8.7 THERMAL HISTORIES OF PLANETS

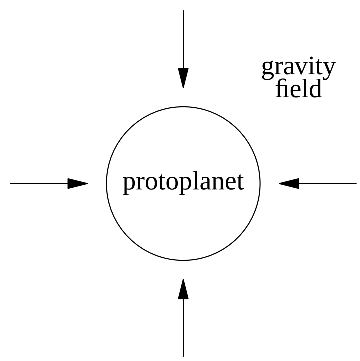
From the previous discussion, it should be clear that the evolution of any planet (including moons and asteroids) depends on

- -initial composition
- -thermal history

Since we saw that either accretion model required subsequent heating to produce the current, differentiated structure.

For this reason, geologists have devoted considerable effort to understanding how temperatures of planets evolve - this can only be done through complex computer models. Without going in to details - it is worth understanding a little bit about how these work.

Consider a 'protoplanet' which has formed through collisions of planetesimals. Now, it is large enough that it is attracting gravitationally a lot of the material in the neighborhood. What happens?



The accreting material brings in kinetic energy produced from gravitational potential energy. Some of this energy heats up the body, but some of this heat is reradiated into space.

The balance between these three effects is controlled by the *accretion rate*.

1) if material accretes very slowly it has time to radiate a lot of energy away and the planet heats up slowly.

2) if material accretes very rapidly it (and its heat) is buried before it has to radiate away much energy, so the planet heats up fast.

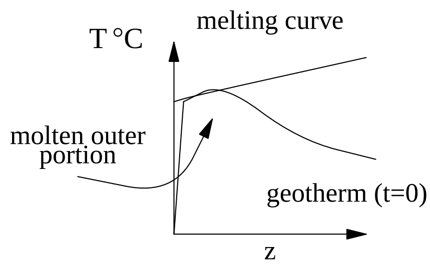
$$\frac{\rho G M(r)}{r}\frac{dr}{dt} = \varepsilon\sigma(T^4(r) - {T_0}^4) + \rho C_p(T(r) - T_0)$$

The first term shows that the gravitational potential energy of accretion depends on the mass that has already accreted - so as the planet grows, more heating occurs at the surface. The planet is often hottest on its outside surface, which can be totally molten.

In the second term, the radiation term, ε is the emissivity - this can be less than 1 if the planet has a proto - atmosphere: 1 if it has none. σ is the Stefan-Boltzmann constant or Stefan's constant (5.67 x 10^{-8}W m^{-2} K^{-4}).

The basic fact is that the shorter the time needed to accrete the planet - the hotter it is. current fads favor reasonably fast accretion - say for the moon 100-10000 years.

After accretion, the planets temperature field looks like



No scale is drawn since this depends on planet's size

What happens from here?

- -planet cools by radiation: outside cools off
- -inner regions heat up due to
  - a) radioactive decay
  - b) core formation - when temperature is high enough to melt iron, it sinks into the interior releasing energy
- -solid state convection occurs-moves heat upward from depth

The precise state of these curves depends on the individual planet and the assumptions made in the specific model (accretion time, radioactive distribution, etc)

Constraints on thermal models:

1) internal structure

2) measured heat flow

3) ages of rocks - can date when rocks first formed on surface to show when surface became solid. In some cases (moon) the last volcanic rocks were implaced a long time ago.

4) present day plate tectonic processes - observed various ways (especially on other planets)

How would this differ between planets?

Using thermal histories of the different planets allows "comparative planetology" - how and why they are different. It's thought that the thickness of the *lithosphere* is the key parameter.

Thin (~100km) lithosphere allows active plate tectonic processes - this occurs when a planet is "young and hot", like the earth.

Thick (> few 100 km) lithosphere occurs for "older and colder" planets with no active tectonics: moon, Mars.

An important note: "young" and "old" are stages of growth - not necessarily ages since planets have different sizes - the earth is now "young" and will get "older".

Traditional view:

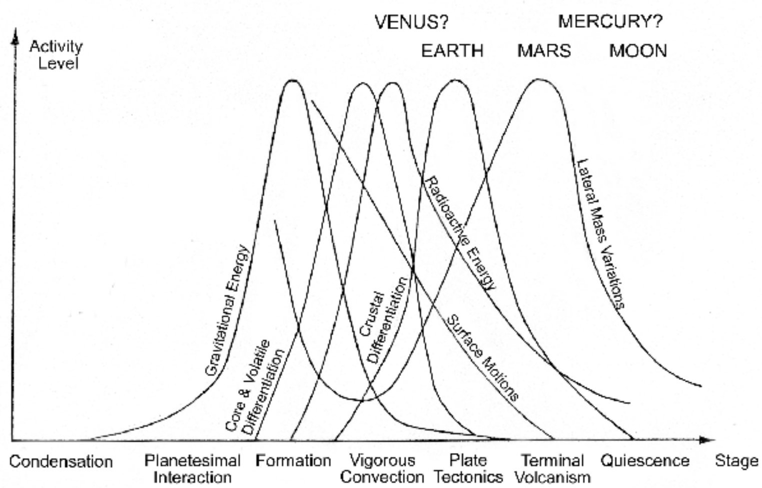
- -internal heat of accretion and radioactivity ~ volume ~ r^3

- -heat loss proportional to surface area ~ r^2

- - cooling rate approximately $\frac{r^2}{r^3} = \frac{1}{r}$

So smaller planets should cool faster (e.g. moon, Mars, Mercury) and be later in their evolution - thick, cold lithosphere.

It had been assumed that Venus would be at a stage similar to the earth and have plate tectonics. Thus, the Magellan results were surprising in that they show little evidence for plate tectonics. If anything, the higher surface temperatures on Venus (due to a runaway greenhouse effect) should keep the internal temperatures higher. Thus, people originally thought Venus may be even "younger" than the earth. Magellan implies Venus is "older" - with no resurfacing in ~ 500 Ma. Why?



The kinds of thermal models for plate tectonics tells us how it transfers heat from the earth's interior. This is important because how a planet works depends on heat transfer. ("heat is the geological lifeblood of a planet")

Balance between heat loss by:

-plate tectonics (earth 70%)

-mantle plumes/hotspots (earth 5%)
estimated from swells

-conduction through continents(earth 25%)

On other planets:

-lithosphere much thicker (maybe?)

-no plate tectonics

-heat transfer by conduction