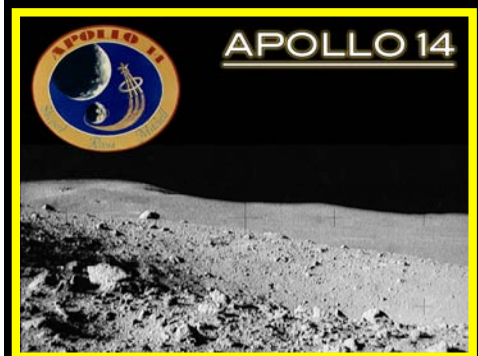
The Moon as a Touchstone for Solar System Science: Framework for Site Selection



James W. Head, Brown University

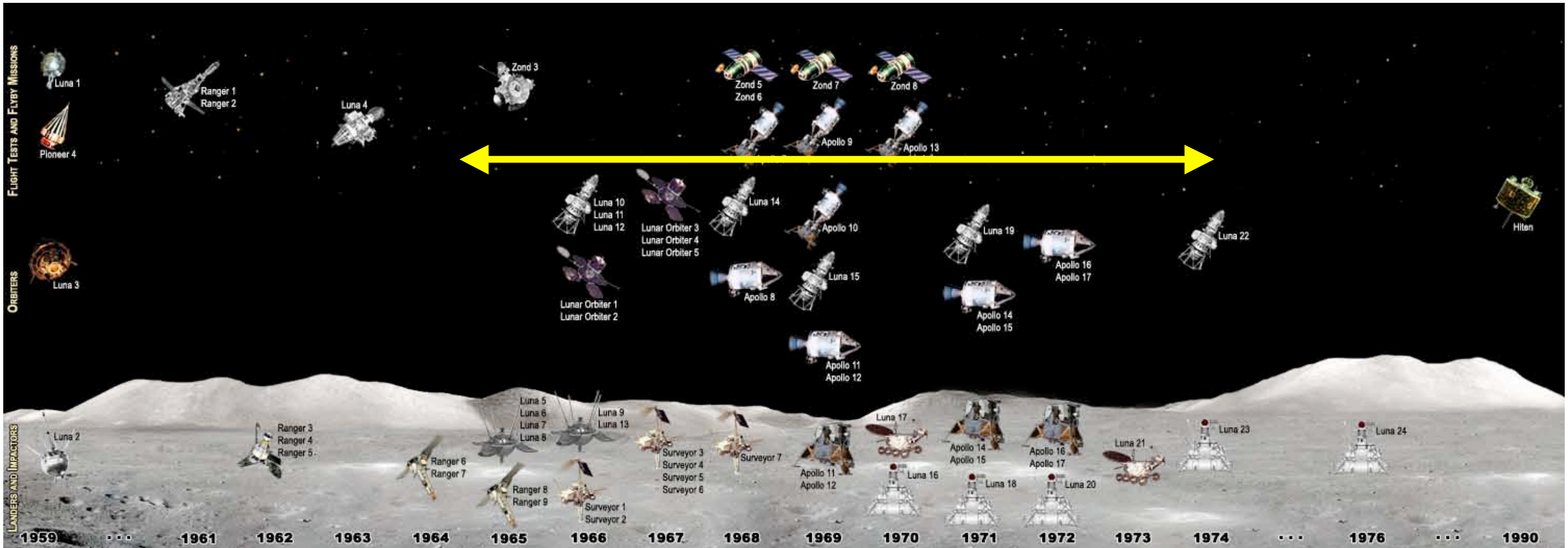
Lunar Glob Site Selection Meeting

Moscow, IKI, January 25-27, 2011

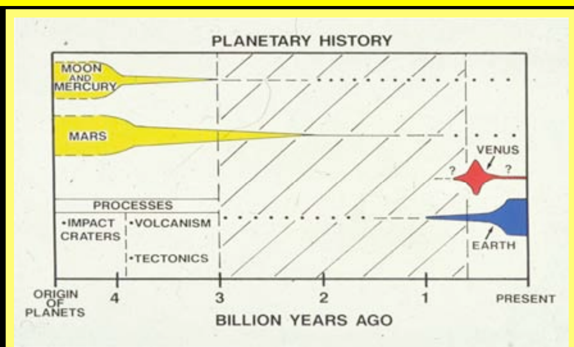
The Moon as a Touchstone for Solar System Science

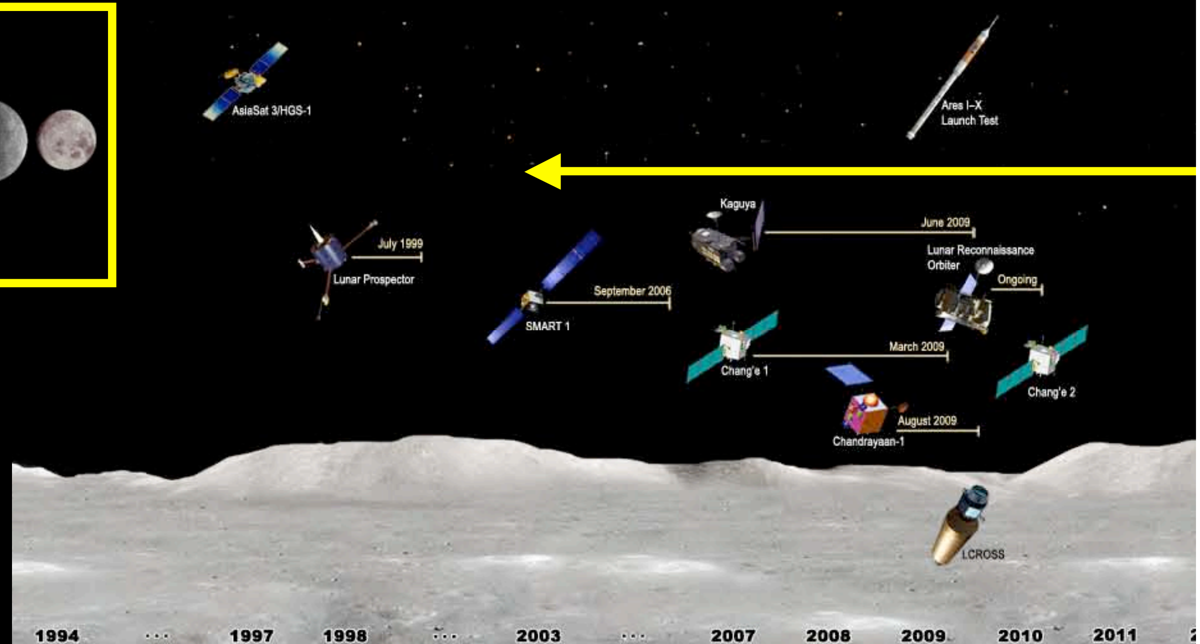
-One or more spacecraft currently orbiting each of the terrestrial planets. (MESSENGER scheduled to orbit Mercury 3/18/11)

-We have fundamental questions about the formation and evolution of each of these planetary bodies, and together the terrestrial planetary bodies as a whole.



-Moon: Dozens of missions, orbiters, landers, rovers, Astronauts!

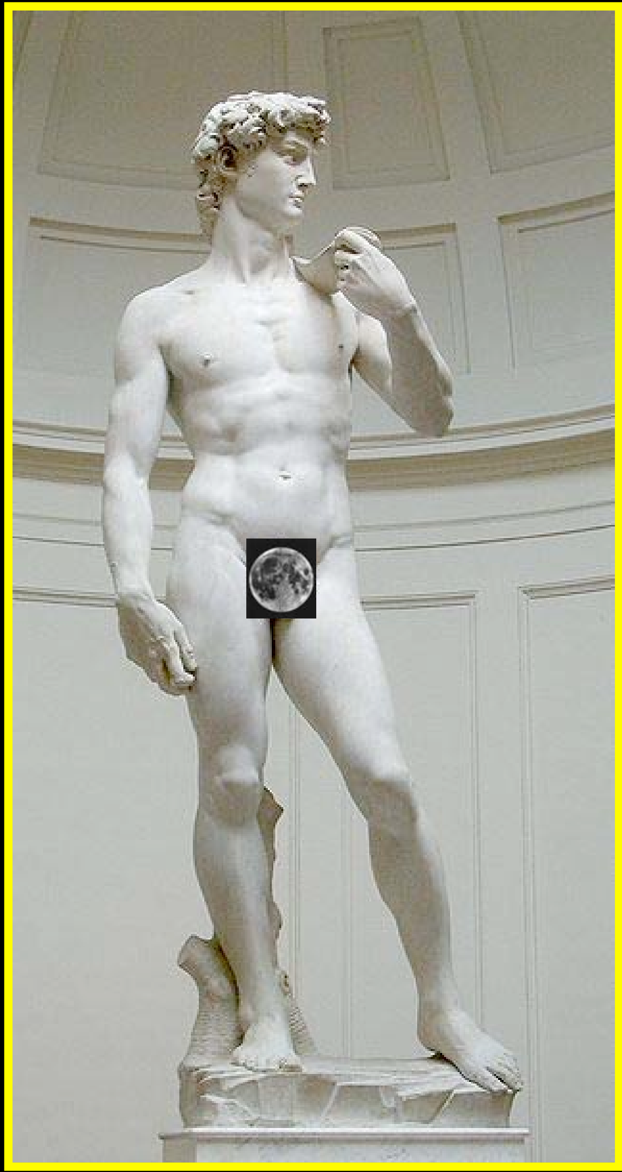




Renaissance in Lunar Exploration - Context and Role in Planetary Exploration

- Renaissance: 2003-2013: Rebirth of lunar science!
  - ESA: Smart-1
  - China: Chang'e 1
  - Japan: Kaguya
  - India: Chandrayaan-1
  - United States: Lunar Reconnaissance Orbiter
  - Russia: Lunar Glob
  - X-Prize
- "Everything has changed but our way of thinking."

