

Chapter 6: Earth and Moon

Earth: a highly differentiated body.

Interior:

average density = 5.5 grams/cm^3

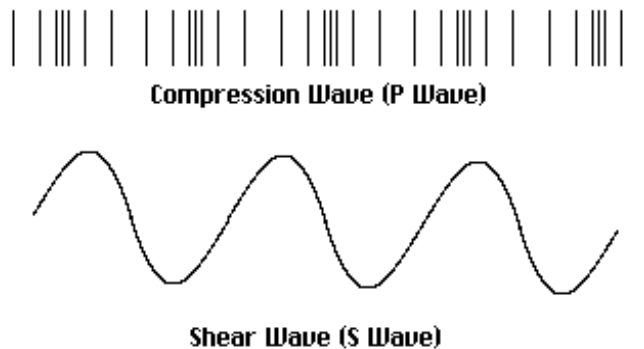
-----> very dense core (13.3 grams/cm^3)

surface rocks: density = 3 grams/cm^3

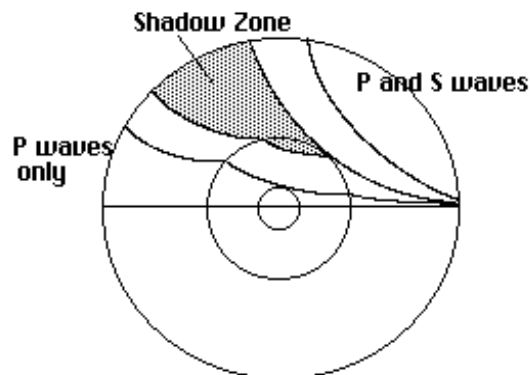
Seismic Waves: tool by which geologists study the Earth's interior.

P Waves: primary waves, compression waves, fastest ($5\text{-}6 \text{ km/sec}$), travel through liquids.

S Waves: secondary waves, shear waves, slowest ($3\text{-}4 \text{ km/sec}$), absorbed by liquids.

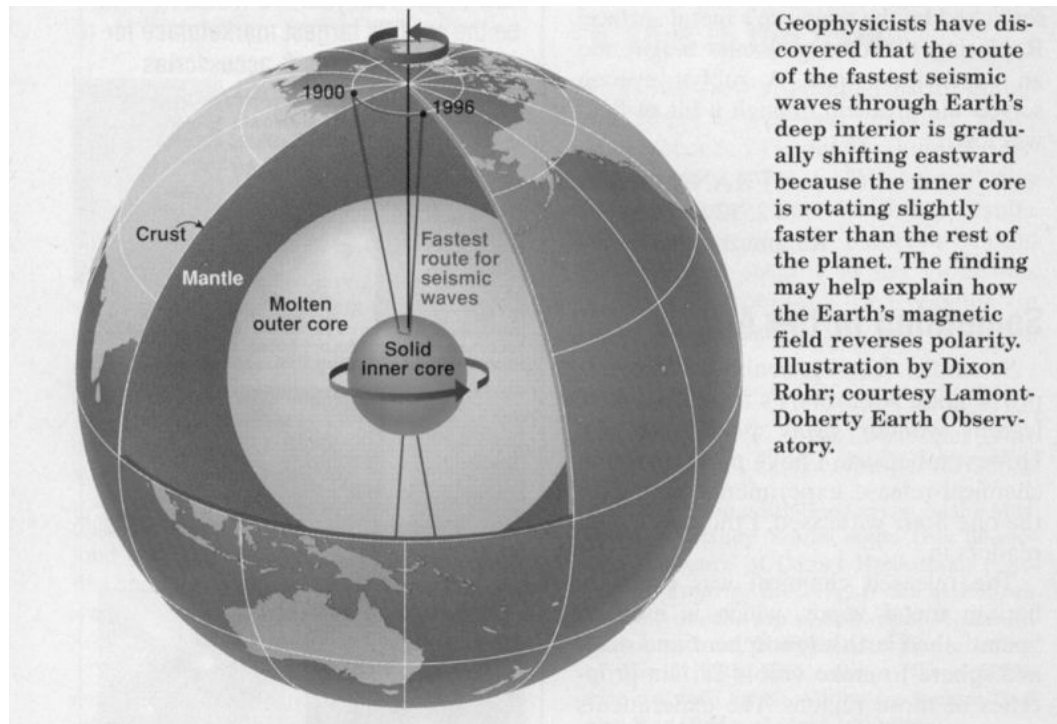


Detection of the Earth's core: liquid core creates a shadow zone where p and s waves are not detected.



