Terrestrial Planets Part 1

General Properties

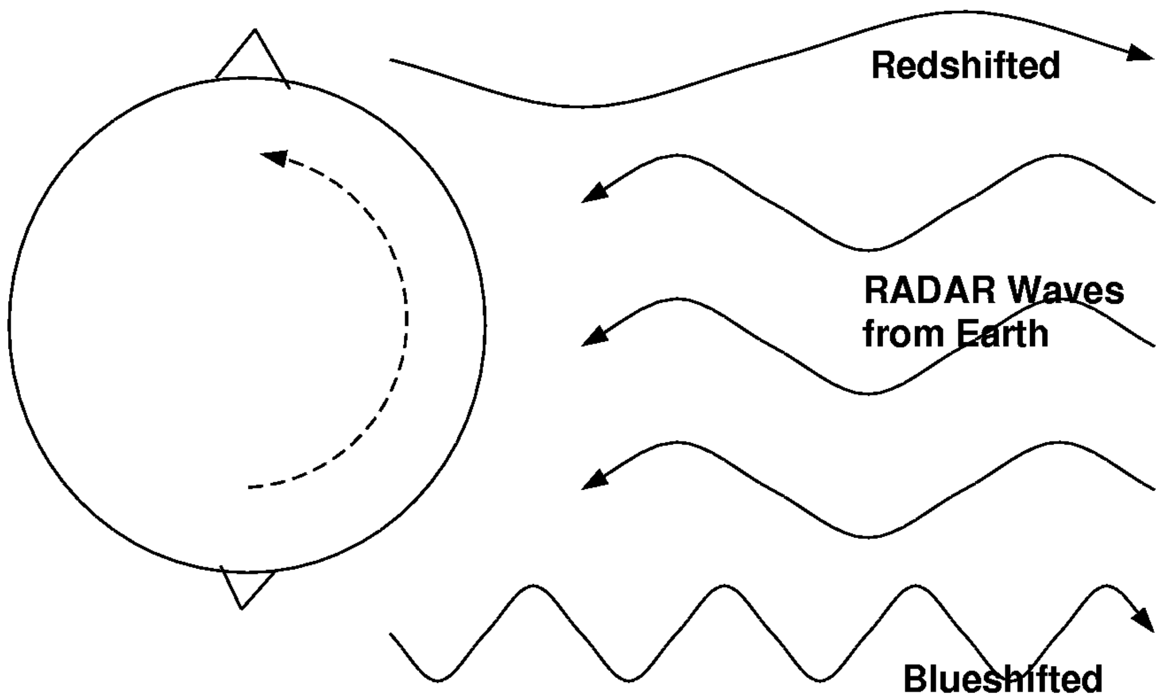
The Earth

Basic Properties

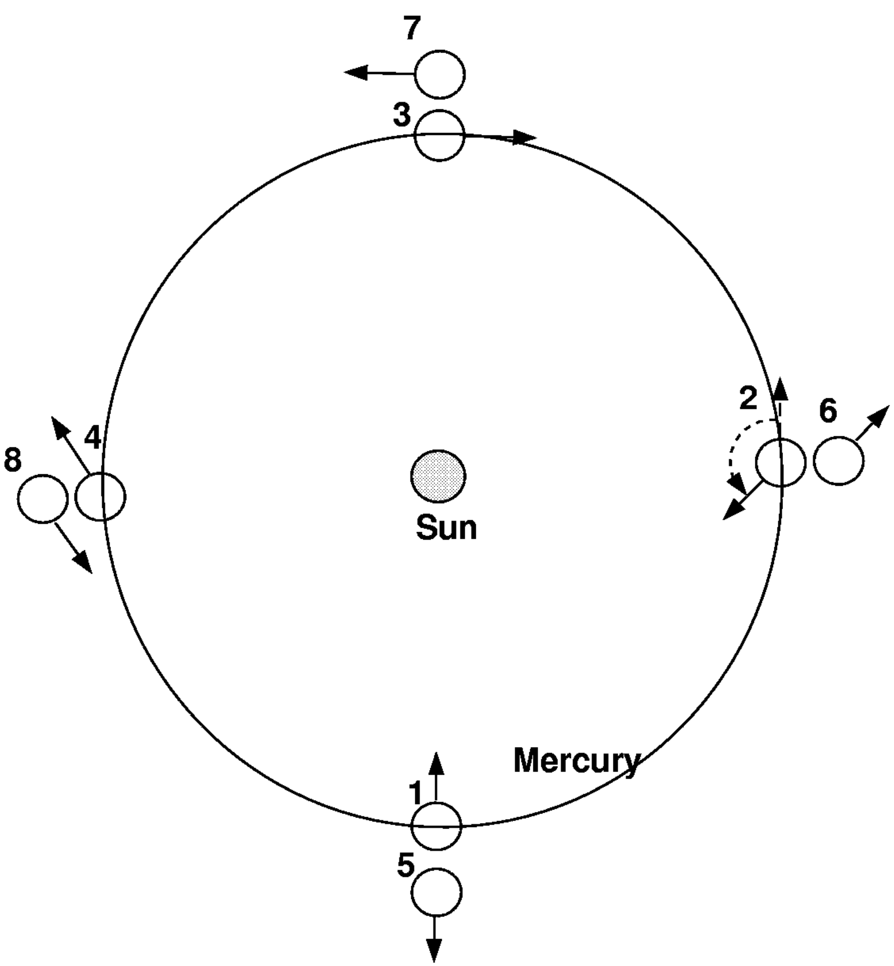
Planet	a(AU)	$M(M_E)$	R(km)	$\rho(g/cm^2)$
Mercury	0.39	0.06	2,439	5.43
Venus	0.72	0.81	6,051	5.25
Earth	1.00	1.00	6,378	5.52
Mars	1.52	0.11	3.397	3.93

Planetary Spins

- Time rotation using surface features
- Use Doppler effect to get rotational speeds



3-2 Spin-Orbit Coupling (Mercury)



General Regions

- Core
- Mantle
- Crust
- Hydrosphere
- Cryosphere
- Atmosphere
- Magnetosphere

The Materials of the Earth and Terrestrial Planets

(Select Examples)

Minerals

Silica - SiO_2 Example: Quartz

Olivines - $(Mg,Fe)_2SiO_4$

Pyroxenes - (Mg,Fe,Ca)SiO_3

Example - Augite

Plagioclase Feldspar - $(Ca,Na),(Al,Si)AlSi_2O_8$

Calcite - $CaCO_3$ Example - Onyx

Igneous Rocks

Basalt - *extrusive* - small crystals (little *annealing*) - feldspars, olivines, pyroxenes

Gabbro - *intrusive* - larger crystals - feldspars, olivines, pyroxenes, hornblende. If mostly labradorite (plagioclase feldspar) > *anorthosite*

Granite - *intrusive* - potash feldspars, quartz, hornblende, mica. Earth's continents are 90% granite.

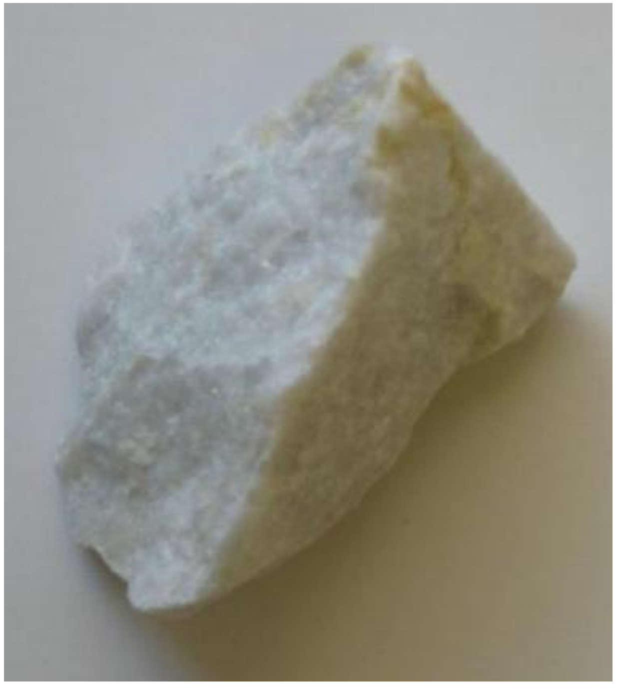
Sedimentary Rocks

Limestone - calcite ($CaCO_3$) and dolomite ($Ca(Mg,Fe)(CO_3)_2$) - carbonate rock produced through both biological and non-biological processes

