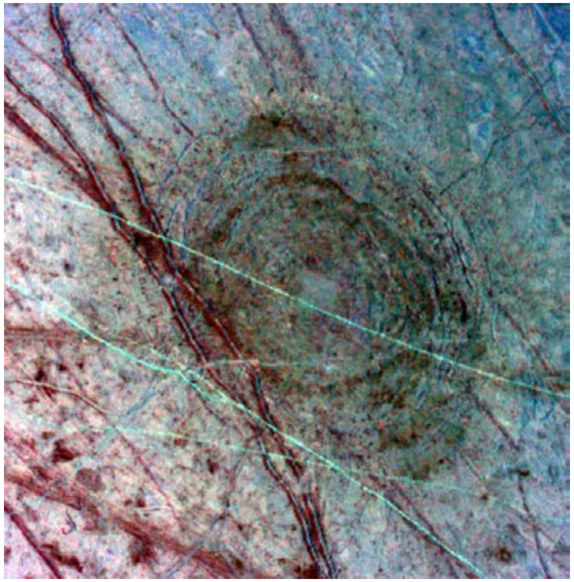
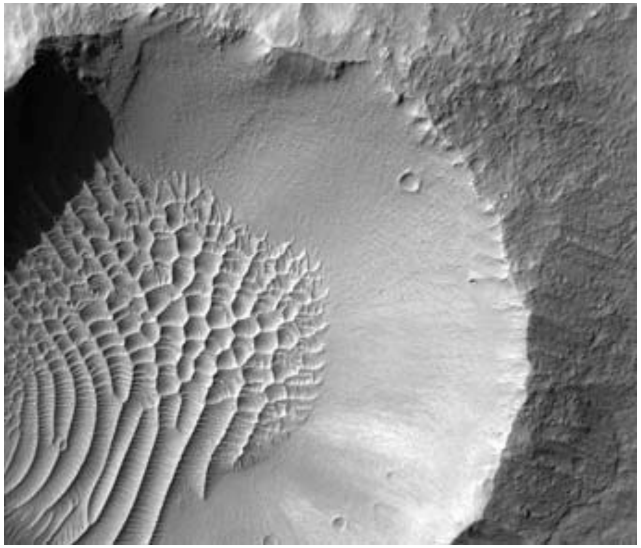
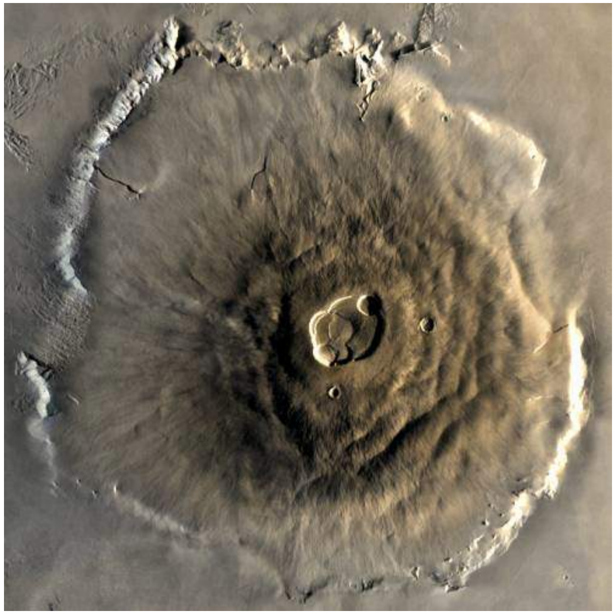
Planetary Surface Processes

Cratering
Gravity
Tectonics
Volcanism
Winds
Fluvial
Glacial
Chemical
weathering



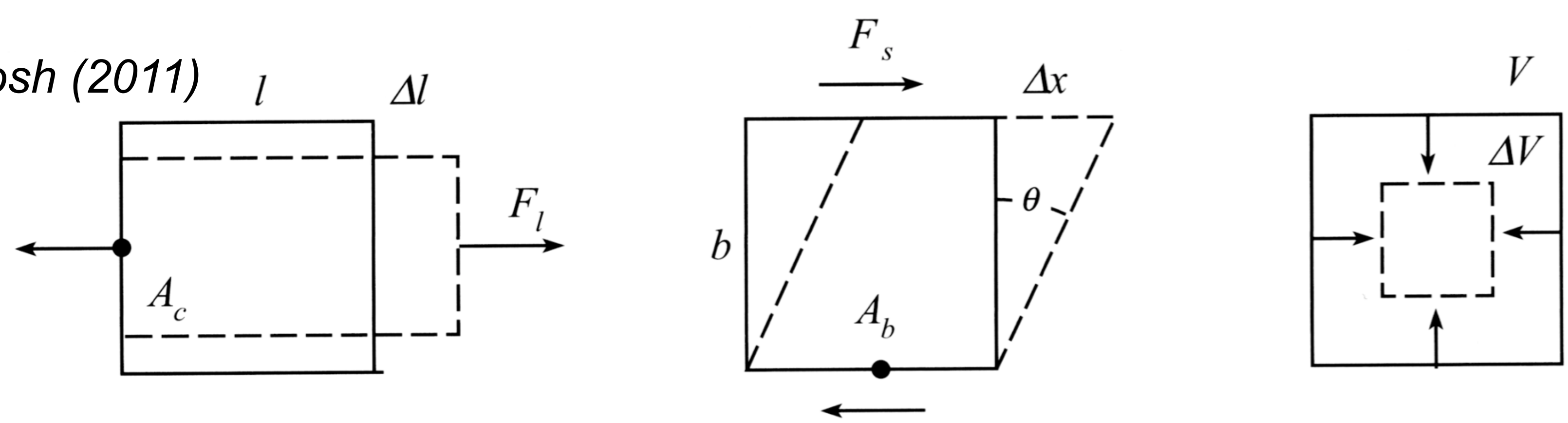




Tectonic Activity

Any crustal deformation caused by motions of the surface. Deformation of a material due to an applied *stress* (force per unit area) is characterized by the *strain* (dimensionless):

Melosh (2011)



longitudinal strain
$\varepsilon_l = \Delta l \,/\, l$

shear strain
$\varepsilon_x = \Delta x \,/\, b \approx \theta$

volume strain
$\varepsilon_l = \Delta V \,/\, V$

Tectonic Activity

Any crustal deformation caused by motions of the surface. Deformation of a material due to an applied *stress* (force per unit area) is characterized by the *strain* (dimensionless)

Elastic materials will respond to stress, but regain original properties when stress is removed

Hooke's law: $\sigma_l = E\,\varepsilon_l$

E is Young's modulus (like a spring constant)

$\sigma_s = 2\mu\,\varepsilon_s$

μ is shear modulus

$p = -K\,\varepsilon_V$

K is bulk modulus

Tectonic Activity

Any crustal deformation caused by motions of the surface. Deformation of a material due to an applied *stress* (force per unit area) is characterized by the *strain* (dimensionless)

Viscous materials will deform or flow in a slow smooth way when stress is exerted

Newtonian viscosity:

$$\sigma_s = 2\eta \, d\varepsilon_s / dt$$

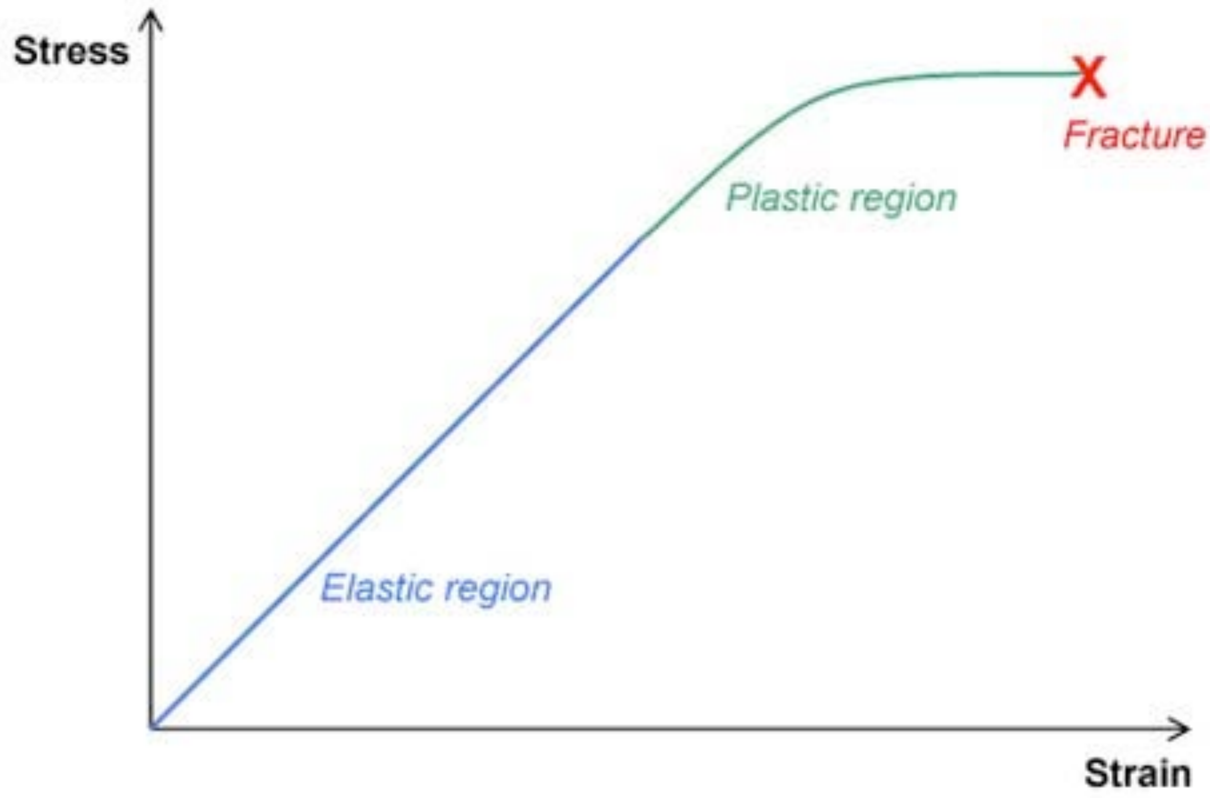
η is viscosity

Tectonic Activity

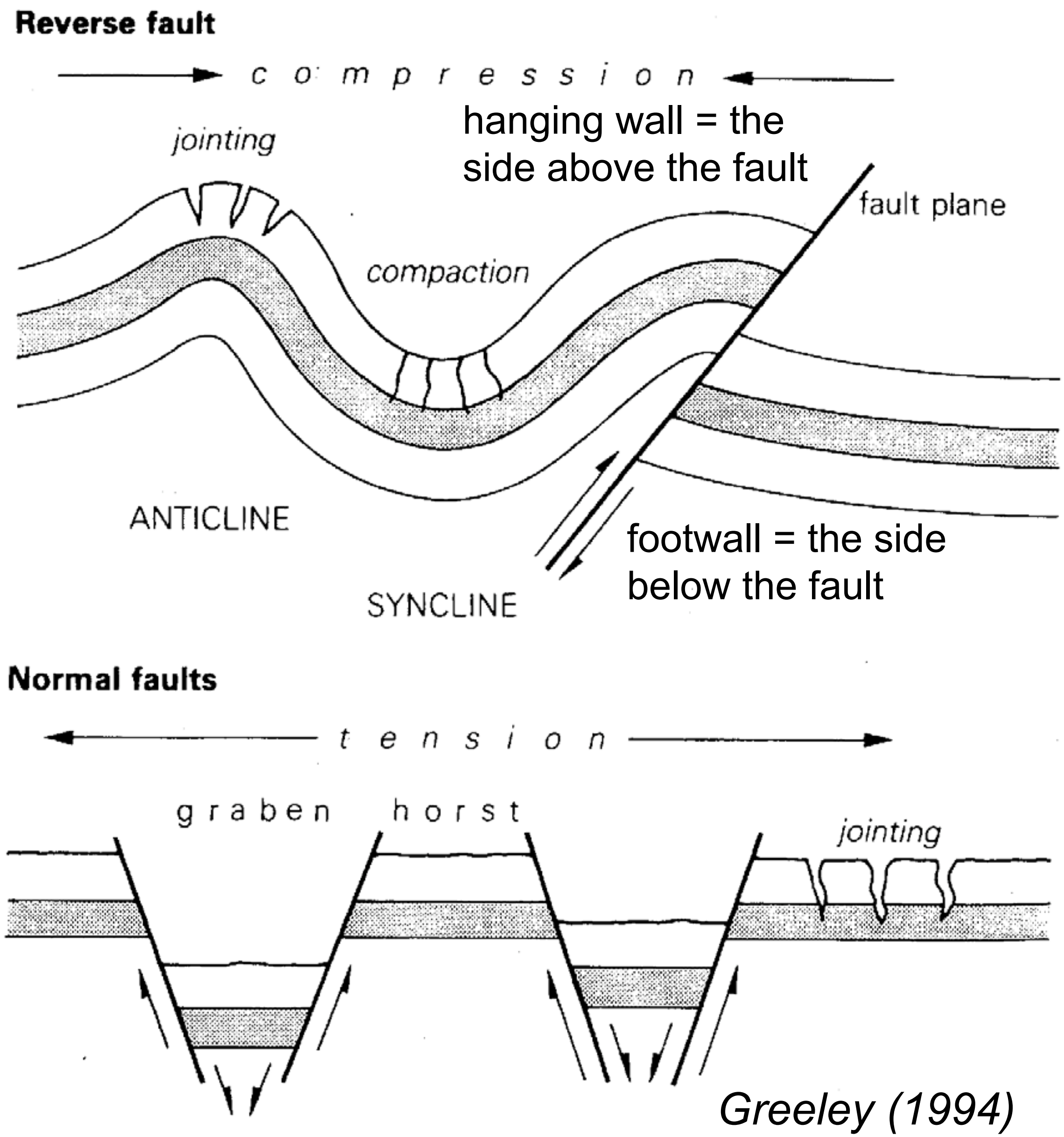
Materials can behave both elastically and viscously; viscoelastic materials may behave elastically on short time periods but viscously on longer (geologic) timescales … *silly putty!*