Presence of a solid inner core is confirmed by the presence of weak reflections off the solid inner core into the shadow zone during earthquakes.

Inner core rotates faster than molten core by $\frac{2}{3}$ of a second per day as determined by timing seismic waves through the north-south direction vs. the equatorial direction. This faster rotation may account for the Earth's magnetic axes flipping.



Internal Structure: divided into three major regions. The crust (lithosphere), mantle (mesosphere) and the core.

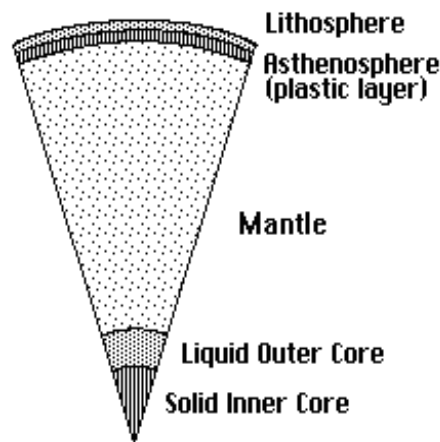
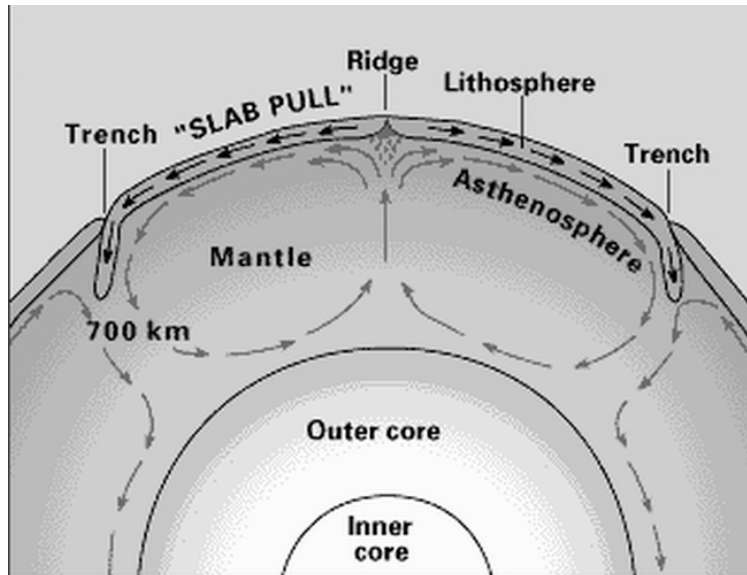


Plate Tectonics:

Earth's crust is divided into continental plates that ride the 'plastic' asthenosphere. Heat from the molten core sets up convection within the asthenosphere (source of the heat is radioactive decay) which drives the plate movement.



Concept Test

The Earth's core is hot due to

- a) solar heating.
- b) large scale meteoroid bombardment.
- c) radioactivity.
- d) heat left over from the Earth's formation.
- e) both c and d

Surface:

Rock Types:

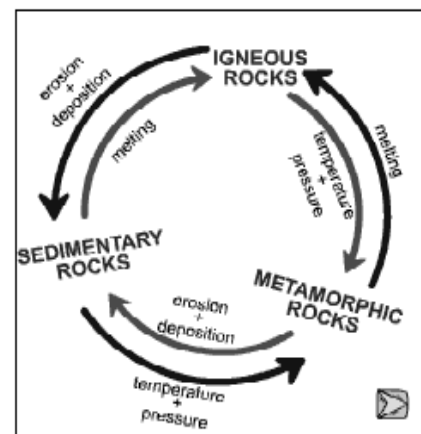
Igneous: volcanic

Metamorphic: modified by high temperatures and pressure.