Sandstone - mostly quartz

Metamorphic Rocks

(igneous or sedimentary rock transformed into a new rock by high temperature, pressure, or the addition of other chemicals)



Marble - limestone transformed by temperature, pressure, water

Quartzite - processed sandstone

Changes of State

Internal structures of solids can change due to T, P (there are many different forms of ice, for example)

Can also undergo solid/liquid *phase change* - i.e. melting

Differentiation

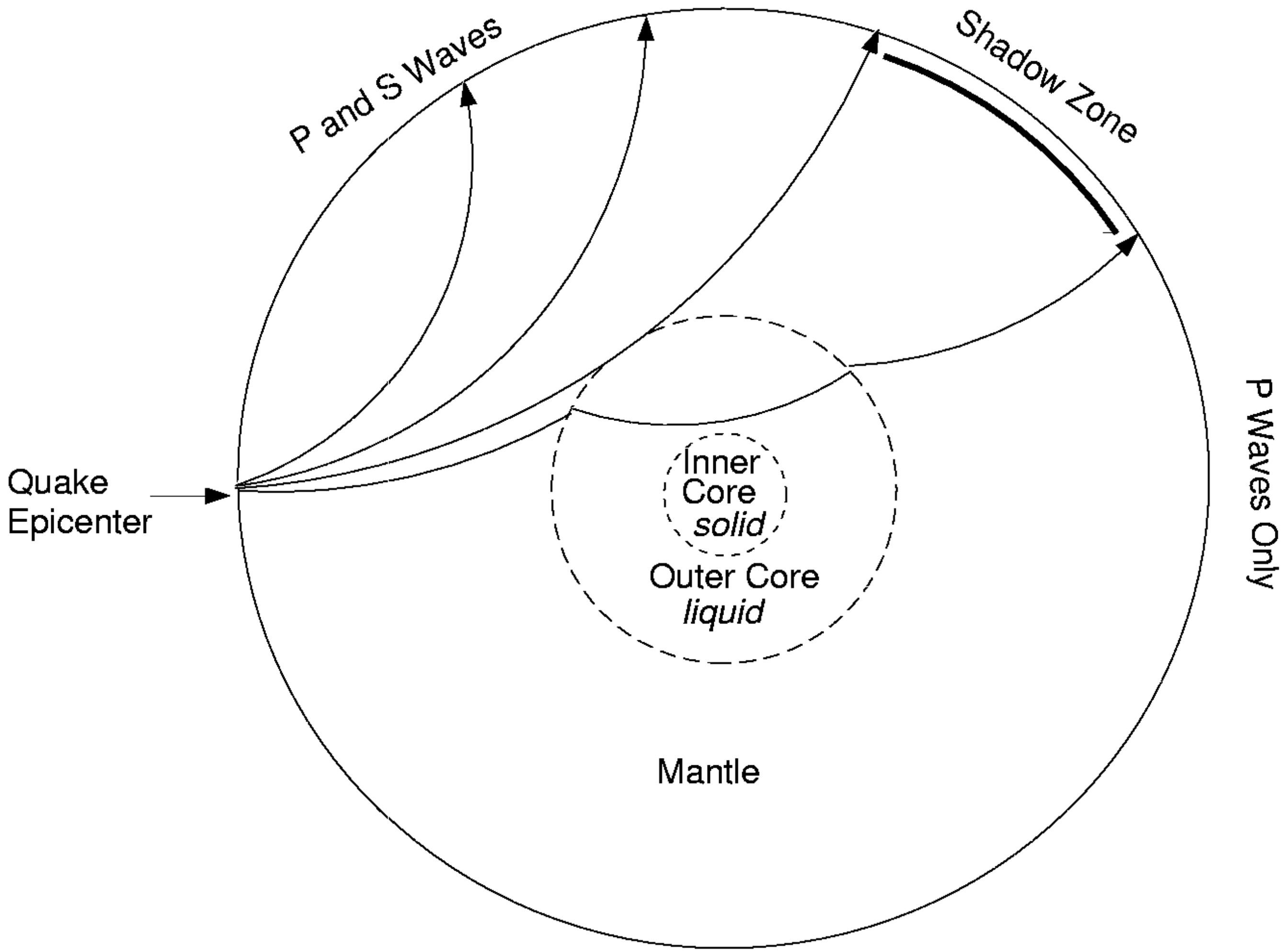
Separates material into different chemical/physical properties.

