Structure and Evolution of the Lunar Interior

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Interior Structure and Evolution

Charge from Chip Shearer:

1. Identify major science problems tied to our further understanding of the lunar interior (both from a lunar perspective and a planetary perspective).
2. Describe how this science fits into the exploration of the Moon.
3. Describe how this science fits into the currently proposed lunar exploration architecture.

What Can We Learn from Investigation of the Lunar Interior?

- The thickness of the crust
- The density and stratification of the mantle
- The size and state of the core
- The temperature profile
- The configuration of the magnetic field
- The level and distribution of seismic activity

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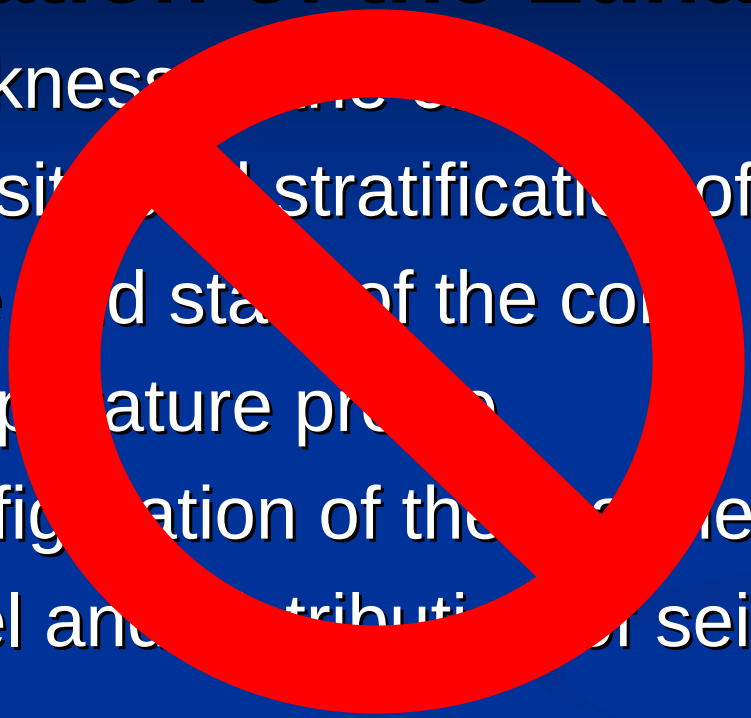

NO! NO! NO!

This is just underground geography, like knowing the capitals of the Baltic Republics

What Can We Learn from Investigation of the Lunar Interior?

The structure, composition, and thermal state of the lunar interior provide fundamental information on the formation of the Earth-Moon system, the evolution of the Moon (including its surface), and differentiation processes of terrestrial planets in general.*

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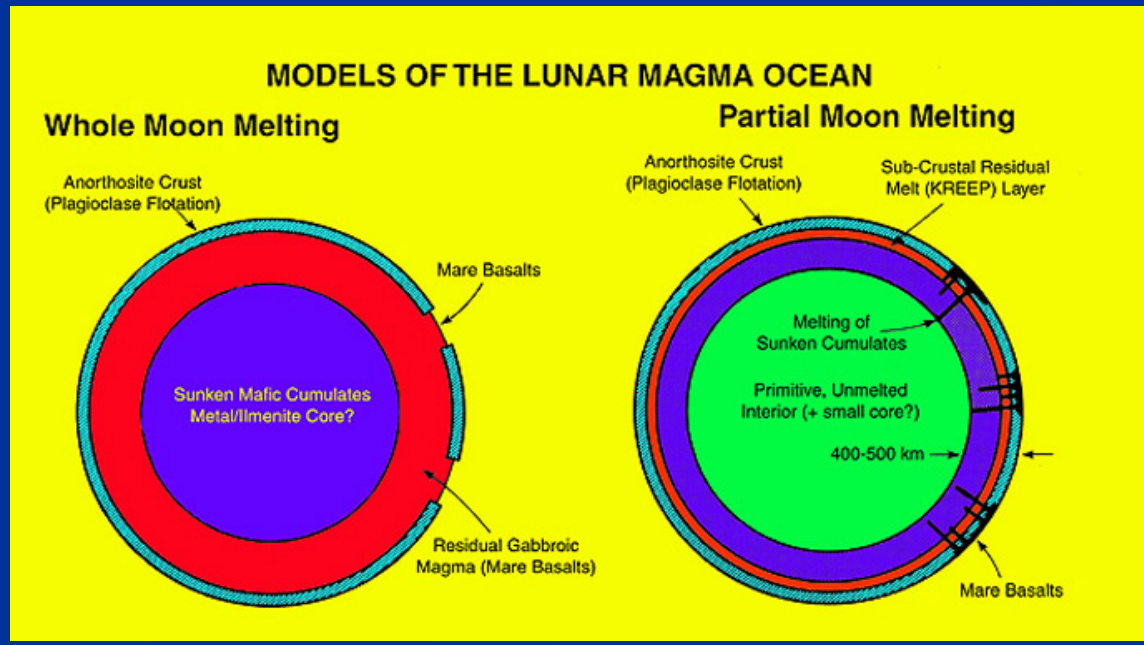
The structure, composition, and thermal state of the lunar interior provide fundamental information on the formation of the Earth-Moon system, the evolution of the Moon (including its surface), and differentiation processes of terrestrial planets in general.*

