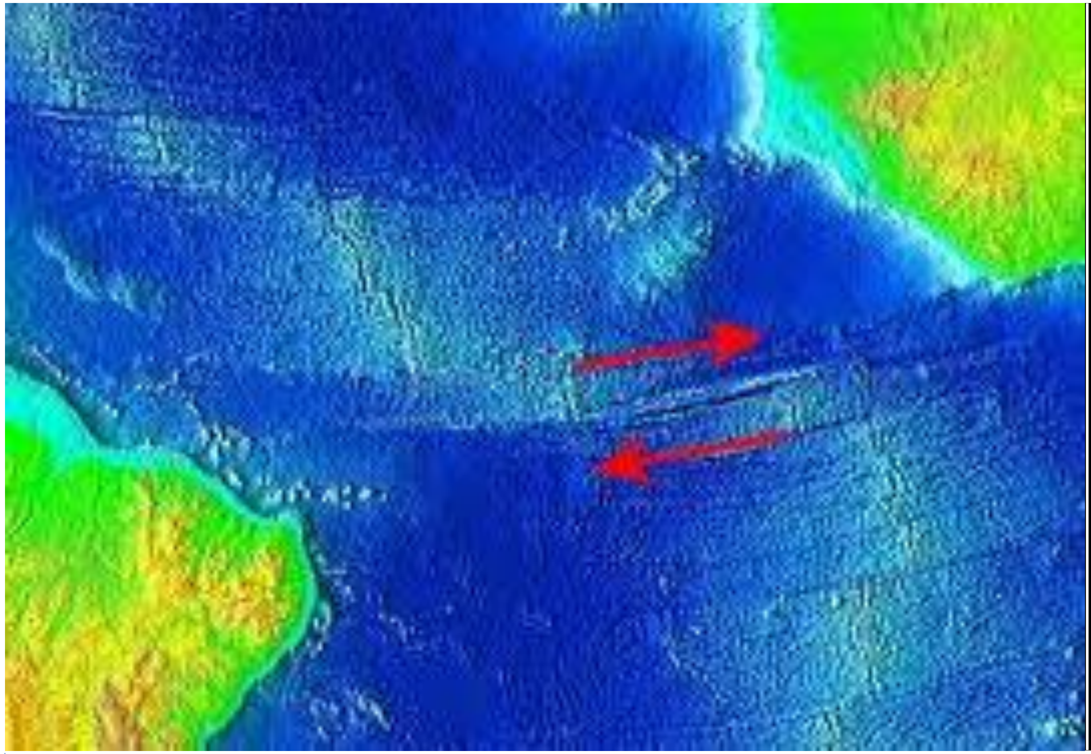
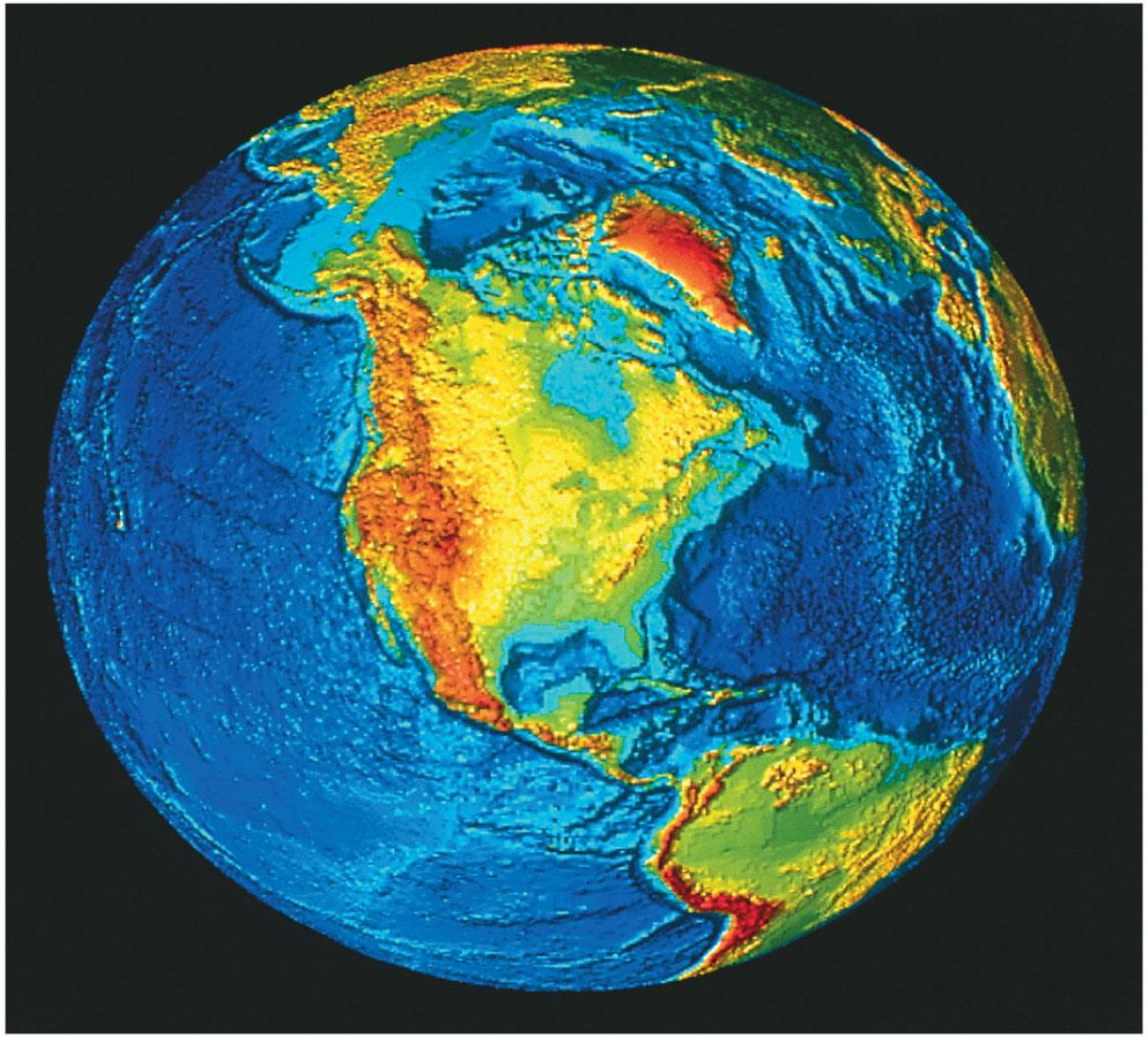



Whole Earth Structure & Geological Structures

(I) Whole Earth Structure



(a)

Photo courtesy of ICDP, GeoForschungsZentrum Potsdam

KTB drilling in Germany reached 10 KM depth

Xenolith in basalt

Diamonds in Kimberlite

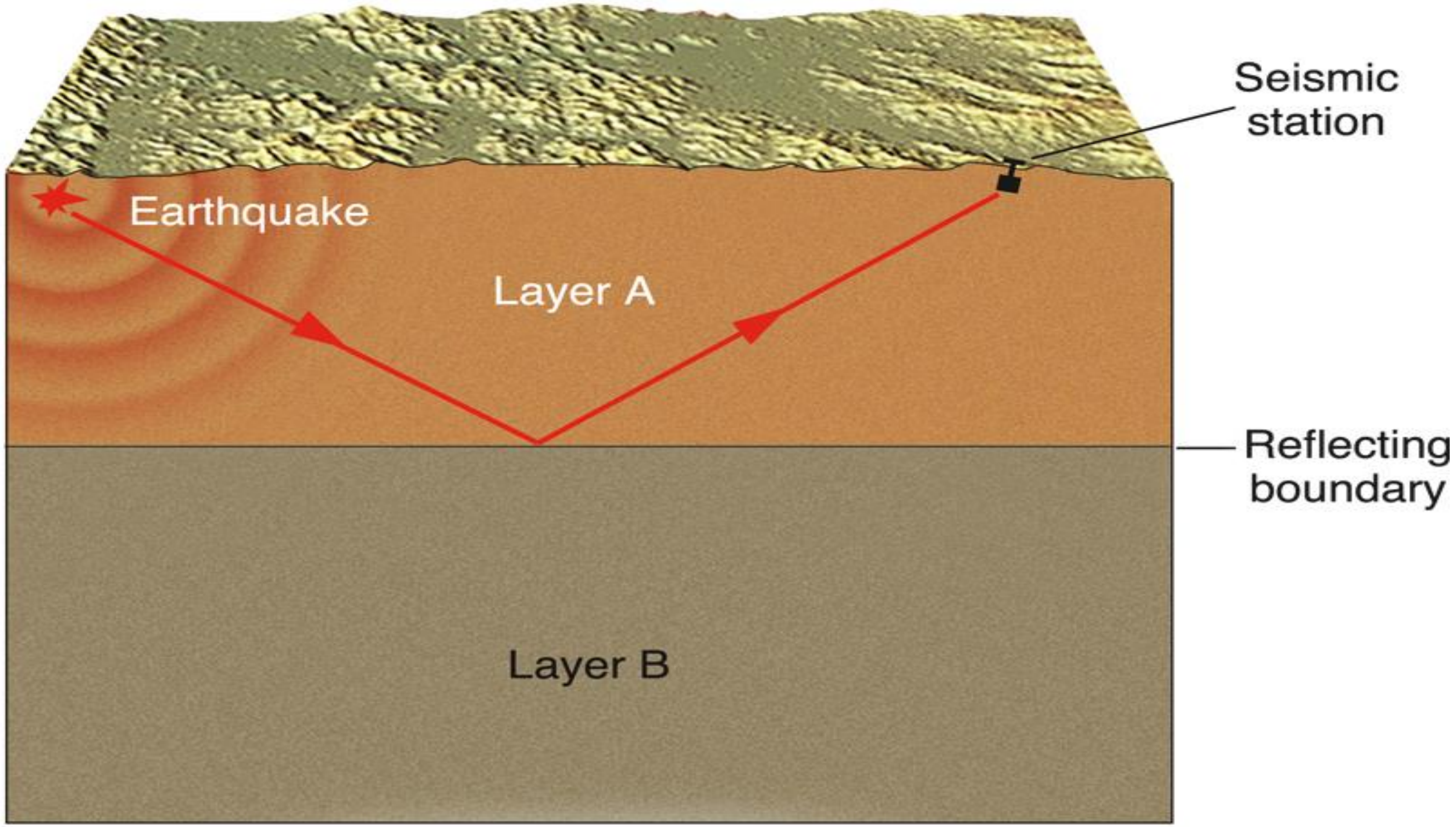
Photo © Reuters New-Media Inc./Corbis

Seismic Imaging

Seismic Reflection

: Waves bounce off major discontinuity

Mark the boundary between rock layers



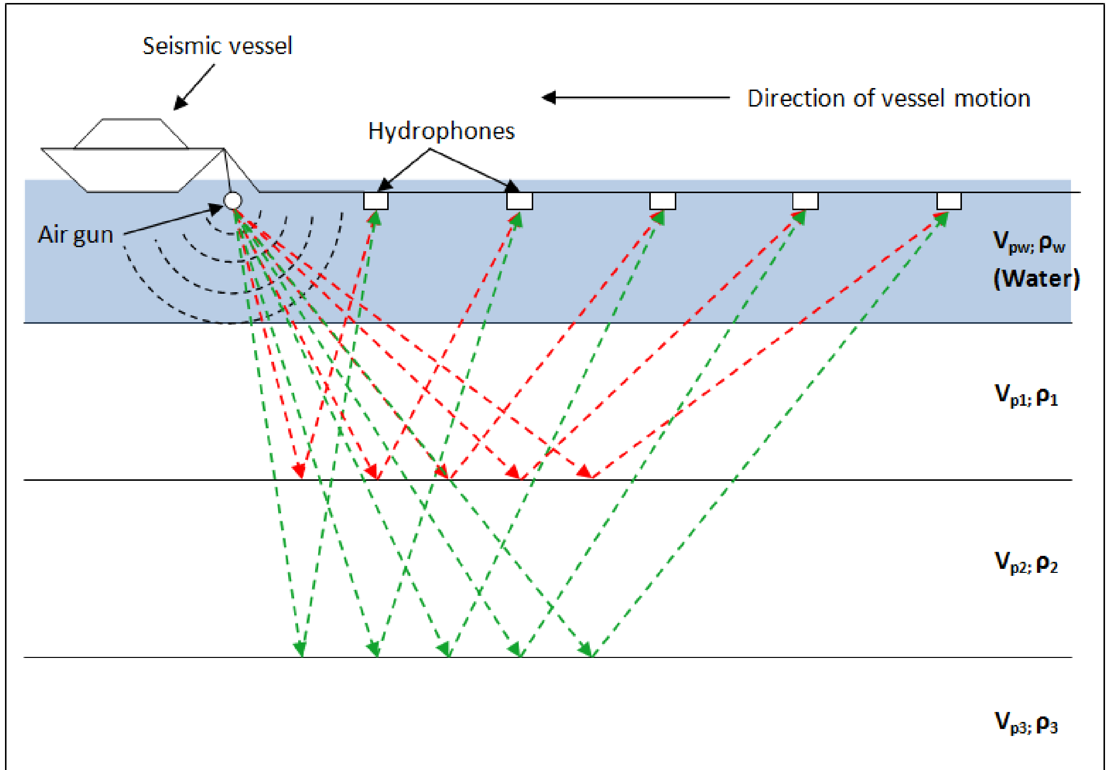
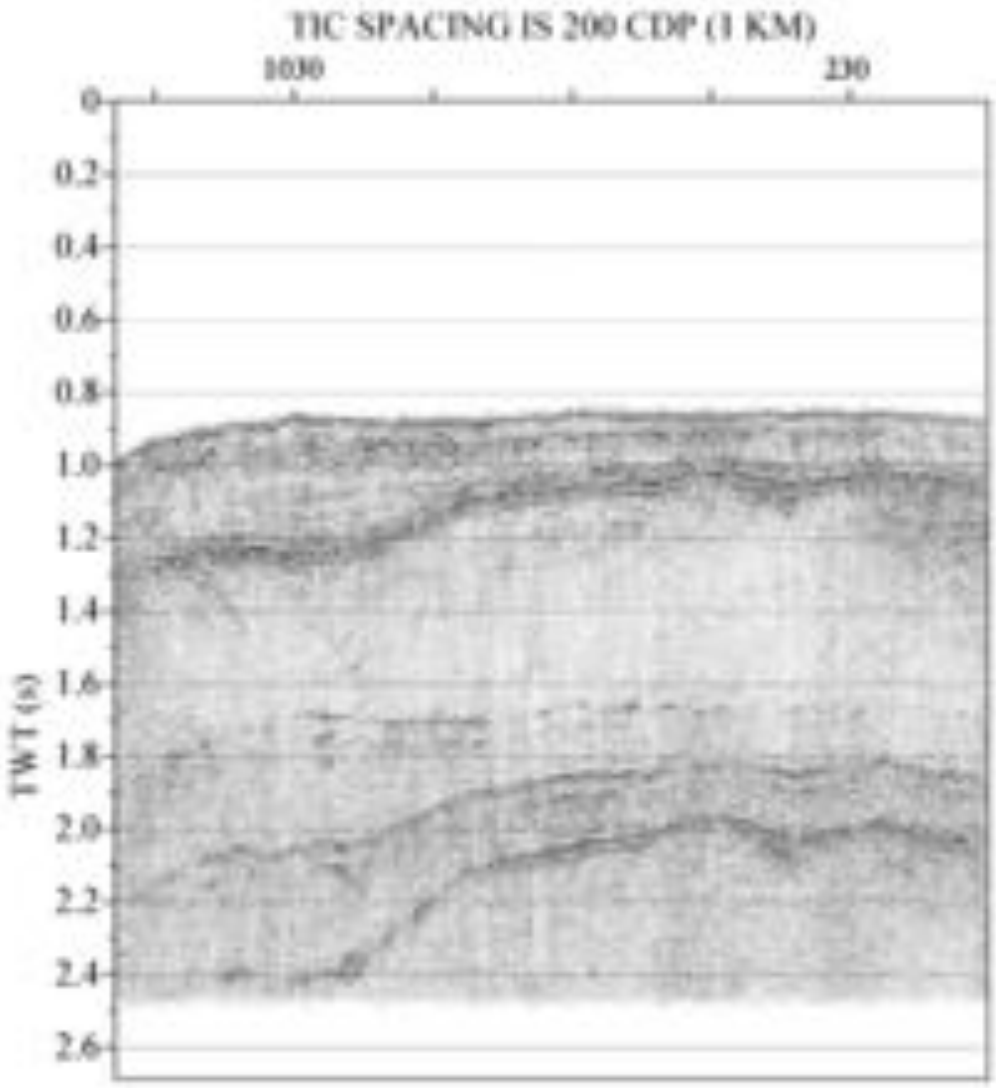


Diagram of a marine towed streamer seismic survey with the raypaths that result from a single shot by an airgun into a streamer containing 5 hydrophones.
--- = raypaths to first reflector; --- = raypaths to second reflector;

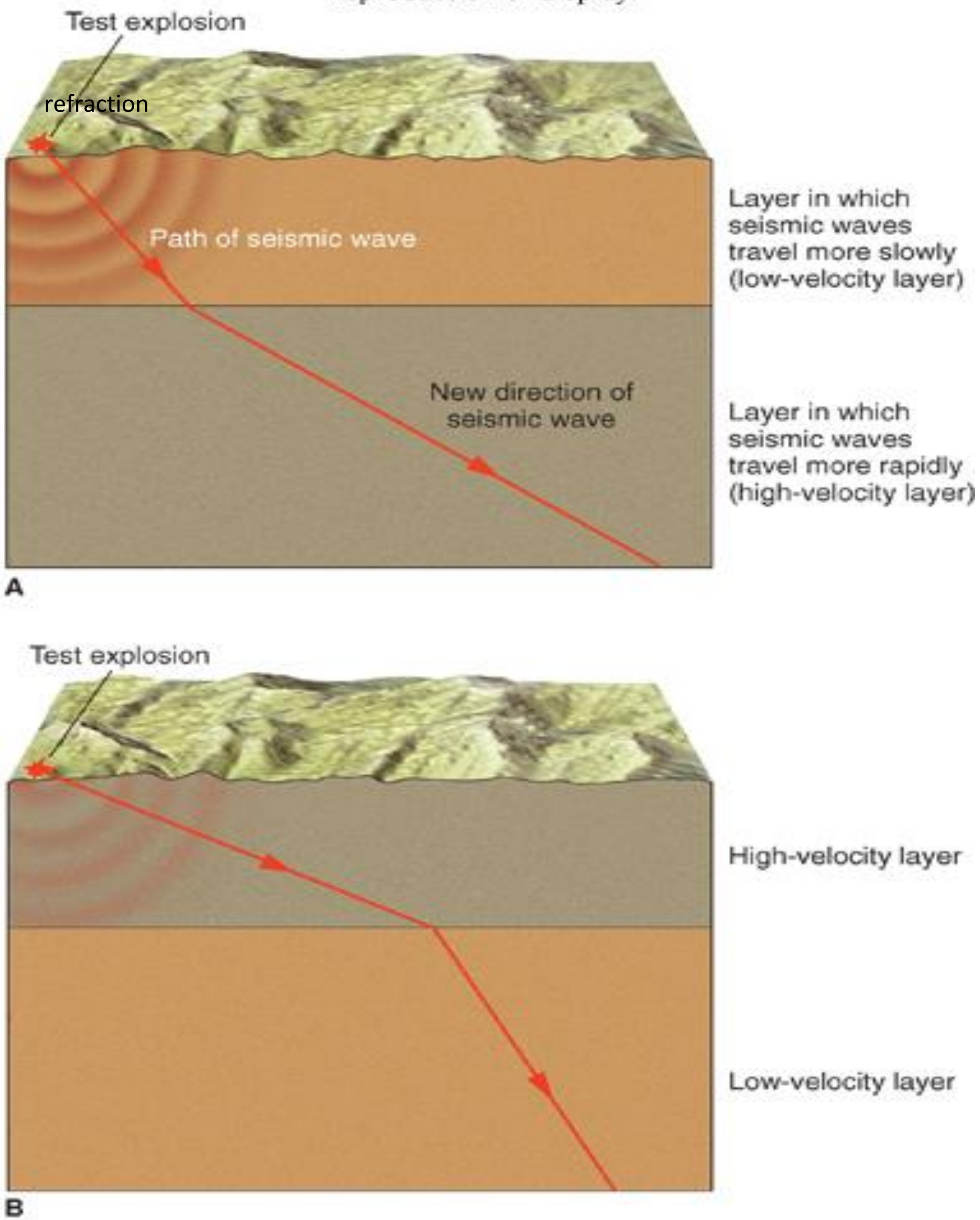


1999 Gulf of Mexico Line 7

Seismic Refraction

: Bending of waves as they pass across the discontinuity.

Seismic wave velocity increases with increasing pressure, decreasing temperature, and increasing rigidity.



