Astronomy 311: Lecture 3 - Planetary Geology

- Terrestrial Planets
  - Layering by density: Core, Mantle, Crust
  - Core: Highest density material, consisting primarily of metals such as nickel and iron in the central core.
  - Mantle: rocky materials of moderate density, minerals that contain Si, O. Thick region surrounding the core.
  - Crust: lowest density rock, granite, basalt forms the outer crust.
  - Seismic studies imply the core consists of two distinct regions: a solid inner core and a molten (liquid) outer core.
  - Generally temperature increases with depth in a terrestrial planet - so how can the inner core be solid whilst the outer core is liquid.
  - Ideal gas law: \( PV = RT \).
  - Inner core is kept solid by the higher pressure at this depth even though the temperature is also higher eg. easier to boil water at the top of Mt. Everst than on the ground.
  - Layering occurs simply because of gravity: highest density material sinks in a liquid: this is differentiation.
  - Thus the temperature was once hot enough inside for their interior rock and metal to melt.
  - Rocks can vary in strength significantly.
  - Rocky material can deform and flow over millions and billions of years.
  - Rocky material breaks when subjected to a sharp force but can deform and stretch when subjected to a slow force over a long period of time.
  - This is why larger SS objects are spherical whilst smaller ones are not: for a larger object, gravity can overcome the strength of solid rock, turning it slowly into a spherical shape. Any rocky object greater than about 500km in diameter will turn into a sphere over a period of about 1 billion years. It helps is the object is molten or gaseous at some point.
  - A planet’s outer layer consists of cool, rigid rock: the lithosphere. This ”floats” on the warmer, softer rock underneath. The lithosphere includes the crust and part of the mantle.
  - Beneath the lithosphere, in the lower part of the mantle, the higher temperatures allow rock to deform and flow much more easily.
A thin lithosphere is brittle and can crack easily whilst a thick lithosphere can prevent volcanic eruptions and the creation of mountain ranges.

• Comparative geology for the terrestrial worlds

– Basic structure is the same: thin crust, thicker mantle and central core.
– There are differences linked to planetary size.
– Generally smaller planets have smaller cores but Mercury has a surprisingly large core for its size - perhaps it once suffered a giant impact which blasted away much of its original mantle and crust. Mercury has a high density (5.43g/cm$^3$) indicating a large core (why?). Its core makes up about 70-80% of the planet’s mass: the Earth’s core makes up only about 32% by mass.
– Mariner 10 measurements also indicated Mercury has a magnetic field (see later: small planets are not supposed to have magnetic fields).
– Recent results suggest the core is molten (ie. semi liquid state) - project?.
– Moon’s core seems surprisingly small compared to its size - could be consistent with the theory that the Moon was ”blasted” of the Earth somehow.
– Lithospheric thickness is inversely related to terrestrial planet size: Mercury and Venus have thick lithospheres (almost to the core) whilst Earth (perhaps 150km?) and Venus have thin lithospheres.
– Major differences in geological activity: change in the surface.
– For example, the Earth is geologically active due to volcanic eruptions, earthquakes, erosion etc.
– However, the Moon and Mercury have almost no geological activity - thats why their surfaces are virtually the same now as a billion years ago.
– Interior heat is the primary driver of geological activity: so what makes some planets hot inside and others not (ie. Earth and Venus are hot inside and Mercury and the Moon are not so hot inside).
– Hot interior means a lot of ”thermal” energy which must have come from somewhere - law of conservation of energy.
– Where does this energy come from? Not from the Sun which only heats up the surfaces to a depth of about a few metres.
– 3 sources:
Heat of accretion: growing planetesimals gains heat in the interior by collisions with other planetesimal (pe to ke to collisions) etc.

Differentiation converts gpe to thermal energy. Drop a brick into a pool. As the brick sinks, friction with the water heats the pool.

Radioactive isotopes in planetesimals decay and release heat - can be quite large especially when the planet was young.

Process started by initial collisions/impacts which melted outer layers and then other two processes join in.

- Cooling off
  - This heat is transported to the outside by 3 processes:
    - Convection: hot material expands and rises and cool material contracts and sinks.
    - Conduction: transfer of heat through contact.
    - Radiation - radiating light (photons) from A to B. Planet loosed heat from its surface in this way.
  - Remember all objects emit thermal radiation characteristic of their temperatures. Also remember Wien’s law.

- Convection cells in the mantle: hot rock rises upwards, deposits its energy at the top and then sinks. Moves 1cm/year and takes $100 \times 10^6$ years to complete a cycle.

- Mantle convection stops at the lithosphere because the lithosphere is too strong for convection.

- Now heat flows to surface by conduction and then radiated away into space.

- Planetary size
  - Size is the most important factor in planetary cooling.
  - A large planet can stay hot much longer than a small one. A large planet is a small planet insulated with a lot of rock layers. Heat from the inside of a large planet takes much longer to reach the surface than heat from a small planet.
  - For example, the small sizes of the moon and Mercury allowed their interiors to cool only a billion years or so after their formation.
  - As they cooled, their lithospheres thickened and mantle convection was confined to deeper and deeper layers with mantle convection having stopped now.
  - With insufficient heat to drive any rock movement, the moon and Mercury are "geologically dead". That is no heat-driven geological activity.
– In contrast, the larger Earth is still hot inside. Mantle convection keeps interior rock in motion and the heat keeps the lithosphere thin and so geological activity can continually reshape the surface.

– Venus is probably as active as the Earth with Mars an intermediate case.

– What's important is the surface area to volume ratio in cooling. Small planets have a large surface area to volume ratio but large planets have a small surface area to volume ratio.