* Which can be obtained from determination of the crustal thickness, the density and stratification of the mantle, the size and state of the core, the temperature profile, the configuration of the magnetic field, and the level of seismic activity.

Major Science Problems

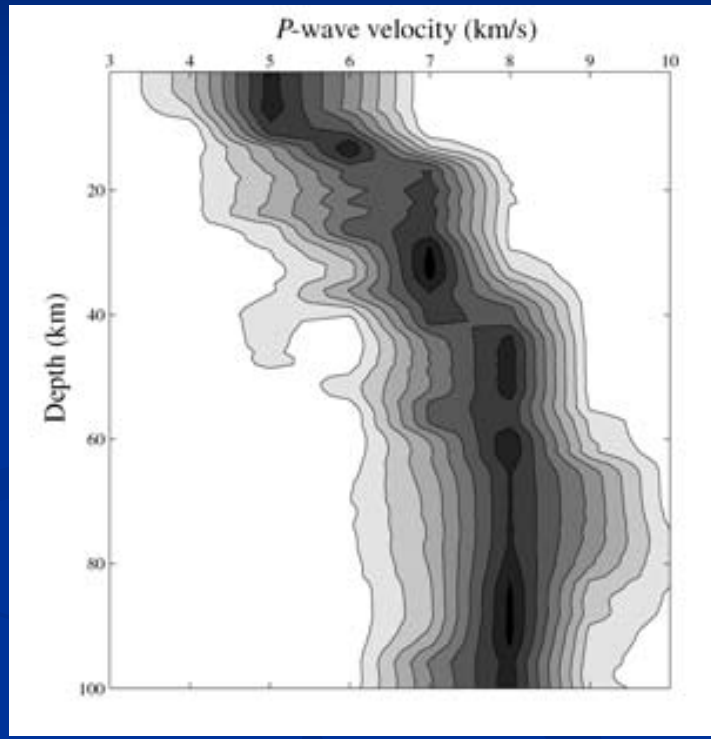
- What were the details of the Moon's formation? (e.g., composition of the accretion disk, degree of melting, …)
- How did the Moon differentiate? (e.g., depth of melting, fractionation processes in the magma ocean, core formation, …)
- How did it subsequently evolve? (e.g., partial melting and basalt generation, core solidification, subsolidus thermal convection, …)



Specific Questions

What is the thickness and vertical structure of the crust?

- New analyses call into question the Apollo-era thickness determination, resulting in a crustal volume uncertainty of nearly a factor of two.
- The nature of the seismically distinct lower crust is not well understood.
- Thickness variations from gravity analyses assume laterally uniform density, which is questionable (see next slide).