A. Einstein.



Renaissance in Lunar Exploration - Context and Role in Planetary Exploration

- Renaissance: 2003-2012:

Rebirth of lunar science!

- Cornerstone:

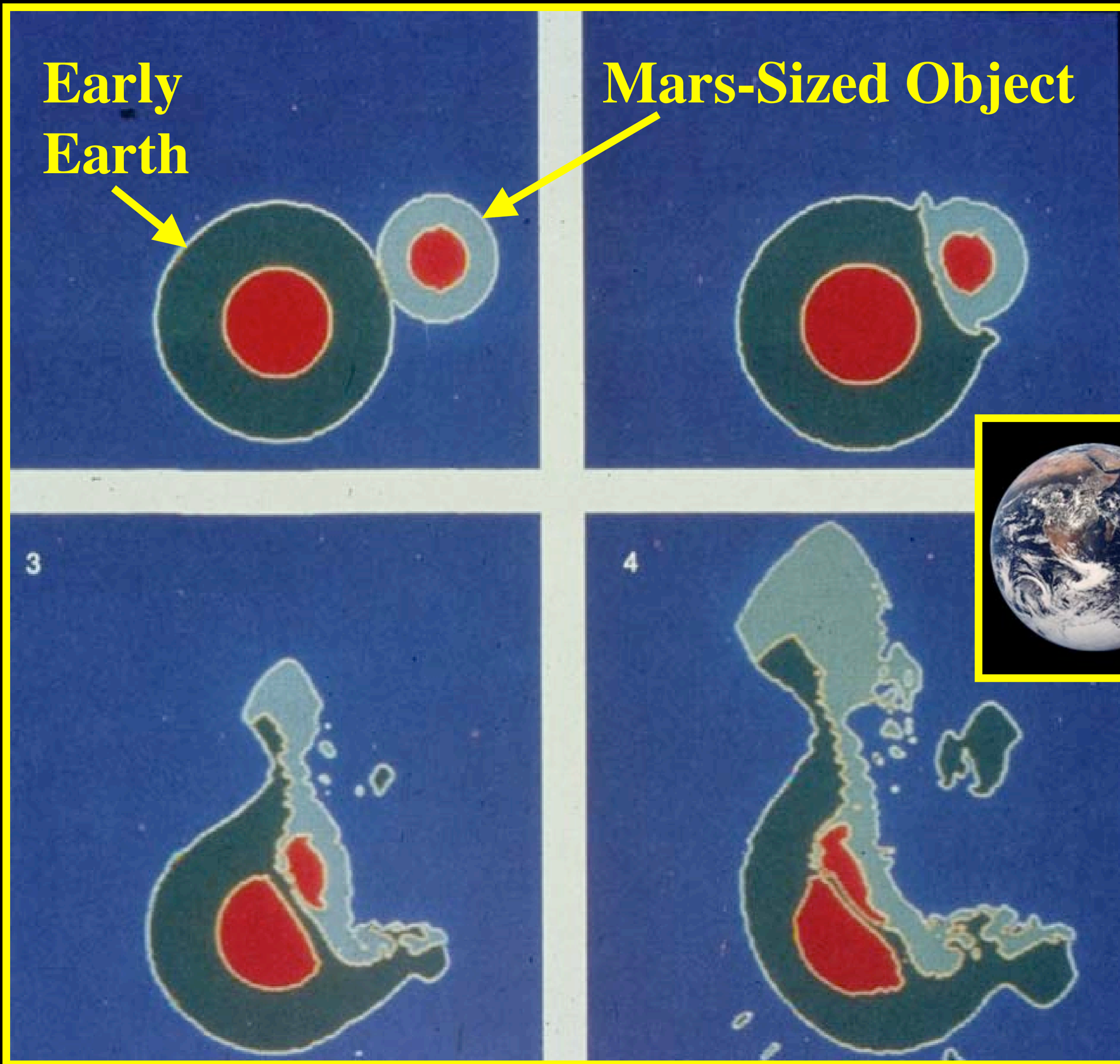
All other stones will be set in reference to it.

- Keystone:

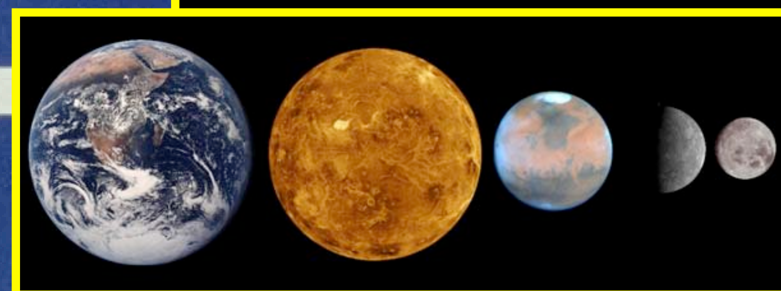
Central cohesive source of support and stability.

- Touchstone: Physical or intellectual measure by which the validity or merit of a concept can be tested.

1. The Moon formed from the impact of a Mars-sized object into early Earth.



-Devolatilization!
-Ejection.
-Reaccretion.

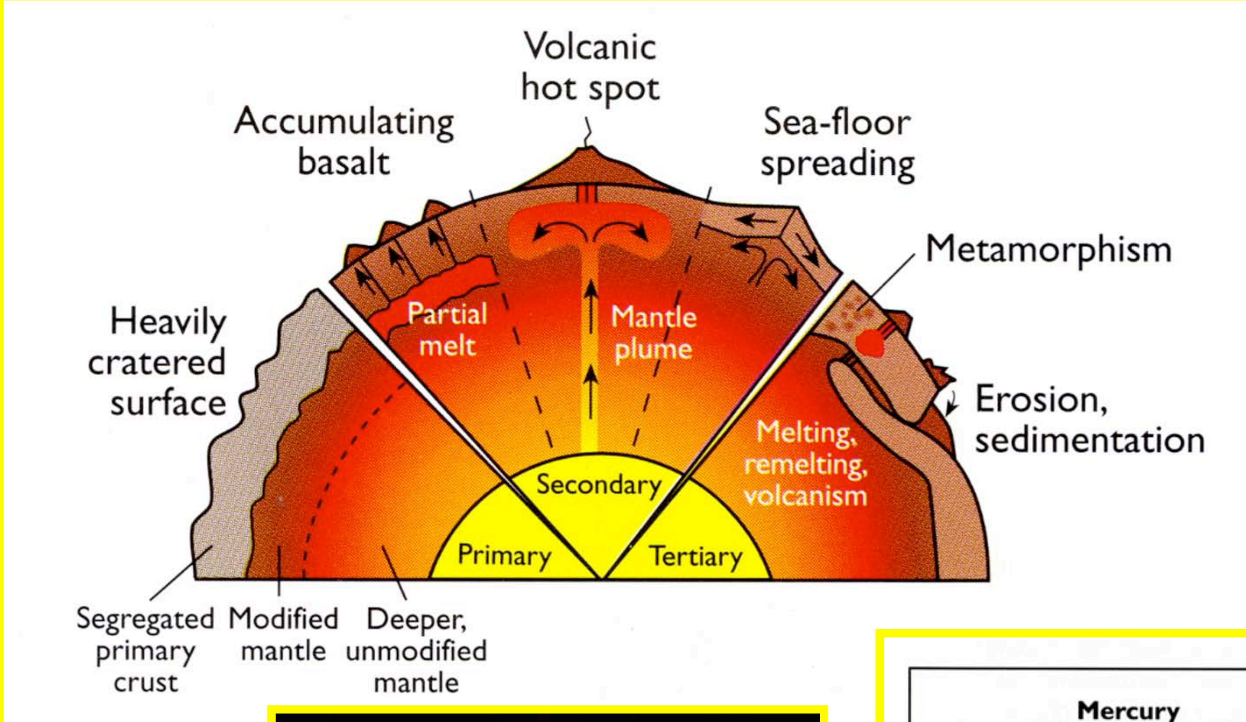


Devolatilization?

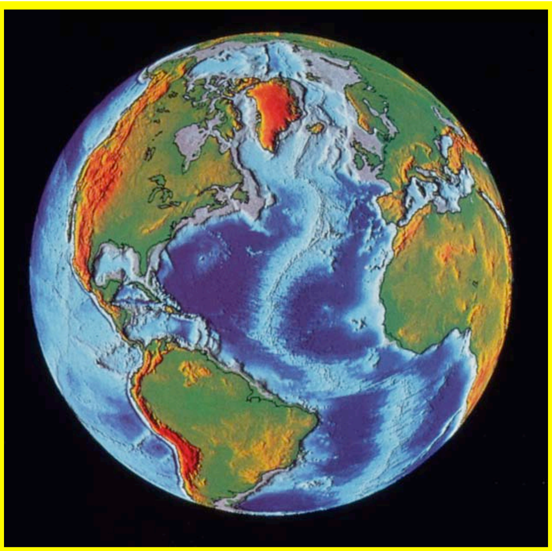
-Saal et al. (glass; Moon)
-McCubbin et al. (apatite; Moon)
-Kerber et al. (pyroclastics; Mercury)
-Sharp et al. (chlorine; Moon)

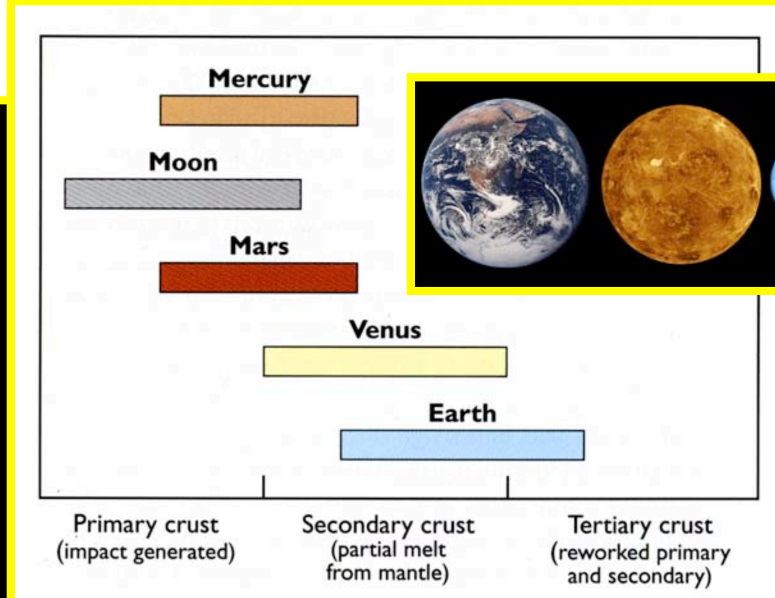
2. The early Moon was characterized by a global-scale magma ocean.