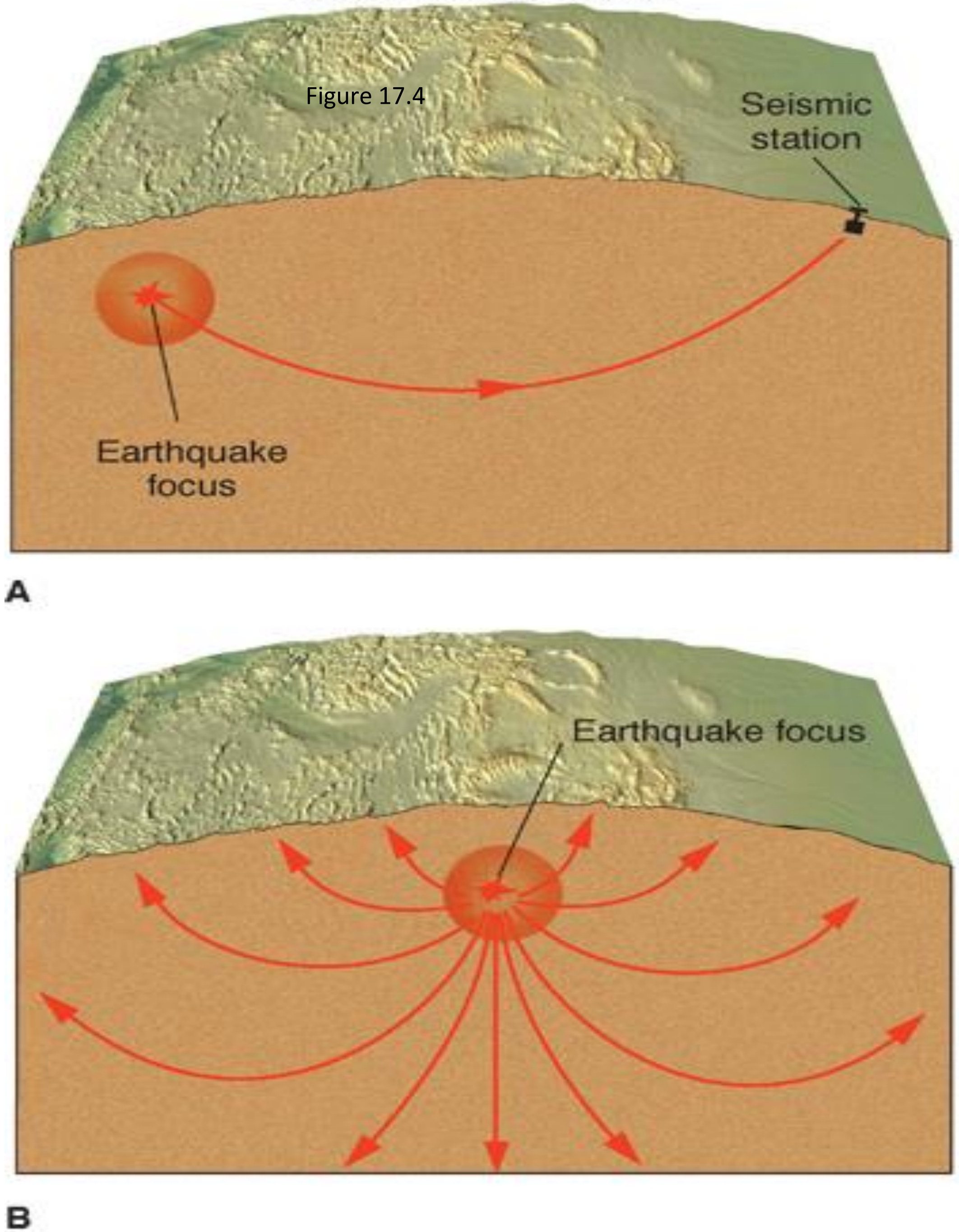


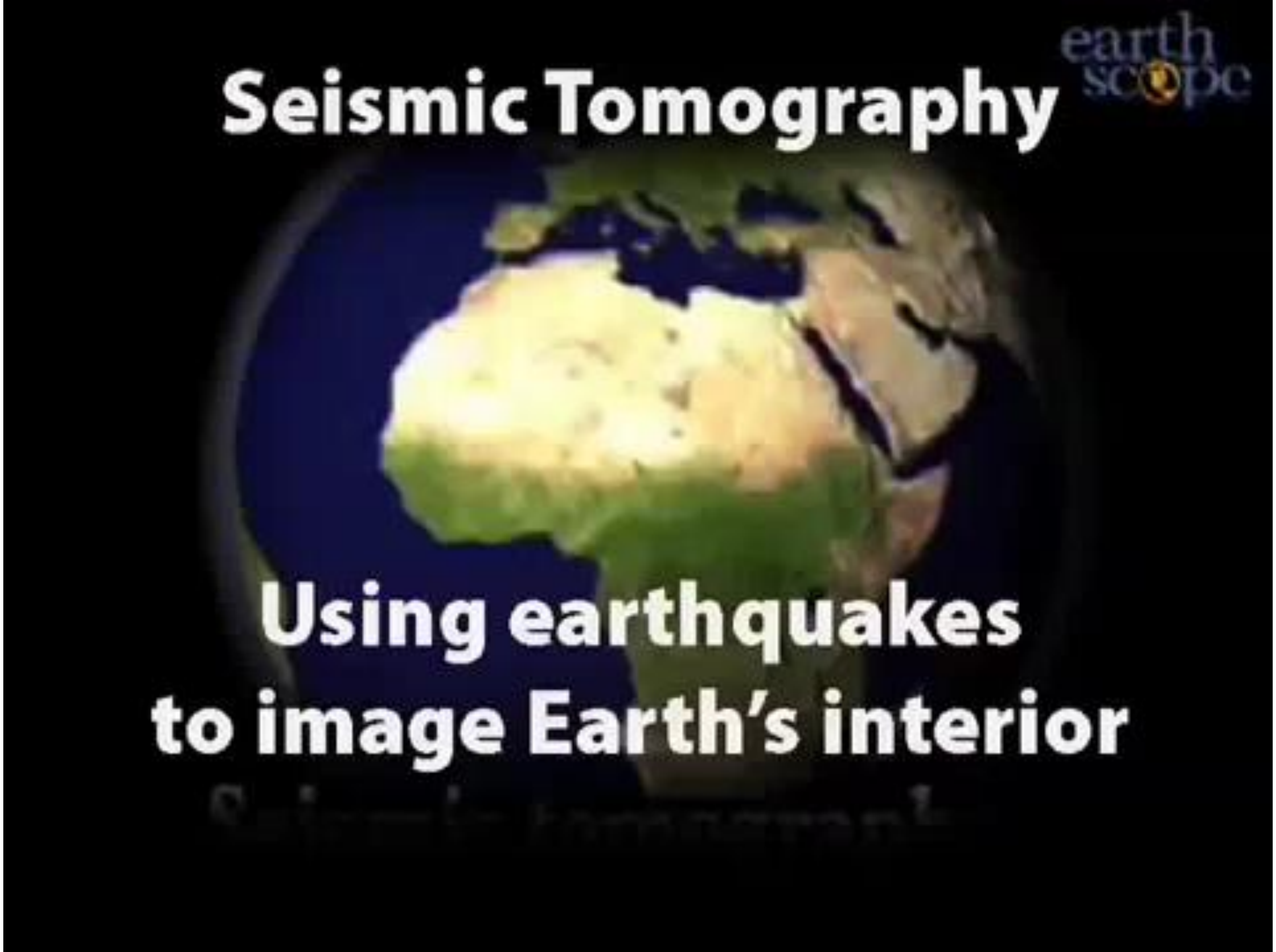
Figure 17.4

Simple model of seismic refraction

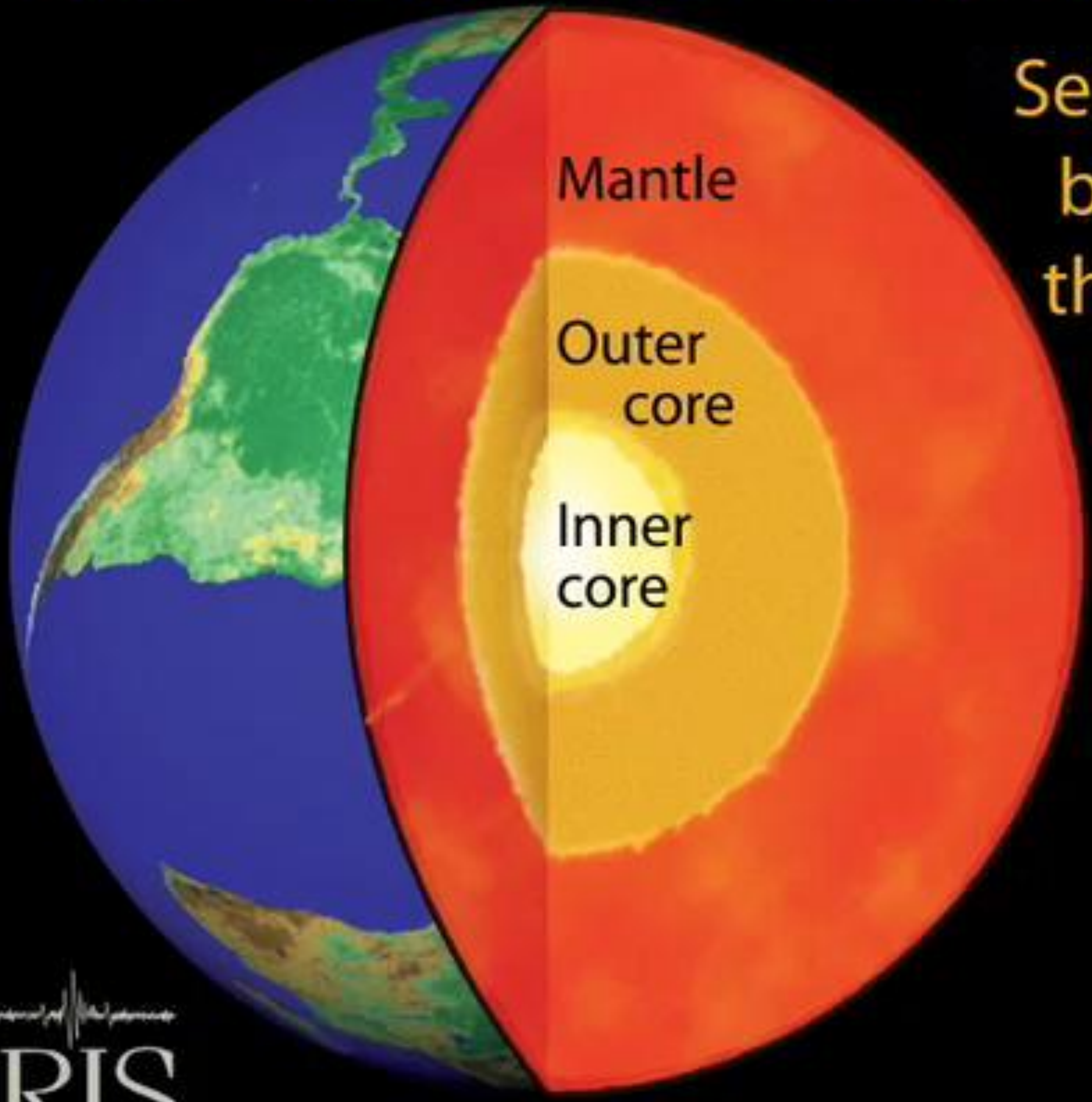
Why do seismic waves travel a curving path in the Earth?

IRIS

earthscope


earth scope
Seismic Tomography
Using earthquakes
to image Earth’s interior

Five P-wave Phases from an Earthquake



Select compressive body-wave paths through the Earth.

Includes:

P

PP

PKP

PKIKP

& Pdiff

IRIS

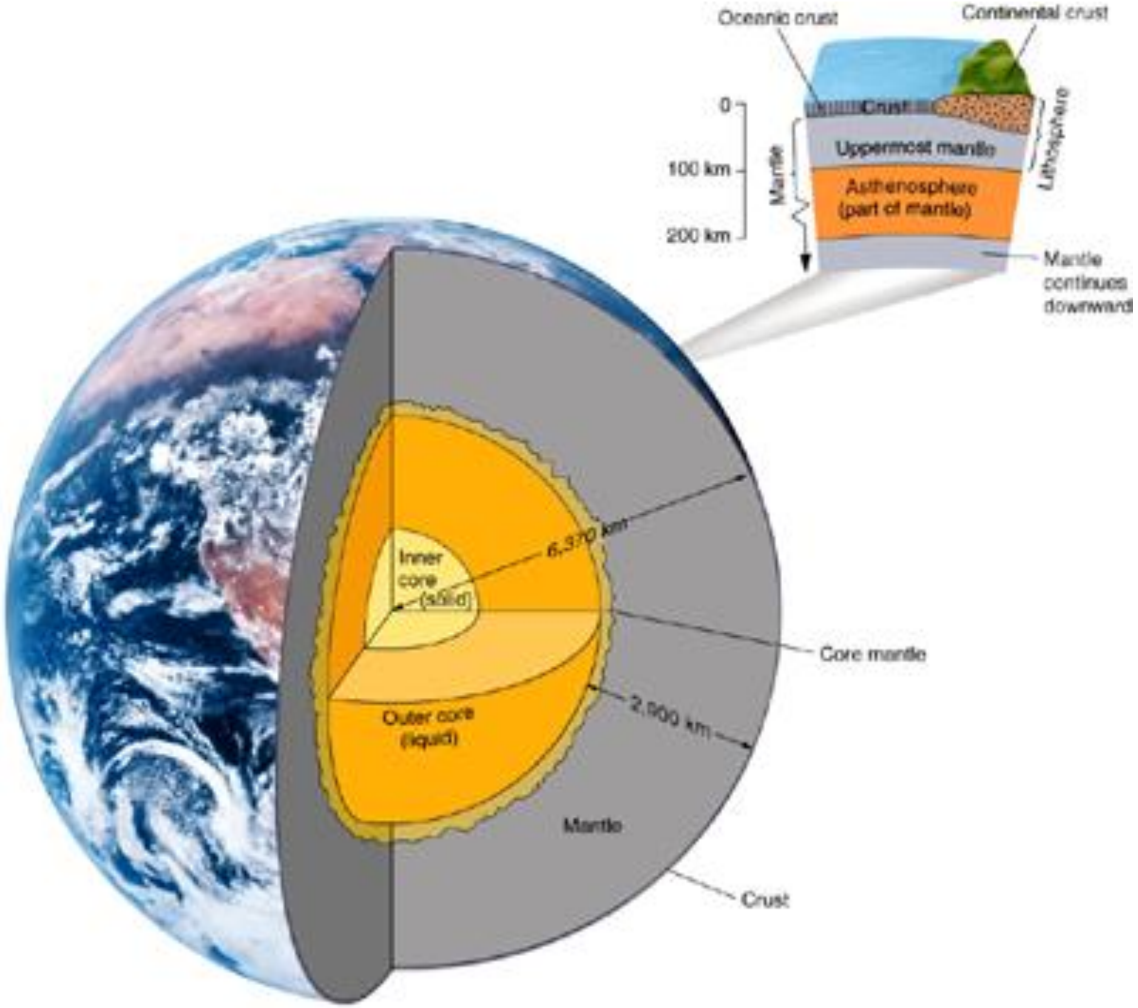
Earth Structure
Major Layers Within the Earth

(A) based on chemical properties:

-- Crust

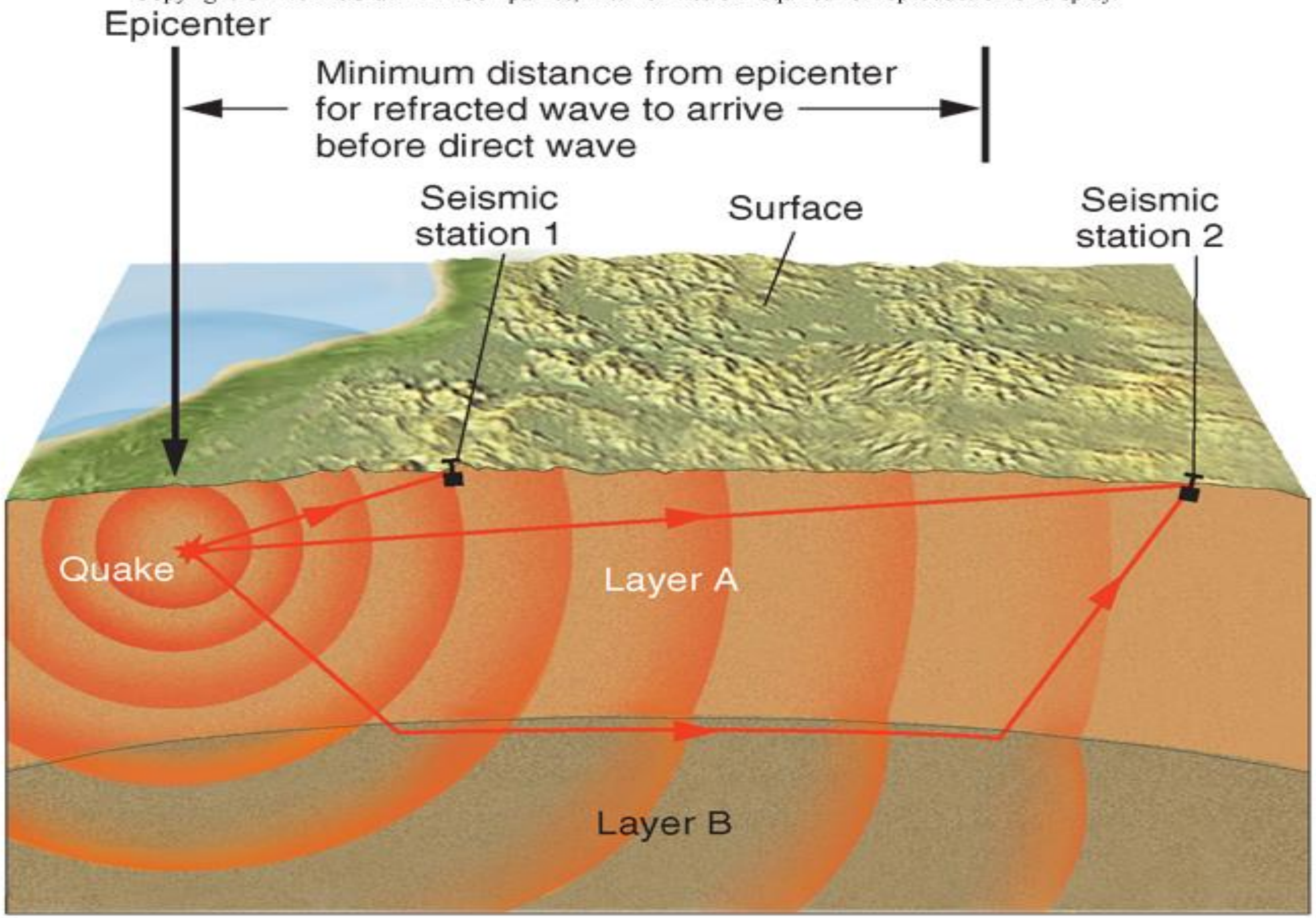
-- Mantle

-- Core



Major Layers of the Earth

Crust - Mantle boundary -"Mohorovicic discontinuity"



Major Layers Within the Earth.

(A) based on chemical properties:

-- Crust

(a) continental (~ 15-75 km)

Granite: Sialic (rich in Si & Al)/ Felsic (rich in feldspar and quartz)

(lighter in weight and color)

(b) oceanic (~ 5-8 Km)

Basalt: Mafic (rich in Mg & Fe)

(heavier and darker)

Major Layers Within the Earth.

