Sulphur, island of Vulcano, Italy

ERTH 1006/1010

Our Solar System

Geochronology

Ch. 23, 8

Summary

- Solar System forms from nebular cloud, termed Nebular Hypothesis
- Planets form by accretion of metallic, rocky fragments between 5.5 and 4.6 Ga (giga-annum)
- Earth, other planets differentiate into core + mantle (silicate minerals; rock)
- Moon forms due to collision with Mars-size body; only silicate material ejected

What Is The Composition of the Solar System?

Why is Nebular Hypothesis so popular?

- predicts Solar System initially homogeneous

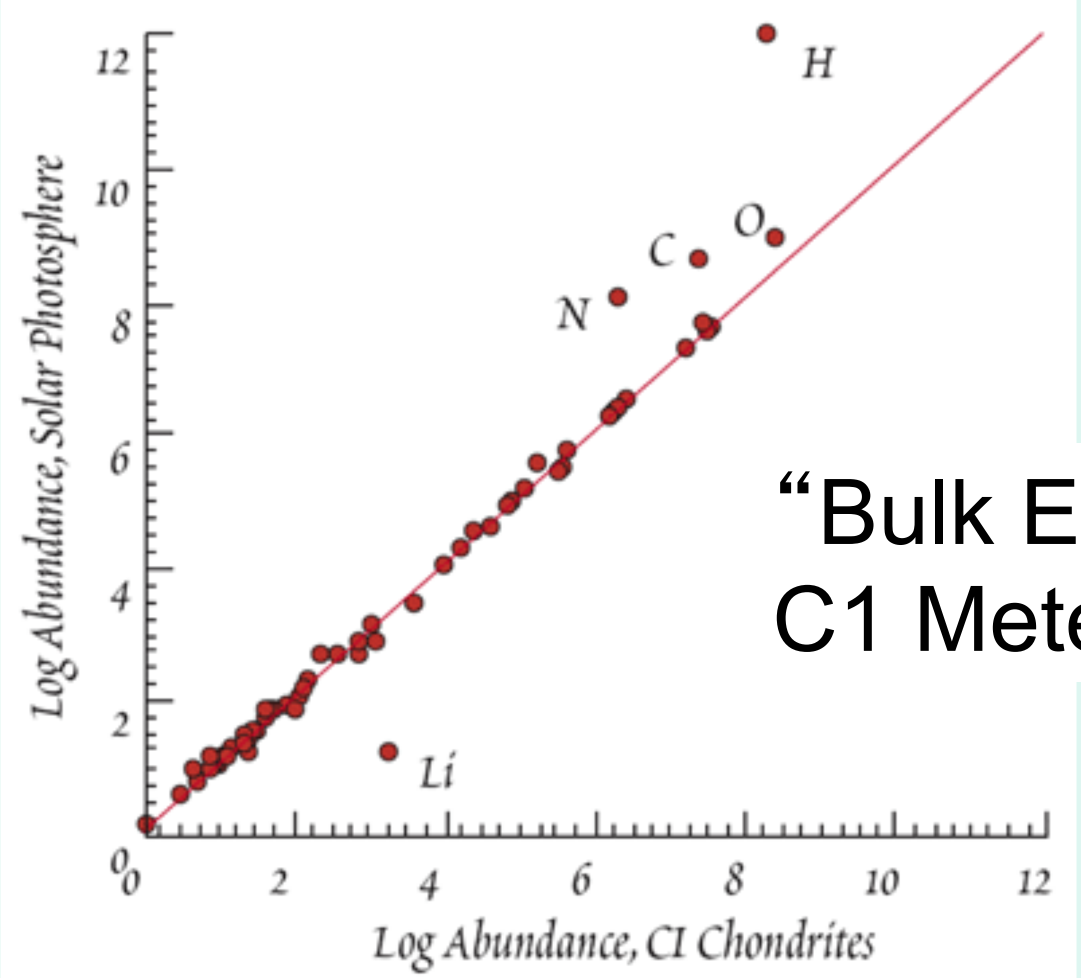
- How can we determine if this is so?

1) Solar abundances

2) Meteorites

3) Average Earth – a problem!

Solar vs. Meteorite Abundances

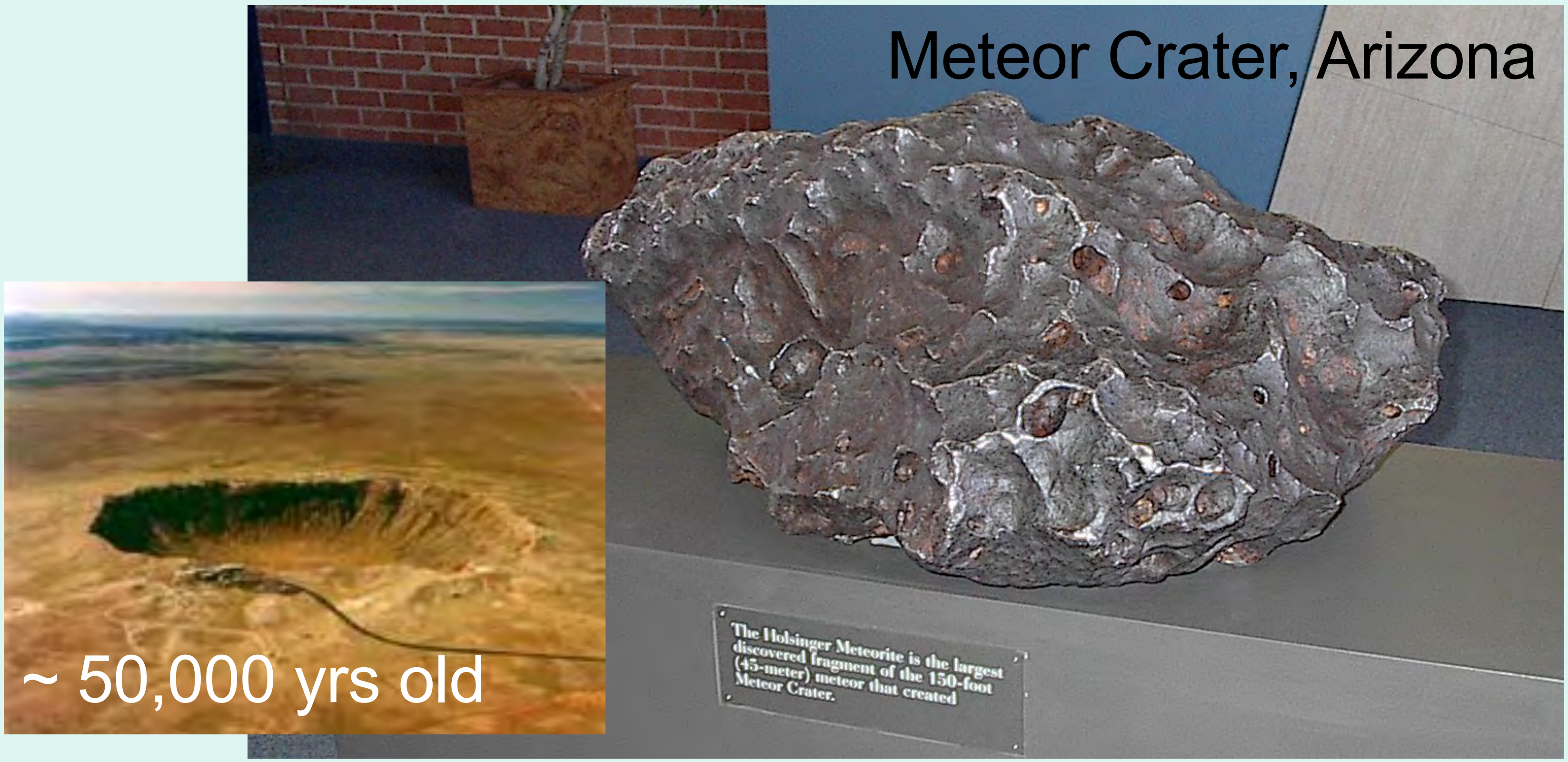


“Bulk Earth” ~ C1 Meteorite

(from D. DePaolo)

Meteorites

Fragments of solar system materials that fall to Earth



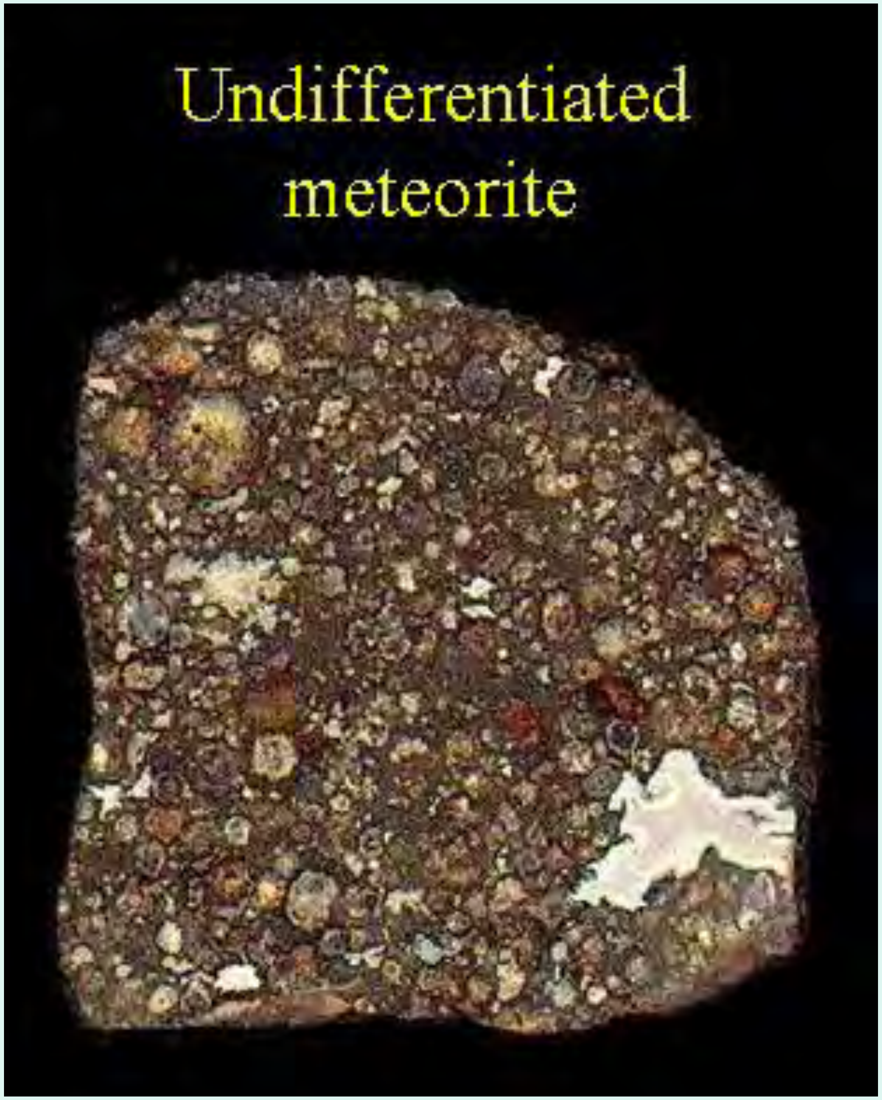
Types of Meteorites

Chondritic: fragments of undifferentiated solar system material

Stony: rocky portions of differentiated planetary bodies

Irons: fragments of metallic cores of differentiated planetary bodies

Stony-irons: both rocky and metallic portions



Impacts in North America

(Royal Astronomical Society of Canada)

