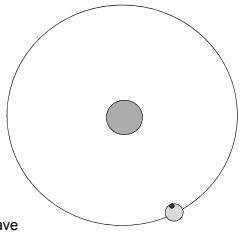
Chapter 12
The Moon and Mercury: Comparing Airless Worlds

The Moon: The View from Earth

From Earth, we always see the same side of the moon.

Moon rotates around its axis in the same time that it takes to orbit around Earth:



Tidal coupling:

Earth's gravitation has produced tidal bulges on the moon;

Tidal forces have slowed rotation down to same period as orbital period

Lunar Surface Features

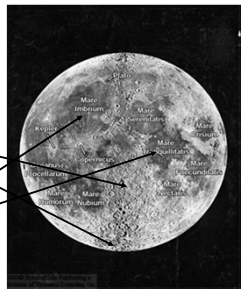
Two dramatically different kinds of terrain:

• Highlands: Mountainous terrain, scarred by *craters*

• Lowlands: ~ 3 km lower than highlands; smooth surfaces:

Maria (pl. of *mare*):

Basins flooded by lava flows



Highlands and Lowlands

Sinuous rilles = remains of ancient lava flows

May have been lava tubes which later collapsed due to meteorite bombardment.

The Highlands

Saturated with craters

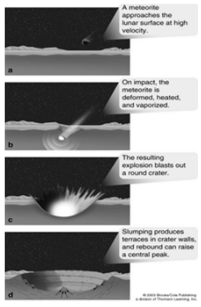
Older craters partially obliterated by more recent impacts

… or flooded by lava flows

Impact Cratering

Impact craters on the moon can be seen easily even with small telescopes.

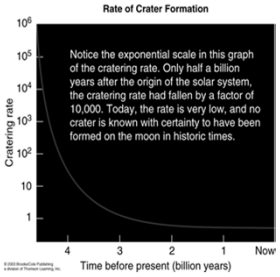
Ejecta from the impact can be seen as bright rays originating from young craters



History of Impact Cratering

Rate of impacts due to interplanetary bombardment decreased rapidly after the formation of the solar system.

Most craters seen on the moon's (and Mercury's) surface were formed within the first ~ ½ billion years.



Missions to the Moon

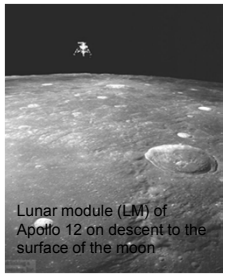
Major challenges:

Need to carry enough fuel for:
- in-flight corrections,
- descent to surface,
- re-launch from the surface,
- return trip to Earth;

need to carry enough food and other life support for ~ 1 week for all astronauts on board.

Solution:

• only land a small, light lunar module and leave everything behind that is no longer needed


Lunar module (LM) of Apollo 12 on descent to the surface of the moon

The Apollo Missions

Table 21-1 Apollo Lunar Landings

Apollo Mission*	Astronauts: Commander LM Pilot CM Pilot	Date	Mission Goals	Sample Weight (kg)	Typical Samples	Ages (10^9 y)
11	Armstrong Aldrin Collins	July 1969	First manned landing; Mare Tranquillitatis	21.7	Mare basalts	3.48–3.72
12	Conrad Bean Gordon	November 1969	Visit Surveyor 3; sample Oceanus Procellarum (mare)	34.4	Mare basalts	3.15–3.37
14	Shepard Mitchell Roosa	February 1971	Fra Mauro, Imbrium ejecta sheet	42.9	Breccia	3.85–3.96
15	Scott Irwin Worden	July 1971	Edge of Mare Imbrium and Apennine Mountains, Hadley Rille	76.8	Mare basalts; highland anorthosite	3.28–3.44 4.09
16	Young Duke Mattingley	April 1972	Sample highland crust; Cayley formation (ejecta); Descartes	94.7	Highland basalt; breccia	3.84 3.92
17	Cernan Schmitt Evans	December 1972	Sample highland crust; dark halo craters; Taurus–Littrow	110.5	Mare basalt; highland breccia; fractured dunite	3.77 3.86 4.48

*The Apollo 13 mission suffered an explosion on the way to the moon and did not land.

Apollo Landing Sites

First Apollo missions landed on safe, smooth terrain.

Later missions explored more varied terrains.


Apollo 11: Mare Tranquilitatis; lunar lowlands


Apollo 17: Taurus-Littrow; lunar highlands

Apollo Landing Sites (2)

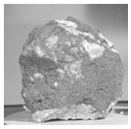
Selected to sample as wide a variety as possible of different lowland and highland terrains.