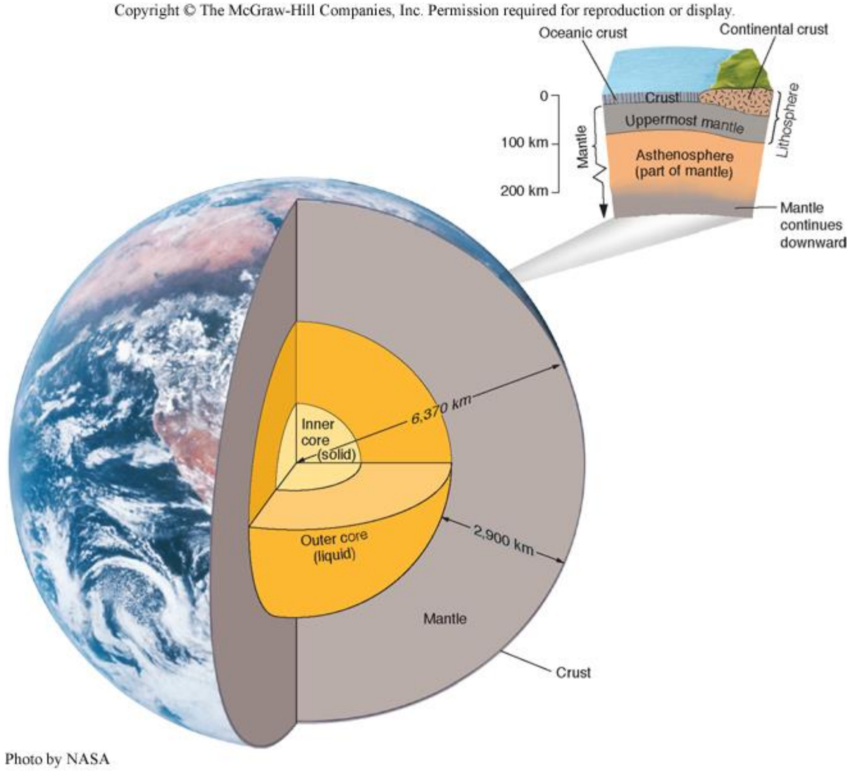
(A) based on chemical properties:

-- Crust

-- Mantle :

from the base of the crust

to ~2900 km depth

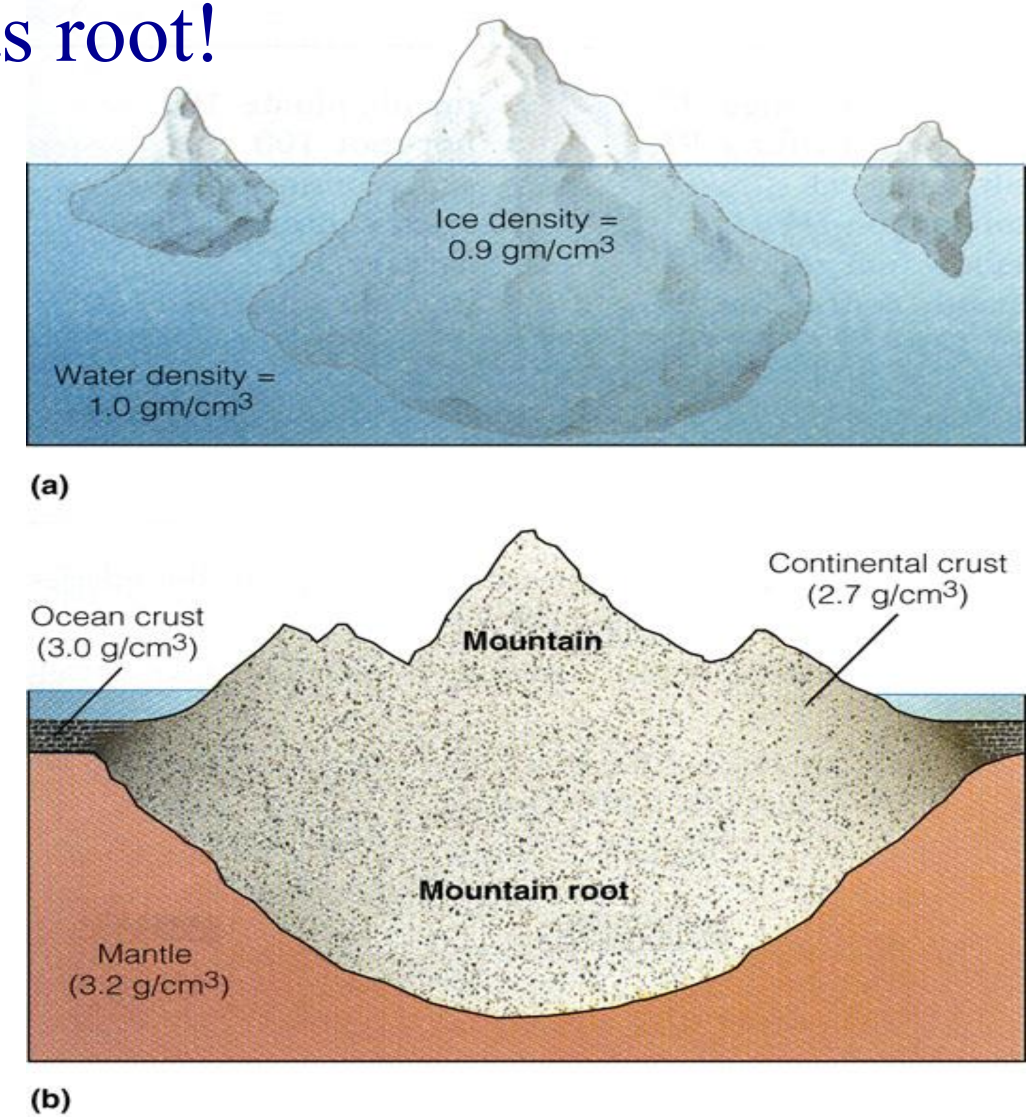


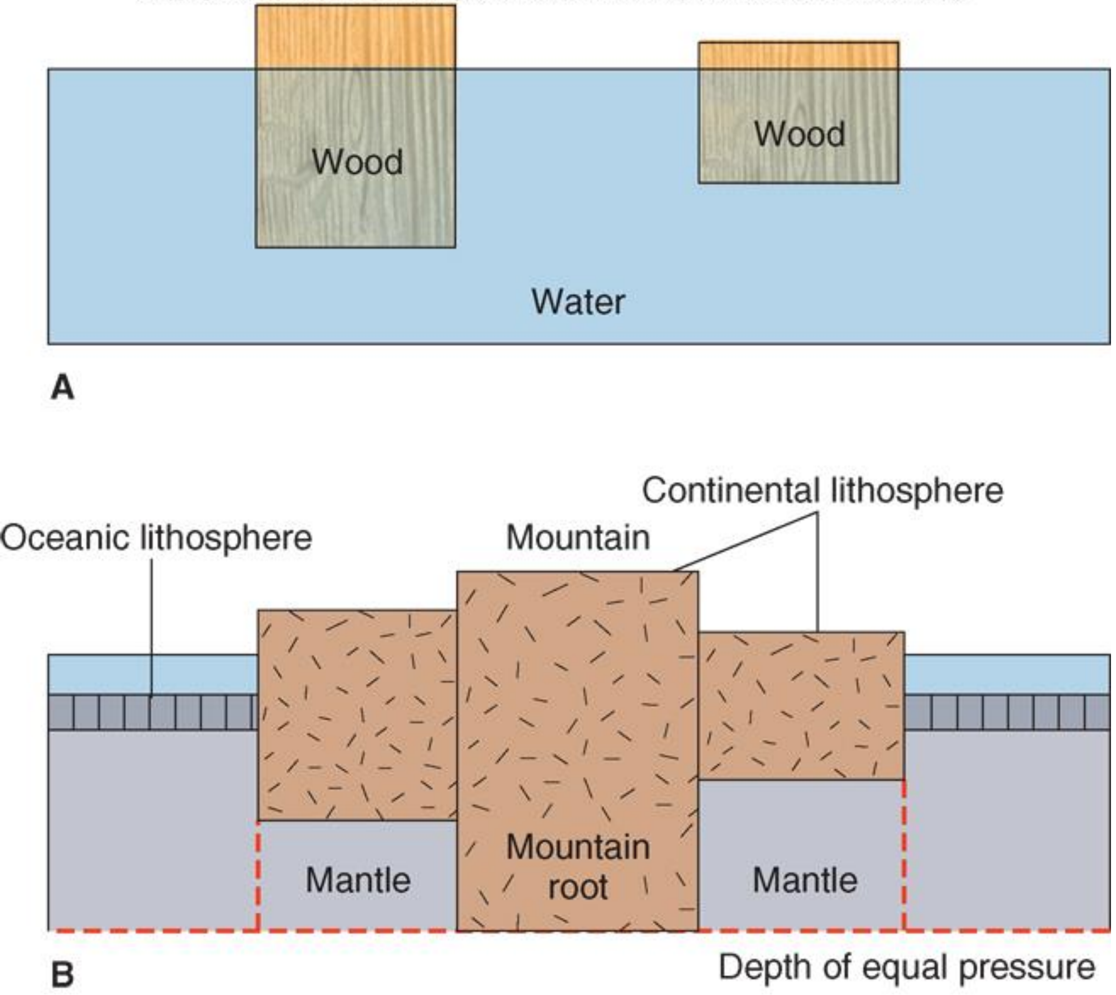
Ultramafic rock

: Higher Mg, Fe, lower Si

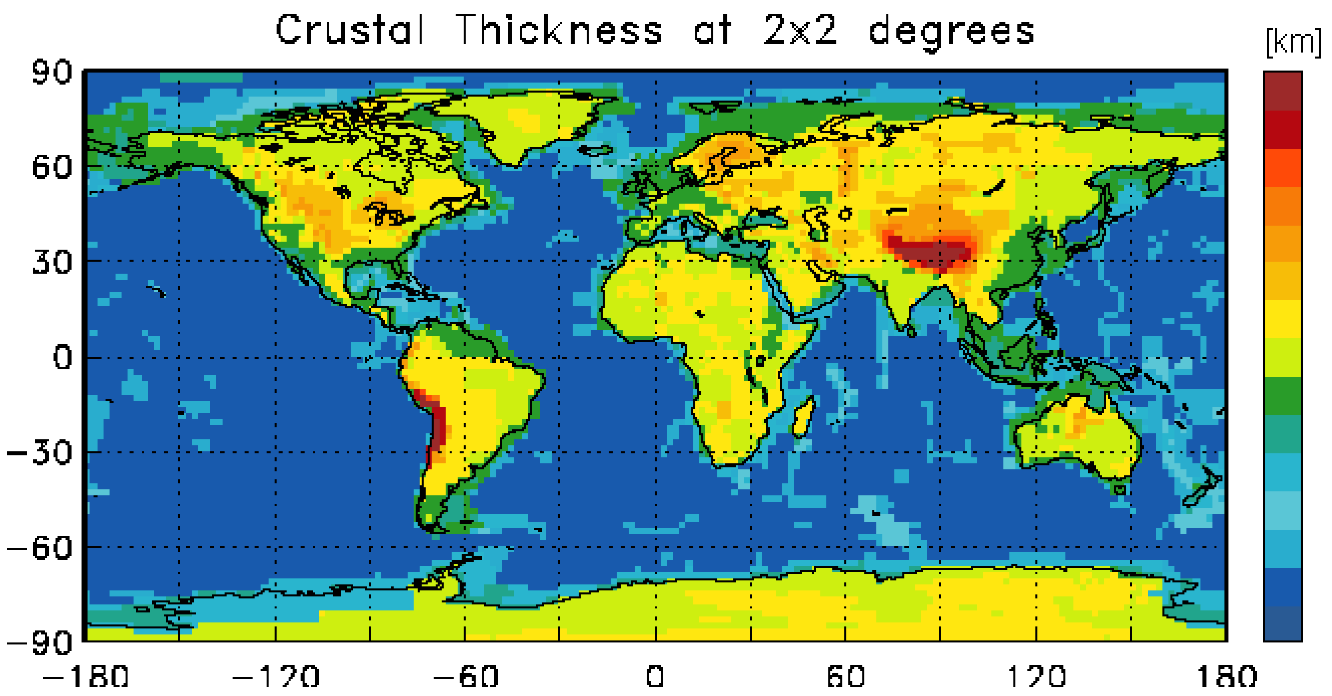
than ocean crust

Isostacy (buoyancy): continent (lighter) float on mantle (heavier), like iceberg float on water; continent has root!





Wood
Wood
Water
A
Continental lithosphere
Oceanic lithosphere
Mountain
Mountain root
Mantle
Mantle
Depth of equal pressure
B

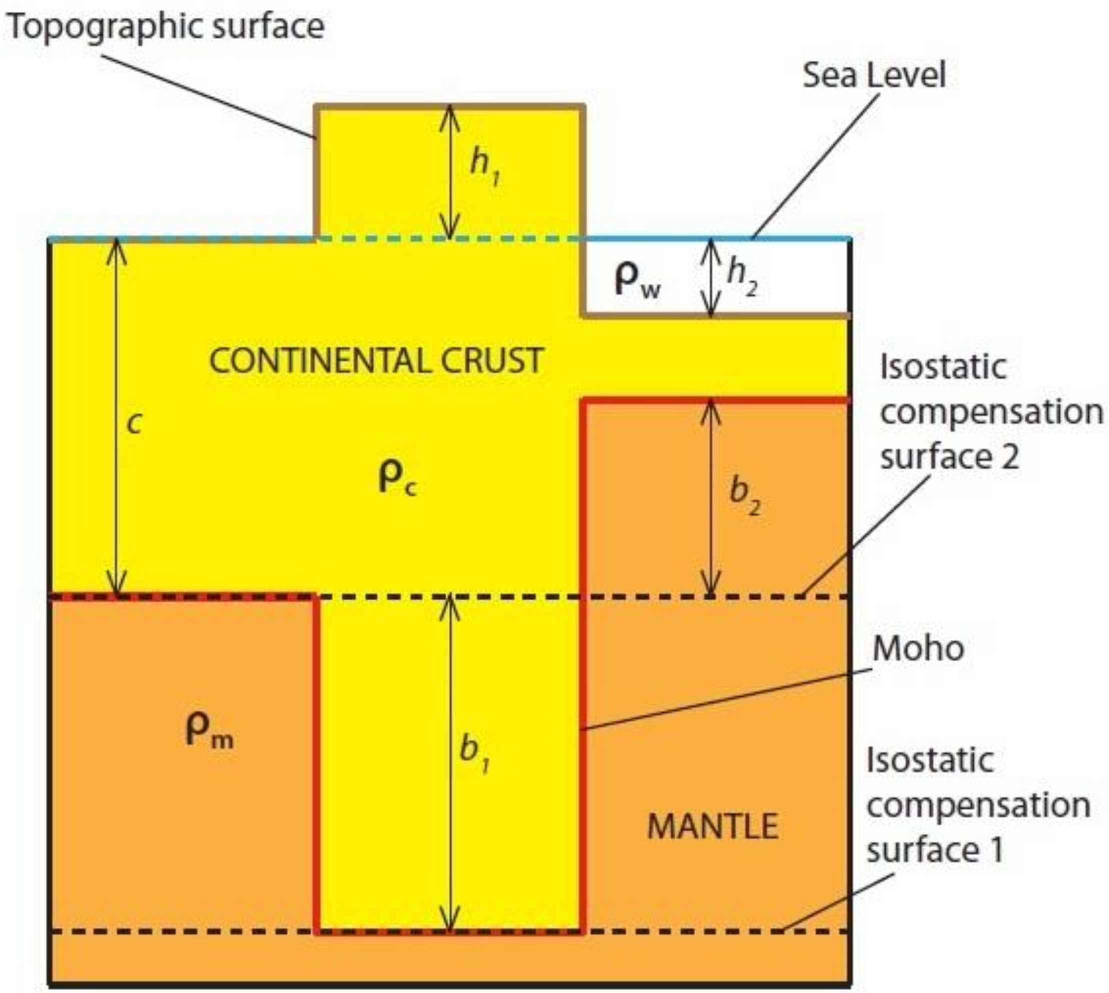


Crustal Thickness at 2x2 degrees
[km]
90
60
30
0
−30
−60
−90
−180
−120
−60
0
60
120
180
70
60
50
40
30
20
10
0

Airy's isostacy model

$b_1 = 5\ h_1$

$b_2 = 3.2\ h_2$



h_1 = elevation of mountain belt (above sea level)
h_2 = depth of marine basin (below sea level)
b_1 = thickness of crustal roots (below depth of Moho in a cratonic area)
b_2 = thickness of lithosphere mantle bulge (above depth of Moho in a cratonic area)
c = thickness of continental crust in an undeformed (cratonic) area (ca. 35 km)

ρ_w = density of sea water (ca. 1,000 Kg/m^3)
ρ_c = density of continental crust (ca. 2,800 Kg/m^3)
ρ_m = density of mantle (ca. 3,300 Kg/m^3)

Major Layers Within the Earth

(A) based on chemical properties:

-- Crust

-- Mantle

-- Core

Metallic

- **Mostly Fe**
- **Small amount of Ni**
- **Maybe some O, Si, S**

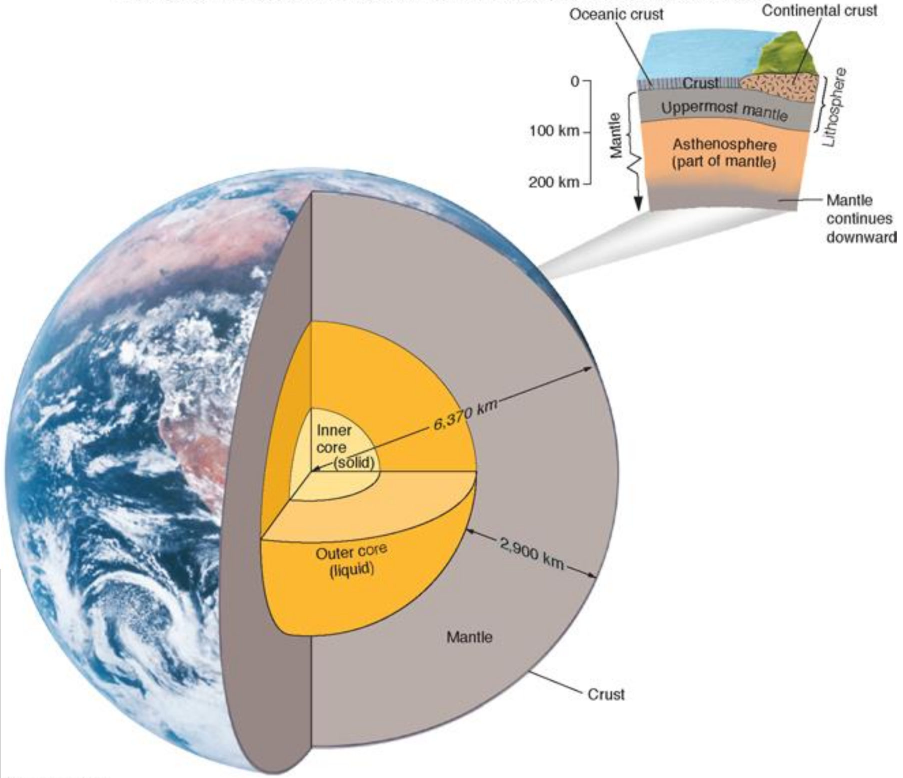


Photo by NASA

Photo by Frank M. Hanna

Major Layers Within the Earth

(B) Based on physical properties:

-- Lithosphere

-- Asthenosphere

-- Mesosphere

-- Outer core

-- Inner core

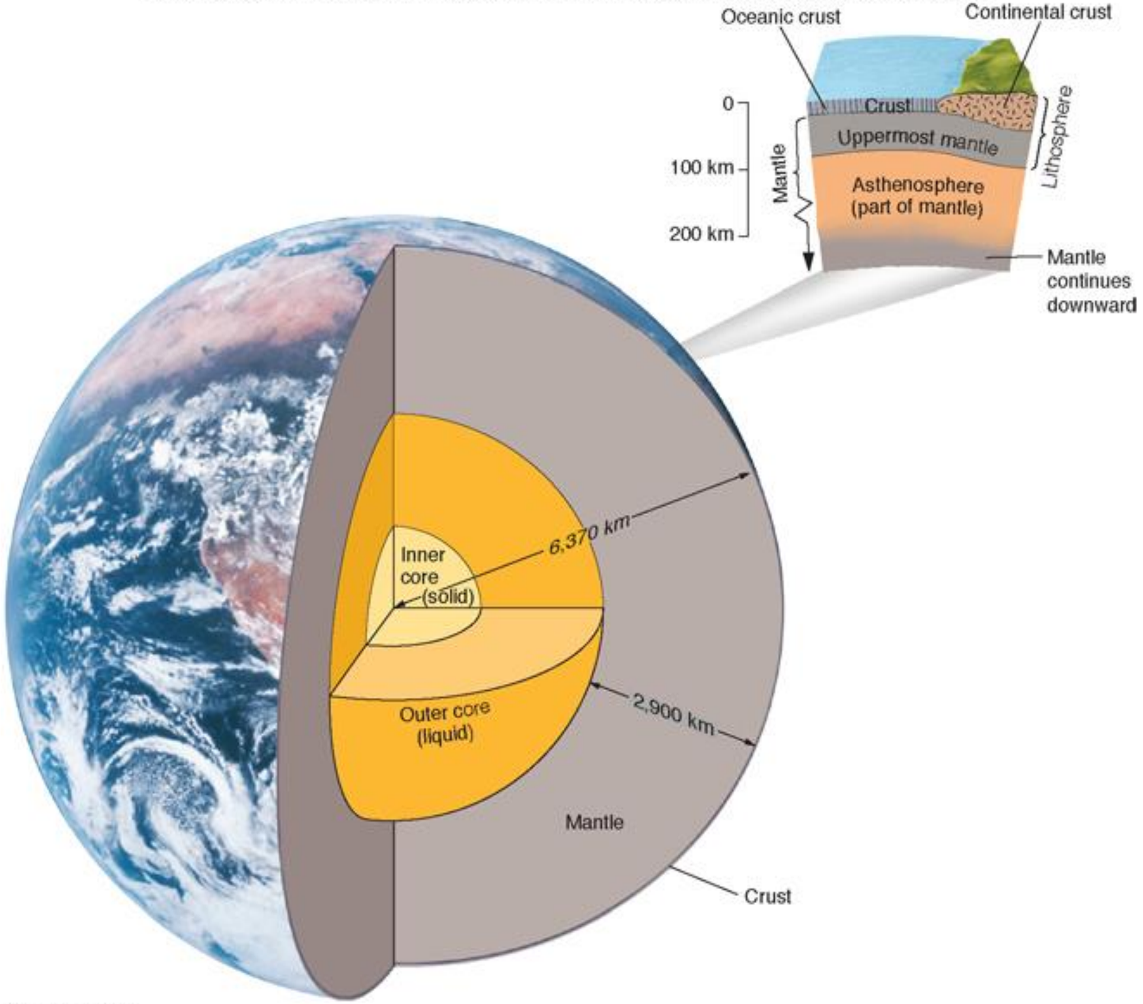


Photo by NASA

Major Layers Within the Earth

(B) based on mechanical properties

-- Lithosphere

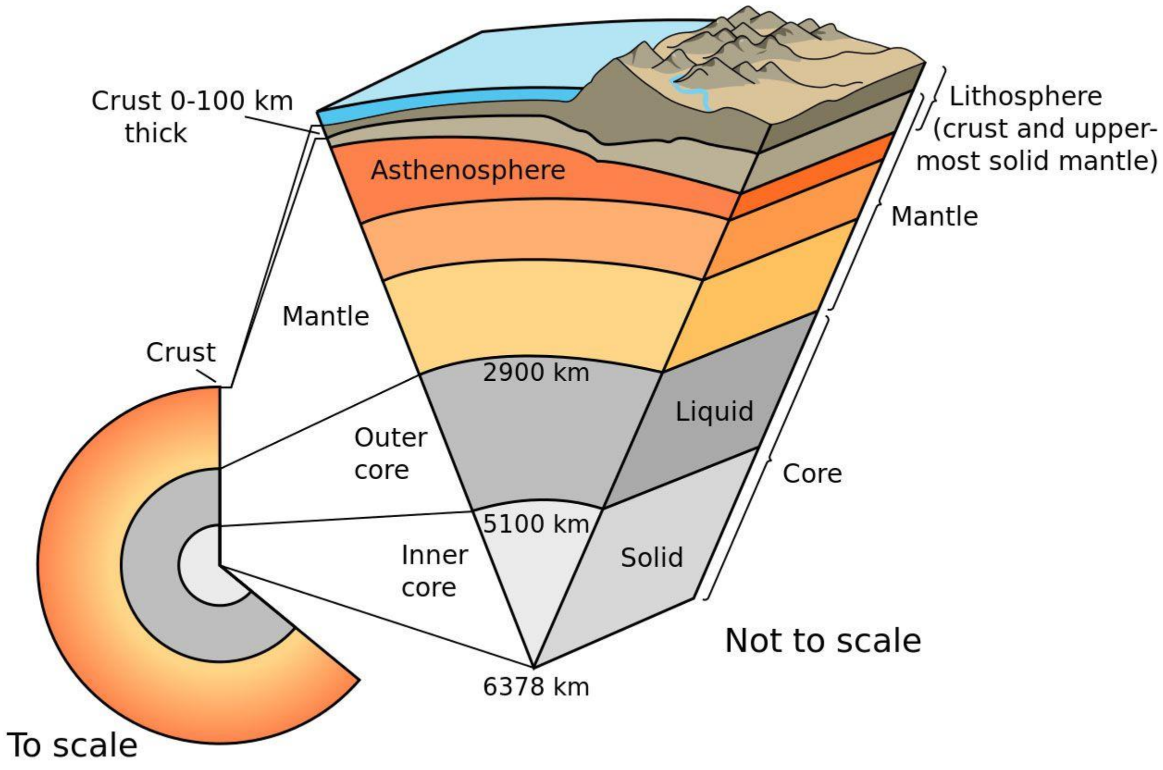
: cold, strong outermost shell (~100 km thick)

