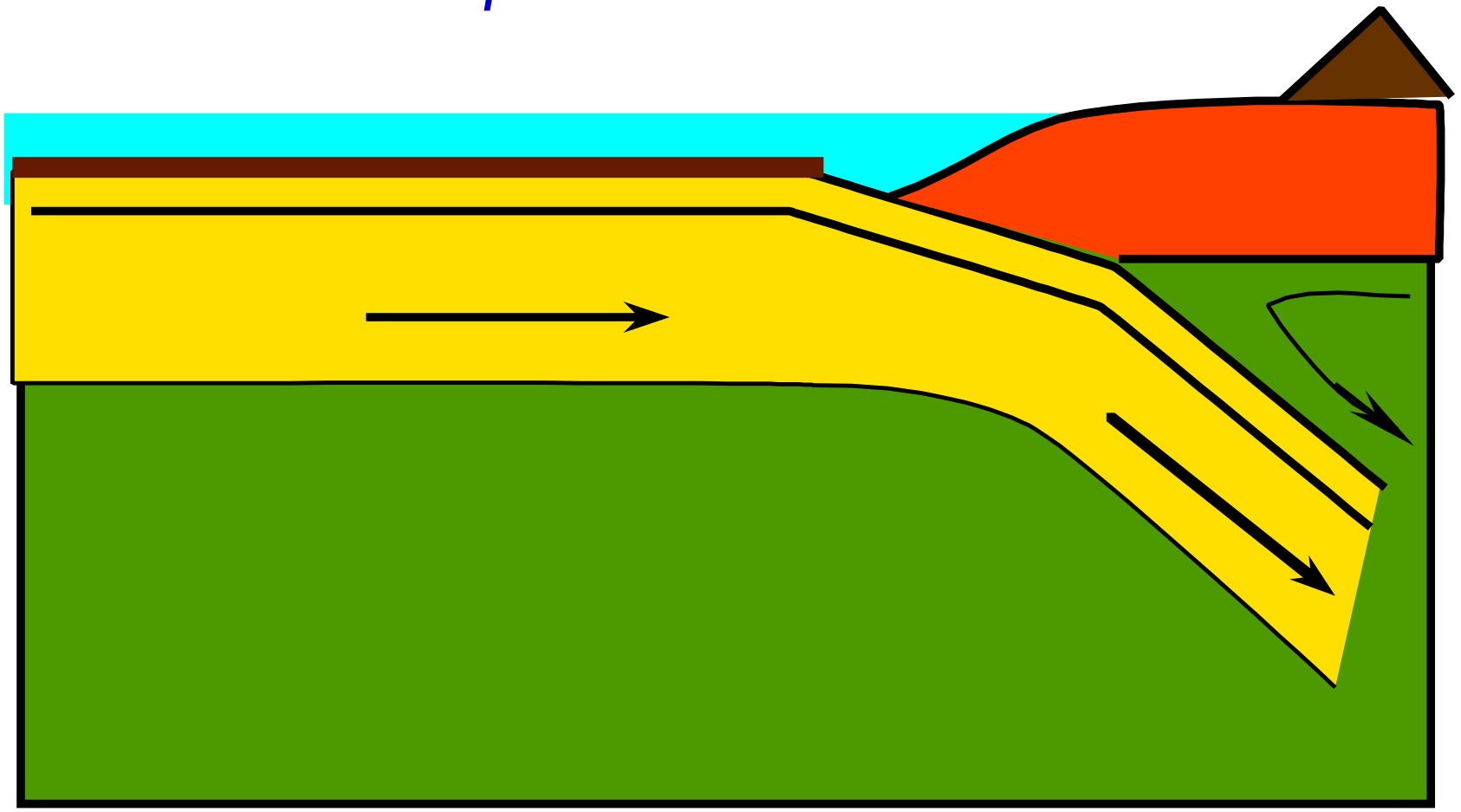
- Decompression
- Water Added

How do we decompress and add water to the mantle??

- **ridges**
- **subduction zones**
- **hot spots**

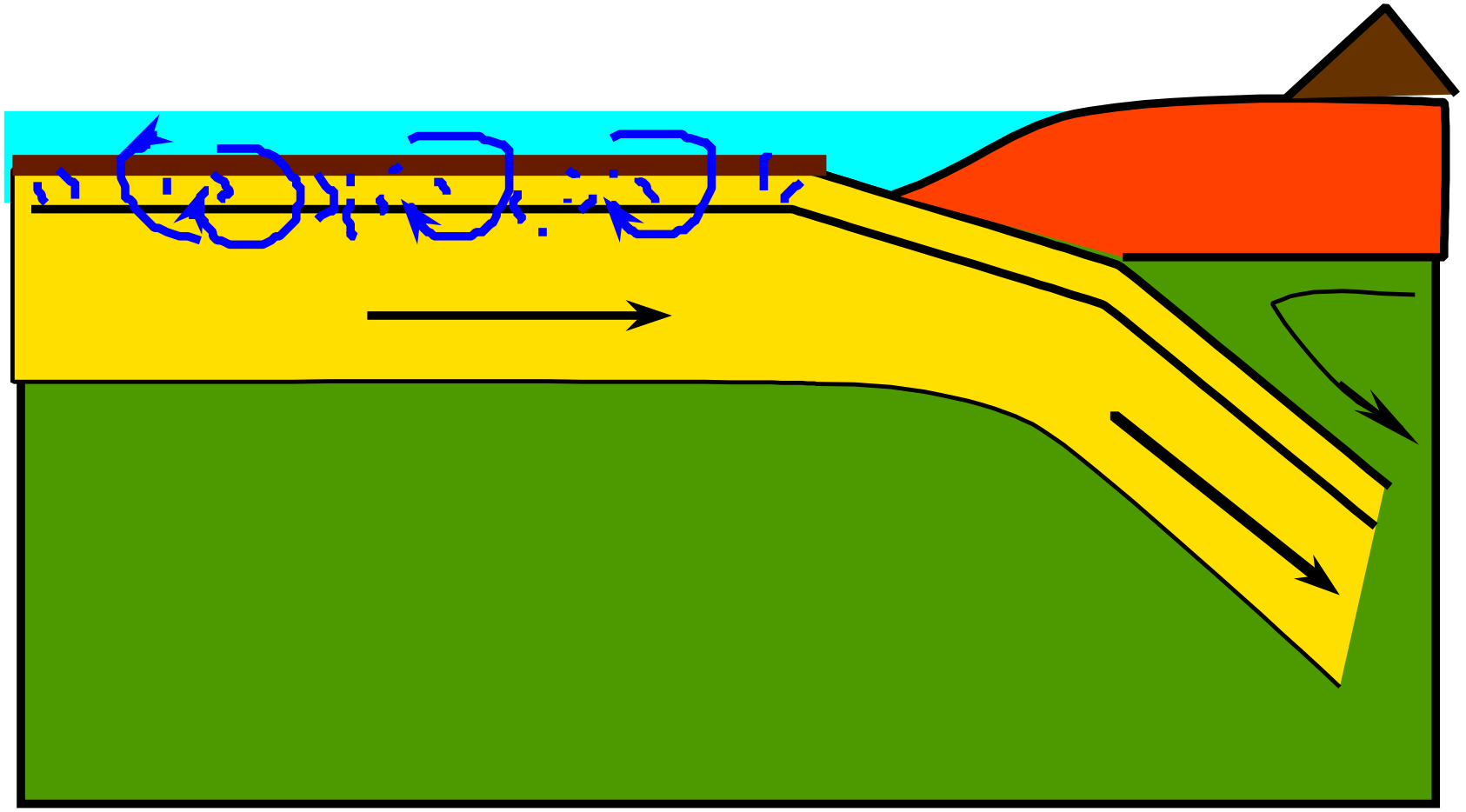
Subduction Zones:

mantle flow?