Usually at low temperatures materials tend to be brittle, and at high temperatures they tend to be ductile (much deformation before fracturing)

Elastic vs. plastic deformation



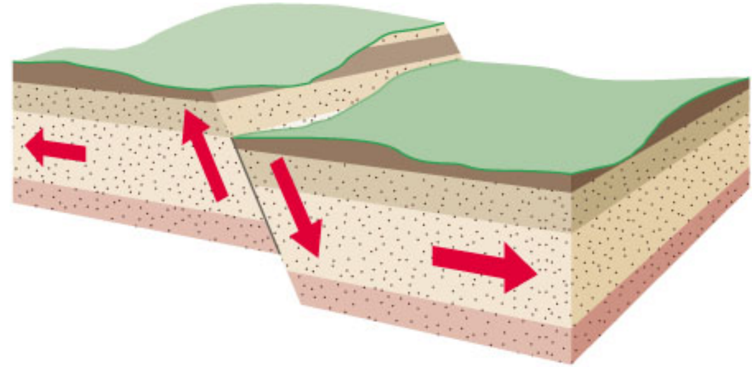
Horizontal Stresses



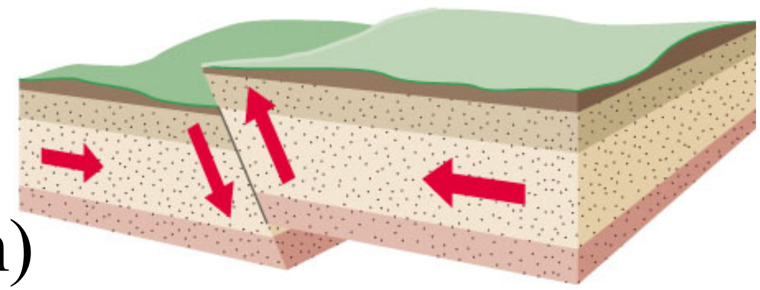
Faults

- Faults are where the crust fails, causing deformation
- Normal fault = footwall displaced upward, reverse (thrust) fault = displaced downward

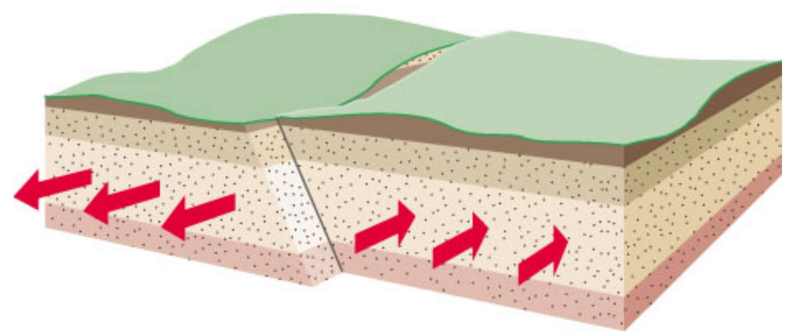
Normal
(extension)



Thrust
(compression)



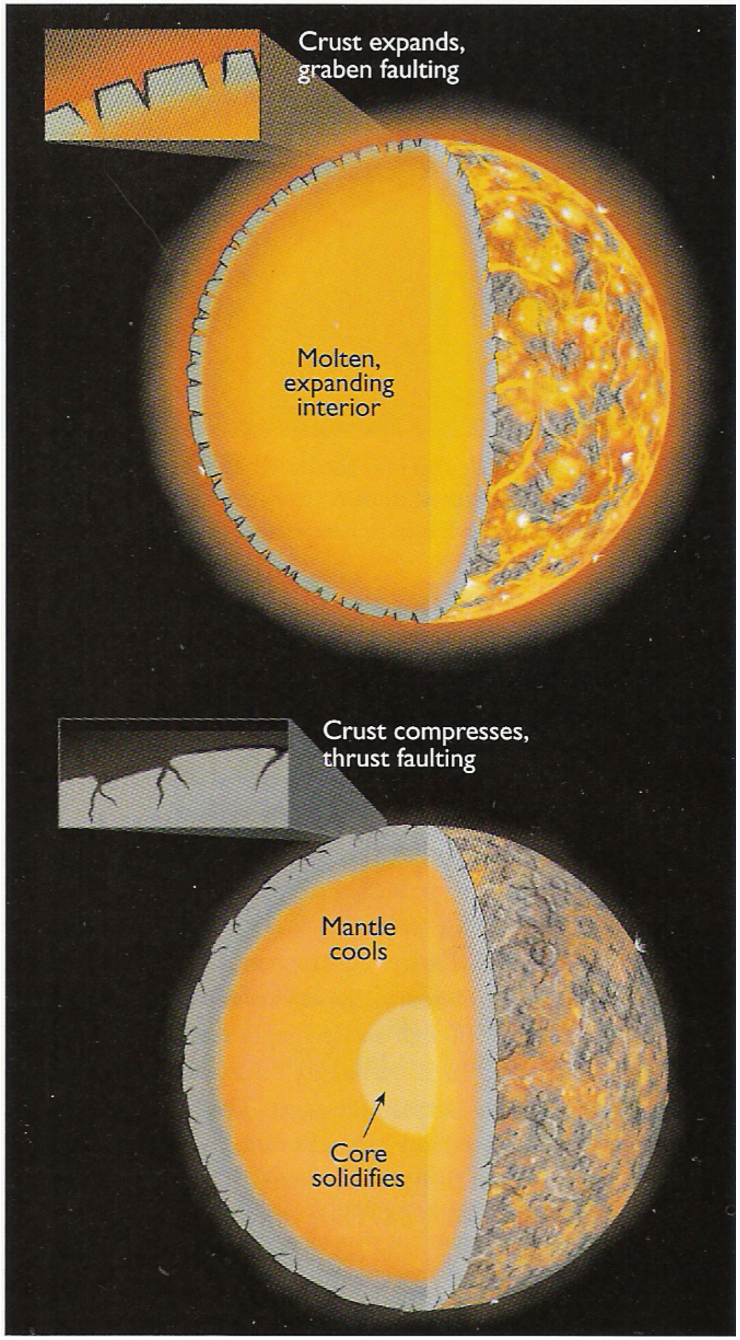
Strike-slip
(shearing)

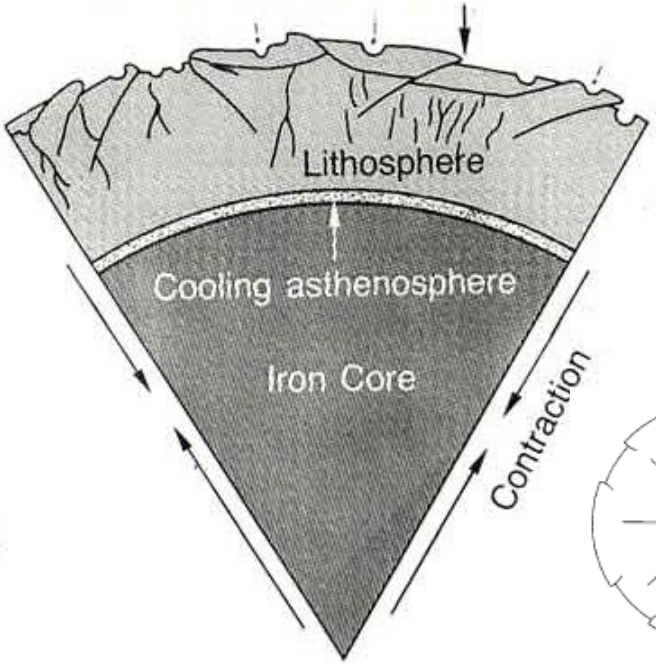


SIMPLEST Tectonics - *As planet cools*

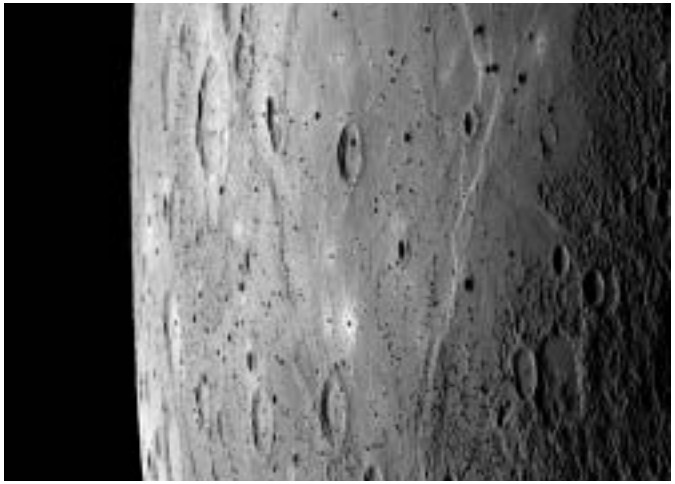
- *Early* - global volcanism
  - Global expansion caused crust to crack
  - lava leaked through
- *Later* - global contraction
  - Mantle and core cooled, compressed the crust
  - Compressional tectonics