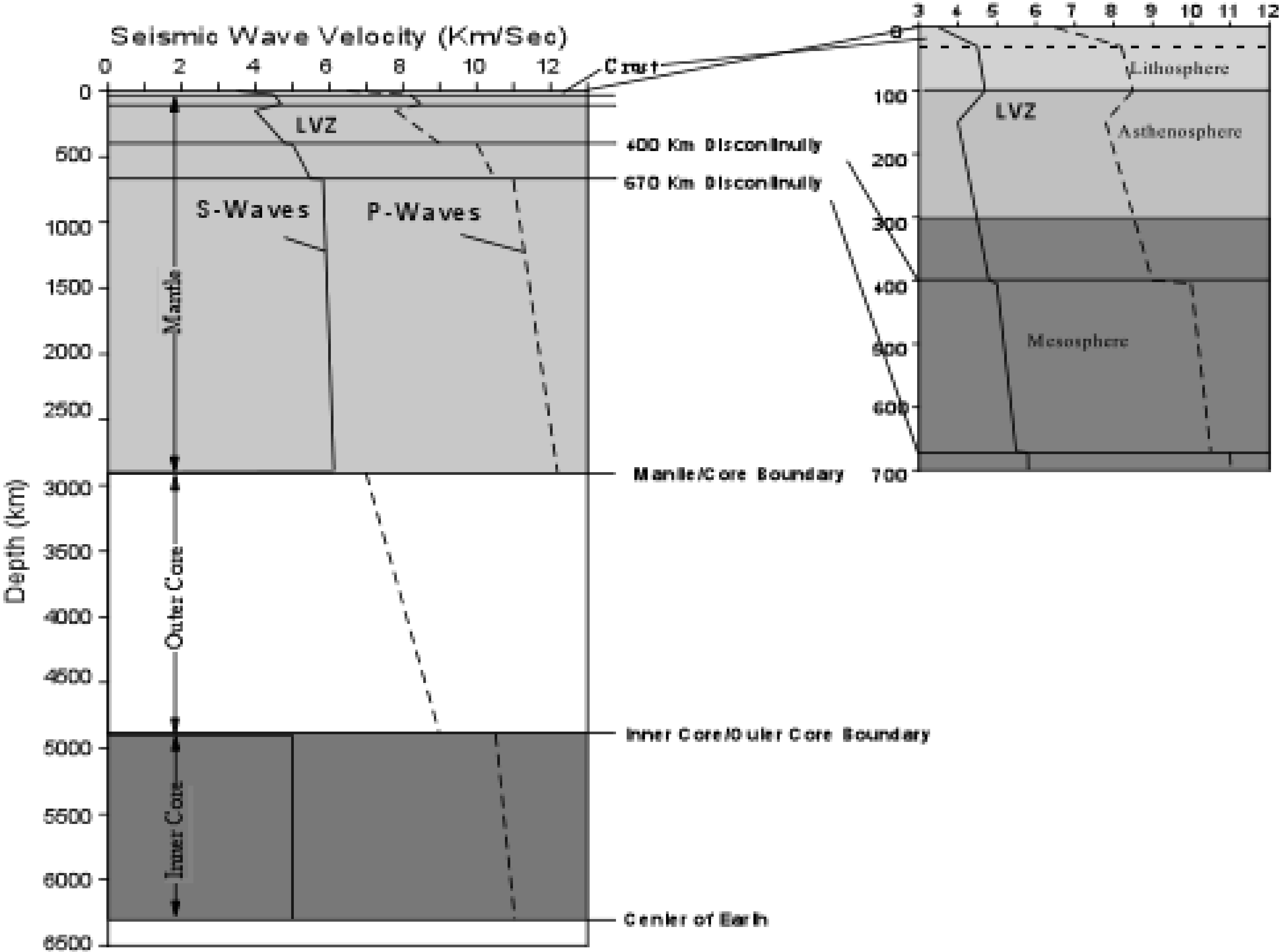
Crust

+

Uppermost Mantle

(rigid)





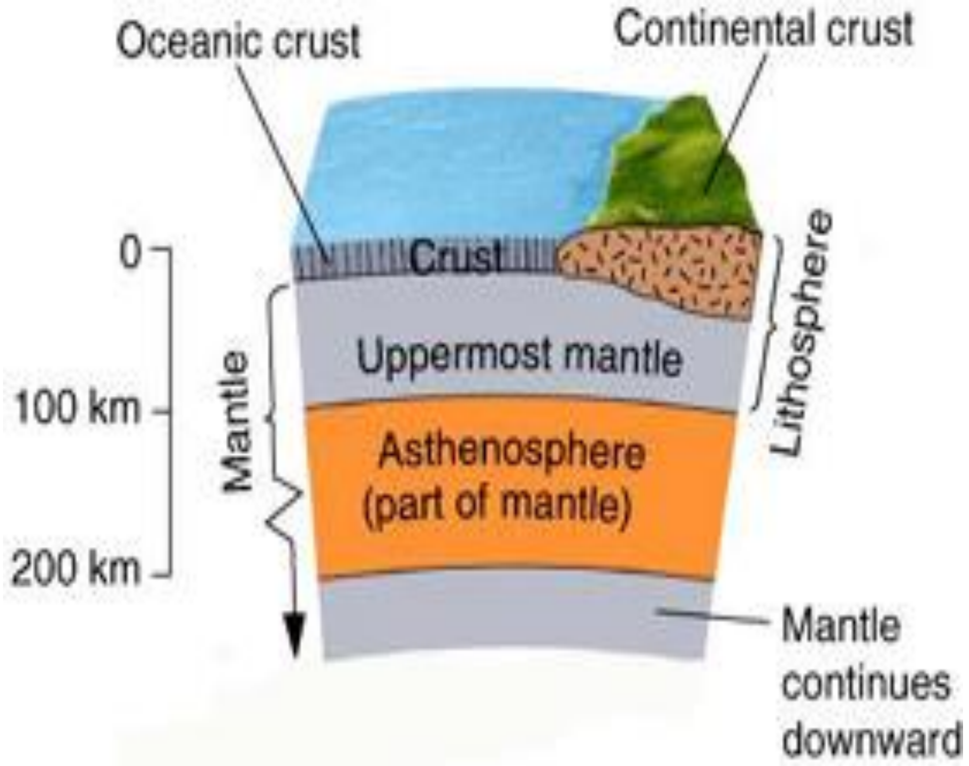
Seismic Wave Velocity (Km/Sec)
0 2 4 6 8 10 12
Crust
LVZ
400 Km Discontinuity
670 Km Discontinuity
S-Waves
P-Waves
Mantle
Mantle/Core Boundary
Outer Core
Inner Core/Outer Core Boundary
Inner Core
Center of Earth
Depth (km)
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000 5500 6000 6500
3 4 5 6 7 8 9 10 11 12
0 100 200 300 400 500 600 700
Lithosphere
LVZ
Asthenosphere
Mesosphere

(B) based on mechanical properties:

-- Lithosphere

-- Asthenosphere: ductile second shell (~100 -300 km depth)

Plastic, soft & weak due to partial melting



(B) based on mechanical properties:

-- Lithosphere

-- Asthenosphere

-- Mesosphere

: less ductile third shell (~ 300 km to the base of the Mantle ~ 2900 km)

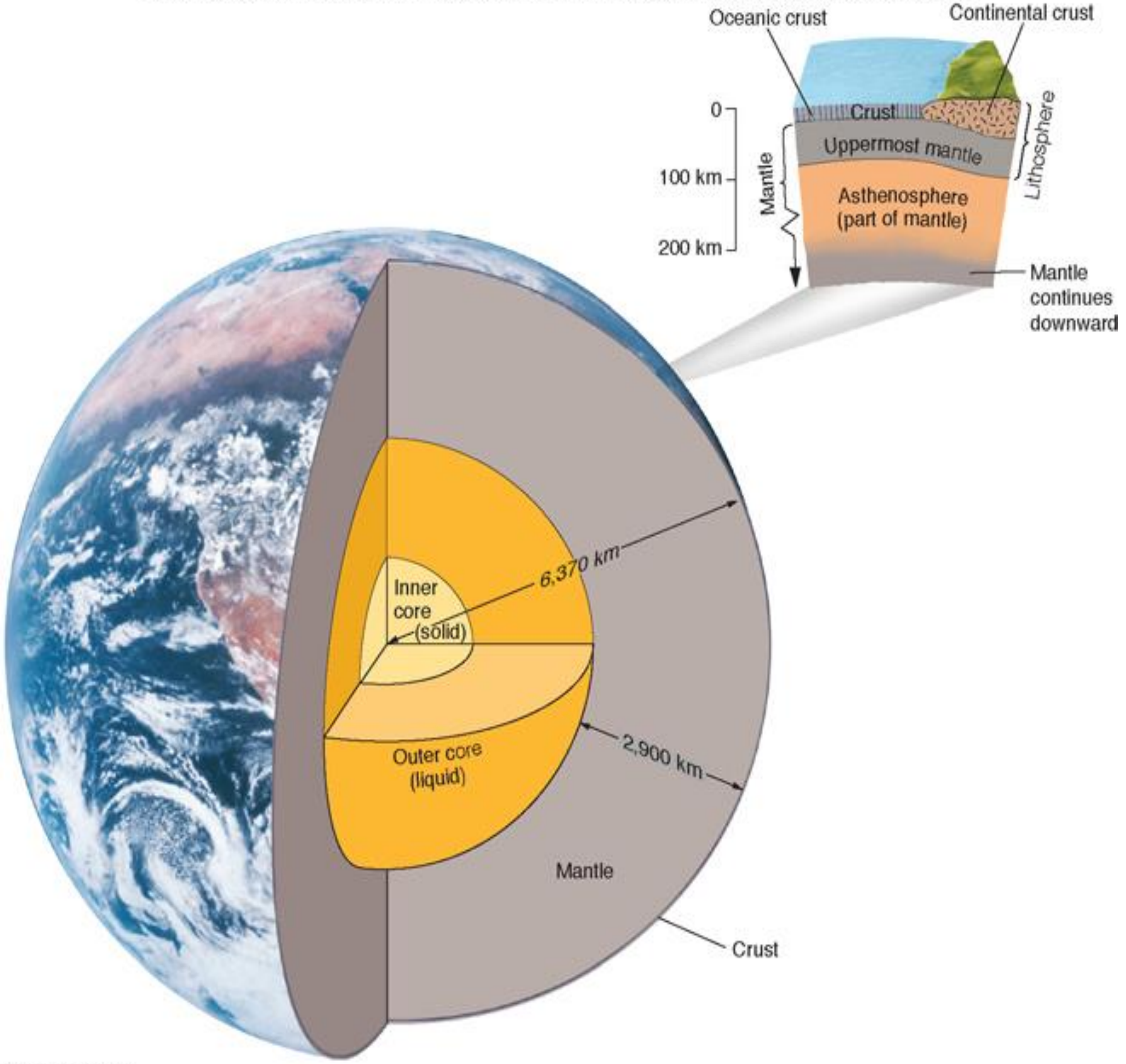
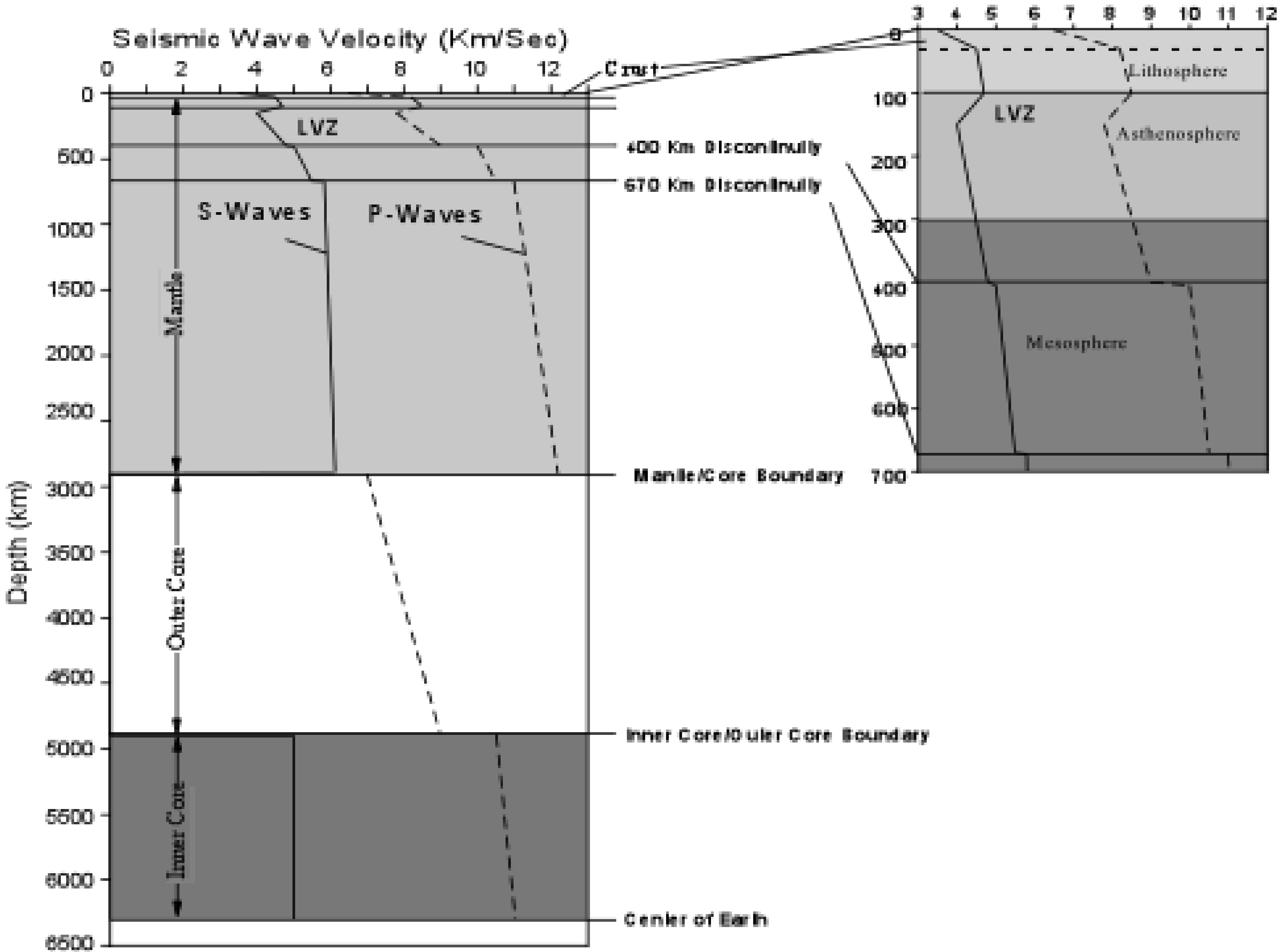
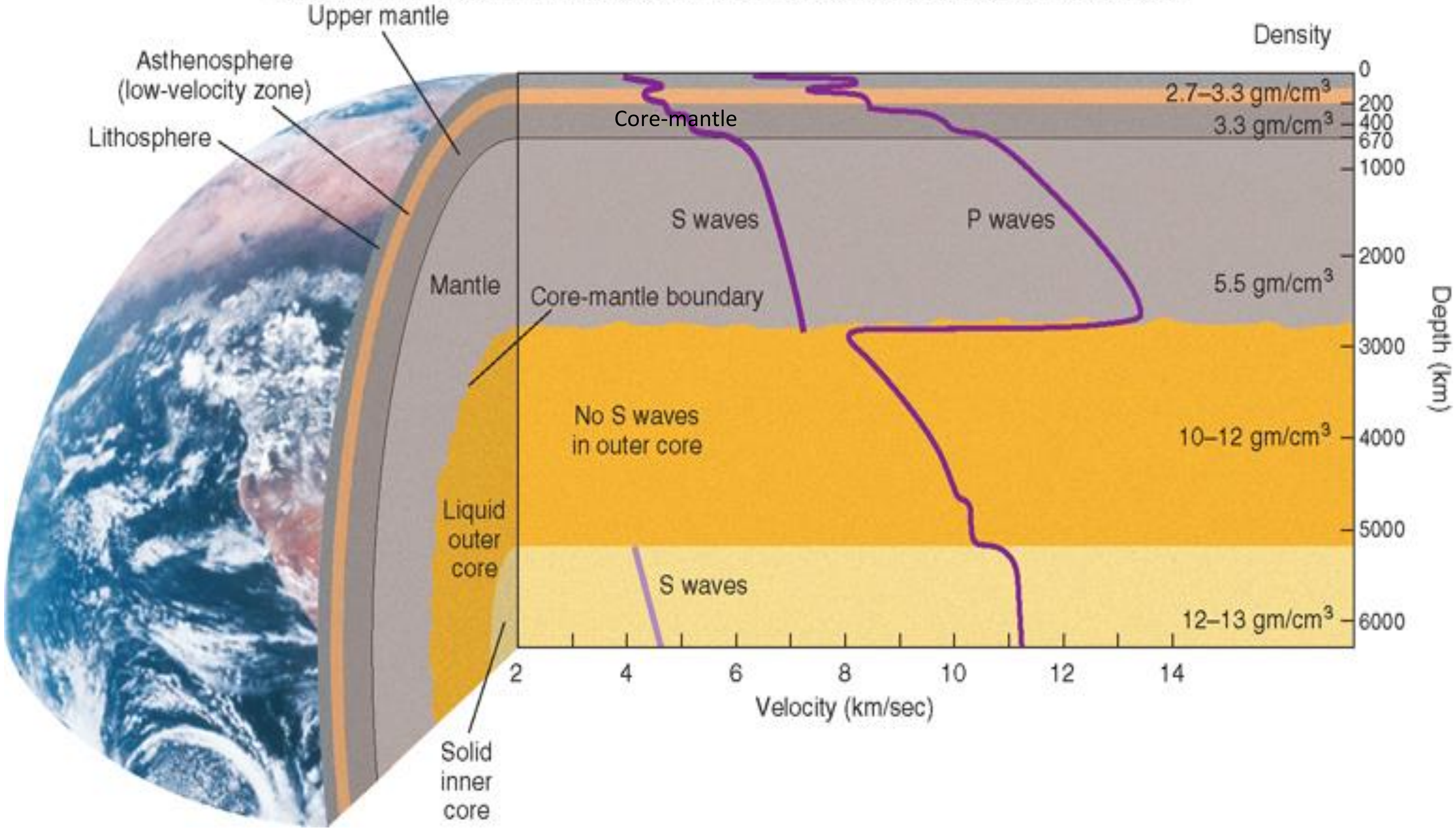


Photo by NASA


Seismic Wave Velocity (Km/Sec)
0 2 4 6 8 10 12
Crust
LVZ
400 Km Discontinuity
670 Km Discontinuity
S-Waves
P-Waves
Mantle
Mantle/Core Boundary
Depth (km)
Outer Core
Inner Core/Outer Core Boundary
Inner Core
Center of Earth
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000 5500 6000 6500
3 4 5 6 7 8 9 10 11 12
Lithosphere
LVZ
Asthenosphere
Mesosphere
0 100 200 300 400 500 600 700



Core - Mantle boundary
: Sharp change in seismic velocity

(B) based on mechanical properties:
-- Lithosphere
-- Asthenosphere
-- Mesosphere

-- Outer core : liquid
(~ 2,300km thick from the base of the mantle)

-- Inner core: solid
(innermost 1,200 km of the earth)