Ex. - separation by density in a magma melt

Ex. - separation of rock & metal in a planet's youth

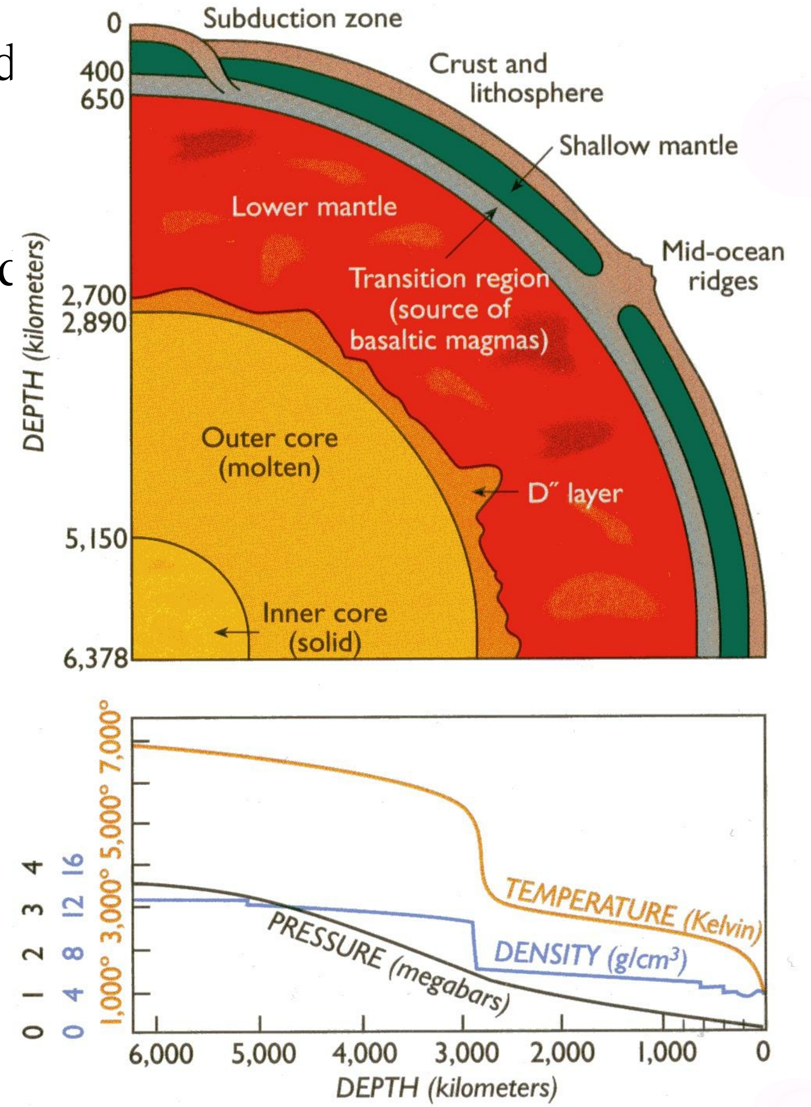
Earth's Interior

Seismic Waves



Chemical Boundaries

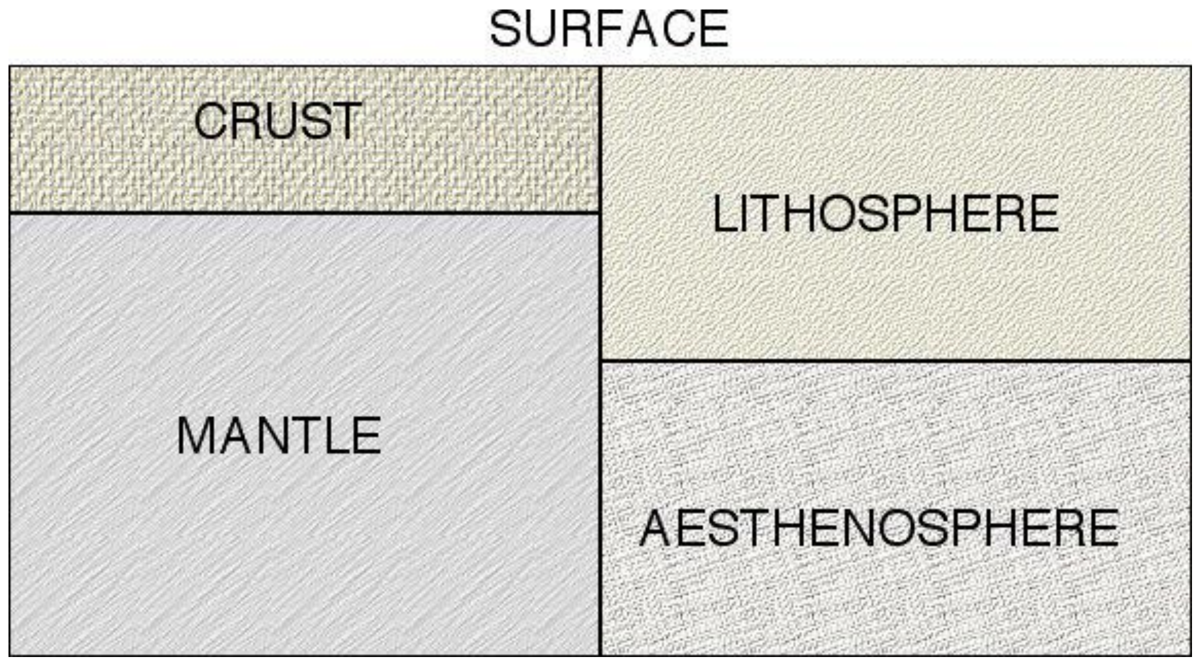
- **Core** - solid center & liquid envelope - mostly Fe with some Ni, S - motion in liquid core generates Earth's magnetic field
- **Mantle** - rock - mostly olivines & pyroxenes - location below the crust is detected by a change in seismic wave speed
- **Crust** -lighter rock - rich in feldspars
- Oceanic Crust - thinner crust under ocean floors
- Continental Crust - thicker - "floats" on mantle due to *isostatic equilibrium*



