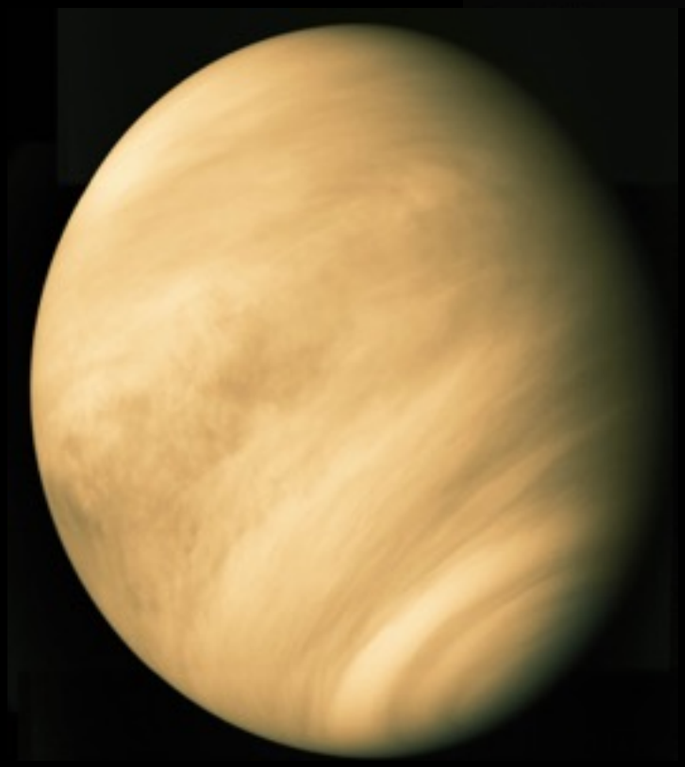
The habitability of Earth

Outline

- How does learning about life on Earth influence the search for life elsewhere?
- Is there a danger of the search for life simply becoming the search for Earth-like environments (i.e. too narrow in scope)?
- What makes the Earth suitable for life?
- Water + organics + energy.
- Vulcanism, magnetic fields, plate tectonics: geological activity.
- So should we start by looking for geologically active worlds in the Solar System?

Worlds in the inner Solar System



What Makes the Earth Habitable?

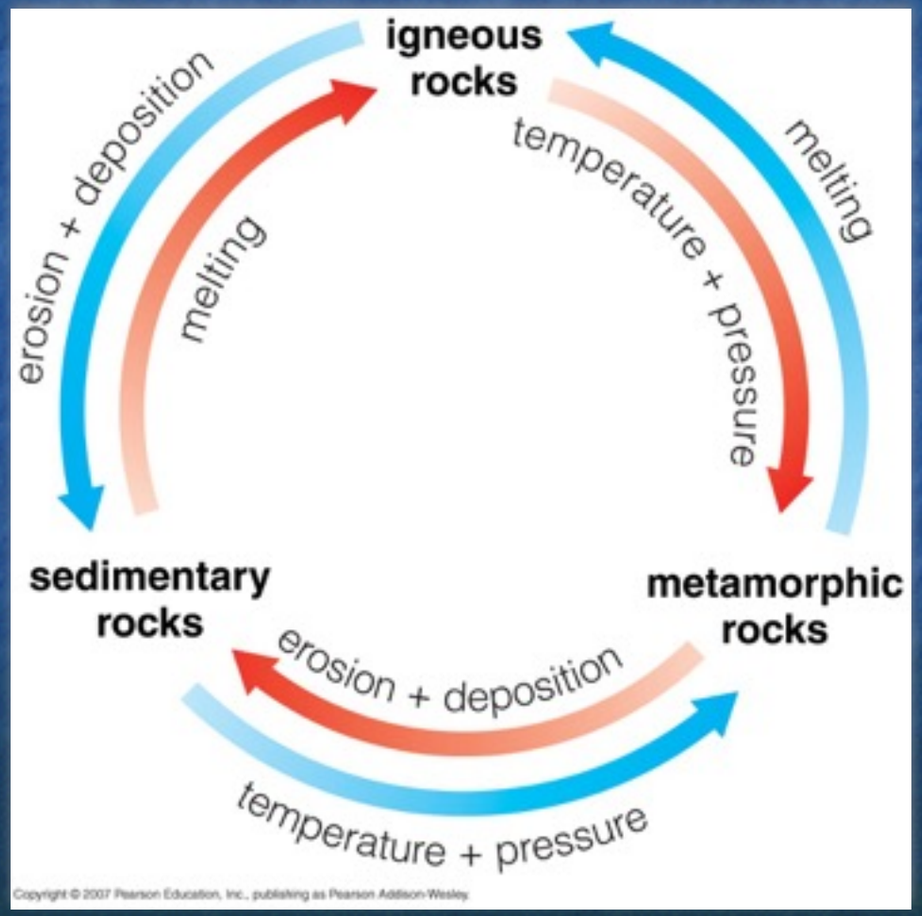
- Distance of Earth from Sun (not too close, not too far)
- Liquid water
- Surface gravity
- Atmosphere
- Magnetic field
- Solid surface
- Building blocks of life
- Climate suitable for life
- Plate tectonics

The Rock Cycle

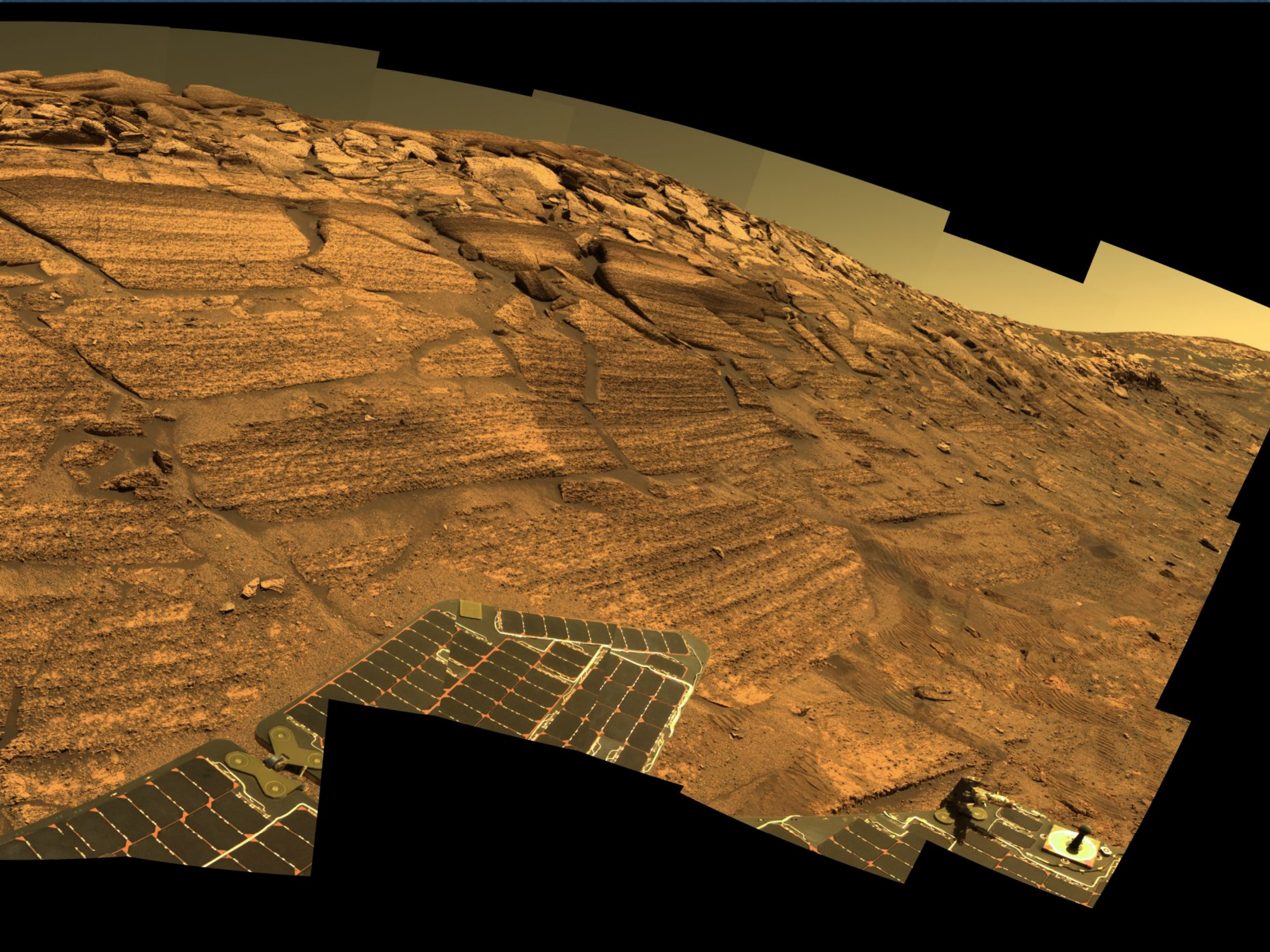
a This solidified lava is an example of igneous rock.

b Metamorphic rock has gone through transformations that often give a contorted appearance.