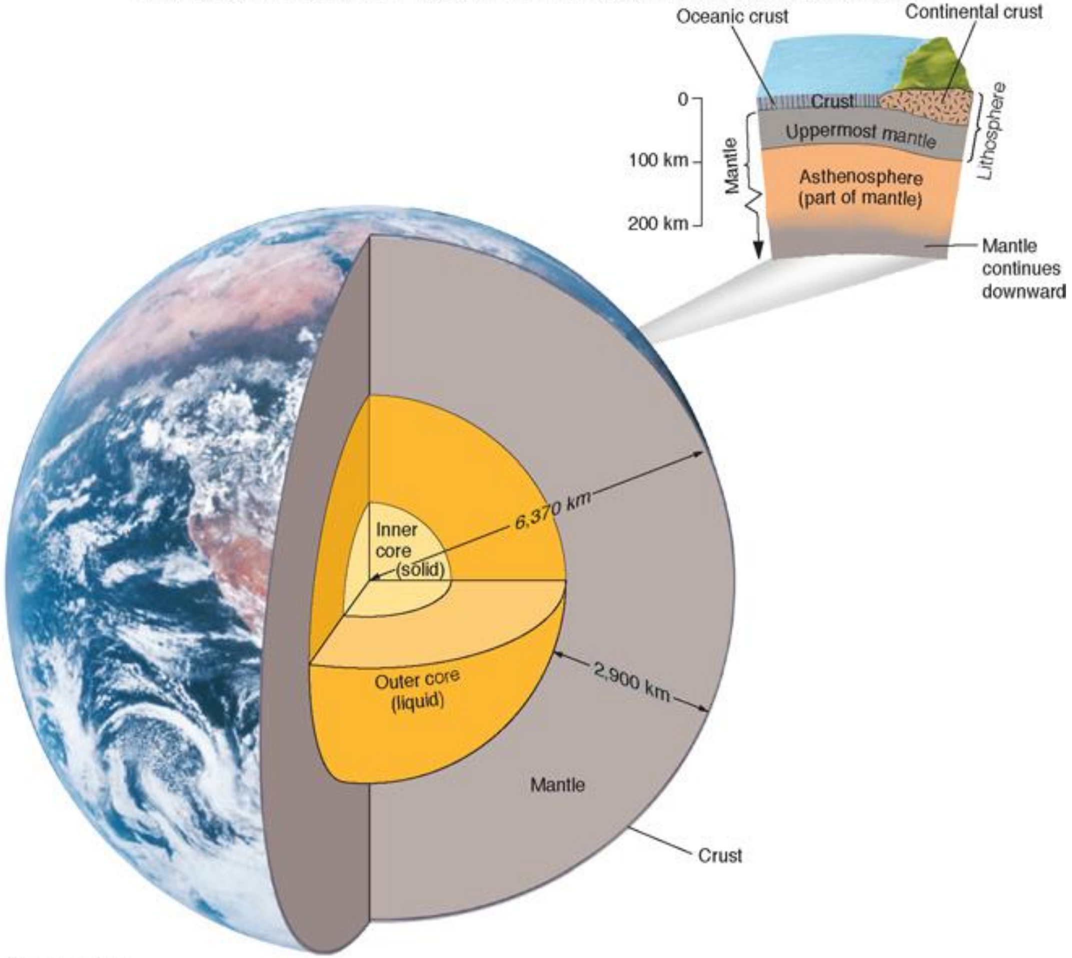
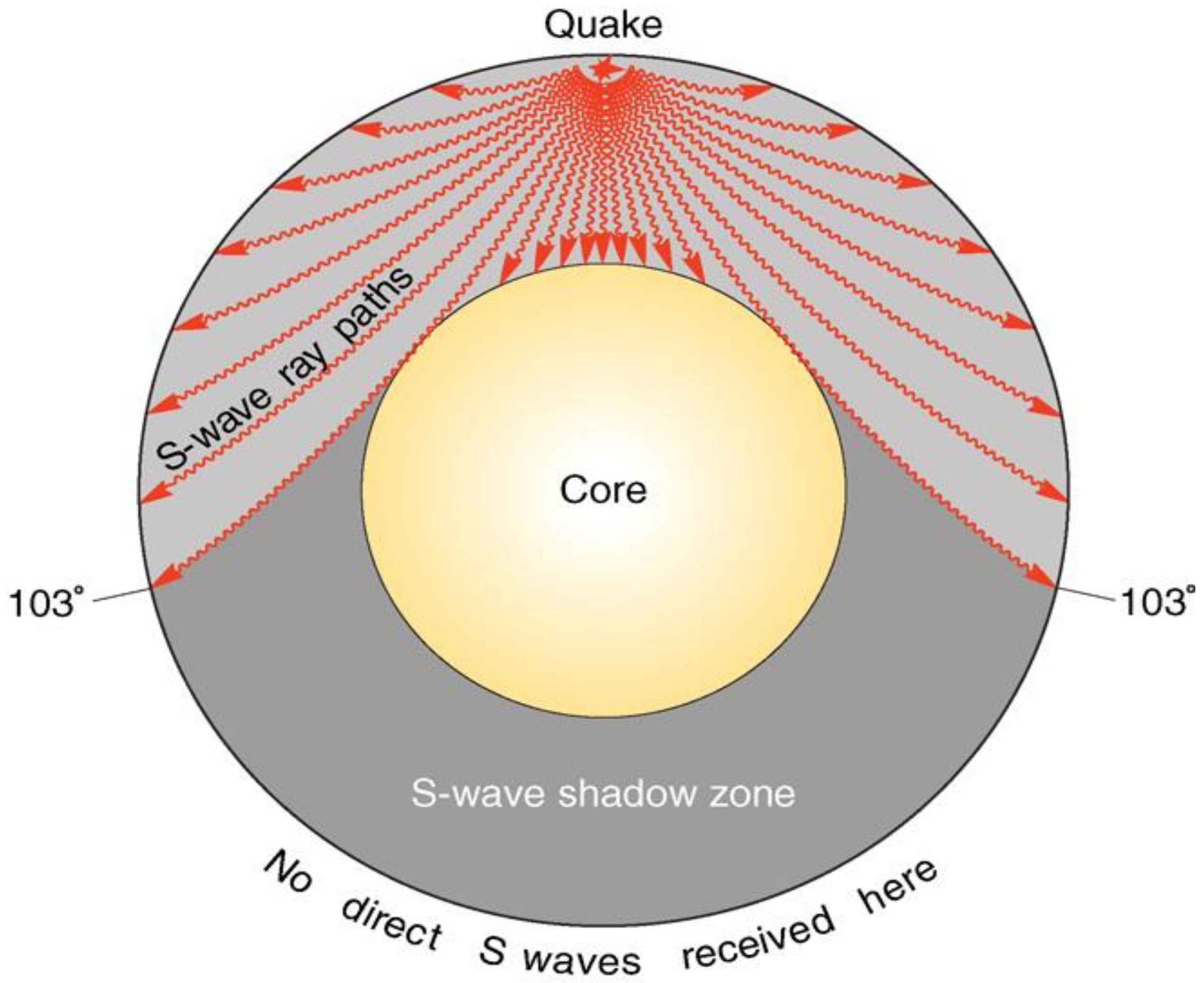


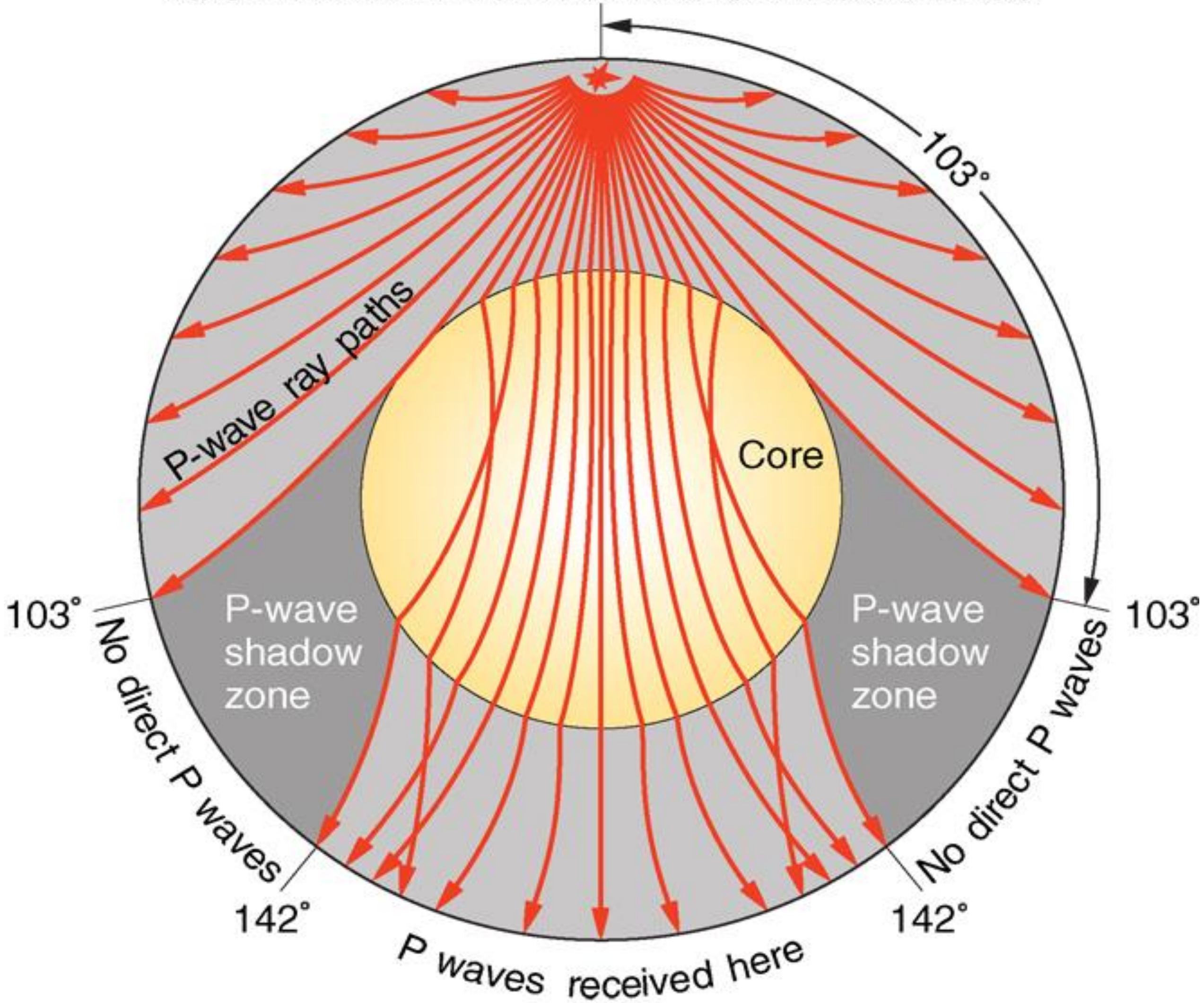
Photo by NASA

Size of the core & physical state of the outer core based on **S-wave shadow zone**



Sizes of inner core & outer core based on

P-wave shadow zone

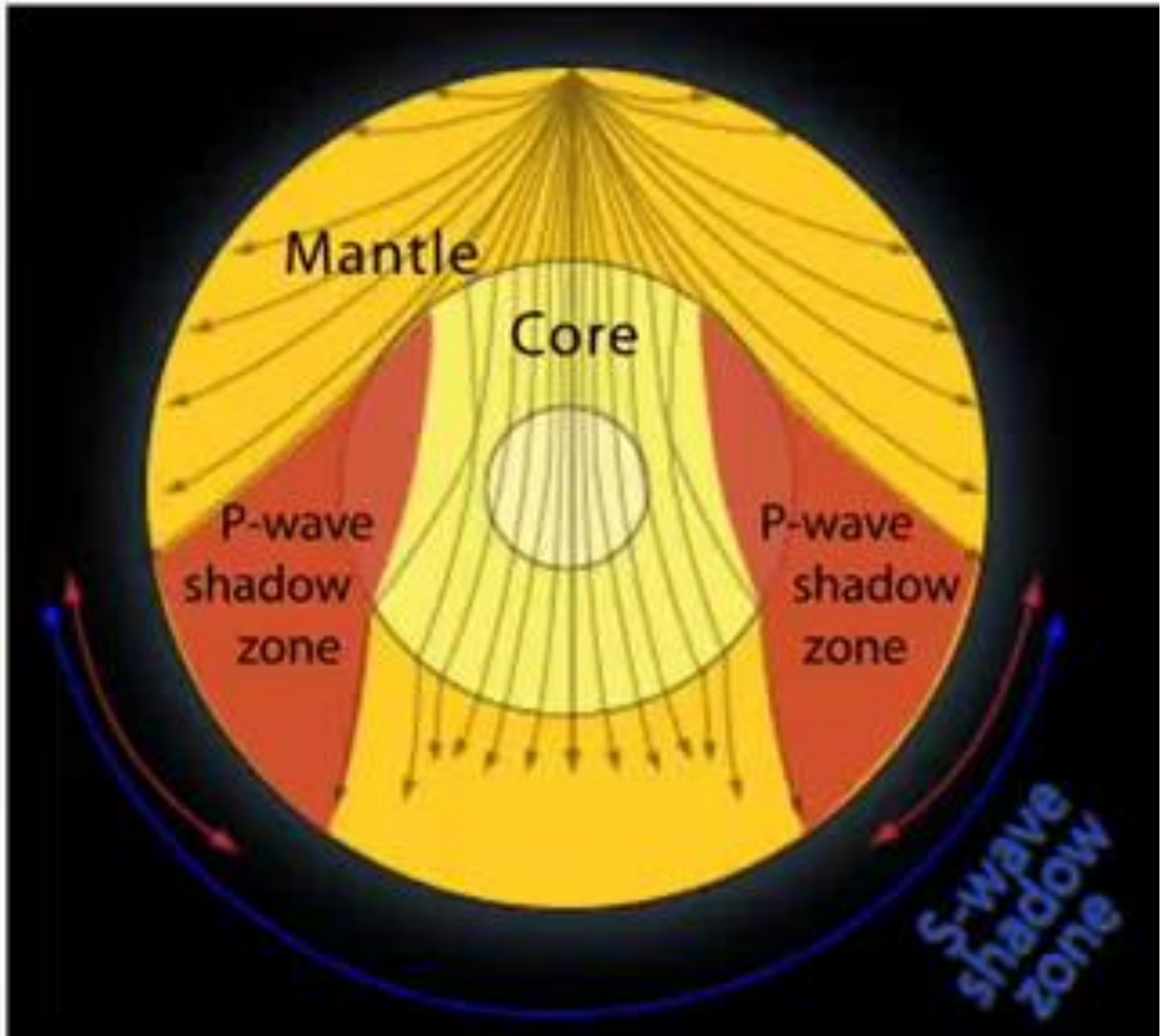


Seismic Shadow Zones

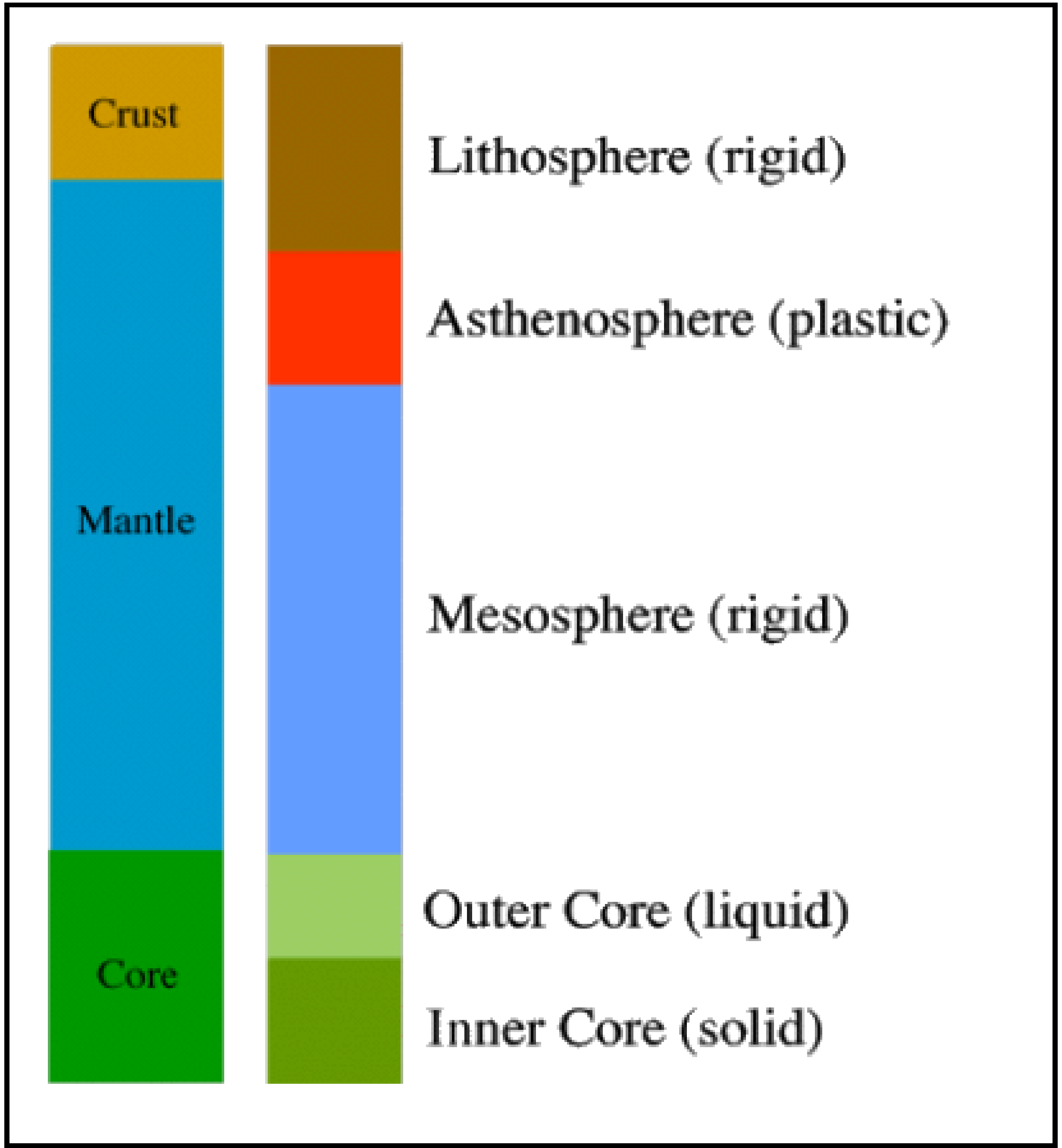
How the mantle and core were determined using the arrival times of direct P and S body waves

P waves (primary) are compressive waves that travel through solids & liquids.

S waves (secondary) are shear waves that travel through solids only.