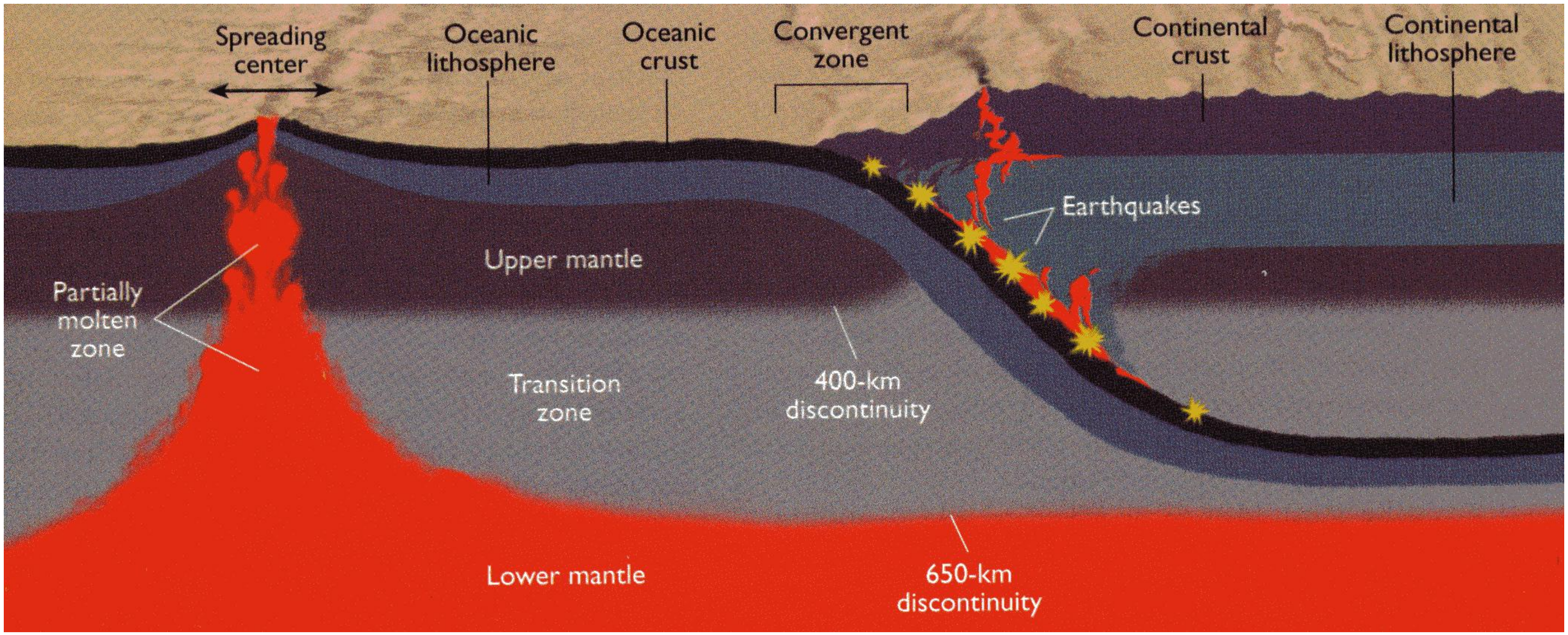
Physical Boundaries

Crust & upper mantle - solid *lithosphere*

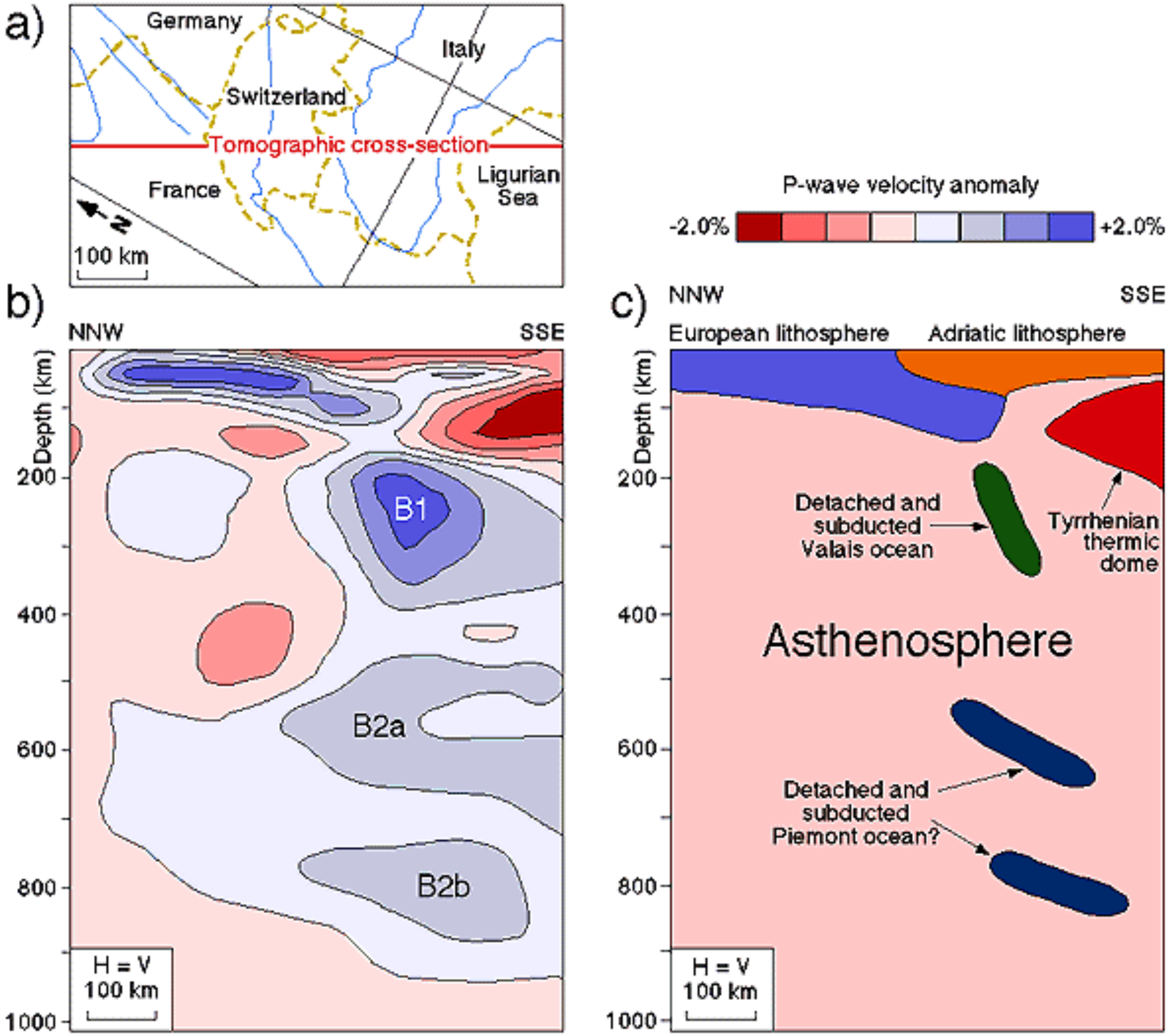
Below is partly liquid *aesthenosphere*

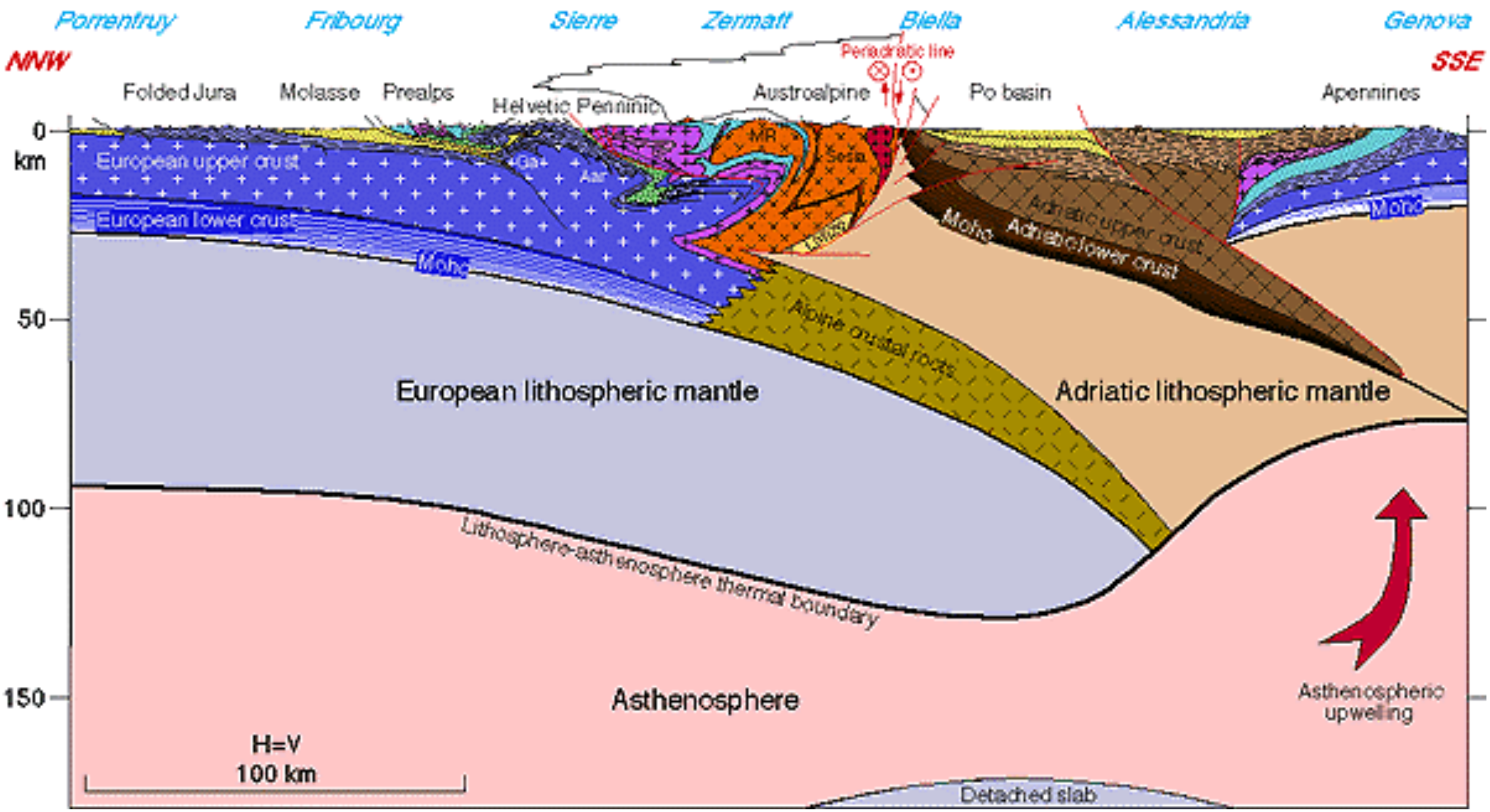


Chemical (crust/mantle) and physical (lithosphere/aesthenosphere) boundaries need not coincide!!

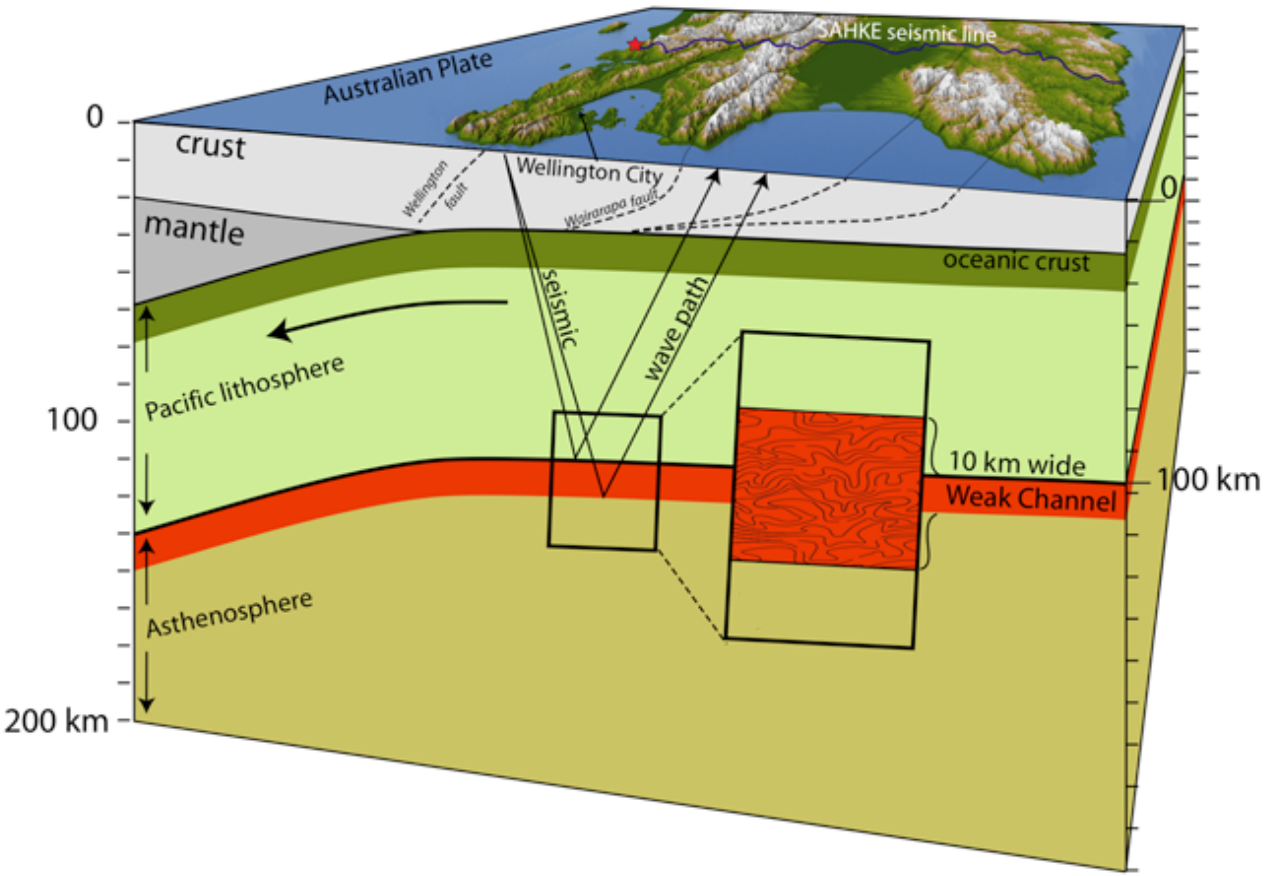

Spreading center
Oceanic lithosphere
Oceanic crust
Convergent zone
Continental crust
Continental lithosphere
Earthquakes
Upper mantle
Partially molten zone
Transition zone
400-km discontinuity
Lower mantle
650-km discontinuity