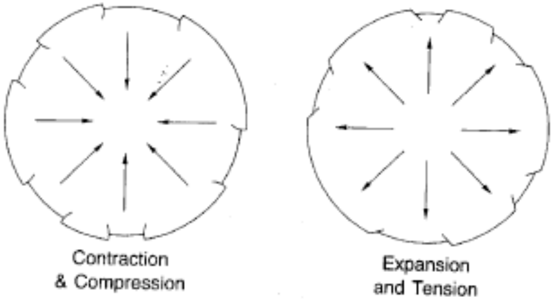
Mercury

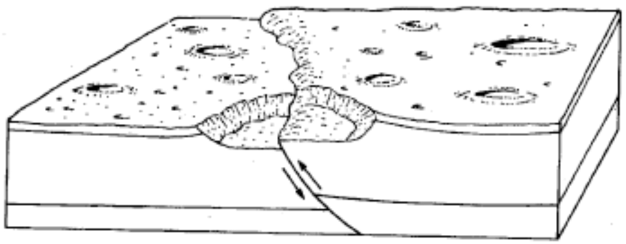


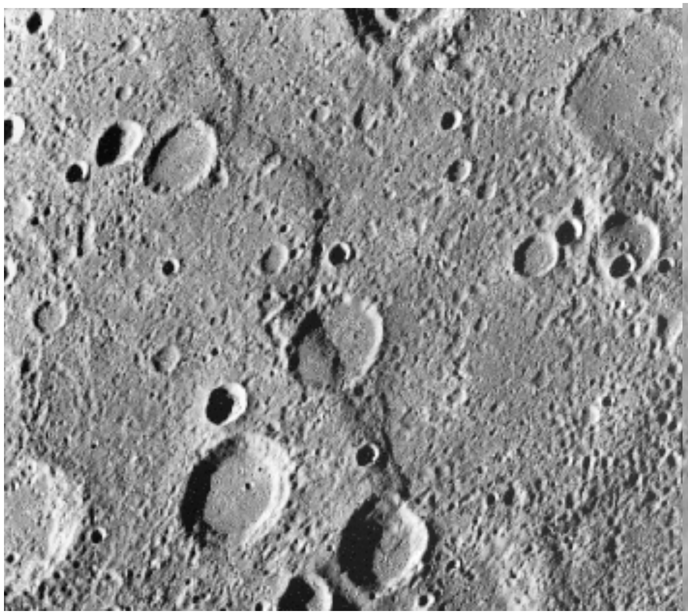


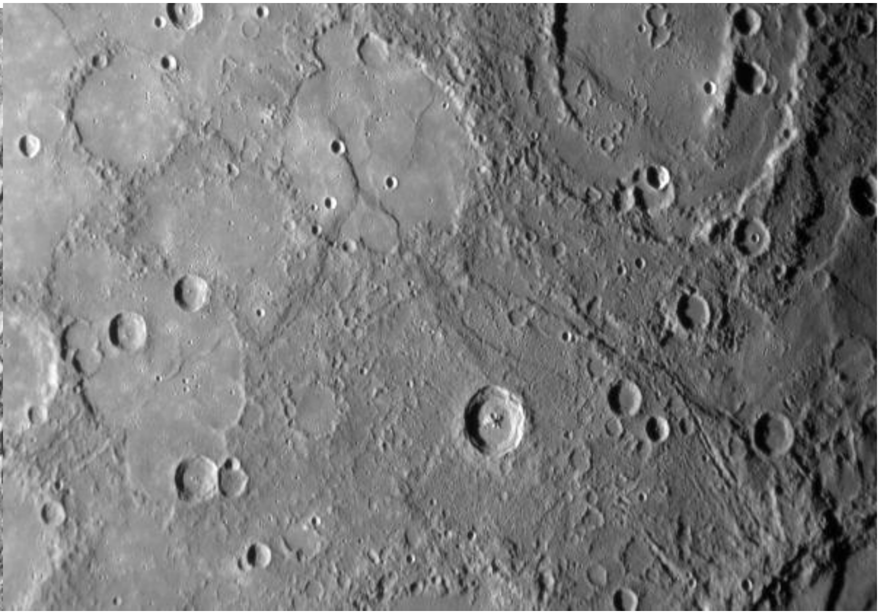
Mercury: Shrinking as it cools





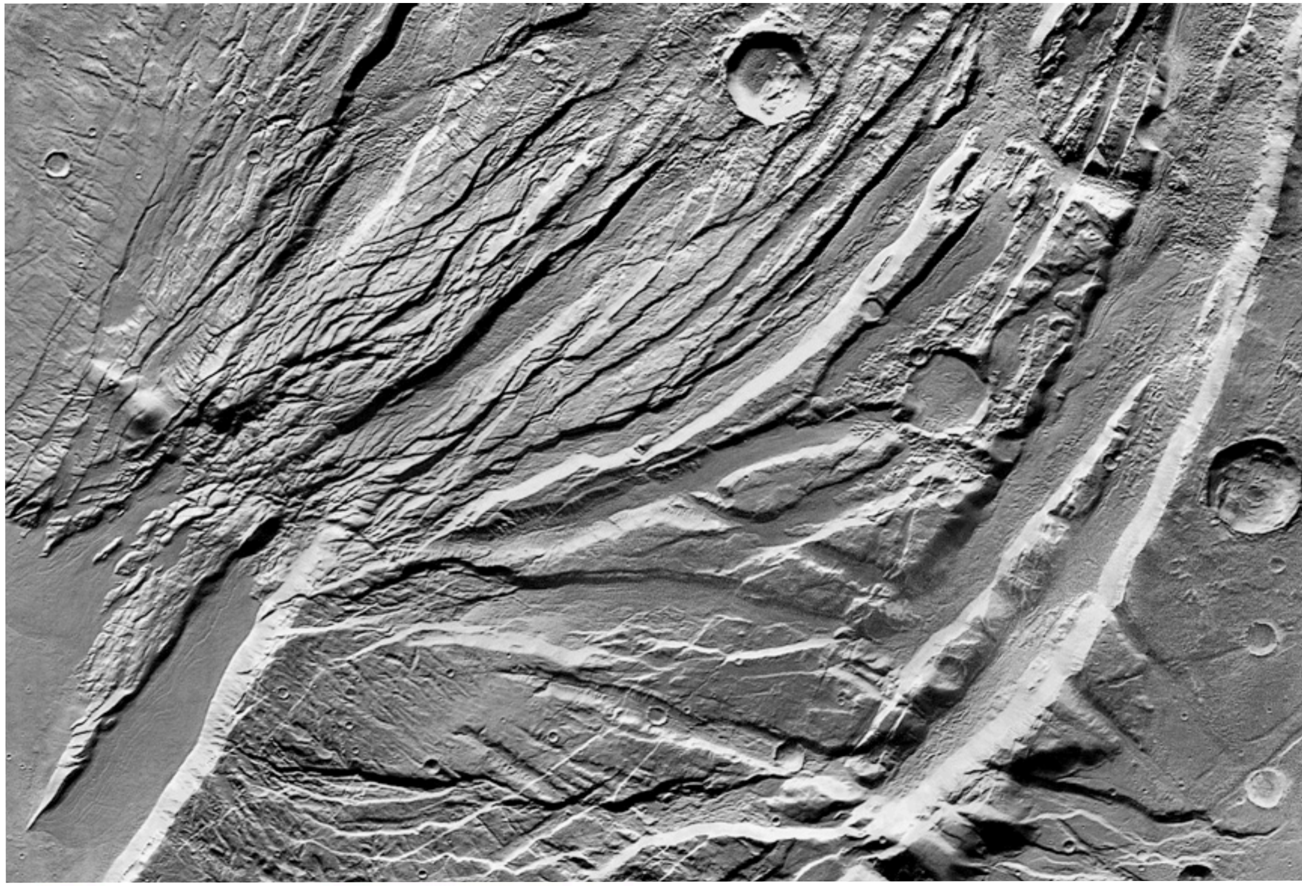






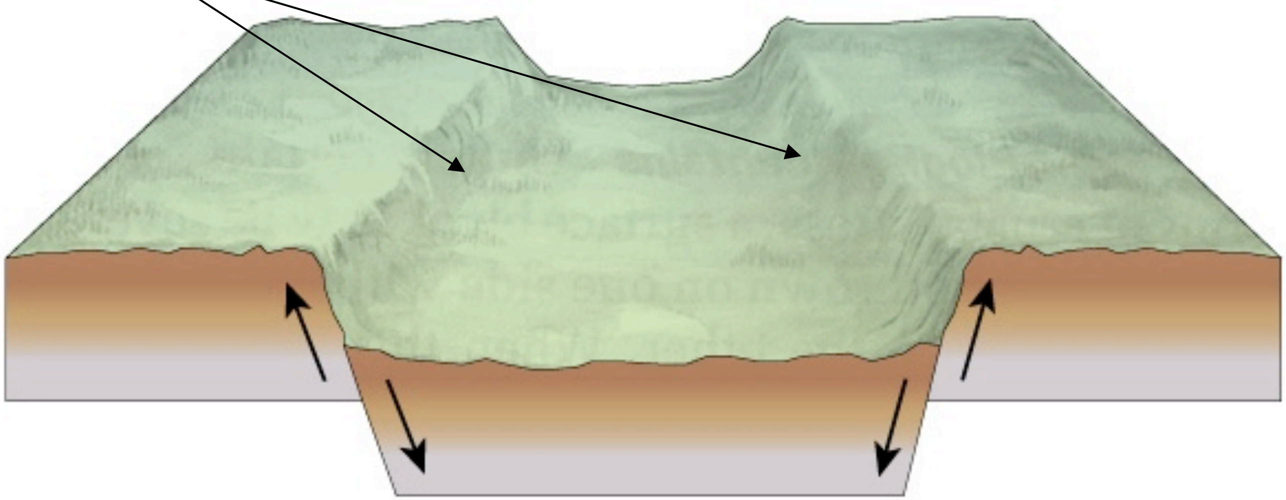
Graben

- Extension stress
- Rift valley

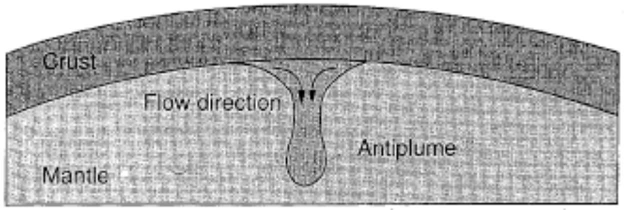


Mars

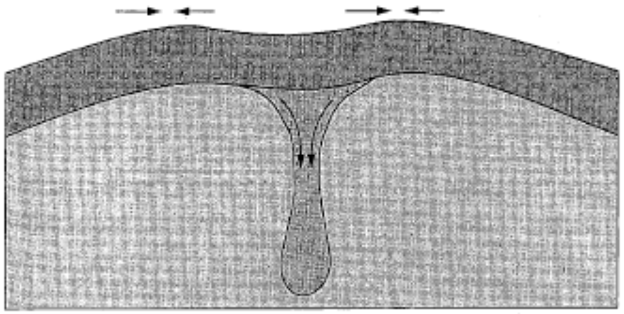
Scarps

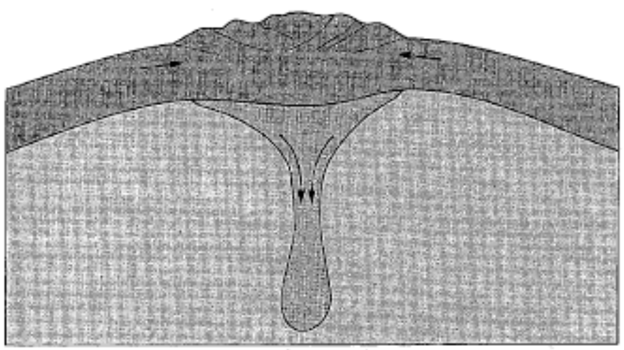


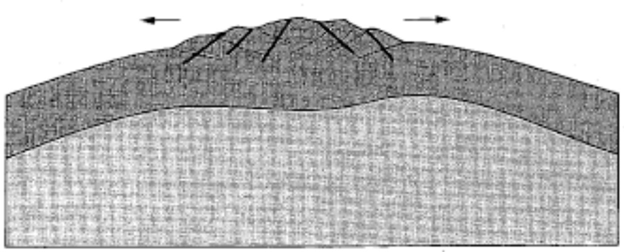
Vertical Stresses

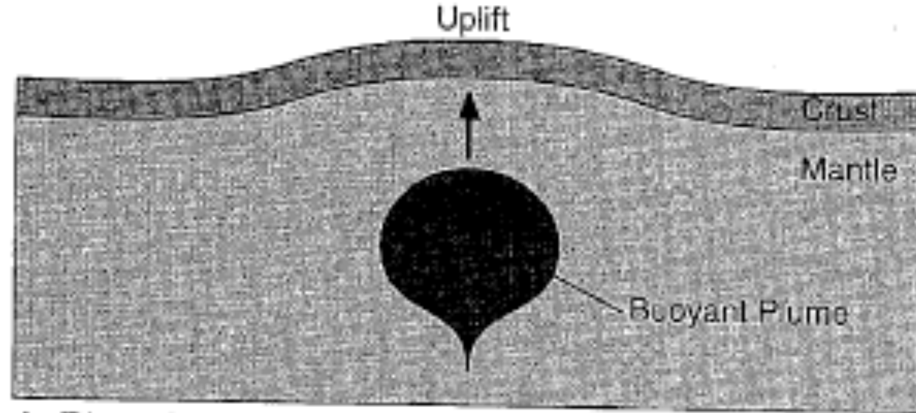


1. Downwelling plume develops in mantle and drags on crust

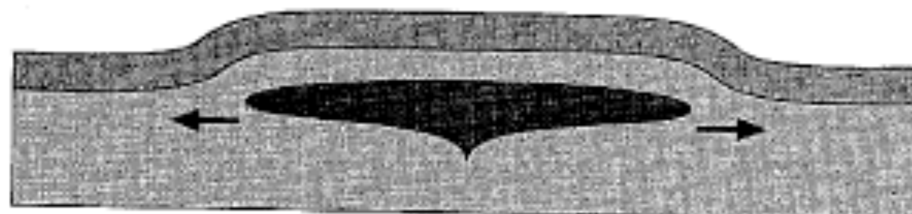

2. Crust buckles in response to compression

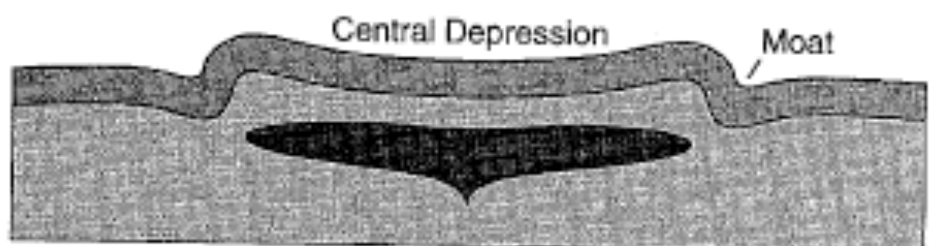