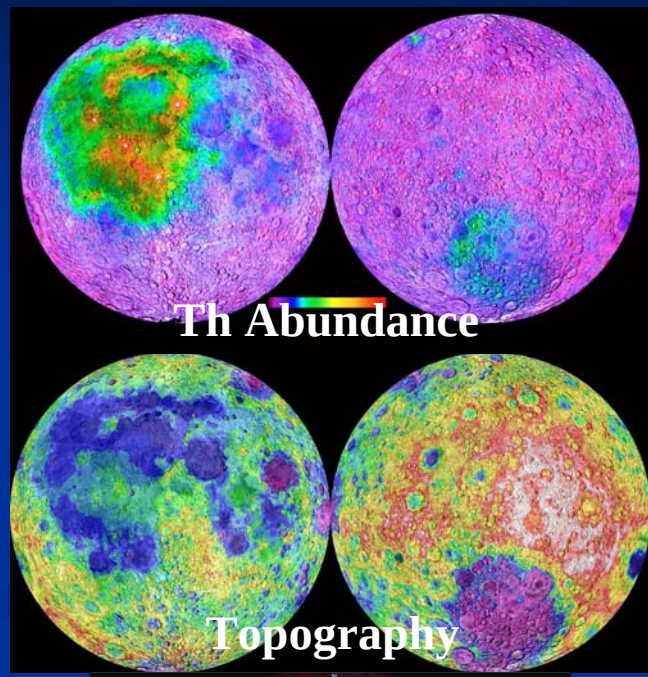


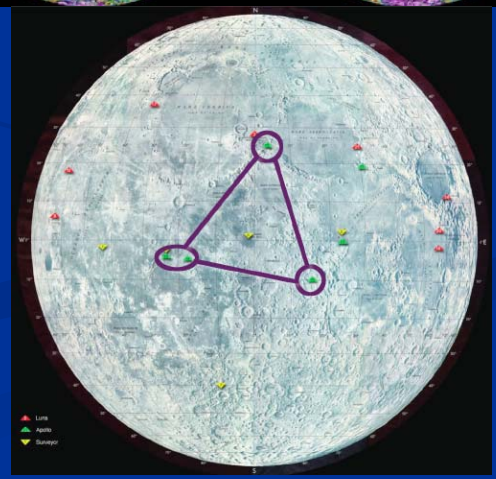
Khan et al., 2000

Specific Questions

What is the magnitude and depth extent of lateral variations in composition?

- Remote sensing has revealed distinct crustal provinces that appear to be related to deep-seated compositional differences.
- Gravity and topography show a dichotomy between near- and far-side crust.
- These variations may have roots in the mantle.
- Seismic measurements are spatially restricted.