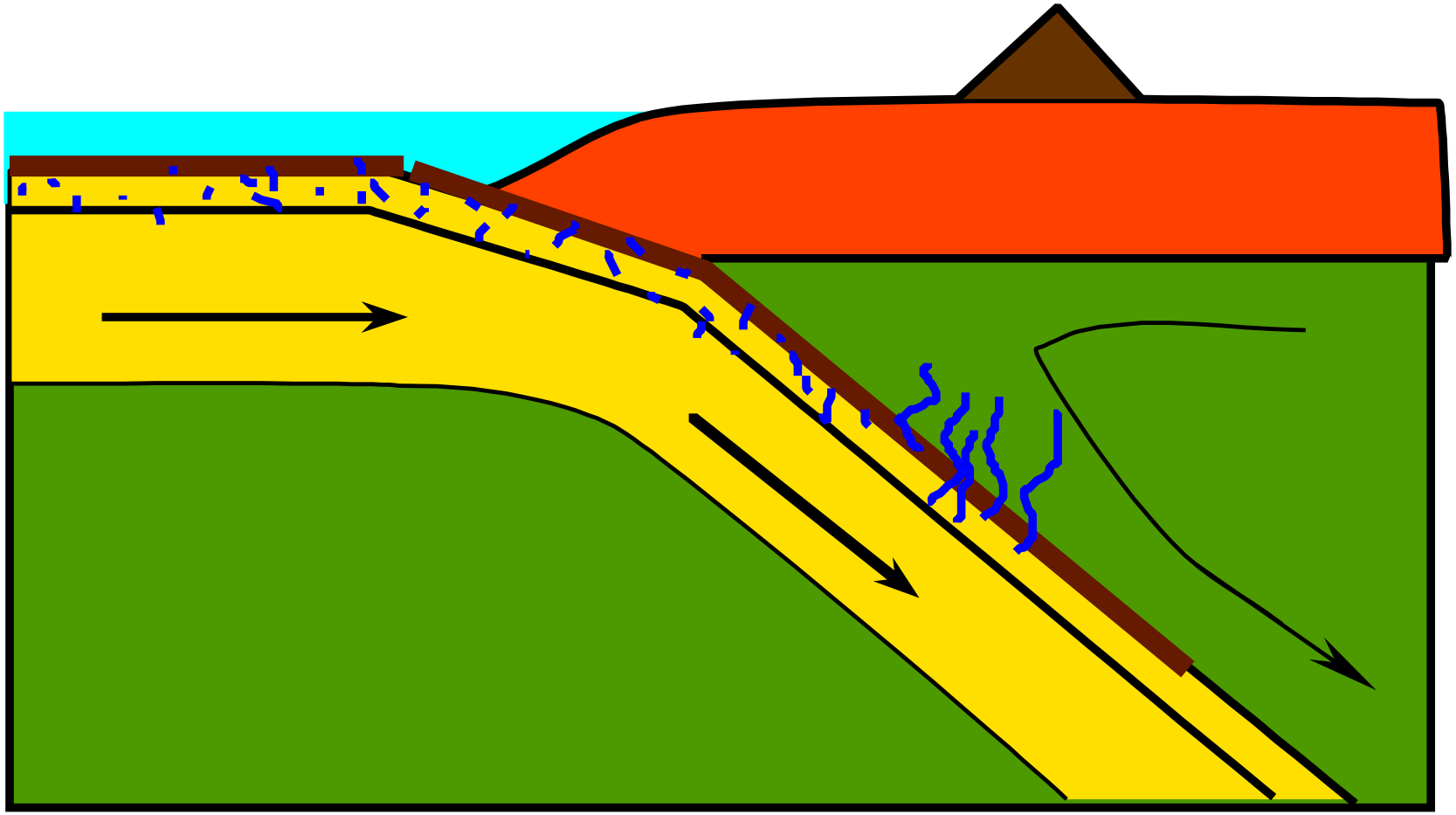


Subduction Zones:

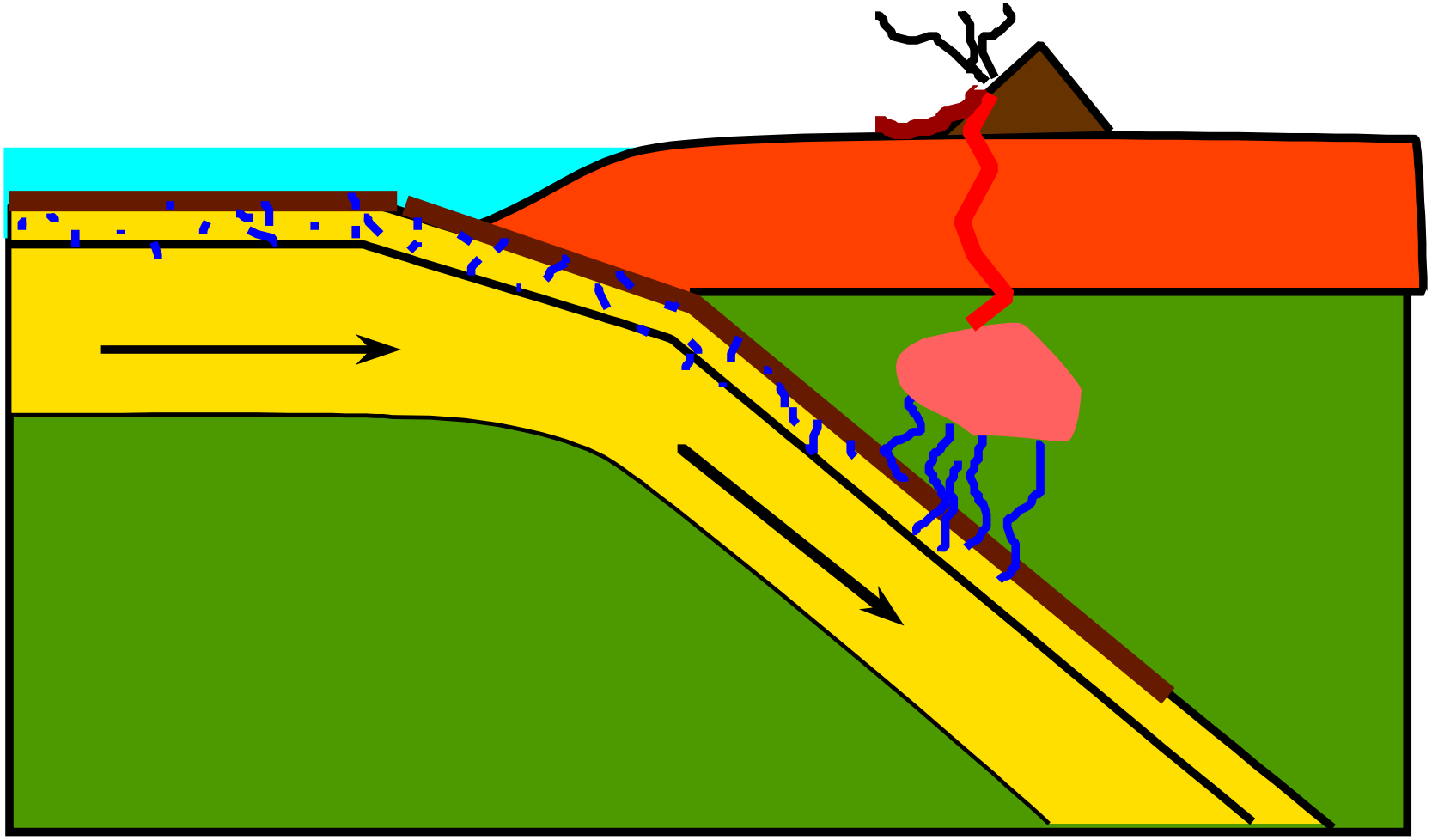
At sea, top of plate reacts with water...