Sedimentary: formed by erosion and deposition

Rock Cycle:

The Earth continuously recycles rocks. New rocks are formed by lava during volcanic eruptions. Wind and rain weather igneous rocks to form sedimentary rocks.



Rock cycle.

(TAT)

Sedimentary rocks subjected to heat and pressure are transformed into metamorphic rocks. Metamorphic rocks are melted to form fresh lava.

Composition of Crust: 45% silicon, 27% oxygen. Silicon and oxygen form minerals called silicates.

Concept Test

Over the last 10 - 100 million years, the largest scale changes on the surface of the Earth were caused by

- a) glaciation.
- b) erosion by wind and water.
- c) man made pollutants.
- d) continental drift.
- e) comets and asteroids.

Processes that change the Earth's surface:

- a. erosion (primary reason impact craters are not seen)
- b. plate tectonics

Atmosphere: 78% nitrogen, 21% oxygen, 1% argon, 0.03% carbon dioxide, less than 2% water vapor.

Origin of Atmosphere:

1. Original atmosphere (volatile elements) boiled off?
2. Volcanic activity released heavier gases:
 - a. nitrogen
 - b. sulfur compounds
 - c. carbon dioxide
 - d. water vapor
 - e. chlorine
3. Carbon dioxide is absorbed by rocks.
4. Life enhances oxygen and nitrogen.

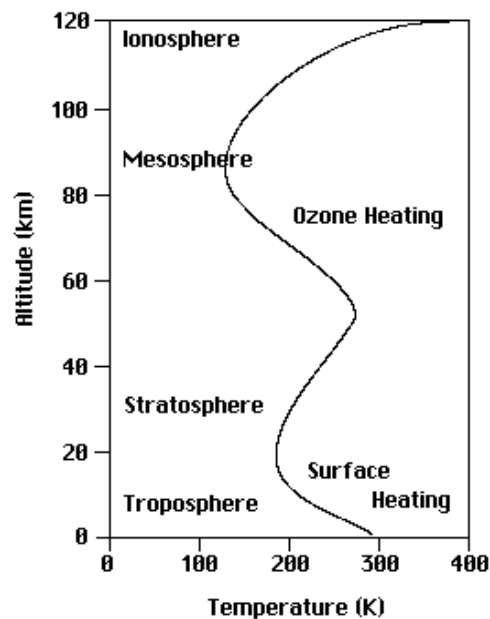
Structure of Atmosphere

Troposphere - region where clouds and weather occurs. Temperatures decrease from the surface to around -67 F.

Stratosphere - region of the ozone layer where UV sunlight is absorbed causing ozone heating, where the temperature climbs to around 50 F at the top.

Mesosphere - temperatures decline to around -105 F.

Thermosphere (Ionosphere) - Sun's UV ionizes atoms producing a heating effect, and AM radio waves bounce off this layer



Greenhouse Effect

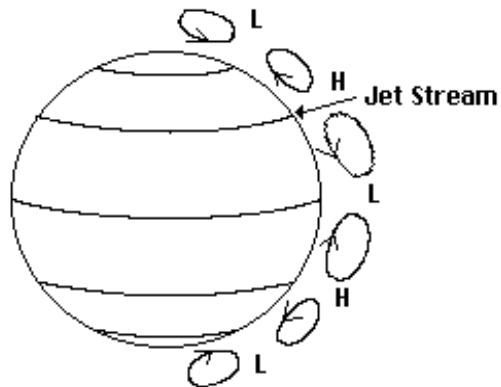
Visible radiation is absorbed by the earth's surface which re-radiates the solar radiation as heat that is absorbed by carbon dioxide and water vapor. Increased carbon dioxide levels caused by burning of fossil fuels will cause the Earth's atmosphere to become warmer than normal. This in turn will cause melting of polar ice caps and flooding of low lying lands.