3. Crust thickens and a highland plateau develops


4. Downwelling ceases and highland spreads gravitationally

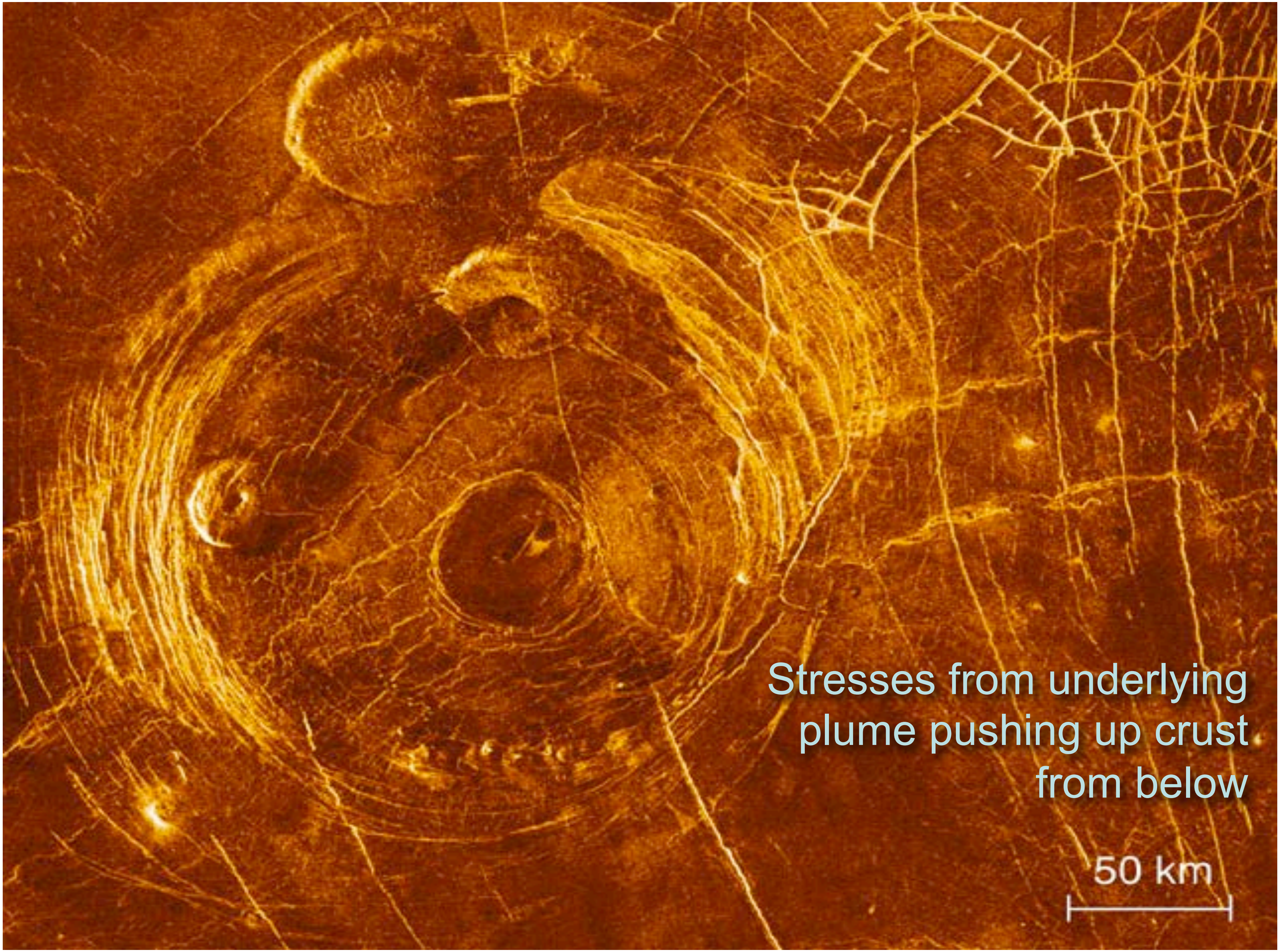


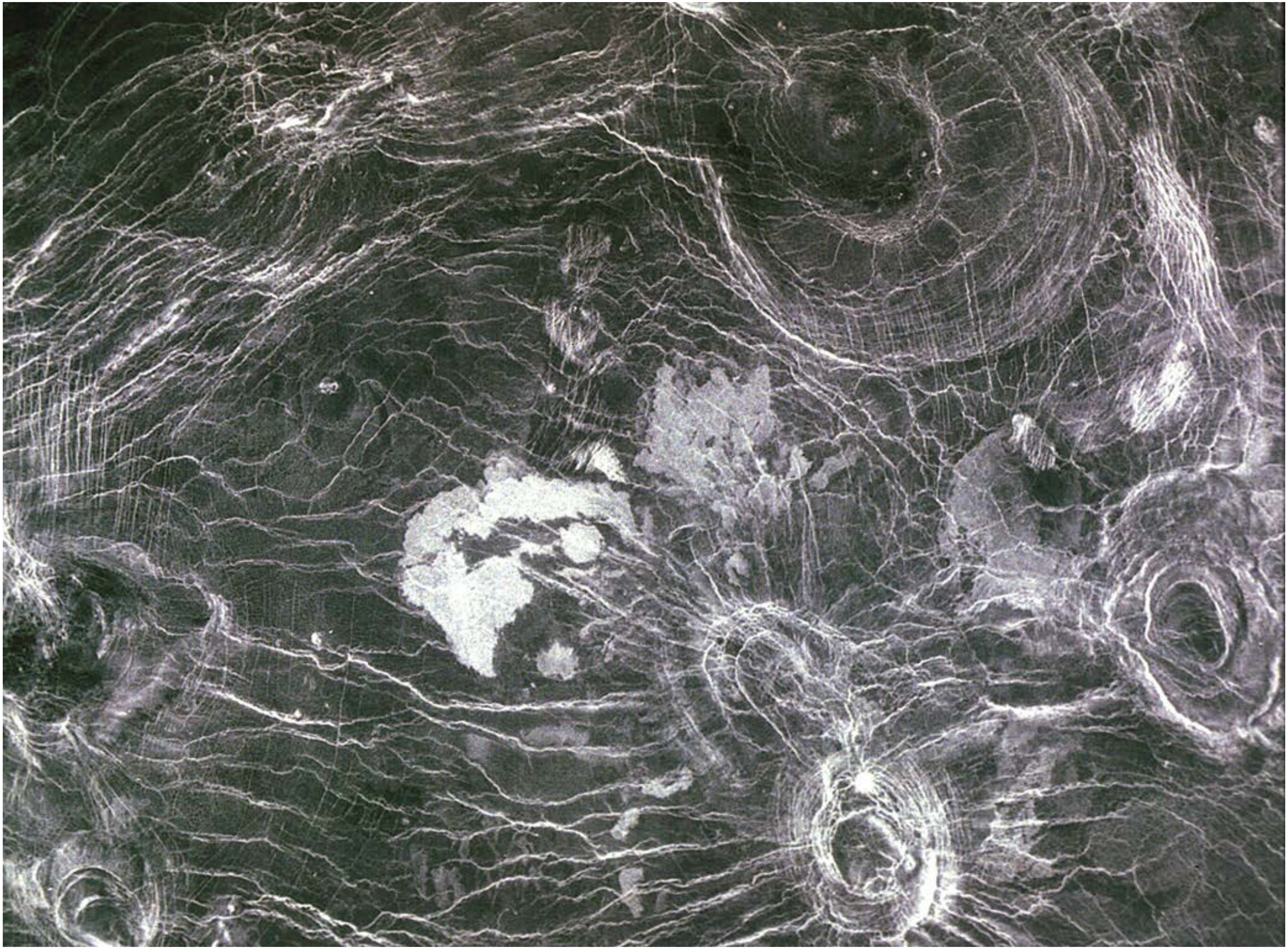
A. Rise of mantle plume


B. Plume spreads and flattens

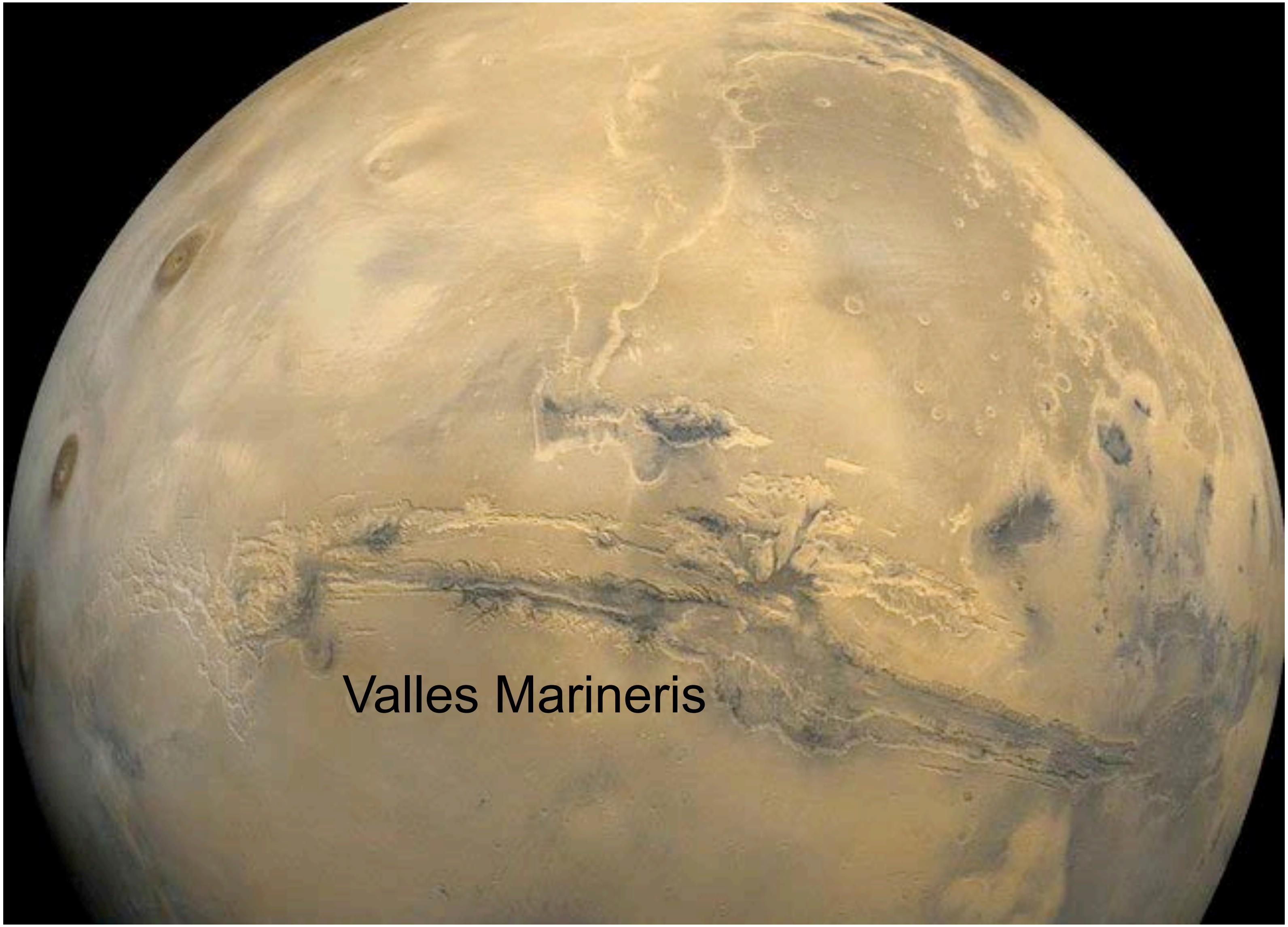


C. Plume cools and moat and depresson form

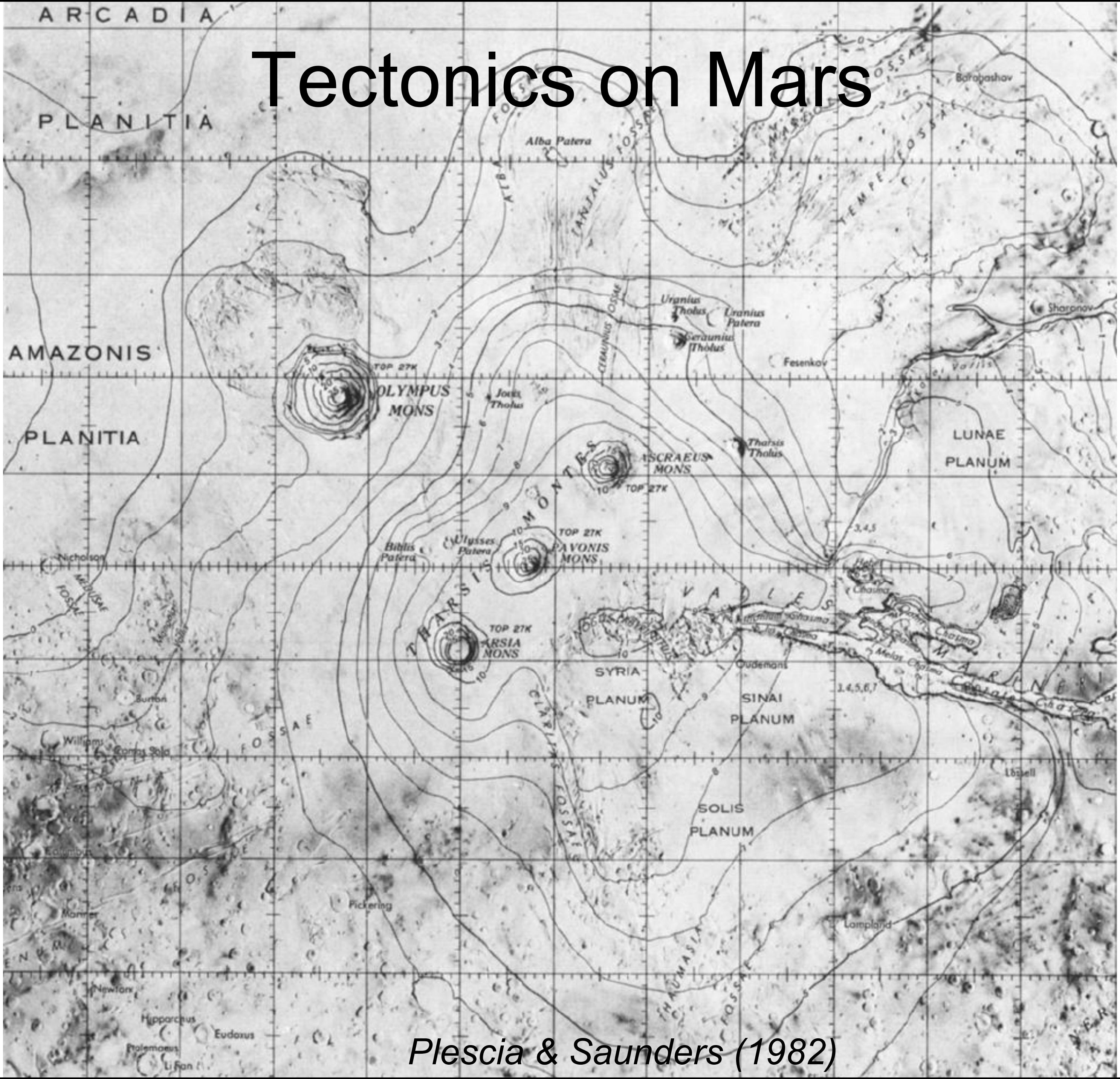

Stresses from underlying
plume pushing up crust
from below
50 km



Tectonics on Mars



Tectonics on Mars



Plescia & Saunders (1982)

Tectonics on Mars

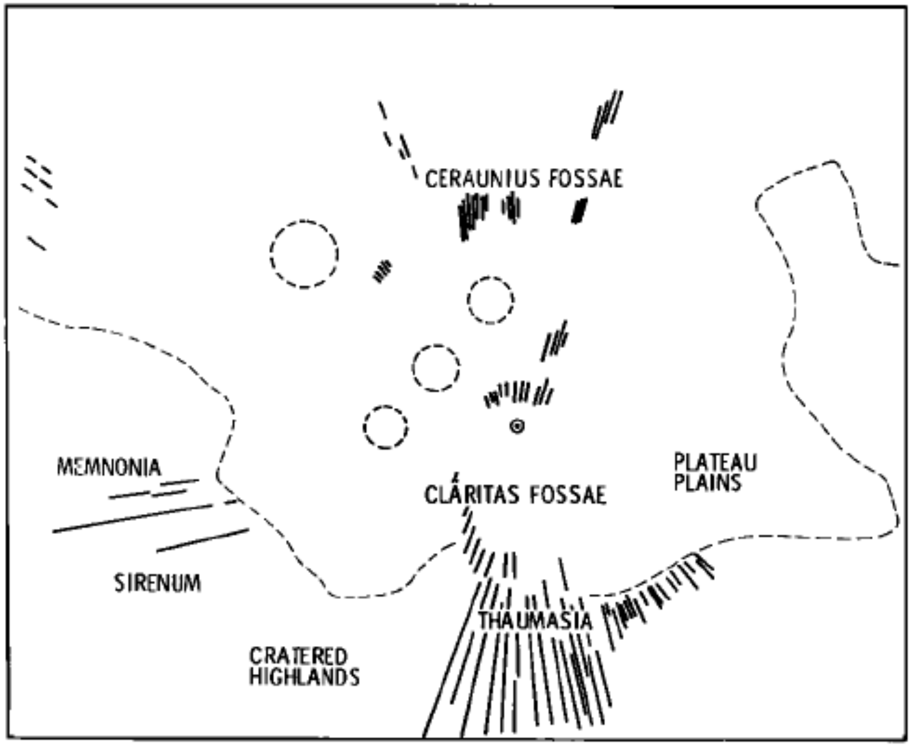


Fig. 6. Schematic sketch map of the exposed faults and units associated with the Syria center of faulting. Circled dot denotes center at 8°S, 100°W. Dashed circles represent future location of Tharsis shields.