Major Layers Within the Earth



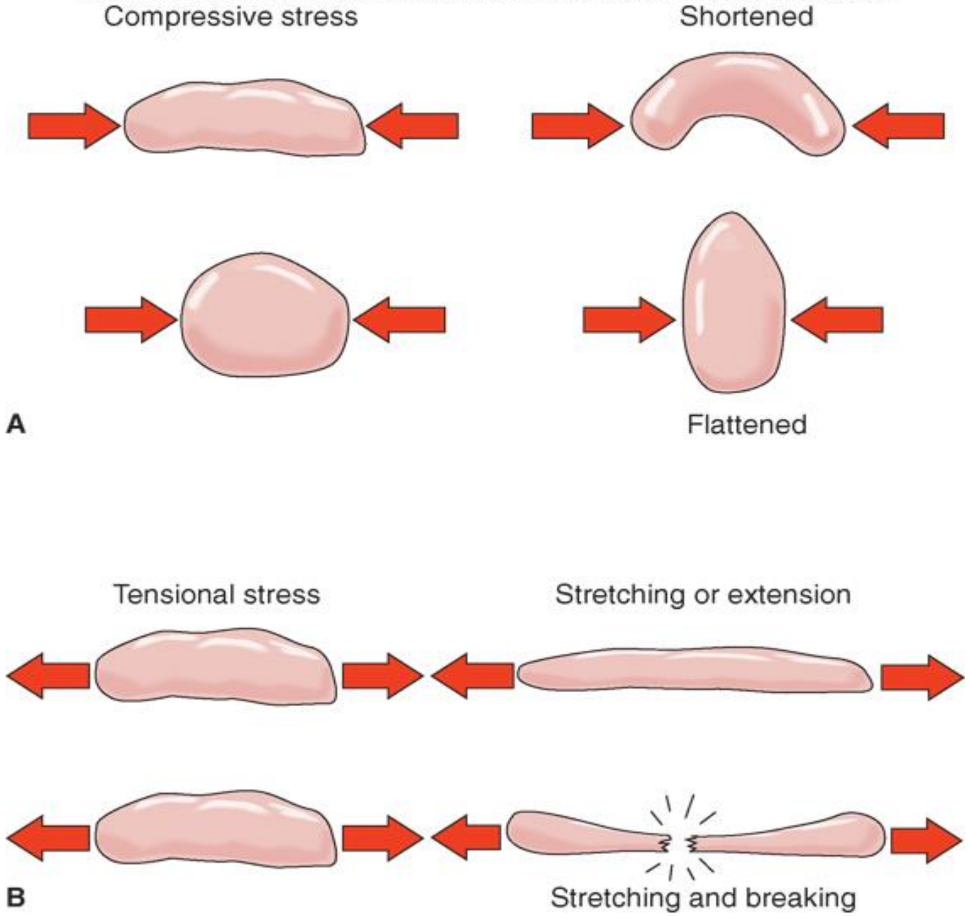
(II) Geologic Structures

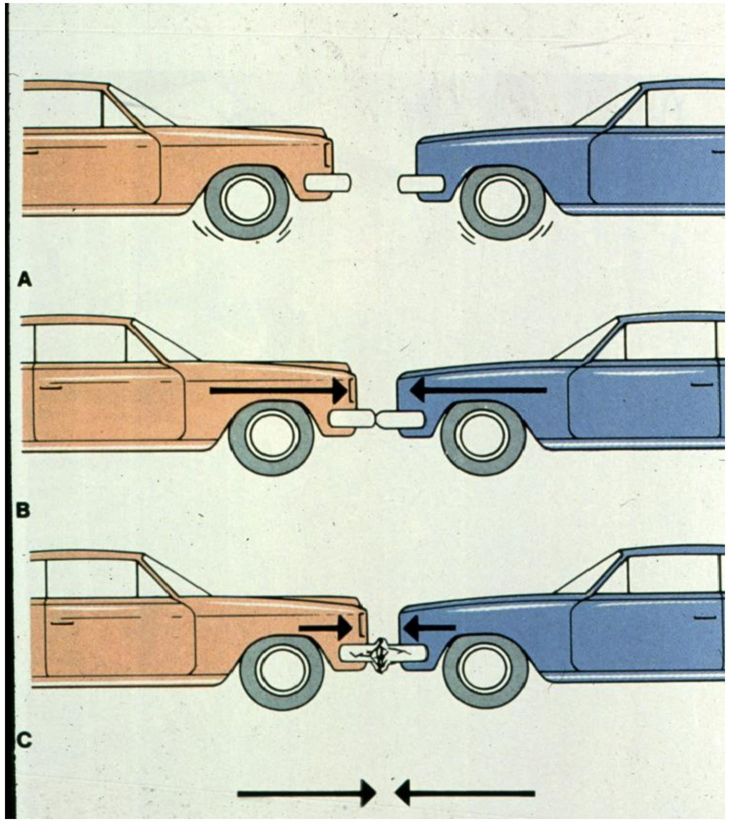
Photo by C. C. Plummer

Stress

(A) **Compressive stress**: shorten the body involved

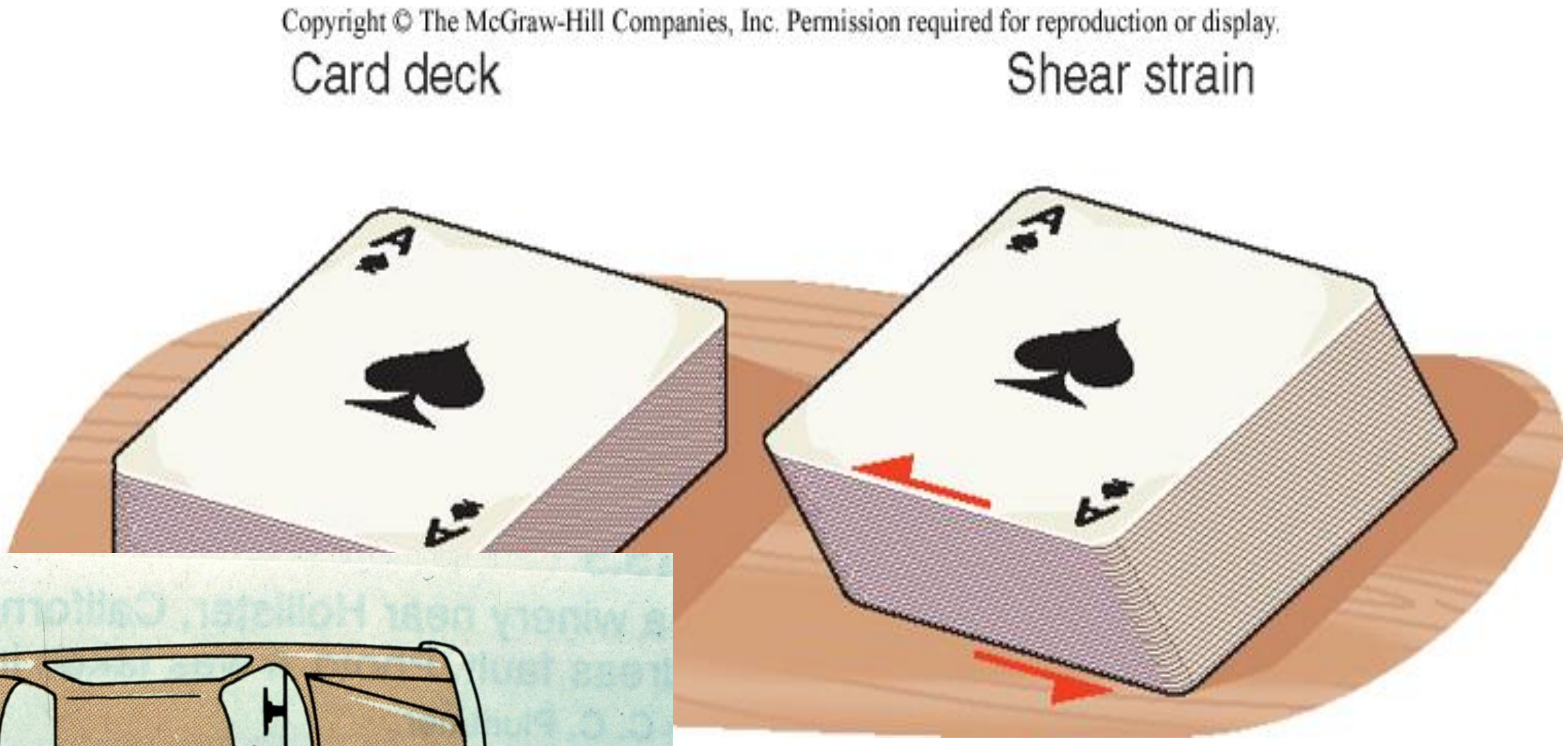
(B) **Tensional stress**: elongate, or pull apart, a body

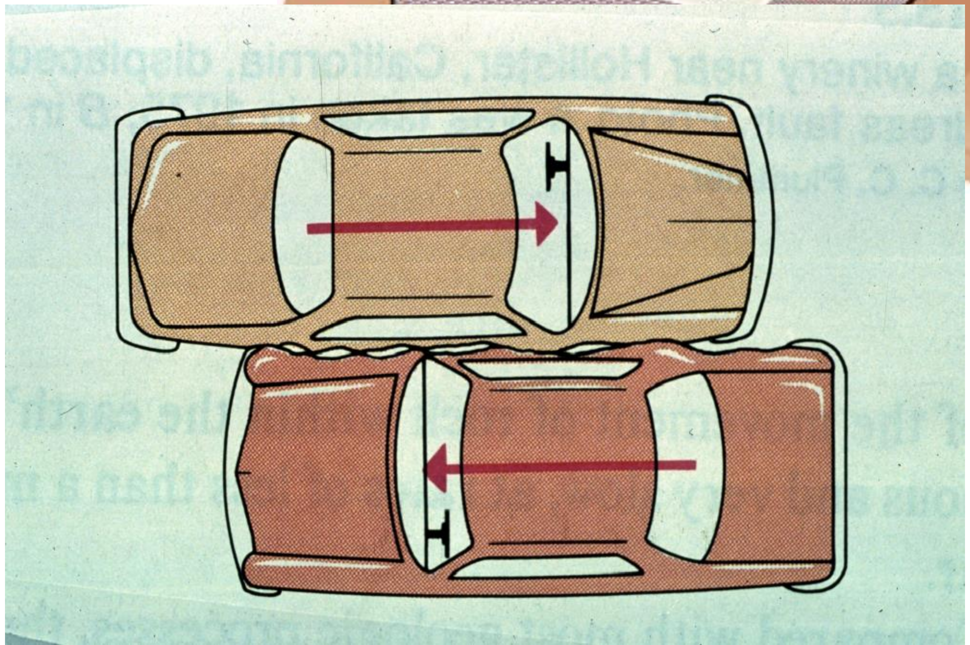




(C) **Shear stress**: changes in shape, rotation

Shear stress





<u>Strain</u> (deformation)

- change in size/shape in response to stress

(A) **Elastic strain**

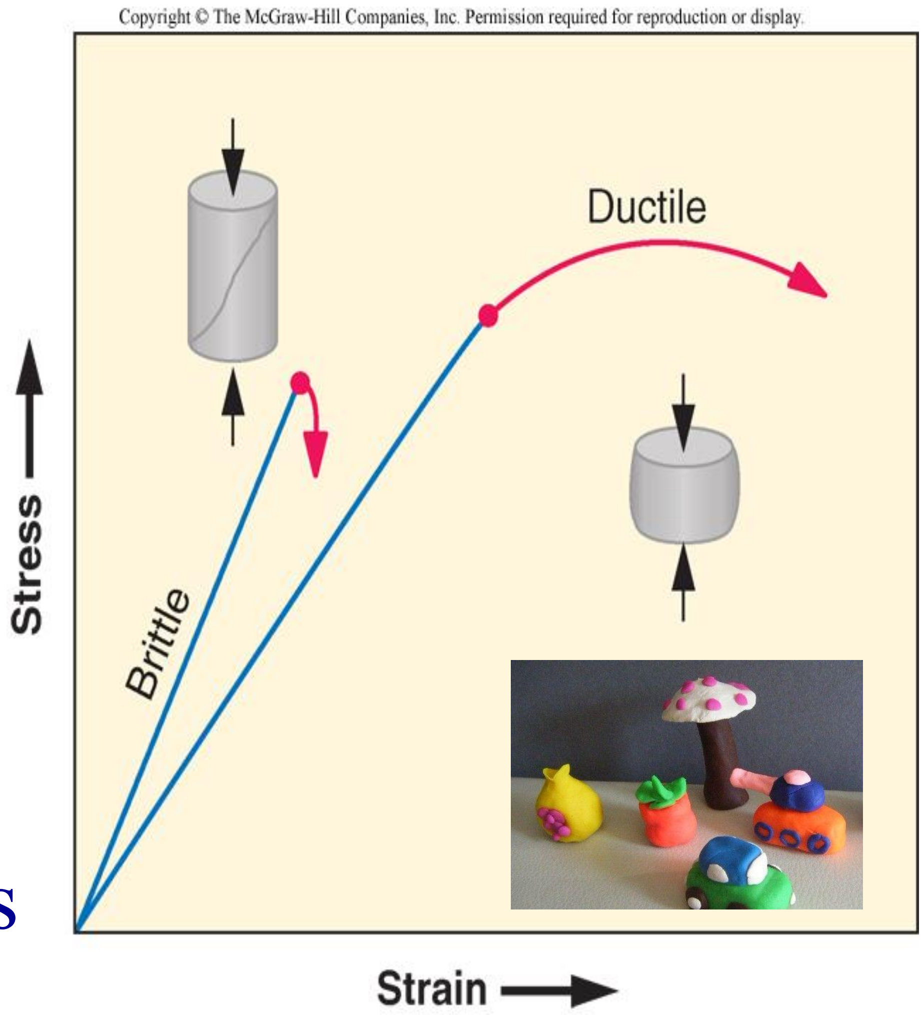
-recover to original shape
after stress is released

(B) **Plastic (ductile) strain**

- change size/shape without
fracturing the materials

(C) **Brittle strain**

- rupture/fracture with stress



(II) Geologic Structures

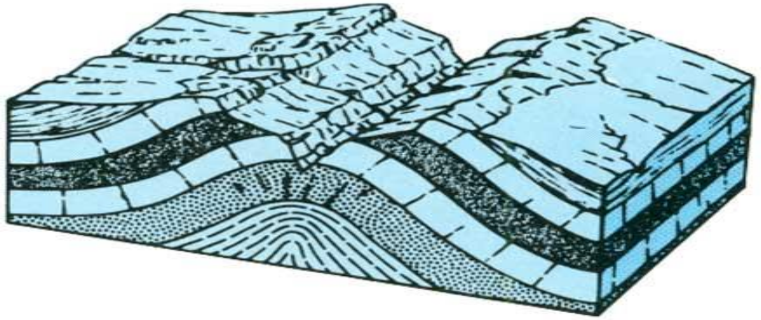
(A) Structures by plastic deformation

Folds - bends & wraps in rock layers

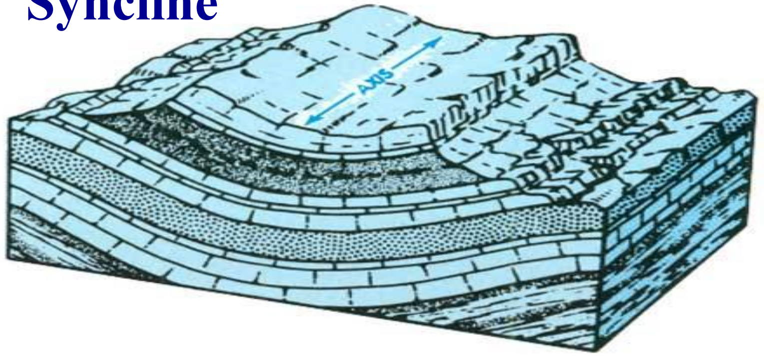
-- **Anticline**: arched fold

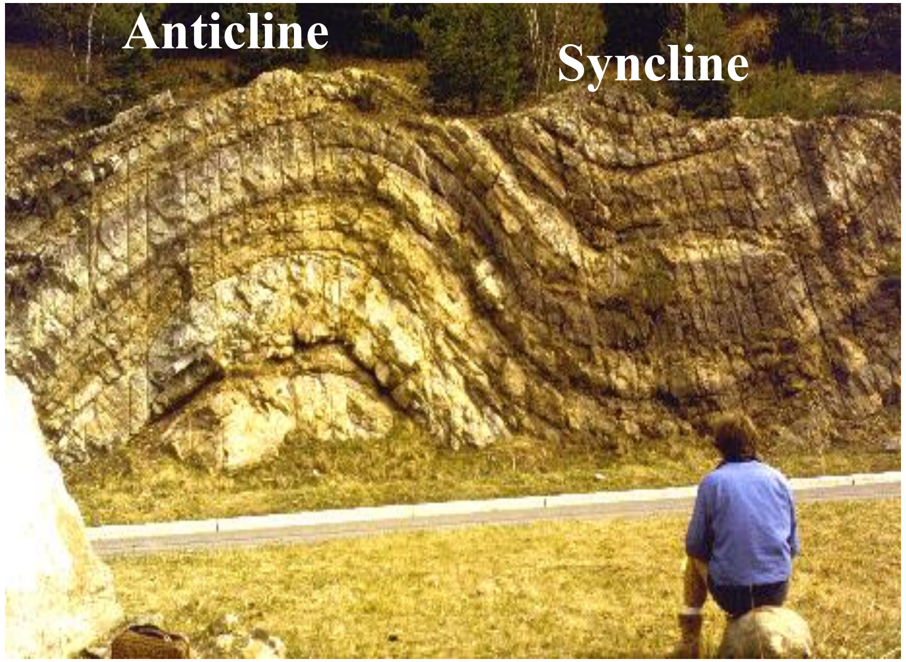
-- **Syncline**: trough-like fold

Anticline



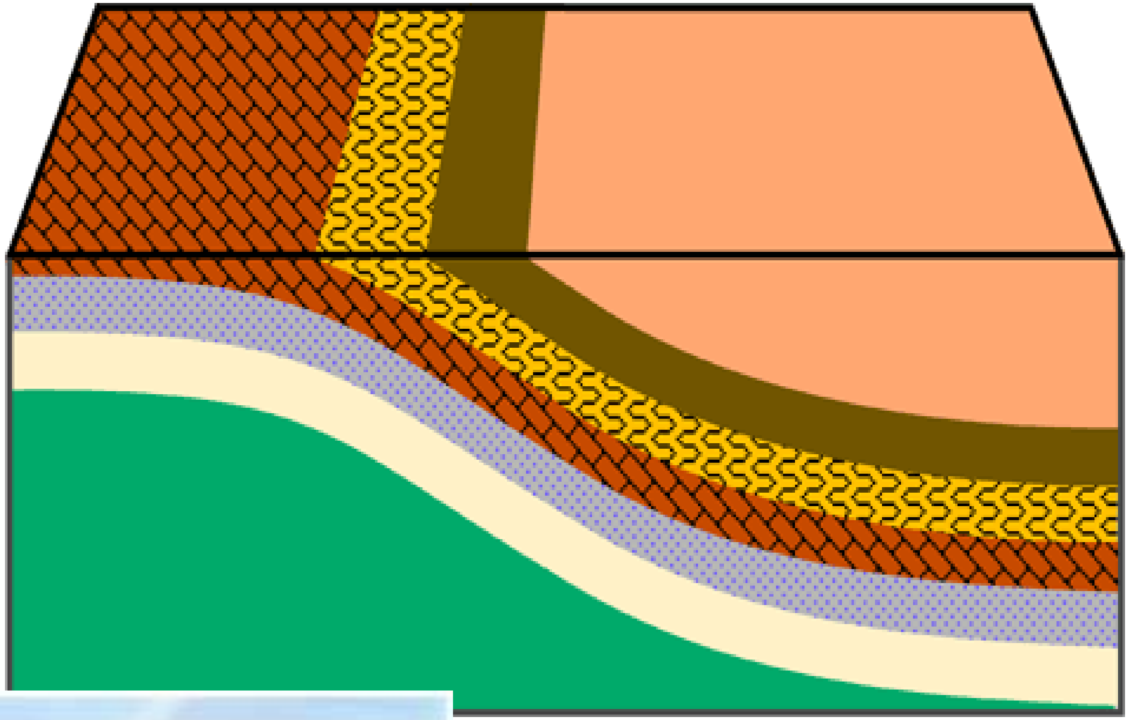
Syncline





-- **Monocline**

one-limbed fold



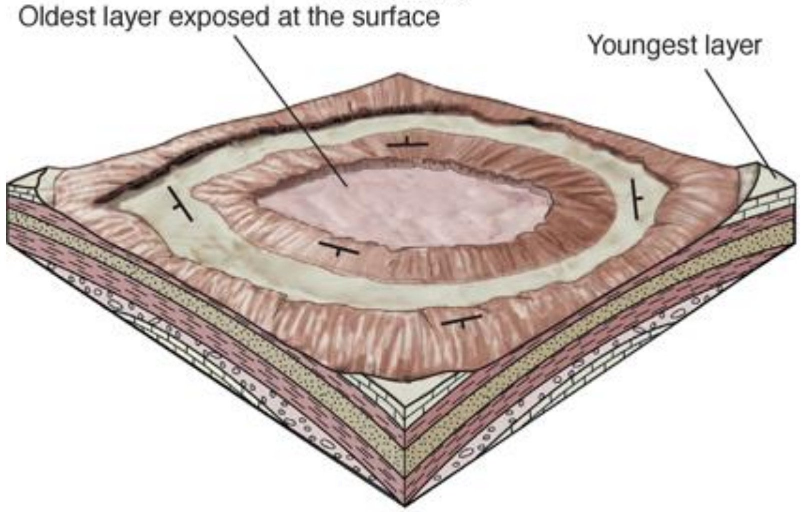
(A) Structures by plastic deformation

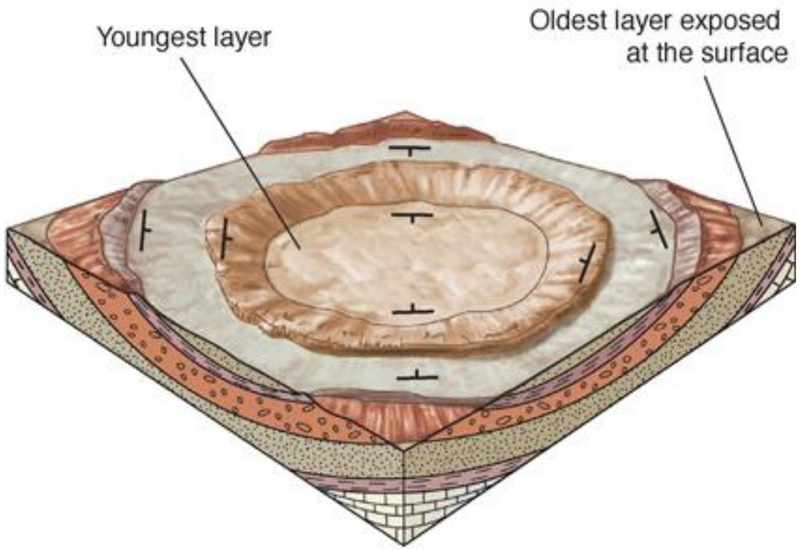
Dome: beds dip away from a central point

Oldest bed in the center
youngest bed at the rim

Basin: beds dip toward a central point

Youngest bed in the center
oldest bed at the rim

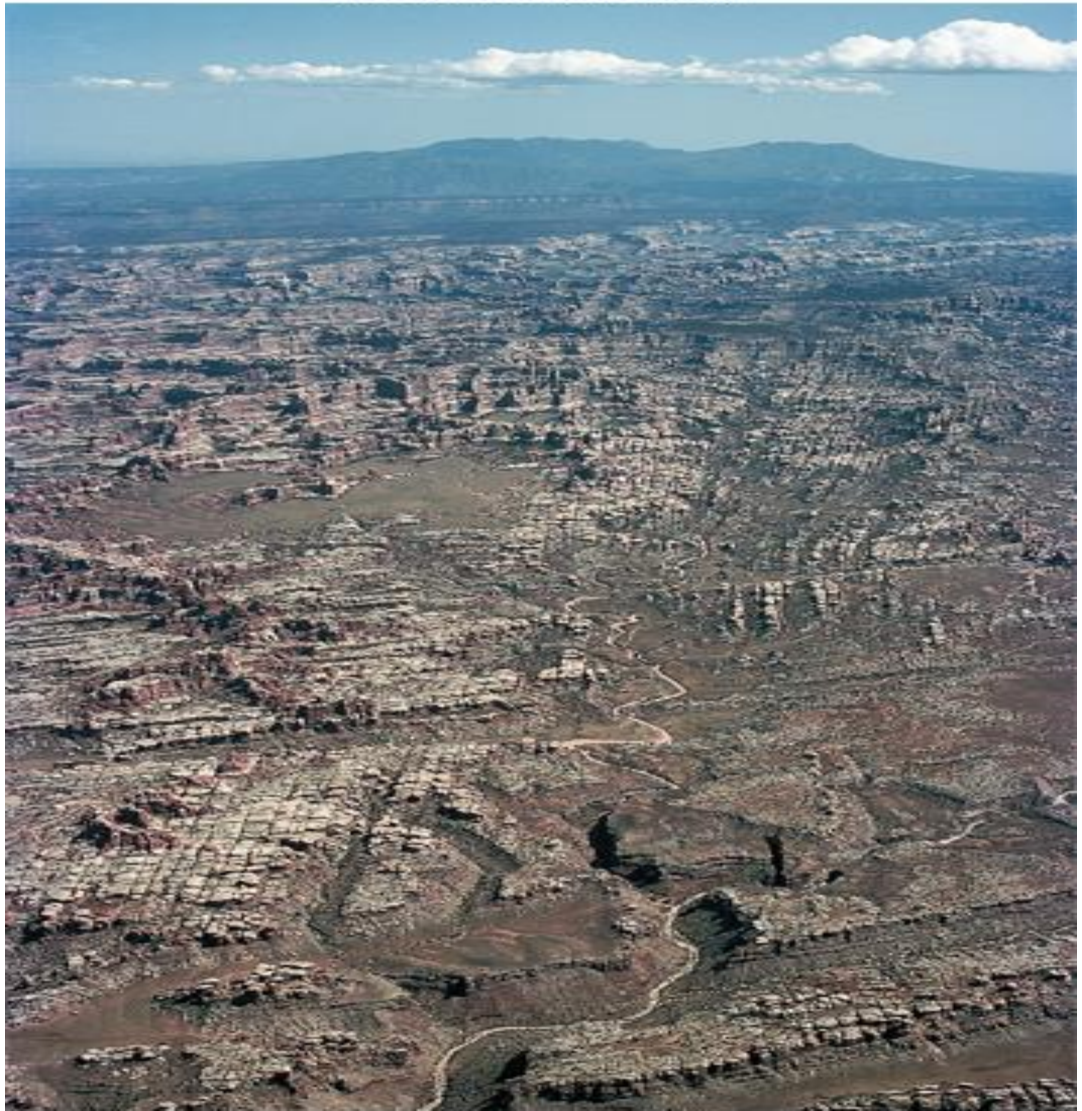




Dome

Photo by D.. Rahm, courtesy of Rahm Memorial Collection, Western Washington University

