Mon. Oct, 02, 2017

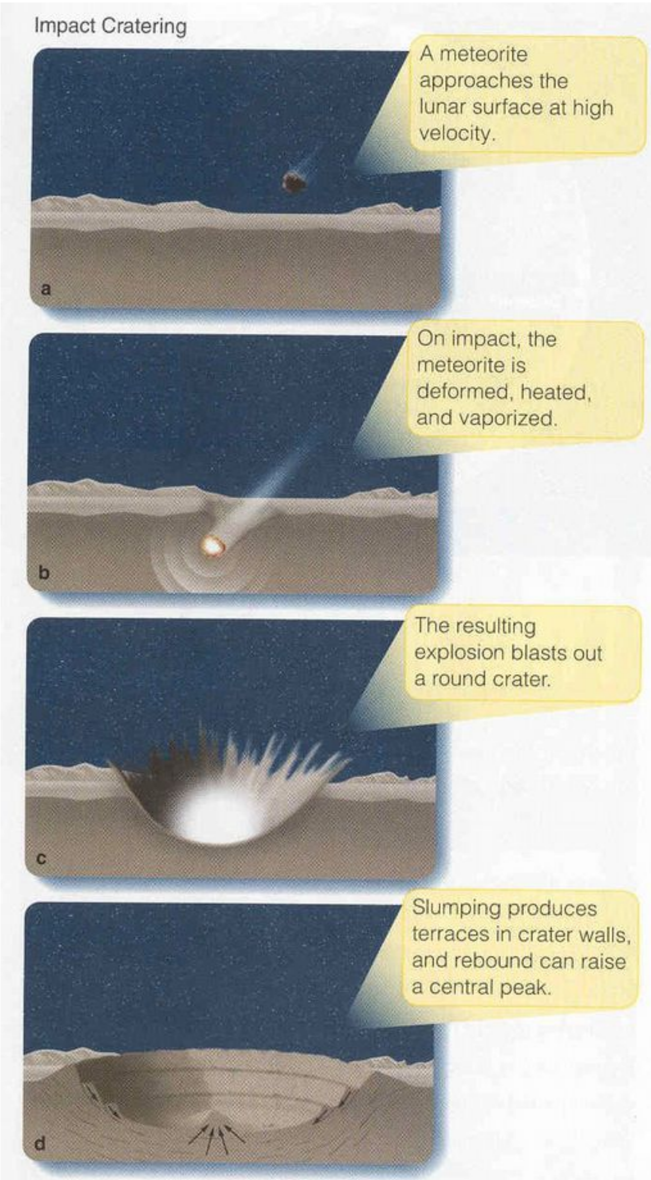
- Reading:
    - For Today
        - Shoemaker and Hackman, 1962 “Stratigraphic Basis for Lunar Time Scale”. (Use my electronic version, which has better images and maps.)
        - Christiansen Chapter 4 on Moon (on reserve)
    - For Friday: Bugiolacchi et al. 2008 Lunar Maria Basalts and Lawrence et al. 1998 Global Elemental Abundance Patterns
    - Alternate lecture time (gone Oct. 16, 18, 20)

- Today: Shoemaker and Hackman, plus intro to lunar geology

Lunar Geology-- Overview

- Maria vs Terrae division
- Details of cratering mechanics and statistics
- History of volcanism (primarily in the maria)
- Application of superposition principles to crater dominated world

Formation of an impact crater



From the Astro 1050 text: Horizons by Seeds

- Crater caused by the explosion
  - Impactor is melted, perhaps vaporized by the kinetic energy released
- Temporary "transient" crater is round
- Gravity then causes walls to slump inward forming "terraces"
- Movement of material inward from all sides (trying to fill in the hole) may push up central peak in the middle.
- Final crater is typically ~10 times the size of the impactor

Examples of craters on the moon

- Images on line at
  The Lunar and Planetary Institute:
  http://www.lpi.usra.edu/expmoon/lunar_missions.html

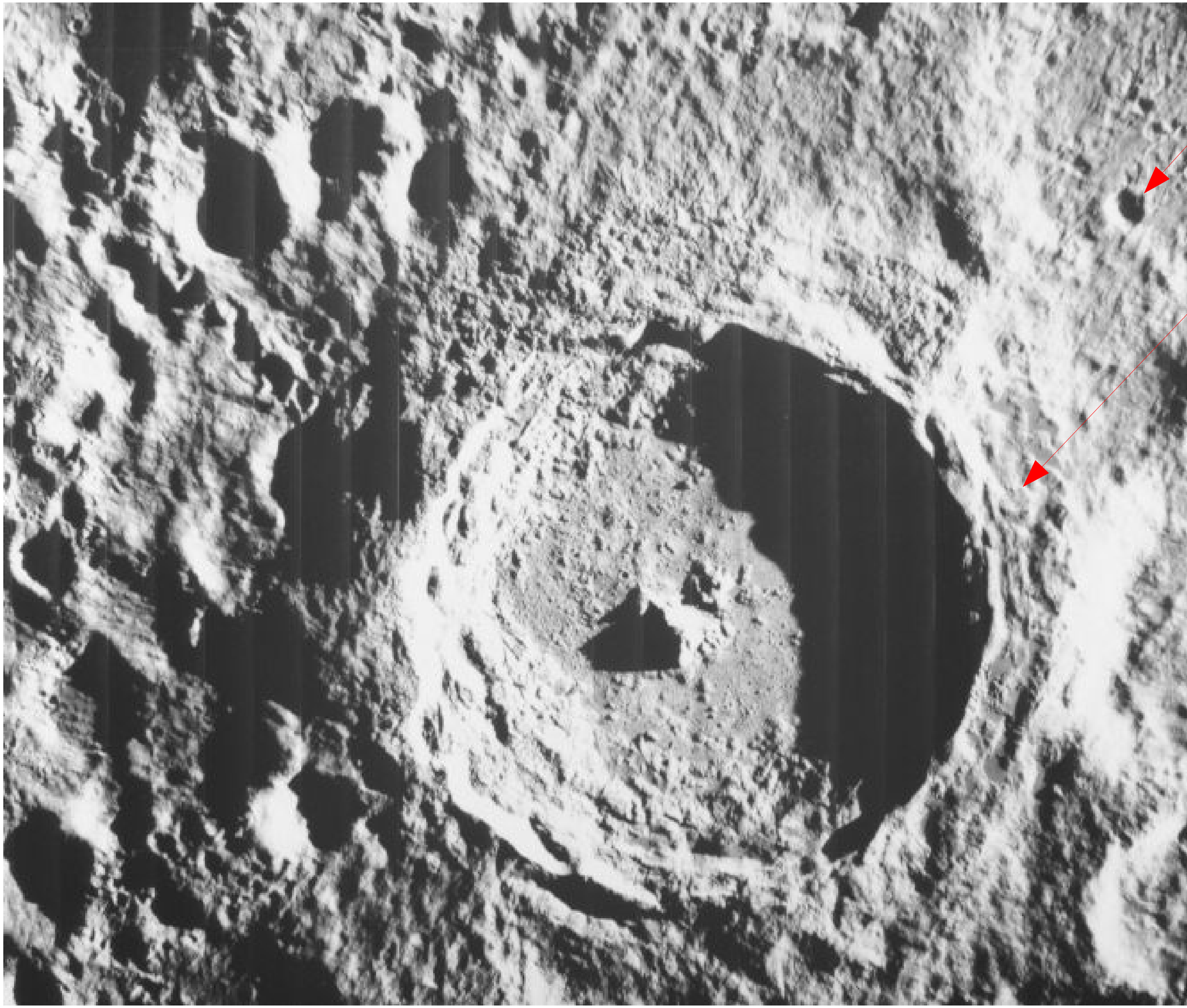
- Detailed record of Apollo work at:
  http://www.hq.nasa.gov/office/pao/History/alsj/frame.html