Crustal Formation and Evolution: Primary, Secondary, Tertiary



S. R. Taylor





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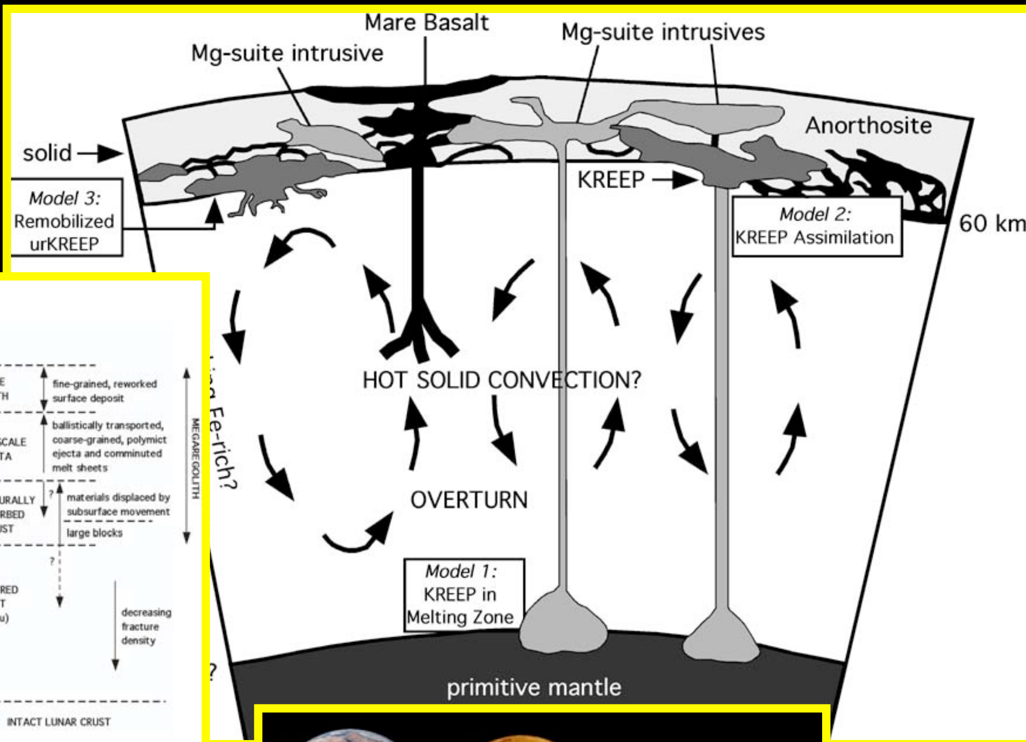
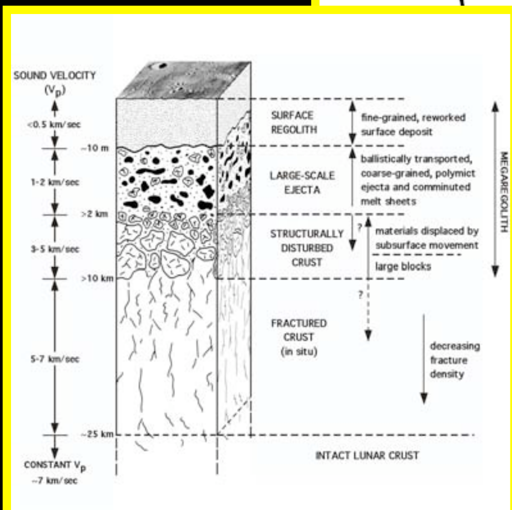
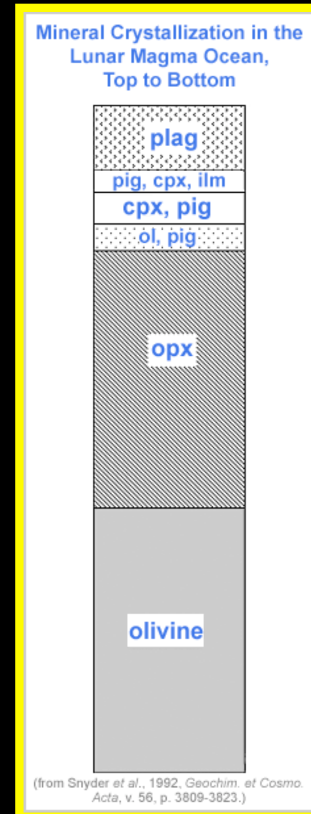
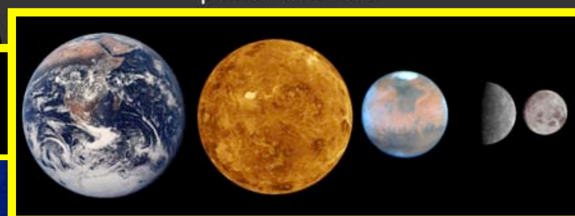
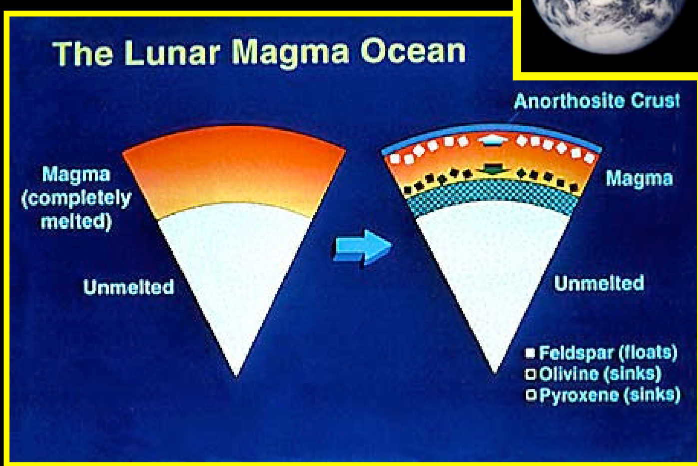
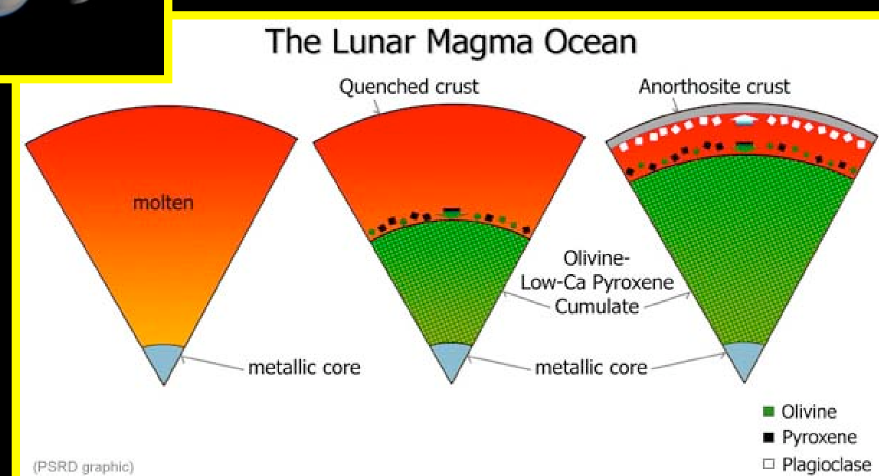