Geology of Our Solar System

The Moon

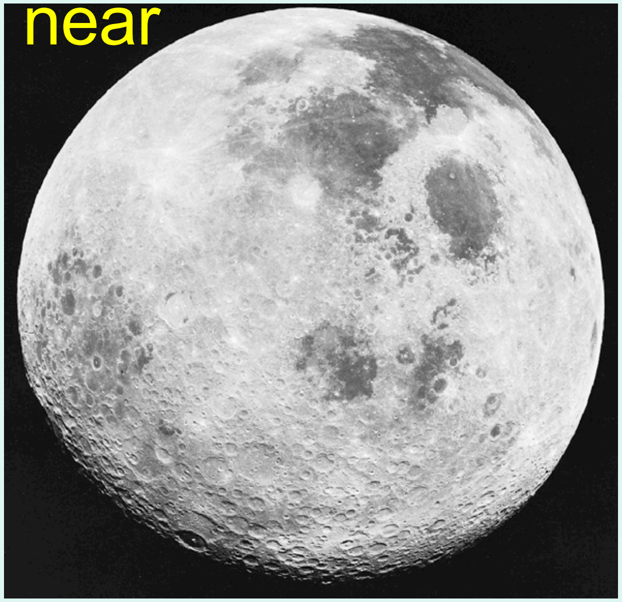
The Moon

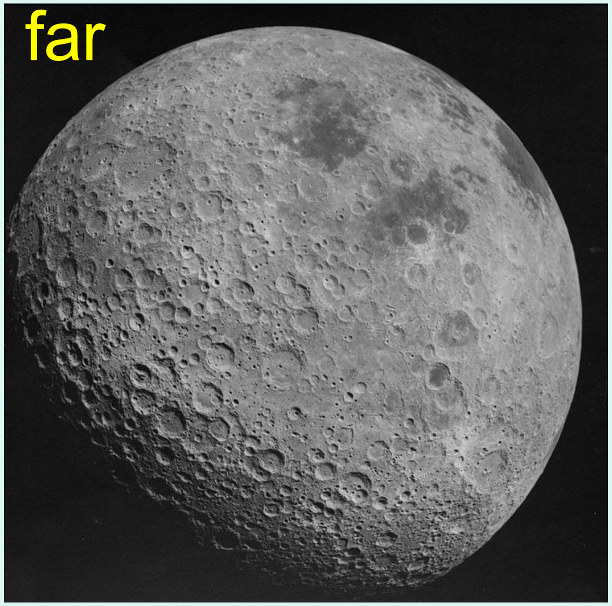
Highlands: anorthosite (feldspar), 4.5 billion yrs old, cratered

-floating scum on molten Moon

Maria: younger impact basins, filled by lava flows: 3.8 - 3.2 billion years old

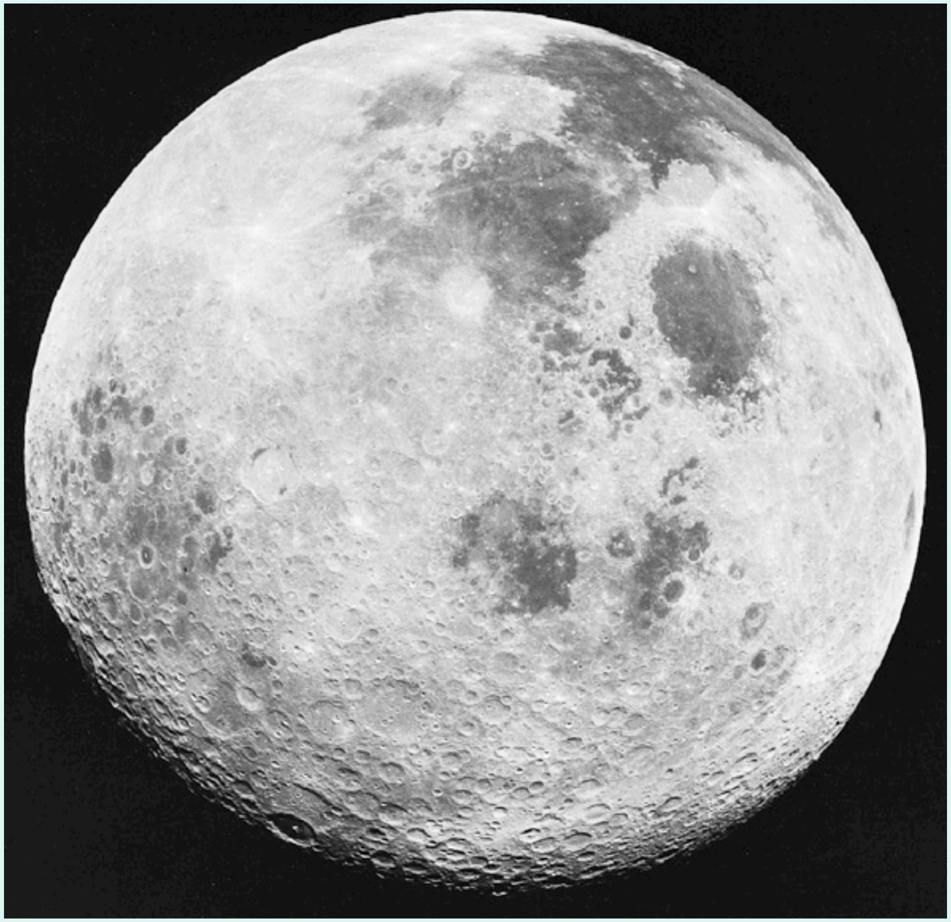
Lunar Surface: covered by REGOLITH: debris from impacts





(NASA)

Does the Earth Look Like This?

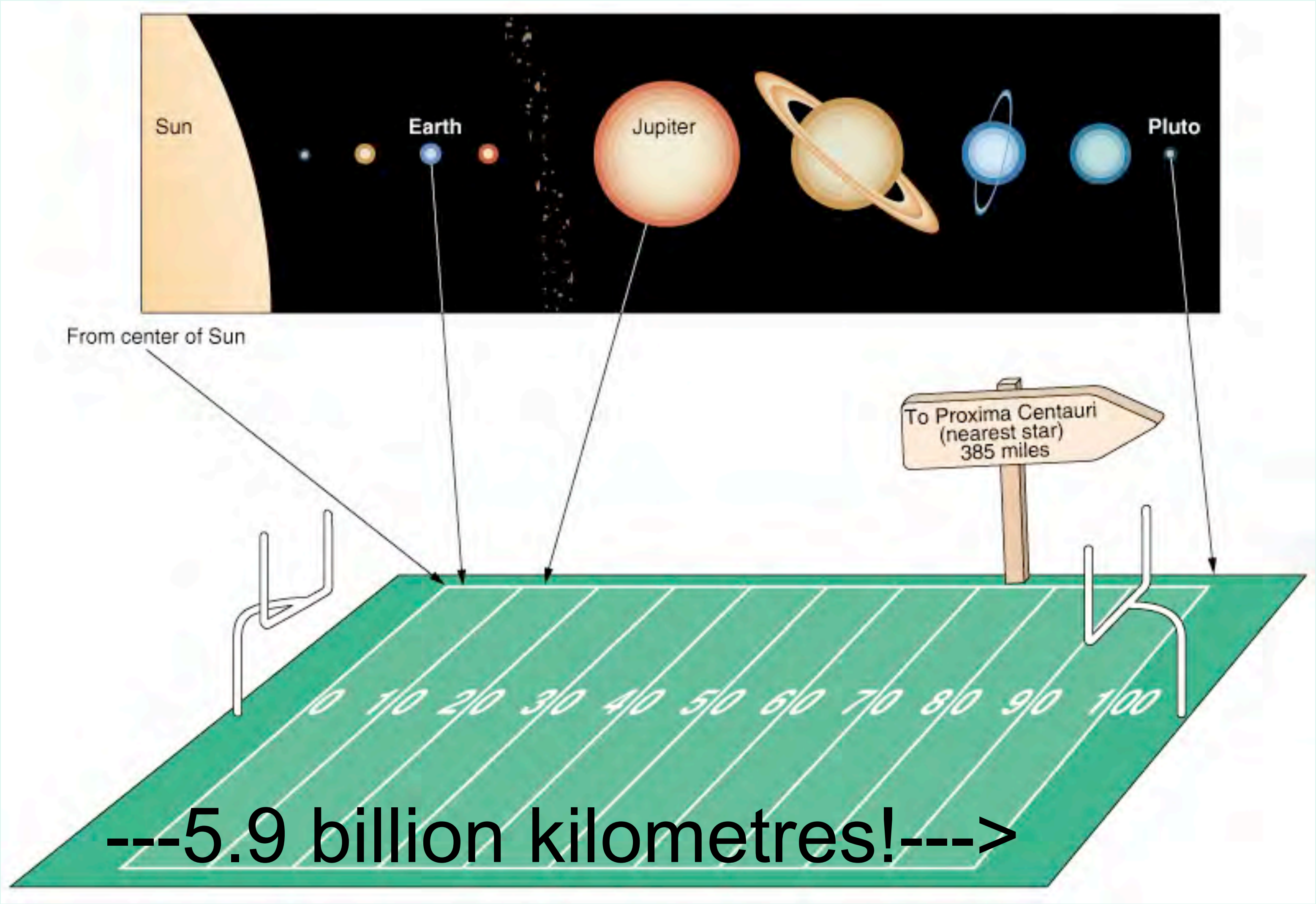


Question to Ponder:

Is Earth pock-marked by impact craters like the Moon?

Why not?