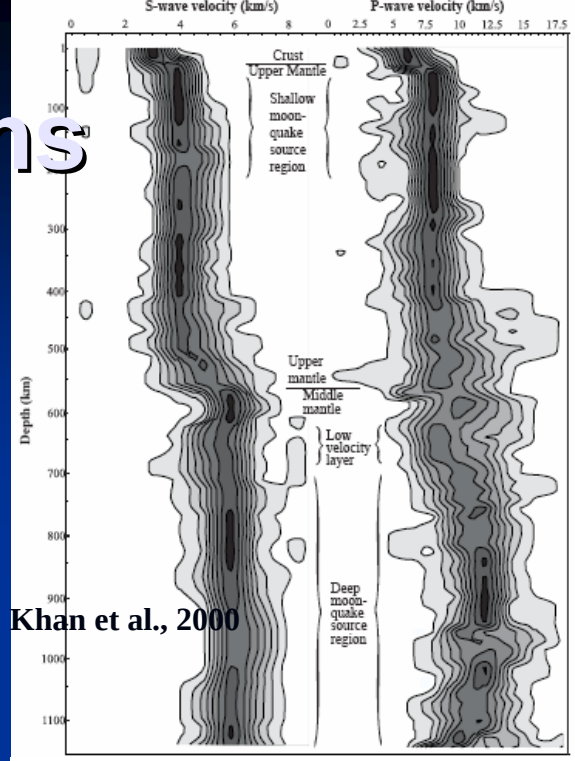




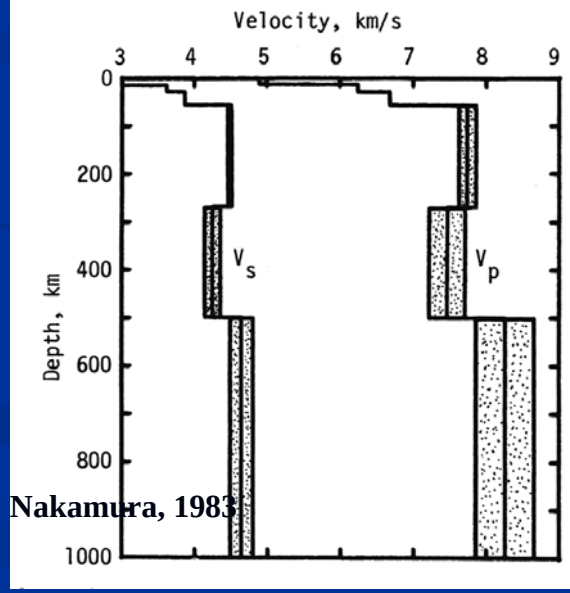
Specific Questions

What is the nature and extent of the 500-km discontinuity?

- Seismic profiles indicate a jump in velocity around 500-600 km depth.
- May denote the depth extent of the magma ocean.
- May indicate the depth extent of the mare basalt source region.
- May exist only beneath Imbrium-Procellarum.
- May not exist! (see limitations in seismic coverage)



Khan et al., 2000

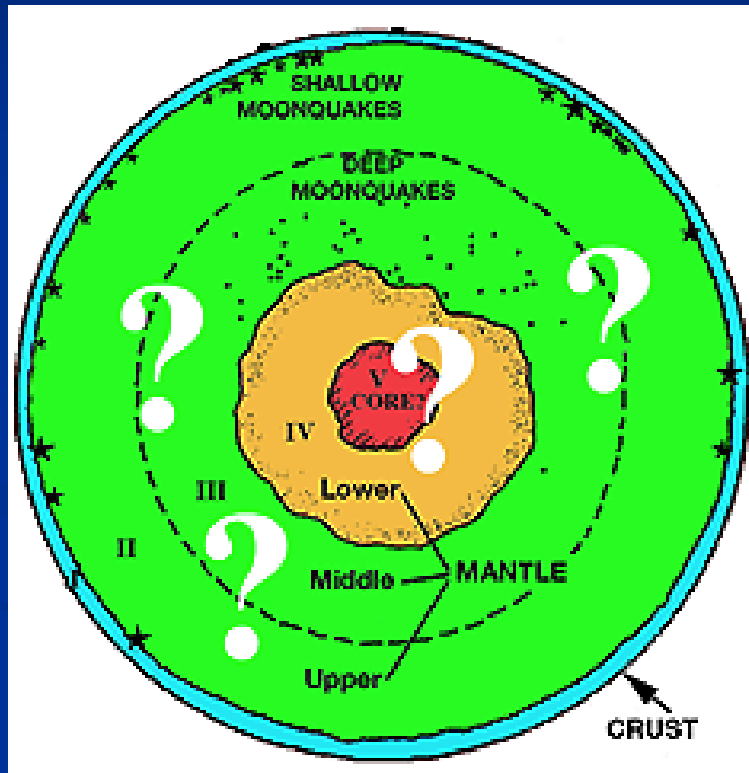


Nakamura, 1983

Specific Questions

What is the structure of the lower mantle?