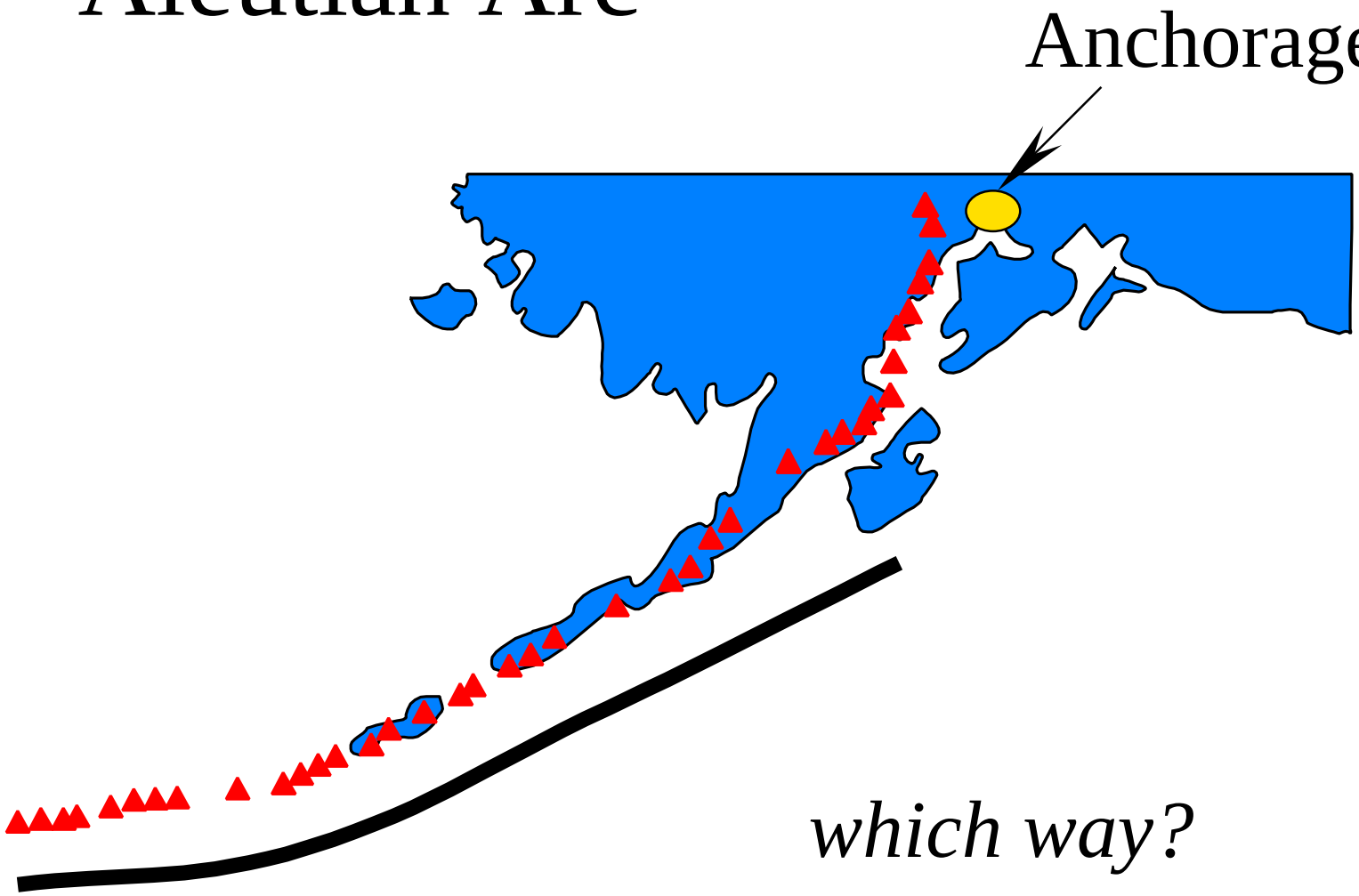
wet crust subducts
warms,
sweats out water...



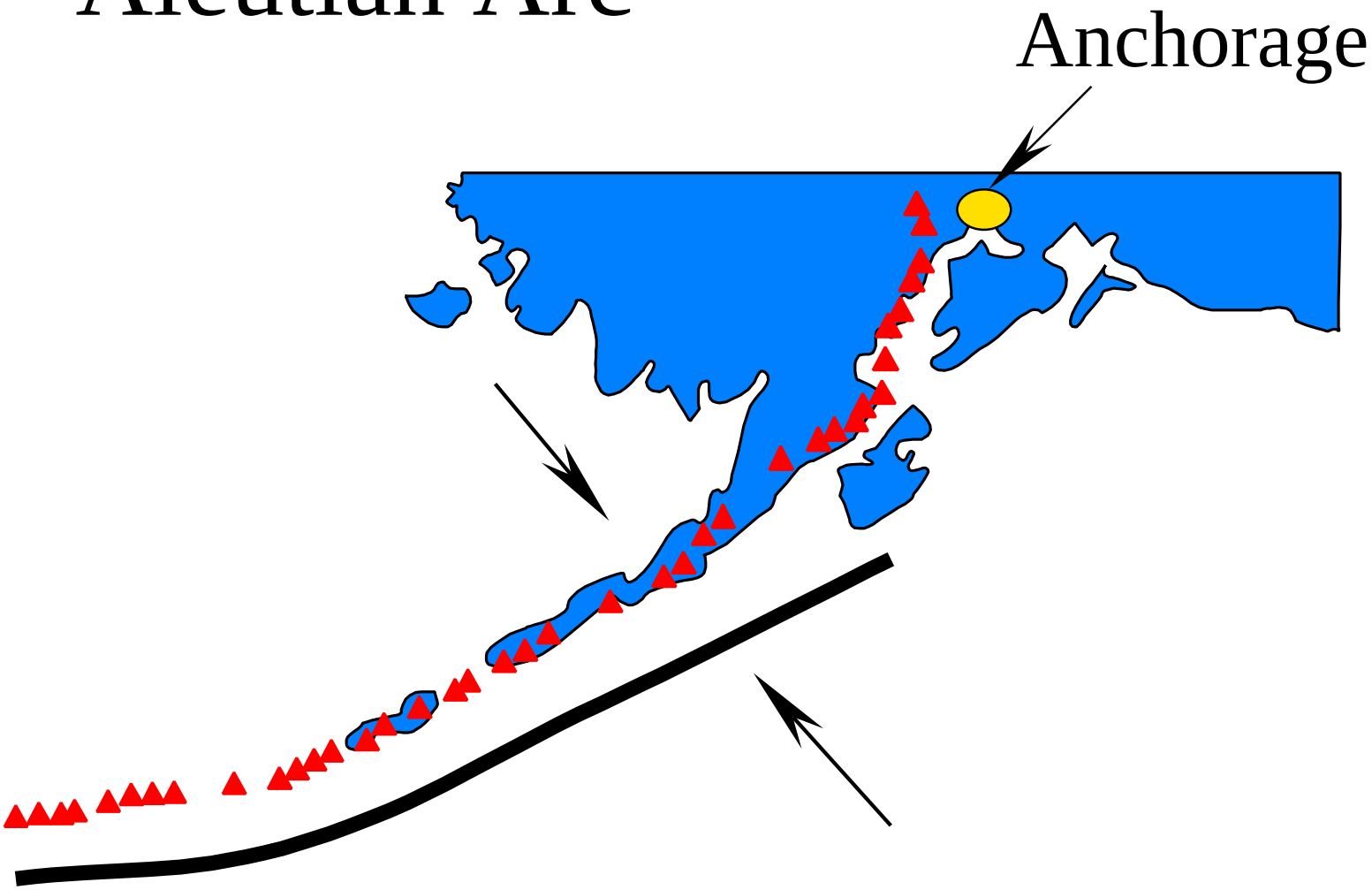
water --> **mantle wedge**,
--> basalt arc volcanism...



Aleutian Arc

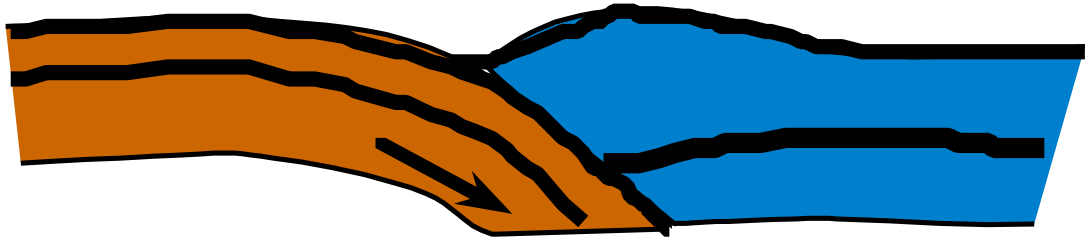


Aleutian Arc

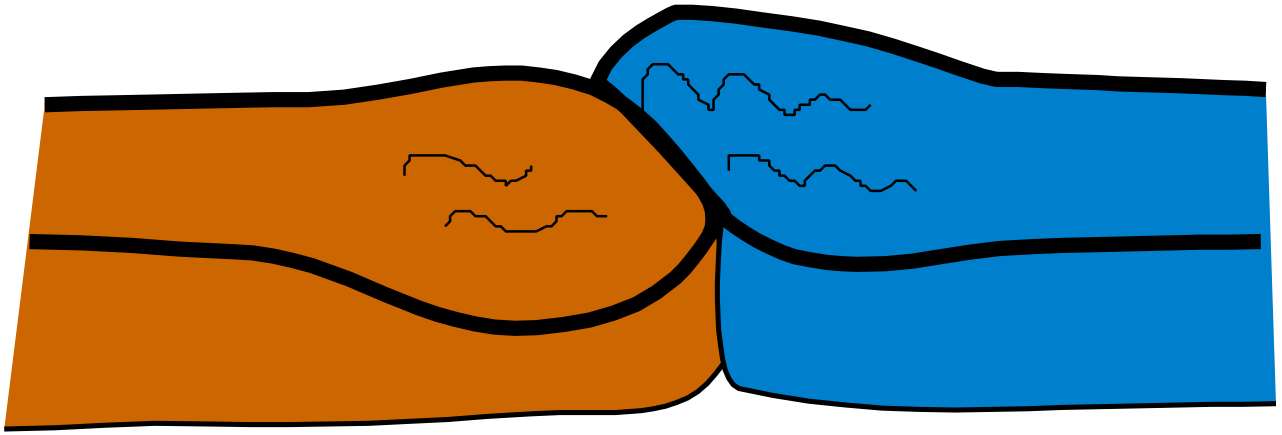


what happens when subduct a continent?