Deep Subduction (example)





Porrentruy
Fribourg
Sierre
Zermatt
Biella
Alessandria
Genova
NNW
SSE
Periadriatic line
Folded Jura
Molasse
Prealps
Helvetic
Penninic
Austroalpine
Po basin
Apennines
0
km
50
100
150
European upper crust
European lower crust
Moho
Aar
MR
Sesia
Adriatic upper crust
Adriatic lower crust
Alpine crustal roots
European lithospheric mantle
Adriatic lithospheric mantle
Lithosphere-asthenosphere thermal boundary
Asthenosphere
Asthenospheric upwelling
H=V
100 km
Detached slab



There seems to be a very fluid boundary layer (discovered in 2015)

Surface Processes

Volcanic
Underground Magma

Mount St. Helens, Washington

Tectonic - plate motion

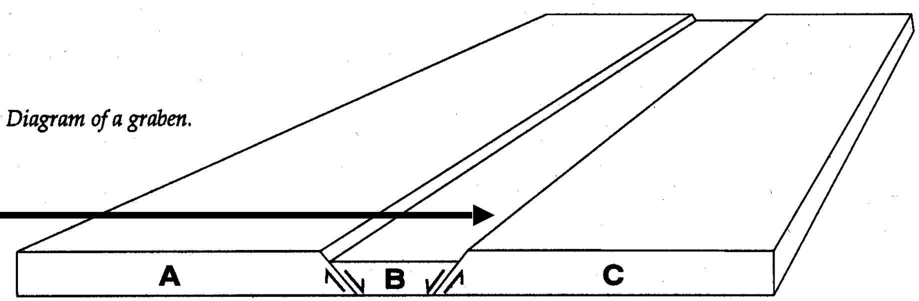
Plate collision

Plate subduction

San Andreas Fault, California

Faulting: can be laterally (as in the San Andreas Fault) or vertically, as occurs in *graben*.

Figure 2.4. Diagram of a graben.



1 Day Magnitude 2.5+ Earthquakes

Impact Cratering

Meteor Crater, Arizona

Age Dating of Rocks

^{40}K----->^{40}ArHalf-life=1.3 billion years (by)

Example: start with 100 ^{40}K atoms (and no ^{40}Ar)

Time Elapsed	^{40}K	^{40}Ar
0 by	100	0
1.3 by	50	50
2.6 by	25	75

Age of Earth - 4.5-4.6 by

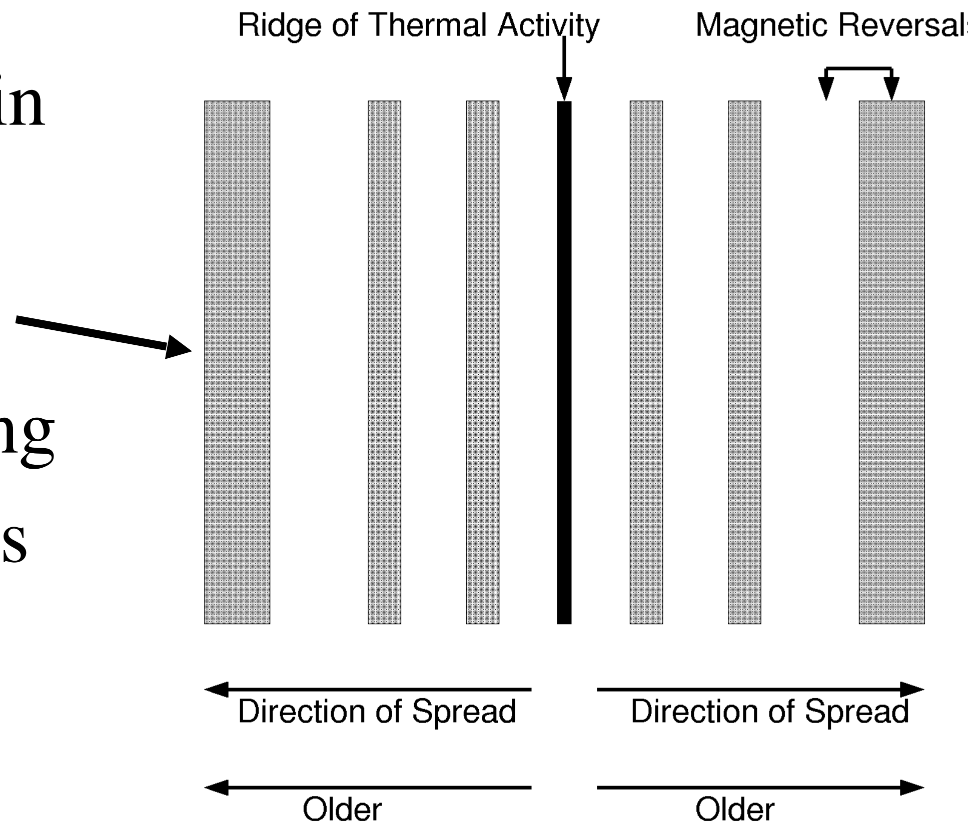
Another method: crystal damage from particle decay: #damage streaks/cm^3 + #parent atoms+half-life gives time since rock solidified.