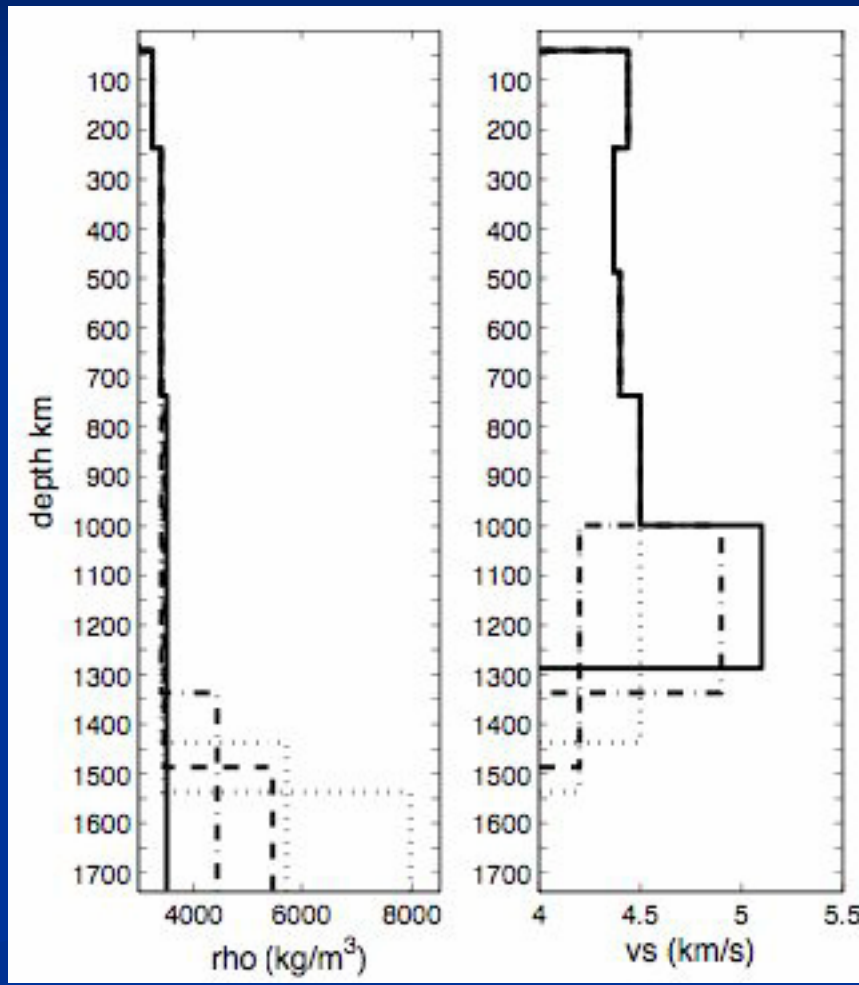
- Simple magma ocean models predict late-stage mantle overturn, the but timing and efficiency are not known.
- Is mantle well mixed, or is there remnant stratification?
- Was there a global overturn, or was it localized?
- Is the lower mantle increasingly Mg-rich, or is there a significant garnet cumulate?
- Seismic models have almost nothing to say below 800-1000 km.



Specific Questions

What is the nature of the core?

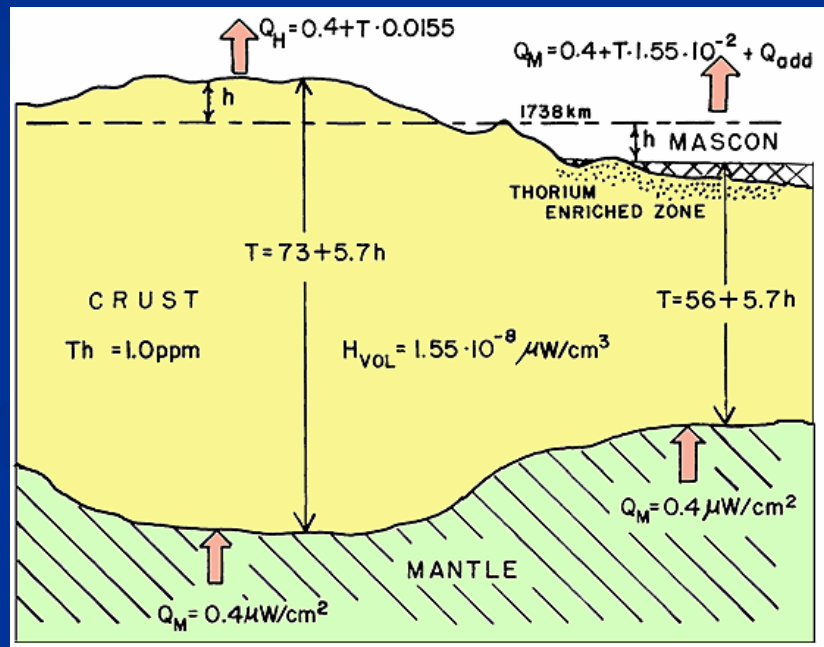
- The composition of the core has implications for the dynamics of the Giant Impact, the composition of the mantle and the existence of an early dynamo.
- Current data indicate a small core (<450 km), composed of Fe plus some Ni, S, C, is likely. But a dense, Ti-rich silicate magma cannot be excluded.
- May be solid or liquid, depending on the composition.



Specific Questions

What is the thermal state of the Moon?