Oceanic plates **subduct**



Continental plates usually do not

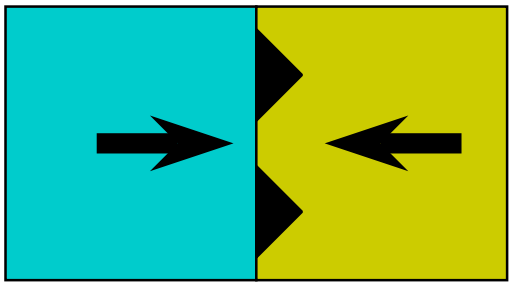


Affects geologic record -- how?

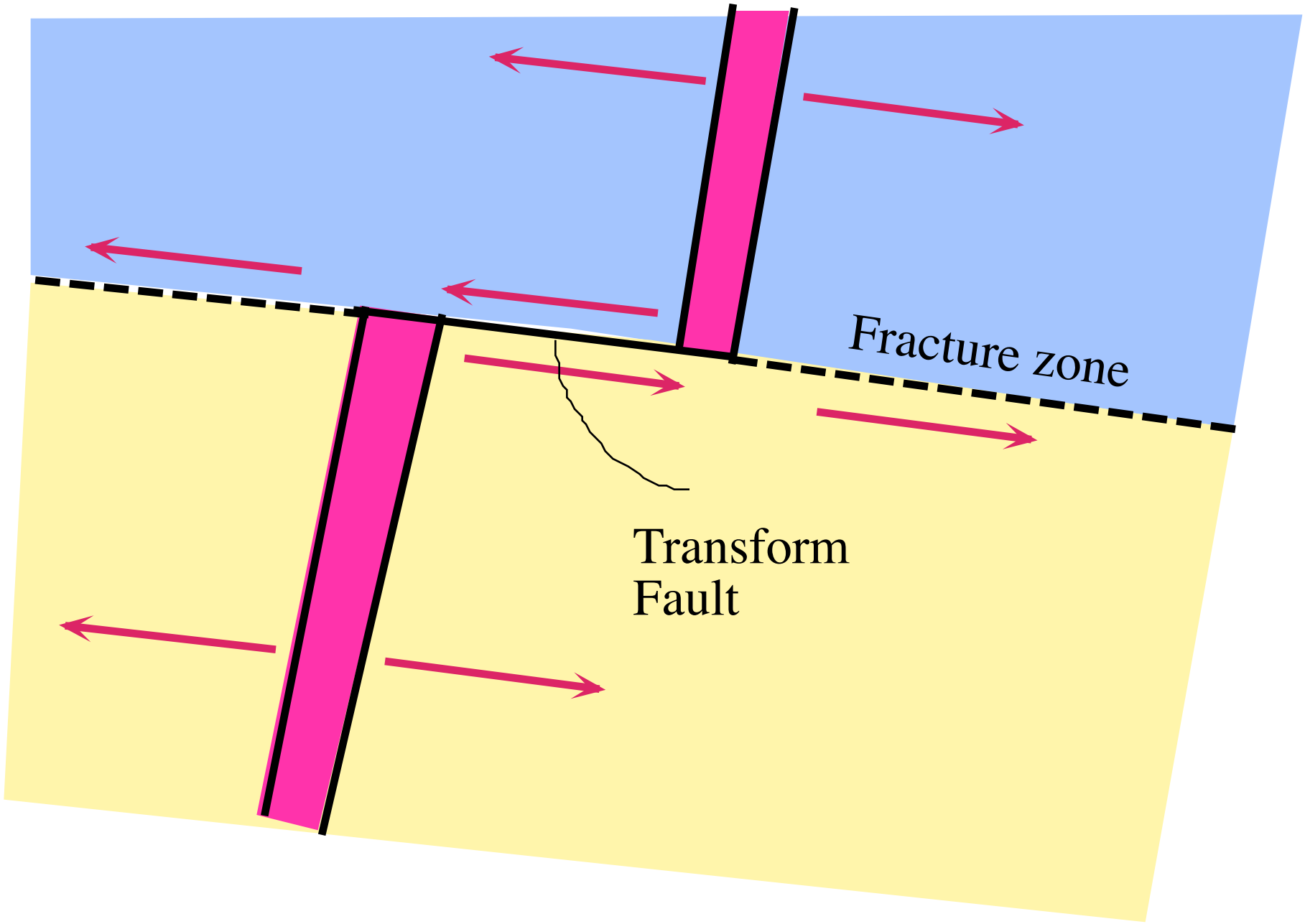
Convergent Boundaries

- **Subduction Zone**
  requires an oceanic plate to subduct
  Aleutians

- **Continent-Continent-Collision**
  two continental plates
  Himalayas

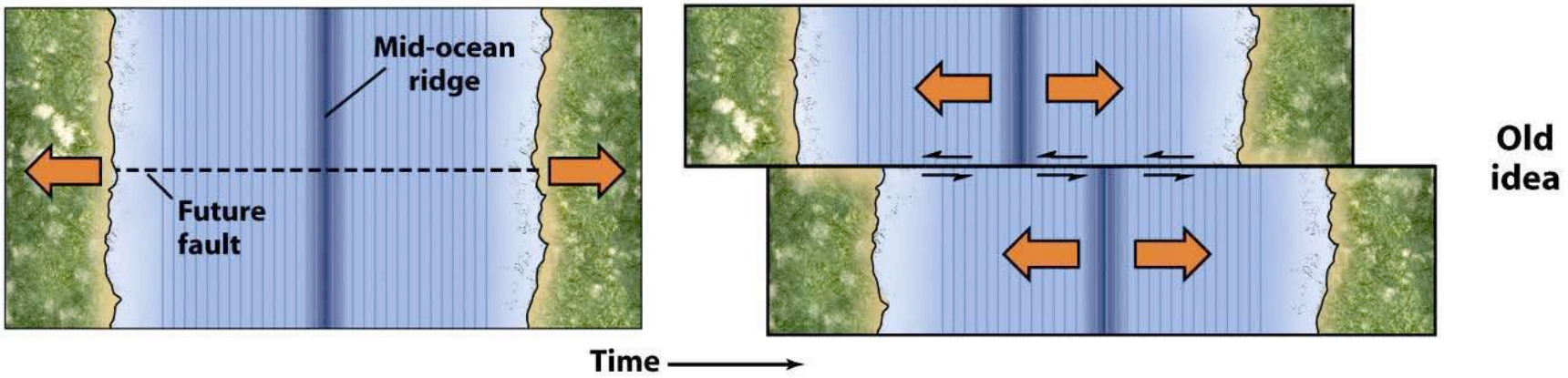


Review:

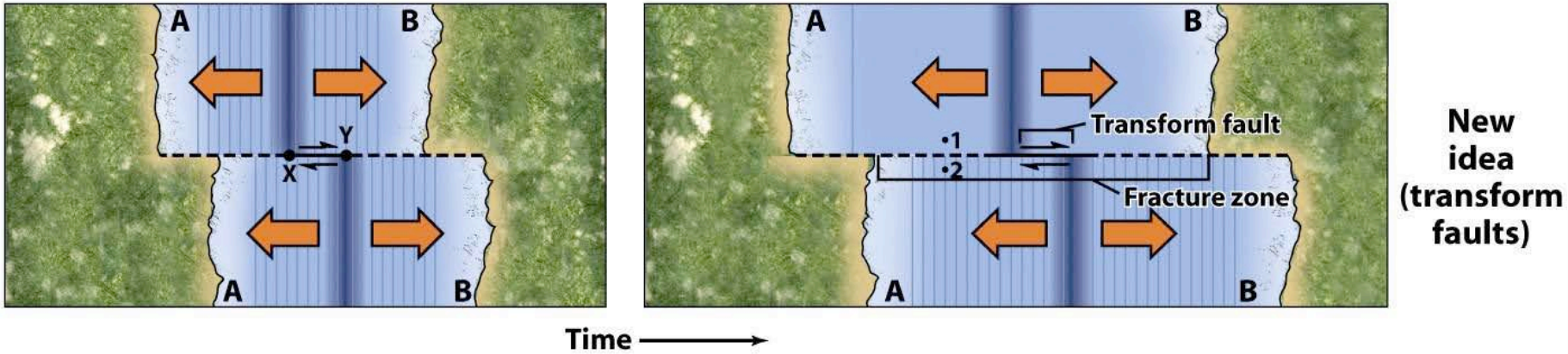


Transform Boundaries

- **Oceanic transforms – Offsets along the MOR.**
  - **Older interpretation – Faulting occurs after MOR forms.**