Our Solar System



---5.9 billion kilometres!--->

(from Davidson et al., Prentice-Hall)

Vital Stats

Terrestrial

Jovian

Planet	Diameter (km)	Density (g/cc)
Mercury	4878	5.43
Venus	12104	5.24
Earth	12756	5.52
Mars	6794	3.90
Jupiter	142796	1.34
Saturn	120000	0.69
Uranus	52400	1.27
Neptune	50450	1.58
Pluto (dwarf)	*2400*	*1.70*

Mercury

-innermost, 2nd smallest

-First imaged in 1974, Mariner 10

-Heavily cratered highlands

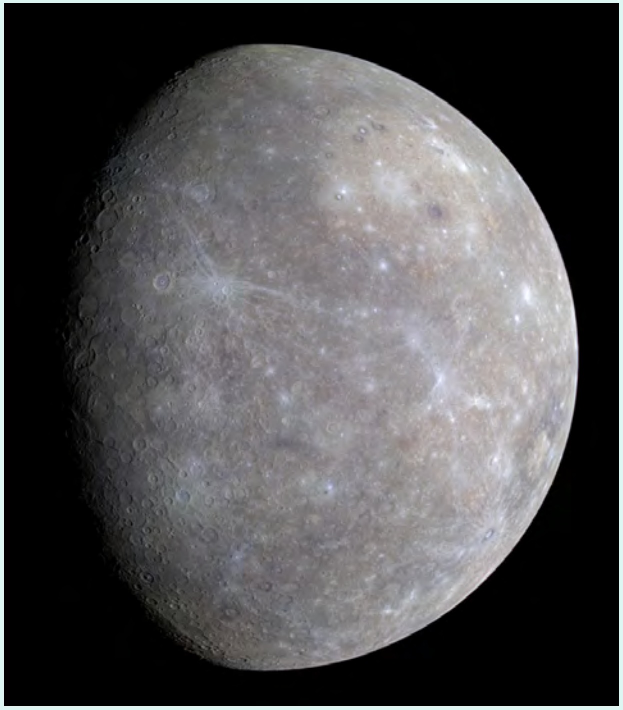
-No atmosphere

-1 Mercury "day" = 176 Earth days

-Temperature extremes:

   -Night = -170^{o}C

   -Day = +427^{o}C



Wikipedia

Venus

-atmosphere 97% CO_2, shrouded in clouds

-Temperature up to 475^{o}C, runaway greenhouse

-Surface mapped by radar – lots of studies of geology at Carleton

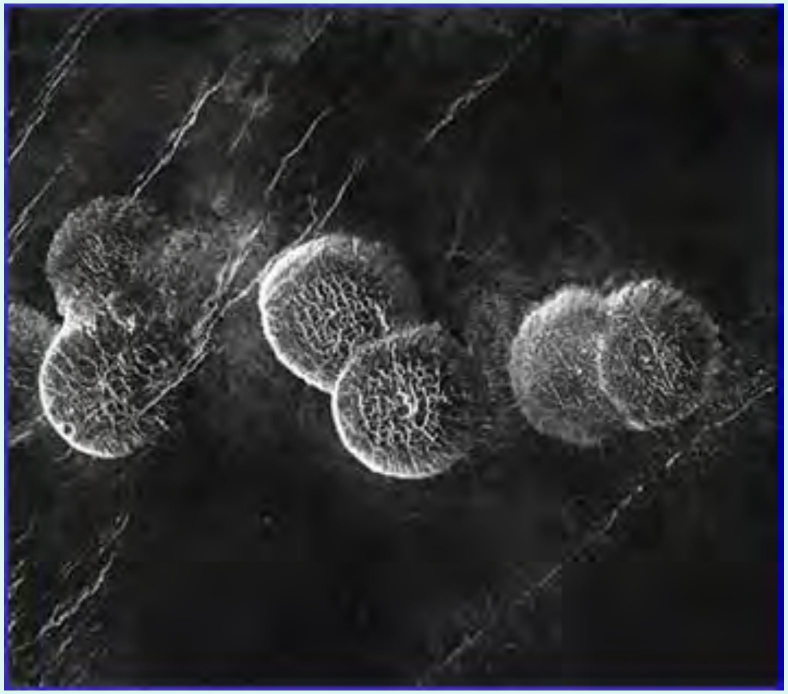
NASA

-Venus surface similar to Earth

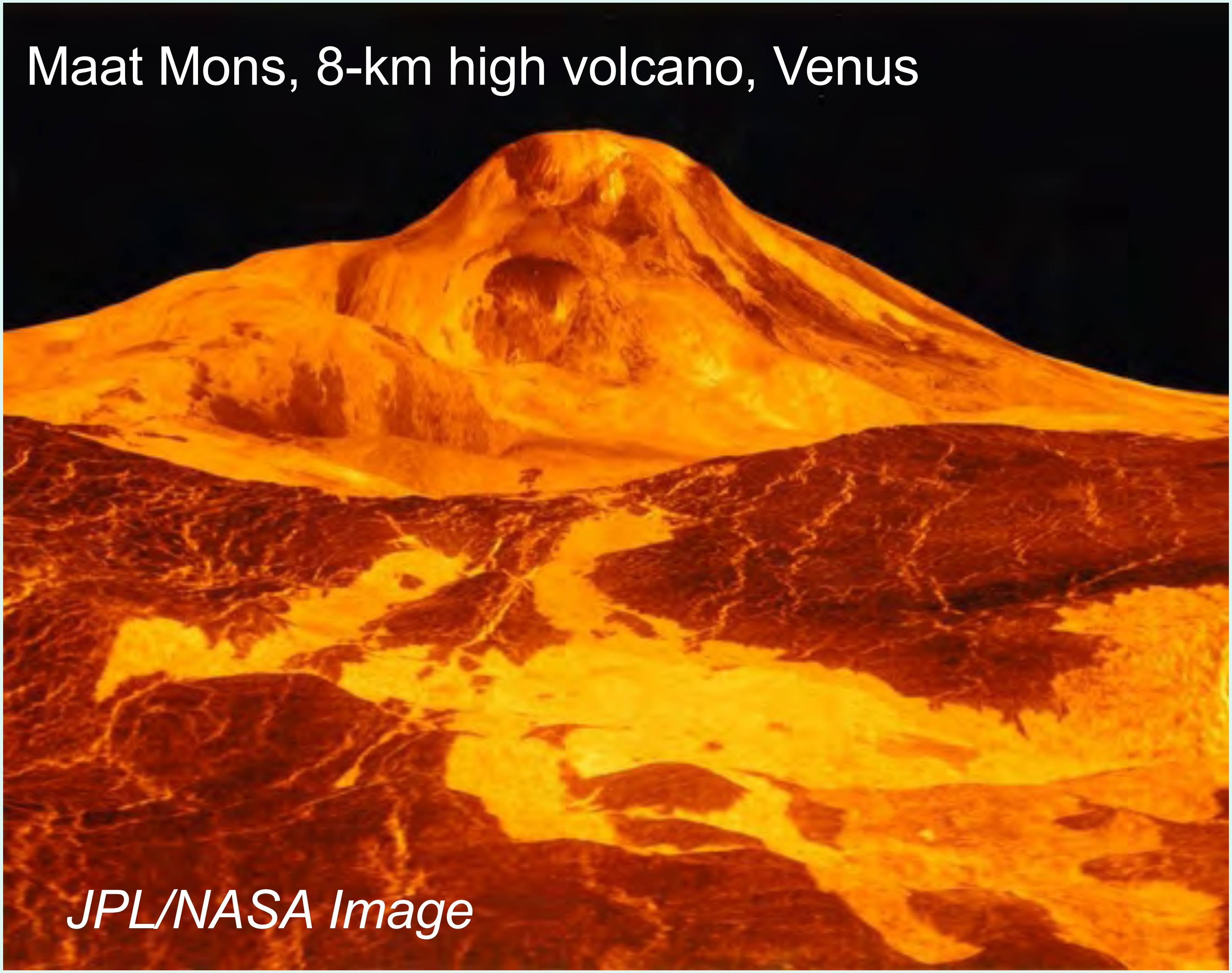
-Low crater density; abundant recent volcanism; faults; mountain ranges 10 km high

-Clearly mantle convection on Venus, but no plate tectonics for ~ 0.5 by

Pancake volcanoes



http://volcano.oregonstate.edu/oldroot/volcanoes/planet_volcano/venus/unusual.html


Maat Mons, 8-km high volcano, Venus
JPL/NASA Image

Mars

-atmosphere CO_2, trace H_2O; 1% density of Earth's

-Polar icecaps: south CO_2, north H_2O with veneer of CO_2

-Surface rocky, sand dunes

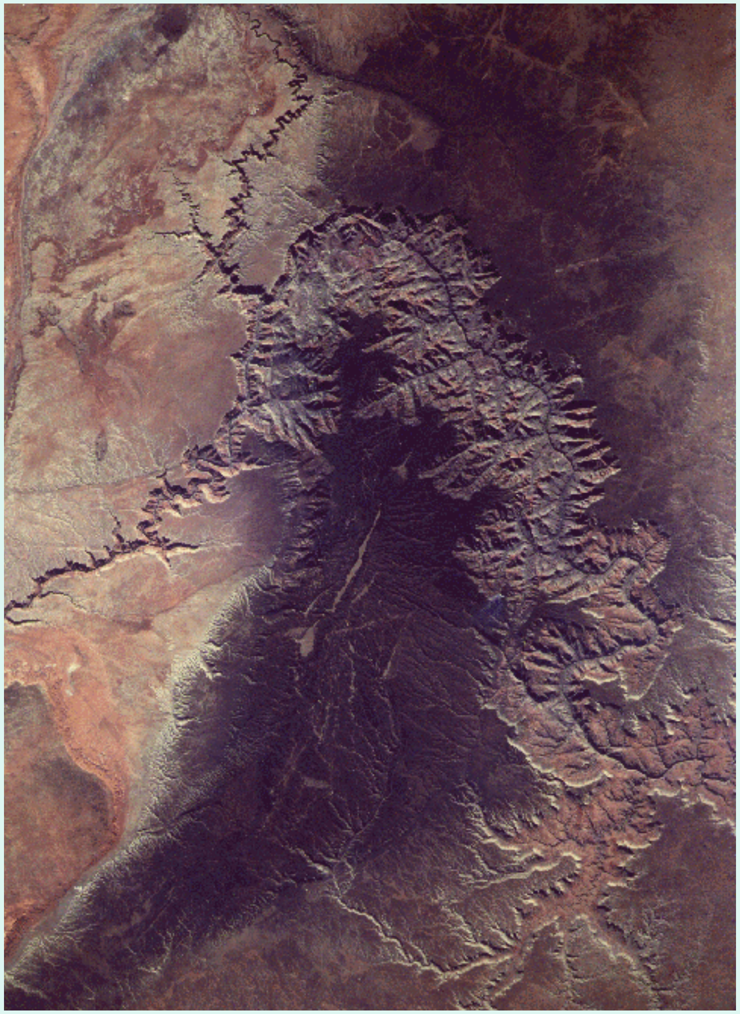
jpl.nasa.gov

Mars

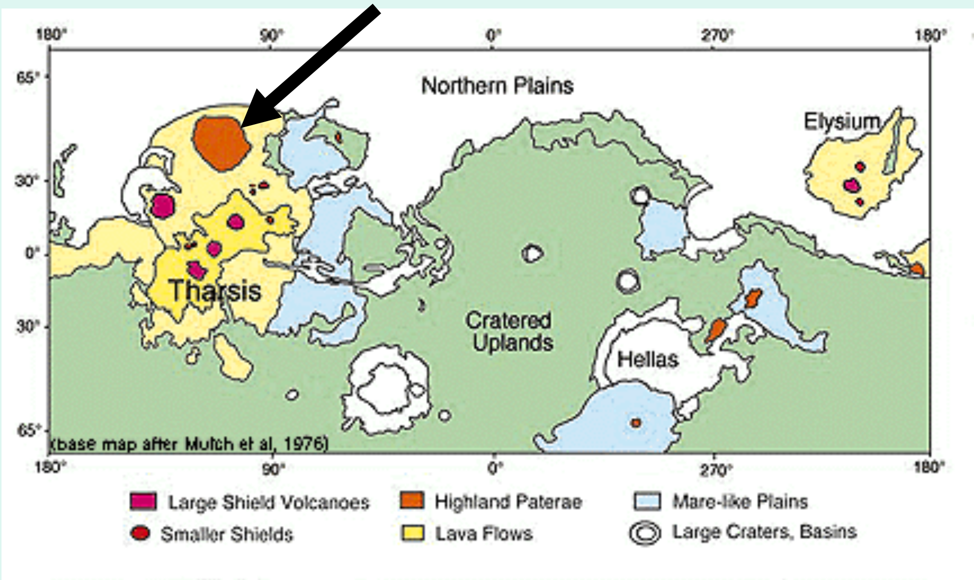
-Massive volcanoes, Olympus Mons 23 km high, 550 km across!