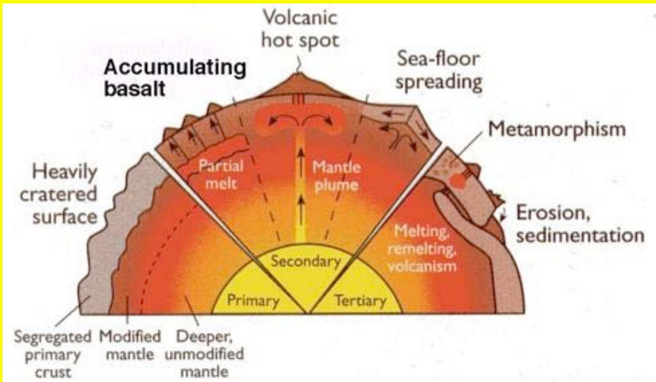


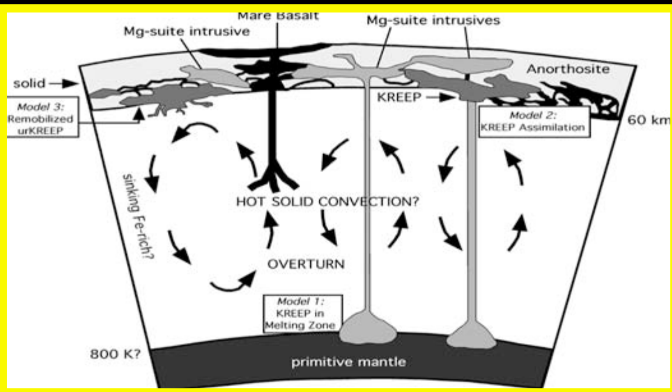




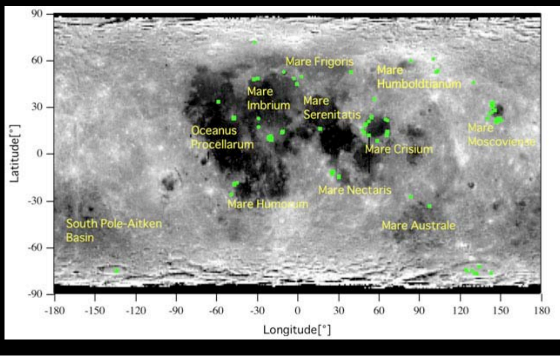


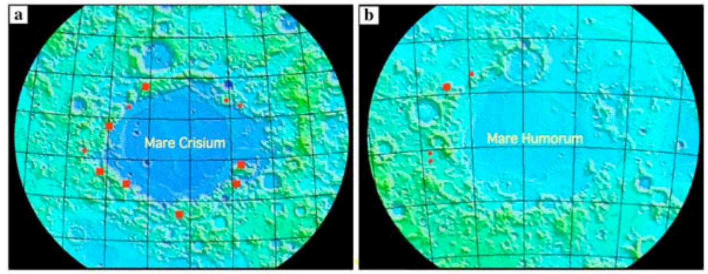
3. The Moon initially differentiated into chemical layers, including crust and mantle, that set the stage for further evolution.

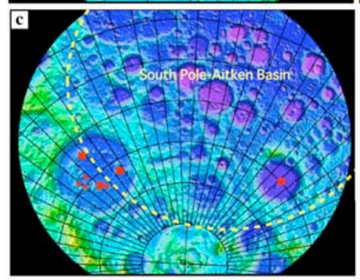




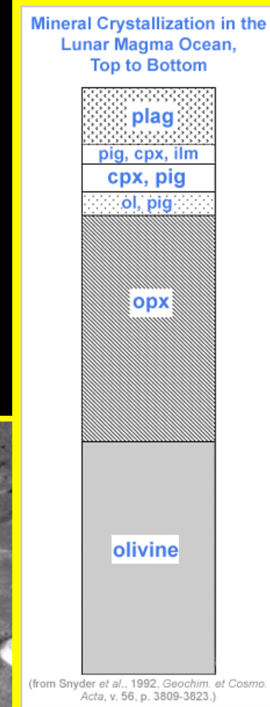
Primary, Secondary, Tertiary Crust

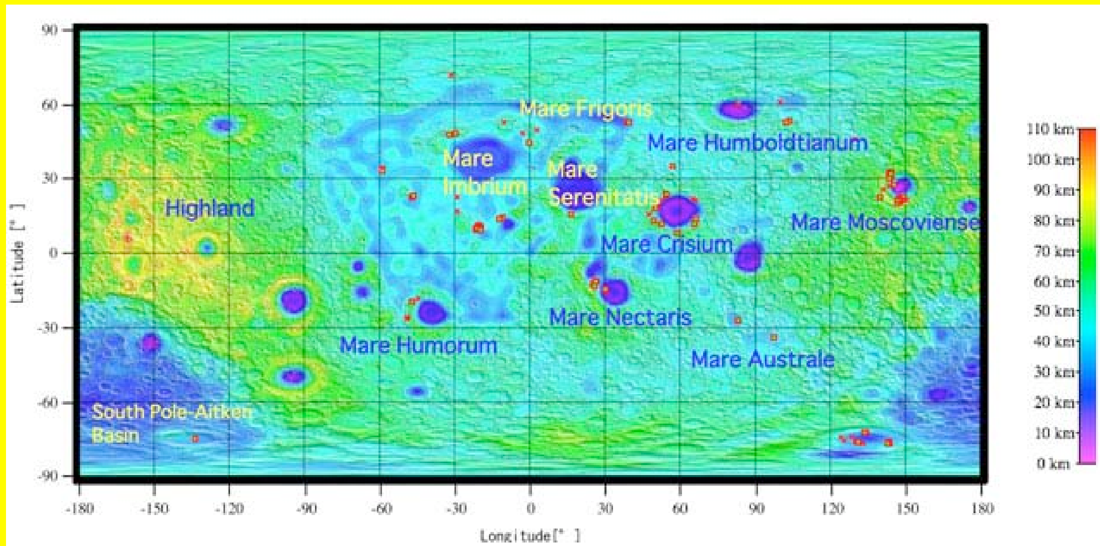




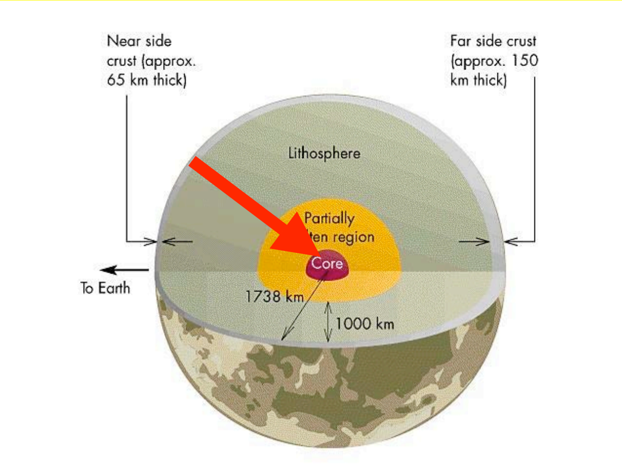


(Yamamoto et al., 2010)





4. The chemical and thermal nature of these stratified layers may have led to net negative buoyancy, large-scale overturn, and significant vertical mixing.



Anorthositic Crust

Magma Ocean Cumulates
(dense ilmenite-rich cumulates with high concentration of incompatible radioactive elements)

(olivine-orthopyroxene cumulates; later-crystallized, denser, more Fe-rich compositions at top)

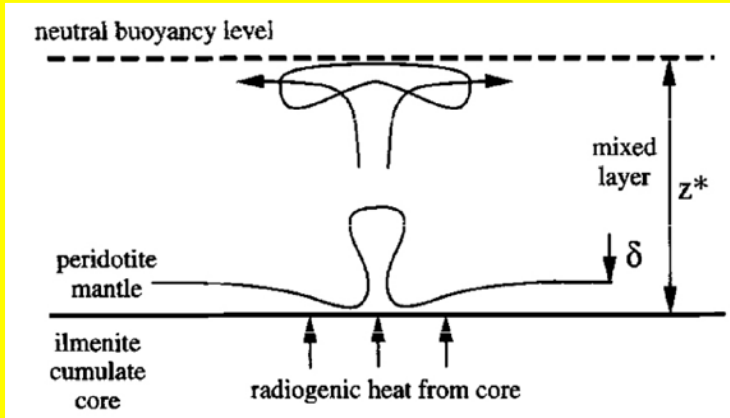
Primitive Lunar interior

-The Prelude- (Hess and Parmentier, 1995)

1. Lunar Magma Ocean (LMO) crystallization.
2. Forms chemically stratified interior.
3. Cumulate layers are gravitationally unstable.
4. Rayleigh-Taylor instabilities cause dense cumulates to sink toward center of Moon.

