LUNAR SCIENCE: THE FUTURE IS KEY TO THE PAST.

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Introduction: Future geological field exploration, sampling, and geophysical measurements of the Moon constitute the key to verifying the major hypotheses that have been put forward based on exploration, samples and geophysical data gathered during Apollo and other missions. The "giant impact origin" and "impact cataclysm" constitute the two major current hypotheses that require verification as both are based on limited sample data and neither can fully embrace all existing relevant data sets. We also lack a detailed delineation of the global structure of the Moon and the insights on lunar evolution and the evolution of other terrestrial planets that would come from such delineation. Many other exploration targets relate to exciting questions more specific to the Moon than to these major planetological issues. Finally, targeted sample verification of the potential enrichment of helium-3 in polar regions, in conjunction with the observed enrichment of solar wind hydrogen, pertains directly to investment and public policy questions related to future terrestrial energy demand and lunar settlement.

Giant Impact: The giant impact hypothesis for the origin of the Moon has become entrenched in the scientific literature, the popular scientific press, and as dogma in most academic institutions. It is an attractive hypothesis. Students and faculty alike are remarkably unquestioning about its basic premises. Giant impact forms an implicit if not explicit assumption that underlies most geochemical and geophysical interpretations of new data reported in the lunar science literature.

The major problem with the giant impact hypothesis lies with information we have about the interior of the Moon. The lower lunar mantle, based on analyses of the non-glass component of Apollo 17 orange pyroclastic glass and Apollo 15 green pyroclastic glass, appears to have isotopic and volatile chemical signatures incompatible with current formulations of the giant impact hypothesis, particularly with respect to the temperatures reached in ejected material. Broader sampling of pyroclastic glasses, as well as more detailed geophysical understanding of the sources and origin of their non-glass components, provides critical tests of this hypothesis.

Impact Cataclysm: The possibility that the formation of the last 14 large, mascon lunar basins at ~3.85±0.05 Gy effectively reset the impact ages of most available samples from the lunar crust makes confirmation of the impact cataclysm(s) hypothesis currently impossible. Resolution of the questions related to the proposed single lunar cataclysm at ~3.85 Gy, possible multiple cataclysms at and prior to ~3.85 Gy, or a continuous, declining crater-forming impact flux from ~4.5 Gy provides the opportunity to calibrate the Hadean Eon on Earth and other terrestrial planets. Clearly, the Moon provides the best and most accessible record of the impact history of the inner Solar System, particularly relative to the formation of the extremely large basins, such as South Pole Aitken and the ~35 younger large, non-mascon basins, such as Tranquillitatis. Even the end of large basin formation, and thus probably the end of the Hadean, should be more accurately defined by appropriate samples from Orientale.

Currently known lunar history suggests that two major boundaries can be defined for the Hadean. The first lies at about 4.2 billion years, the end of saturation cratering and the beginning of recognizable very large basin formation in the inner solar system. The second boundary and the potentially definable end of the Hadean rests at about 3.8 billion years, the end of large basin formation. Although not yet fully confirmed, the 3.8 billion year boundary also may be the point at which the first isotopic evidence of life on Earth can be found.

Global Structure: We know the internal structure of the Moon only to a depth of about 500km and even that is limited to the sector under the relative small, front side Apollo seismometer net. Further, very limited data on the size, temperature, and composition of the lunar core comes from several sources, but those sources do not provide the details necessary to understand the history and dynamics of that core. This paucity of information leaves us much in the dark about the following issues:

1. Extent and uniformity of the evolution of the magma ocean.
2. Distribution of Mg-Suite parent igneous bodies in the crust.
3. Original distribution of the magma ocean's residual liquid (urKREEP).
4. Structure and compositional details of the upper mantle (above 500km).
5. Structure and compositional details of the lower mantle (below 500km).
6. Structure and compositional details of the upper and lower mantle transition.
7. Detailed nature of the lower mantle-core boundary
8. Structure and compositional details of the lower mantle-core transition.

Determining the spherical uniformity or nonuniformity of the differentiation of the magma ocean and explaining the apparent 600 My delay in the activation of a lunar core dynamo constitute just two of the many issues with planetary implications that resolution of the above issues could address.

Lunar Evolution: Specific information related to lunar evolution has yet to be gathered in the following areas of great interest to many workers:

1. Global delineation of major geological and geochemical units, particularly on the lunar farside and at the poles and limbs.
2. Stratigraphic and eruptive sequence analysis of pyroclastic glasses.
3. Nature and ages of the cryptomaria.
4. Nature and ages of light plains deposits.
5. Depositional history of polar cometary volatiles.

Polar Helium-3: Over two decades have passed since a University of Wisconsin team identified the potential significance of helium-3 as a terrestrial fusion energy resource. Information exists on the concentration of lunar helium-3 and other solar wind volatiles in titanium-rich mare regolith. On the other hand, the neutron spectrometer data from Lunar Prospector indicates that concentrations of solar wind hydrogen, at least, increase toward the poles, well before regions or areas of permanent shadow are reached. This apparent cold trapping of solar wind volatiles in high latitudes probably enriches the regional lunar regolith in helium-3 and other solar wind resources by as much as a factor of 3 over that sampled by Apollo 11 in Tranquillitatis regolith. Sample verification of such enrichment potentially will affect investment and policy decisions relative to future global energy demand.

Conclusion: Much highly significant science remains to be done on the Moon, based solely on what we now know or can surmise. And this does not include the potential for the use of the Moon by non-exploration sciences as a unique observation platform in space. Further, as in all exploration, new questions and opportunities will arise that will demand our attention.