Atmospheric Circulation:

Low pressure: regions of warm air rising.

High pressure: regions of cool air falling.

Earth's rotation breaks the circulation pattern into cells.



Ozone: Filters out ultraviolet radiation. CFCs break down the ozone.

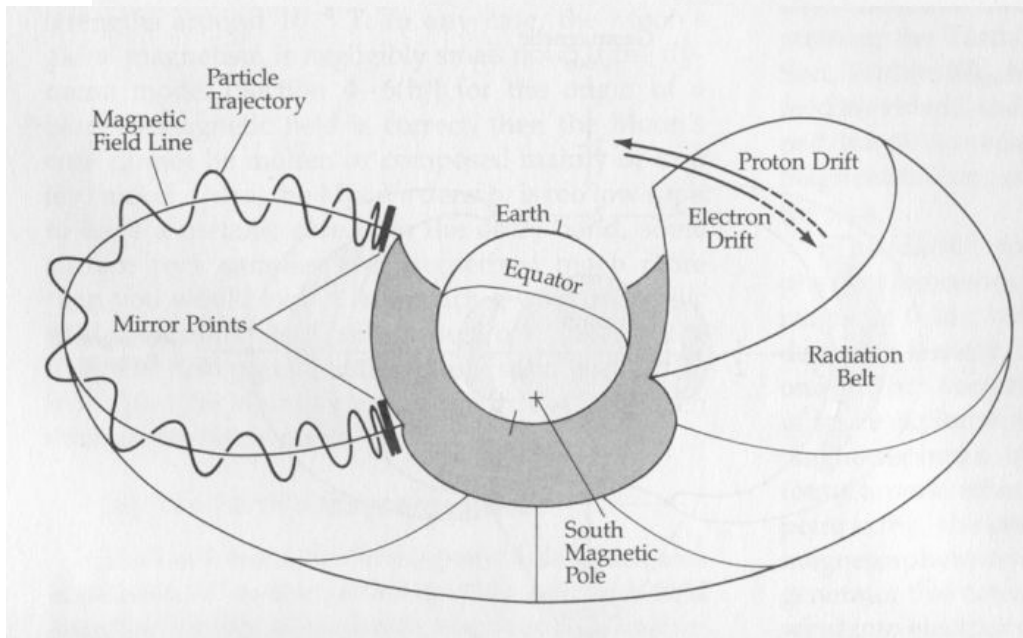
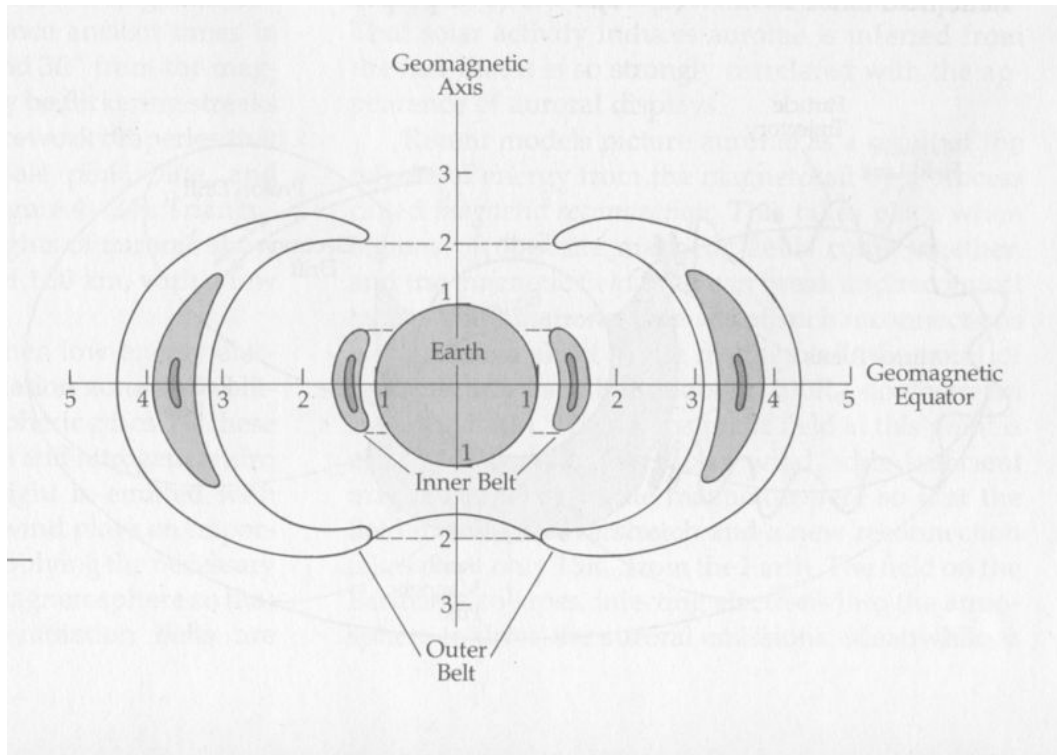
Magnetosphere