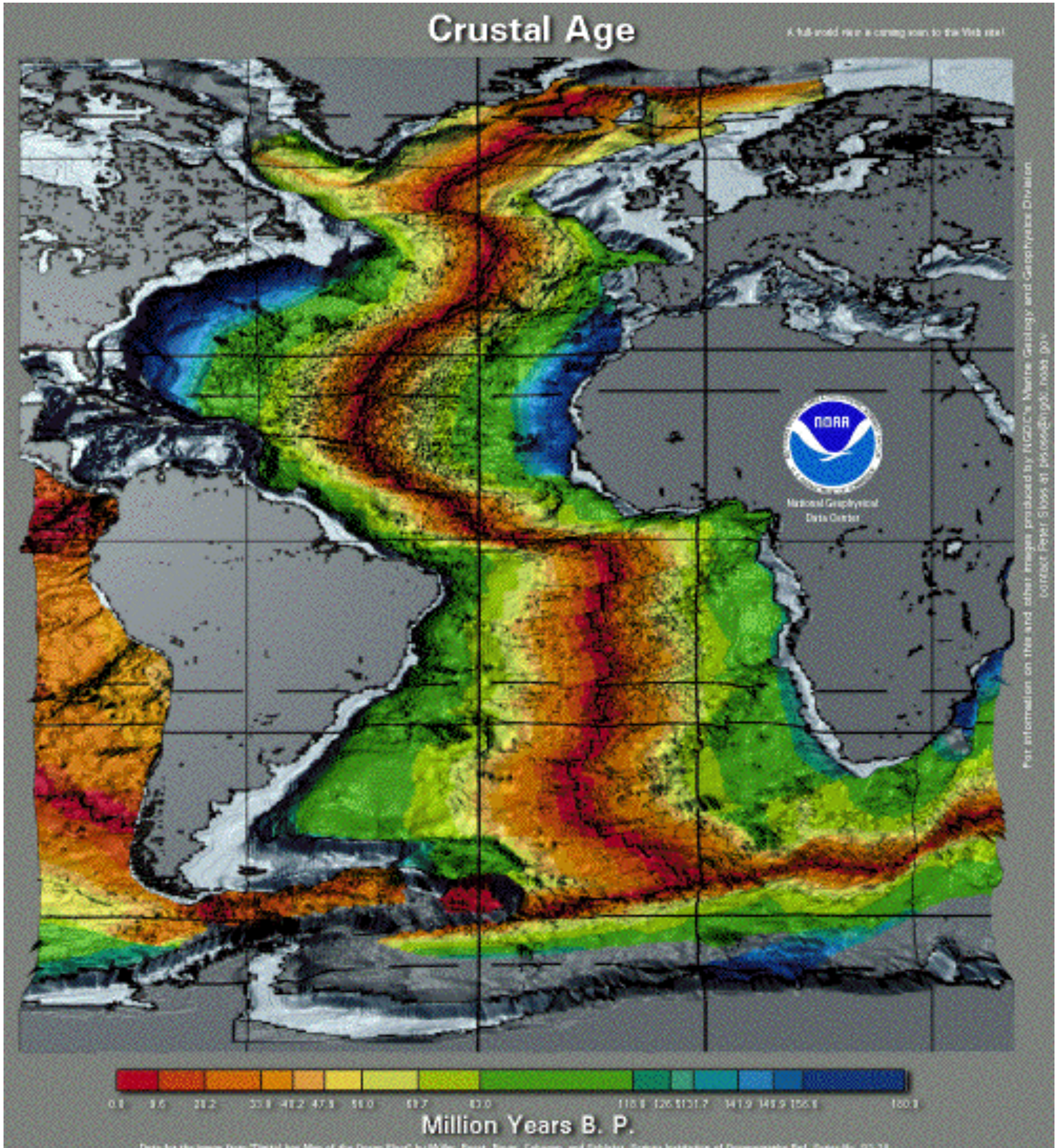
Plate Tectonics & Continental Drift

- 1620's - Francis Bacon - coastlines match
- 1922 - Alfred Wegener proposed theory of Continental Drift - mechanism unknown
- 1963 - Seafloor spreading recognized
- 1966 - Wide acceptance of CD and development of global model of plate tectonics

Evidence

- Atlantic coastlines
- Magnetic pole reversals in material on each side of mid-Atlantic Ridge
- Laser ranging/radio timing
- Measure drift along faults




Crustal Age
NOAA
National Geophysical
Data Center
Million Years B. P.
For information on this and other images produced by NGDC's Marine Geology and Geophysics Division

Consequences of Plate Tectonics

Crustal plates are in motion, carrying continents with them

•Plates collide and can build mountains (Himalayas). Often oceanic and continental plates collide with oceanic plate subducted - example: Pacific Rim - earthquakes and explosive volcanism(such as Mount St. Helens)

•Sequential volcano building on plates travelling over mantle plumes - example: Hawaiian Islands (usually “gentler” eruptions)

•Plate motion is episodic - The current episode began about 300 My ago.

Heat Transport

- Radiative - light
- Conductive - solid-solid thermal motion
- Convective - cycling flow of fluid
- Advective - 1-way outflow of fluid

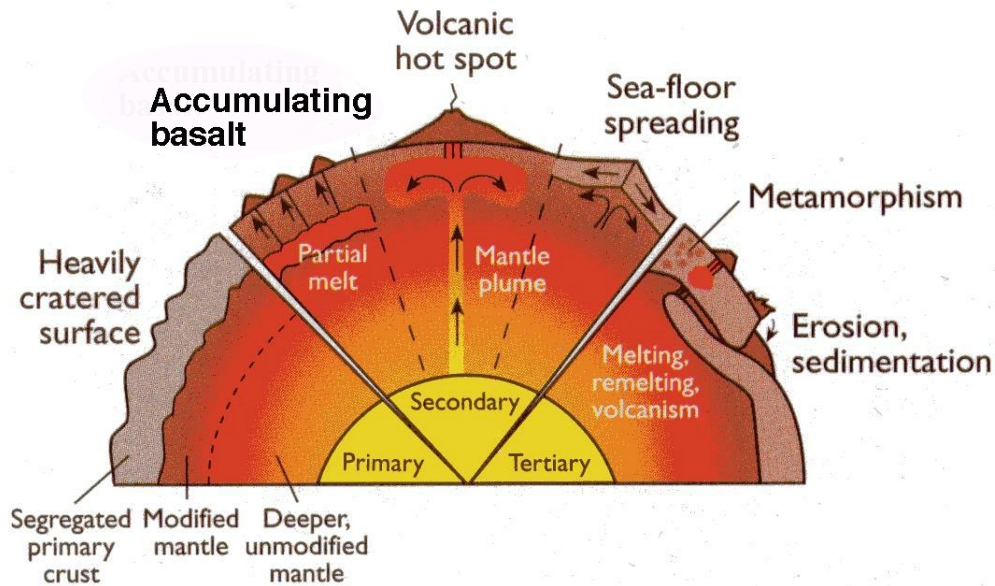
Heat in the Earth due to natural radioactive decay plus some left over from formation

History of Earth's Interior

- Planet forms from "homogeneous" ball
- Partial to total melting from impacts & radioactivity
- Outer parts begin to solidify
- Interior differentiation - Iron sinks to core
- Plate tectonics driven by internal convection

3 Stages of Crust Development

- ***Primary Crust*** **- original solidification, subject to heavy impact during early solar system ("*late heavy bombardment period*").**
- ***Secondary Crust*** **- hot mantle material reaches surface through volcanic action and new crust exposed in seafloor spreading.**
- ***Tertiary Crust*** **- further re-working of crust material by subduction, metamorphic processes, erosion, and sedimentation.**



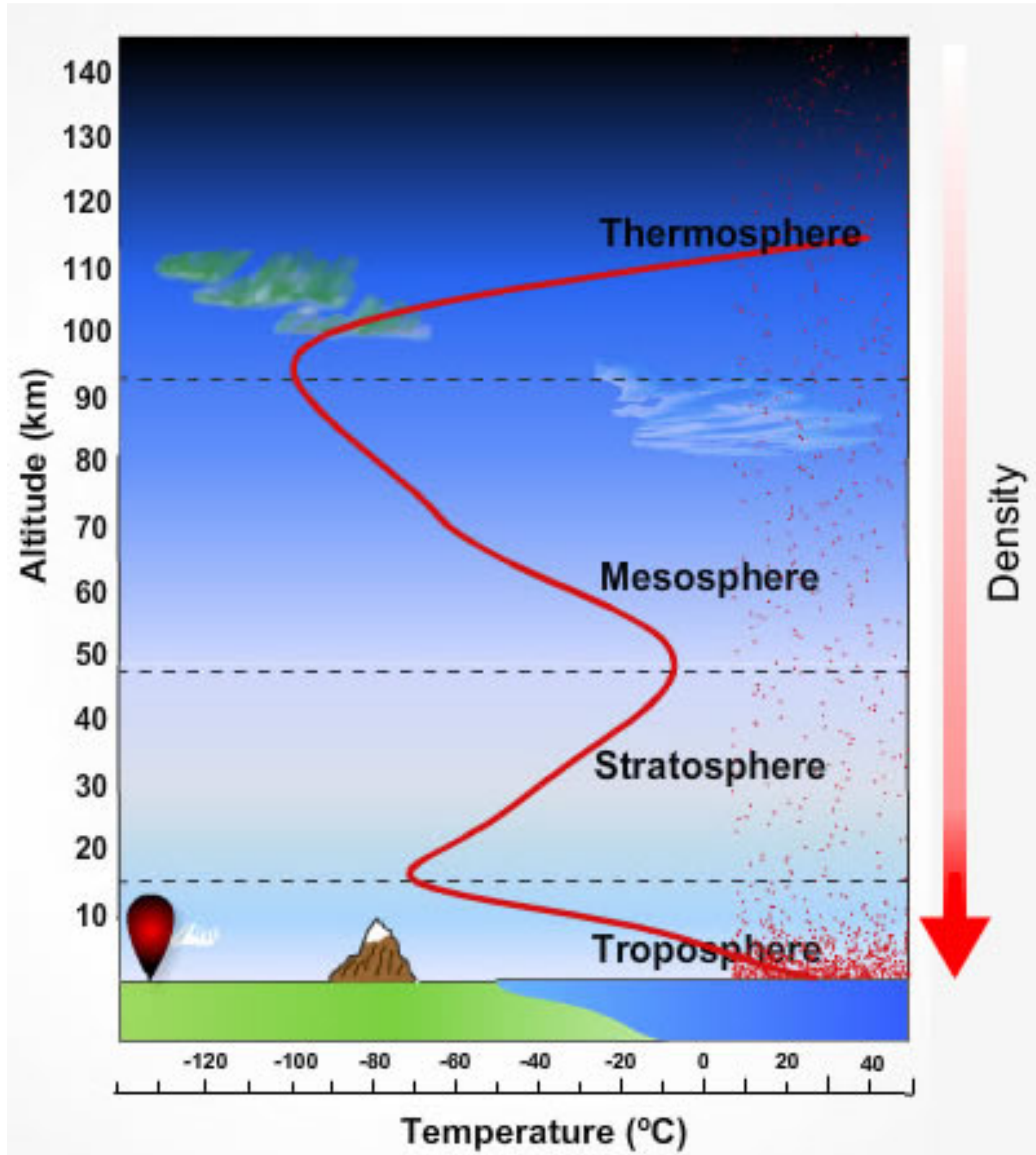
Today: no primary crust remaining (erosion, subduction, etc.)

