Lecture 19

Part 2: Climates of the Past

1) The geologic timescale:
   - the age of the Earth/ Solar System
   - the history of the Earth

2) The evolution of Earth's atmosphere - from its origin to present-day

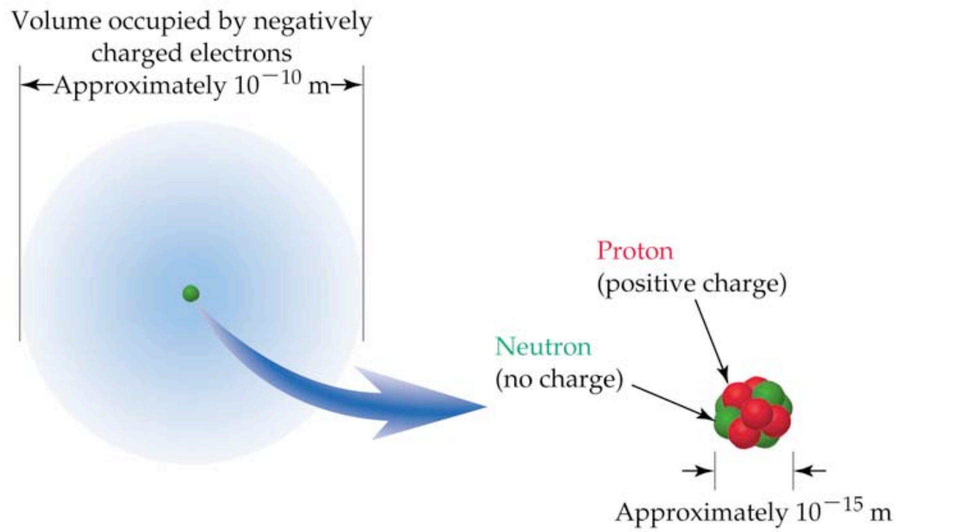
3) The co-evolution of life

Textbook: Chapters 10, 11, 12 (and some of 8)

Dating rocks, part 1

Basics of Chemistry/Physics: A reminder:

Atoms have protons (positively charged) and neutrons (neutral) in a central nucleus. The number of electrons (negatively charged) surrounding the nucleus is equal to the number of protons for an atom with no overall charge.



Atomic number of atom = number of protons
Mass number of atom = number of protons + neutrons

e.g. Rubidium-87 is written $^{87}_{37}Rb$
Atomic number = 37, Mass number ("atomic weight") = 87
i.e., the Rb atom has 37 protons and 50 neutrons in the nucleus

Isotopes

isotope = atoms with the same number of protons but different number of neutrons (p.97 Kump)

a *radioisotope* is unstable, undergoes radioactive decay, and changes into another more stable element

half-life = the time for half the atoms in a sample to decay

Vital for dating materials and biogeochemistry (i.e., understanding how biology affects the chemistry of the solid Earth and atmosphere)

e.g. carbon has two stable isotopes, ${}^{12}_{6}C$, ${}^{13}_{6}C$

and various radioisotopes, including

${}^{14}_{6}C$ with a half-life of 5570 years

${}^{15}_{6}C$ with a half-life of 2.3 seconds

Dating rocks, part 2

Look at a radioactive element and measure the amount of its daughter (decay product) in the rock

e.g. Rubidium-87, which decays to Strontium-87 with a half-life of 49 billion years