- How do crater forms change with size?
  - Small ones are simple bowls
  - Intermediate ones show central peaks
  - Very large ones are called "basins"

- The Highlands vs. the Mare

- Volcanism on the moon

Crater Forms vs. Size (Tycho region)



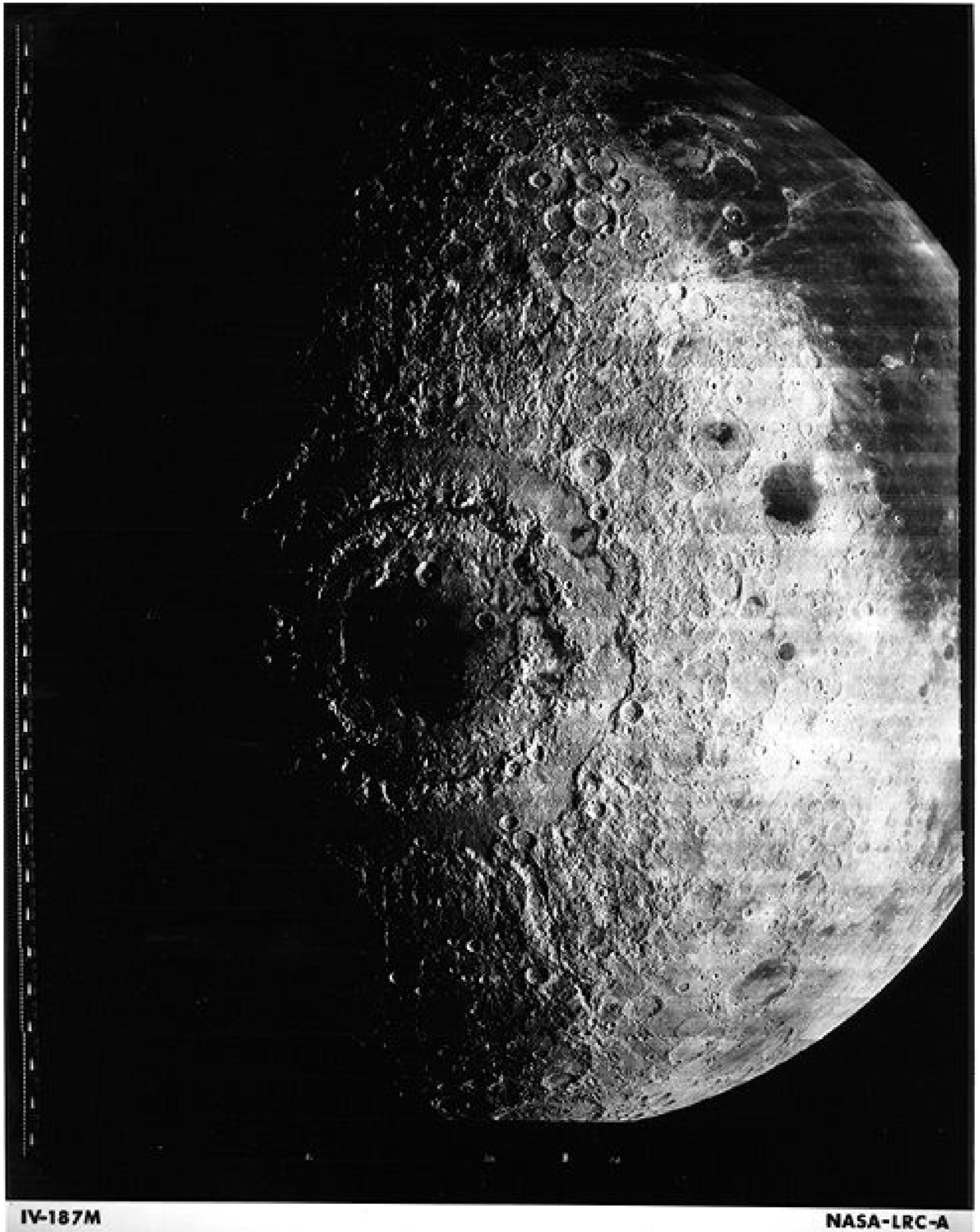
- Small:
  - simple bowl
- Larger:
  - terraces on walls
  - central peak

Exaggerated Shadows

- Many pictures taken near “terminator” to enhance shadows
- That tends to give false impression of how rugged terrain really is
- Typical crater depth is only ~1/10 of diameter

Ejecta Blanket

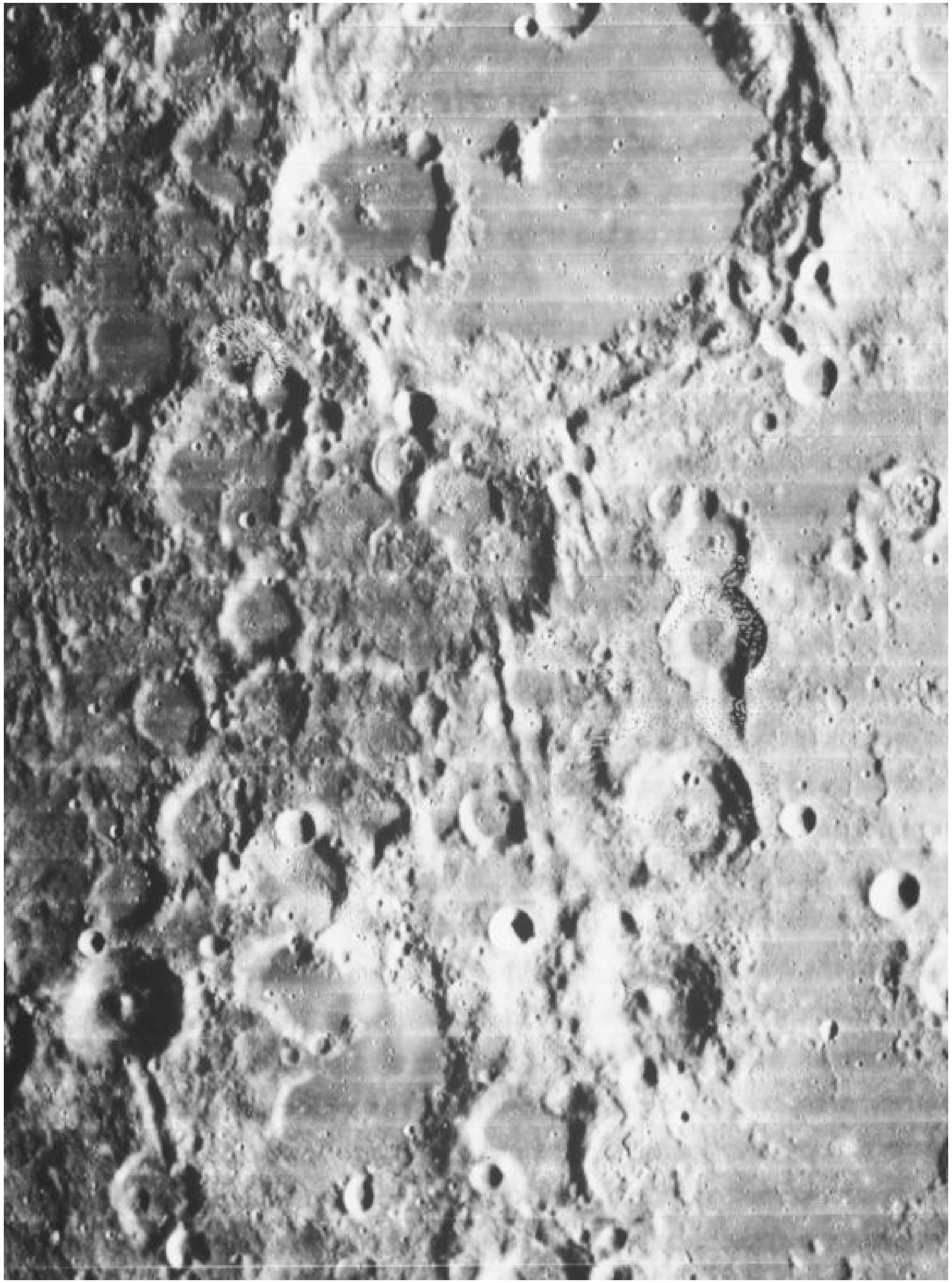
- The material from the crater forms an “ejecta blanket” around the crater
- It causes many small “secondary” craters where pieces of ejecta fall back