-Deep valleys: running water; lakes; slumps due to ice melting in soil?

-Two moons, captured asteroids



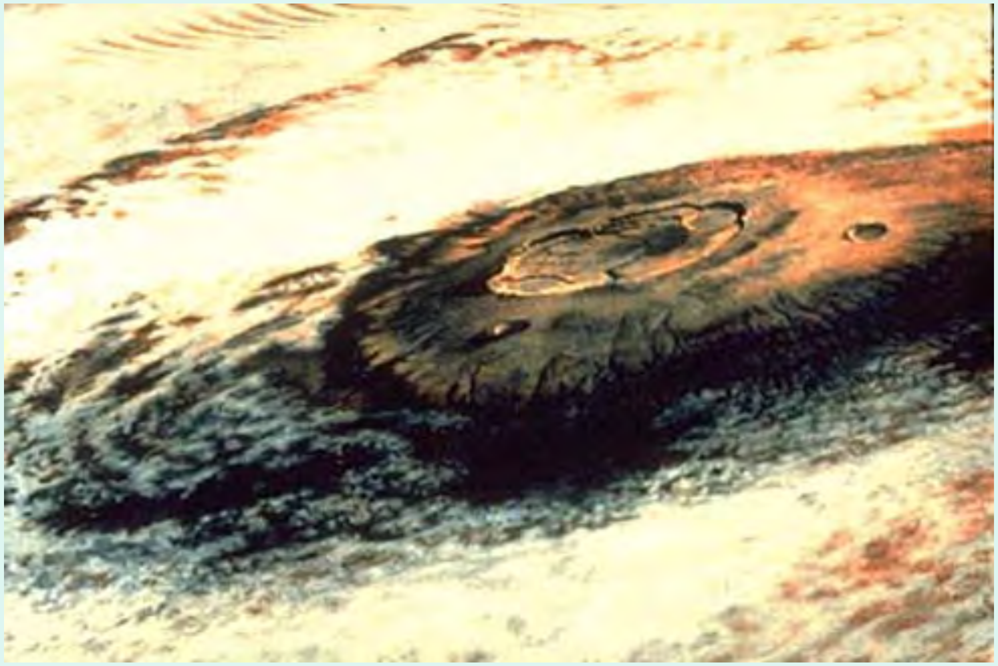
Wikipedia



Volcanoworld

Geologically quiet for billions of years

Olympus Mons



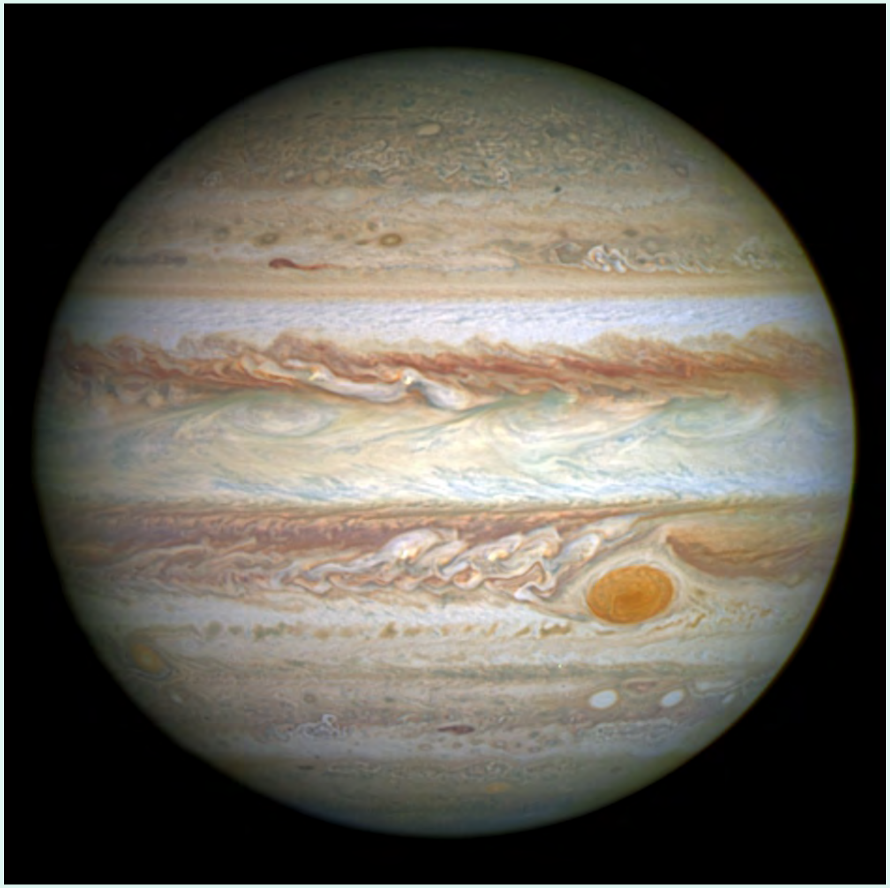
JPL/NASA

Jupiter

-mass 2.5 times combined mass of all other planets

-Atmosphere H, He, CH_4, NH_3, H_2O, S compounds; stormy

-Bands driven by internal heat loss



NASA, Hubble

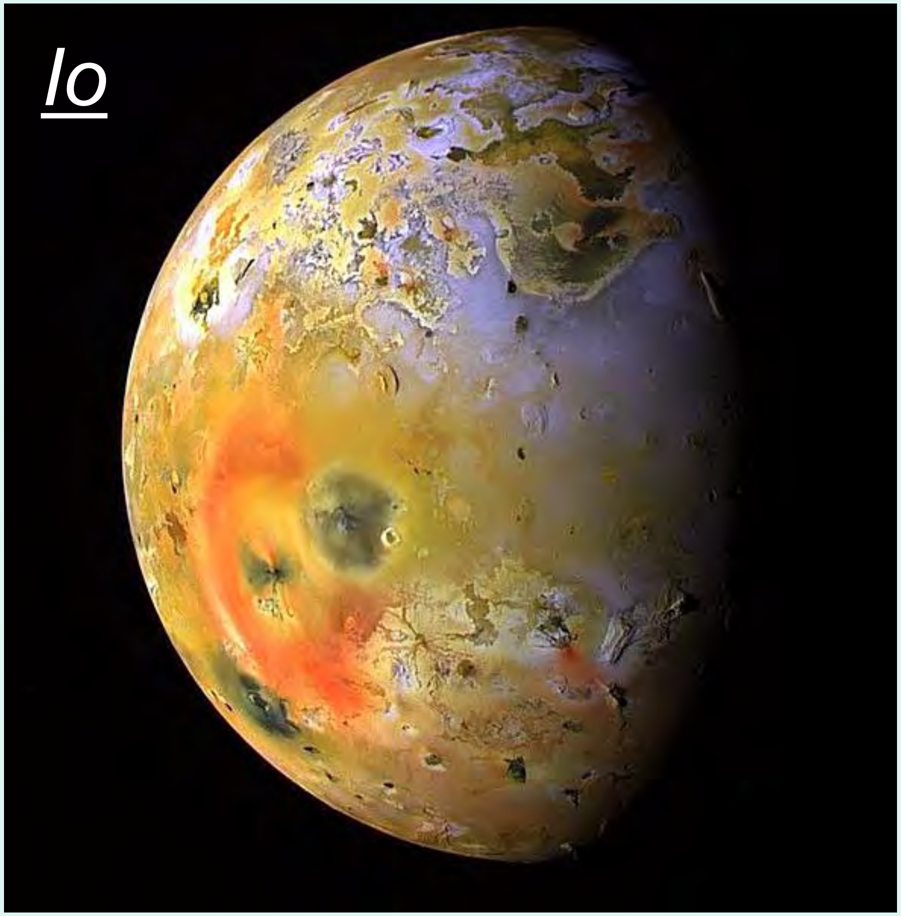
Jupiter

-Liquid H exists at depths > 1000 km

-May have rocky or metallic core

-4 largest moons > our Moon

-Innermost, Io, volcanic (>400)!