$$^{87}_{37}\mathrm{Rb} \rightarrow \, ^{87}_{38}\mathrm{Sr} + \beta$$

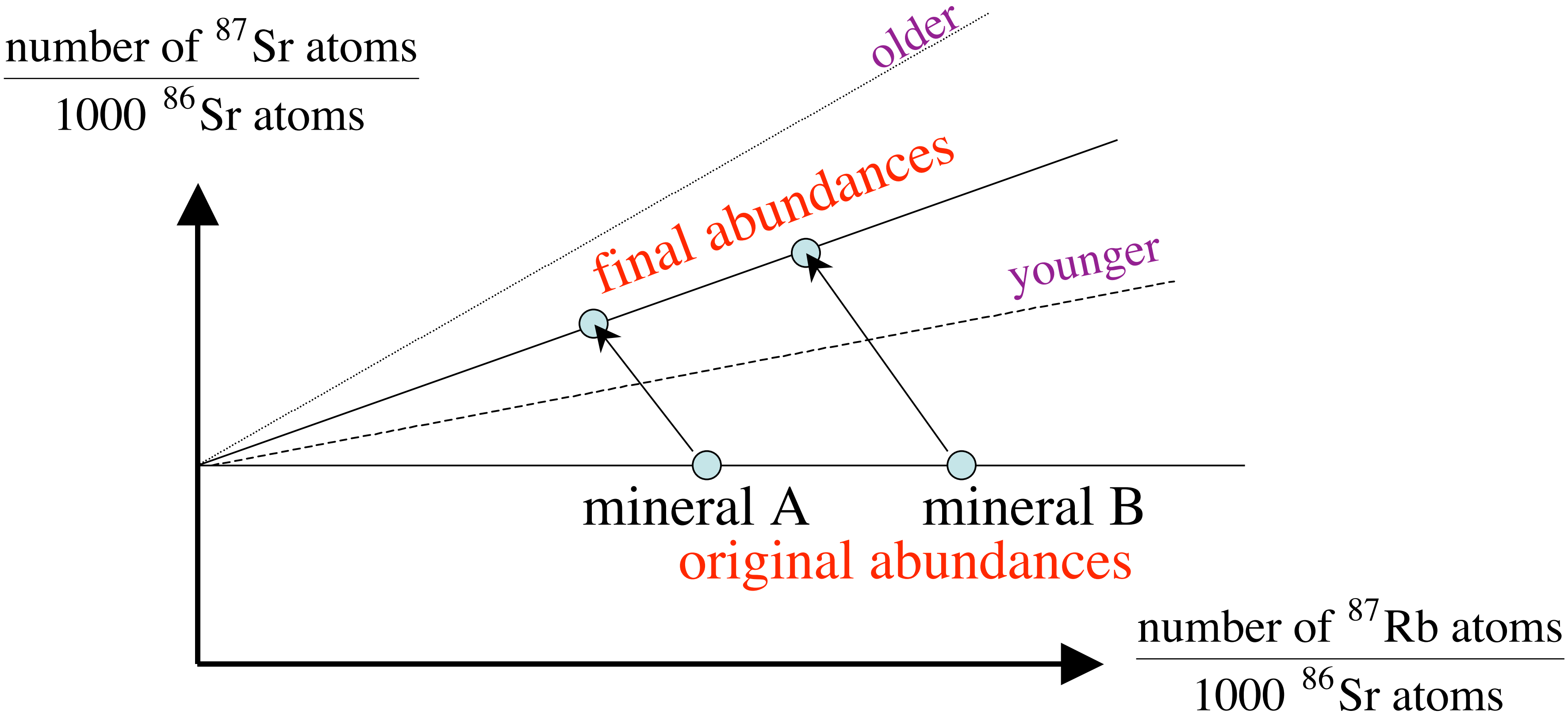
a “Beta ray” = a high-energy electron that is ejected

The amount of Sr-87 present depends on 3 things:

1) Amount of Rb-87 originally in the rock
2) Amount of Sr-87 originally in the rock
3) Time (which decreases Rb-87 atoms and adds Sr-87 atoms)

Dating rocks, part 3

We can look at different minerals in the rock that started off with different Rb contents. (Abundance is given relative to the unchanging abundance of a stable isotope, in this case Sr-86).



Age is proportional to the slope. Slopes on such plots are “isochrons”

Age of the Solar System & Earth

Meteorites called "chondrites" have not been altered by heating or melting and are bits of rock that were not incorporated into a planet. They are leftovers from the formation of the planets.

^{87}Rb-^{87}Sr gives an age for chondrites of 4.56±0.01 billion years old
We can also use other radioisotope pairs and we get <u>the SAME</u> age (e.g. p.189 Kump describes uranium-lead isotopes in chondrites).