Very Large Craters are called "Impact Basins"

- The Orientale Basin

- Basins have multiple concentric rings rather than a single central peak



Imbrium Structure

- Imbrium Basin is Largest of “recent” basins
- Radial pattern of grooves seen pointing back towards it
- Caused by ejecta sent out on grazing trajectories

Superposition
(way to get relative ages)

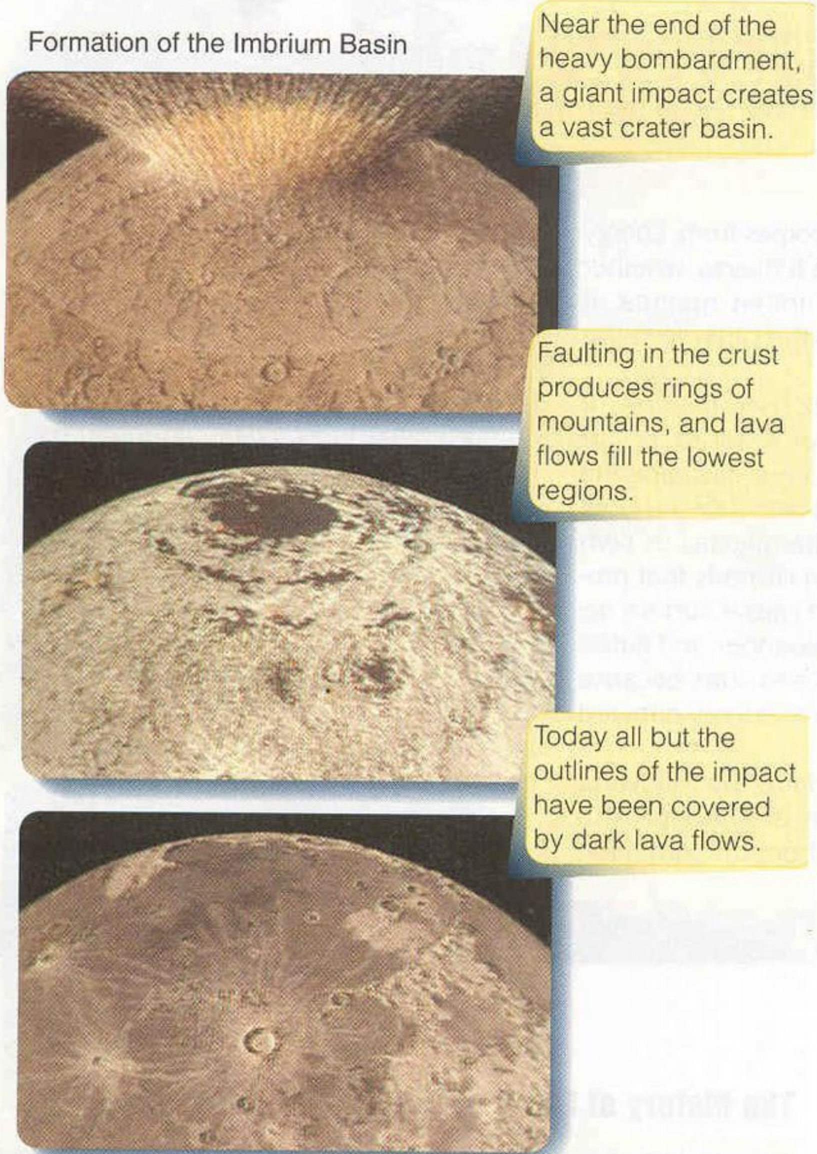


Figure 17-6
Mare Imbrium on the moon has a generally round outline, the consequence of its formation by a giant impact 4 billion years ago.
(Courtesy Don Davis)

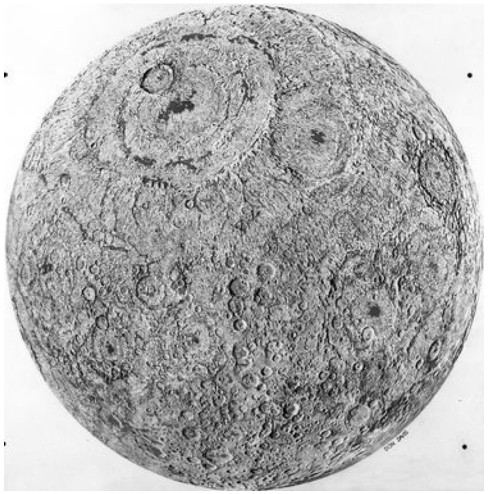
From the Astro 1050 text: Horizons by Seeds

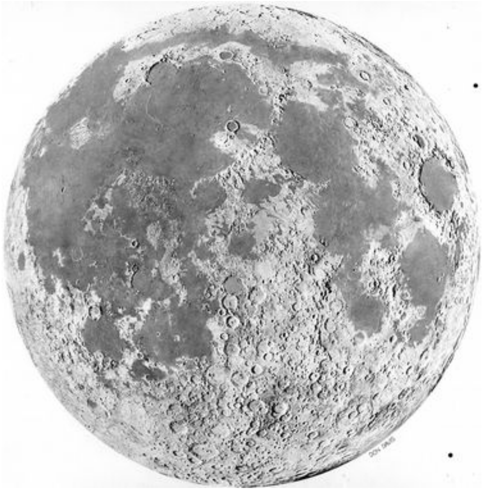
- Newer features are <u>superposed</u> on top of older ones

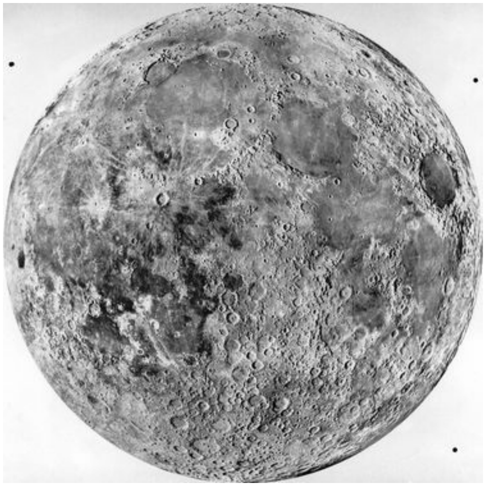
- Large impact forms basin
- Basin floods with lava
- Additional impacts occur in mare lava

- Over time both crater rate and volcanic activity are declining
  - Craters less because debris swept up
  - Volcanism less because moon cooling