jpl.nasa.gov

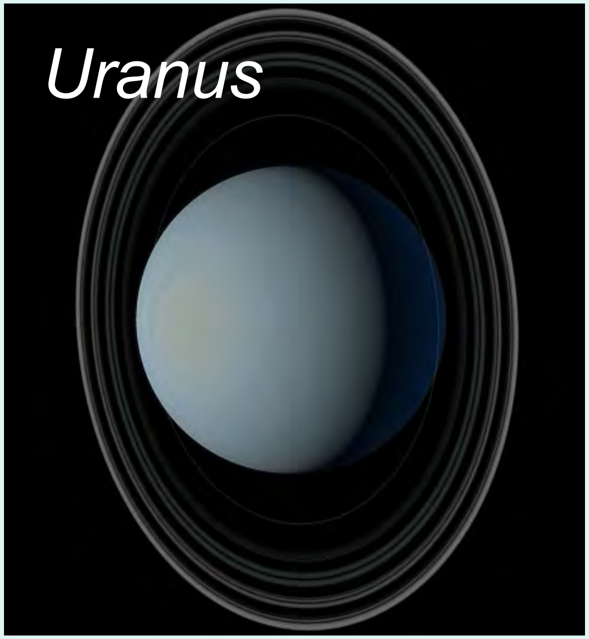
Saturn, Uranus, Neptune

-Gaseous; atmospheres mostly H, He, CH_4

-Uranus and Neptune lack NH_3

-Neptune winds up 1000 km/hr

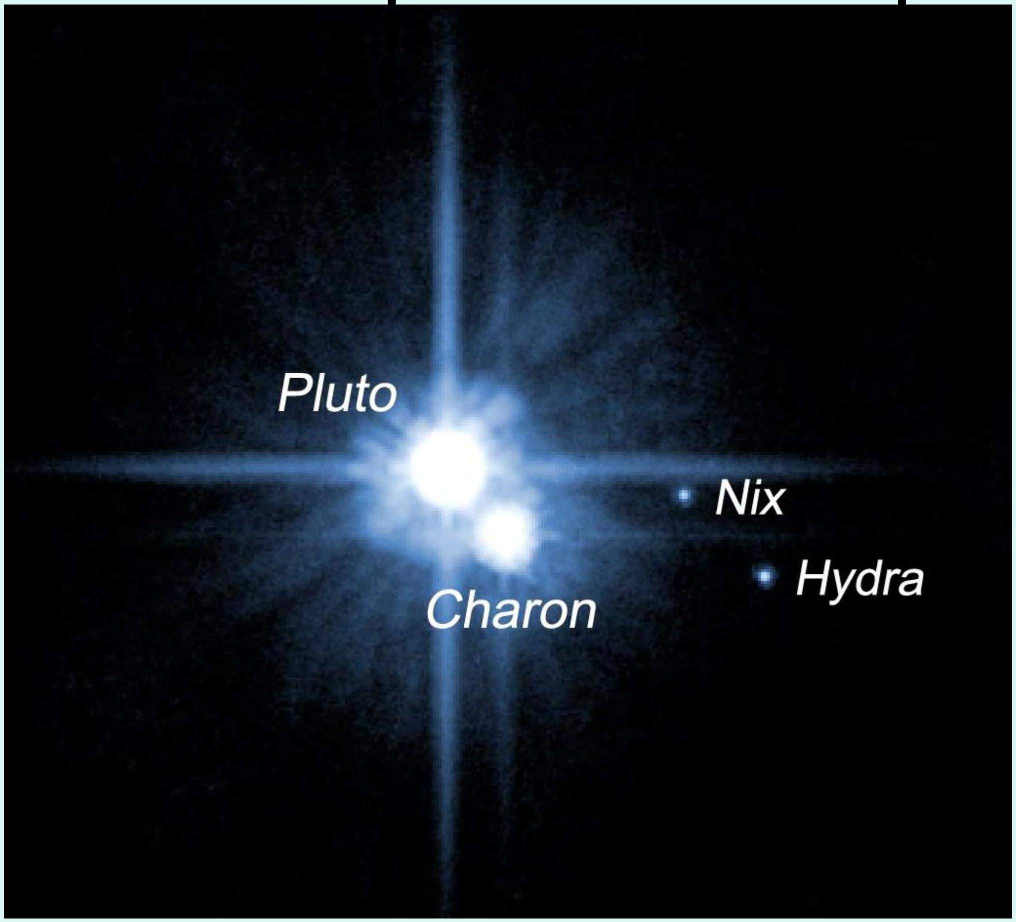
-Recent discover of rings around Uranus; horizontal axis of rotation



NASA

Pluto, a Dwarf Planet

Pluto and moons as seen by Hubble Space telescope



NASA

Pluto relative to Earth

Pluto

-discovered 1930

-30-50% ice, 50-70% rock

-Rotation axis tilted

-Atmosphere 99.7% N_2, trace CH_4

-Satellite Charon; orbit synchronous with Pluto's rotation so face each other

- Two new "moons", Nix and Hydra, 2005

- 2015: *New Horizons* flyby
  - http://time.com/4018747/new-horizons-flyby/

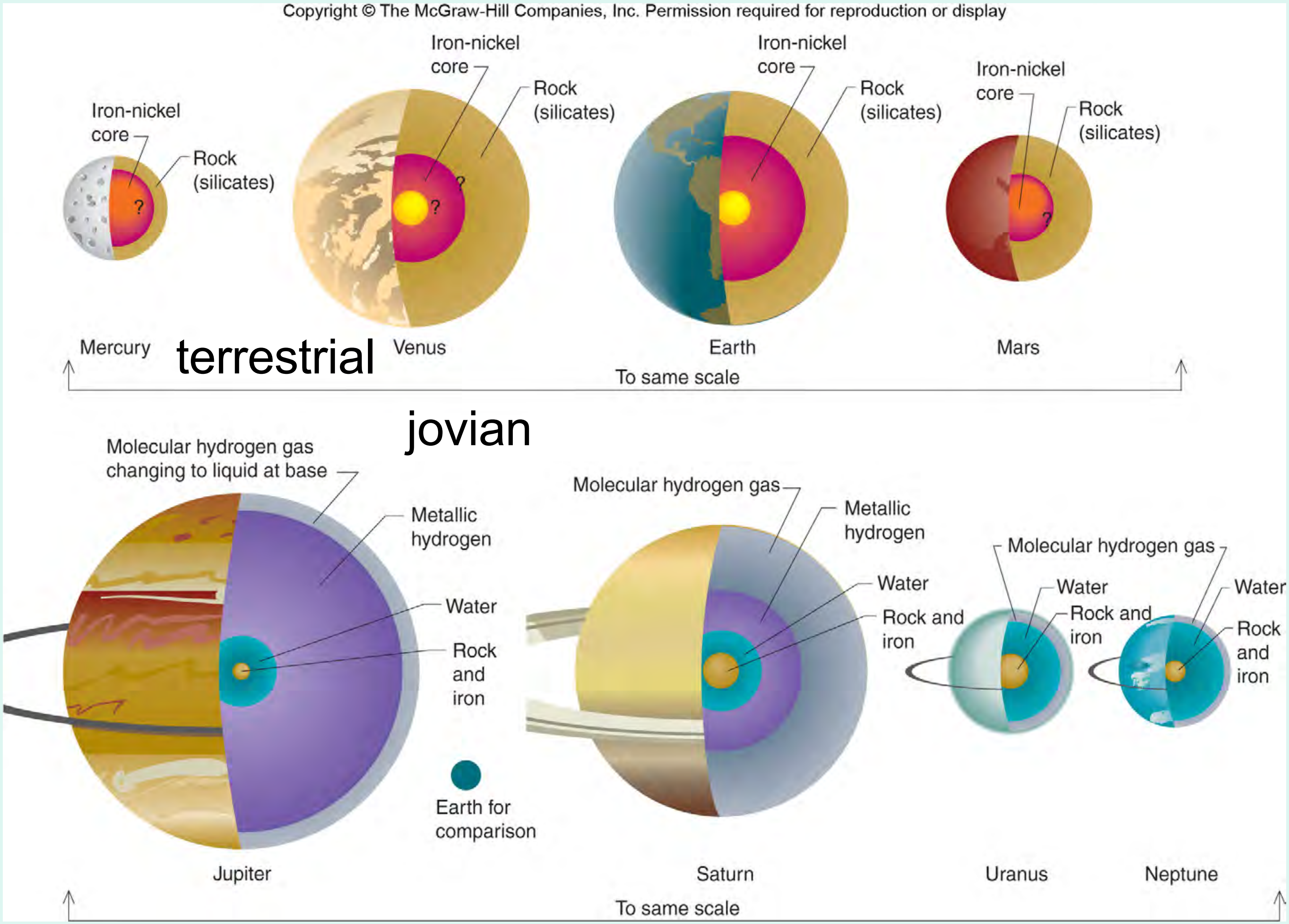


Fig. 23.5 from Plummer et al.

Early Earth

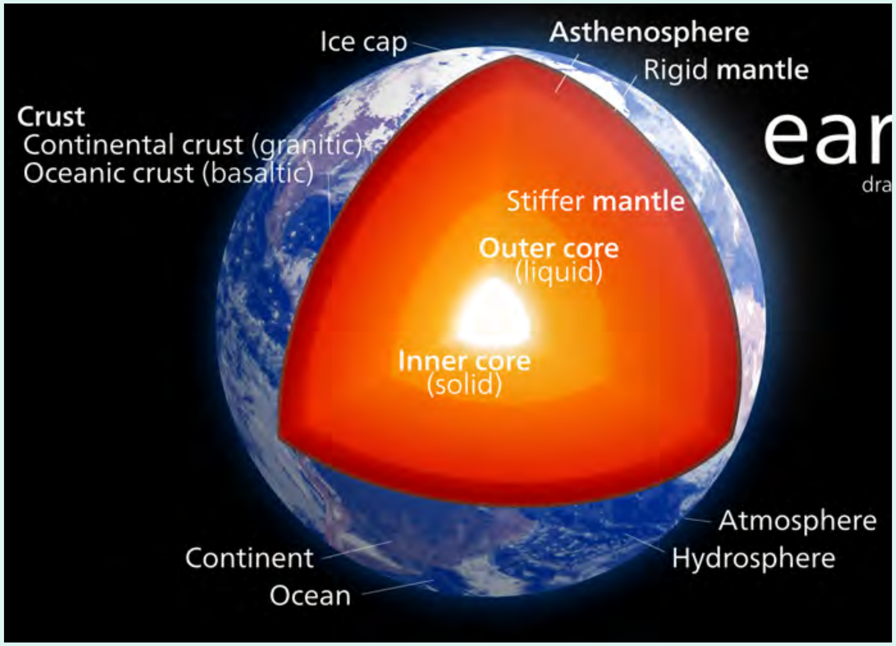
-after Moon formation, have differentiated planet that is mostly molten

-"scum" at surface is Earth's first crust

-crust very unstable

-heat from core, radioactivity

-Earth still cooling today



Wikipedia - Kevinsong

Earth's First Crust

"oceanic" crust - basalt, solidified from melting of the mantle

Hawaiian Volcano Observatory

Continents?

4.5 bya: no continents

Today: 30% of surface is continents

How and when did continents form?

Wikipedia

Geochronology

Chapter 8

TABLE 8.2 Geologic Time Scale

Eon	Era	Period	Epoch
		Quaternary	Holocene (Recent) Pleistocene
	Cenozoic	*Neogene***	Pliocene Miocene
		*Paleogene***	Oligocene Eocene Paleocene
Phanerozoic	**Mesozoic**	*Cretaceous* *Jurassic* *Triassic*	
	Paleozoic	*Permian*	
		Pennsylvanian *Mississippian*	Carboniferous*
		Devonian *Silurian* *Ordovician* *Cambrian*	
Precambrian Time (consists of the Proterozoic, Archean, and Hadean Eons)			

Dating Rocks

-how do we determine how old a rock is?