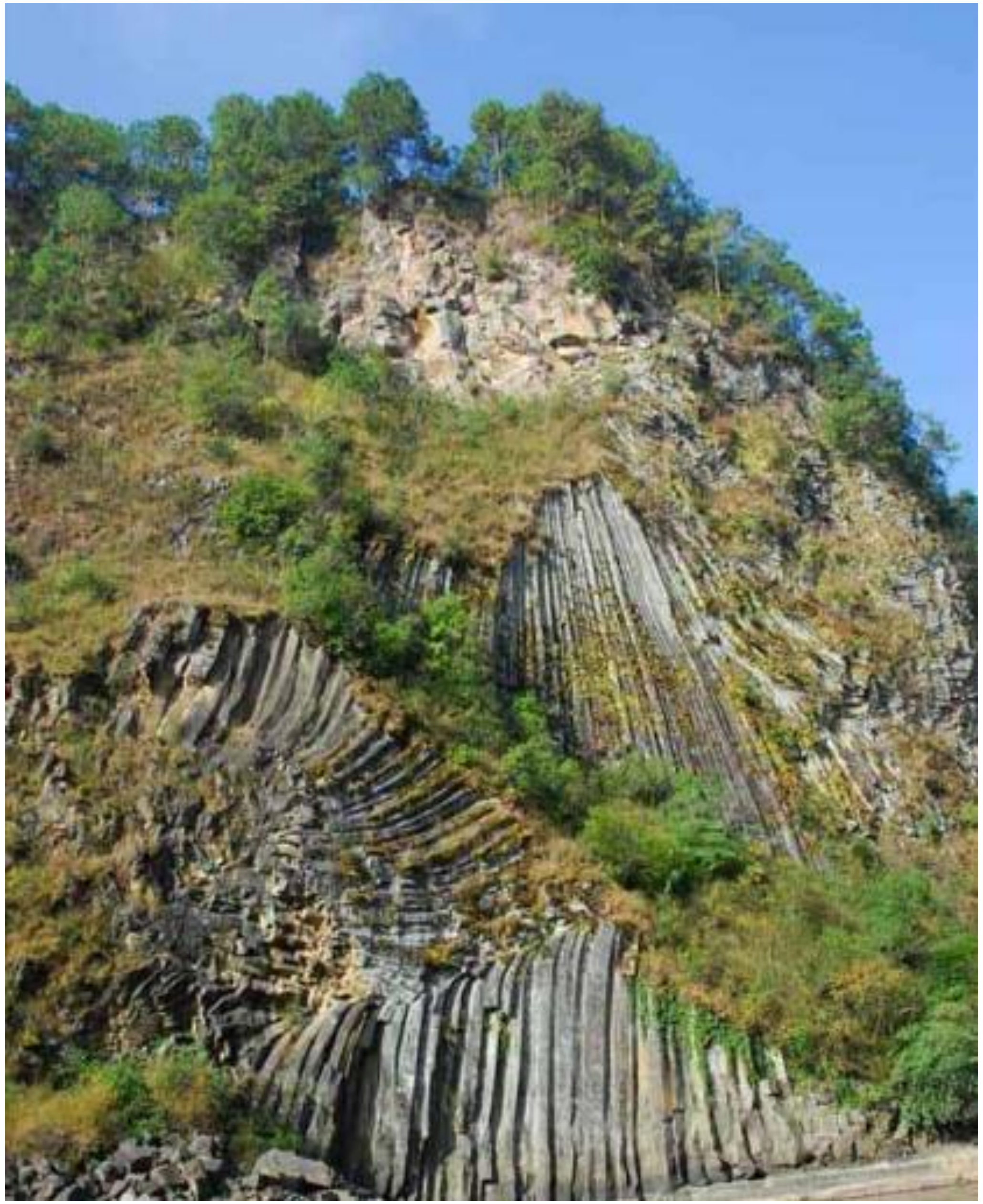
(B) Structures by brittle deformation
: fractures in rocks



a) Joints

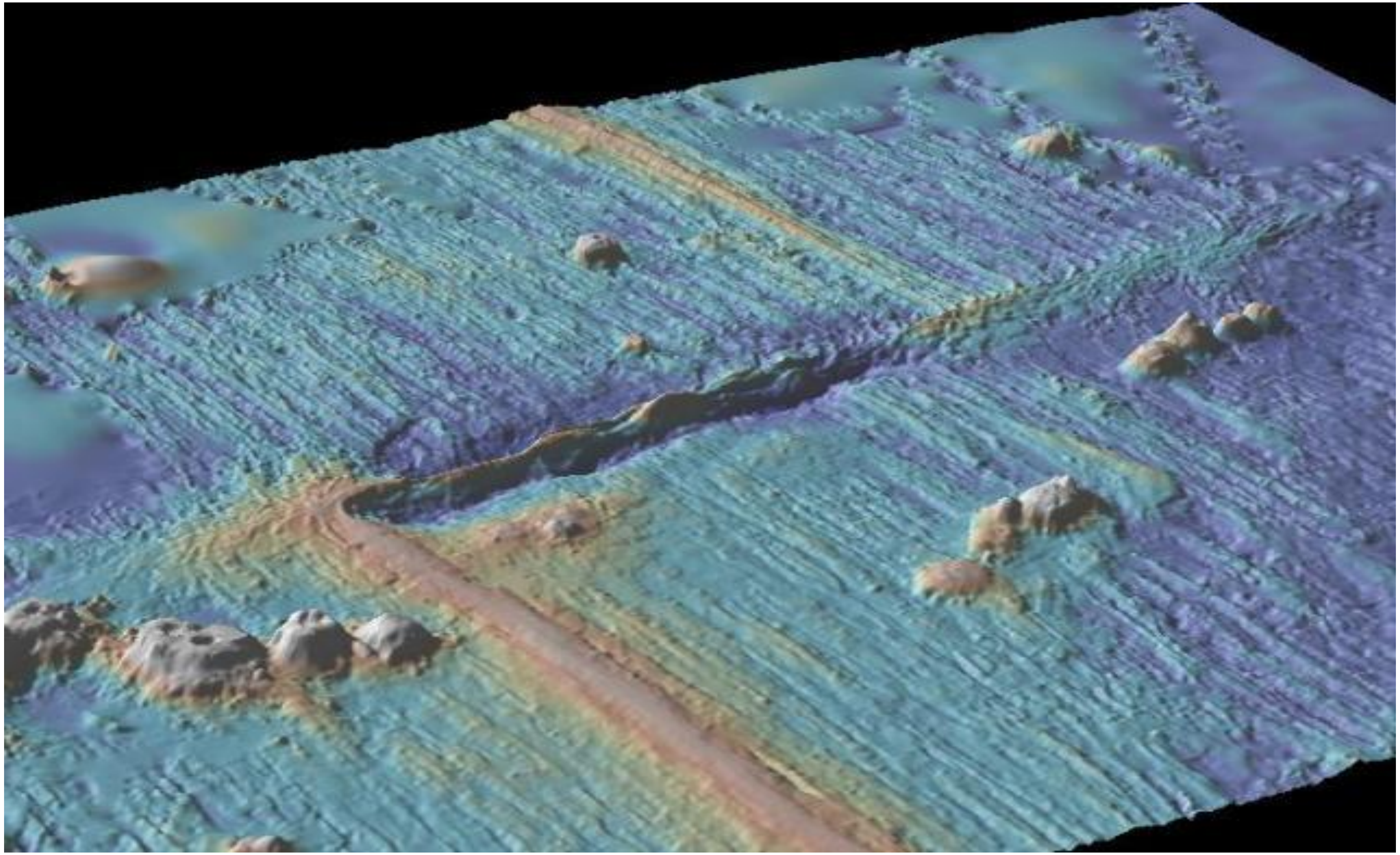
: fractures/cracks
in rocks,
without movement
along fractures

Column Joints: thermal stress

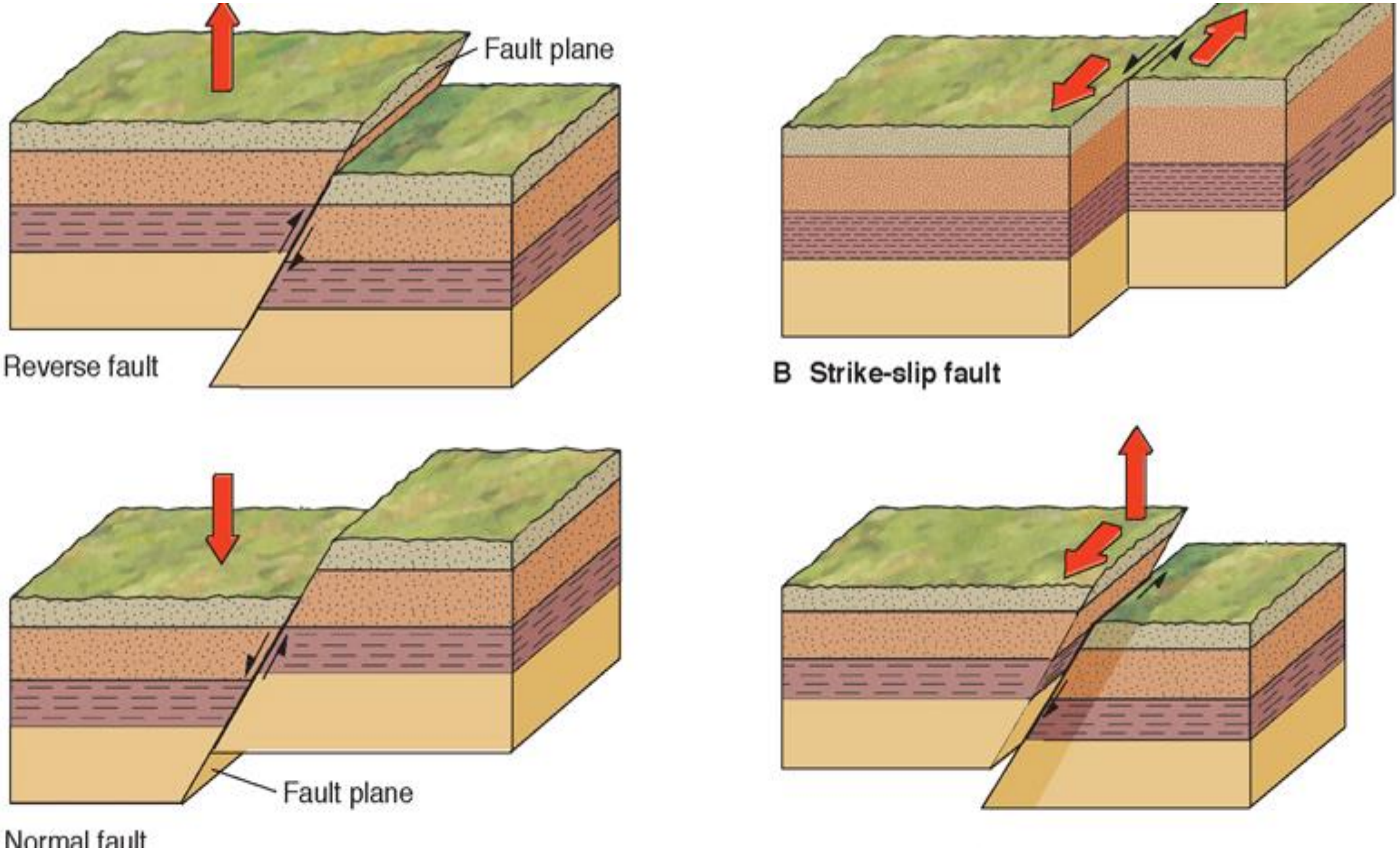


(B) Structures by brittle deformation

b) Faults: rocks move along the fractures



Faults

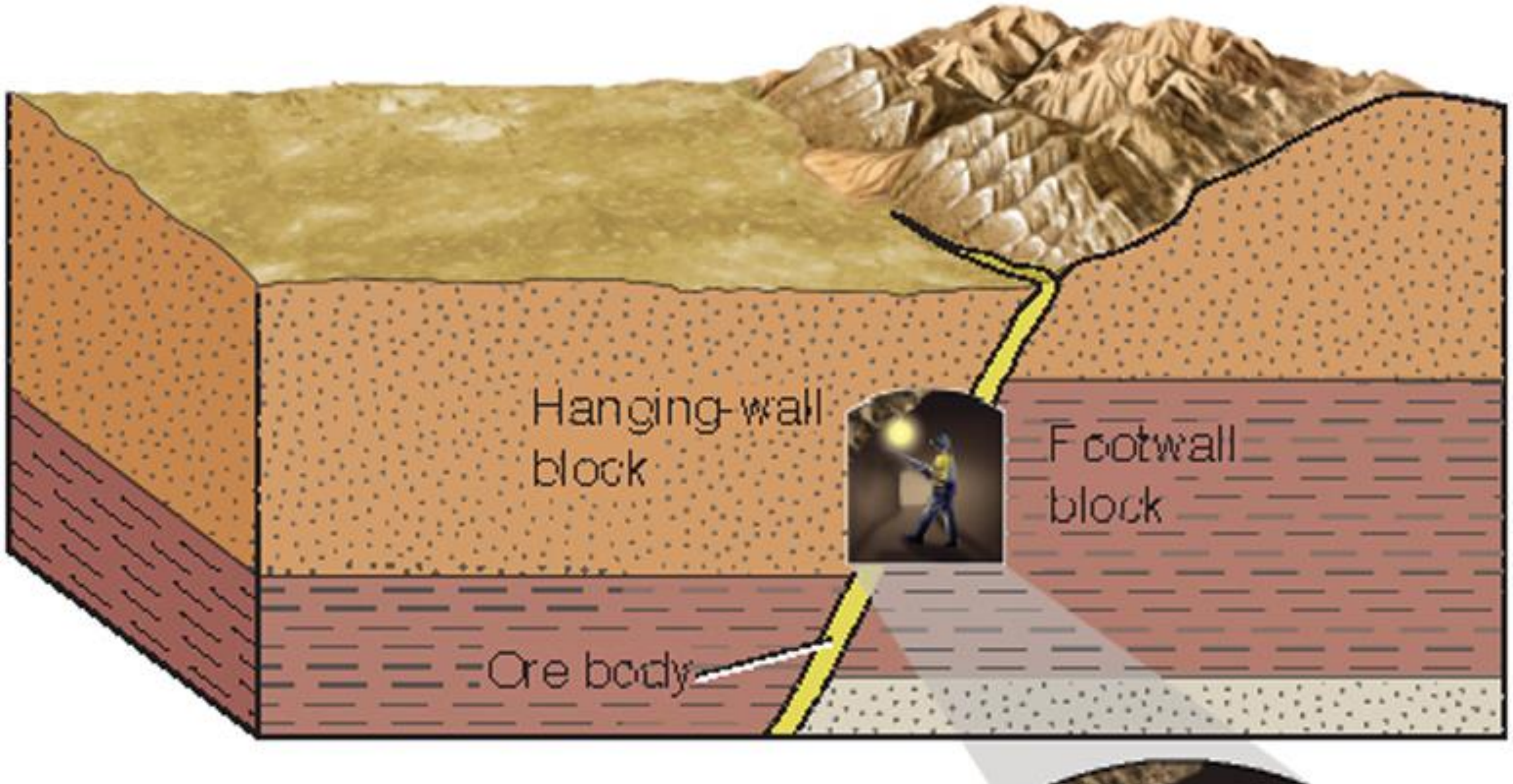

Fault plane
Reverse fault
B Strike-slip fault
Fault plane
Normal fault

Definitions of some terms:

Fault plane = surface of movement

footwall - underlying surface of fault plane

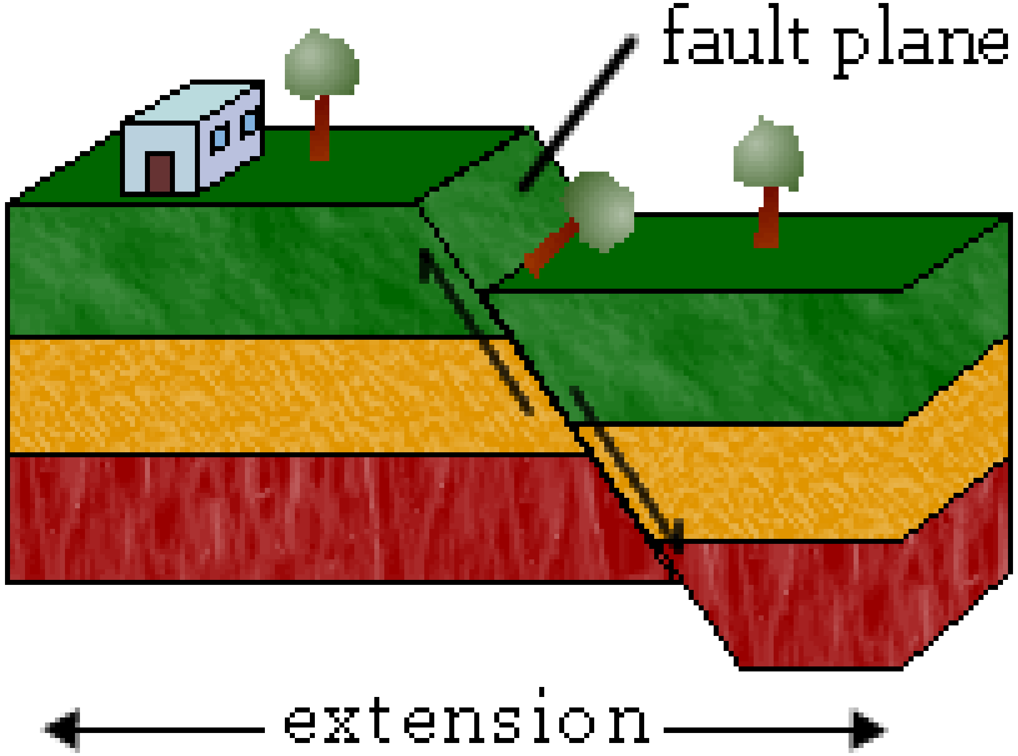
hanging wall - overlying surface of fault plane



<u>Types of Faults</u>

Normal fault

: **hanging wall** block moved **downward** relative to **footwall block** (due to **tensional forces)**



