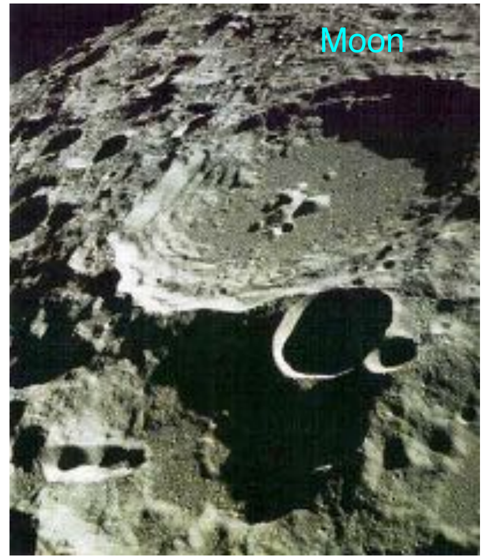
Reading for this week: Chap. 9, Sect. 7.3 (ages), 9.4-9.5, Chap. 10, Sect. 10.1-10.5
Homework 6: due in recitation Friday/Monday (Oct. 18, 21
Midterm grade estimates available on Canvas this week
Public Lecture (extra LC credit) : TONIGHT,8:15pm - MU Great Hall:
Dr. Chris Lintott: *"How to Find a Planet Without Leaving Your Couch*

Last time: **Planetary Surface Processes II**

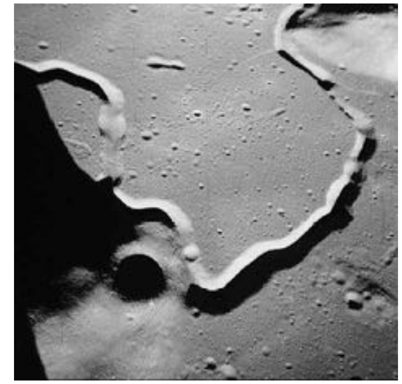
- (plate) tectonics
- Relative Ages via Crater Density
    - more craters, worn-down craters = older surface

Today: **Impact rates, absolute ages, and our Moon**

- Calibrating crater density ages - radioisotope dating
- Planetary Surfaces - the Moon
    - Highlands (old) & Maria (young)
    - impact history of the inner solar system
    - the Moon's surface history



An "old" surface on the lunar farside (4.0 billion yrs)

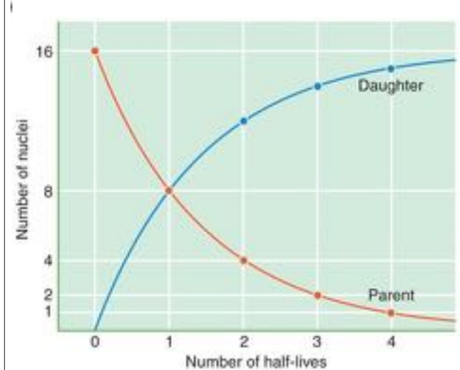


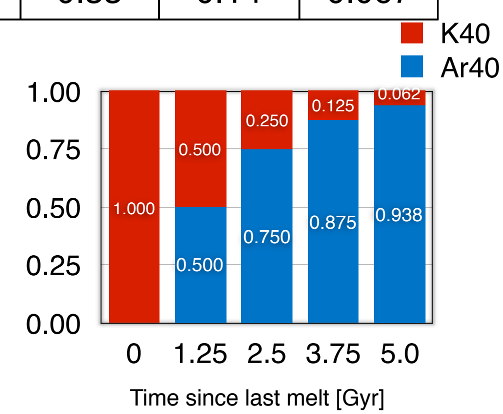
A "new" surface: Hadley Rille (3.2 billion yrs)

Absolute Ages from Radiometric Dating

- *unstable* isotopes
    - an unstable isotope is a form of an element with too many, or too few *neutrons*.
    - example: ^{12}C (6p, 6n) is 'normal' while ^{14}C (6p, 8n) has two extra neutrons, and is *unstable*
- radioactive decay
    - i.e. neutron changes to a proton+electron
    - occurs at random, but with well defined average rate
    - **half life** = time for 1/2 of the unstable isotopes to decay
        - intrinsic property of atomic nuclei
        - unchanged over time
        - specific for a given decay channel
- example: $^{40}K \rightarrow {}^{40}Ar$; half life = 1.25×10^9 yr