Original Lunar Age System





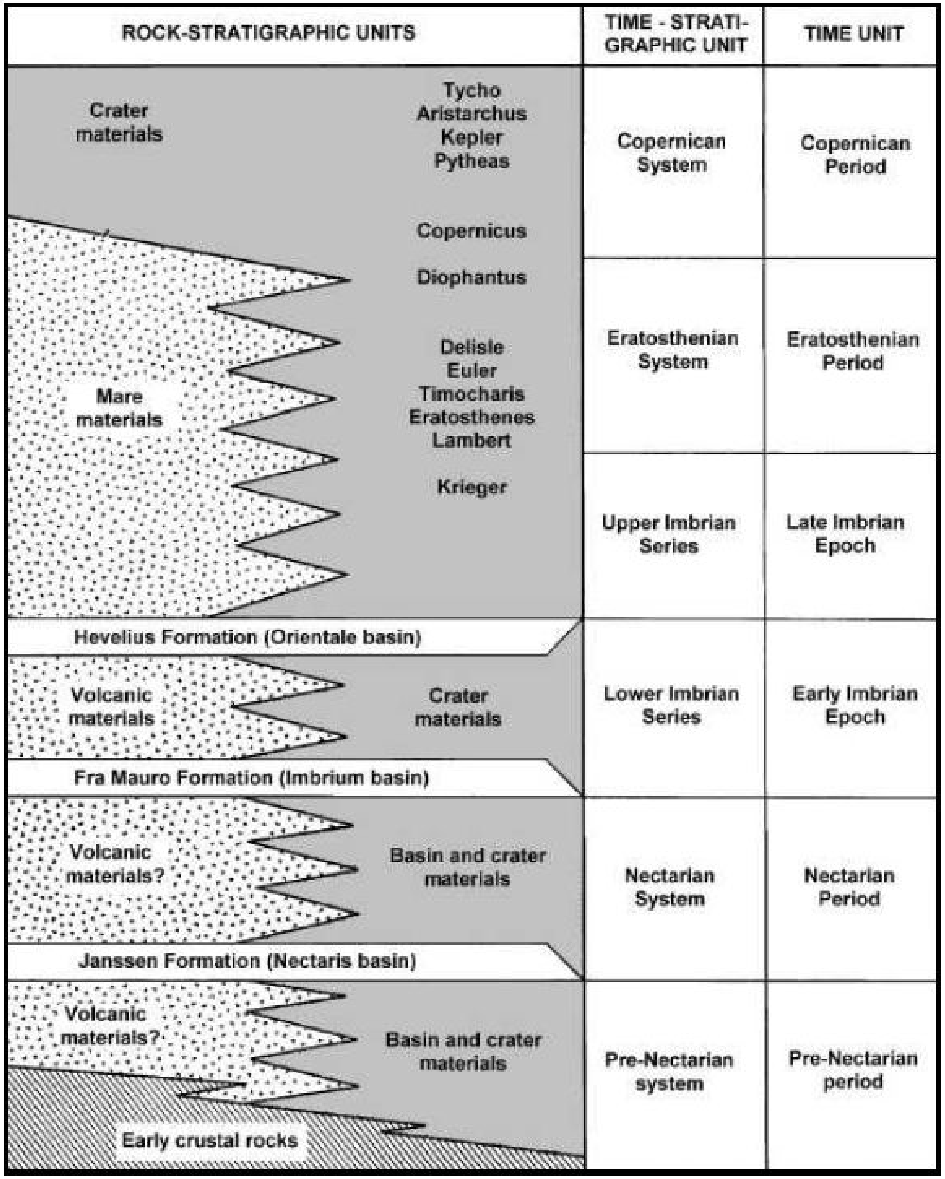


FromWilhemls and Davis

Originally defined in terms of Copernicus region – but later generalized to the whole moon. Earliest 3 somewhat reorganized in later papers.

- Copernican (younger fresh post-mare craters)
- Eratosthenian (older degraded post-mare craters)
- Procellarian (mare fill -- assumed all mare similar age)
- Imbrian (basins and ejects from Imbrium impact)
- Pre-Imbrian (old cratered highlands)