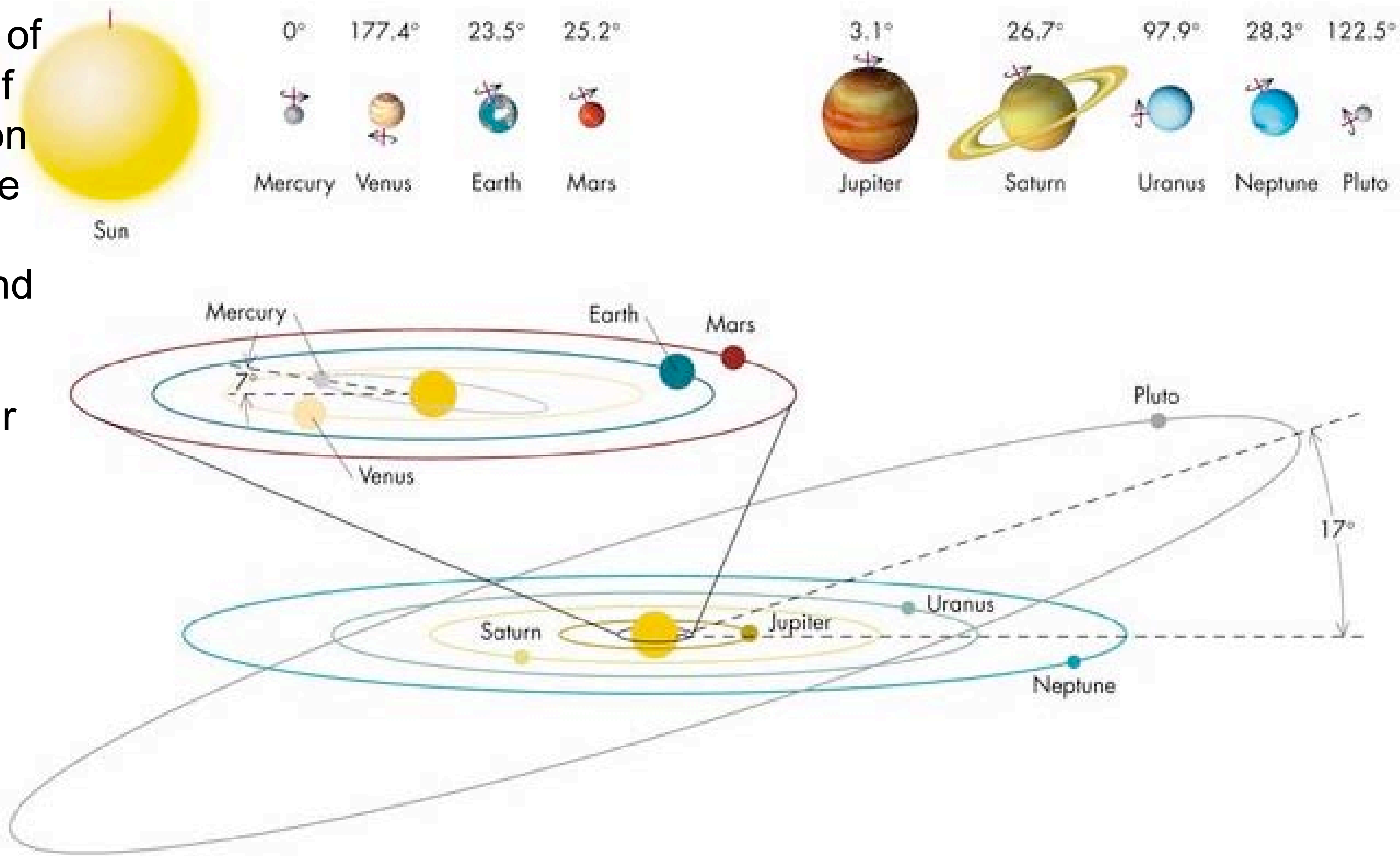
Oldest Moon rocks (from Apollo astronaut collection) = 4.44 b.y.

Oldest Mars rock (a Martian meteorite) = 4.5 b.y.

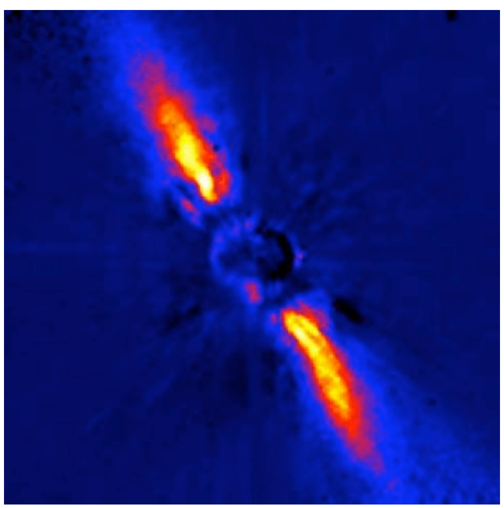
Oldest Earth rock fragment = 4.4 b.y.