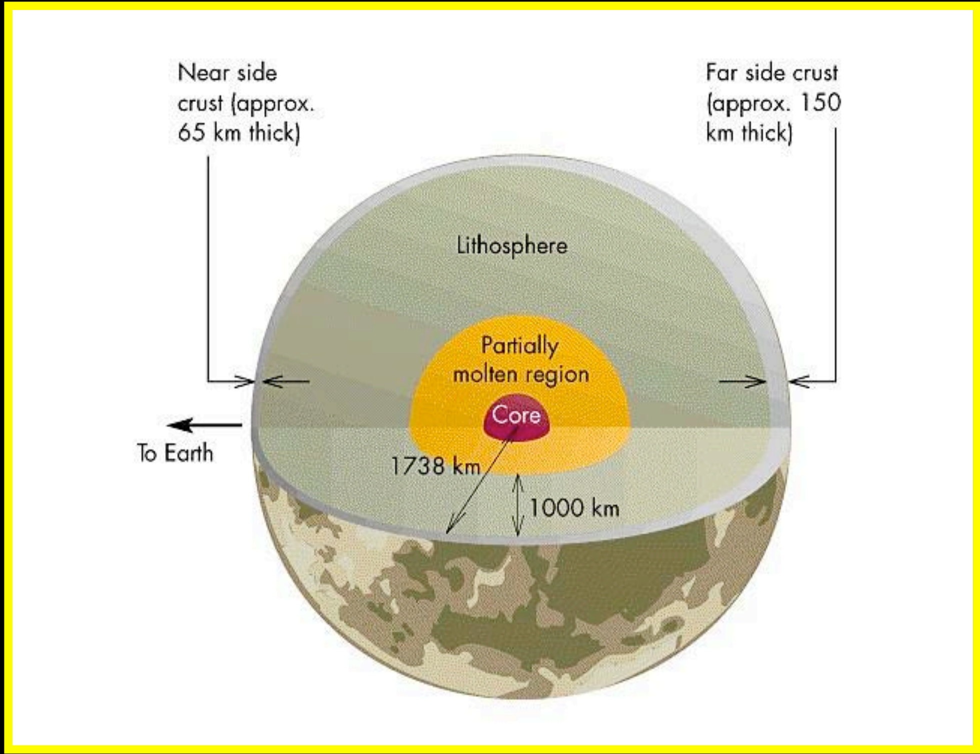
-The Aftermath-

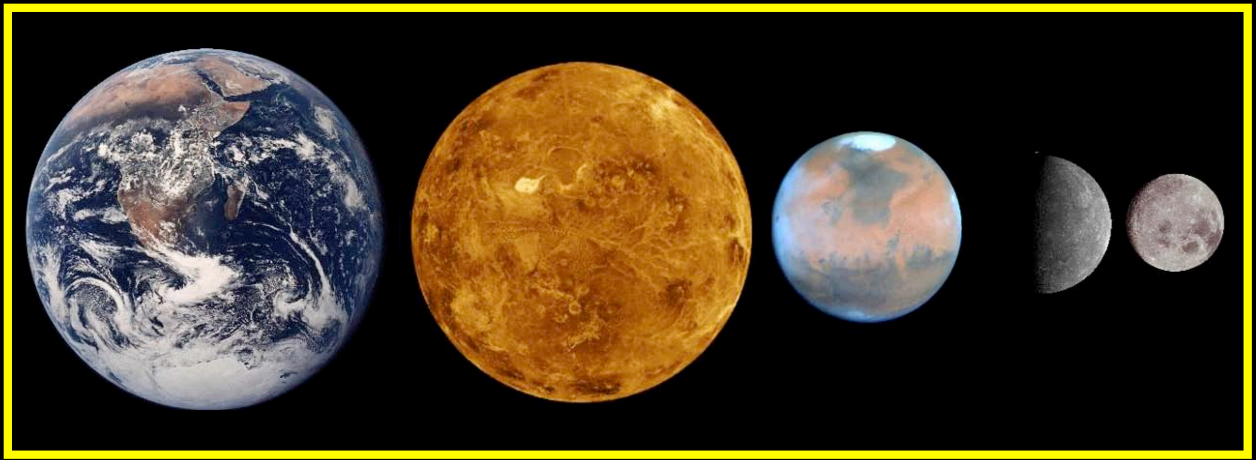
5. Dense cumulates form core.
6. Ilmenite-rich cumulate core undergoes radioactive heating, melts overlying mantle.
7. Thermal plumes rise into chemically stratified surroundings; mixing, homogenization.
8. Melting at top of mixed layer produces mare basalts.
9. Onset time is post-overturn, duration is long.



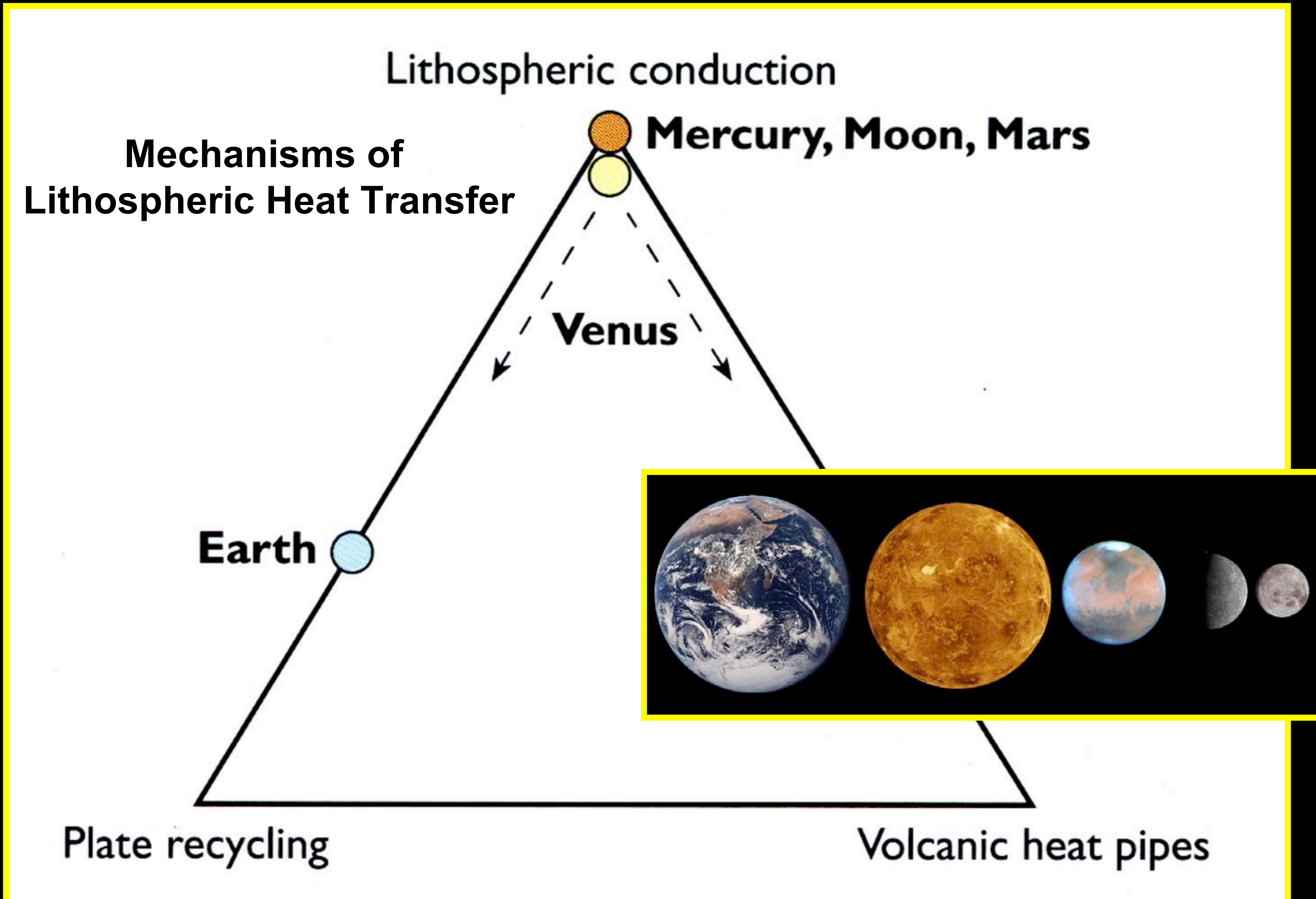
5. The Moon is stratified into mechanical layers; the lithosphere, the outer thermal boundary layer, thickened and became less heterogeneous with time.

(Solomon and Head, 1980)



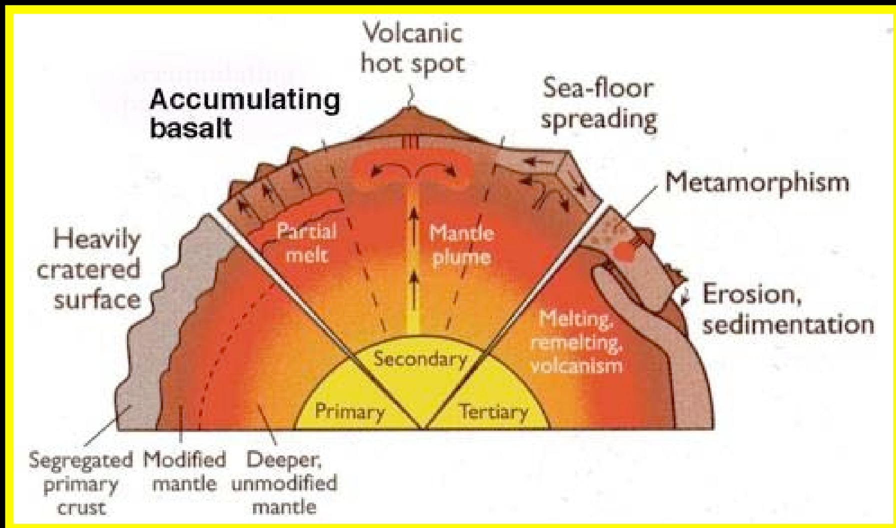


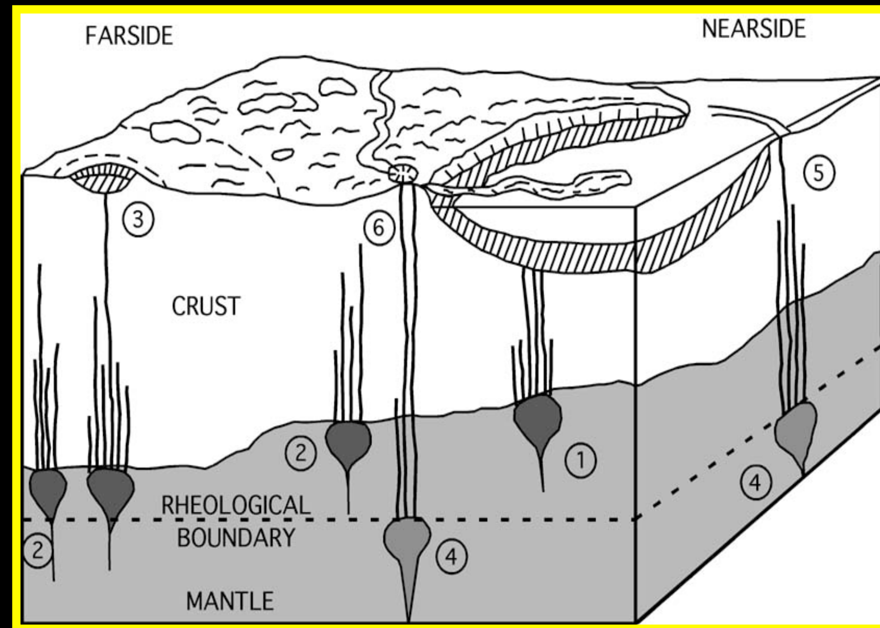
6. Tectonically, the Moon is a one-plate planet, characterized by a globally continuous lithosphere.