Moon Rocks

All moon rocks brought back to Earth are **igneous** (= solidified lava)
No sedimentary rocks => No sign of water ever present on the moon.

Different types of moon rocks:


Vesicular (= containing holes from gas bubbles in the lava) basalts, typical of dark rocks found in maria


Breccias (= fragments of different types of rock cemented together), also containing *anorthosites* (= bright, low-density rocks typical of highlands)


Older rocks become pitted with small micrometeorite craters

The History of the Moon

Moon is small; low mass → rapidly cooling off; small escape velocity → no atmosphere → unprotected against meteorite impacts.

Moon must have formed in a molten state ("sea of lava");

Heavy rocks sink to bottom; lighter rocks at the surface

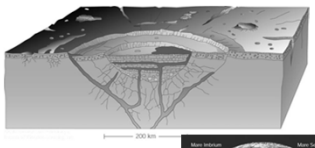
No magnetic field → small core with little metallic iron.

Surface solidified ~ 4.6 – 4.1 billion years ago.

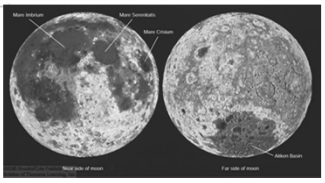
Heavy meteorite bombardment for the next ~ ½ billion years.

Alan Shepard (Apollo 14) analyzing a moon rock, probably ejected from a distant crater.

Formation of Maria

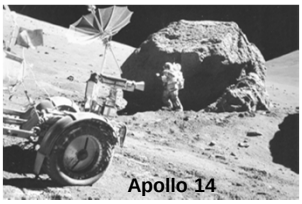


Impacts of heavy meteorites broke the crust and produced large basins that were flooded with lava



Formation of Maria (2)

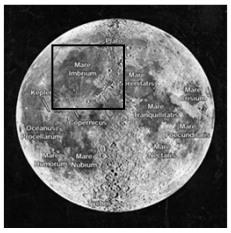
Major impacts forming maria might have ejected material over large distances.

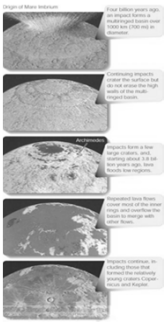


Large rock probably ejected during the formation of Mare Imbrium (beyond the horizon!)

Origin of Mare Imbrium

Terrain opposite to Mare Imbrium is jumbled by seismic waves from the impact.

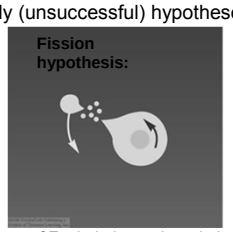




The Origin of Earth's Moon

Early (unsuccessful) hypotheses:

Fission hypothesis:



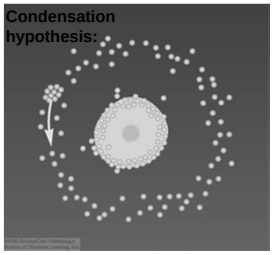
Break-up of Earth during early period of fast rotation

Problems: No evidence for fast rotation; moon's orbit not in equatorial plane

The Origin of Earth's Moon

Early (unsuccessful) hypotheses:

Condensation hypothesis:



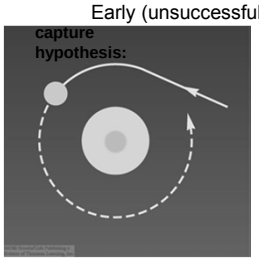
Condensation at time of formation of Earth

Problem: Different chemical compositions of Earth and moon

The Origin of Earth's Moon

Early (unsuccessful) hypotheses:

capture hypothesis:



Capture of moon that formed elsewhere in the solar system

Problem: Requires succession of very unlikely events

Modern Theory of Formation of the Moon

The Large-Impact Hypothesis

- Impact heated material enough to melt it

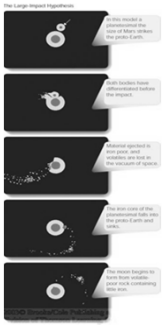
→ consistent with "sea of magma"

- Collision not head-on

→ Large angular momentum of Earth-moon system

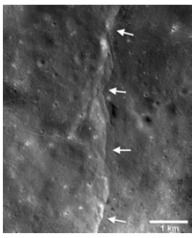
- Collision after differentiation of Earth's interior

→ Different chemical compositions of Earth and moon



New Discoveries

Tidal Forces Massaging Moon



Thousands of small (< 10 km) thrust fault scarps have been found on the Moon by the NASAs Lunar Reconnaissance Orbiter (LRO). These tiny faults are oriented in such a way that scientists have concluded that they are caused by the combination of lunar shrinking and tidal forces caused by the Earth.

http://moon.nasa.gov/newsdisplay.cfm?Subsite_News_ID=50263&SiteID=6&SiteID=1

New Discoveries

The Moon has an atmosphere!