RADIOMETRIC DATING

-Decay of one isotope to another: depends on time, parent/daughter

-Must also date a mineral that is resistant to diffusion of isotopes

-Best is ZIRCON - $ZrSiO_4$

Radioactive Decay

An example: the U-Pb system

^{238}U -> ^{206}Pb: $t^{1/2}$ = 4.5 billion yrs

$$^{206}Pb_p = {}^{206}Pb_t + {}^{238}U\,(e^{\lambda t} - 1)$$

λ= decay constant (= 0.693/$t^{1/2}$)

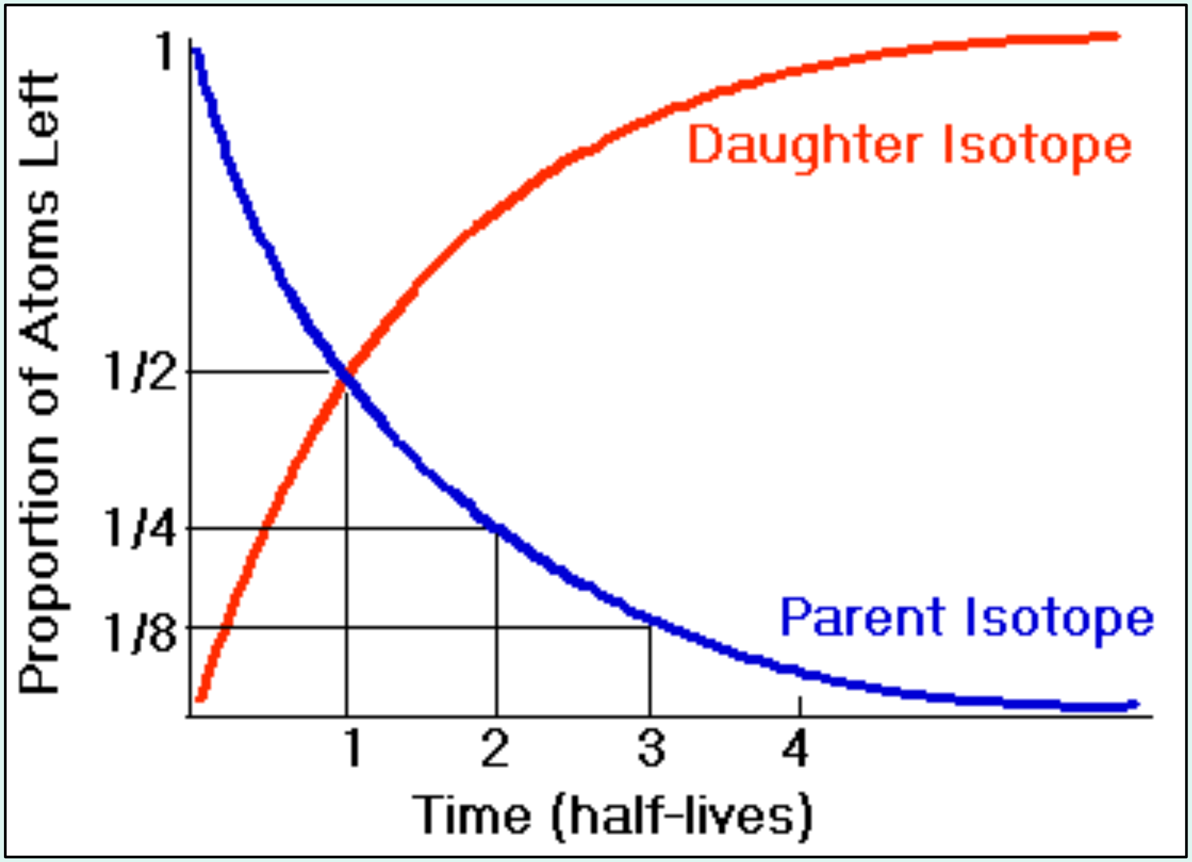
p = present day

t = time of crystallization

Zircon: $^{206}Pb_t = 0$; all Pb is from decay

<u>*Half-life*</u>

https://www.geo.arizona.edu/antevs/ecol438/geochron.html



Measure number of parent, daughter atoms, can calculate number of half-lives that have passed.
Maximum six half-lives – too little parent left

Other Decay Schemes

$^{235}U \rightarrow\ ^{207}Pb$ $t^{1/2} = 0.7$ Ga

$^{232}Th \rightarrow\ ^{208}Pb$ $t^{1/2} = 14$ Ga

$^{87}Rb \rightarrow\ ^{87}Sr$ $t^{1/2} = 49$ Ga

$^{147}Sm \rightarrow\ ^{143}Nd$ $t^{1/2} = 106$ Ga

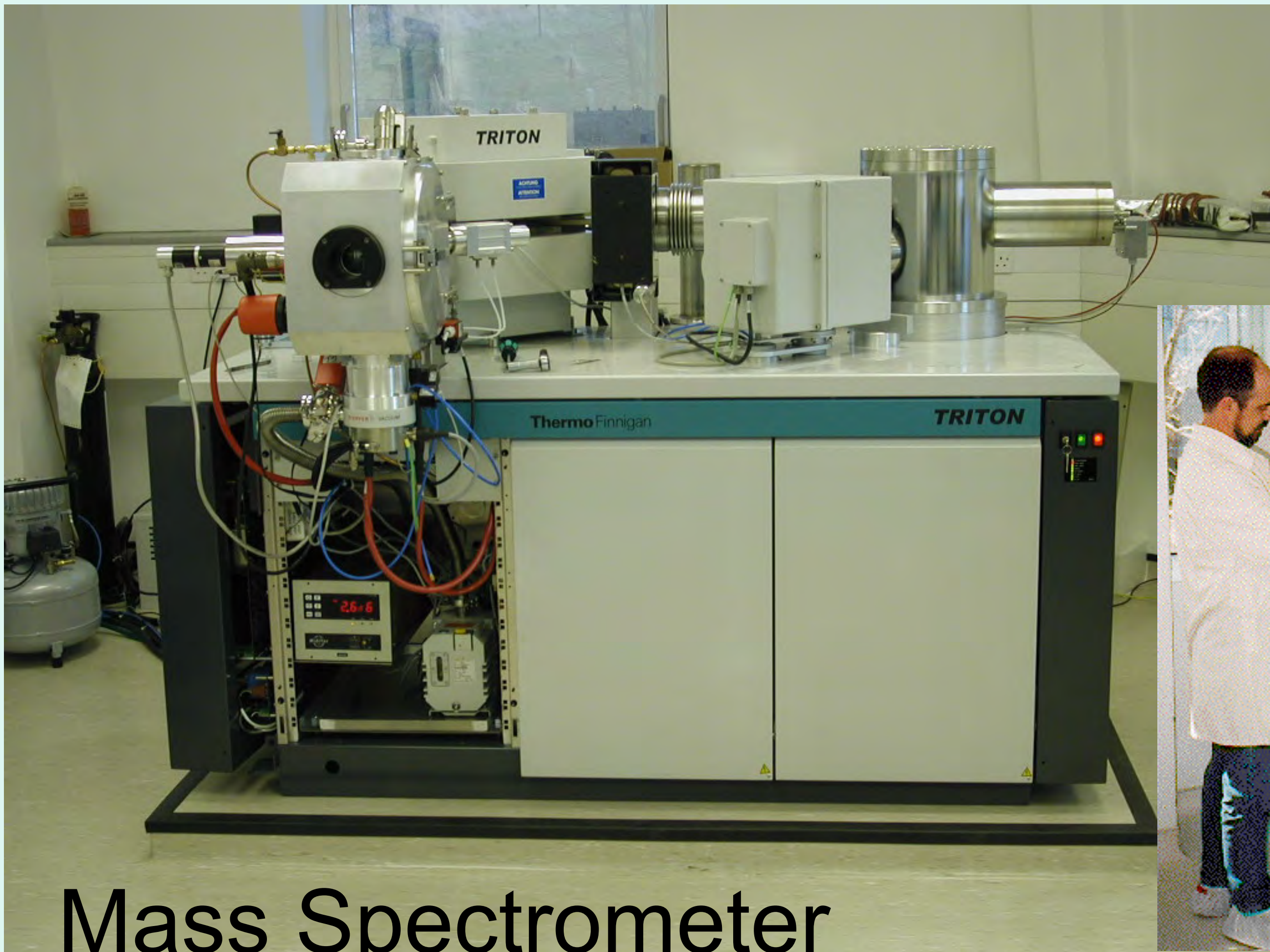
$^{40}K \rightarrow\ ^{40}Ar$ $t^{1/2} = 1.3$ Ga

$^{176}Lu \rightarrow\ ^{176}Hf$ $t^{1/2} = 35.3$ Ga

$^{187}Re \rightarrow\ ^{187}Os$ $t^{1/2} = 45.6$ Ga

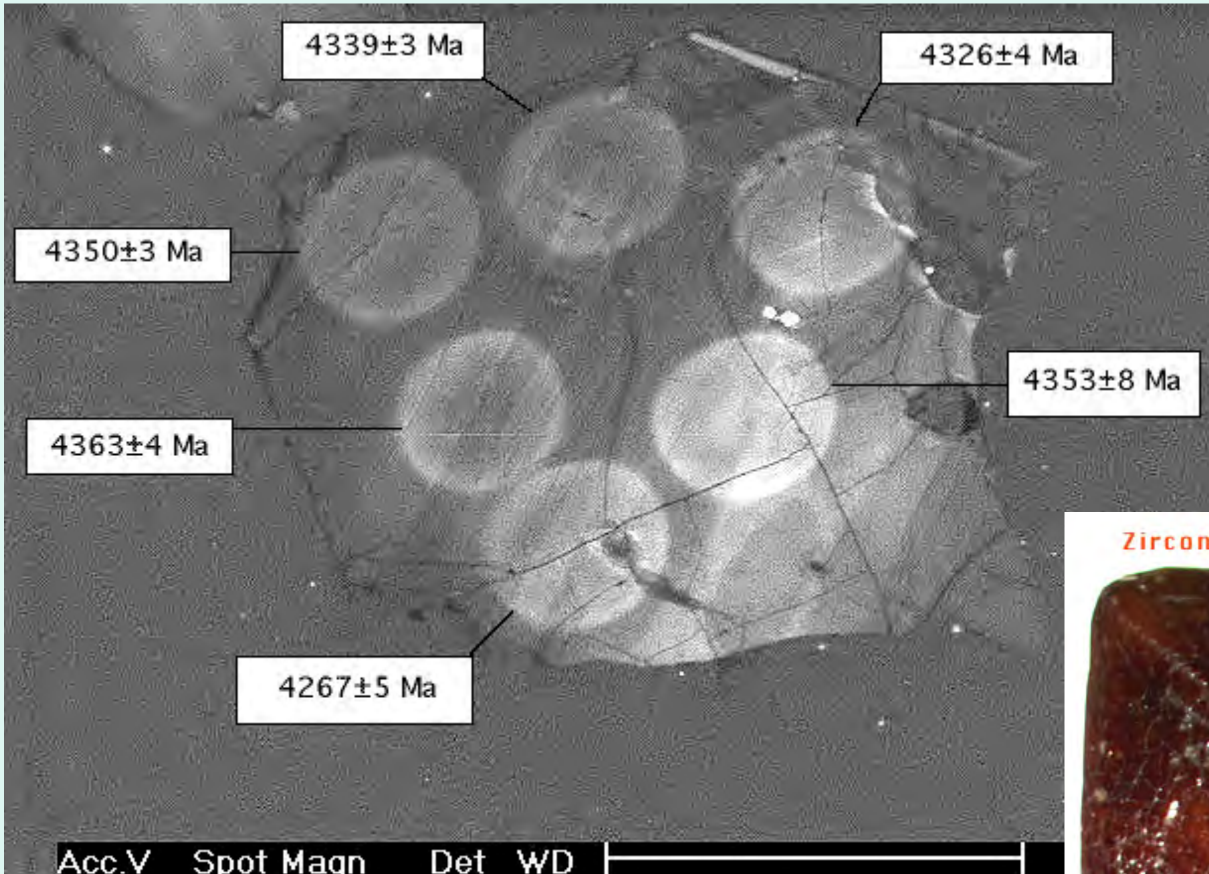
(You are not responsible for knowing this information)