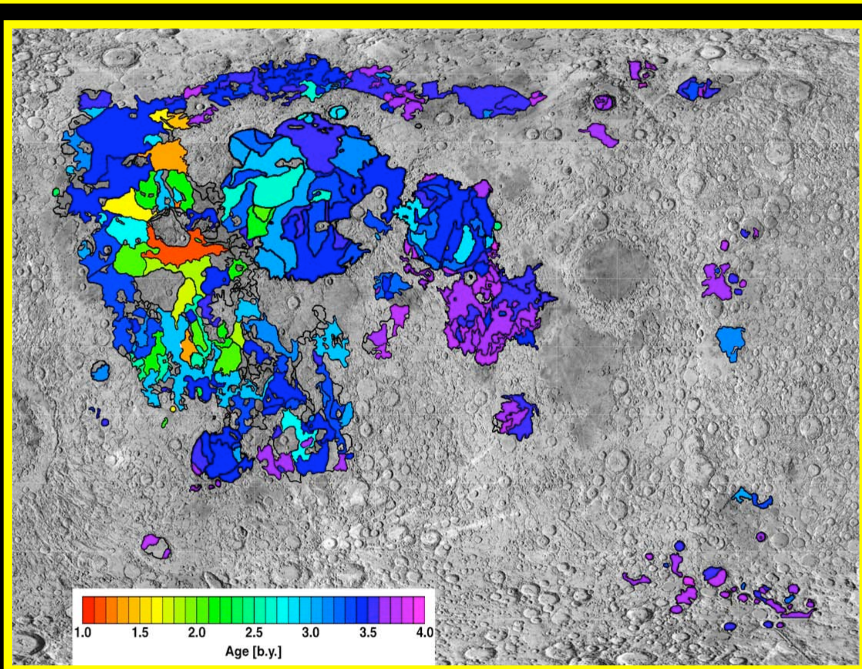


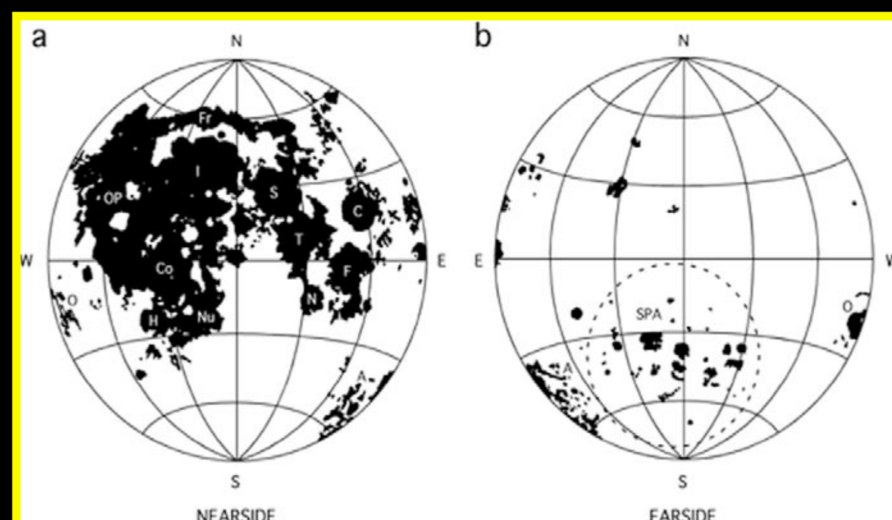
S. C. Solomon

7. Lunar volcanism records processes of mantle melting in space and time and the volcanic record reflects the general thermal evolution of the Moon, including the state and magnitude of stress in the lithosphere.