Magnetosphere: region of magnetic lines of force that surrounds the Earth.

Magnetic Field: molten core plus rotation produces a magnetic field (dynamo effect).

The magnetic poles have switched directions throughout the Earth's history as recorded in the geological record. This may be due to the fact that the solid inner core rotates faster than the molten outer core.

Van Allen Belts: regions within the magnetosphere that trap high energy electrons and protons from the solar wind.



Aurora: regions around the magnetic poles where high concentrations of charged particles reach the atmosphere.

The Moon

Basic Data:

Density = 3.3 grams/cm³

Diameter = 3476 km

Synodic Month = 29.5 days

Sidereal Month = 27.3 days

Orbital Inclination = 5 degrees

Surface Gravity = 1/6 Earth's Gravity

Atmosphere: none

Surface Features

Craters:

- impact craters: ejecta blankets, secondary craters, round shape, rays (most are of this type).

- volcanic craters: domes topped with crater, elongated craters

Maria: "Lunar Seas", Volcanic flows that have filled in large impact basins resulting from asteroid impacts. Very young features. Youngest features are impact craters on the maria.

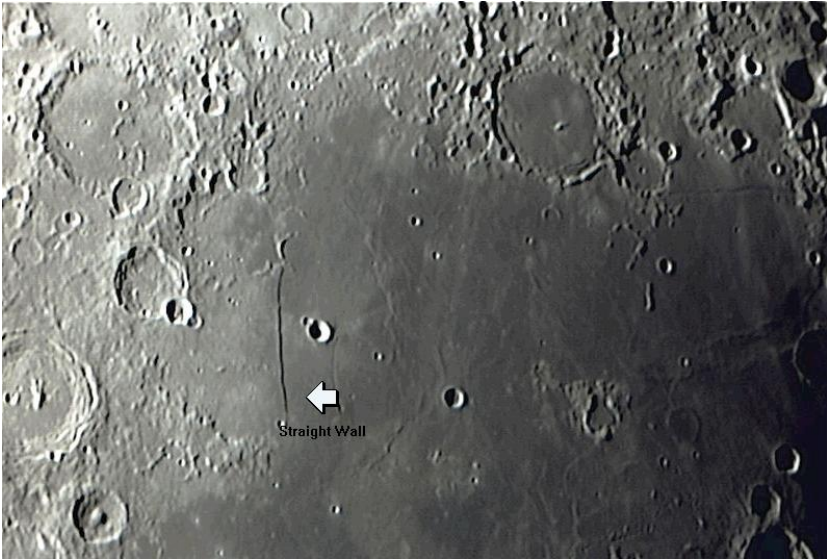
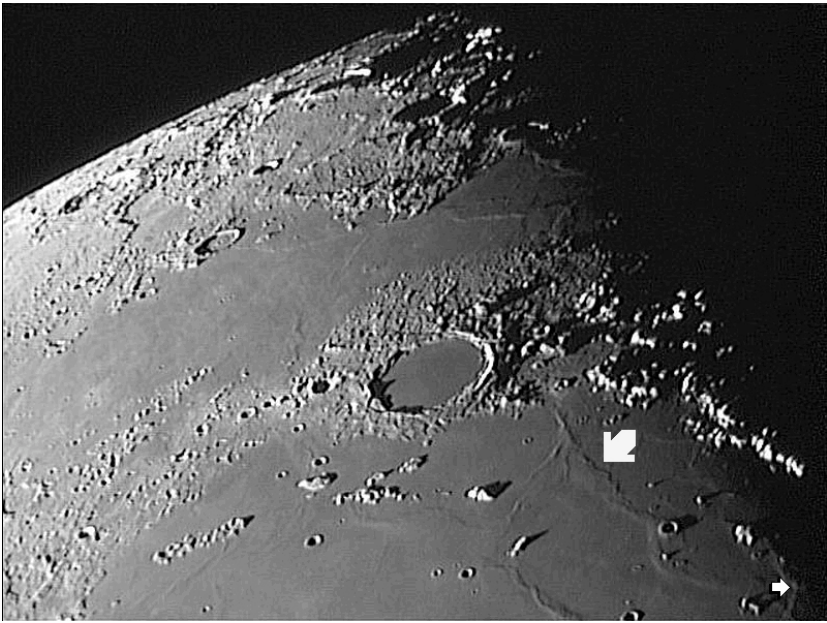
Highlands: Oldest features. Formed by bombardment by meteoroids. Made of lower density rock.