Secondary crust: production still occurring at Mid-Atlantic Ridge, large shield volcanoes such as Hawaiian Islands

Tertiary crust: continents.

Earth’s Atmosphere

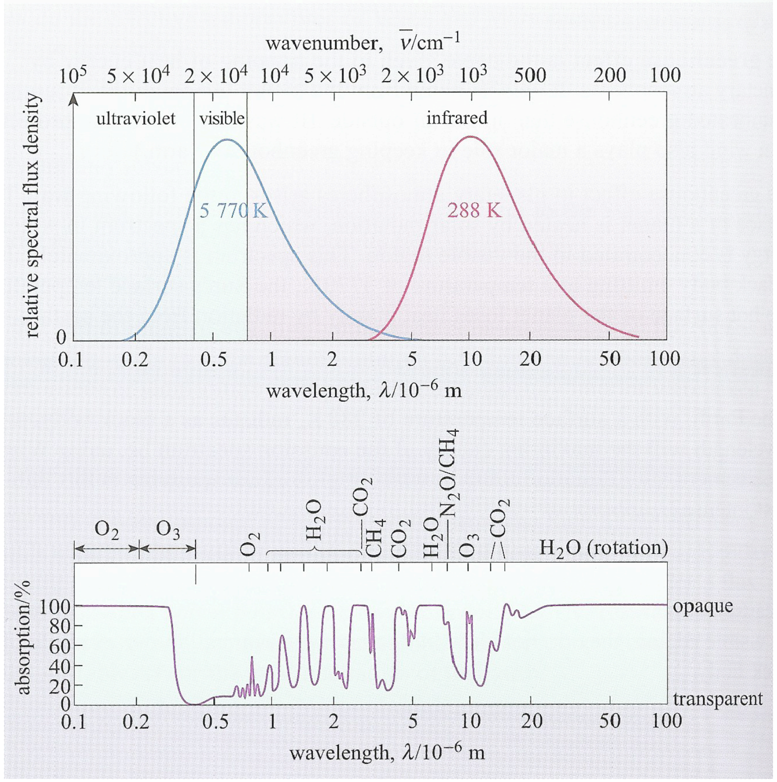
- **Chemical Composition: 78% N_2, 21% O_2**
- ***Troposphere* heated by ground - weather**
- ***Stratosphere* heated by O_3 layer at 20-30 km**
- ***Mesosphere* - T drops**
- ***Thermosphere* - T rises due to UV and X-ray heating - ionizes the gas to produce ionosphere**

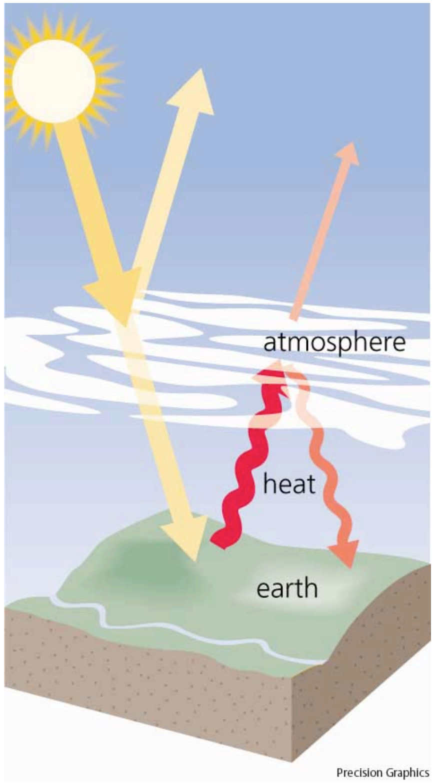


Temperature Structure

- Atmosphere NOT *isothermal* NOR *isobaric*
- Heated ground induces *convection*
- *Adiabatic* process - no heat *transfer* out of “cells” (until they reach their “destinations”
- *Adiabatic T-gradient* or *T-profile*
- *Latent Heat of Condensation* of Water vapor
- *Wet Adiabatic T-gradient* - about 6K/km

Greenhouse Effect

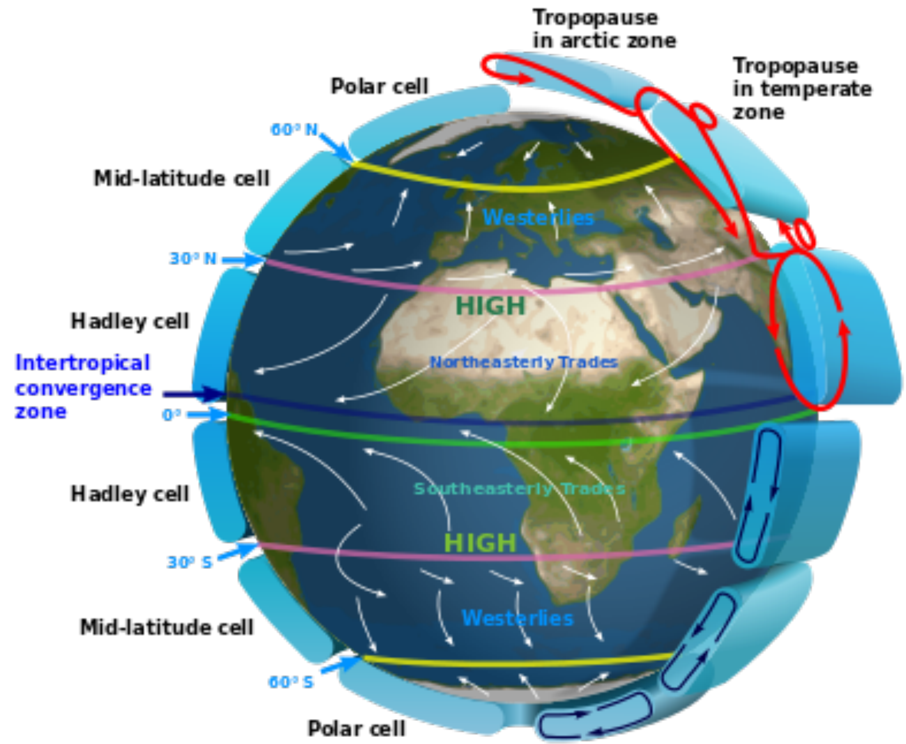




The greenhouse effect warms a planetary surface by warming the atmosphere above it. Due to the Sun's surface T, Light from the Sun peaks near wavelengths where the Earth's atmosphere is transparent, so little heating of it occurs. The light that is absorbed by the ground heats the ground, when then radiates at ***its*** characteristic T, which is a lot cooler, and peaks in the IR. Unlike visible wavelengths, the IR is filled with absorption bands due to various molecules. These molecules absorb the IR, effectively depositing that energy in the atmosphere, and warming it. The warm molecules radiate at those same wavelengths that they absorb at, and half of the radiation is back in the direction of the surface of the planet.