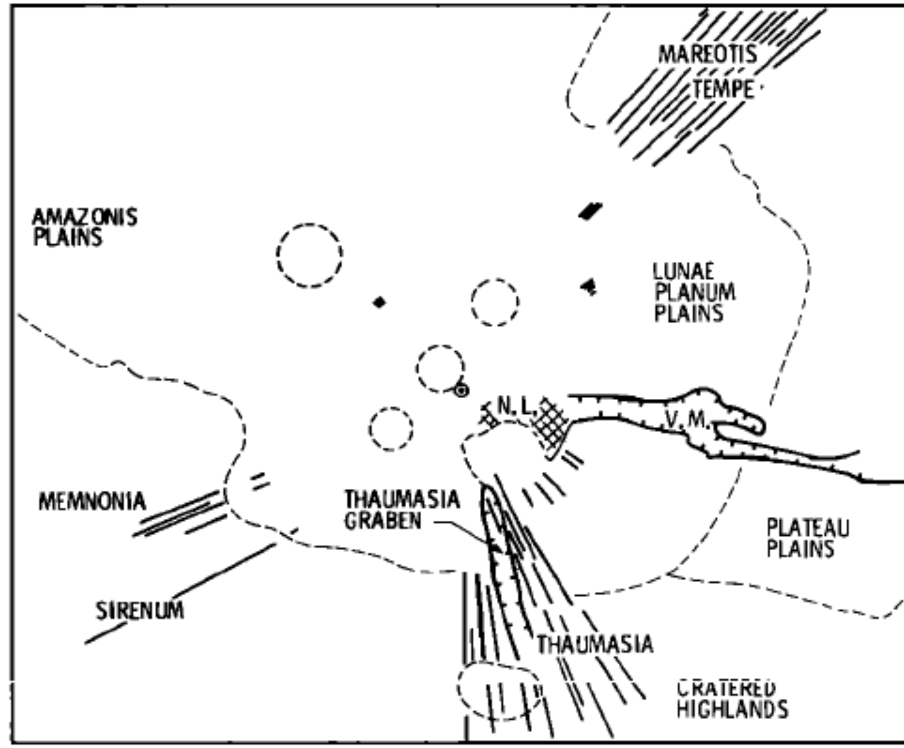
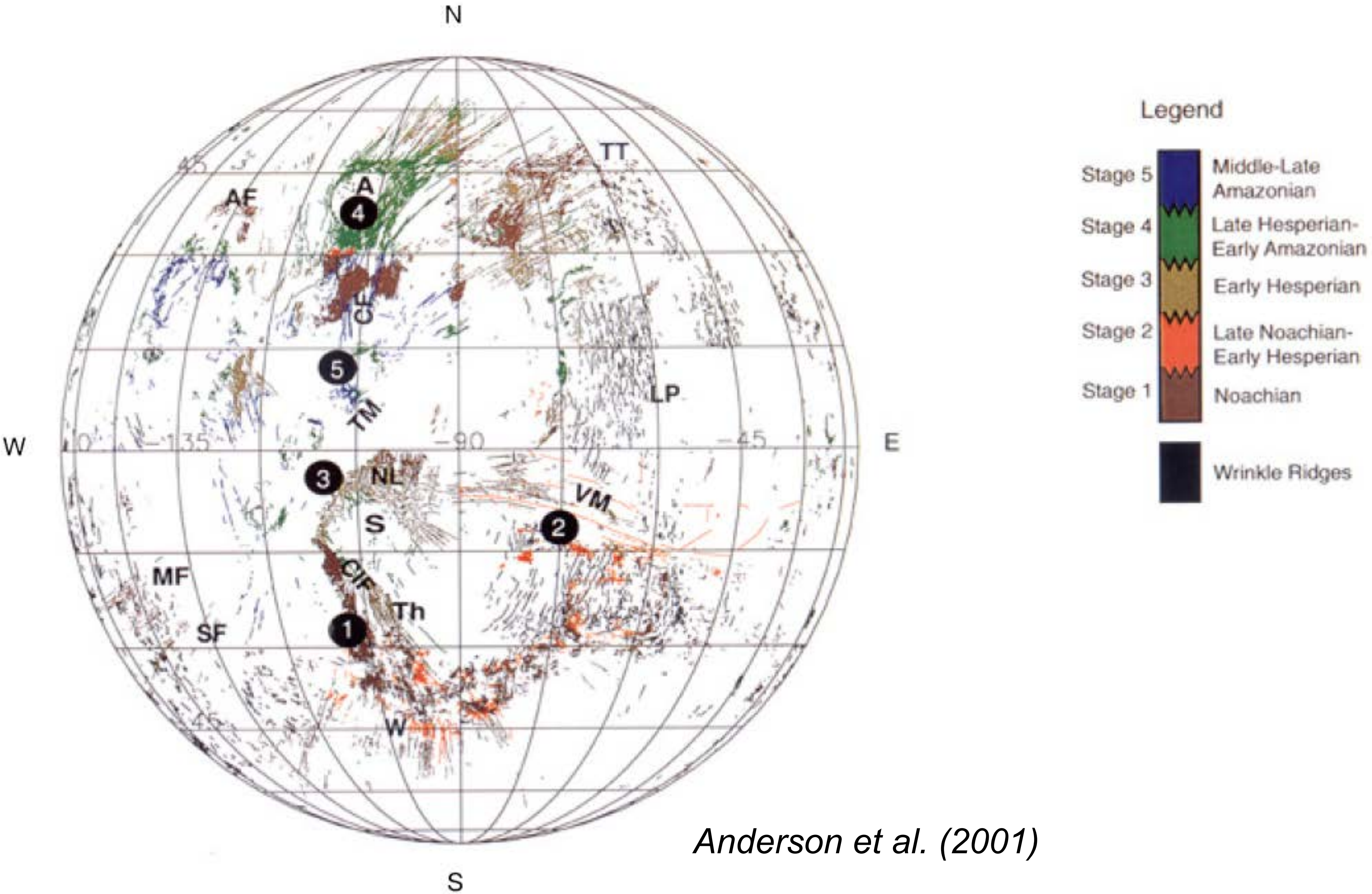


Fig. 9. Schematic illustration of the fractures associated with the Pavonis I episode of faulting, center located at 4°S, 110°W and denoted by the circled dot. Dashed circles denote the future location of the large Tharsis shields.

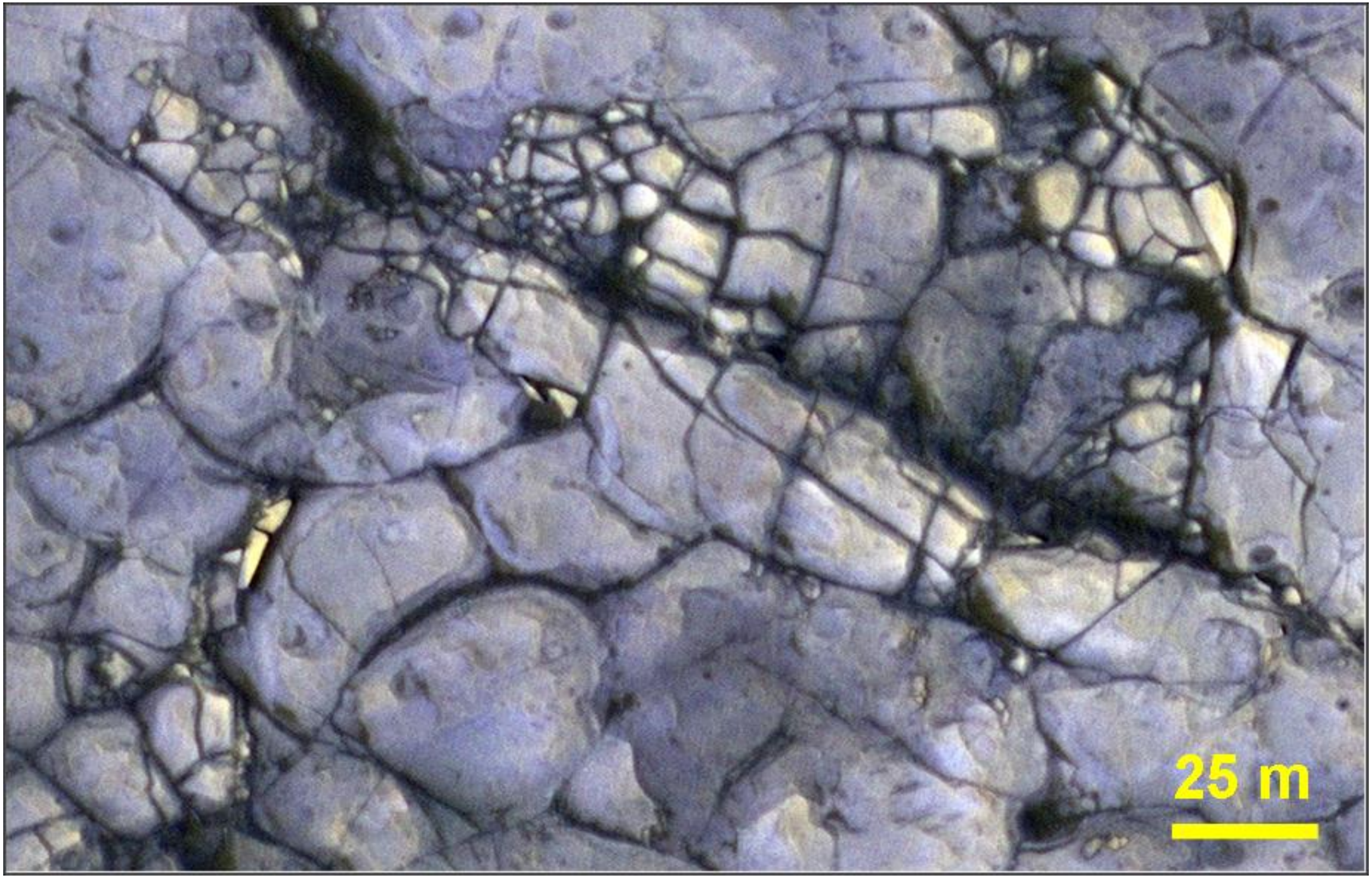
Plescia & Saunders (1982)

Tectonics on Mars



Anderson et al. (2001)

Tension at smaller scales (Mars)

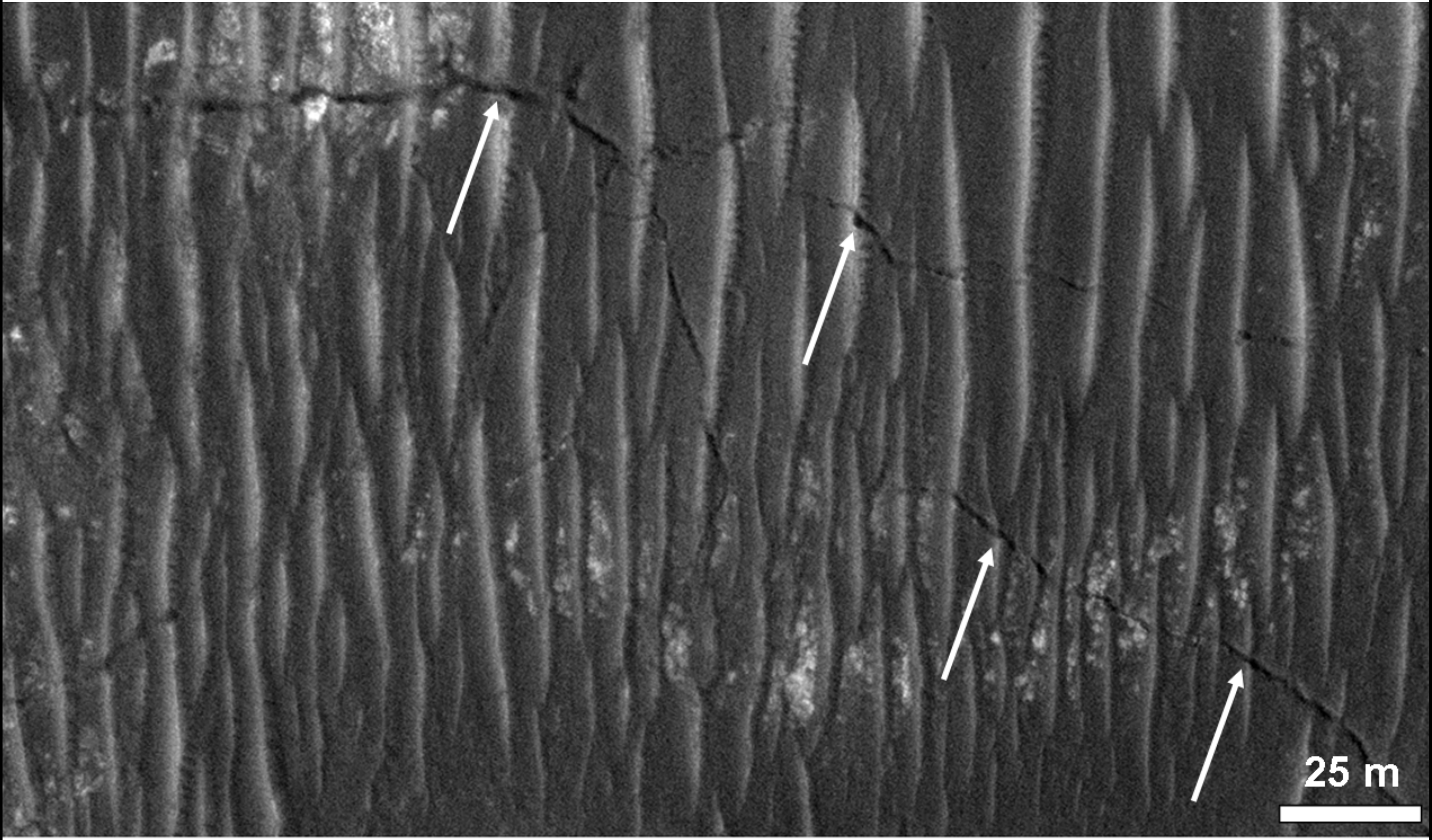


Tension at smaller scales (Earth)

Earthquakes!