Age of Earth (from deducing same original lead isotopes in the Earth's mantle as originally in meteorites) = 4.56 b.y.

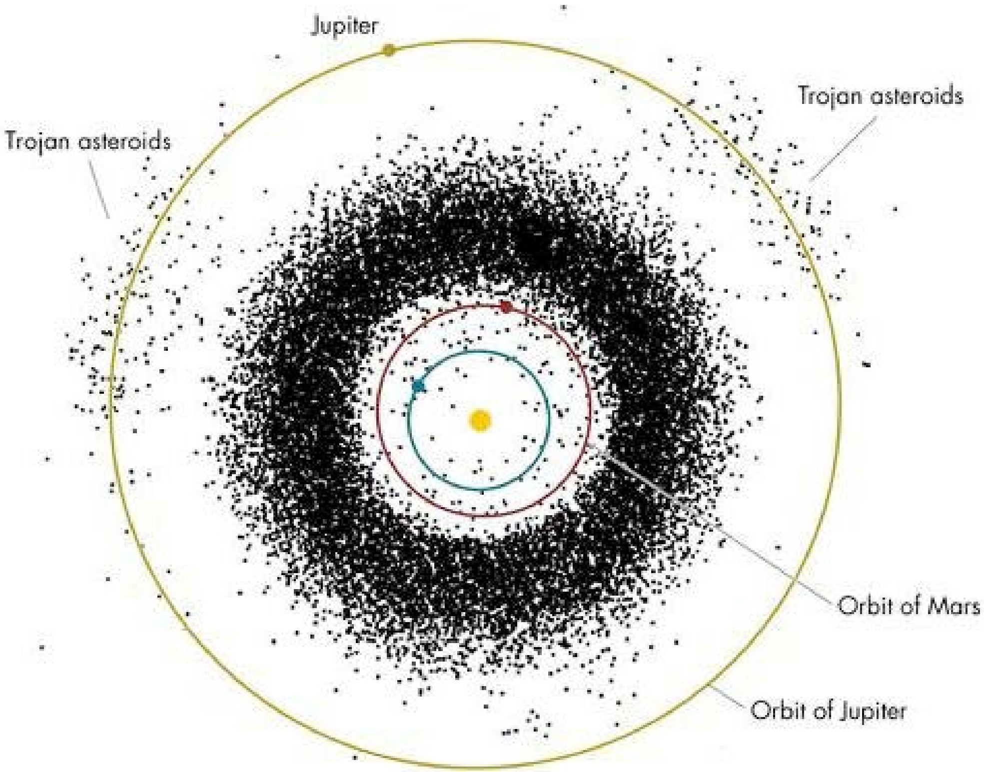
The Solar System formed by gravitational collapse of a large, **rotating** cloud of matter. The central region grew denser and became the Sun. The remainder became a **disk** of gas and dust, **the solar nebula**.



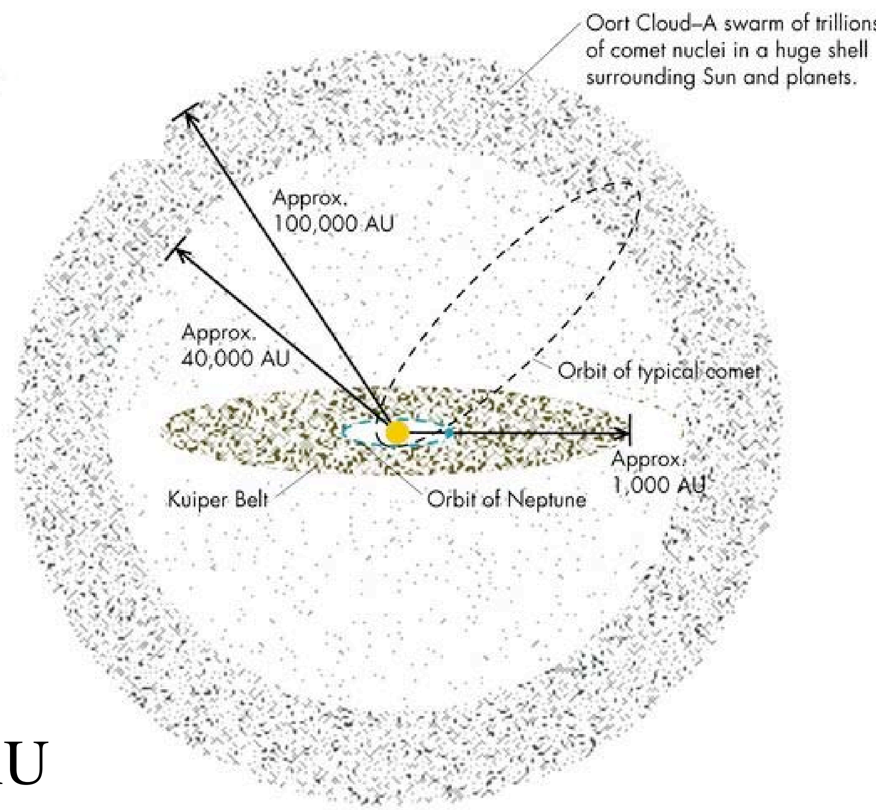
We can see circumstellar discs that support this theory