		1 half-life	2 half-lives	3 half-lives	4 half-lives
Element	**Start**	**1.25 Gyr**	**2.5 Gyr**	**3.75 Gyr**	**5.0 Gyr**
Potassium 40	1000	500	250	125	62
Argon 40	0	500	750	875	938
Ratio K/Ar	--	1	0.33	0.14	0.067





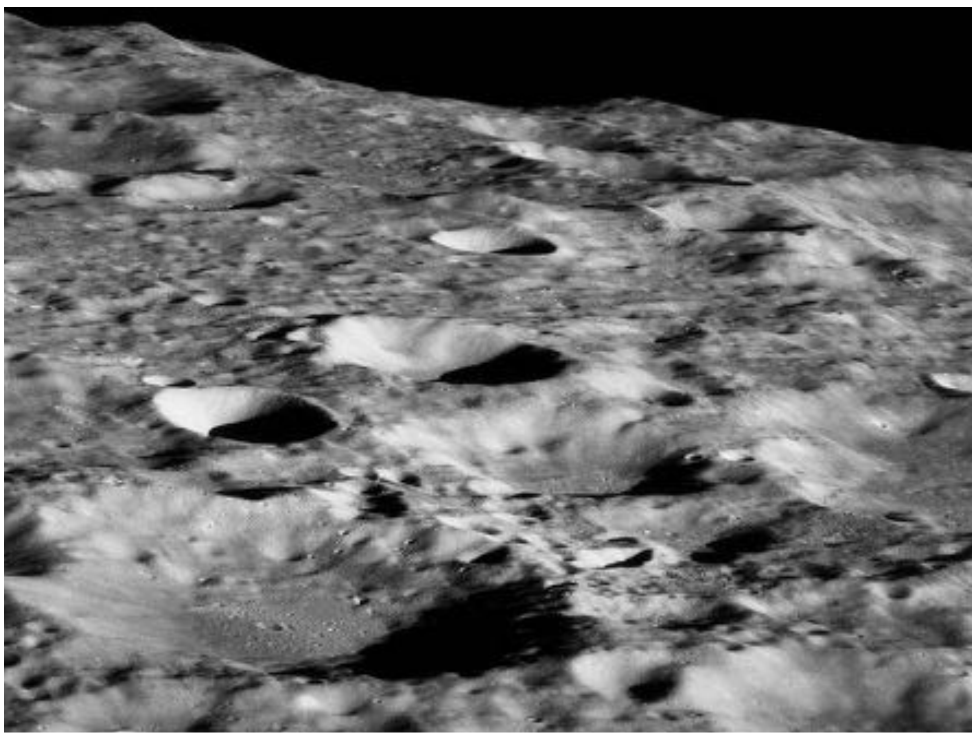
Useful Isotopes for Dating

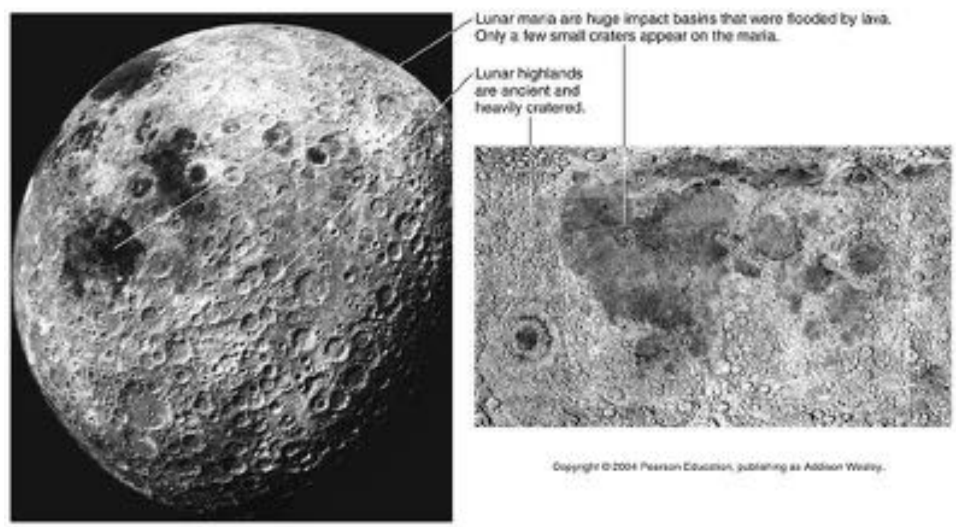
- 1000 to 100,000 years: ^{14}C -> ^{14}N
  - half-life = 5730 years
  - biological specimens (bone, wood,...)
- $2x10^8$ to $10x10^9$ yrs: ^{40}K -> ^{40}Ar
  - half-life = $1.25x10^9$ years
  - rocks! ^{40}K common in minerals, ^{40}Ar inert gas
  - melting resets the clock
- 10^9 to 10^{11} years: ^{238}U -> ^{206}Pb
  - half-life = 4.5 x 10^9 years
  - ^{238}U relatively rare, but ^{206}Pb much rarer
  - both in solid form

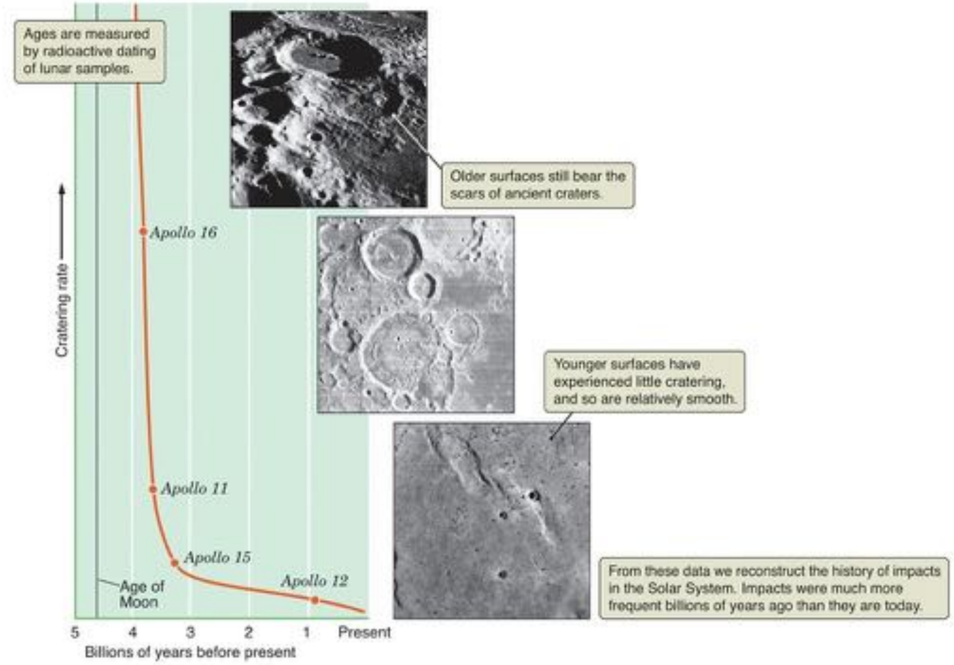
Connecting Relative Age (cratering) with Absolute age (radiometric)

- Only surfaces with absolute ages:
  - Earth and its Moon
- Earth's cratering record largely erased
- the MOON!

  a key object for connecting the two methods
- lunar samples from various regions can help calibrate cratering rates







The Earth's Moon:

a cratering record for the entire inner Solar System

- **Lunar Highlands** (bright parts; also called "terrae")

  - Heavily cratered
  - Apollo sample ages: 4.0 Gyr to 4.3 Gyr
  - lighter rock types (feldspar, breccia)
  - Record of early, heavy bombardment

- **Lunar Maria** (more than one "Mare") (dark parts)

  - lightly cratered - crater density 1/30 of highlands
  - Apollo samples: 3.2 to 4.0 Gyr (but some younger)
  - Basalts and other denser rock types