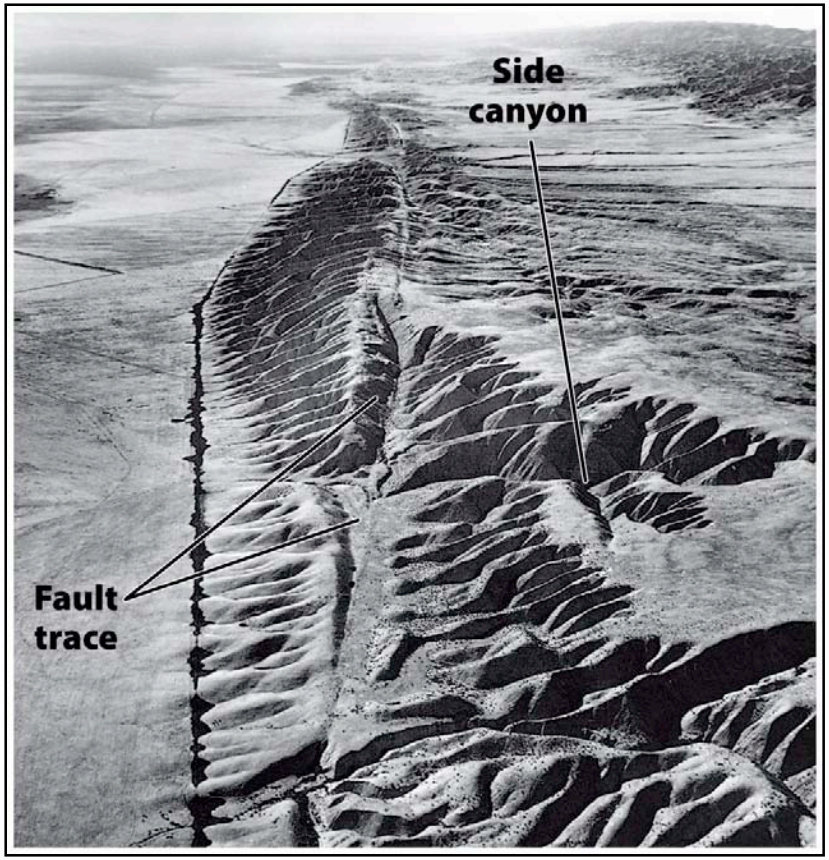


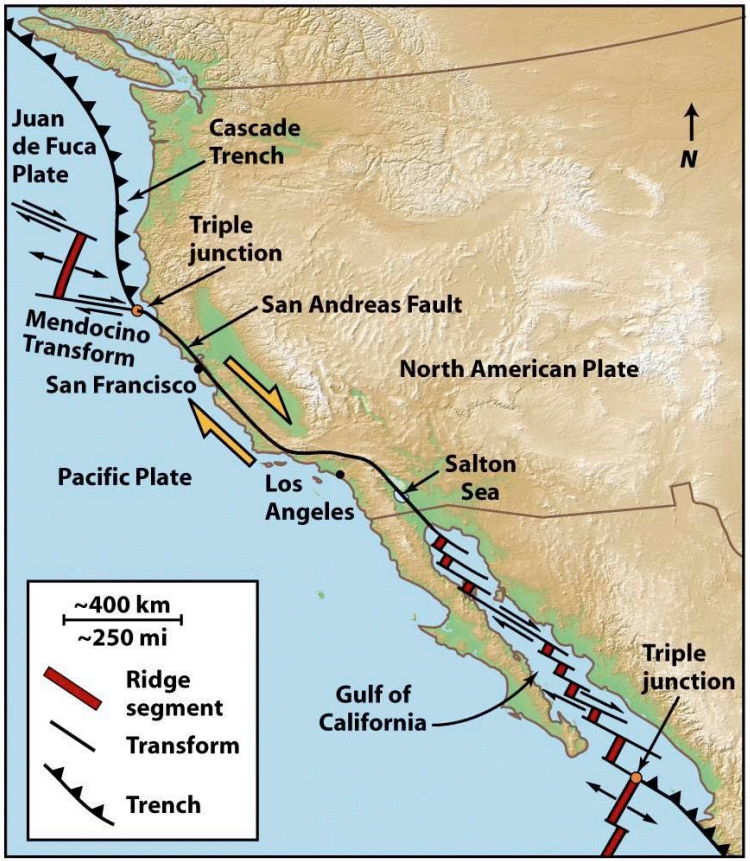
  - **Modern interpretation – Faulting occurs with the MOR.**

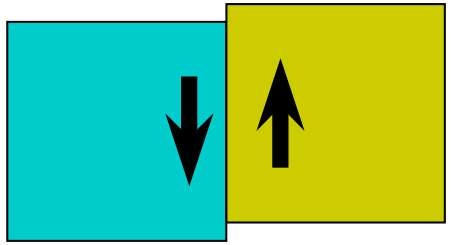


Transform Boundaries

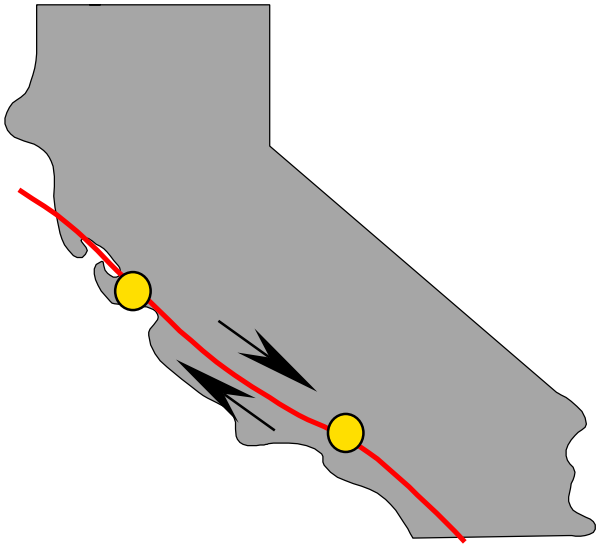
- **Continental transforms – Chop continental crust.**
  - **Example: The San Andreas Fault.**