NASAs LADEE mission has revealed a very thin atmosphere that contains traces of neon, hydrogen and helium. The atmosphere is thought to be the result of near continuous impacts from micrometeorites and the solar wind. The Moon's atmosphere has a pressure only 1 billionth of the Earth's!

http://sservi.nasa.gov/articles/nasas-ladee-spacecraft-finds-neon-in-lunar-atmosphere//

New Discoveries

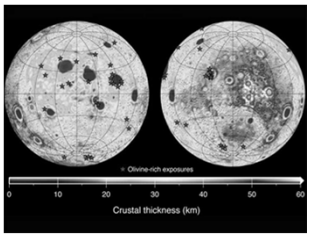
The Moon has water!

NASAs Moon Mineralogy Mapper on India's Chandrayaan-1 mission has detected traces of water near the lunar surface. This water is believed to have come from sources deep in the Moon and was seen at high latitudes. This new finding will undoubtedly change the currently accepted model of lunar formation.

http://www.jpl.nasa.gov/news/news.php?release=2013-262/

New Discoveries

The Moon's gravity field shows its geology!



NASAs GRAIL mission has revealed an uneven distribution of materials beneath the surface, pointing to a much later end to impacts than previously thought.

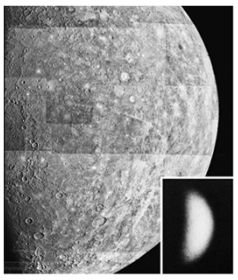
http://solarsystem.nasa.gov/news/2013/11/07/nasas-grail-mission-puts-a-new-face-on-the-moon/

Mercury

Very similar to Earth's moon in several ways:

- Small; no atmosphere
- lowlands flooded by ancient lava flows
- heavily cratered surfaces

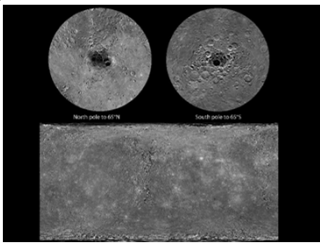
Most of our knowledge was based on measurements by Mariner 10 spacecraft (1974 - 1975)



View from Earth

Mercury (2)

The recently completed Messenger mission added a lot of detailed information, including the first complete images of the entire planet.



http://www.nasa.gov/mission_pages/messenger/multimedia/messenger_gallery.html

Rotation and Revolution

Like Earth's moon (tidally locked to revolution around Earth), Mercury's rotation has been altered by the sun's tidal forces,

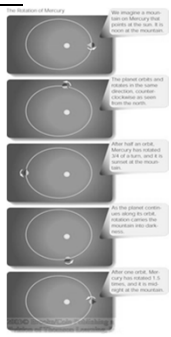
but not completely tidally locked:

Revolution period = 3/2 times rotation period

Revolution: ≈ 88 days
Rotation: ≈ 59 days

→ Extreme day-night temperature contrast:

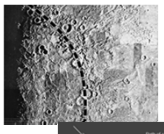
100 K (-173 ºC) – 600 K (330 ºC)



The Surface of Mercury

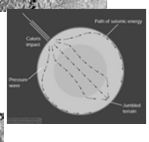
Very similar to Earth's moon:

Heavily battered with craters, including some large basins.



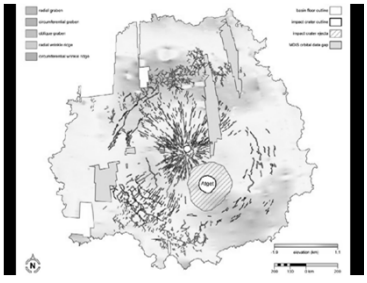
Largest basin: **Caloris Basin**

Terrain on the opposite side jumbled by seismic waves from the impact.