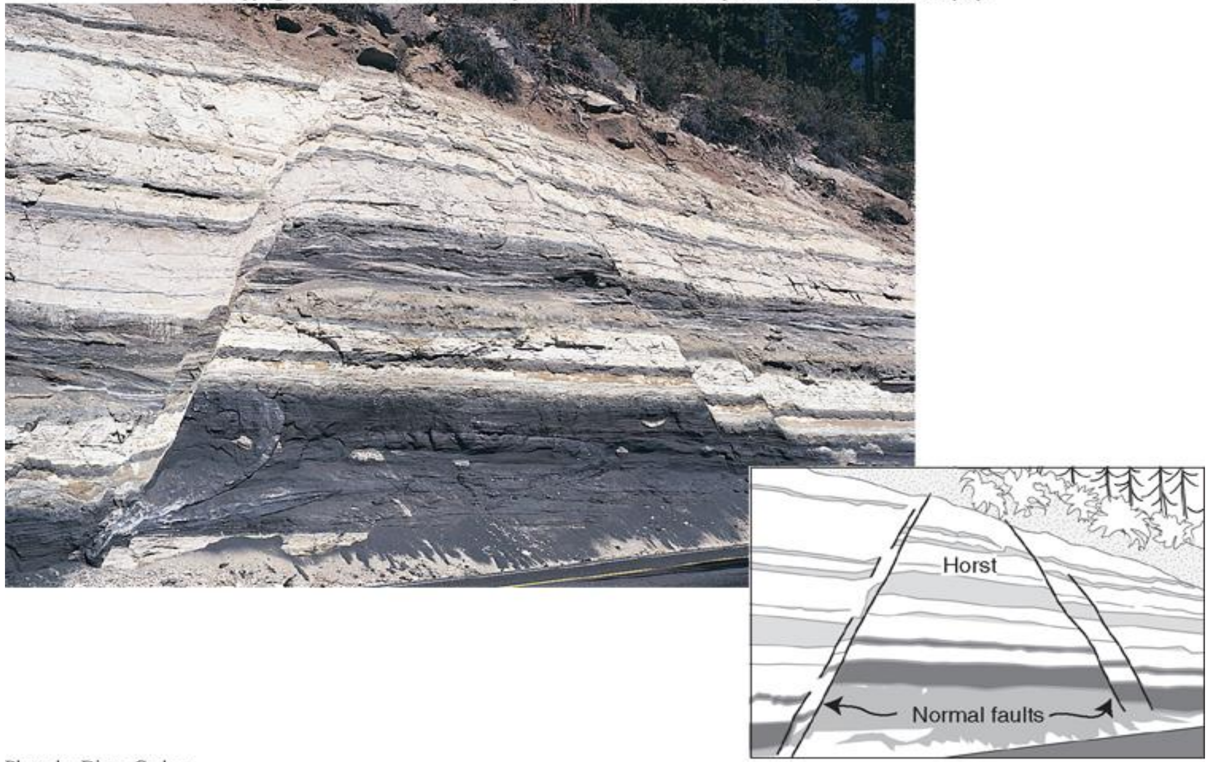
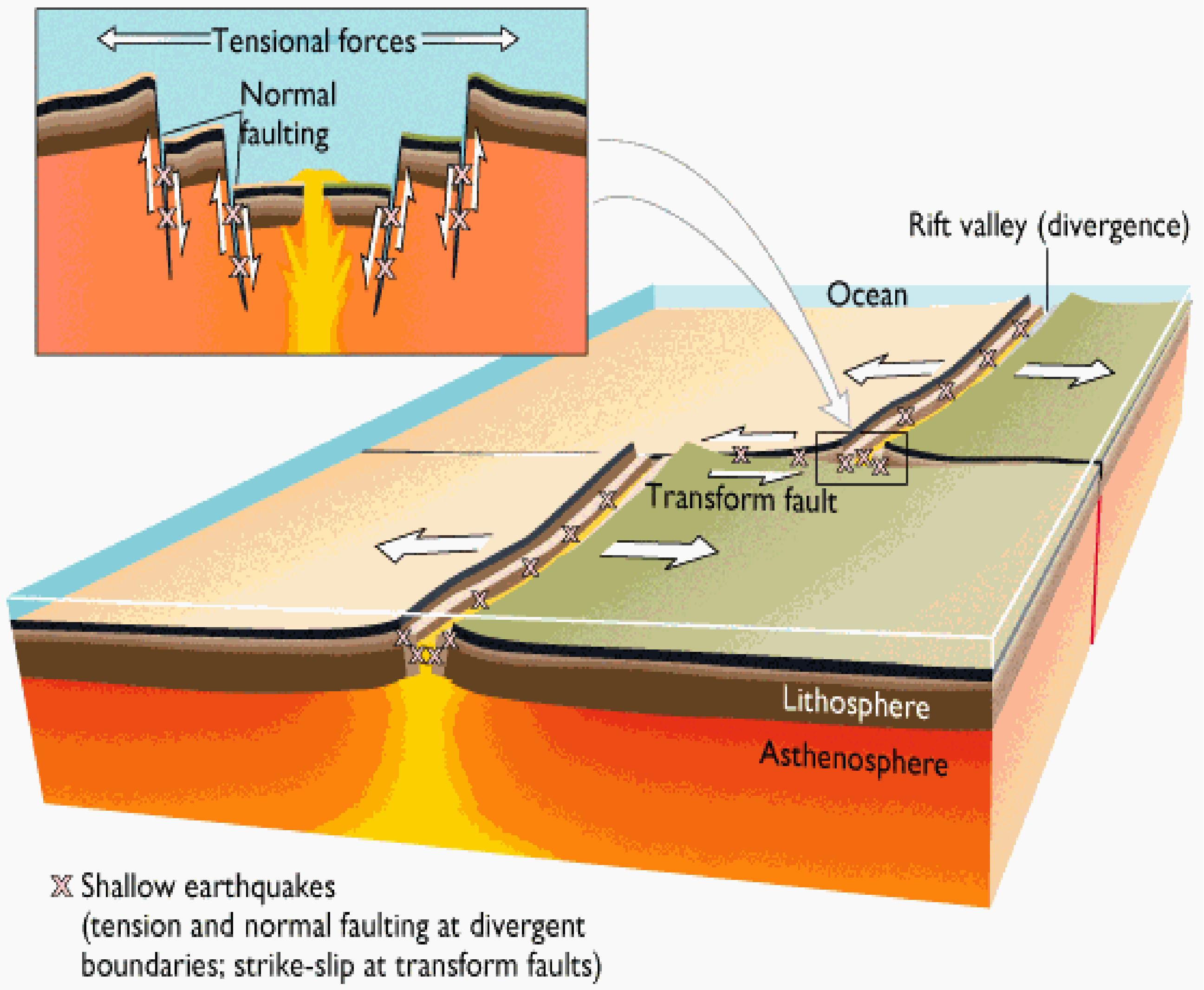
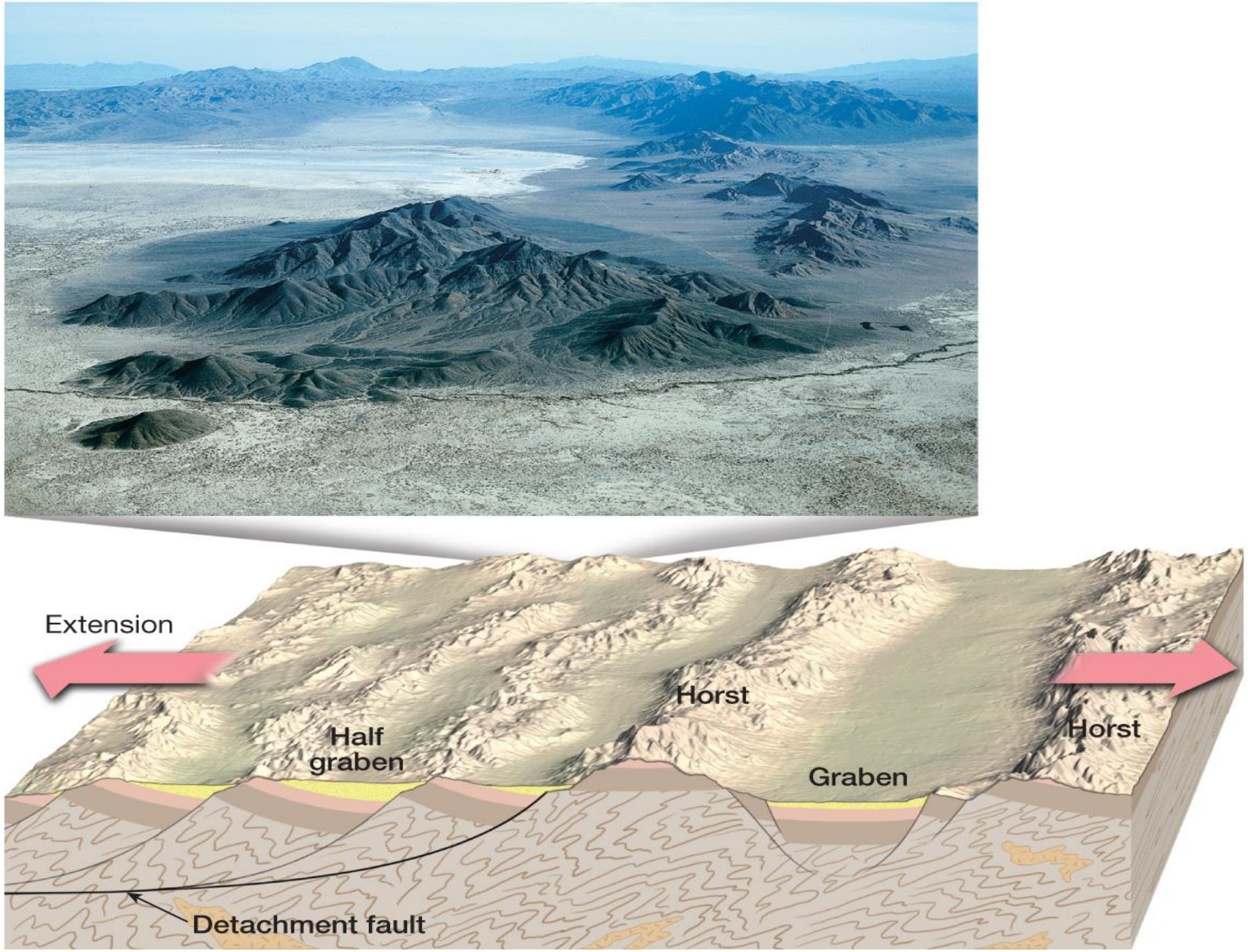


Photo by Diane Carlson

Normal faults: e.g., Mid-Ocean Ridge

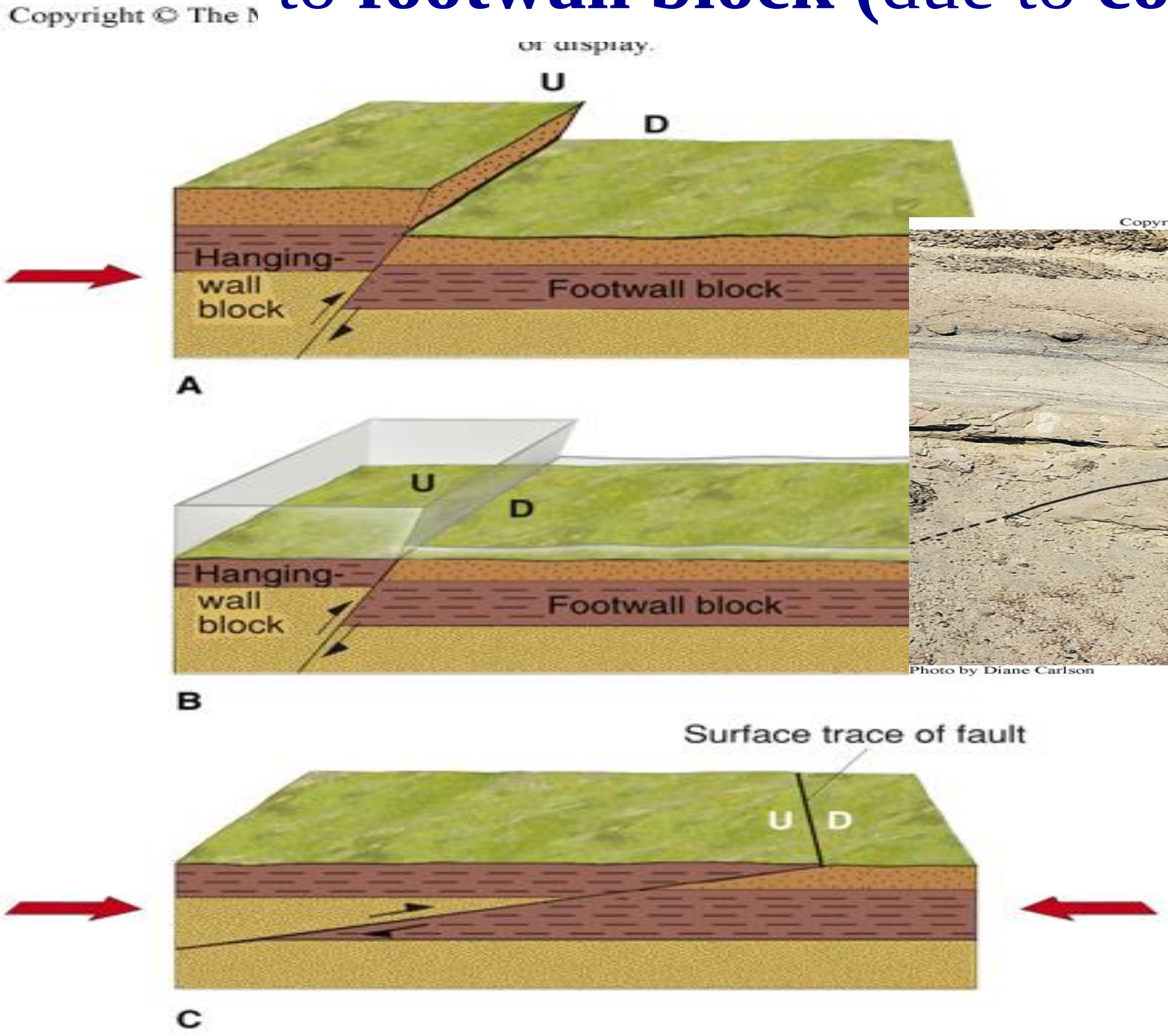


Normal faults: e.g., **Basin and Range**



Reverse fault

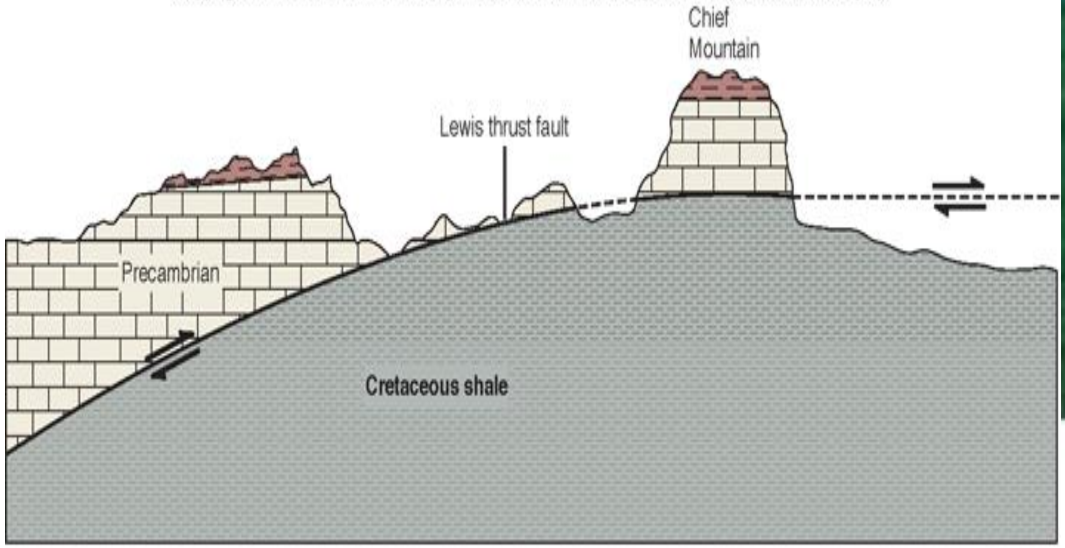
: **hanging wall** block moved **upward** relative to **footwall block (**due to **compressive forces)**



Thrust fault

: **low angle reverse fault**

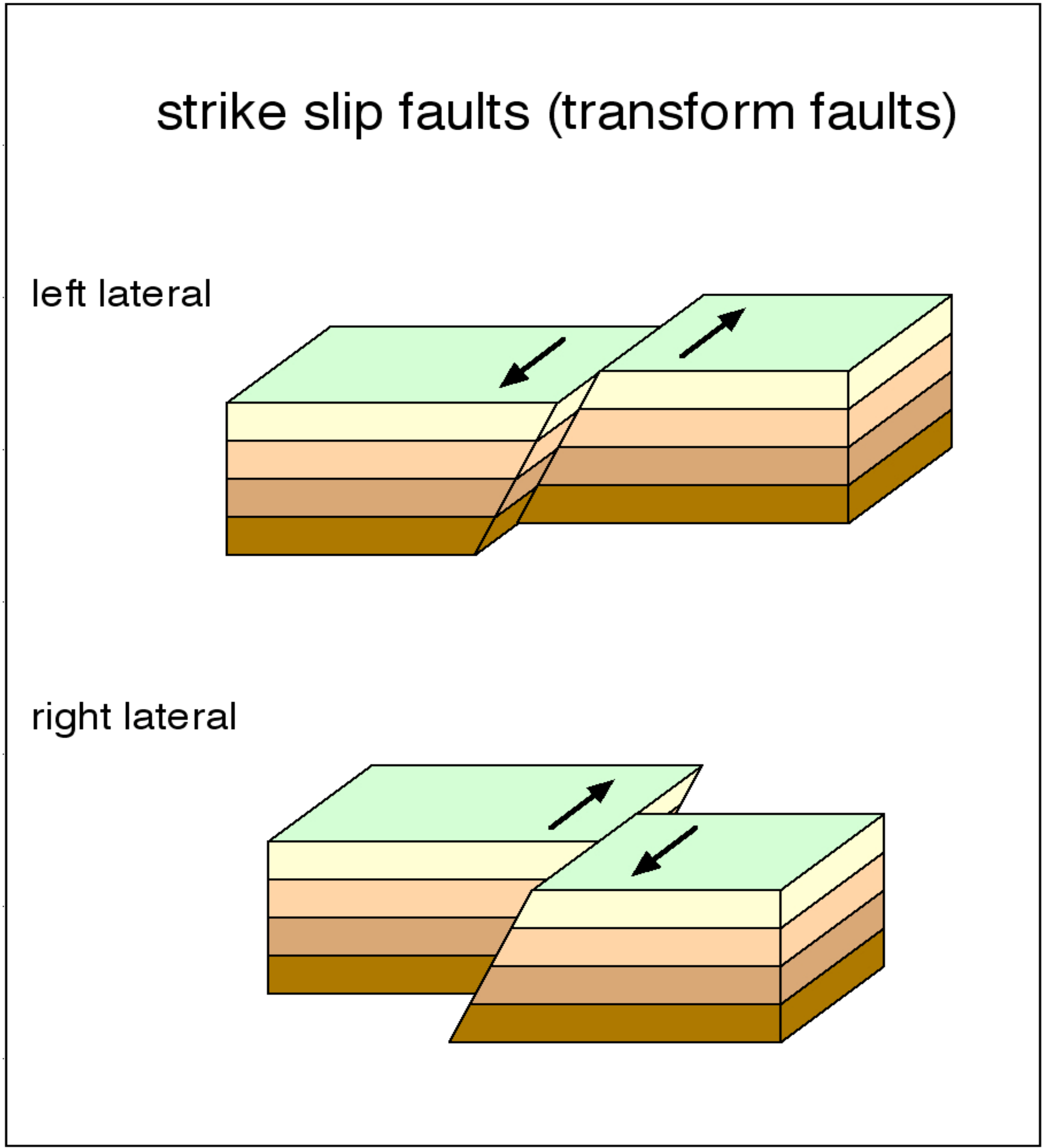
Thrust fault: e.g., Chief Mountain at Glacier National Park



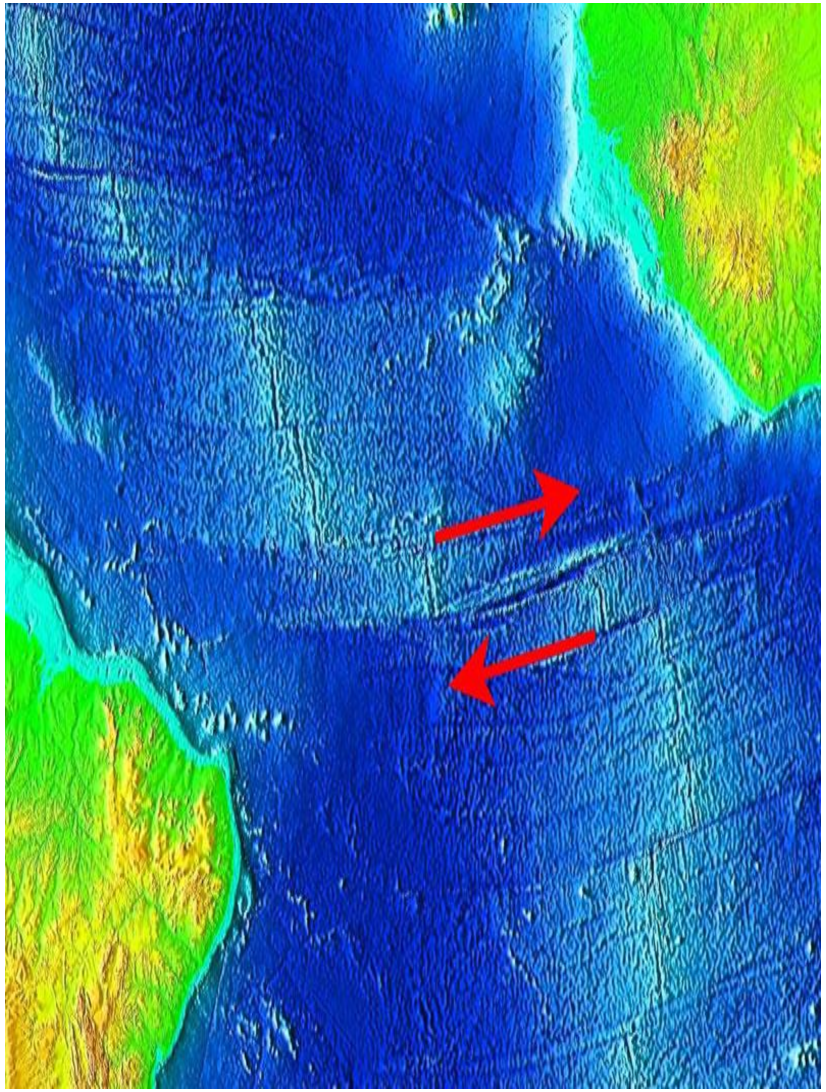
B

Photo by Frank M. Hanna

Strike slip fault: horizontal movement



Strike-slip fault



e.g., Fracture zones on ocean floor

Strike-slip fault

e.g., San Andreas Fault