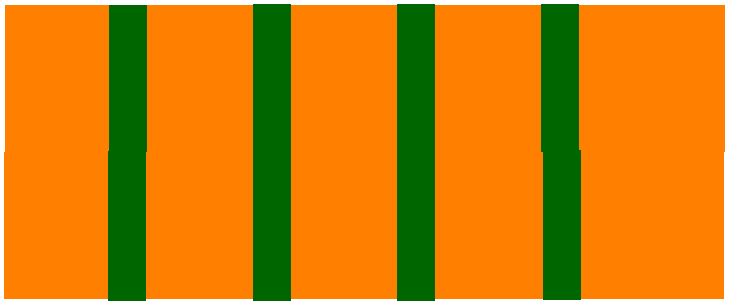




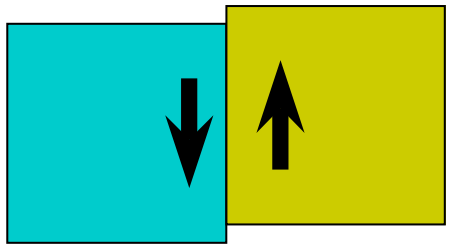
- **Transform**



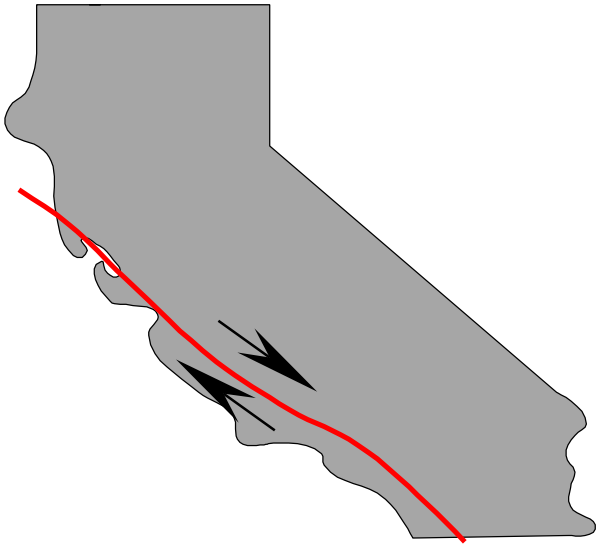
- San Andreas Fault



- Big Earthquakes, No Volcanoes
- Offsets

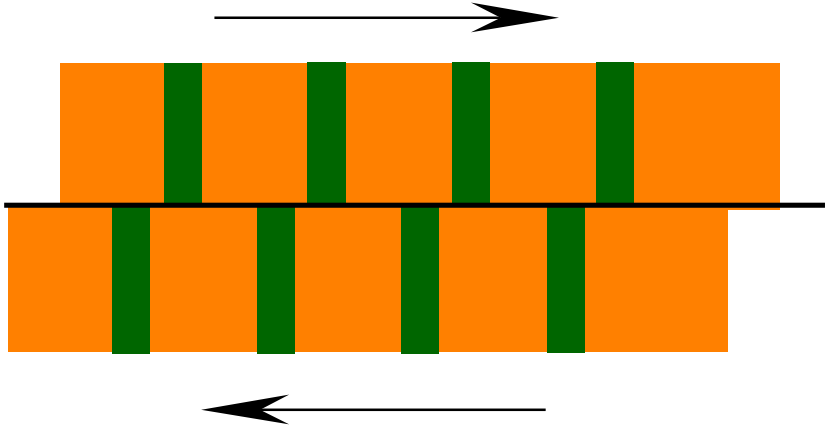


- **Transform**



- San Andreas Fault

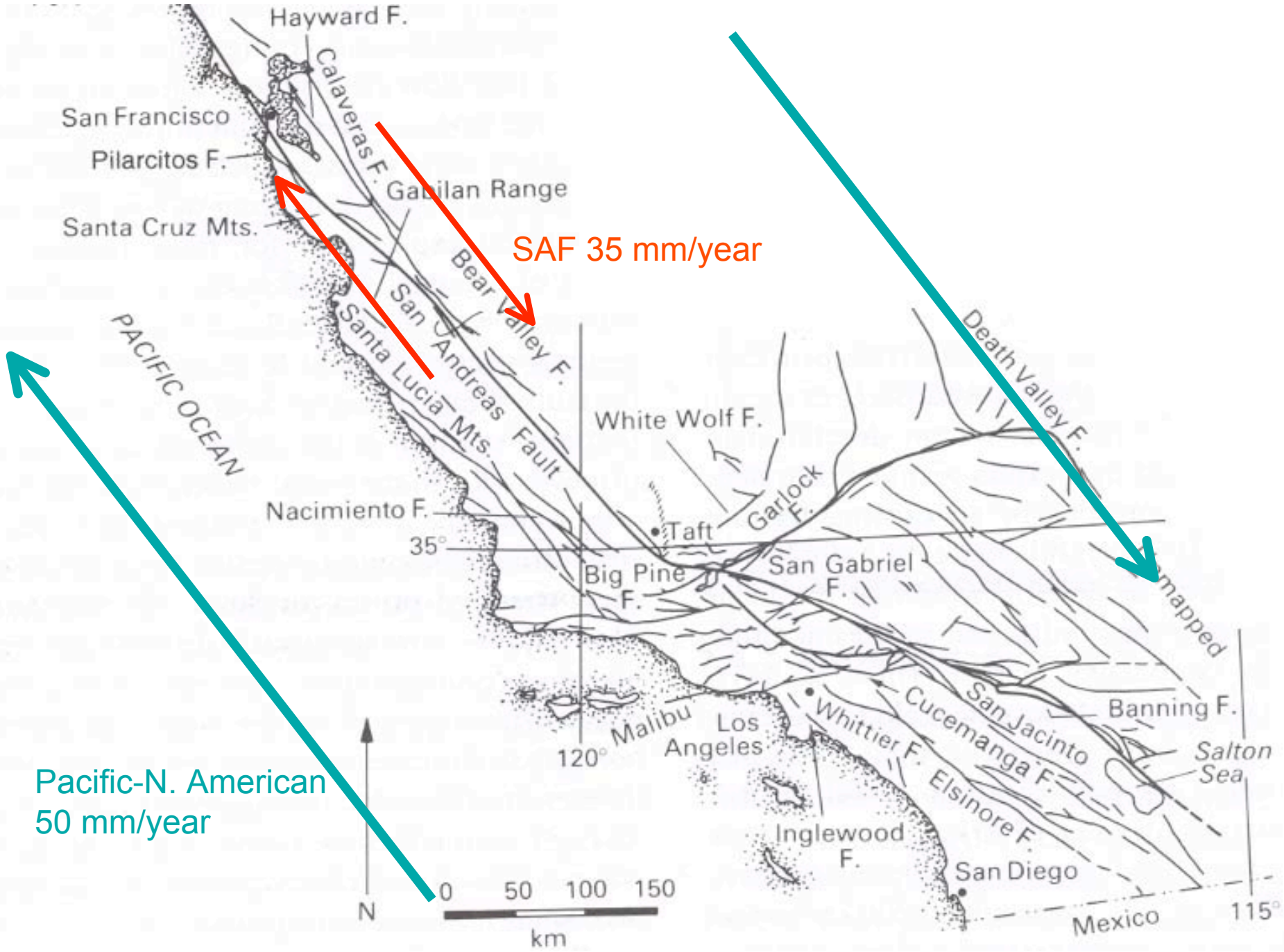
right lateral

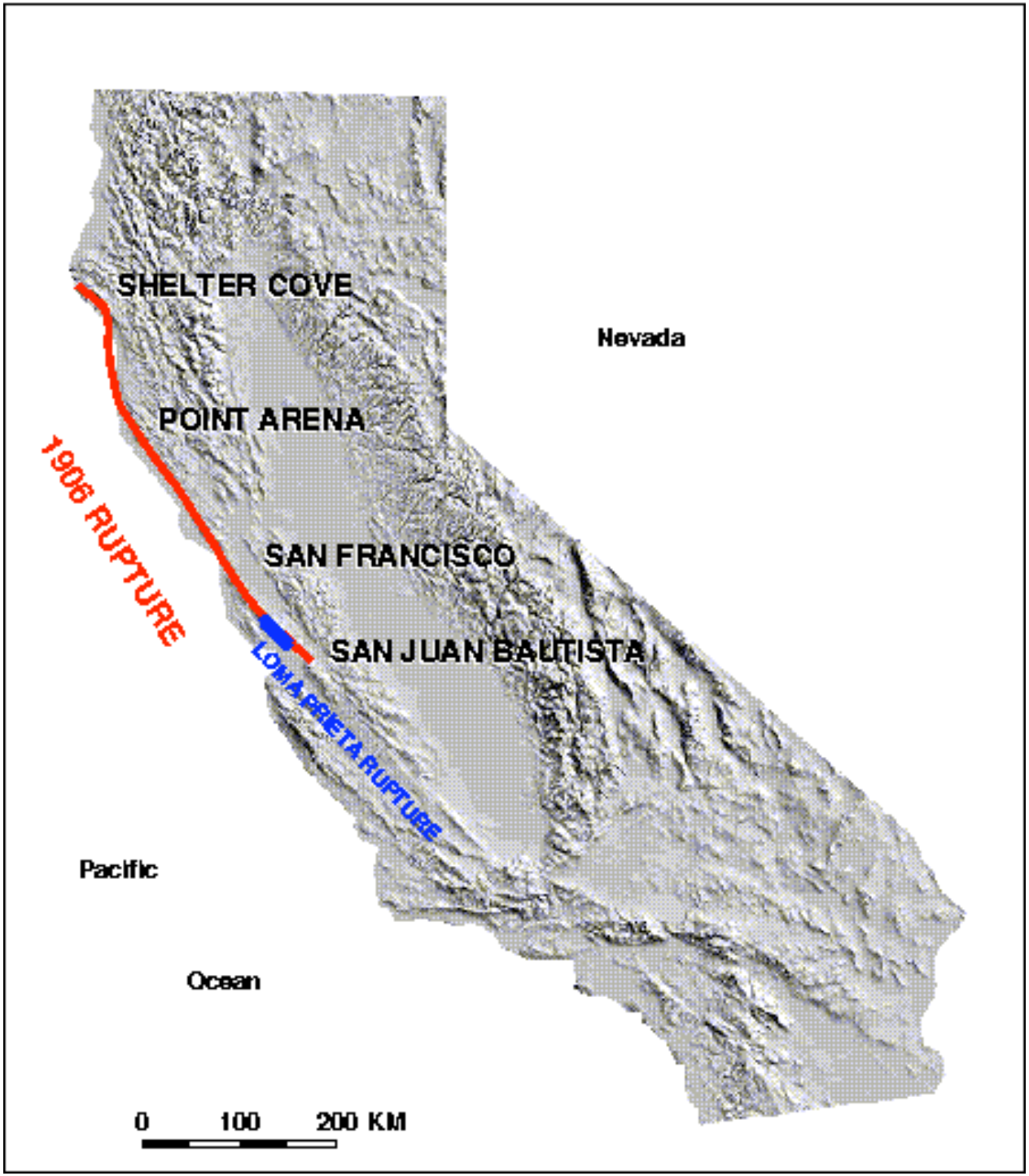


- Big Earthquakes, No Volcanoes
- Offsets

slides-general

1. Earthquakes occur on a statistically-predictable cycle