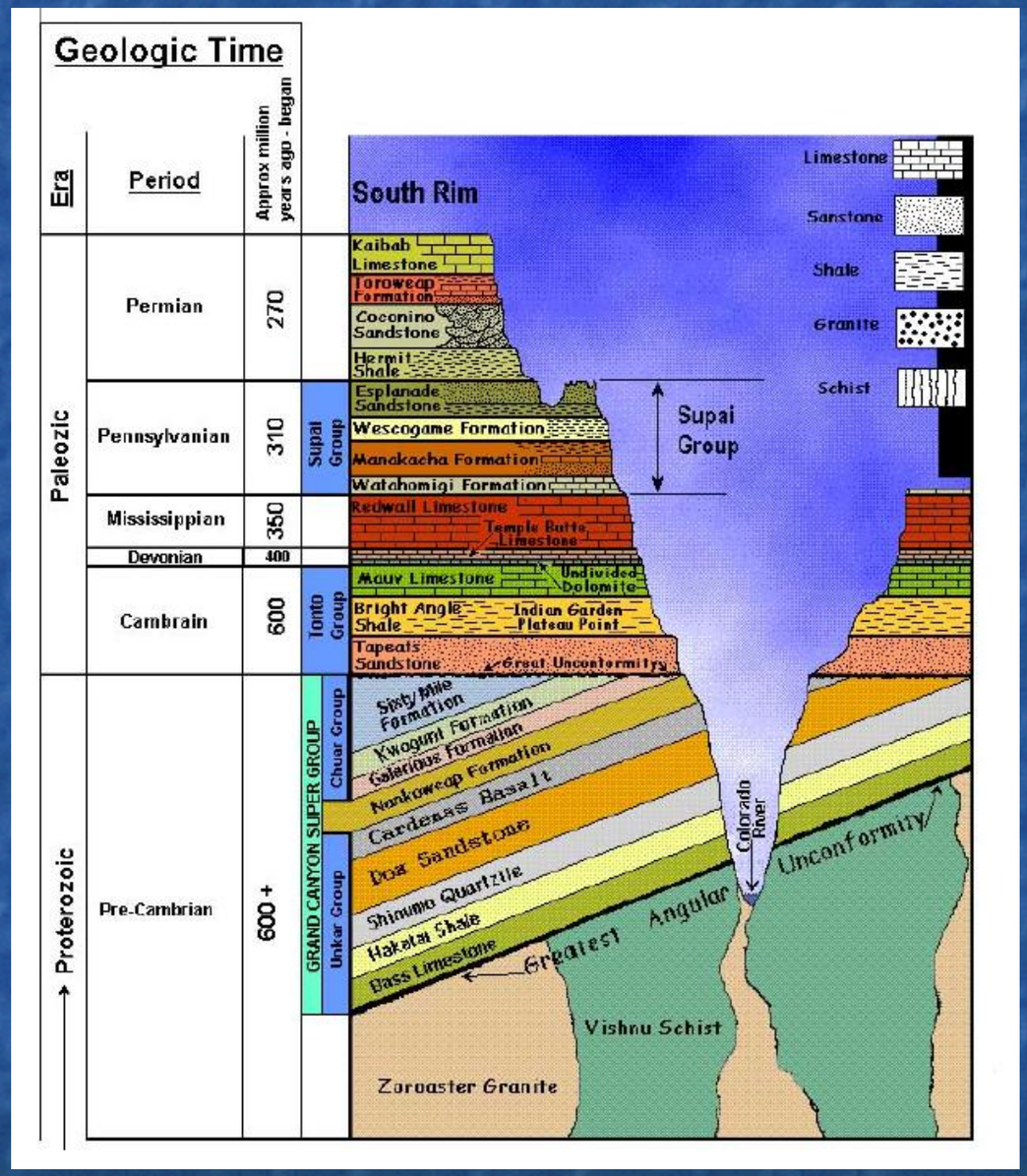
c Sedimentary rock tends to build up in layers like those visible here.



Strata in Sedimentary Rocks

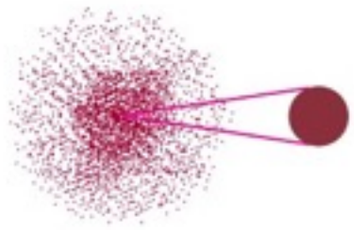
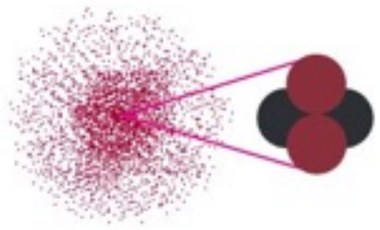


Grand Canyon Strata



Atomic Numbers, Isotopes, etc.

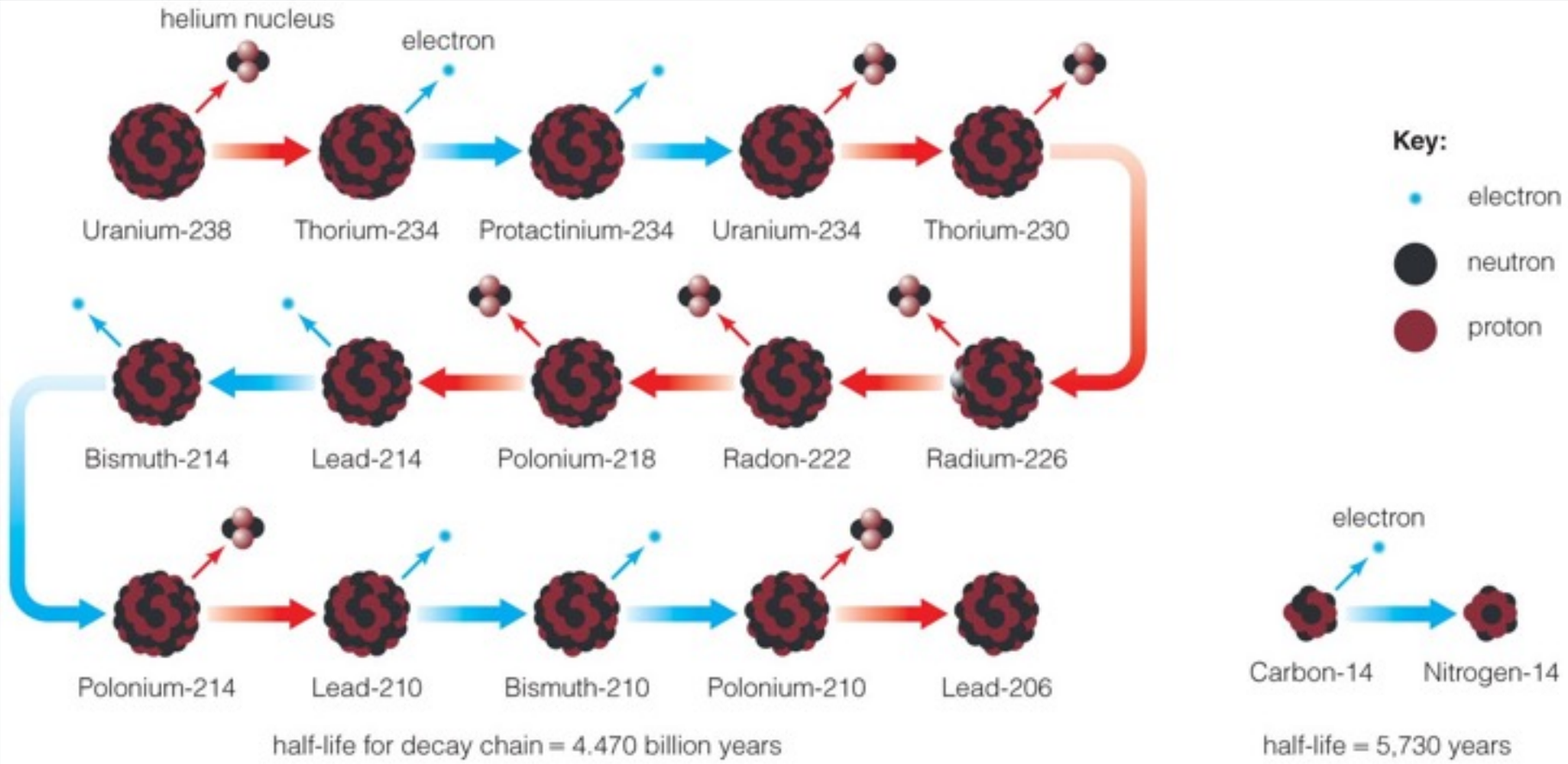
atomic number = *number of protons*
atomic mass number = *number of protons + neutrons*
(A neutral atom has the same number of electrons as protons.)

Hydrogen (^{1}H)	Helium (^{4}He)	Carbon (^{12}C)
		
atomic number = 1	atomic number = 2	atomic number = 6
atomic mass number = 1	atomic mass number = 4	atomic mass number = 12
(1 electron)	(2 electrons)	(6 electrons)

*Different **isotopes** of a given element contain the same number of protons, but different numbers of neutrons.*

Isotopes of Carbon

carbon-12	carbon-13	carbon-14
		
^{12}C	^{13}C	^{14}C
(6 protons + 6 neutrons)	(6 protons + 7 neutrons)	(6 protons + 8 neutrons)



a Uranium-238 decays through a chain of individual decay processes, eight of which involve the emission of a helium nucleus, ultimately leaving lead-206 as its stable daughter isotope. The half-life for the decay chain as a whole is 4.47 billion years.

b Carbon-14 decays by emitting an electron from its nucleus, which changes one neutron into a proton to make nitrogen-14 as its stable daughter. The half-life of carbon-14 is 5,730 years.