Concept Test

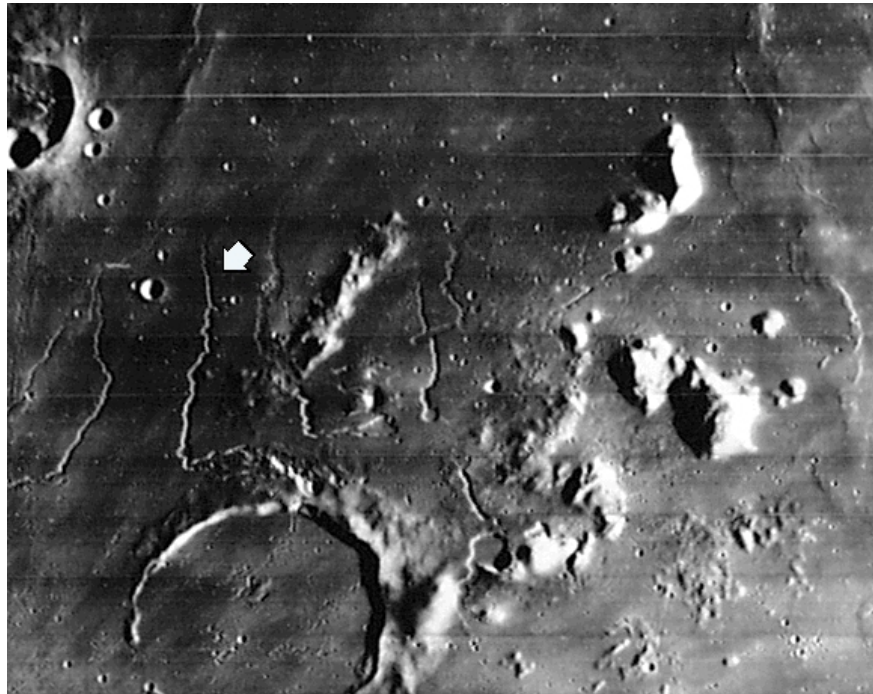
The reason that the Earth's surface has few meteor craters compared to the Moon is that

- a) the Moon blocked almost all meteoroids that otherwise would have hit the Earth.
- b) the atmosphere causes all objects entering from space to burn up before they hit the ground.
- c) the Earth's surface has been modified by various forces which cover or remove traces of the craters.
- d) all meteorite impacts break the crust and release lava from the mantle to fill in the hole.