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
White Wolf F.
Death Valley F.
Nacimiento F.
Garlock F.
Taft
35°
Big Pine F.
San Gabriel F.
mapped
Malibu
Los Angeles
120°
Whittier F.
Cucemanga F.
San Jacinto
Banning F.
Salton Sea
Elsinore F.
Inglewood F.
San Diego
Mexico
115°
Pacific-N. American
50 mm/year
N
0 50 100 150
km



1906 Earthquake
Magnitude 7.8

6 meters
of slip on a
fault 500 km
long

earthquake cycle

Fault at boundary between plates is “locked”

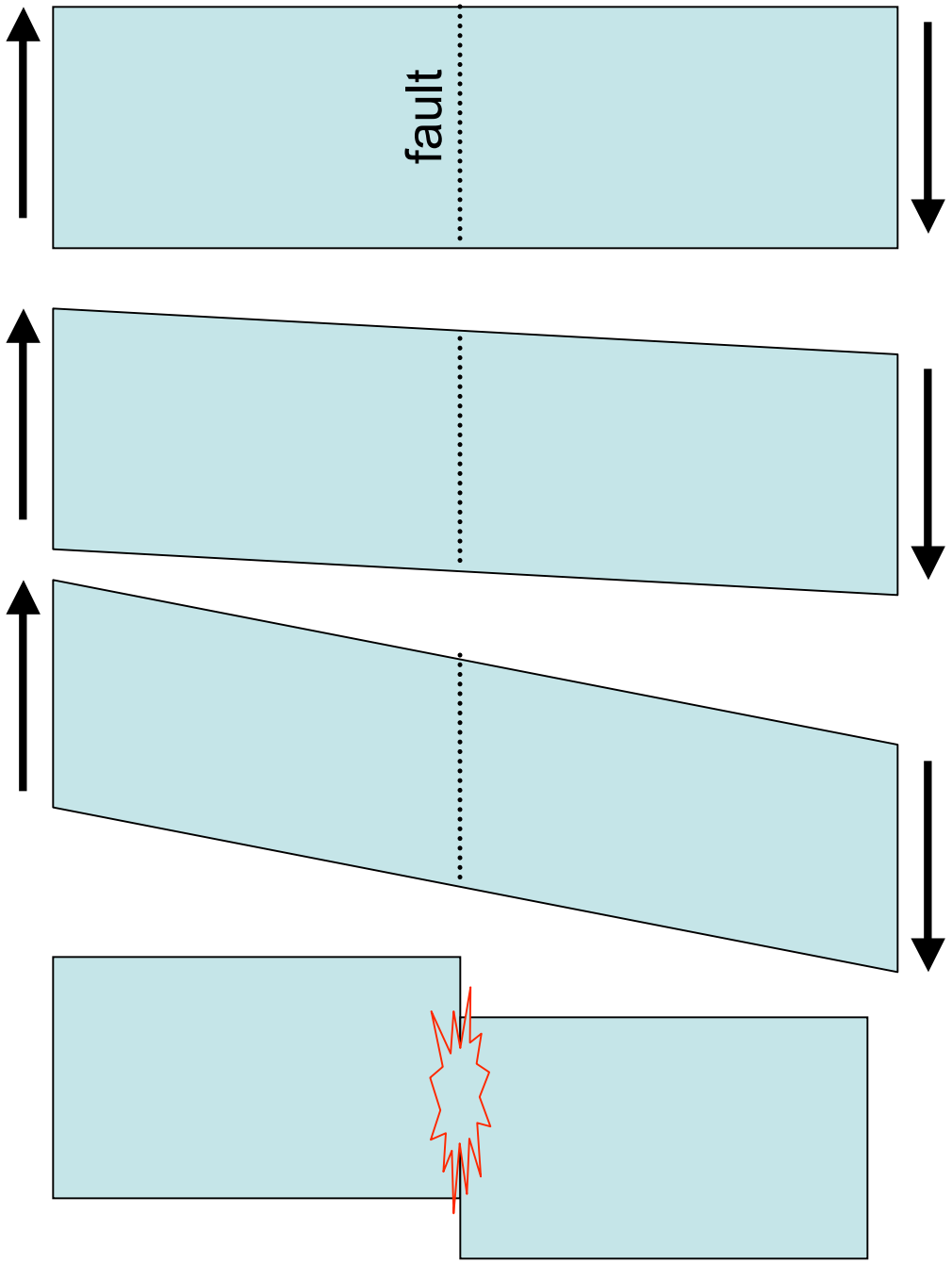
Stress builds up on fault as plates move