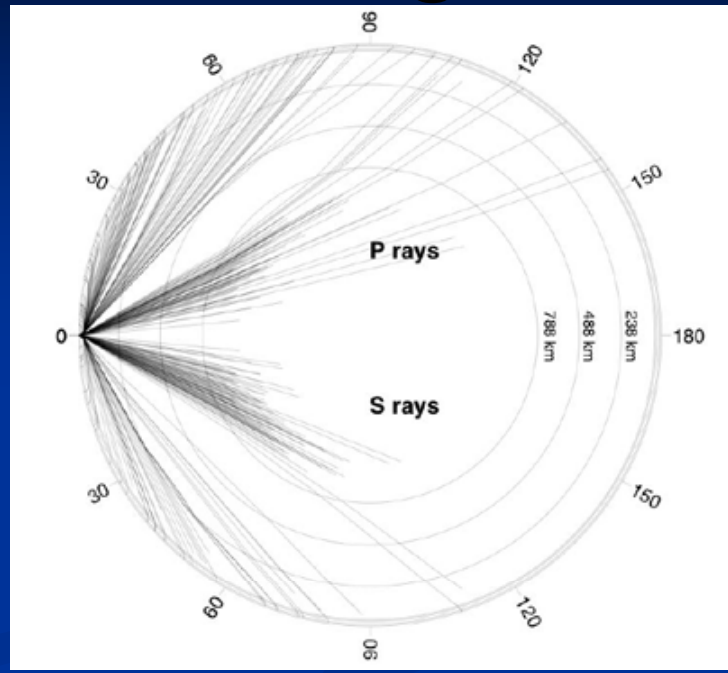
- Heat flow has implications for lunar bulk composition and distribution of heat-producing elements.
- It also provides a key constraint on thermal models, which bear directly on understanding the differentiation history.
- Only Apollo 15 and 17 made heat flow measurements, which differ by 50%.
- Both sites are close to PKT-HFT boundary, making interpretation difficult.



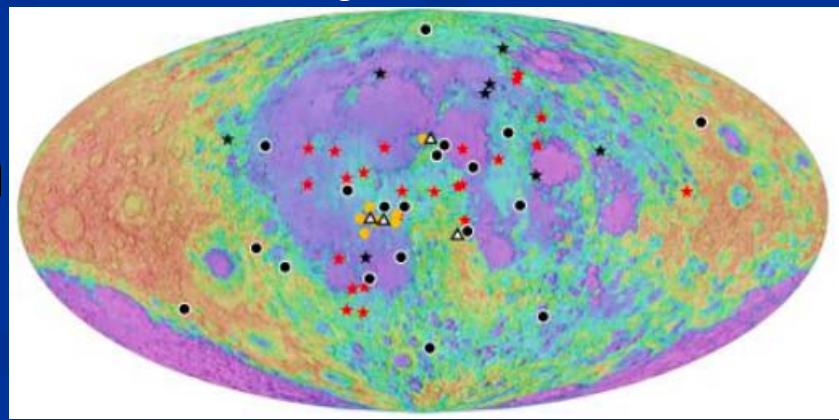
Langseth et al. (1976) PLSC 7th, 3143-3171.

Limitations of Seismic Coverage

- Seismic arrivals give velocity information for the deepest point on ray path.
- There is a gap in coverage between ~500–800 km.
- Only 10 P arrivals (and only 2 S arrivals!) sample below 500 km.
- There is also a geographic concentration of sources in the vicinity of PKT.



Lognonné and Johnson, 2007



Gagnepain-Beyneix et al., 2006

How Does This Science Fit in With the Exploration of the Moon?

- Investigation of the interior is vital for understanding some of the highest priority science questions regarding the Moon.
- The geophysical instrumentation has been developed and refined, and is relatively low-mass and low-power.
- Emplacement of seismometers and (especially) heat flow probes would benefit from the “human touch”, but they do not require further tending.
- See Clive Neal’s implementation talk this afternoon.

How Does This Science Fit in With the Current Architecture?

- A polar site is quite lovely.
  - Not same old Imbrium-Procellarum area.
  - Close to far side.
  - Small diurnal thermal variation in subsurface.
- But …

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A SINGLE SITE DOES NO GOOD WHATSOEVER!

Pink = Requires additional sorties, not necessarily human-tended