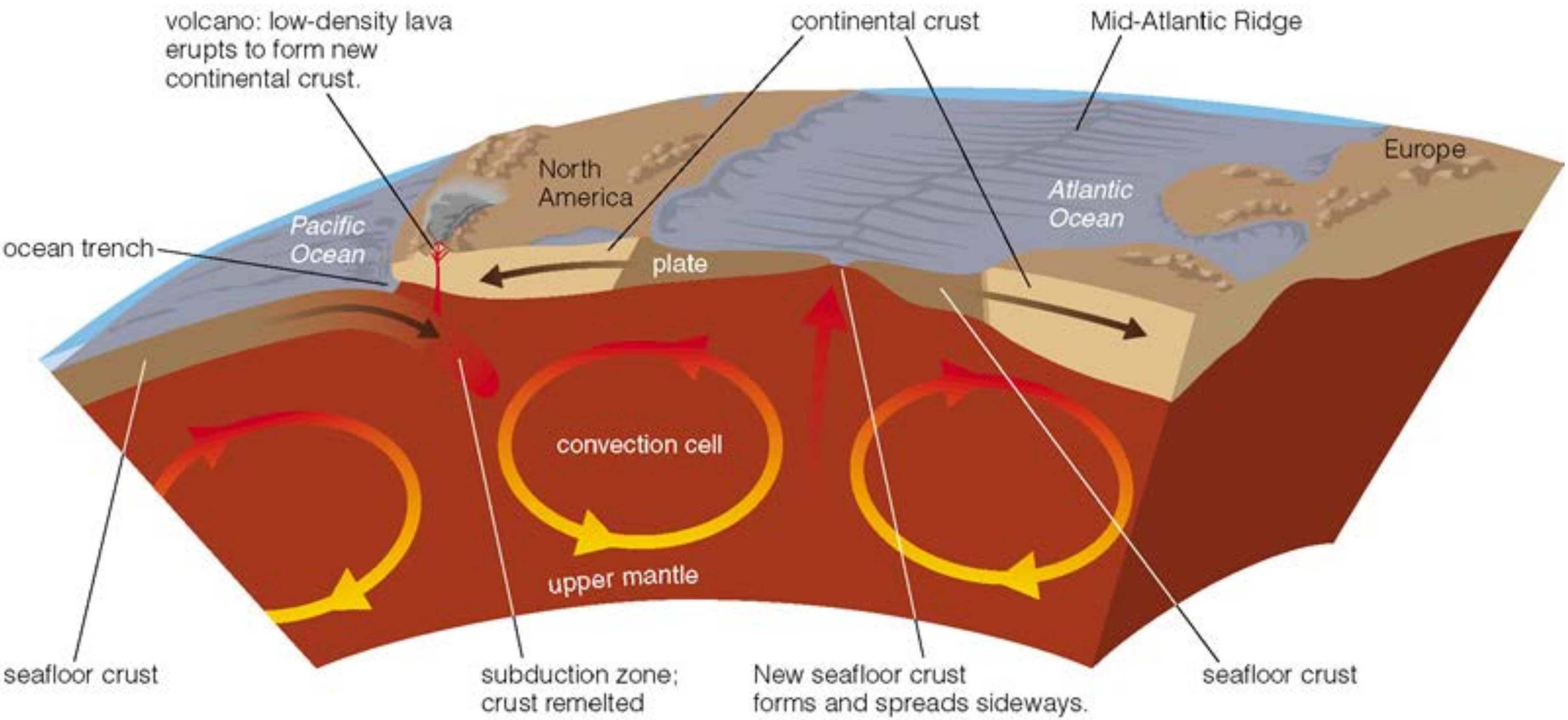
Richter scale is logarithmic:
$\log_{10}E = 12.24 + 1.44M_R$

Is Mars tectonically active today?

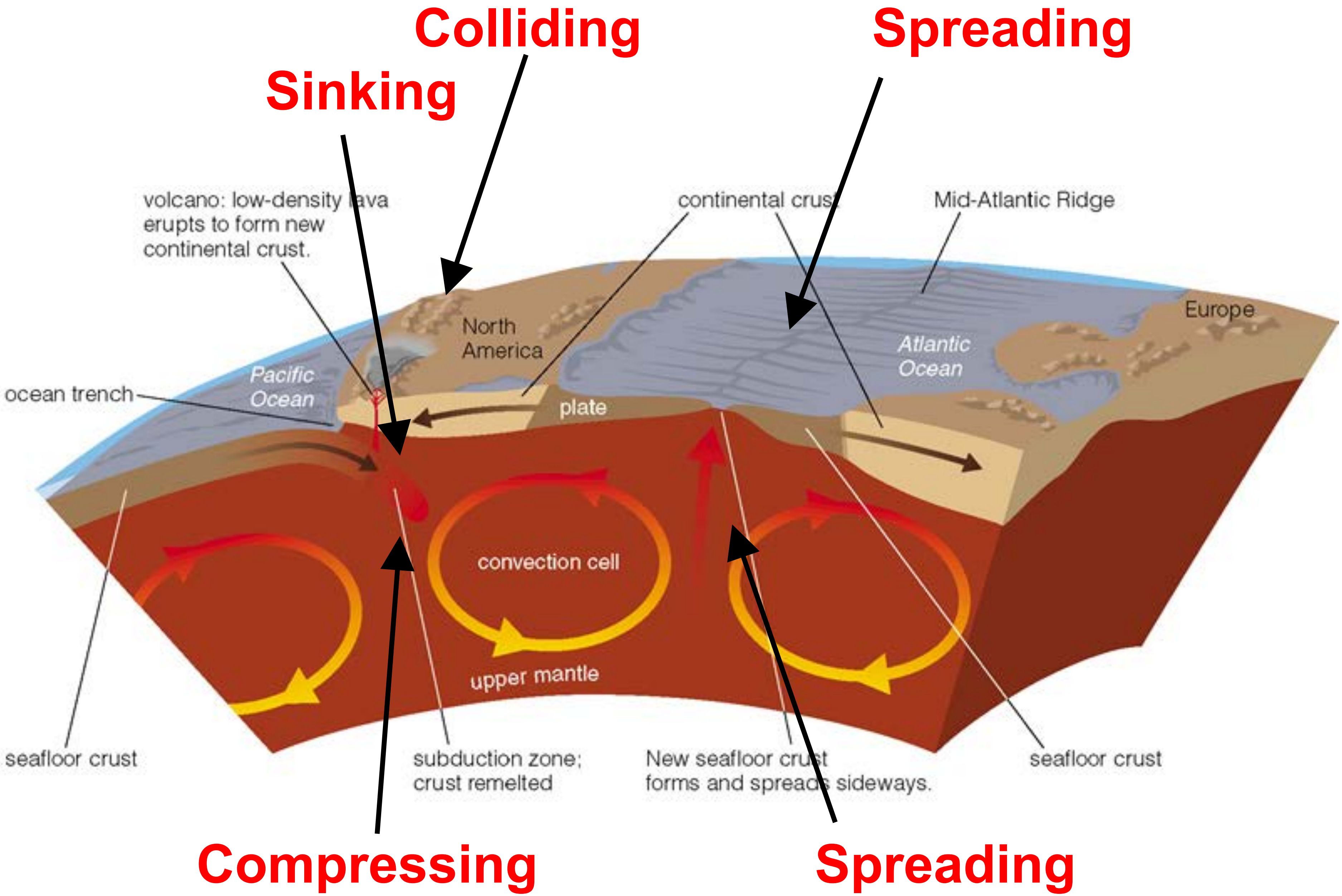


Wray & Ehlmann (2011)

Plate Tectonics



Strong convection drives recycling of crust on time scale of ~100 MY


Colliding
Spreading
Sinking
volcano: low-density lava erupts to form new continental crust.
continental crust
Mid-Atlantic Ridge
North America
Europe
Atlantic Ocean
Pacific Ocean
ocean trench
plate
convection cell
upper mantle
seafloor crust
subduction zone; crust remelted
New seafloor crust forms and spreads sideways.
seafloor crust
Compressing
Spreading

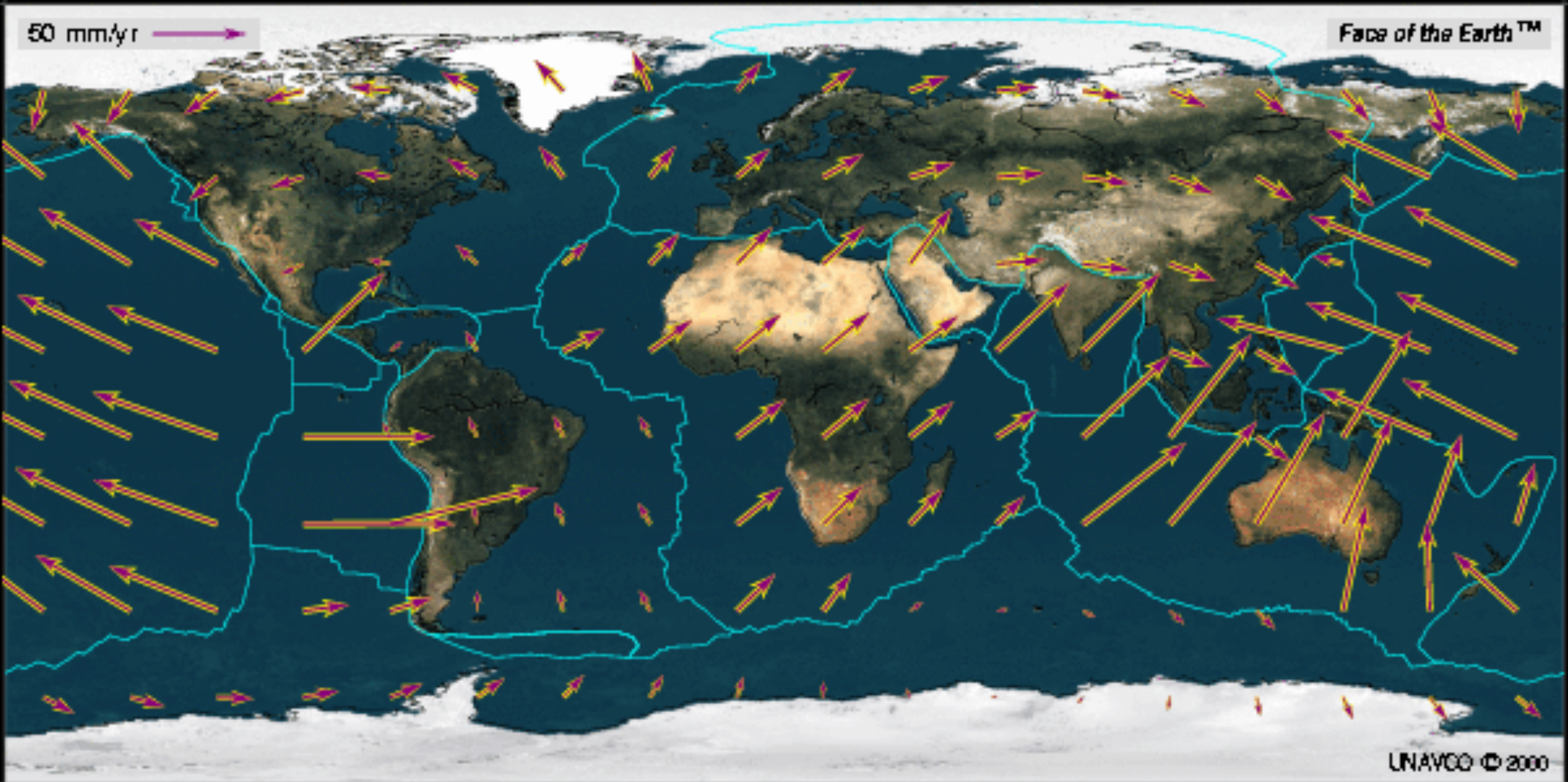
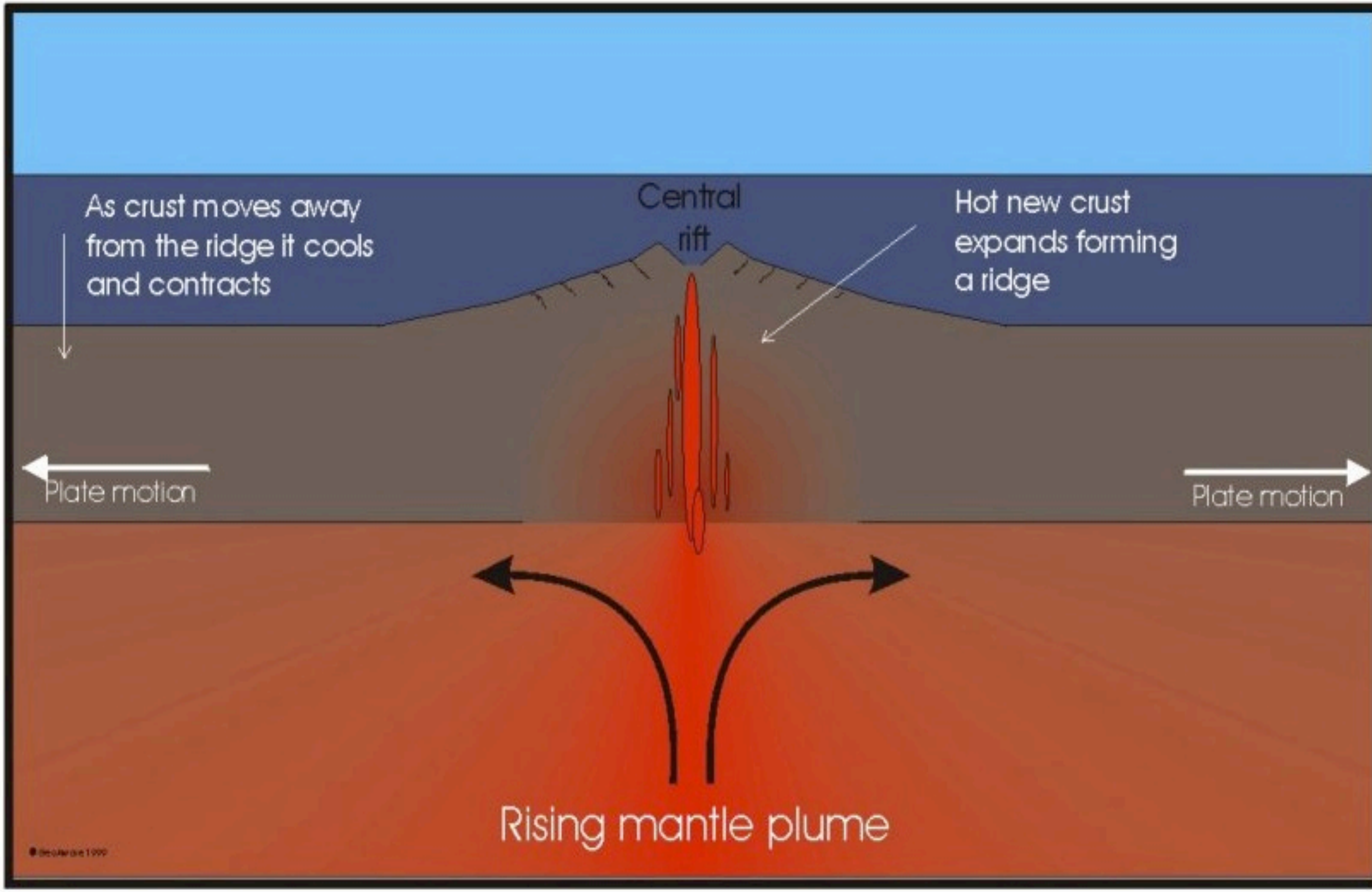
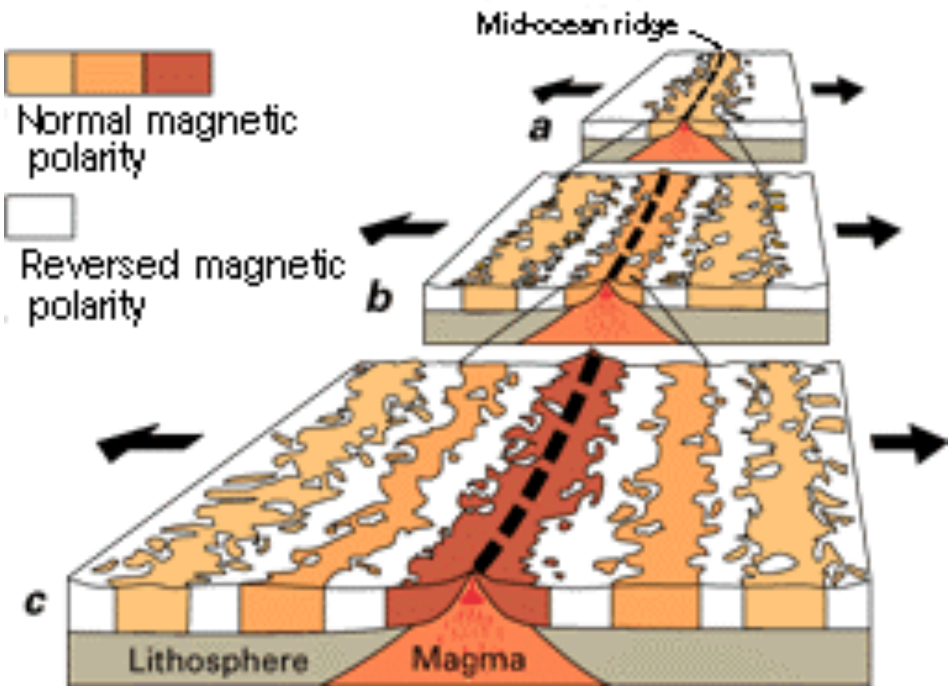