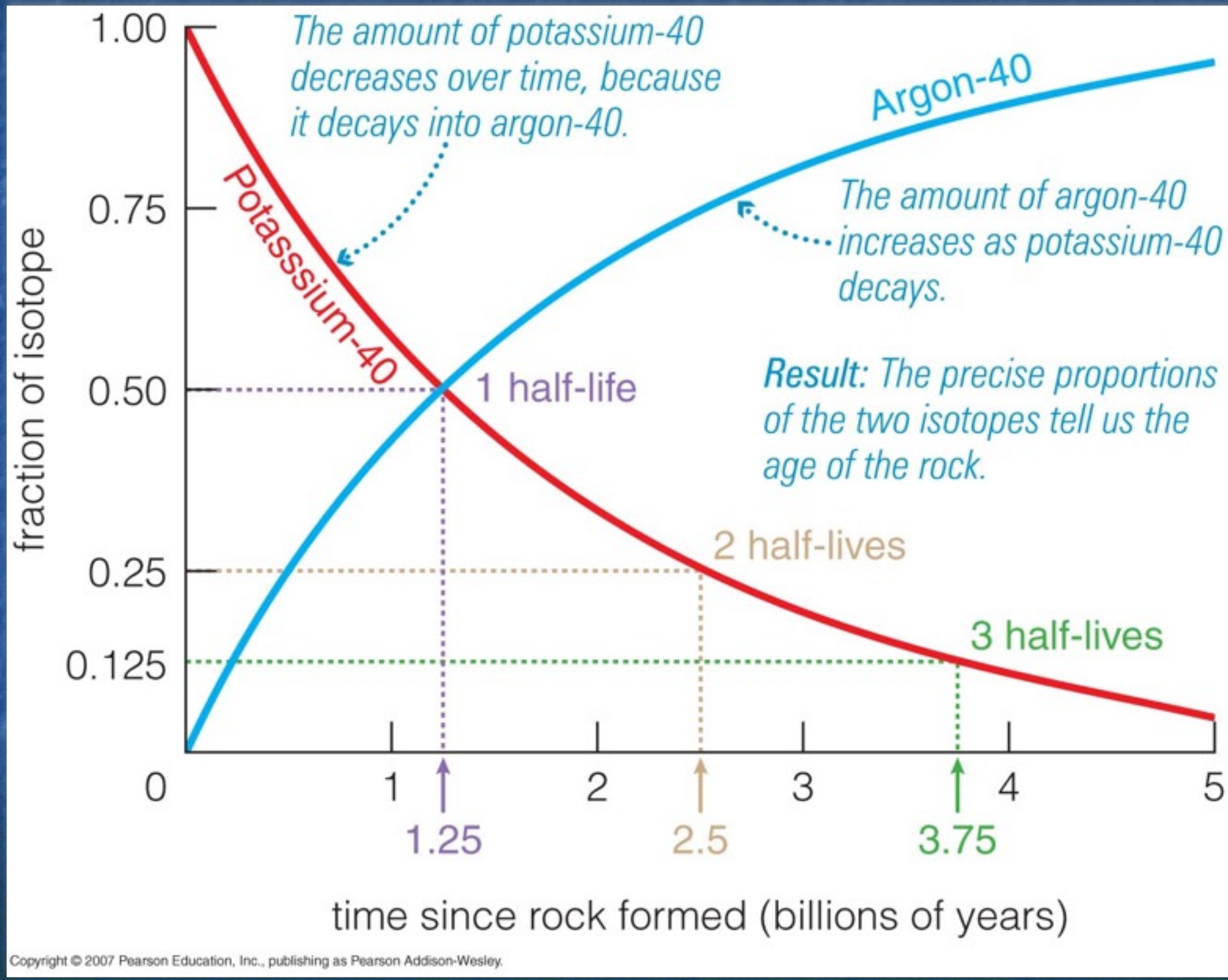
55	56	57	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
Cs	**Ba**	**La**	**Hf**	**Ta**	**W**	**Re**	**Os**	**Ir**	**Pt**	**Au**	**Hg**	**Tl**	**Pb**	**Bi**	**Po**	**At**	**Rn**
Cesium 132.905 4519	Barium 137.327	Lanthanum 138.905 47	Hafnium 178.49	Tantalum 180.947 88	Tungsten 183.84	Rhenium 186.207	Osmium 190.23	Iridium 192.217	Platinum 195.084	Gold 196.966 569	Mercury 200.59	Thallium 204.3833	Lead 207.2	Bismuth 208.980 40	Polonium (209)	Astatine (210)	Radon (222)
87	88	89	104	105	106	107	108	109	110	111	112		114		116		
Fr	**Ra**	**Ac**	**Rf**	**Db**	**Sg**	**Bh**	**Hs**	**Mt**	**Ds**	**Rg**	**Uub***		**Uuq***		**Uuh***		
Francium (223)	Radium (226)	Actinium (227)	Rutherfordium (261)	Dubnium (262)	Seaborgium (266)	Bohrium (264)	Hassium (277)	Meitnerium (268)	Darmstadtium (271)	Roentgenium (272)	Ununbium (285)		Ununquadium (289)		Ununhexium (292)		

- The systematic names and symbols for elements greater than 111 will be used until the approval of trivial names by the IUPAC.

The discoveries of elements with atomic numbers 112, 114, and 116 have been reported but not fully confirmed.

58	59	60	61	62	63	64	65	66	67	68	69	70	71
Ce	**Pr**	**Nd**	**Pm**	**Sm**	**Eu**	**Gd**	**Tb**	**Dy**	**Ho**	**Er**	**Tm**	**Yb**	**Lu**
Cerium 140.116	Praseodymium 140.907 65	Neodymium 144.242	Promethium (145)	Samarium 150.36	Europium 151.964	Gadolinium 157.25	Terbium 158.925 35	Dysprosium 162.500	Holmium 164.930 32	Erbium 167.259	Thulium 168.934 21	Ytterbium 173.04	Lutetium 174.967
90	91	92	93	94	95	96	97	98	99	100	101	102	103
Th	**Pa**	**U**	**Np**	**Pu**	**Am**	**Cm**	**Bk**	**Cf**	**Es**	**Fm**	**Md**	**No**	**Lr**
Thorium 232.038 06	Protactinium 231.035 88	Uranium 238.028 91	Neptunium (237)	Plutonium (244)	Americium (243)	Curium (247)	Berkelium (247)	Californium (251)	Einsteinium (252)	Fermium (257)	Mendelevium (258)	Nobelium (259)	Lawrencium (262)

Half-life



Fossils

a A dinosaur bone preserved in sandstone in Dinosaur National Monument, which straddles Utah and Colorado.

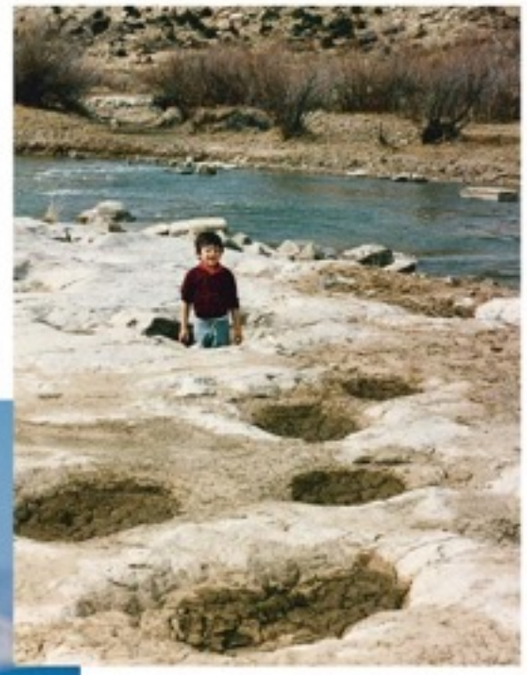
b A 190-million-year-old petrified (stone) tree in Arizona.

c These 375-million-year-old impressions are casts of dead organisms (called ammonites) made when minerals filled the empty space left after the organism decayed.

e An insect preserved in hardened tree resin (often called *amber*).

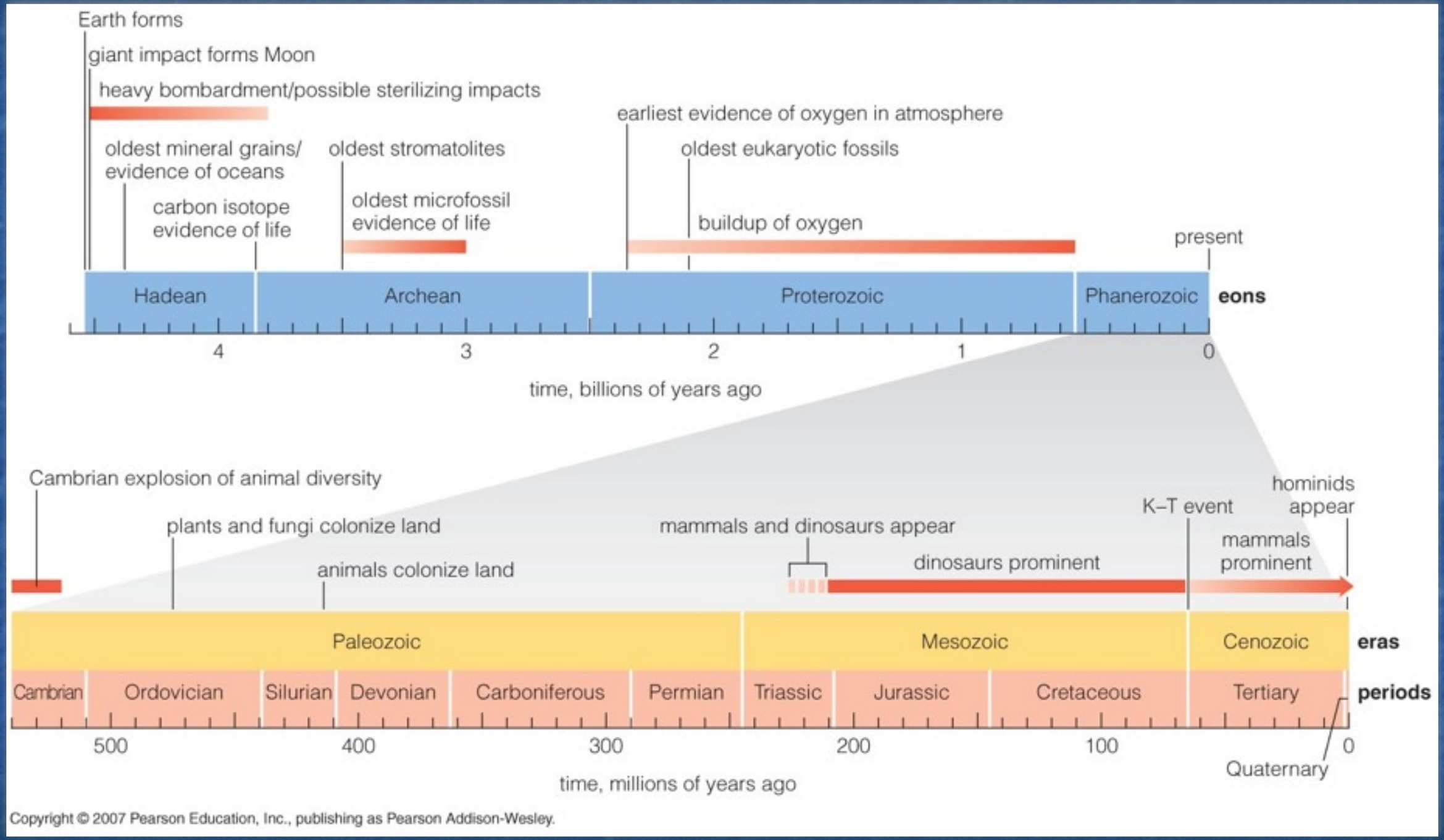
d This 40-million-year-old leaf still retains organic material, including DNA.

f These tusks belong to a whole 23,000-year-old mammoth discovered in Siberian ice in 1999.



g This boy is standing in a 150-million-year-old dinosaur track in Colorado.