Instruments



Mass Spectrometer

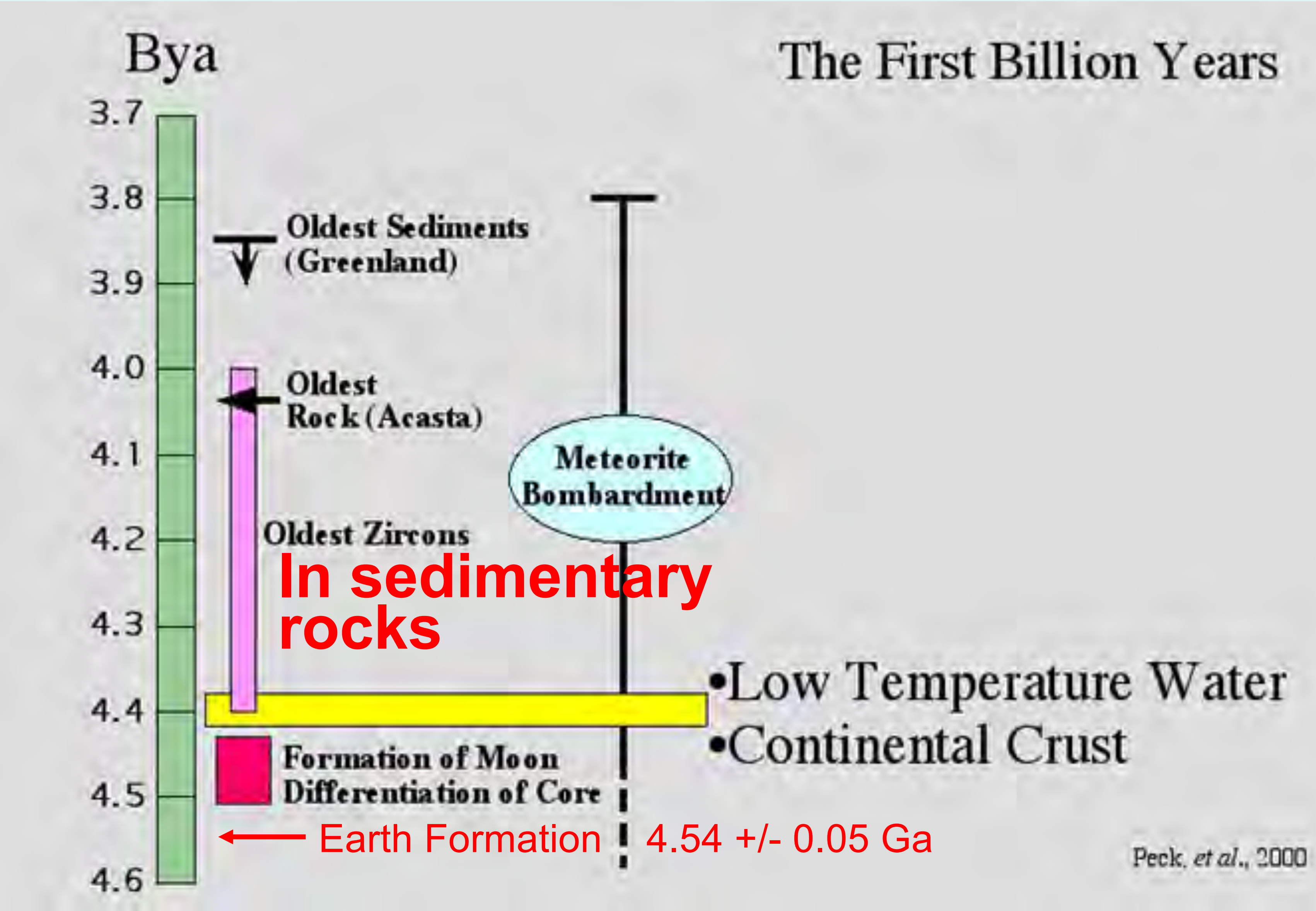
Zircon: primarily in continental rocks



$^{238}U \rightarrow ^{206}Pb$

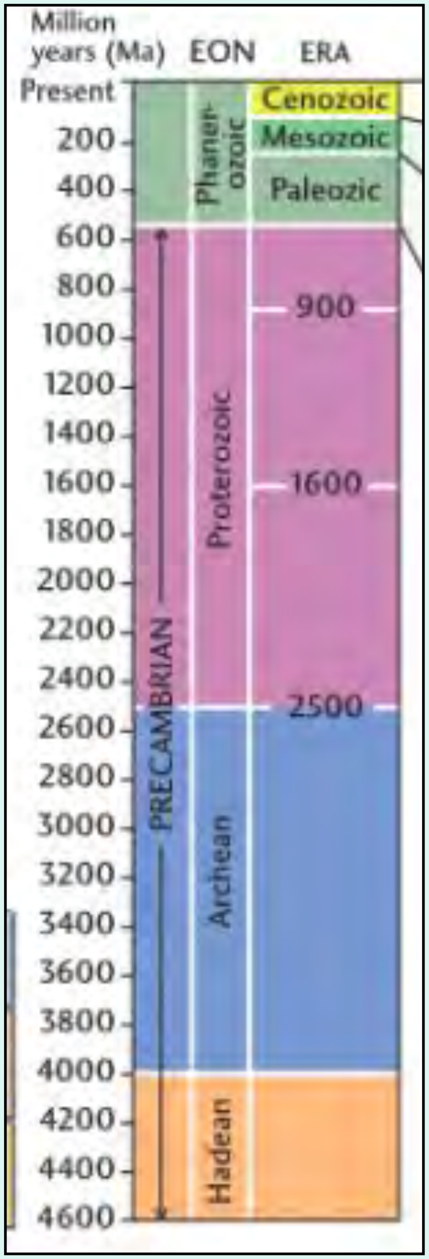
Older -> more ^{206}Pb

Earth's Oldest Continental Crust



Two Kinds of Crust

	Oceanic Crust	Continental Crust
First Appearance	~ 4.5 Ga	~4.4 Ga
Where Formed	Beneath oceans	Continent margins
Composition	Basalt (lo Si)	Granitic (hi Si)
Extent	Widespread	Very localized
How formed	Melt of mantle	Melt of crust