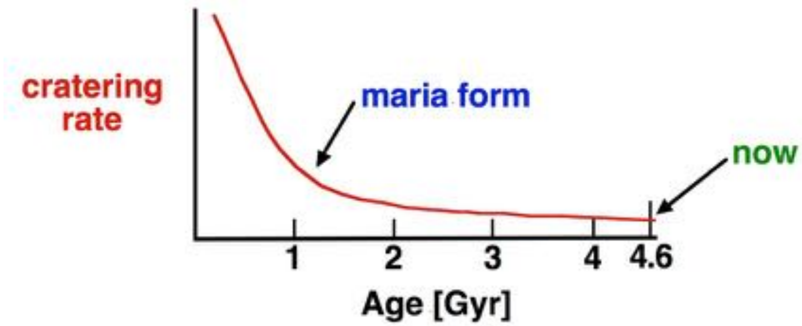
Chronology from samples provides a history for the Moon

Lunar Surface History

- 4.6 Gyr ago: formation via "Giant Impact"
  - impact of a Mars-sized object with primitive Earth
  - debris accretes to form molten Moon
  - differentiation and solidification
- 4.6 – 3.8 Gyr ago: intense bombardment
  - continuing impacts obliterate original surface, form terrae
  - some huge impacts form basins (i.e. future maria)
- 3.8 – 3.2 Gyr ago: lava flows fill maria
  - lava wells up from below to flood basins:
  - i.e. maria form with denser rock
- 3.2 Gyr ago to now: continued cratering
  - lava flows (mostly) ceased 3.2 Gy ago
  - further surface changes from impacts

Impact History of the Inner Solar System

(based on the lunar chronology)



The cratering rate has been the same for the Earth... then and now

This chronology also applies to Mercury, Venus and Mars.

Late heavy bombardment

Pearce et al., Astrobiology, 18, 343 (2018)

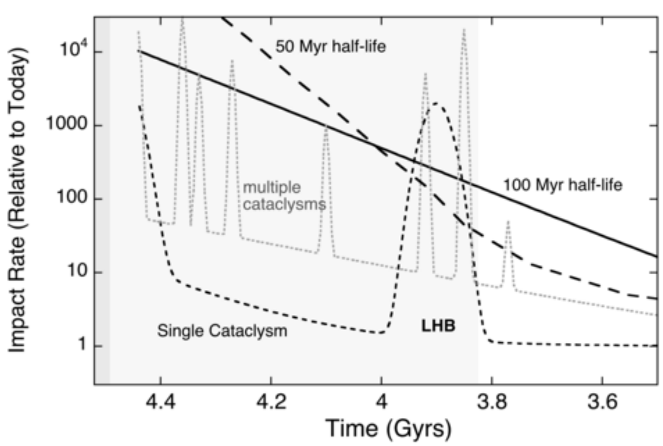
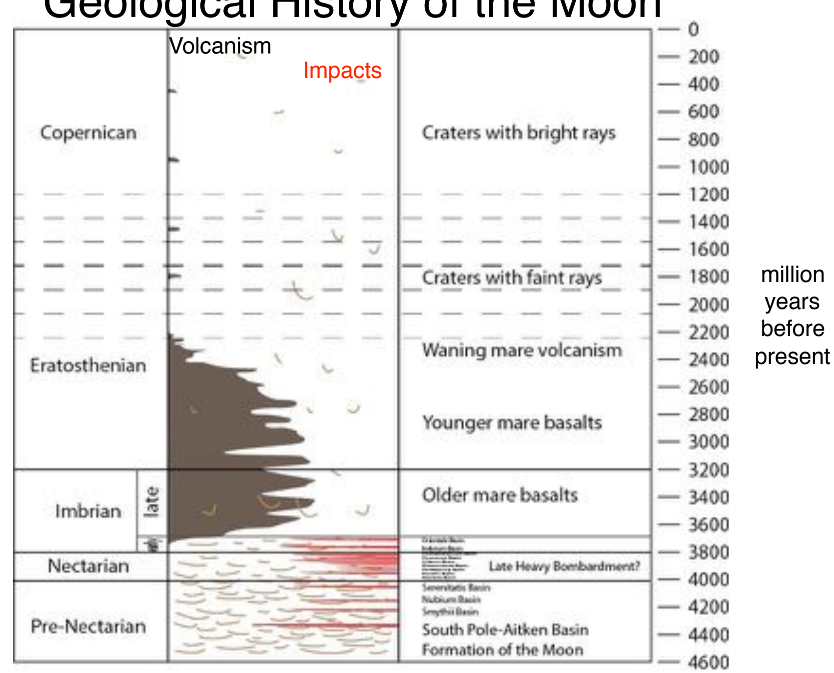
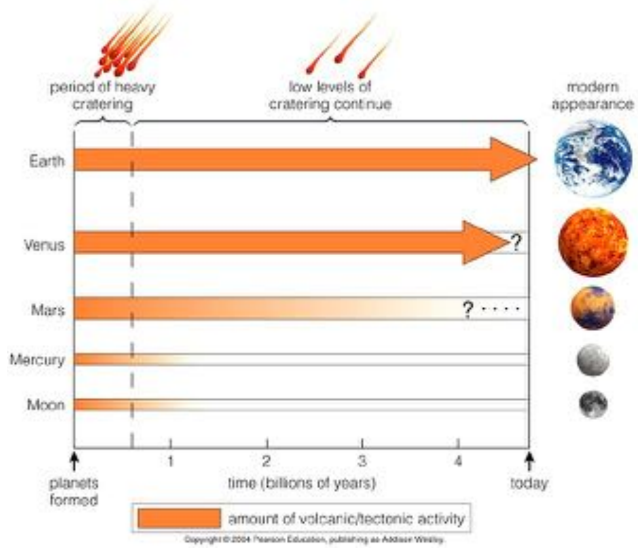