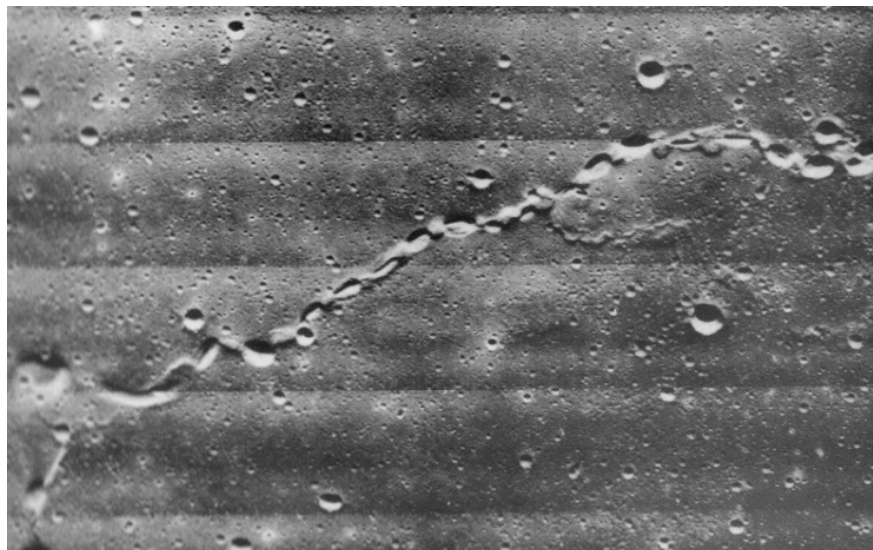
Rilles: Straight line features that were formed by surface movement



Sinuuous Rilles: Formed by volcanic lava flows. Often found flowing out of rimless craters.



Lava Tubes: Lava flowing in a channel will form a skin of solidified lava over the top creating an insulating layer, allowing the lava to flow farther from its source.



Composition

Basalts: igneous rocks formed from cooling lava. Maria.

Breccias: rock fragments fused together by impacts. Highlands.

KREEP: Potassium, rare earth elements, and phosphorus rich basalt. Highlands.

Age: Radioactive dating of lunar samples gives ages of about 3.1 to 3.9 billion years for the maria and 4.1 billion years for the highlands.

Concept Test

Why are some large crater walls sharp and steep while others are more rounded?

- a) Different volcanoes make different craters.
- b) Age differences.
- c) Size differences among the impact bodies.
- d) Composition differences among the impact bodies.
- e) Seismic activity on the Moon.

Interior: Picture is not clear. Low density of surface rocks indicates that the core is deficient in iron.

Lunar Seismology Results

Crust is on average 60 km thick. The side facing the Earth is slightly thinner (a result of the Earth's tidal pull on the Moon when it was still molten.

Core is about 700 km in diameter and may be partially molten. Core measurements were made using:

- a. Gravity measurements from Lunar Prospector.
- b. Magnetic field measurements from the induced field as the Moon moves through the Earth's magnetic field, using satellites released in orbit by Apollo 15 and 16.
- c. Libration measurements using laser pulses bounced off reflectors left behind by Apollo astronauts. Librations (apparent wobbling of the Moon) allow us to see about 59% of the Moon's surface. The librations are produced because of the inclination of the Moon's orbit and equator. The Moon rotates at a steady rate but because of the changing speed of the Moon in its eccentric orbit we see an apparent rocking motion along the east-west and north-south directions.

Lunar Libration: Over time, we can see more than 50% (~ 59%) of lunar surface because of lunar librations.