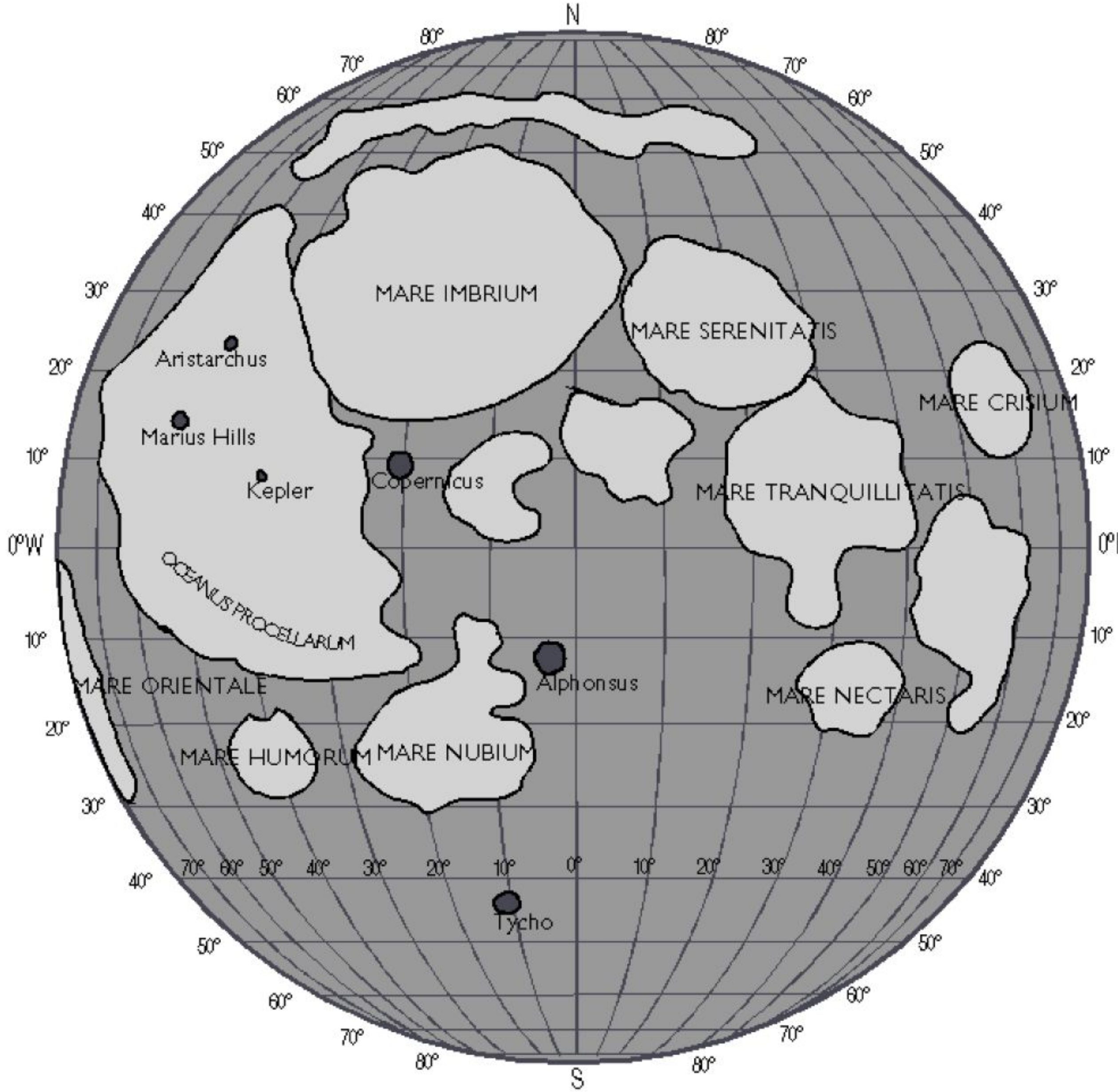
Revised Lunar Age System



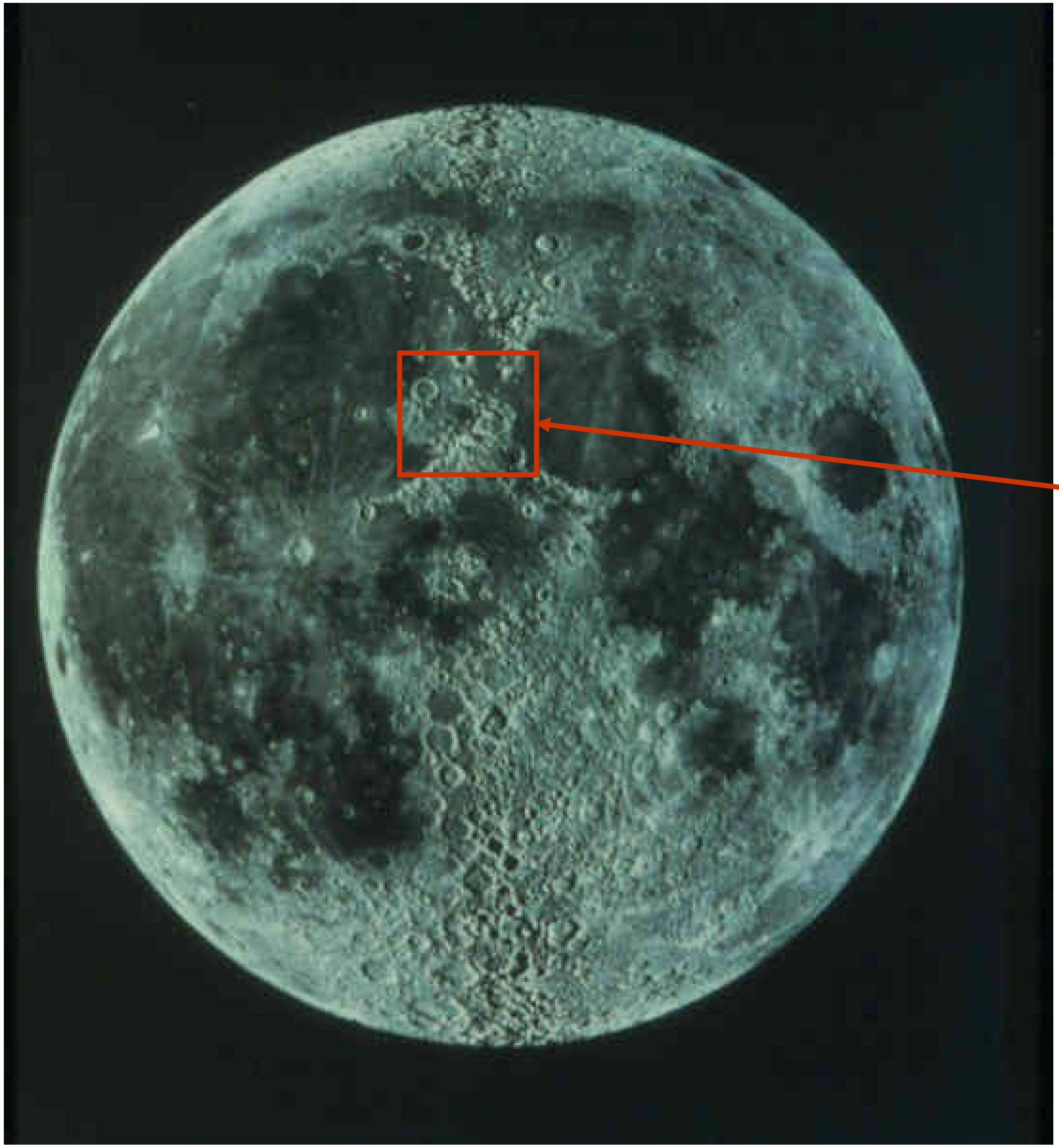
From Wilhemls 1987

- Original Pre-Imbrian broken into Pre-Nectarian and Nectarian
- Drop Procellarian since maria ages differ. Move much of what was "Procellarian" mare plus original Imbrian into
  - Lower (Early) Imbrian
  - Upper (Late) Imbrian
- The Nectaris, Imbrium, and Orientale impacts divide the time units
- The Janssen, Fra Mauro, and Helvius Formations are those basin ejecta deposits
  (Apollo 13 was heading for the Fra Mauro formation -- to help date the Imbrium Impact)

Major Lunar Features



Apollo 15: Maria, Highlands boundary

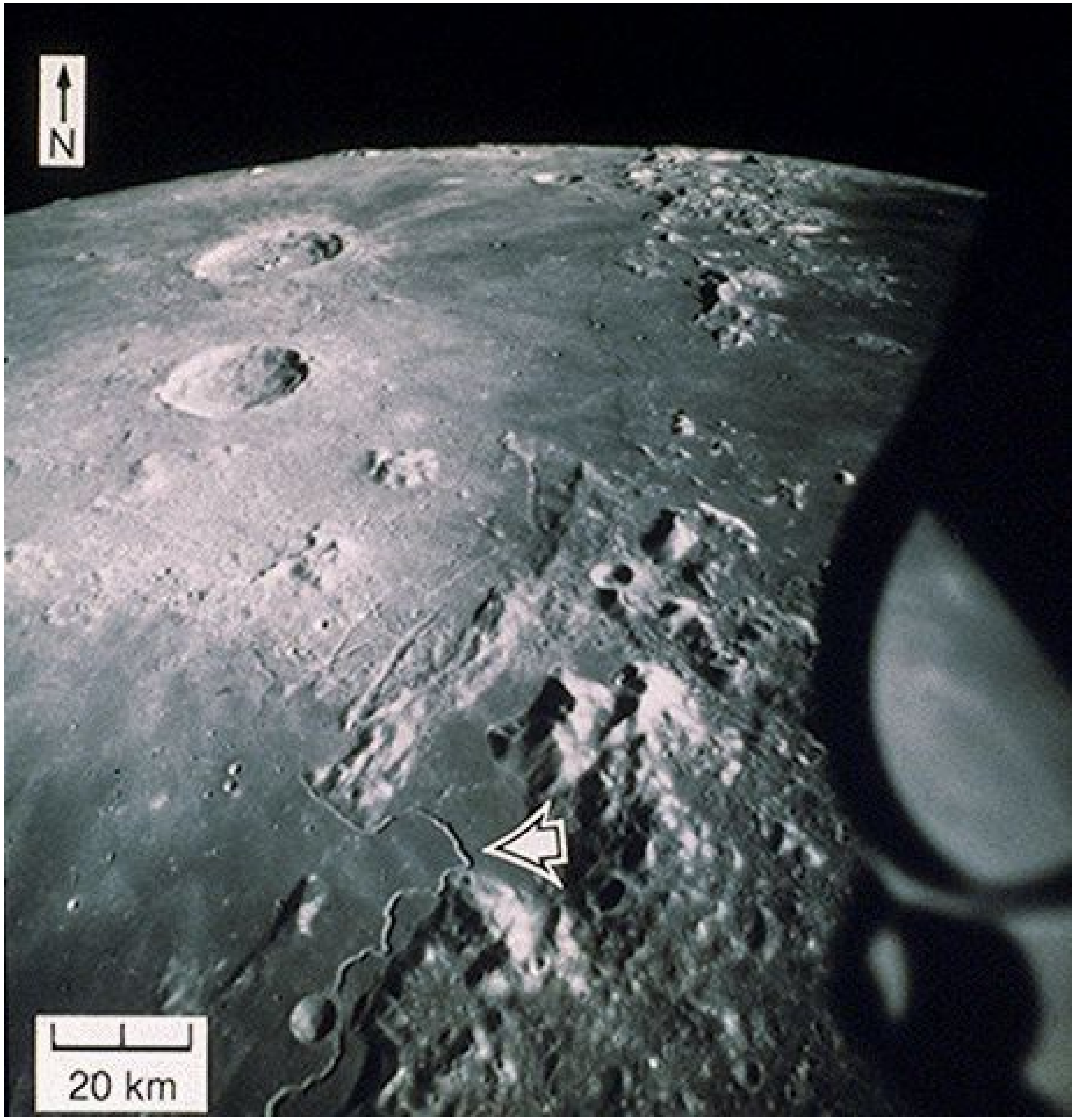


- Terra or Highlands
  - Bright cratered areas
- Mare or "Oceans"
  - Dark less cratered areas
  - Typically found within the large impact basins