Figure 2. Four possible scenarios for the late heavy bombardment, calibrated to crater counts and surface ages at the Apollo landing sites. All scenarios except the 50 Myr half-life model are supported by the available data. Reprinted by permission from Springer Nature: Zahnle *et al.* (2007).

Geological History of the Moon



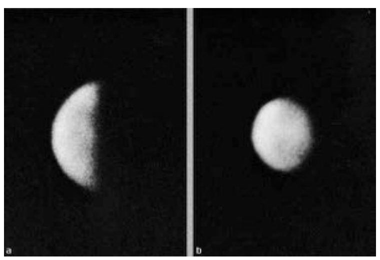
http://www.planetary.org/blogs/emily-lakdawalla/2013/09301225-geologic-time-scale-earth-moon.html



Mercury

- **The Basics:**
  - Mass = 0.06 x Earth
  - Diameter = 0.38 x Earth
  - Surface Gravity = 0.41 x Earth
  - Atmosphere: almost none
  - view from Earth: at best, like Moon w/ naked eye
  - visits: flybys by Mariner 10 (1974 and 1975)

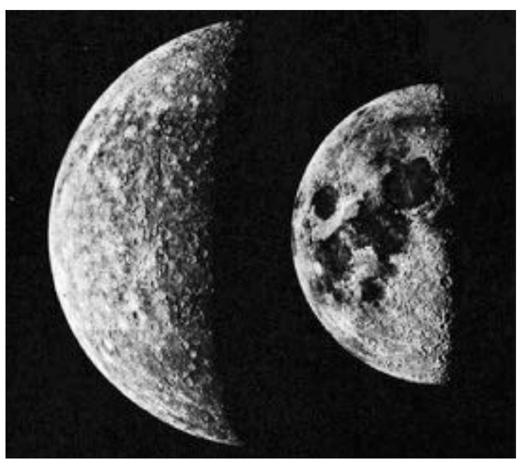
    Messenger (Jan. 2008, Oct. 2008, Sept. 2009)
  - orbiter! Messenger (March 2011)