The Geological time scale

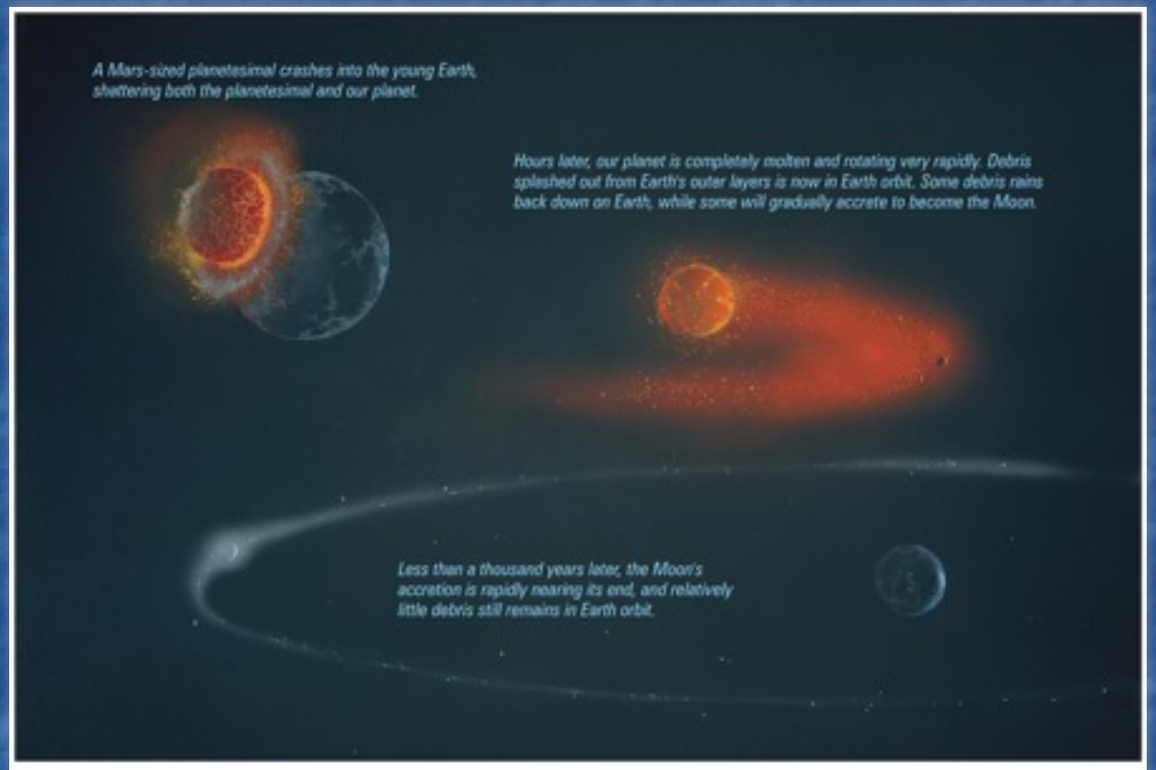


How Old is the Earth?

- It must be older than the oldest minerals found on Earth (4.4 Gyr old)
  - zircon found in Australia
- It must be older than the oldest Moon rocks (4.4 Gyr old)
  - we know that the Moon formed after the Earth
- It must be younger than the oldest meteorites (4.57 Gyr old)
- Scientists now estimate that the Earth is about 4.54 Gyr old