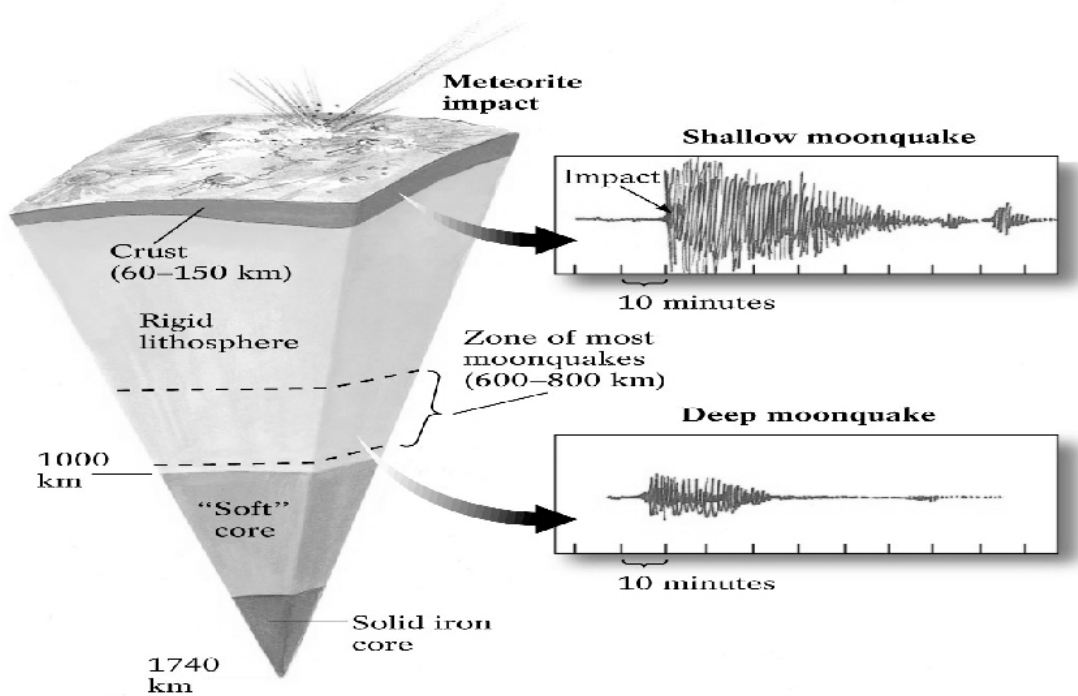
Daily libration: due to changing angle at which moon is viewed during the night (actually due to rotation of the Earth, but easily explained by daily rotation of celestial sphere around the Earth).

Libration in longitude:

Moon moves fastest when closest to Earth; rotation on its axis doesn't keep up.

Libration in latitude:

Occurs because Moon's rotation axis is inclined to axis of its orbit.



Photos Illustrating Lunar Libration

Origin of the Moon

Fission Hypothesis: Moon split off a fast rotating Earth leaving the Pacific Ocean.

Faults: 1. Material would not have remained in orbit.

2. Moon would have formed in equatorial plane.

3. Continental drift indicates that the Pacific Ocean could not have been formed according to the hypothesis.

4. Presence of KREEP material. If the Moon and Earth formed at the same time they would have the same composition. KREEP material is a type of basalt rich in potassium, rare earth elements and phosphorus relative to the Earth. KREEP is abundant in the highlands (ejected by collisions) and may represent material left over from the magma oceans that formed the maria.

Capture Hypothesis: Earth captured a minor planet.

Faults: 1. Lack of iron. Moon's composition should be similar to other minor planets.

2. Physically improbable.

Accretion Hypothesis: Moon formed from material left over in the Earth's orbit.

Faults: 1. Lack of iron is not explained.

2. Angular momentum between the Earth and Moon is not predicted.

3. Presence of KREEP material.

Impact Hypothesis: Moon was formed from the impact of a Mars sized body.

Explains:

1. Composition: Moon formed from the crustal portions of the Earth and impacting body. The iron in the Earth was already locked up in its core and the core of the impacting body would have been absorbed by the Earth. This would explain the lack of iron in the Moon.

2. Lack of volatiles: boiled off during vaporization resulting from the impact.

3. May explain presence of gold and platinum in Earth's surface (came from body that struck the Earth).

Tides and the Future of the Earth-Moon System

Tidal Friction slows the rotation of the Earth. Conservation of angular momentum causes the Moon's orbit to increase in size until the Earth keeps one face towards the Moon (Moon will be fixed over one location of the Earth). When this occurs the rotational period of the Earth will equal the rotation and revolution periods (~47 days) of the Moon. This will take several tens of billions of years, which is far greater than the probable life span of the Earth-Moon system.