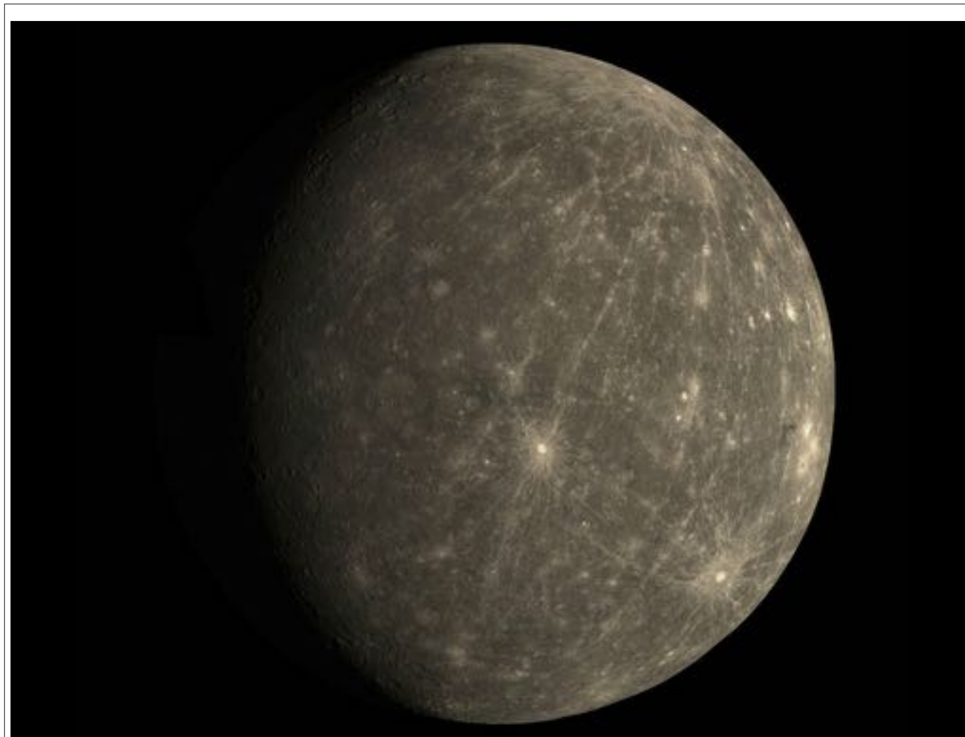


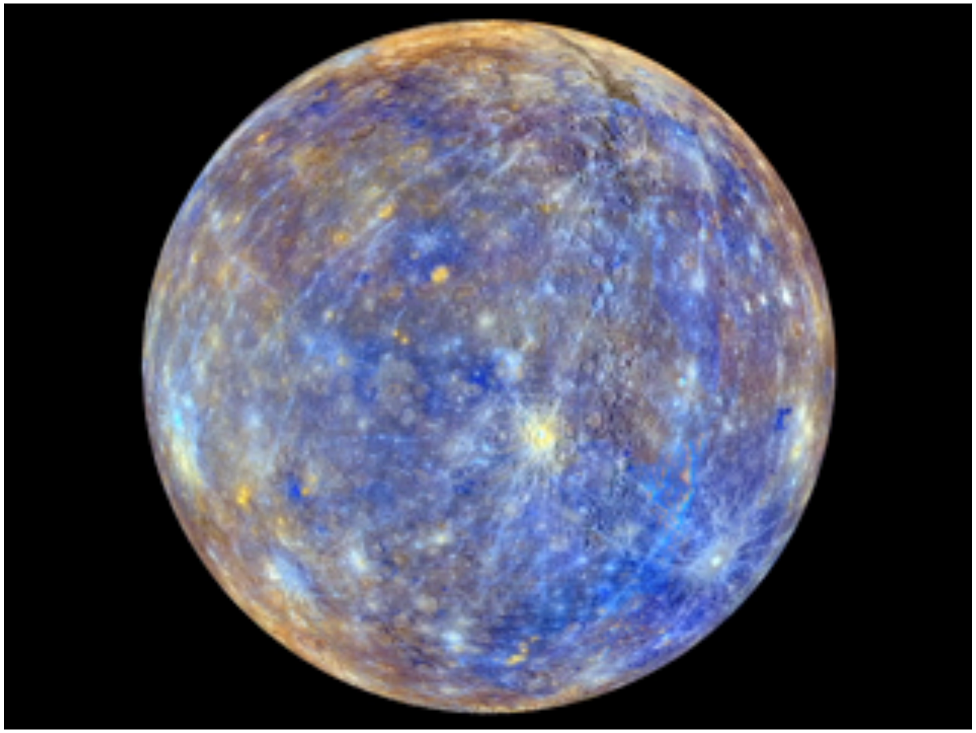
View from Earth

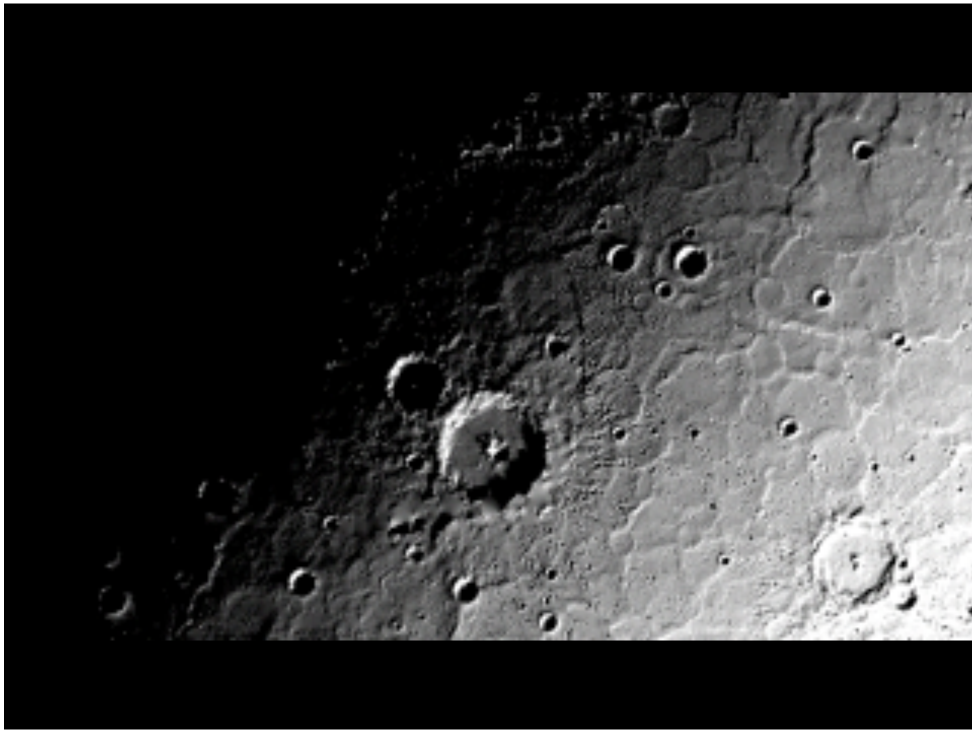
Mariner 10 view

Moon, to scale

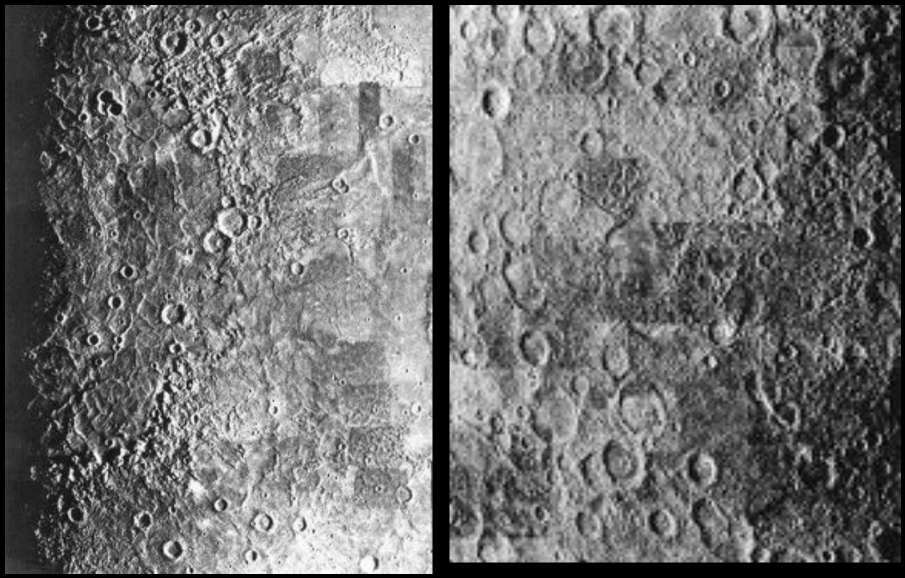






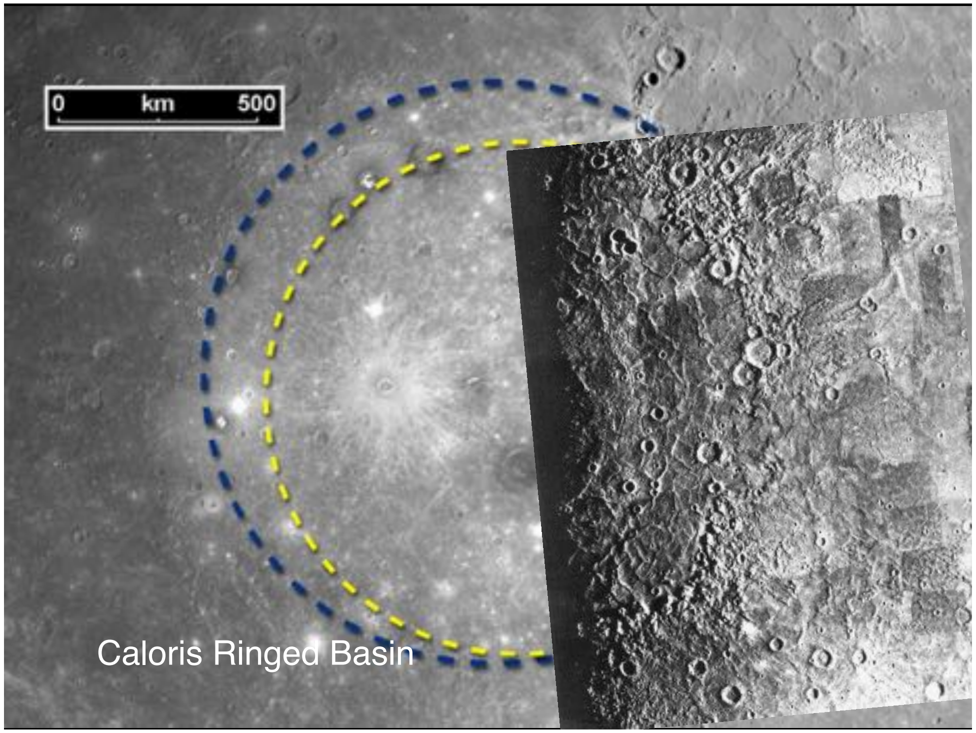


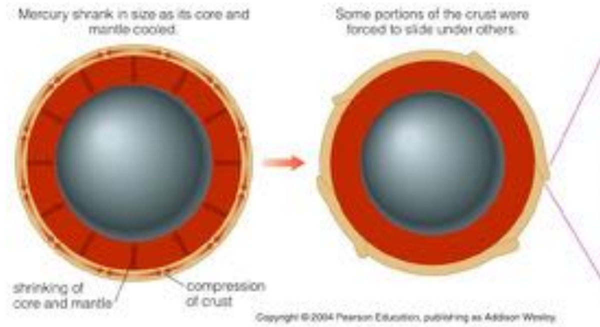
- **Mercury's Surface:**
  - Dominated by impact craters
  - Ejecta more compact than Moon (higher gravity)
  - Some flooded basins
  - large Caloris basin – multiringed
  - some "fresh" intercrater plains (possibly old...)
  - "Scarps" relatively recent – crustal shrinkage



Caloris Ringed Basin

Terrain opposite Caloris


0 km 500
Caloris Ringed Basin


Mercury shrank in size as its core and mantle cooled.
Some portions of the crust were forced to slide under others.
shrinking of core and mantle
compression of crust
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