Phanerozoic
0.57 Ga - now

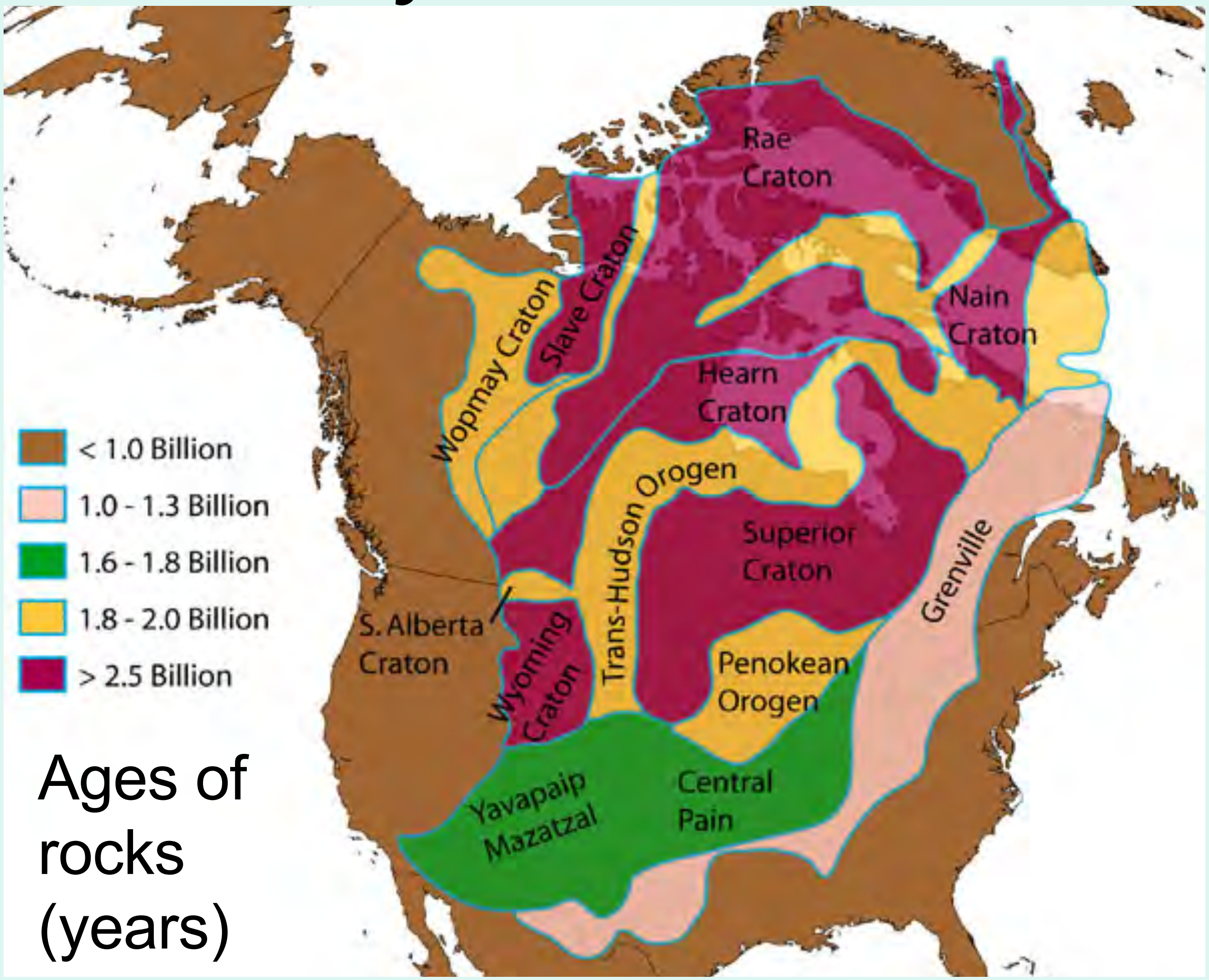
Proterozoic
2.5 - 0.57 Ga

Archean
4.0 - 2.5 Ga

Hadean
4.55 - 4.0 Ga

The Eons of the Geologic Time Scale

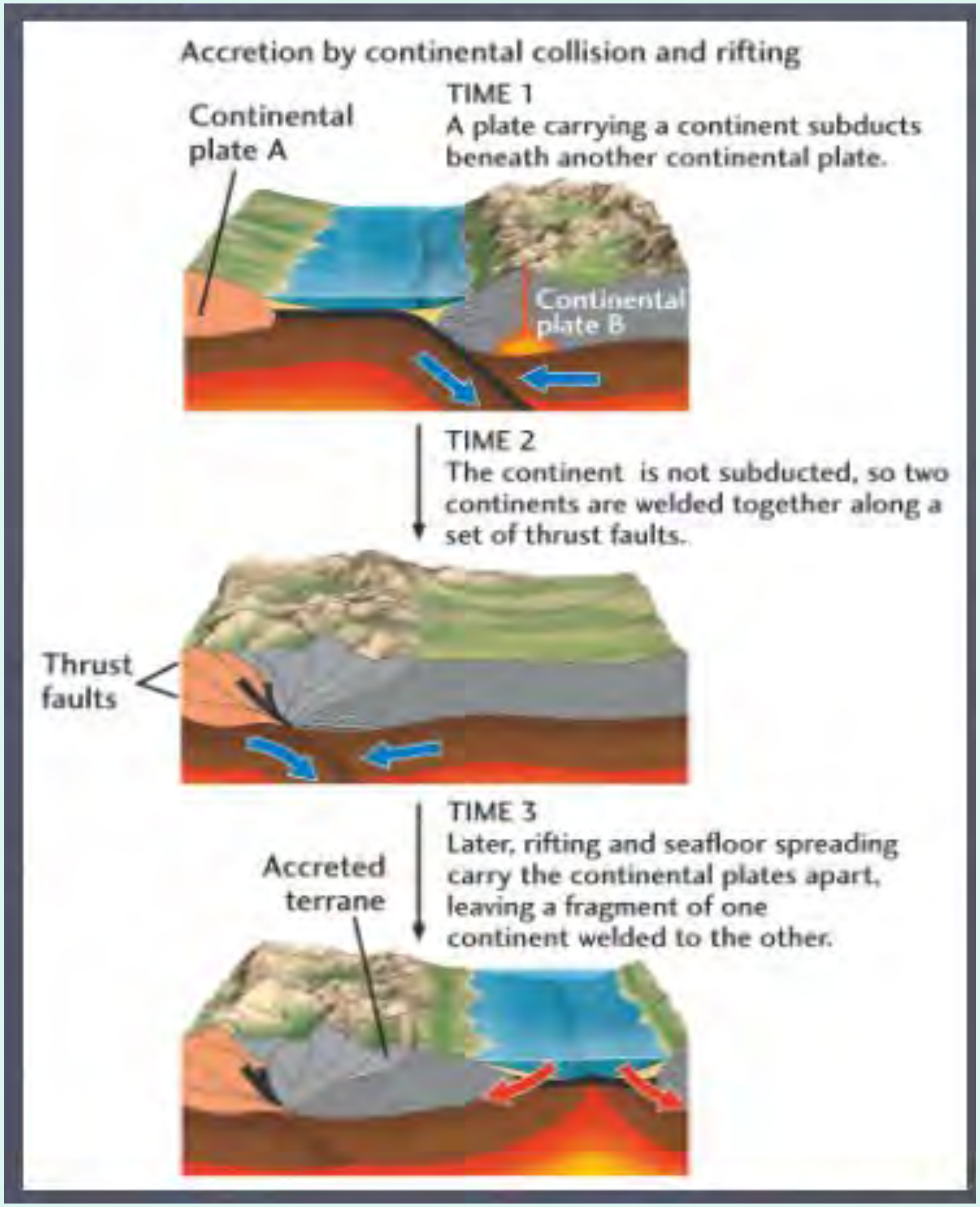
Assembly of a Continent



Ages of rocks (years)

Orogens: Growth by addition of small continental masses along margins of cratons

Note old orogens in craton as well



How Orogens Form by Accretion

The Atmosphere

-first atmosphere H, He;
swept away by solar wind

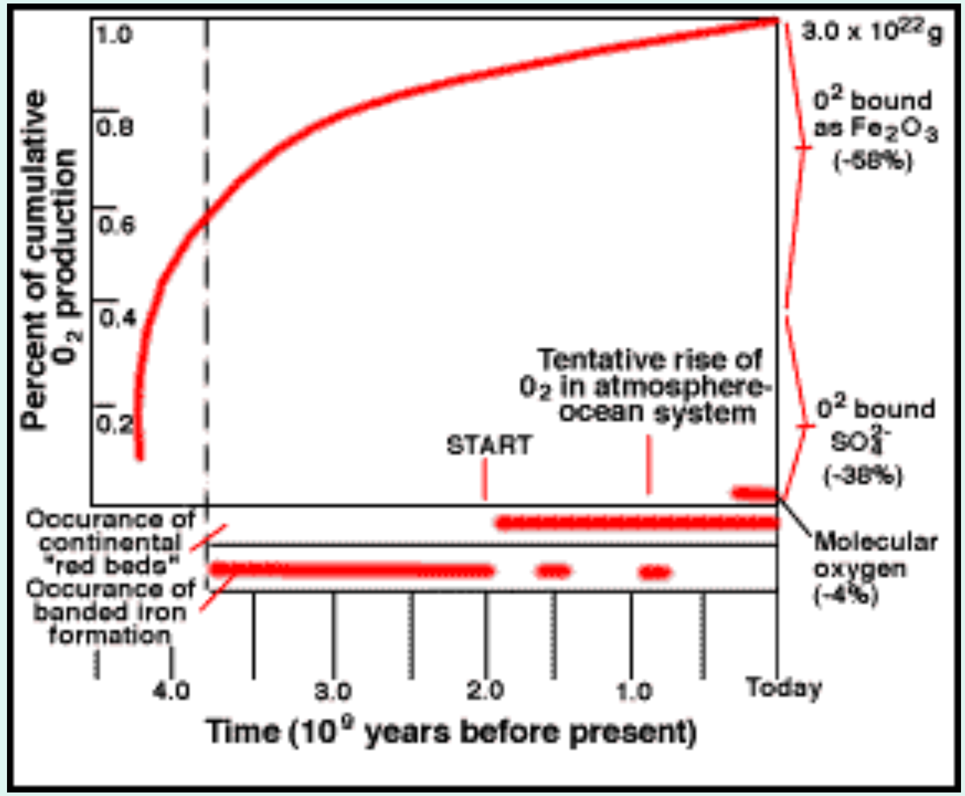
-volcanism --> H_2O, CO_2, H, S
- second atmosphere!

-Earth cools enough that condensed H_2O pools, forms lakes, oceans – *removes H_2O*

- *CO_2 removed* by photosynthesis, carbonate rocks

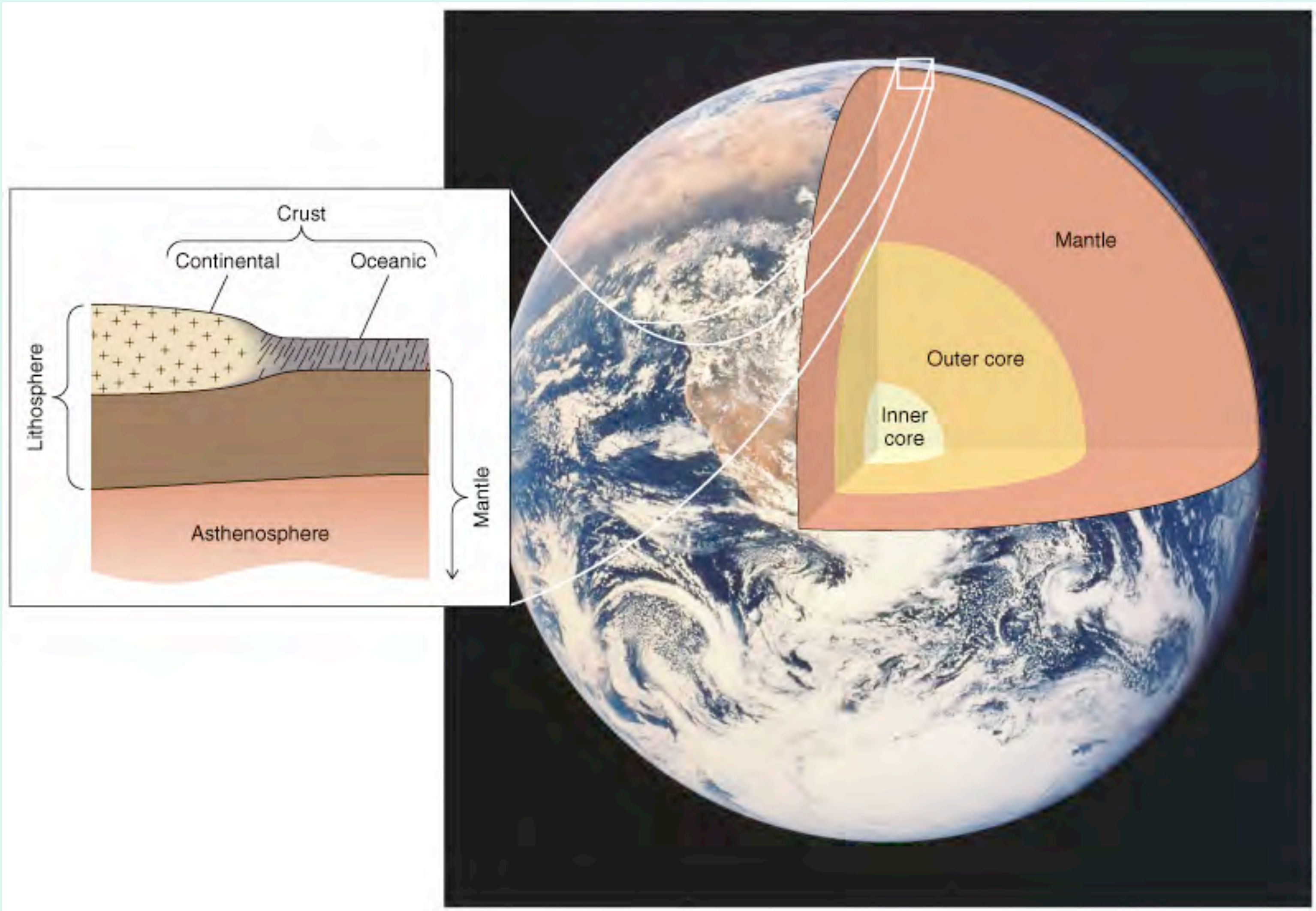
-eventually N, O dominate atmosphere (organic activity)

-but no free O_2 for first 2.5 billion years of Earth history



www.globalchange.umich.edu

Next: The Earth is a Layered Planet!



Davidson et al., 2000