Stress exceeds strength of fault

Fault suddenly slips in an earthquake

Plate boundary moves

Fault locks again

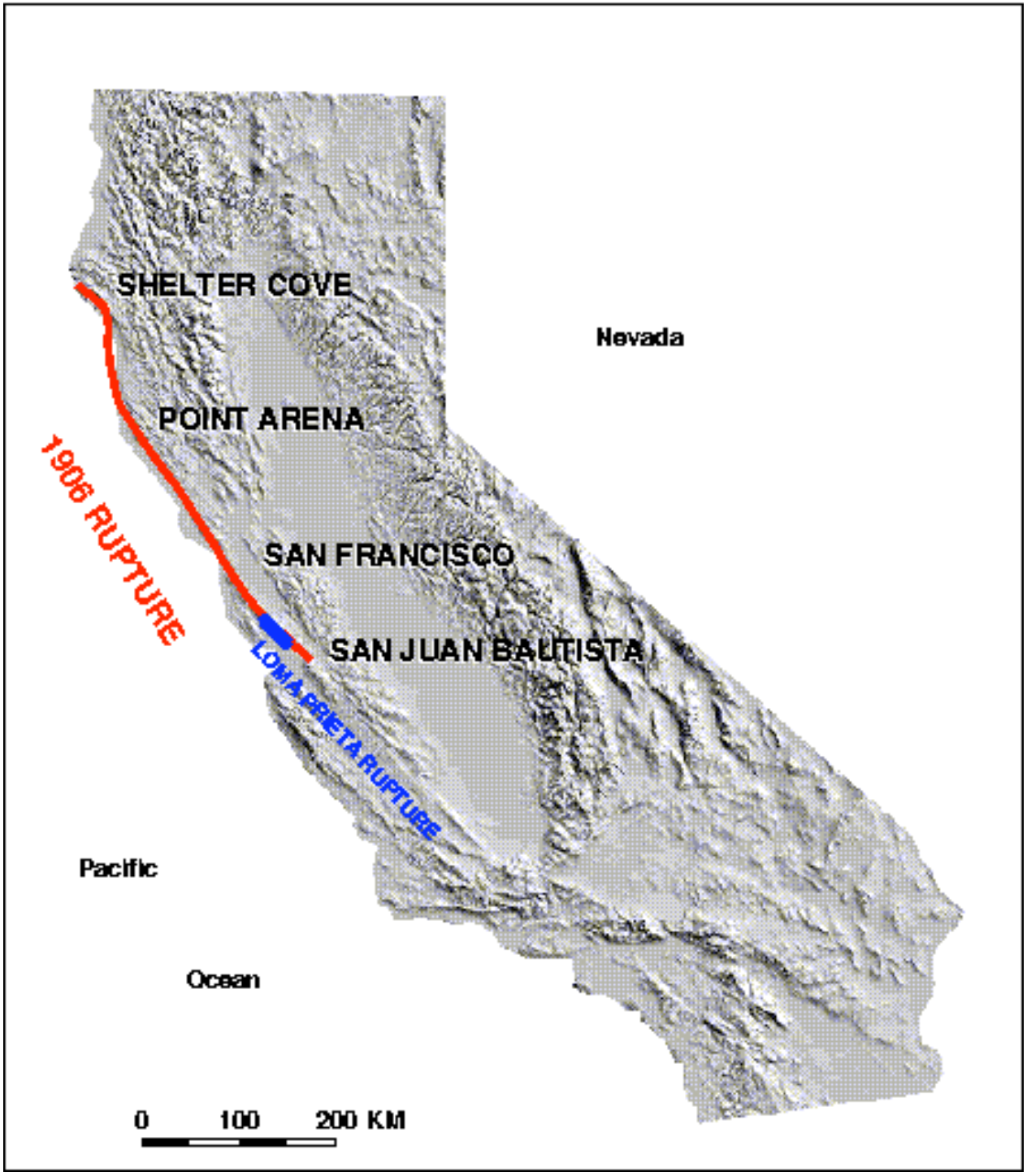


fault locked

loading

more loading

Earthquake !



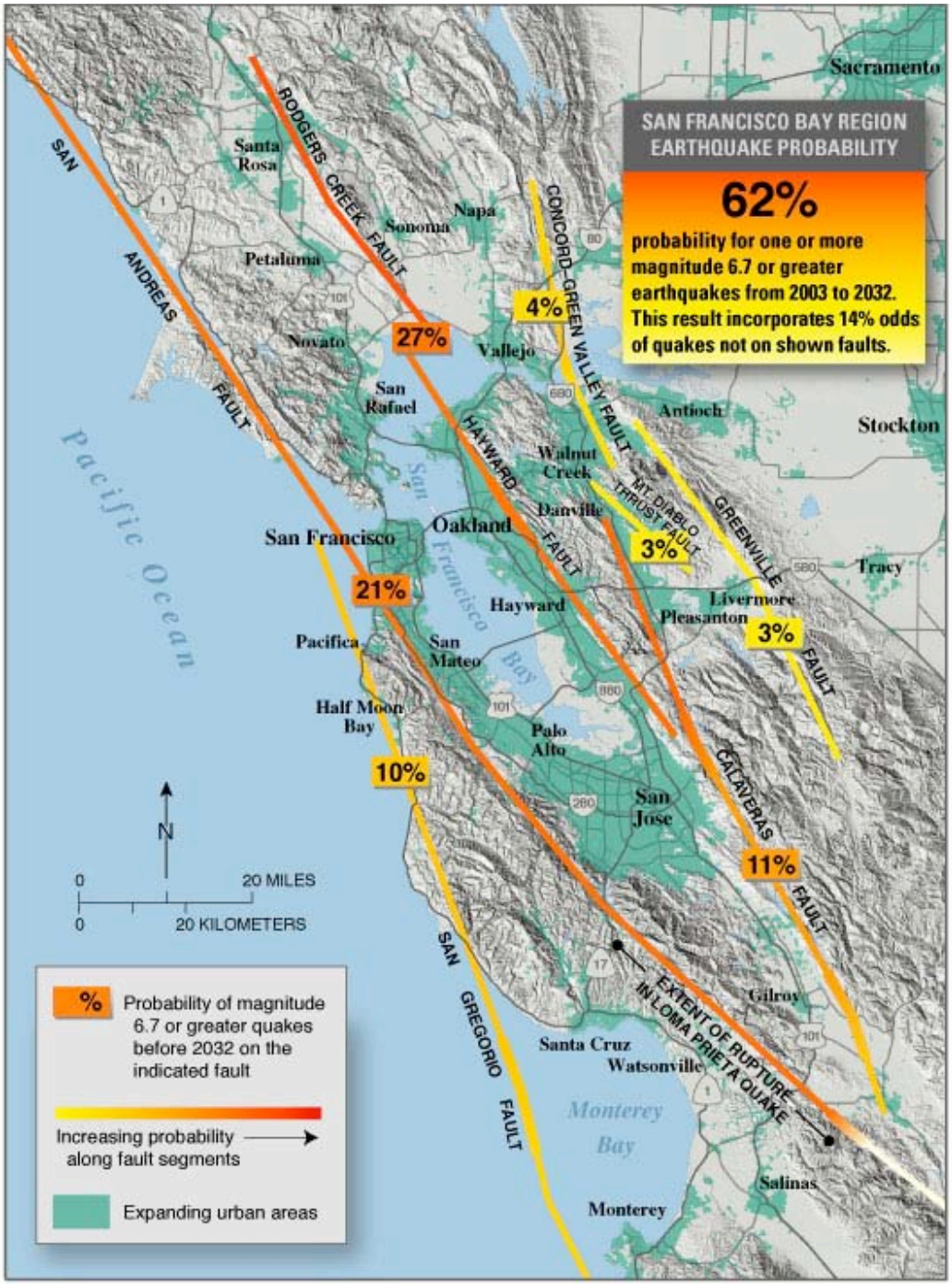
Earthquake Repeat Time
Mean time interval between large earthquakes on a particular fault

For San Andread
6 meters = 6000 mm

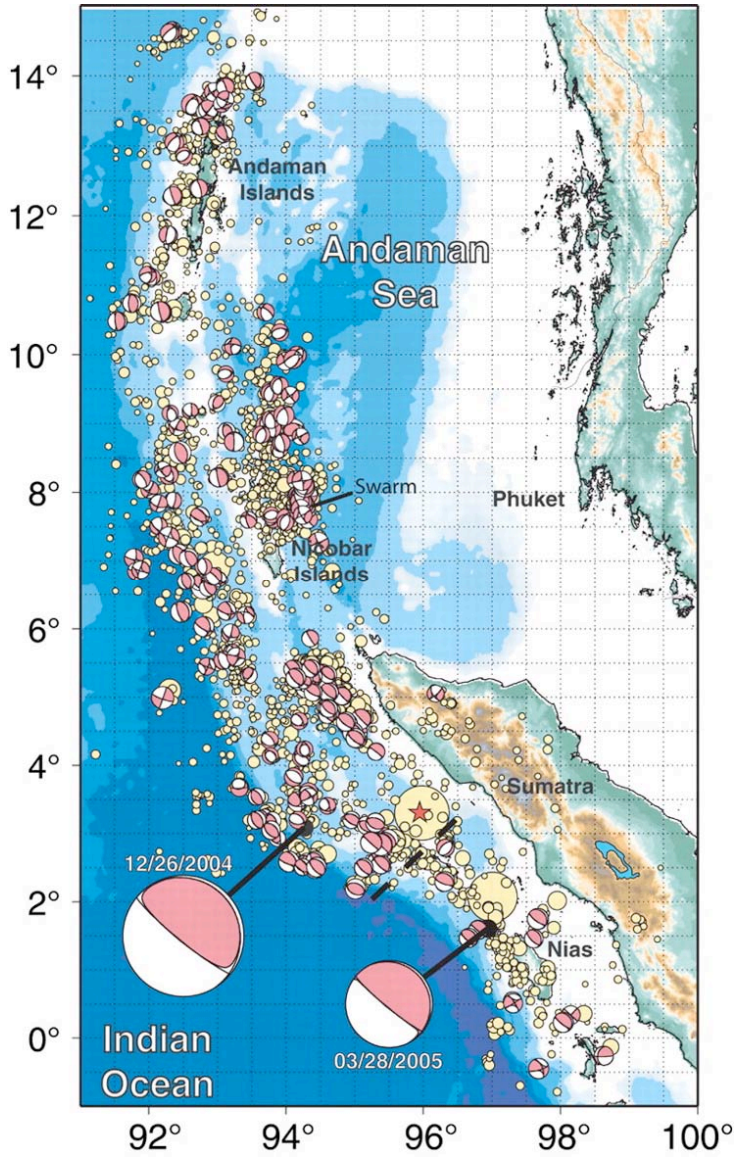
6000 mm / 35 mm/year
= 170 years

170 years of plate motion was released by this earthquake

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



Scientific basis for earthquake risk assessments



Lay et al, Science (2005)

Aftershocks of Sumatra Dec 2004

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.