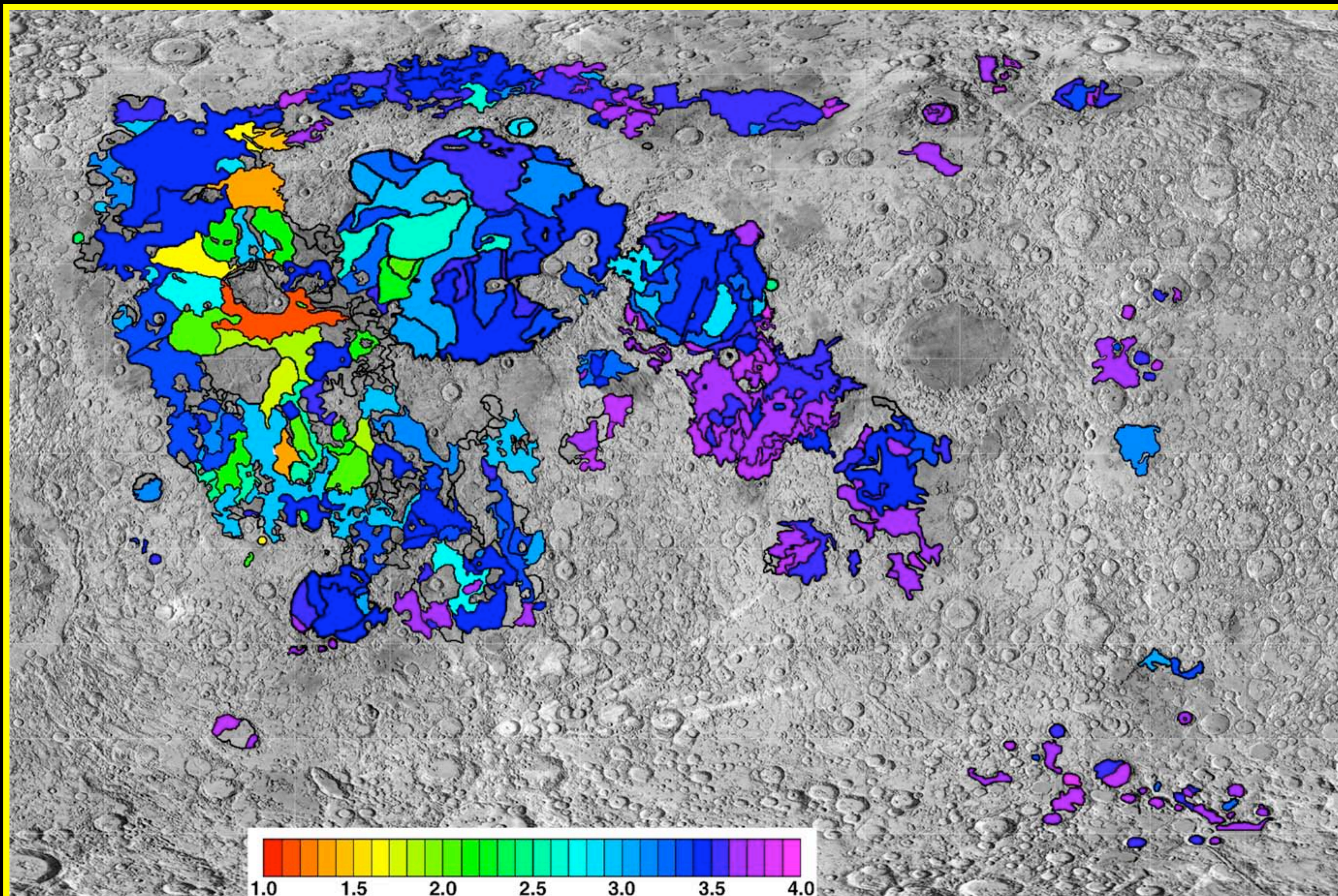






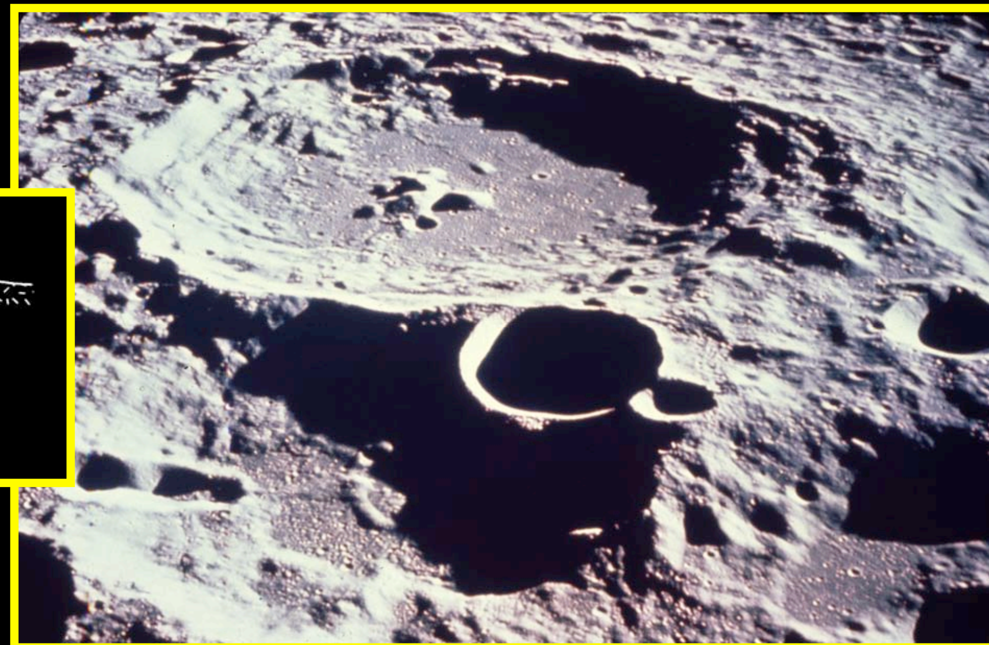


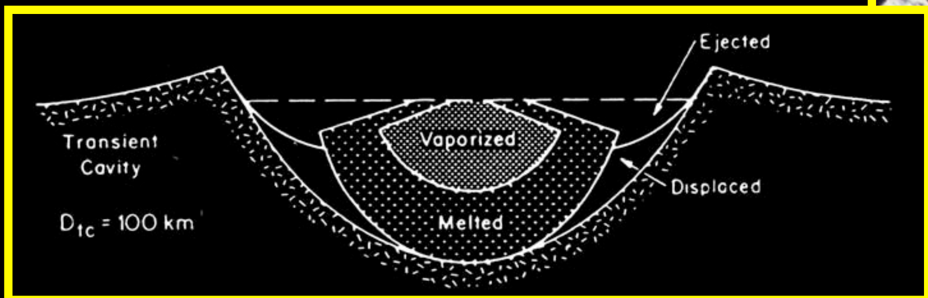
Dating Distinctive Mare Basalts Units

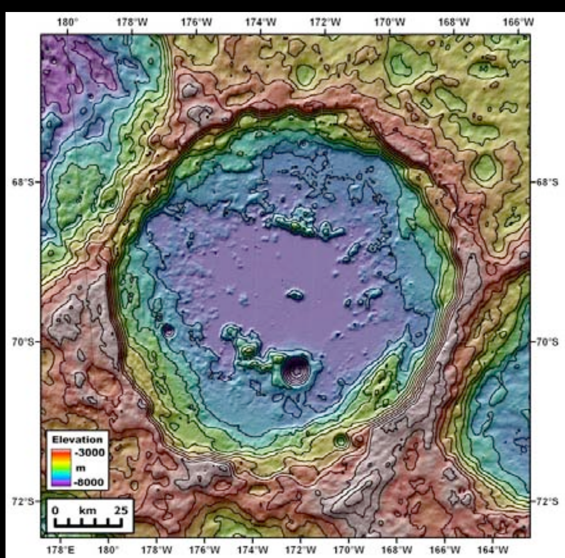


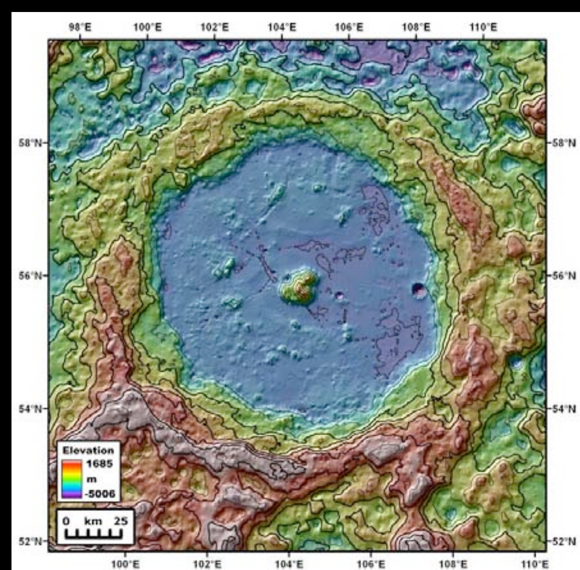
(Hiesinger et al., 2000, 2002, 2003, 2008; Hiesinger and Head, 2006)

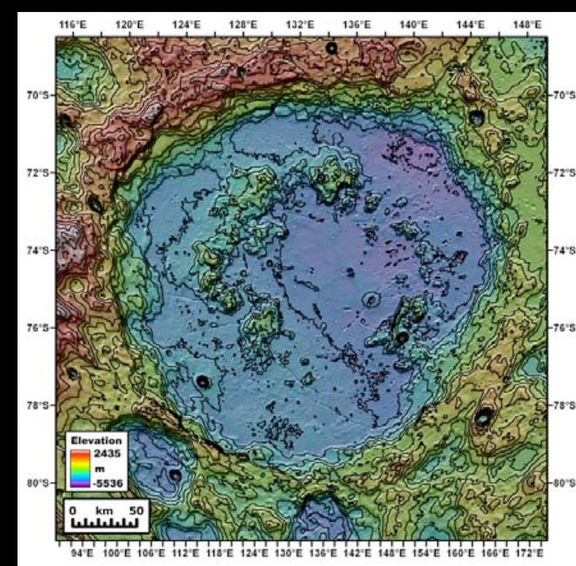
8. The Moon is a fundamental laboratory for the study of impact cratering processes, particularly at the complex crater to multi-ring basin scale.



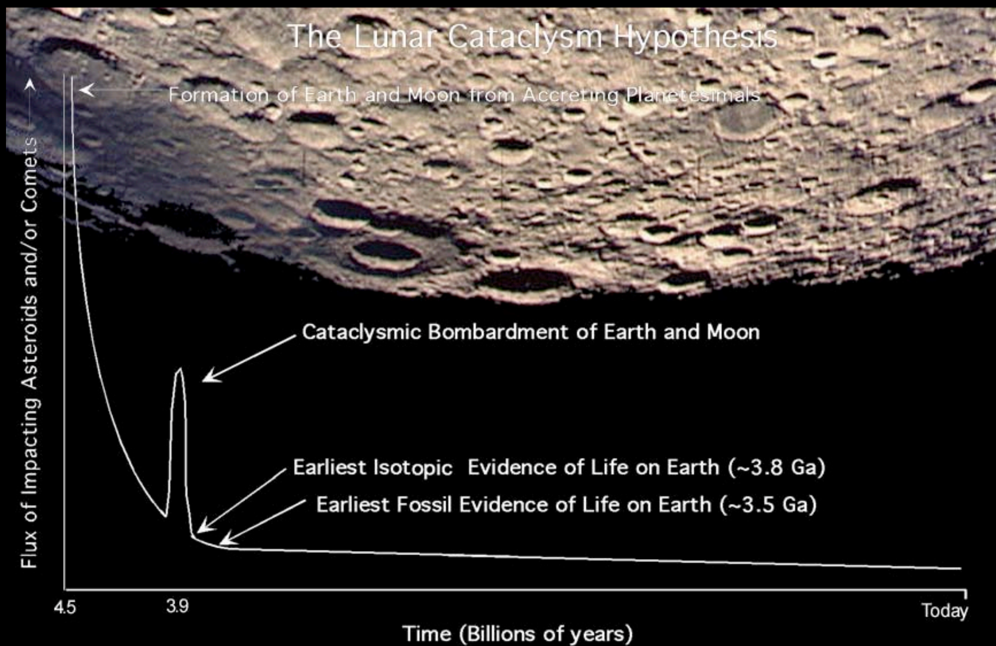




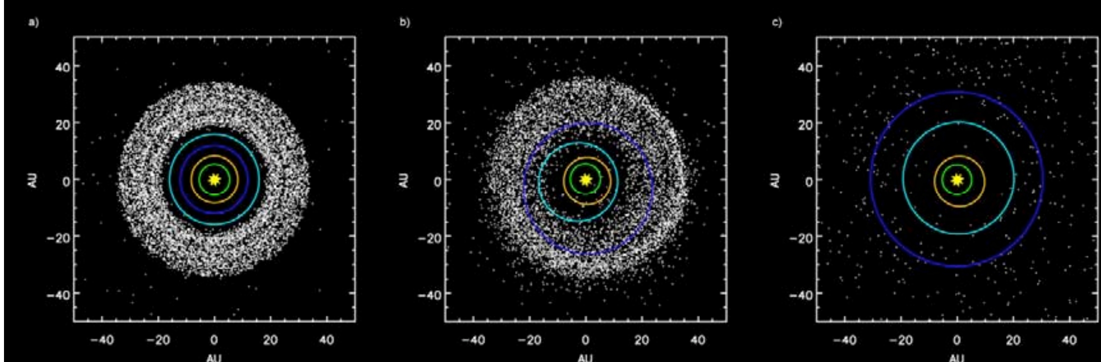




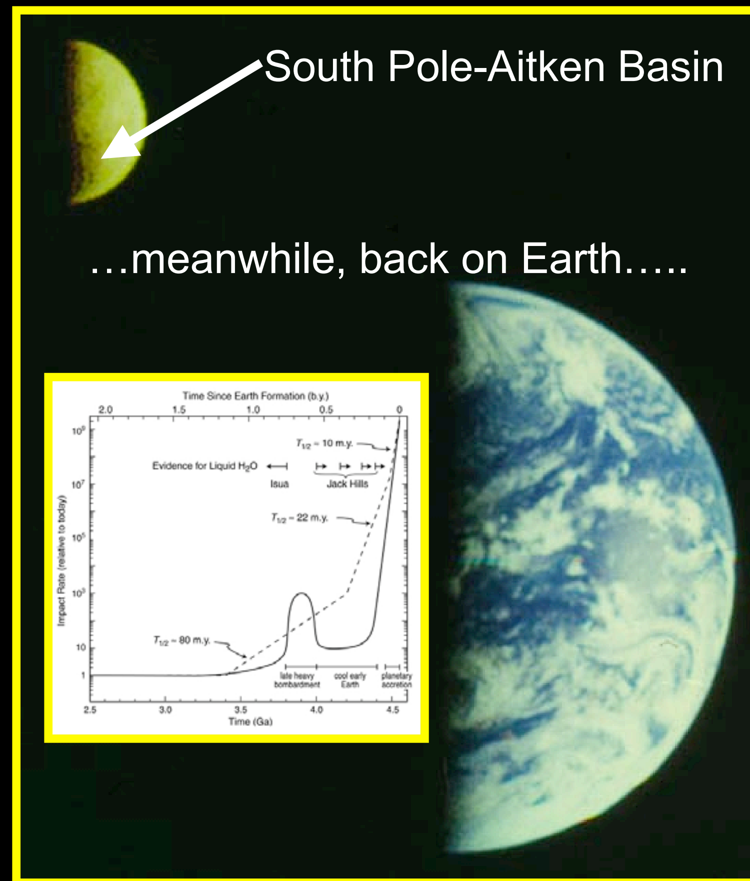
9. The Moon is a template for the record of the distribution and history of impactors in the inner solar system.



