Extraterrestrial Life: Lecture #8

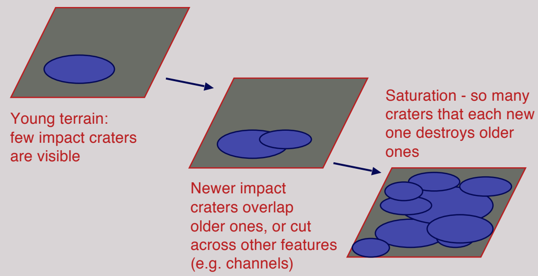
New homework: due next Thursday… can post queries of general interest at www.et-life.blogspot.com

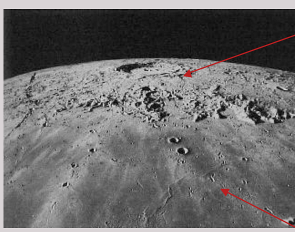
Last time: long term climate regulation

Today: dating of rocks and surfaces

- when was the first life on Earth?
- how has the atmosphere evolved over billions of years?
- which planets have been volcanically active, and when did that activity cease?

Relative ages of terrain on Moon, Mars, Mercury etc can often be determined visually by looking at the cratering on the surface

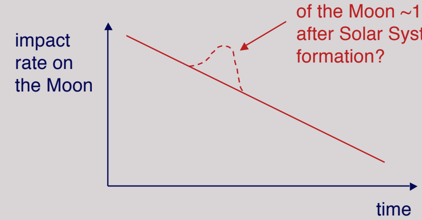




Heavily cratered terrain: ~4.6 billion years old

Younger terrain: ~3 billion years old

Overall, the rate of cratering has declined since the early history of the Solar System



Venus has relatively few impact craters:

- small bodies will not penetrate the atmosphere
- lack of **large** craters suggests that the surface is resurfaced relatively often

Galilean satellite of Jupiter: same environment but very different patterns of cratering on the surface

Absolute age dating

Absolute dating of rocks is possible in the lab, by measuring the abundance of radioactive elements and their decay products

An **isotope** is an atomic nucleus with a given number of protons and neutrons:

e.g. Carbon-12 has 6 protons and 6 neutrons
…carbon-13 has 6 protons and 7 neutrons

Radioactive isotopes are unstable, and decay into other isotopes (`daughter' isotopes) via a variety of processes

Example: decay of uranium 238

$$^{238}\mathrm{U} \rightarrow {}^{234}\mathrm{Th} + {}^{4}\mathrm{He}$$

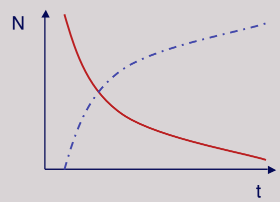
The timescale for this reaction is 4.5 billion years. The thorium is itself unstable and eventually decays to a stable isotope of lead.

Radioactive decay is probabilistic - cannot be predicted.

Given one atom of ^{238}U, there is a **fixed probability** that it will decay in the next second. If it survives, there is the same chance of decay in the next second.

The **half-life** is the timescale on which 50% of the original nuclei will have decayed - varies enormously among different radioactive isotopes

Result is exponential decay of the abundance of the parent nucleus



$$N(t) = N_0 e^{-t/\tau}$$

number of nuclei originally present (N_0)

decay time (τ)

Example: ^{40}K -> ^{40}Ar

Suppose that when a rock solidifies, a small sample of it contains 1000 atoms of radioactive potassium

After one half-life (1.25 billion years):

- ~500 parent nuclei (^{40}K) remain
- ~500 daughter nuclei (^{40}Ar) have been formed, and remain trapped in the rock

If we **measure** a 50/50 ratio between potassium and argon, can conclude that the rock is one half-life or 1.25 billion years `old' - that's when it last solidified so as to trap the daughter products…

This works because rocks have very specific chemical composition - uranium is *not* uniformly spread throughout the Earth but rather is concentrated in particular minerals

In the previous example, *before* the rock formed the potassium would still decay, but the argon would escape and would not be incorporated into the same material

Long-lived isotopes

Rely on long-lived isotopes to date the formation of the Solar System and the age of the Sun

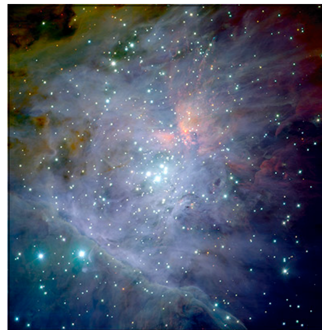
- no rocks on Earth survive from the first ~500 million years
- oldest rocks are parts of meteorites that contain calcium and aluminium
- dated at 4.567 billion years old, using uranium / lead chronometer

This age is conventionally the `age of the Solar System'

Short-lived isotopes

Short-lived (much less than a billion years) isotopes are useless for dating the Solar System - they've all decayed long ago. Rather:

- constrain the birth environment of the Sun - isotopes form in supernova explosions so if we see the daughter products trapped in rocks we know the rocks must have formed not so long after a supernova explosion
- can be used to date relative events early in the Solar System history - e.g. the formation of the Moon



The Orion Nebula and Trapezium Cluster
(VLT ANTU + ISAAC)

ESO PR Photo 03a/01 (15 January 2001) © European Southern Observatory

^{26}Al decays with a half-life of only 700 thousand years

Presence of this isotope at above average abundance in the early Solar Nebula suggests formation in a dense cluster of stars

Reliability of radioactive dates depends upon knowing that the rock is unaltered since formation:

- lunar samples: re-evaluation of the formation of the Moon last year (40 million years after the formation of the Solar System)…cosmic ray contamination

- terrestrial samples: **igneous** rock has solidified from a liquid; **metamorphic** rock has been transformed by high pressure; **sedimentary** rock is compressed sediments

Often, errors are not dominated by difficulties of the measurement, but by possible systematic effects…