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Lunar Geoscience: Key Questions for Future Lunar Exploration

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The last several decades of intensive robotic exploration of the Moon has built on early Apollo and Luna exploration to provide fundamental knowledge of Earth's satellite and an excellent perspective on the most well-documented planetary body other than Earth. This new planetological perspective has raised substantial new questions about the nature of the origin of the Moon, its early differentiation and bombardment history, its internal thermal evolution, the production of its secondary crust as exemplified by the lunar maria, and tertiary crust as potentially seen in steep-sided domes and impact melt differentiates, the abundance of interior volatiles and their role in volcanic eruptions, and the abundance of surface volatiles and their concentration in polar regions. On the basis of this new information, a series of specific outstanding geoscience questions can be identified that can serve as guides for future human and robotic exploration. These include: 1) What is the nature and abundance of impact melt seas and what rock types do they produce upon differentiation and solidification? 2) Where are lunar mantle samples located on the lunar surface and what processes are responsible for placing them there? 3) What processes are responsible for producing the silica-rich viscous domes, such as those seen at Gruithuisen? 4) What are the volatile species involved in the emplacement of lunar pyroclastic deposits and what clues do they provide about deep magmatic volatiles and shallow volatile formation processes? 5) How do we account for the differing characteristics of regional dark mantling pyroclastic deposits? 6) When did mare basalt volcanism begin (earliest cryptmaria) and how and where is it manifested? 7) Was there extensive volcanism and resurfacing prior to mare basalt volcanism; if so, what is its origin and how is it manifested? 8) Are there other shallow magmatic intrusions besides floor-fractured craters, and if so, what is their origin? 9) What clues can we derive from the geology and gravity structure of floor-fractured craters concerning the modes of emplacement and magmatic evolution of shallow intrusions; does differentiation and volatile build-up take place? 10) What are the factors that explain the formation of complex craters, peak-ring basins and multi-ring basins? 11) What are the ages of key multi-ring basin impact melt sheets and how do they help to determine lunar impact chronology and flux? 12) How can lunar crustal density and thickness structure revealed by GRAIL be related to geological impact, magmatic and tectonic processes? 13) What is the origin, distribution and mode of emplacement of polar and circum-polar volatile deposits? 14) What is the origin of central peaks and their often unusual mineralogy and how do we account for the evidence for heterogeneous melt composition and structure? These and other major geoscience questions form the basis for robust and exciting future international robotic and human exploration and sample return missions. A series of candidate sites of interest are identified that can address these questions.