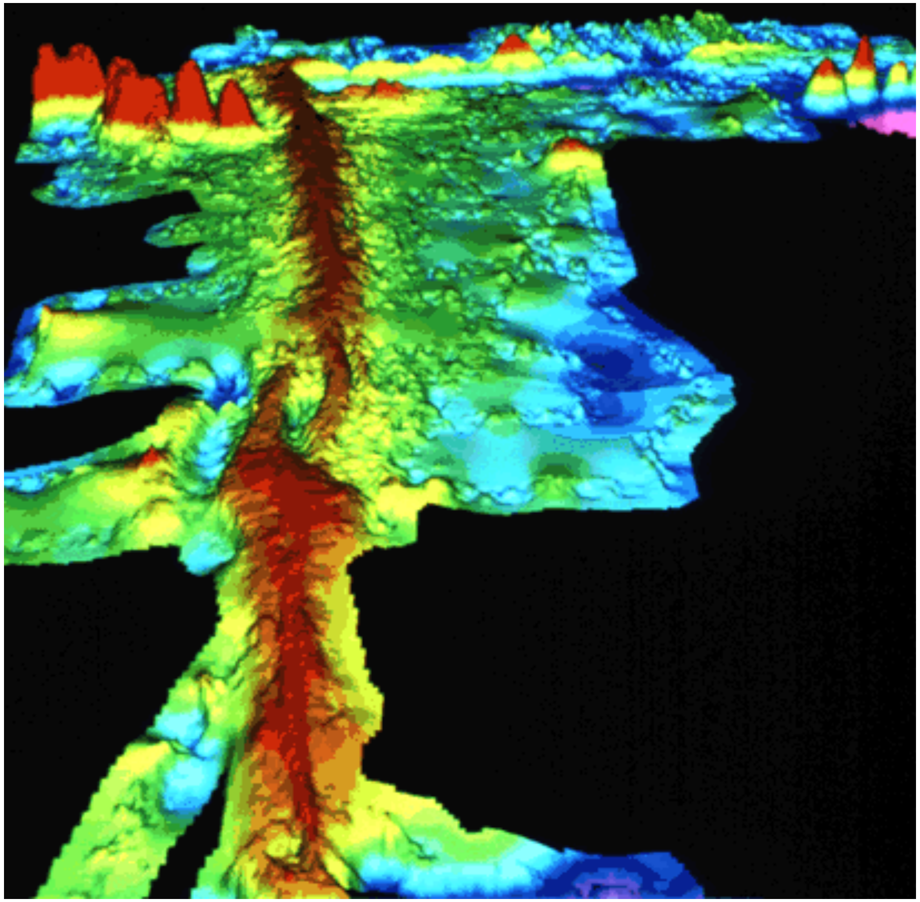
Plate motions measured with accurate GPS
Typically cm / year