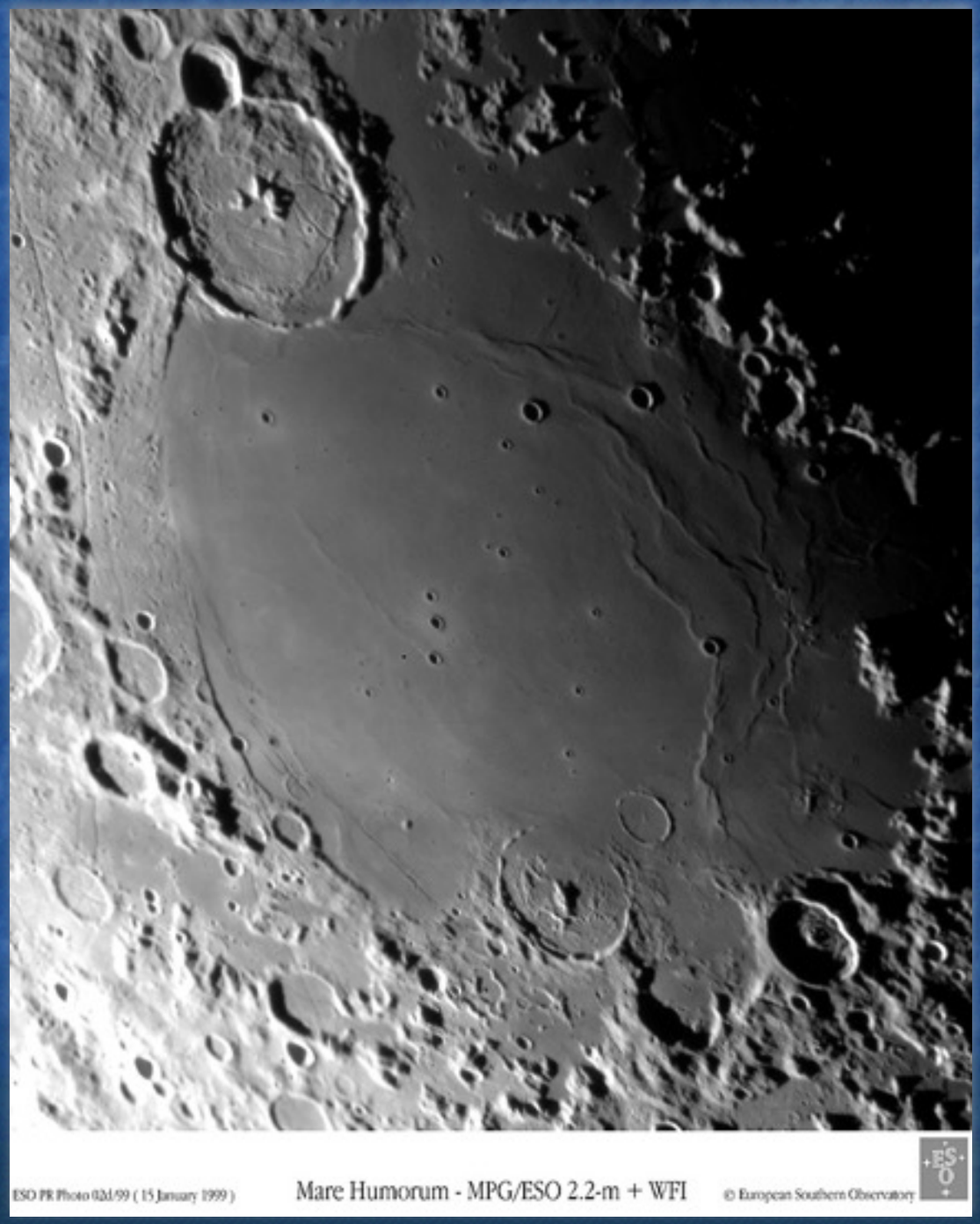
Formation of the Moon

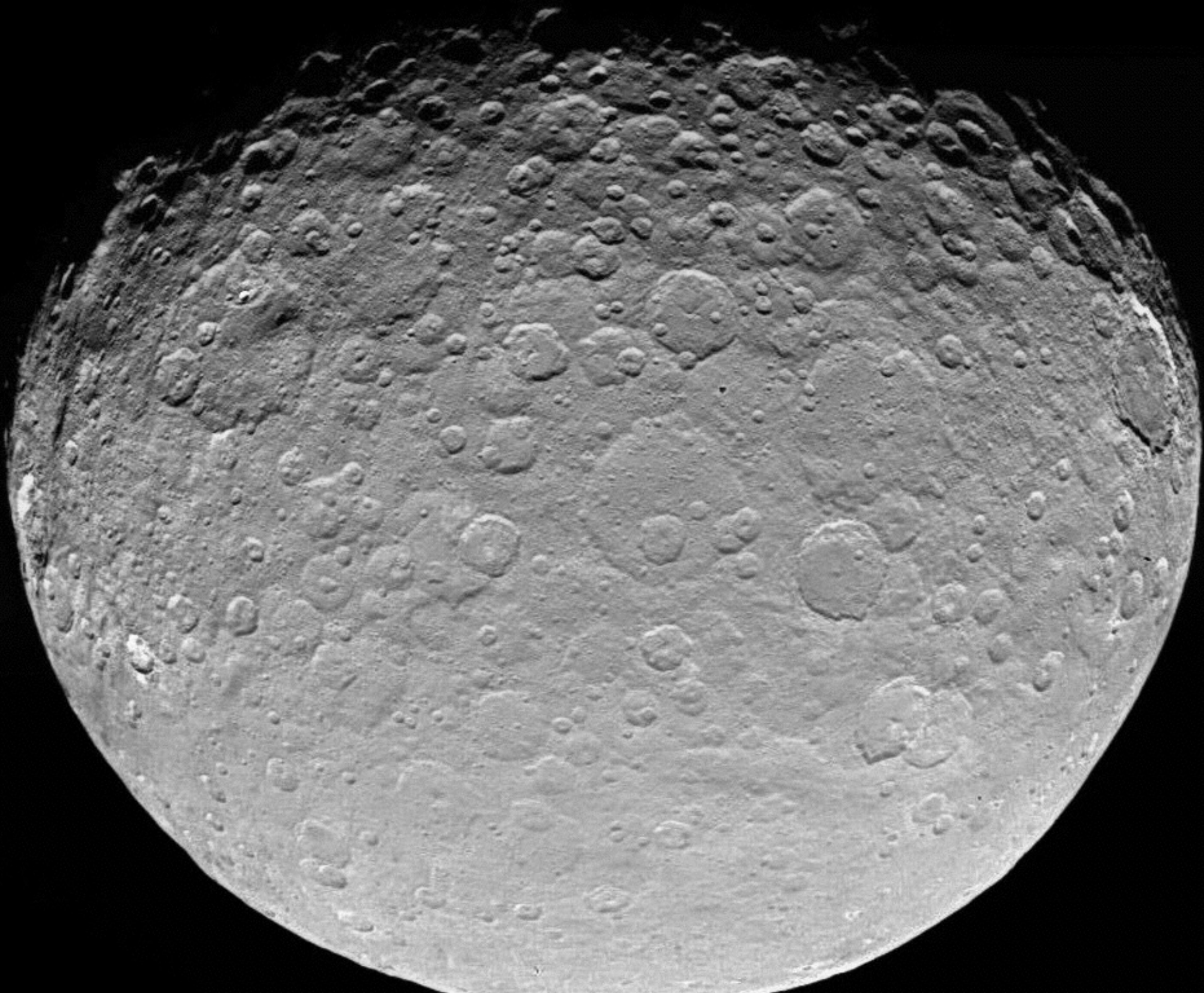
- The Moon is thought to have formed very soon after the Earth formed
  - within 50–150 Myr
- It is thought to have formed as the result of the impact of a Mars-sized object



Heavy bombardment on the Moon

- The surface of the Moon preserves a record of ancient impact craters
  - this evidence has been erased on the Earth
- The lunar maria exhibit relatively few craters
  - these surfaces are about 3.0–3.9 Gyr old
- Most impacts on Earth must therefore have occurred during the Hadean era



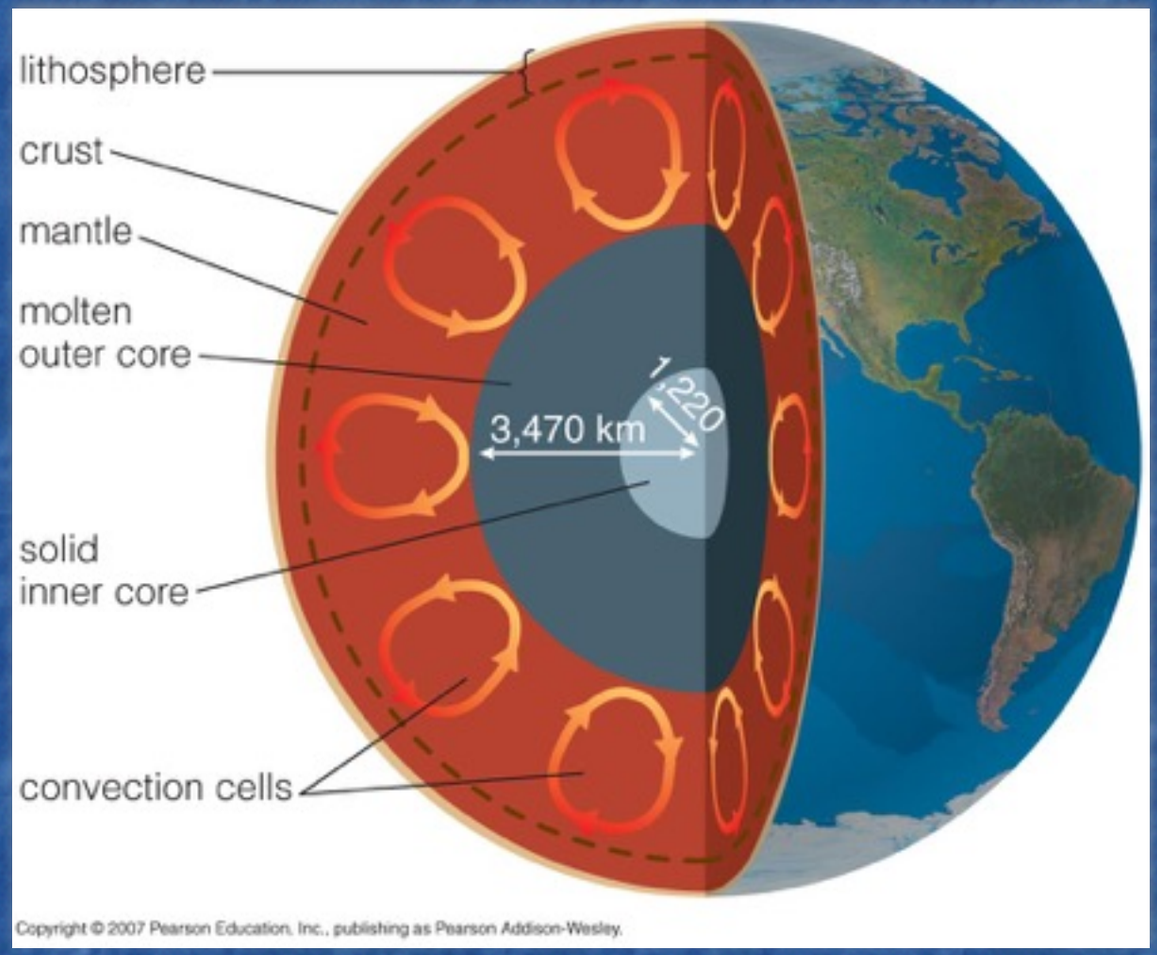


Life during the Hadean era

- Radiometric dating of zircons indicates that Earth's crust had already formed 4.5 Gyr ago
- This implies that the Hadean Earth may have been habitable at that time
- Frequent impacts may or may not have sterilized the Hadean Earth
  - sufficiently large impacts could have vaporized all of Earth's oceans!

Earth's Interior

- The interior of Earth has several important effects on the surface
  - Volcanoes have built up much of the atmosphere
  - Plate tectonics have shaped the continents
  - Earth's magnetic field shields life from the solar wind



Geology

Vulcanism

Magnetic field

Plate tectonics

Creates and replenishes

Protects

Recycles

Atmosphere

Plate Tectonics

- Earth's surface is broken up into plates which float on the mantle and move around slowly
- Movement of these plates is responsible for
  - mountain building
  - sea floor spreading
  - earthquakes
  - volcanic hot spots
  - subduction
  - rift valleys
  - continental drift