…on the Moon…..

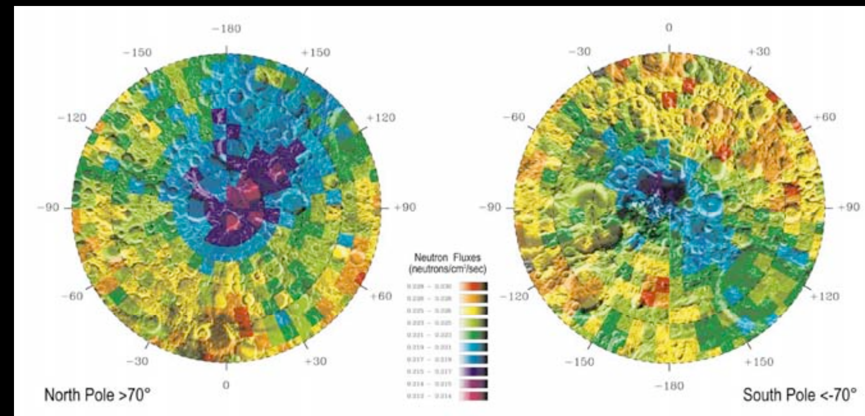


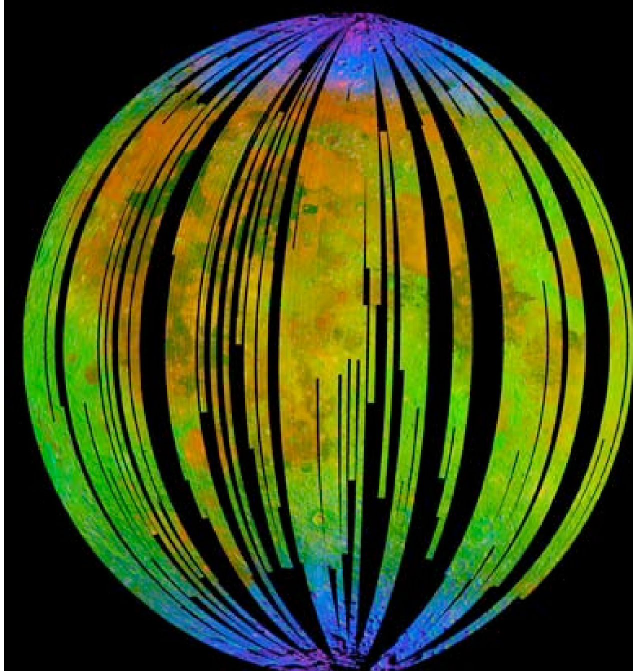
…meanwhile, in the outer solar system…..

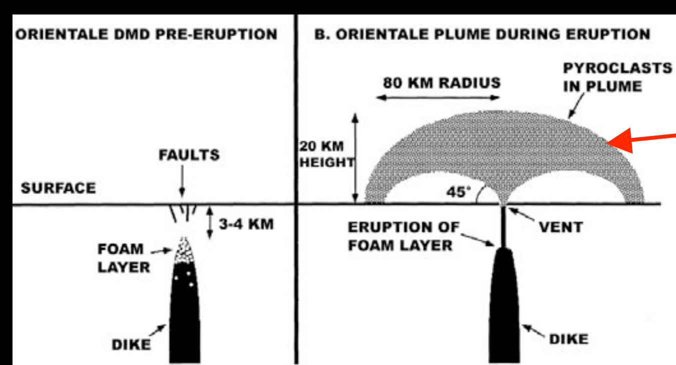


10. Volatiles play a more important role in lunar evolution than previously thought.

- Neutron Spectrometer.
- Chandrayaan-1 (Moon Impact Probe, Moon Mineralogy Mapper, Mini-SAR).
- LCROSS.
- Lunar polar deposits.
- Lunar pyroclastic glasses.
- Lunar apatite.

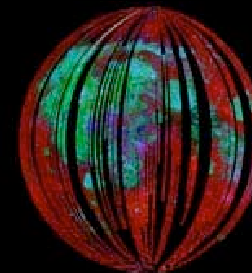






The Lunar Renaissance
"Everything has changed but our way of thinking."

- The distribution of rocks from the lunar sample collection can now be mapped globally.

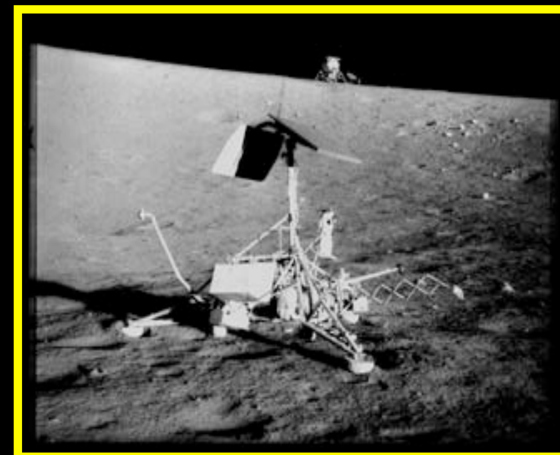



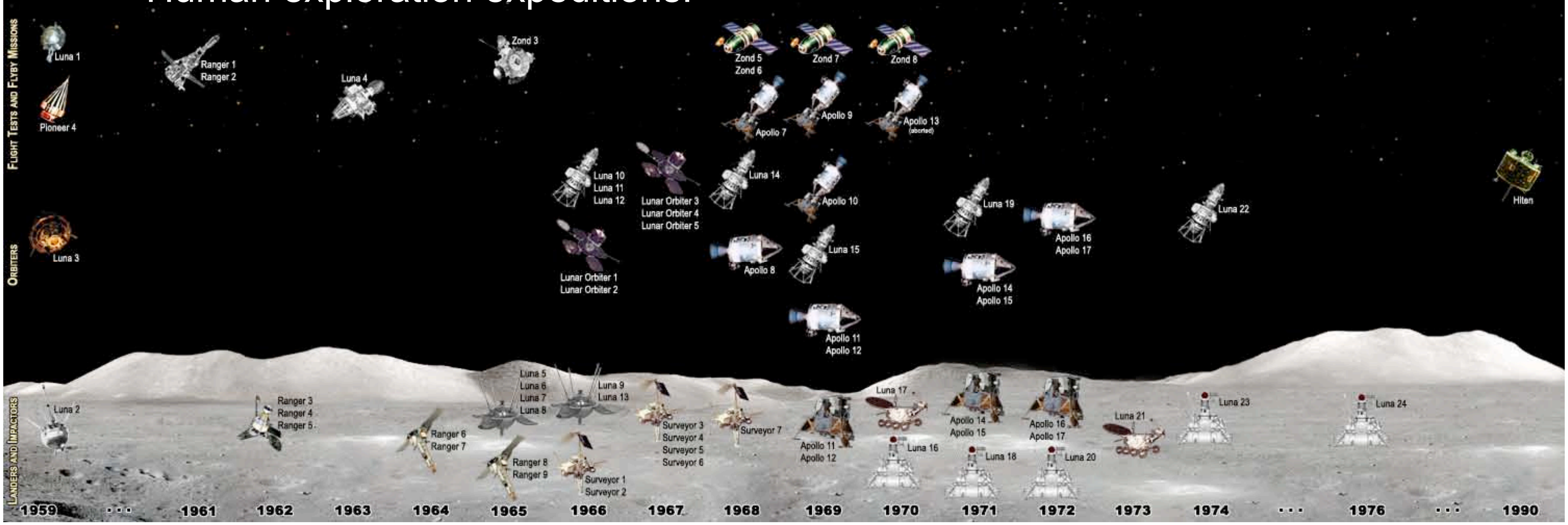
- New minerals and rock types are being discovered.
- The provenance of recognized rock types can be studied and established using new very high spatial and spectral resolution data.


- The mineralogy and context of individual large boulders and clusters of boulders can be mapped and then placed in their geological context.
- Models of crustal stratigraphy can be tested and depth of sampling of craters can be assessed.
- Refined models of crustal stratigraphy and evolution can be constructed.
- New avenues of communication are being opened between planetary scientists utilizing approaches such as mineralogy, petrology, geochemistry, geology, spectroscopy, geophysics, etc.

Lessons For Future Lunar Exploration

- The basic framework provided by the Lunar Renaissance will crisply define the critical scientific and exploration questions to be addressed by a range of new robotic and human lunar missions:
  - Orbiters:
  - Landers:
  - Geophysical networks:
  - Integrated rovers:
  - Sample return:
  - Human-Robotic partnerships:
  - Human exploration expeditions:





Lunar Resource/Glob Missions

- Fundamental framework of science results and these guiding questions provide excellent perspectives for site selection.

- Currently working with the LOLA team and A. T. Basilevsky to define the best sites from a scientific and engineering standpoint.

- Detailed analyses scheduled to commence on February 1, 2011 with the arrival of A. T. Basilevsky and M. A. Ivanov.

- Report to Site Selection group in the early Spring.