Caloris Basin

Detailed geologic map of the Caloris Basin made from information gained from the Messenger spacecraft.



http://www.nasa.gov/mission_pages/messenger/multimedia/messenger_gallery.html

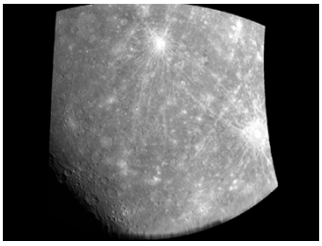
"New" Large Impact Basin

Messenger's more complete coverage of Mercury has led to the discovery of new impact basins, such as Rembrandt (700 km across). Rembrandt is relatively young (4 by).

http://apod.nasa.gov/apod/ap090504.html

Craters on Mercury

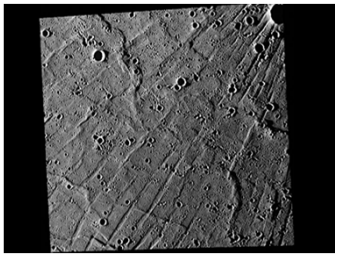
The upper crater is Kuiper, named for Dutch-American planetary astronomer and Mariner 10 team member Gerard Kuiper (1905-1973). At the right edge is the 80-km diameter crater named for French composer Claude Debussy (1862-1918).



http://www.nasa.gov/mission_pages/messenger/multimedia/messenger_gallery.html

Unusual Features

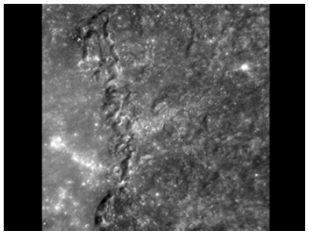
This image from 2011 shows the radiating troughs of Pantheon Fossae ("Fossae is Latin for trenches"). Pantheon Fossae a unique geologic feature on Mercury.



http://www.nasa.gov/mission_pages/messenger/multimedia/messenger_orbit_image20120913_1.html

Unusual Features (2)

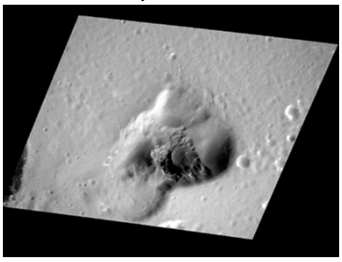
Raditladi is a relatively young basin; the depth from the floor to its rim is around 3.5 km (over 2 miles) as measured by the Mercury Laser Altimeter - twice the average depth of the Grand Canyon.



http://www.nasa.gov/mission_pages/messenger/multimedia/messenger_gallery.html

Unusual Features (3)

This kidney-shaped depression lies along the inner margin of the Caloris basin The depression is the vent of a small, explosive volcano, similar to other volcanic vents on Mercury.



http://www.nasa.gov/mission_pages/messenger/multimedia/messenger_gallery.html

Lobate Scarps

Curved cliffs, probably formed when Mercury shrank while cooling down

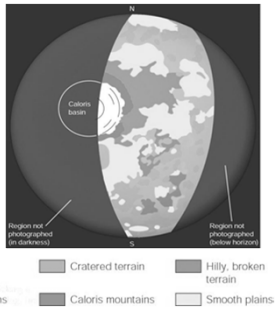
The Plains of Mercury

No large maria, but intercrater plains:

Marked by smaller craters (< 15 km) and secondary impacts

Smooth plains:

Even younger than intercrater plains



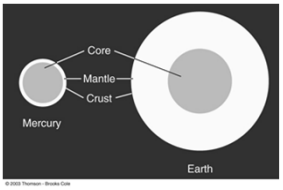
The Interior of Mercury

Large, metallic core.

Over 60% denser than Earth's moon

Magnetic field only ~ 0.5 % of Earth's magnetic field.

Possible remnant field from earlier.



Liquid metallic core should produce larger magnetic field.

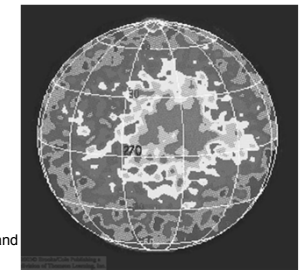
Solid core should produce weaker field.

History of Mercury

Dominated by ancient lava flows and heavy meteorite bombardment.

Radar images suggested icy polar cap.

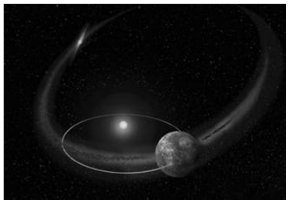
Messenger spacecraft confirmed that there is abundant frozen water and other volatiles deep in craters near the poles.



The ice is covered by a dark, organic-rich layer.

Mercury's Meteor Shower?

Messenger discovered that Mercury is probably being impacted by meteor showers on a regular basis, just like our planet.



https://www.nasa.gov/press/goddard/2014/december/messenger-data-suggest-recurring-meteor-shower-on-mercury