Beta Pictoris (55.4 light years away) is surrounded by a "debris disk" of dust 1-30 micron size. Transient spectral features may be due to infalling comets. There is little dust within 20 AU of the star, probably because it has coalesced into planetesimals /grains: A solar system in the making.



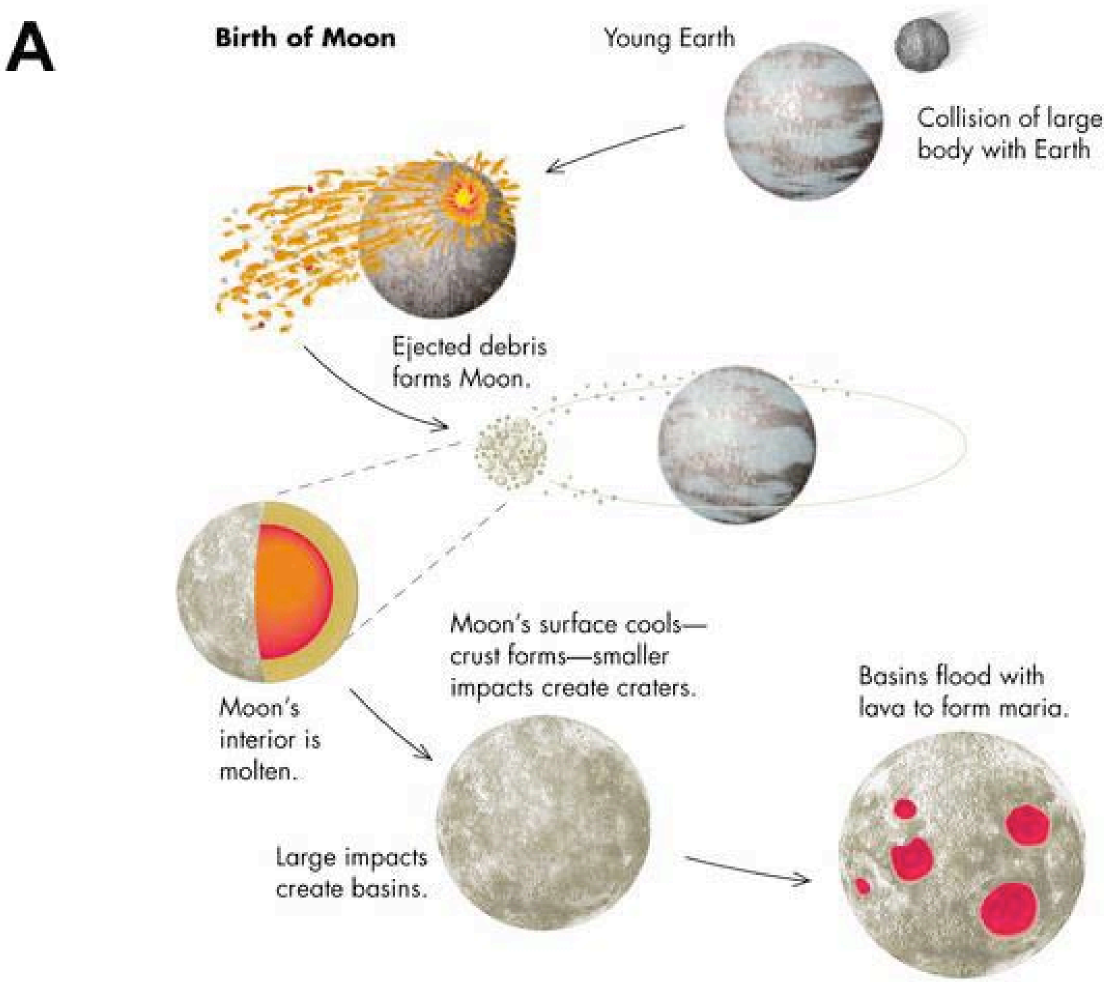
>20,000 asteroids
between Jupiter & Mars