Apollo 15 Landing Site

Edge of Mare Imbrium, near
Apennine Mountains which are really rim of Imbrium Impact Basin

Volcanic Features in Mare

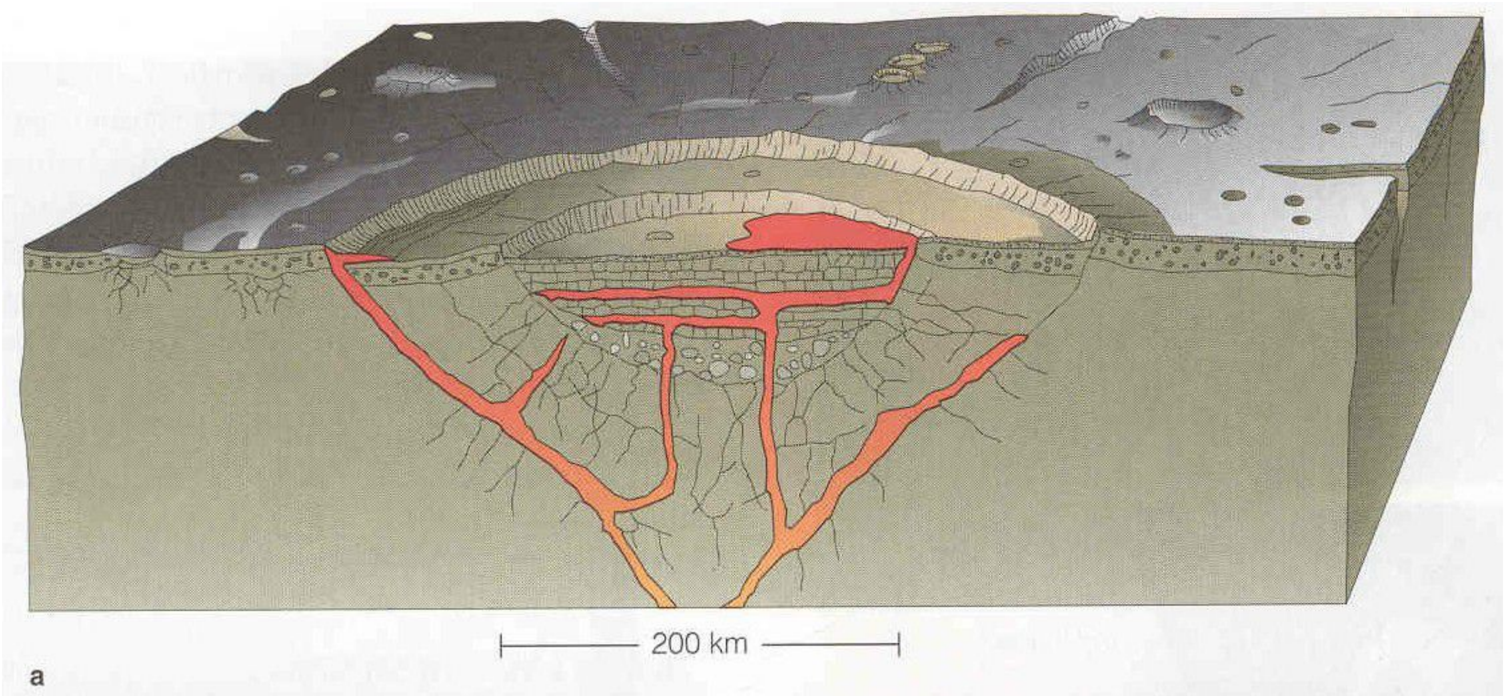


- In 1950's, early 1960's debate about whether Mare were volcanic (internally generated lava) or simply rocks melted by the impact which formed the basin
- Many volcanic features seen in Mare
  - Hadley Rille:
    A collapsed lava tube
- Apollo missions found that Mare rocks were basalts

Apollo 15 approach

Hadley Rille from the Surface

Why do lava flows come out in mare basins?