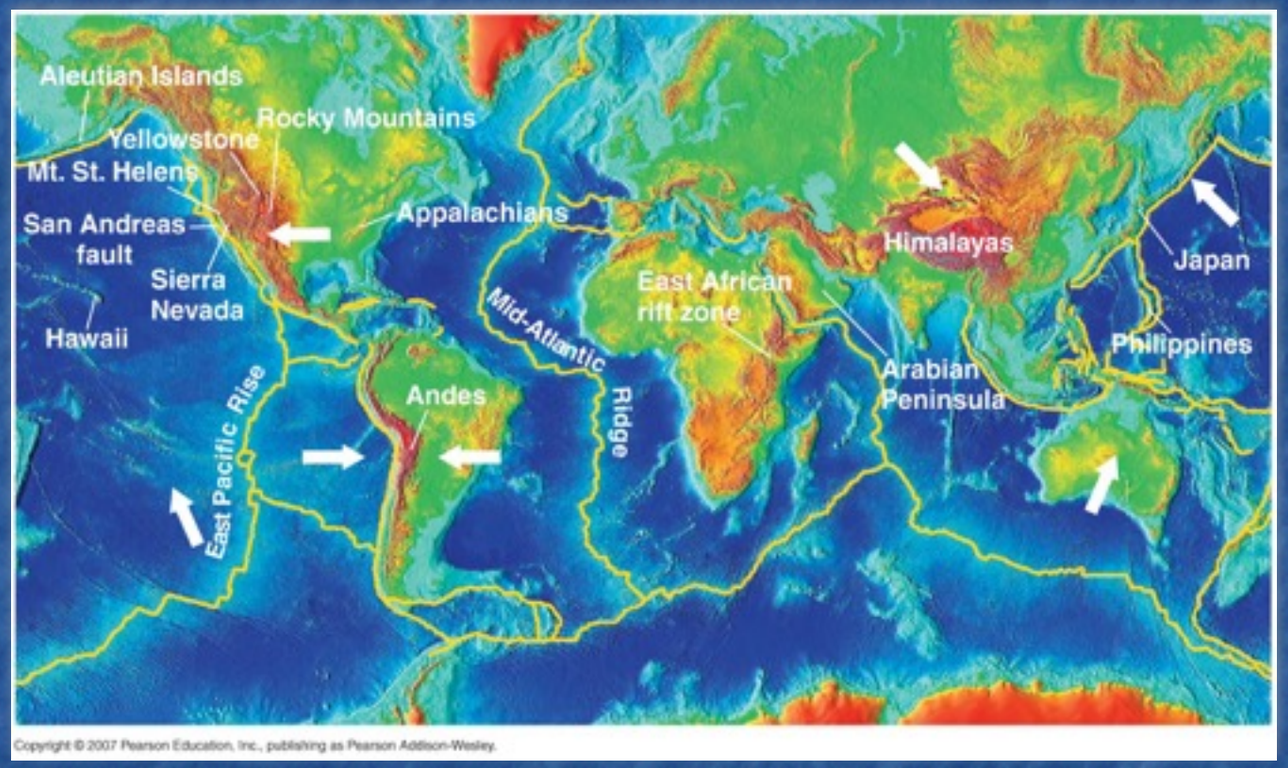
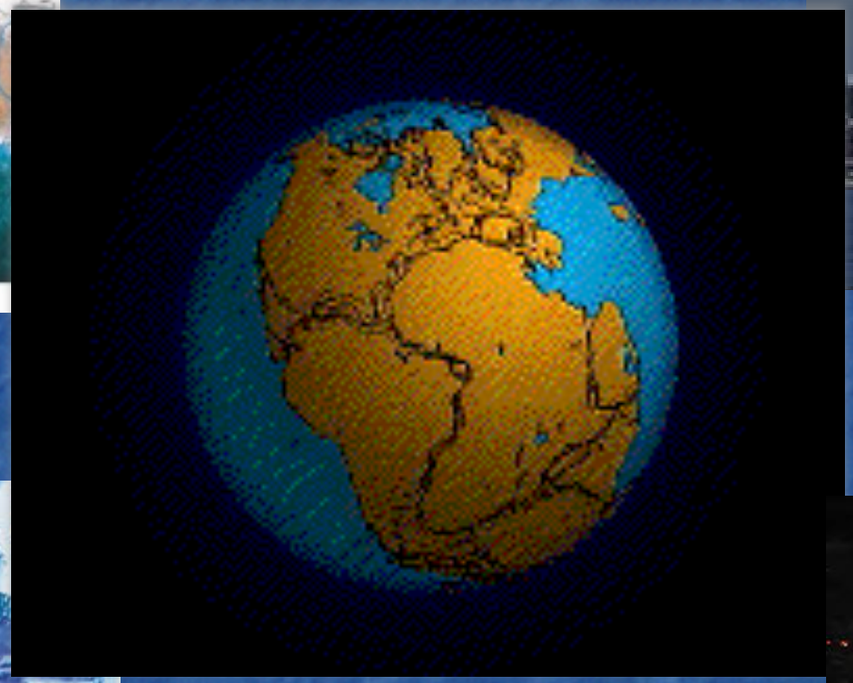
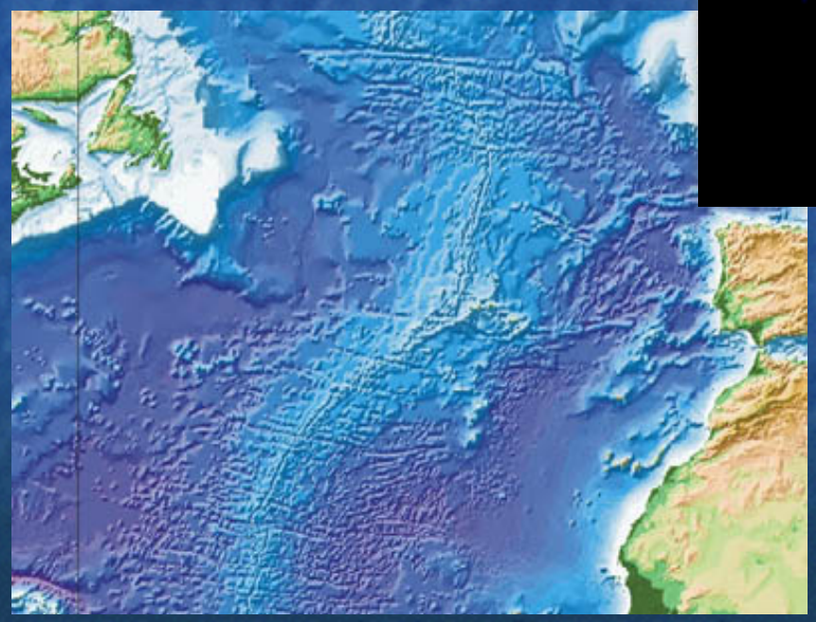