Ice-rich Kuiper Belt
Objects (KBOs)
at 35-1000 AU

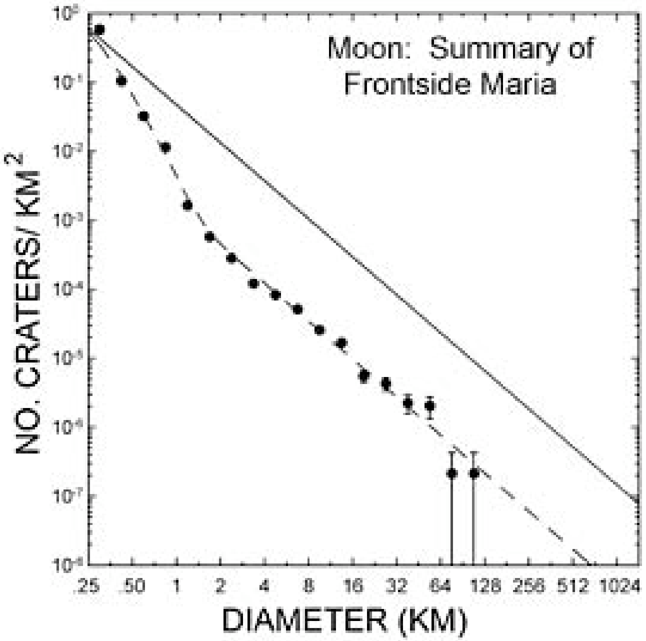
Oort Cloud: a swarm of
10^{12}-10^{13} comets larger
than 1 km in size, orbits at $>10^4$ AU

The Earth-Moon system



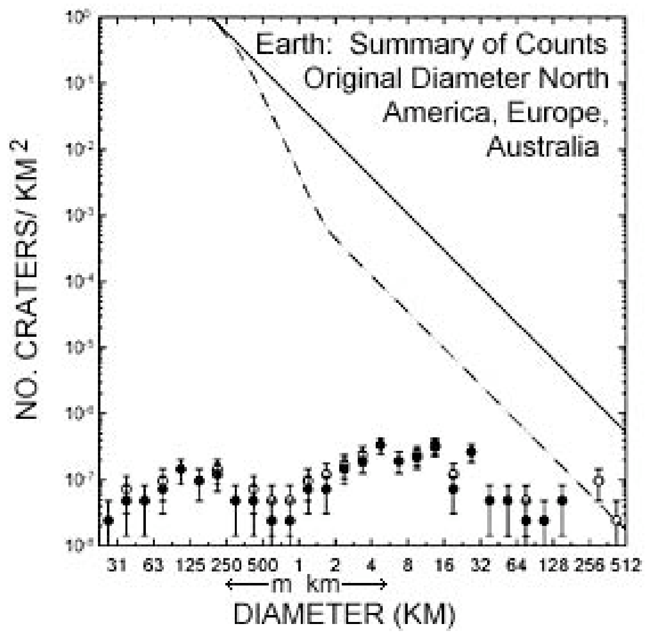
The Moon formed as a result of a large collision with a Mars-sized object. The large impactor coalesced with the proto-Earth, causing much of the planet to melt. Under such conditions, iron (being dense) separated into the Earth's core. However, the impact caused considerable debris to be ejected into orbit around the Earth from the Earth's mantle. The debris accreted to form the Moon.

A violent youthful neighborhood



When an asteroid or comet hits a planet, it makes an **impact crater**. Such craters accumulate with time.

Moon Fig. Crater size distribution in 3.4 Ga lunar lava plains. The line turns up at small sizes because of many small impacts due to "secondary" fragments blown out of craters. The solid line is the crater distribution in very heavily cratered uplands called **saturation equilibrium**; if you added a new crater at this crater density, the new one would obliterate older craters and on average the line would stay about the same.



Qu.) (a) Why are there so fewer craters on the Earth?

(b) At what diameter does the Earth have similar or somewhat greater crater density than the Moon?