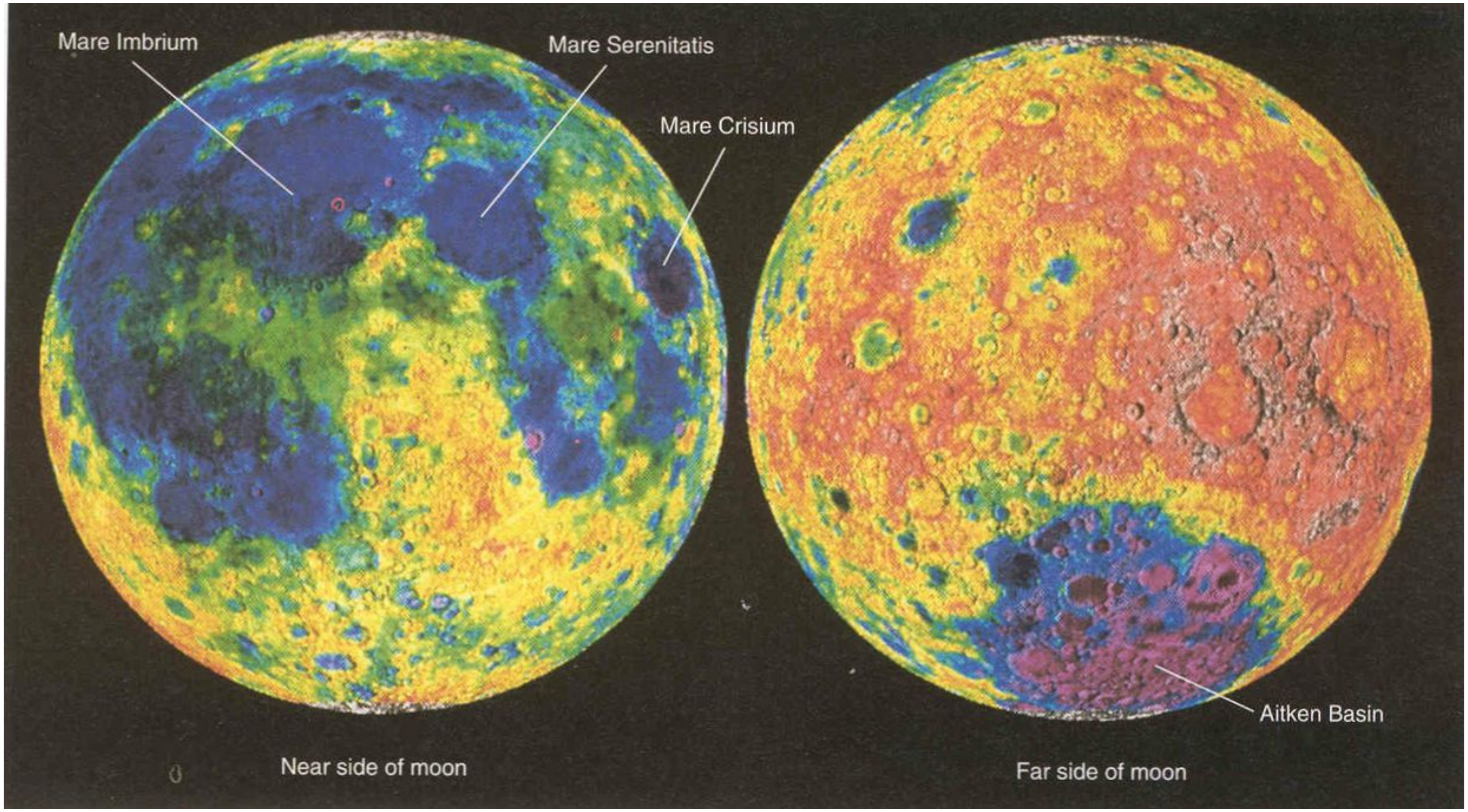


From the Astro 1050 text: Horizons by Seeds

- Mare basins are the lowest areas of the planet
- The crust beneath them is badly fractured by the impacts

- When do the lavas come out?
  - Superposition only gives relative ages
  - Can use crater counts to estimate absolute ages – but need to know crater rates
  - Apollo missions provided samples from which we have radioactive decay ages

Mare are almost all in the low basins on the near side



From the Astro 1050 text: Horizons by Seeds

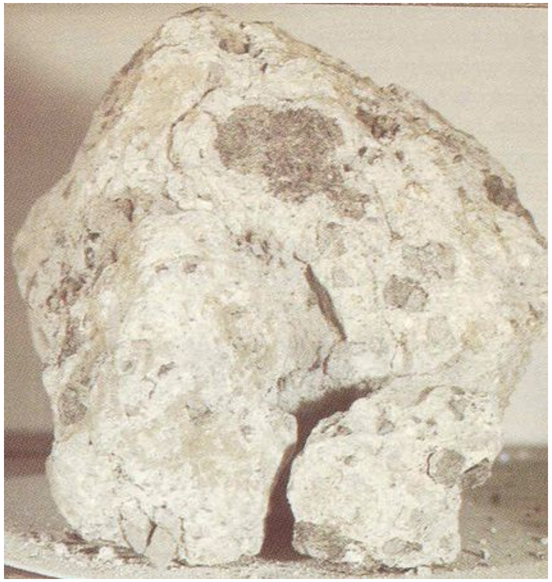
- Elevation map from "Clementine" mission: Blue =low Red =high
- Crust thicker & elevations higher on the far side
- Impact Basins exist on far side – but few are flooded by mare basalts
- Once asymmetry exists, orientation relative to earth locked by tides
- Original cause of asymmetry uncertain

Composition of Mare vs. Highlands

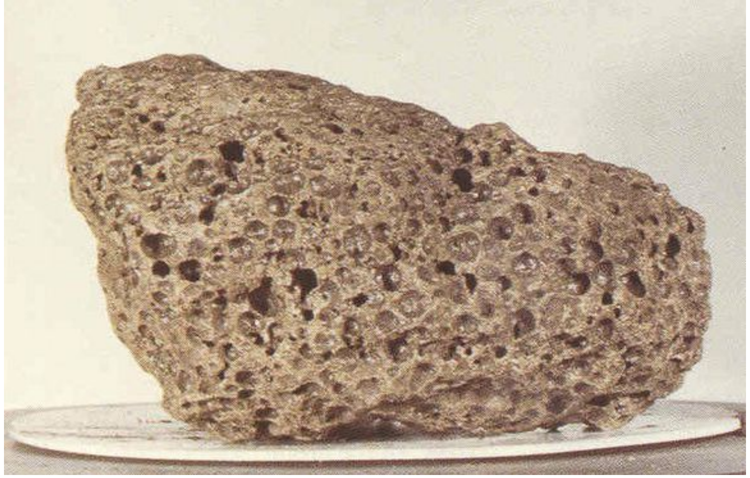
- Highlands: ANORTHOSITE

  (Ca feldspar)

  – Result of very early global magma ocean
    - If you melt lunar mantle completely, and let lighter material float to top, that top material will be ANORTHOSITE
  – Surface layers are "impact breccias"

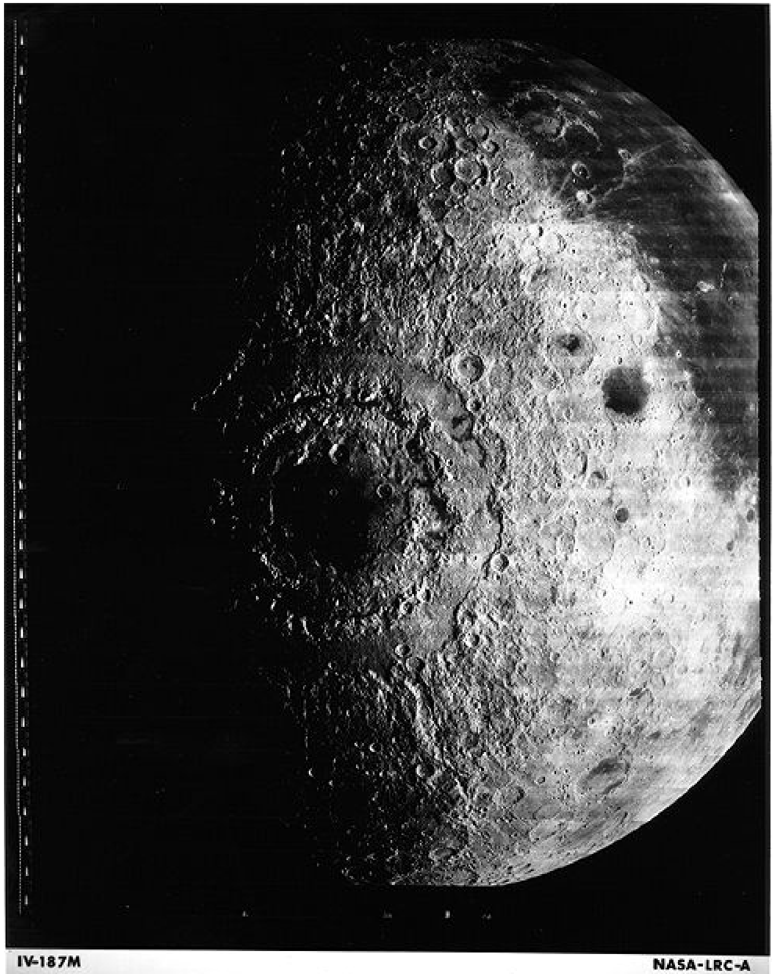


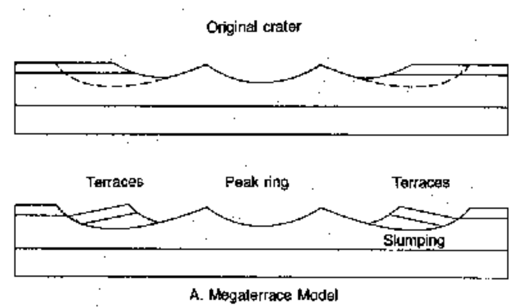
- Mare: BASALT
  – Result of partial (10%) melt of mantle
    - First melting component has composition of basalt
  – Highly vesicular because because of "low" atmospheric pressure, even with (possible) low volatile abundances



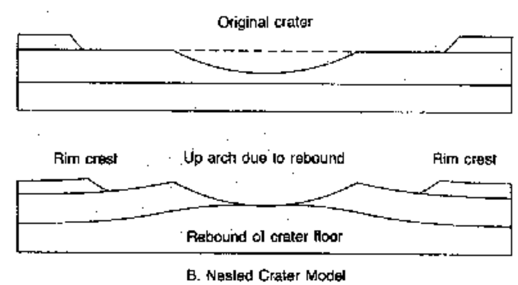
From "The New Solar System" by Beatty et al.