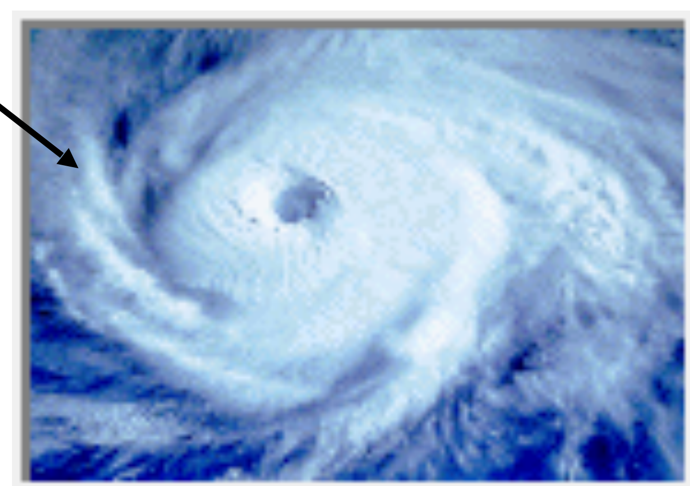
Climate Change Video

Meridional Circulation & Hadley Cells



***Corolis Effect* - a consequence of the conservation of angular momentum. Examples - general low-pressure and high-pressure zones, hurricanes, etc.**

Typhoon Odessa



Urey Reaction

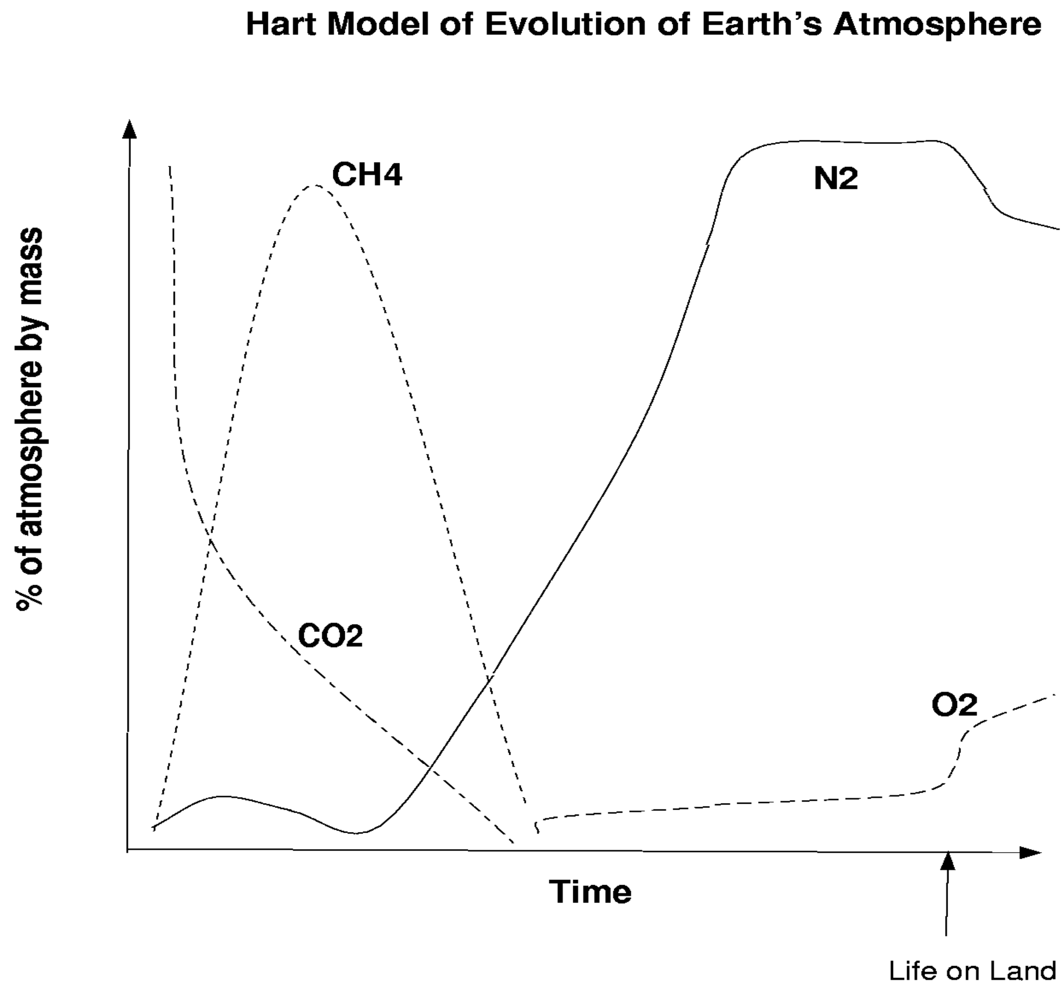
The removal of CO_2 from the atmosphere (and its return)

CO_2 + Silicate Rocks ---(liquid water) ---> SiO_2 + Carbonate Rocks

Earth's rocks and oceans contains enough CO_2 that, if released, would increase the mass of its atmosphere by 30x!!!

CO_2 is recycled into the atmosphere through volcanic action

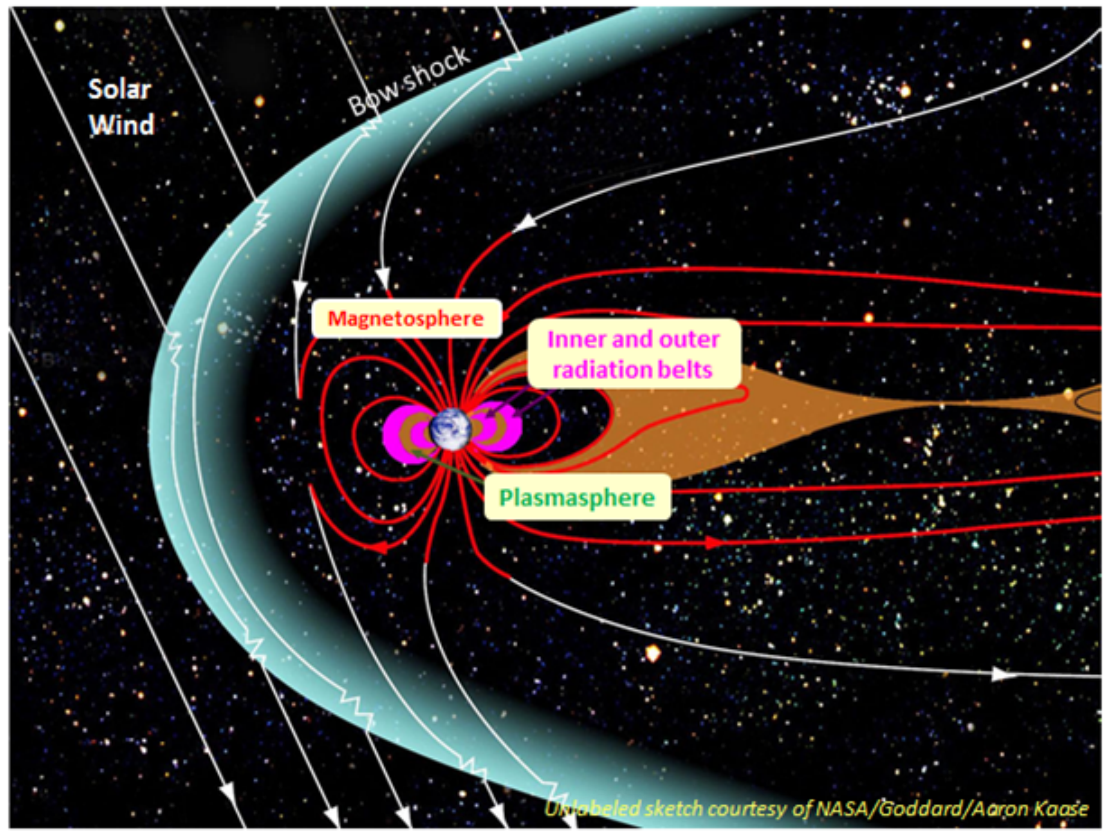
Example: model by Michael Hart, 1979



We will re-visit this later!

Earth's Magnetosphere

- **Magnetic Field generated by liquid core - dynamo effect**
- **Magnetic Field Reversals**
- **Aurorae**



Aurorae in Alaska