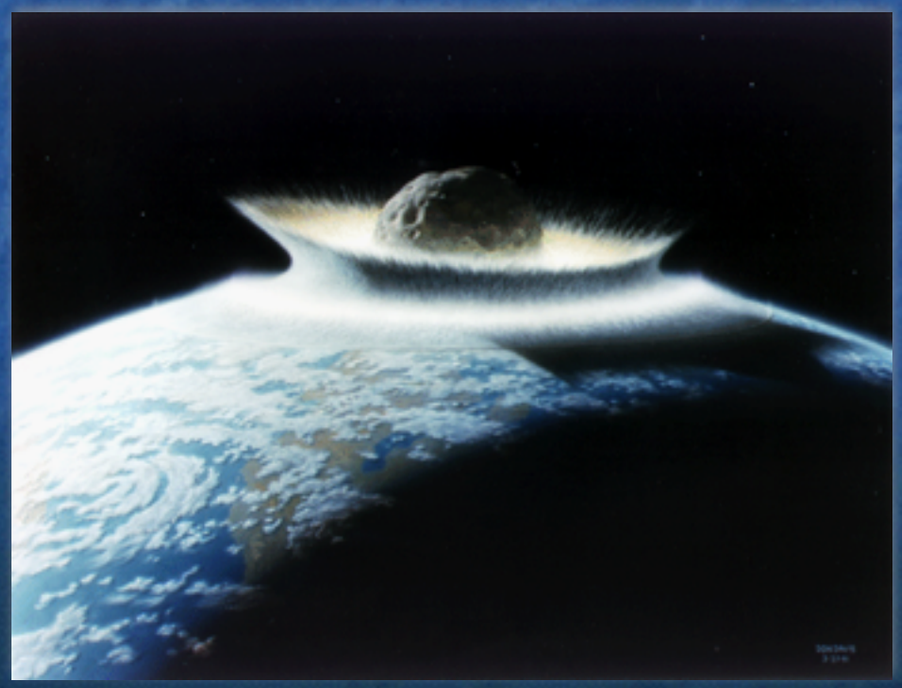
Plate Tectonics at Work

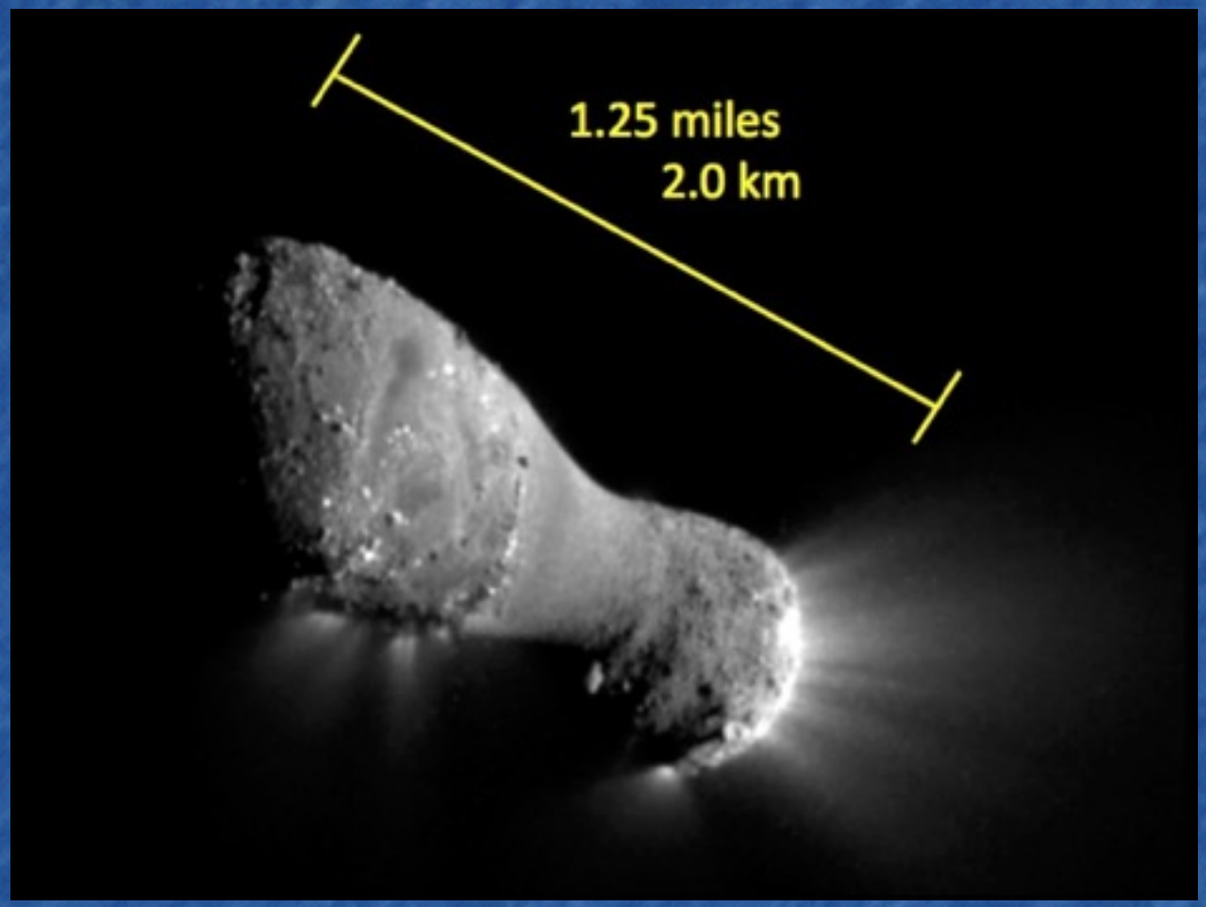




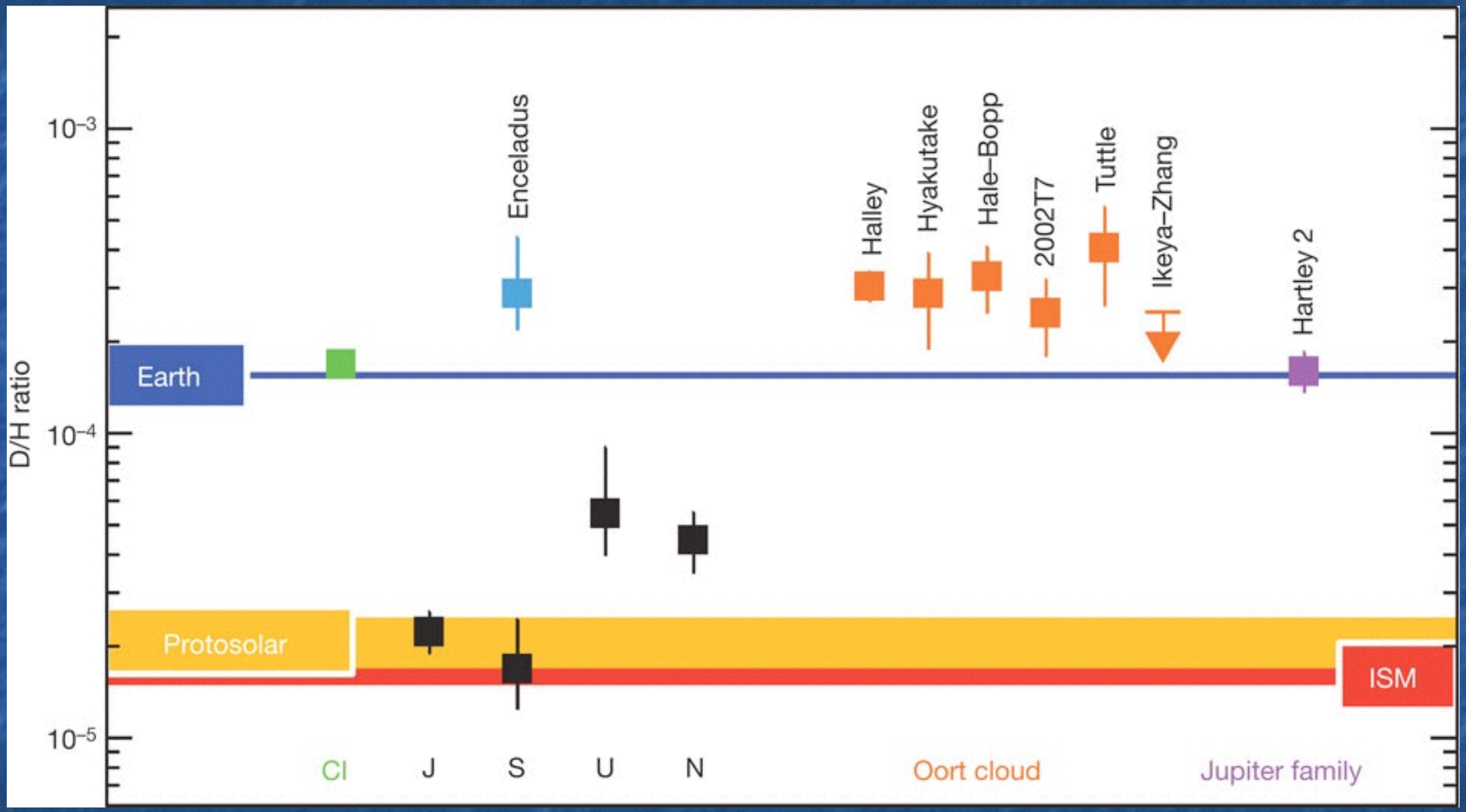
Building Earth's Atmosphere and Oceans

- Earth's atmosphere and oceans were produced by several mechanisms
  - Outgassing (e.g. by volcanoes) of gases trapped within the Earth
  - Material deposited during impacts (including comets)
  - Life!



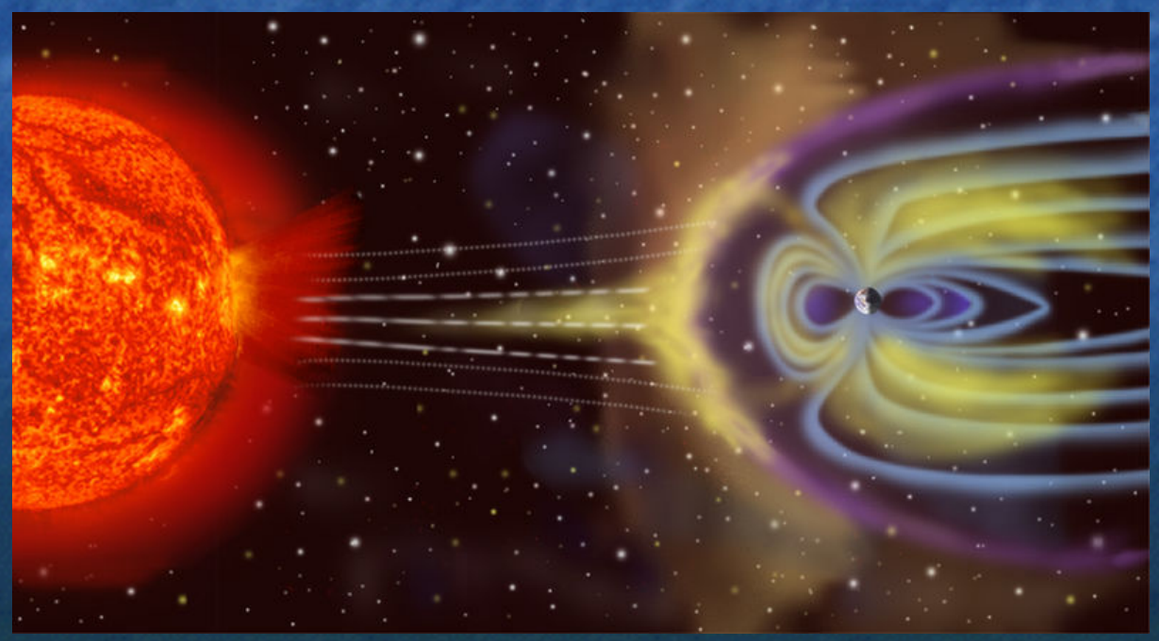

1.25 miles
2.0 km


SPL


D/H ratio
10^{-3}
10^{-4}
10^{-5}
Earth
Enceladus
Halley
Hyakutake
Hale–Bopp
2002T7
Tuttle
Ikeya–Zhang
Hartley 2
Protosolar
ISM
CI
J
S
U
N
Oort cloud
Jupiter family

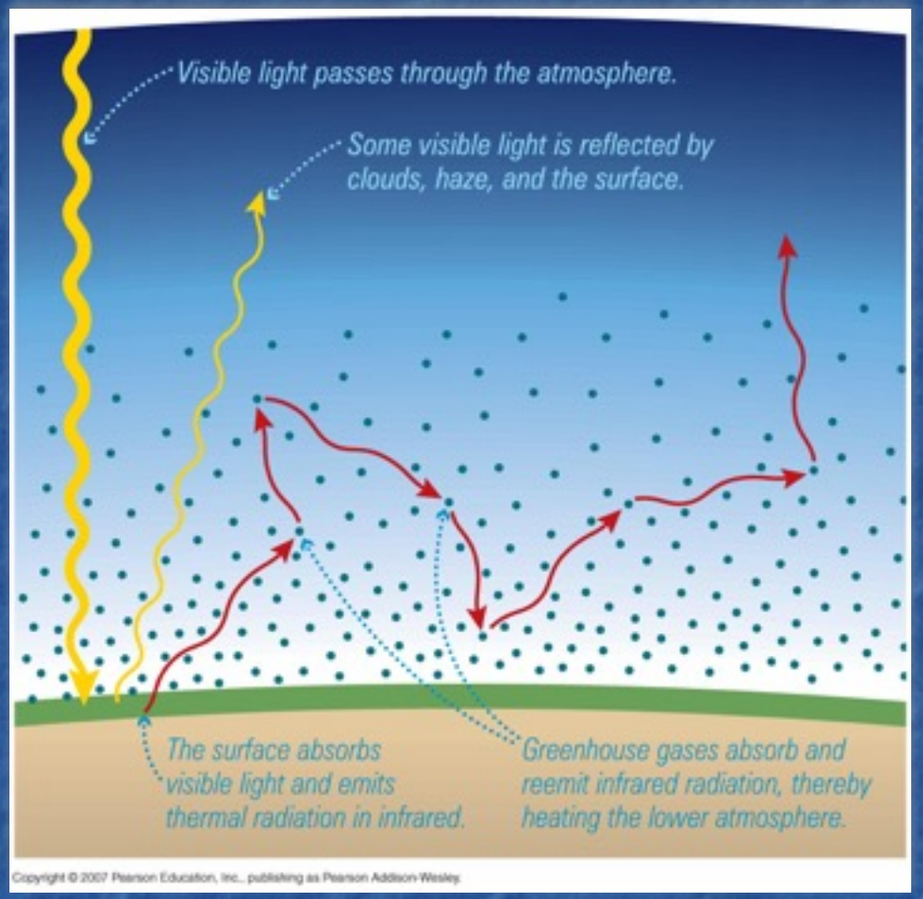
How to Lose an Atmosphere

- Several mechanisms can lead to the loss of part or all of a planetary atmosphere
  - thermal escape (gas molecules move too fast)
  - impact-triggered escape
  - solar wind stripping