Very Large Craters are called "Impact Basins"





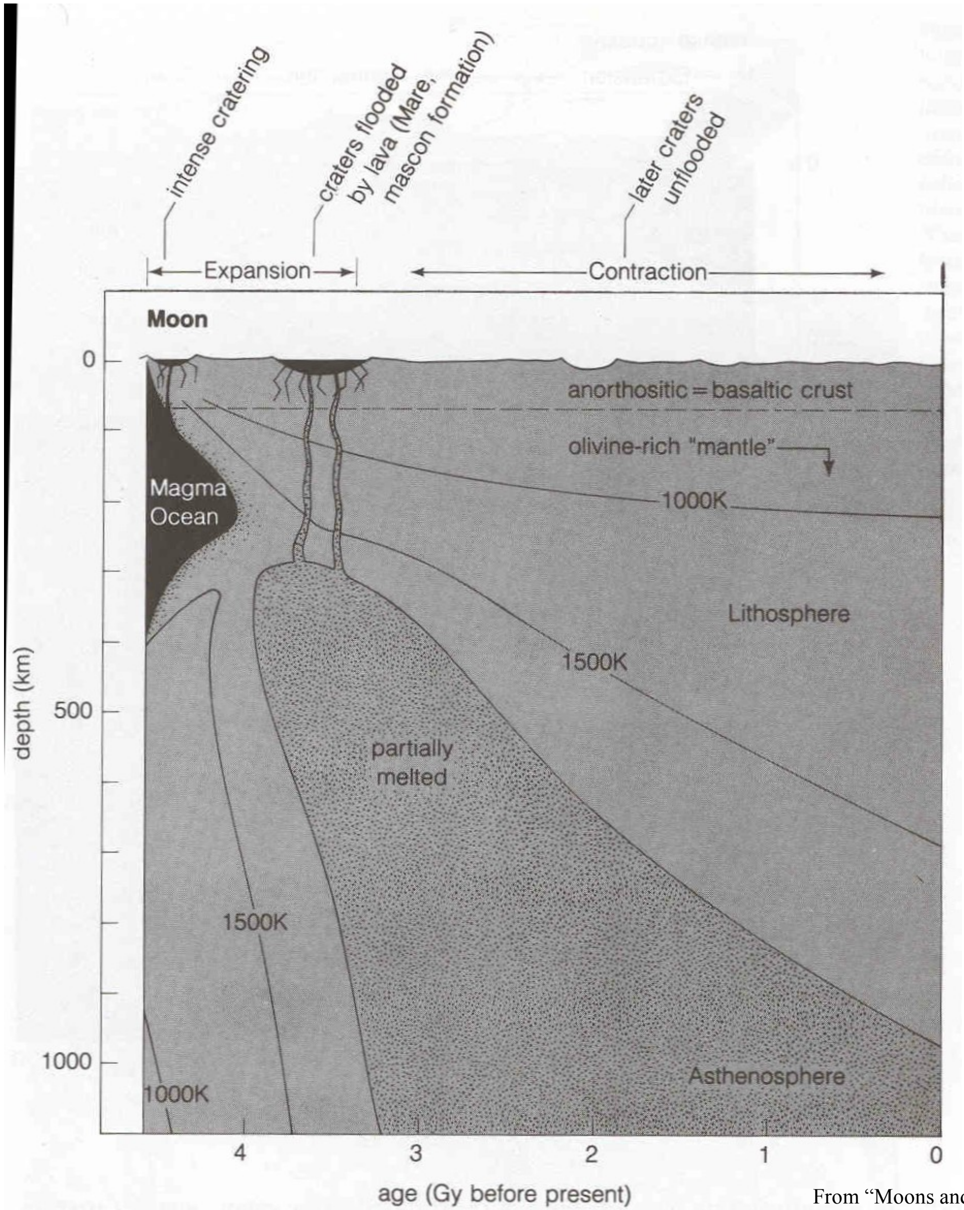
(A) **Megaterraces**, the areas between the outer rings of a basin such as Orientale, are interpreted as large fault bounded terraces, formed during the modification stage of a basin's evolution. The inner rings are uplifts similar to those in peak-ring basins.



(B) **Nested-crater model** explains the multiring structure of large basins as structural discontinuities in the target. Rebound of the deep crater lifts these discontinuities to the surface, where they are expressed as rings. The crater of excavation is much deeper than that inferred for the megaterrace model. Terraces are considered to be minor modifications.

- Note: This is the correct figure 4.16 from text. The published one shows part B twice.

Timing of Activity on the Moon



From "Moons and Planets" by Hartmann

- Formation/Magma Ocean:
  4.5 billion years
- Heavy Cratering:
  4.5 – 4.0 billion years
- Mare Volcanism:
  3.7 – 3.0 billion years
- Later small craters:
  continually decreasing

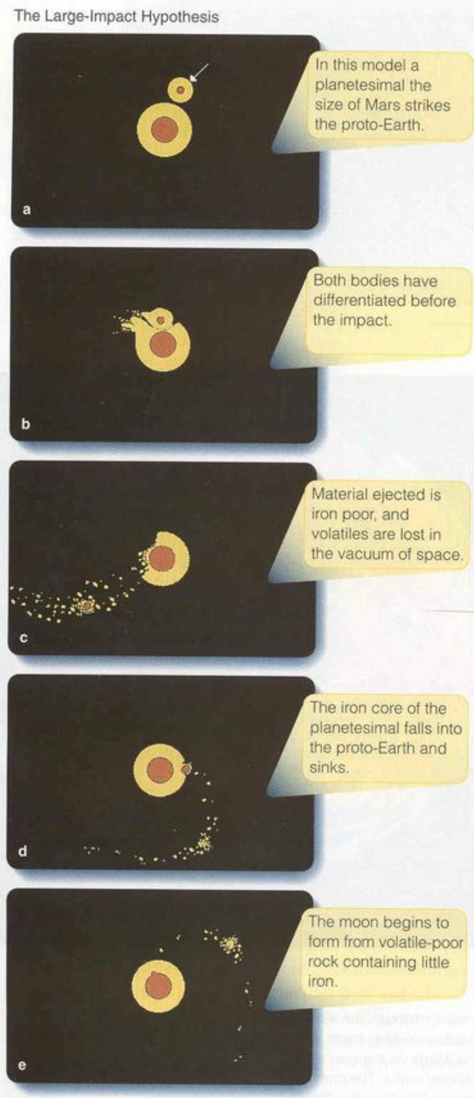


Figure 17-8
Computer simulations of impacts between differentiated bodies suggest Earth's low-density, iron-poor moon might have formed from such an event.

Lunar Origin Problems

- Bulk composition similar to earth's mantle
- Isotopic composition also very similar
- Volatile elements missing (H in H_2O, etc.)
  - (but recent results indicate more volatiles than originally thought)
- Dynamics of orbit unusual compared to other moons

- Most of above explained by Giant Impact Origin Theory
  - Recent complications from amount of volatiles, and questions about how well this mixes material from Earth and impactor

From the Astro 1050 text: Horizons by Seeds