Mid-Ocean Ridge



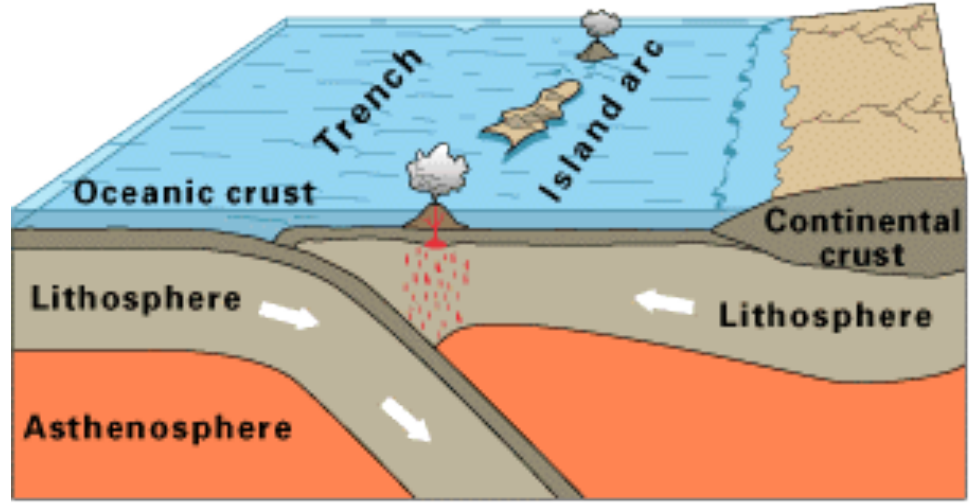
Mid-Ocean Ridge



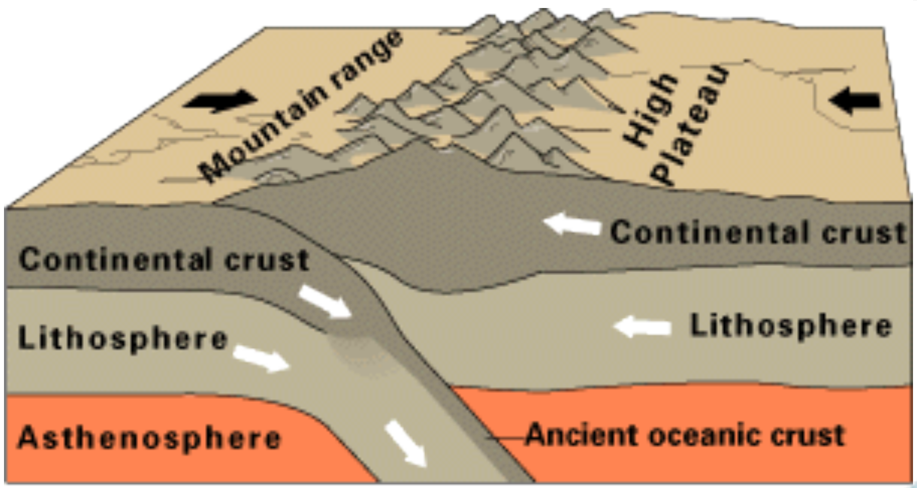


Mid-ocean spreading rate measured from magnetic field reversal pattern

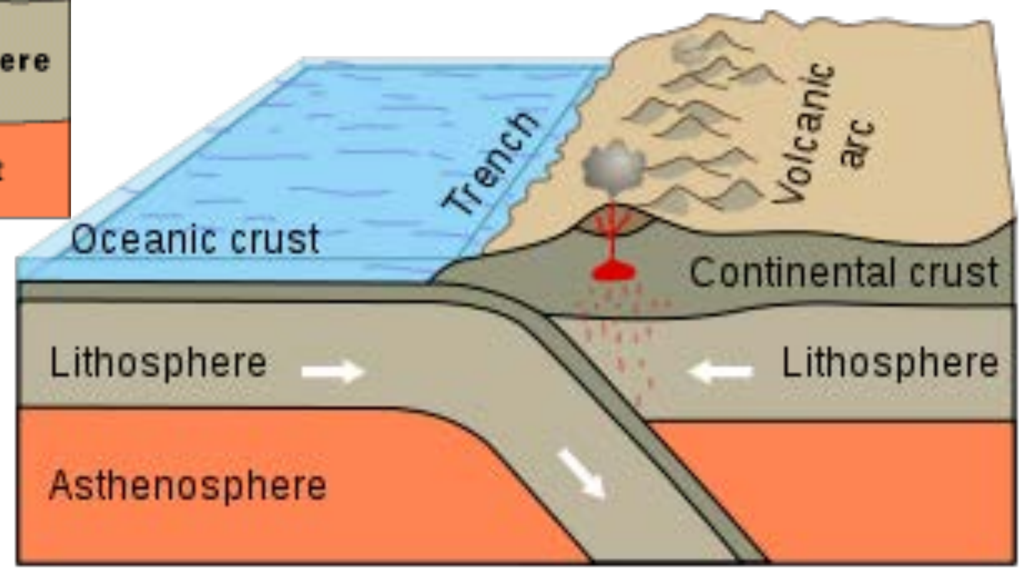
Plate boundaries: Convergence



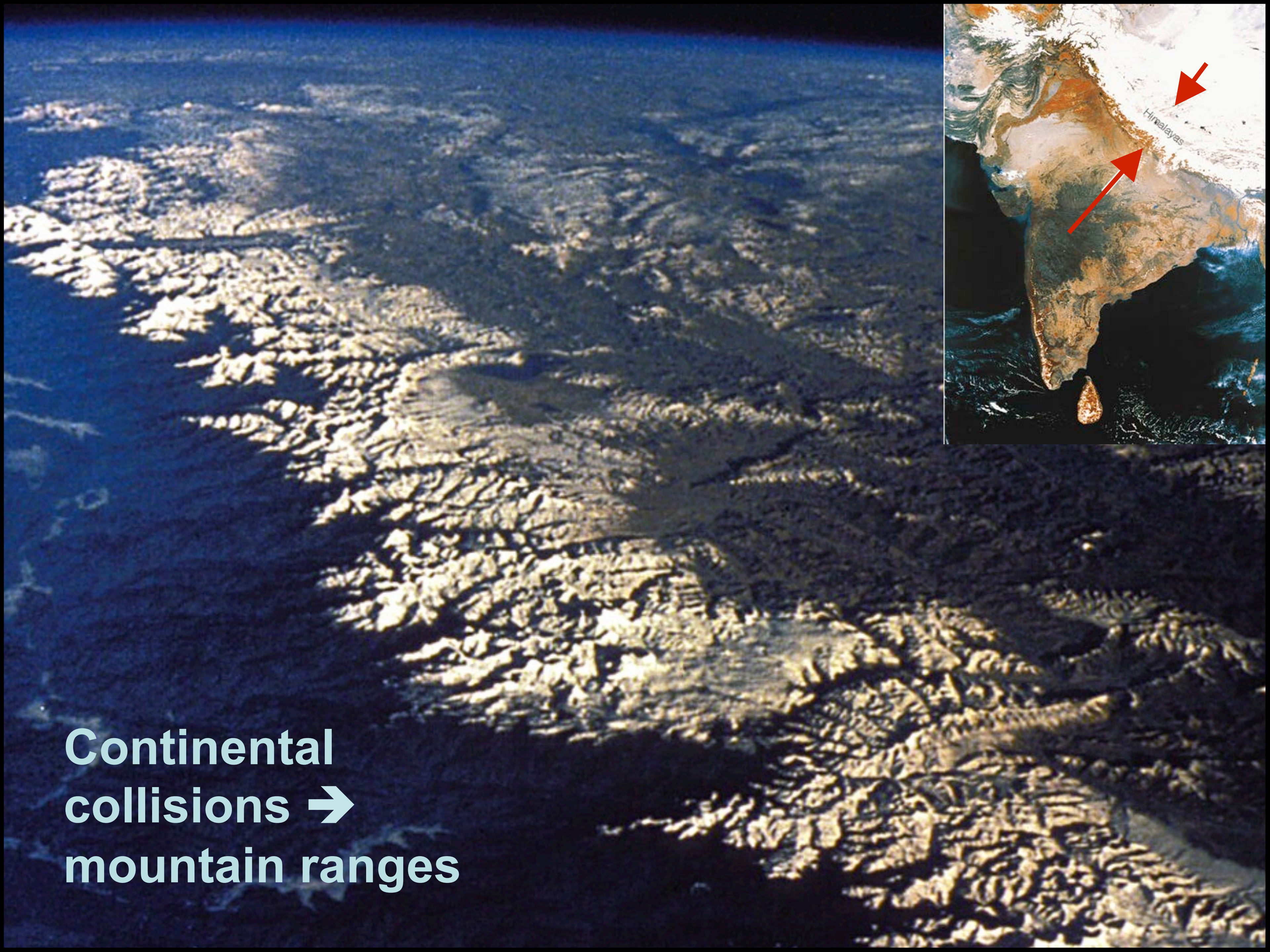
Oceanic-oceanic convergence

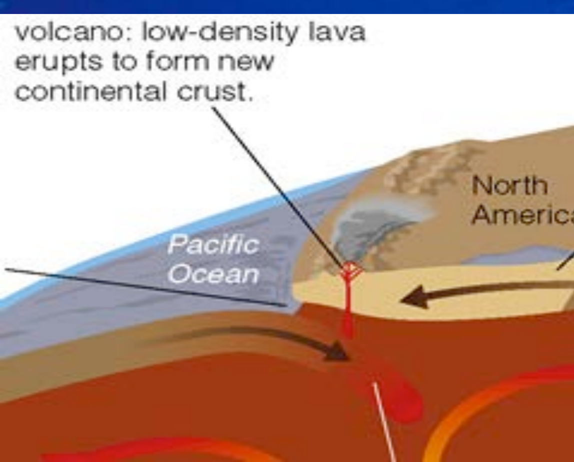


Continental-continental convergence



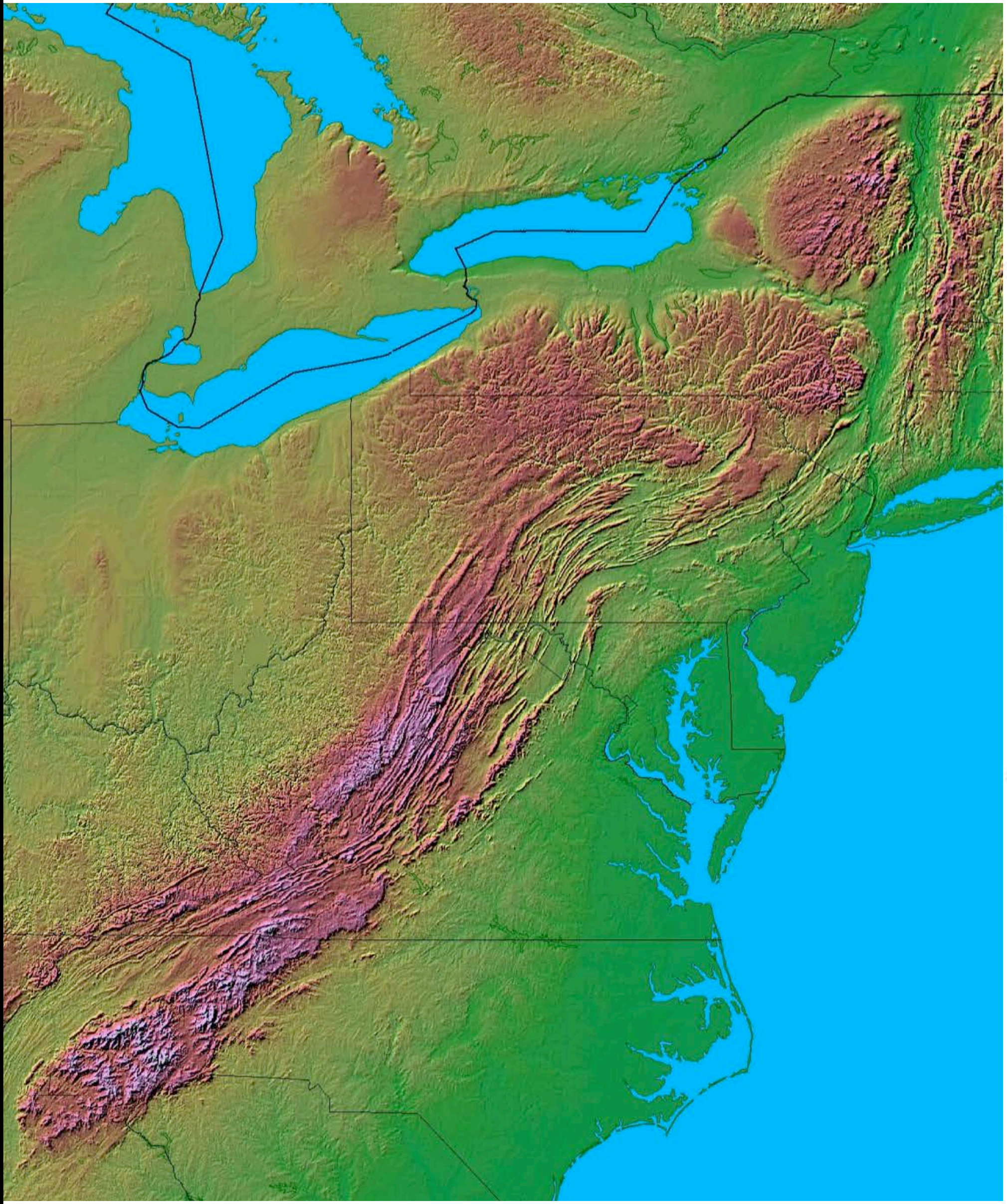
Ocean-continent convergence


Continental
collisions ➔
mountain ranges
Himalayas



Andes - Pacific ocean plate sinks under South American plate

Mountains along former plate boundaries



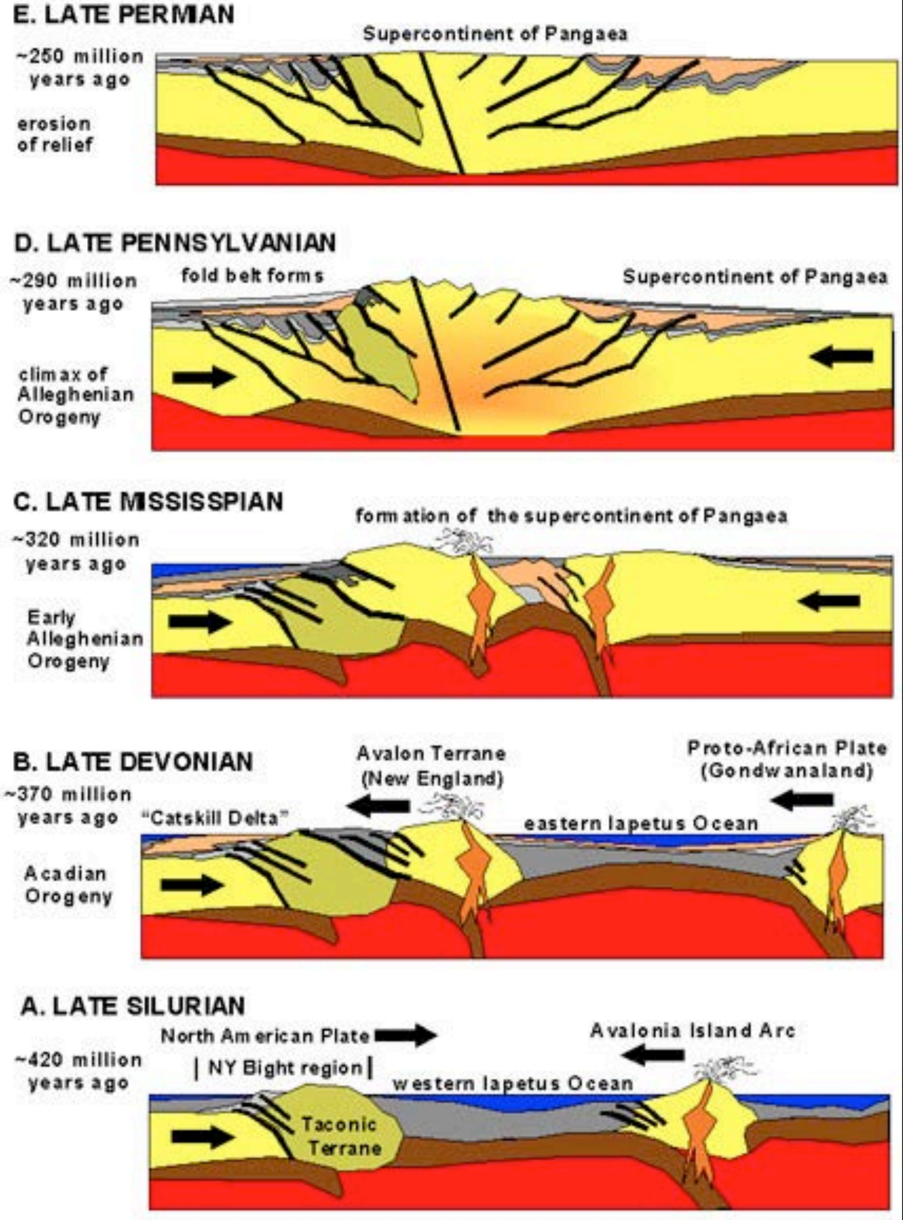
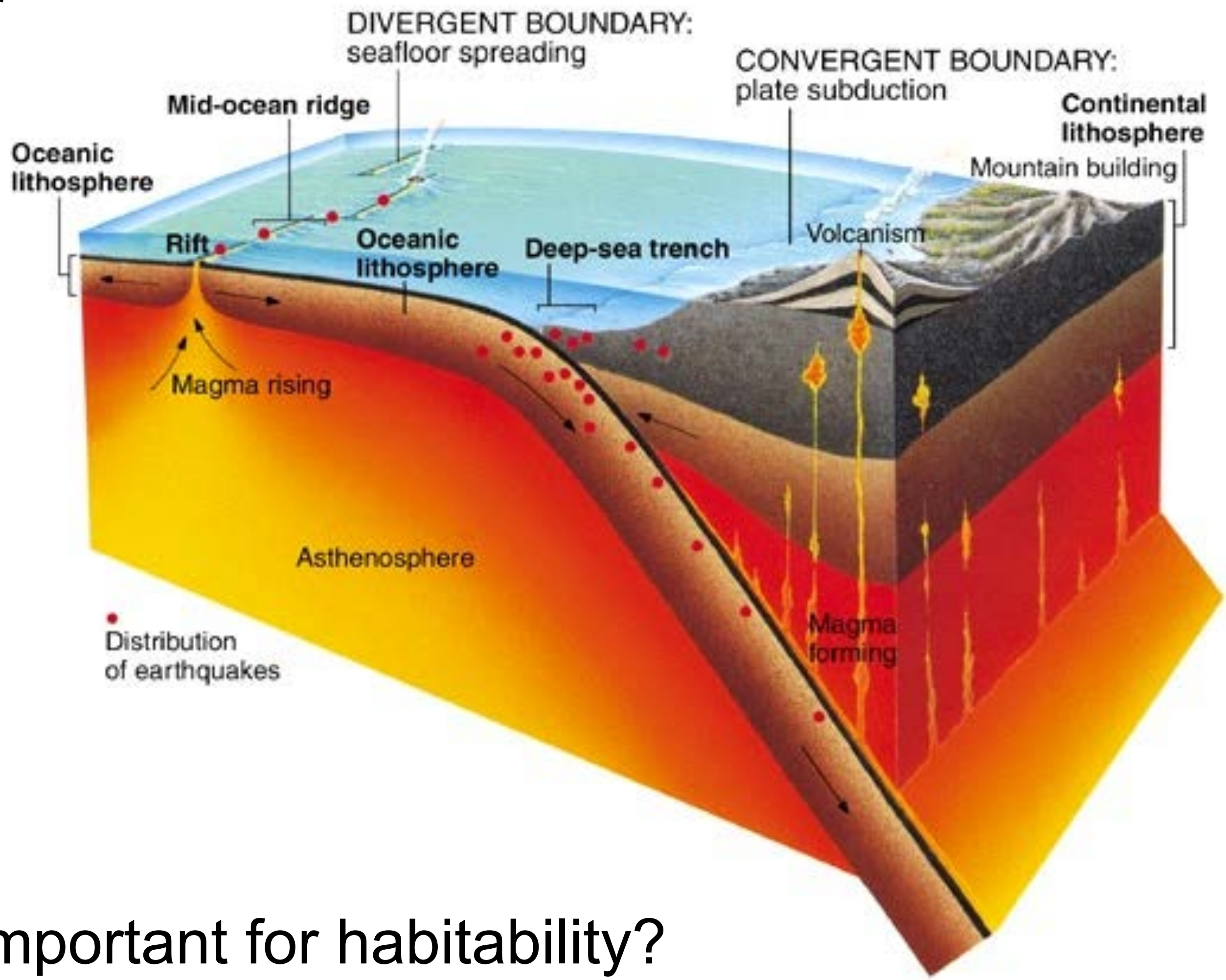


Plate tectonics shaped the Earth

- Seafloor recycling
  - Keeps the seafloor young
  - Ocean ridges and trenches
- Built and shaped the continents
  - Mountain ranges
  - Tectonic features (e.g. faults)
  - Volcanoes
  - Earthquakes



Important for habitability?