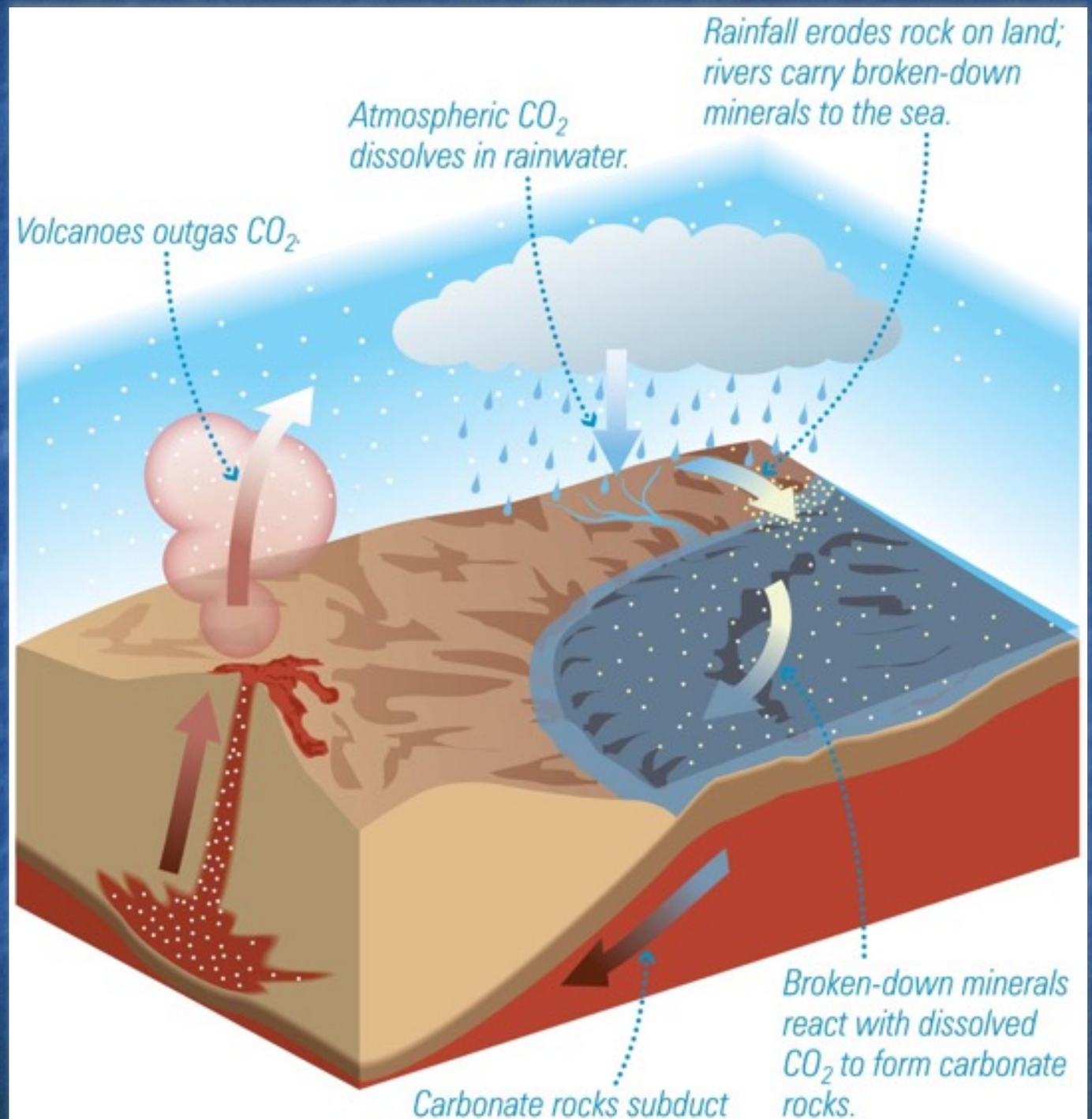
The Greenhouse Effect

- Greenhouse gases in the Earth's atmosphere make the Earth considerably warmer than it would otherwise be
- This is a good thing for life, since it allows liquid water to survive on Earth's surface
- However, by adding manmade greenhouse gases, we are now starting to warm the atmosphere further

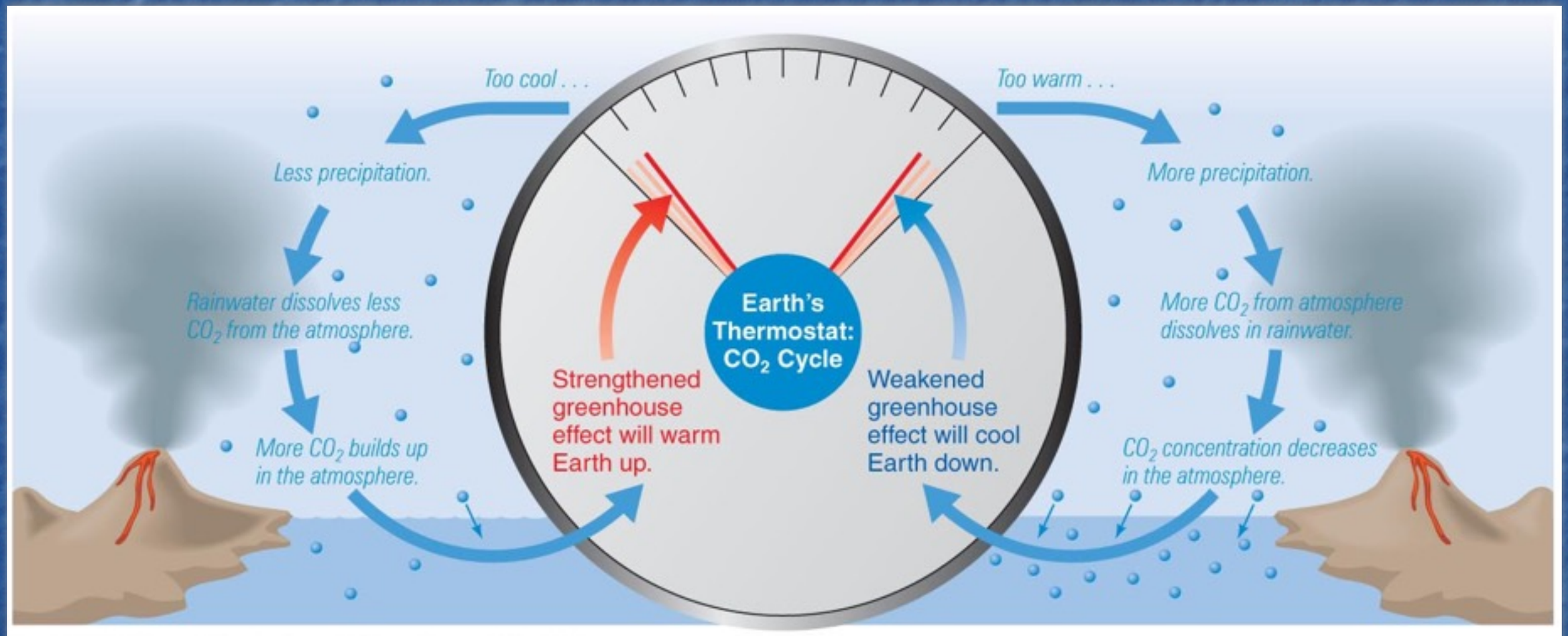


	Without Atmosphere	With Atmosphere	Water
Earth	255 K	285 K	Liquid
Venus	280 K	750 K	Vapor
Mars	214 K	220 K	Ice

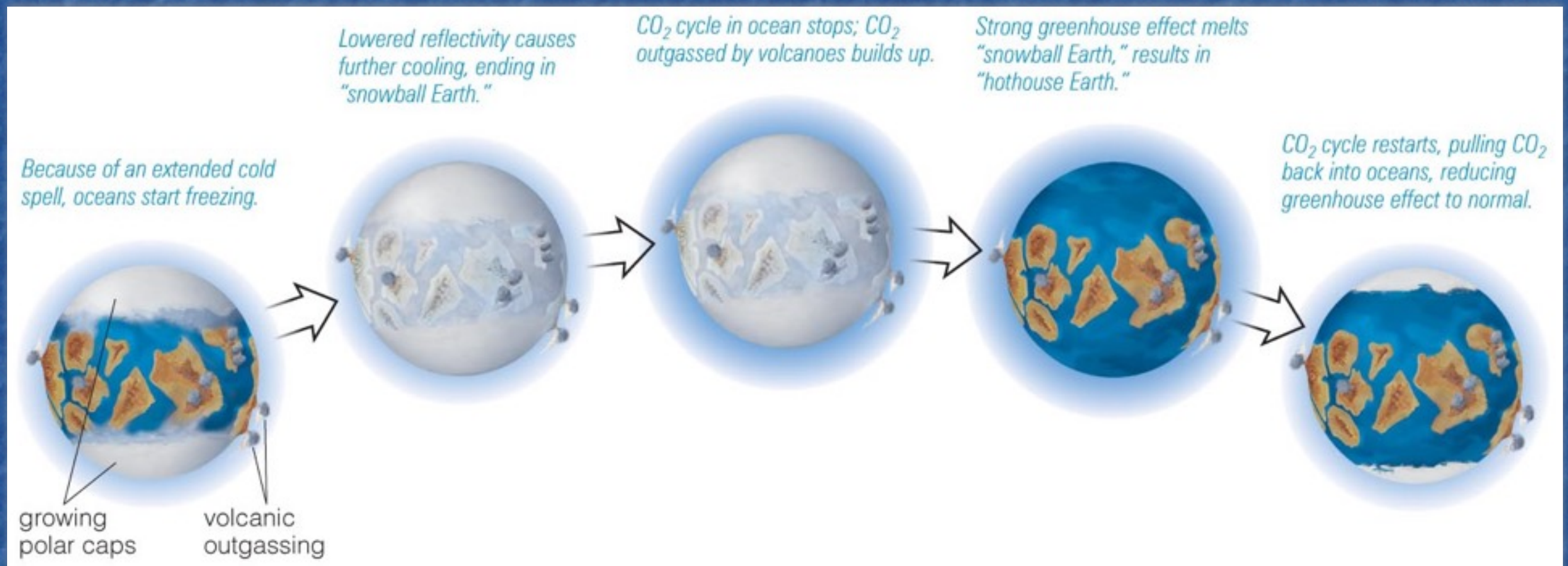
The Carbon Dioxide Cycle



Earth's Carbon Dioxide Thermostat



Snowball Earth



What Makes the Earth Habitable?

- The size/mass of Earth
- Earth's distance from the Sun
- Plate tectonics
- Impacts: not too many, not too few
- Earth's magnetic field
- The stabilizing effect of the Moon
- Earth's atmosphere and greenhouse effect