THE EVOLUTION OF THE LUNAR CRUST: THE VIEW FROM SAMPLES, EXPERIMENTS AND GEOCHEMISTRY.

S. M. Elardo[1] and C. M. Pieters[2], [1]Geophysical Laboratory, Carnegie Institution of Washington, Washington, DC 20015, USA. [2]Geological Sciences, Brown University, Providence, RI 02912, USA. selardo@carnegiescience.edu

Introduction: The origin and evolution of the lunar crust is a particularly difficult aspect of lunar geology to study. The extreme antiquity of the primary and most secondary lithologies in the crust means they potentially record crucial information about geologic processes operating on the early Moon. However, they have also been subject to up to 4.3 billon years of impacts, cosmic rays, and other forms of geologic processing and alteration. More recent endogenous geologic activity affecting the lunar crust appears to be either poorly sampled, less abundant, or both. Nevertheless, recent efforts have demonstrated that an enormous amount of primary information about the geologic processes that were shaping the Moon very soon after its formation is still recorded in the diverse samples of the lunar crust.

Areas of Recent Advances: Laboratory-based studies of the lunar crust, which include geochemical analyses of lunar samples and analog experimental studies, have focused on a number of areas of interest in recent years. Below is a brief and undoubtedly incomplete summary of some of the major advances made since publication of New Views of the Moon (NVM) and areas of ongoing research related to the evolution of the lunar crust.

Age Relationships Among Ancient Lunar Crustal Lithologies: The chronology of the lunar crust has been an area of tremendous advances in recent years. The apparent age overlap in early lunar crustal lithologies, specifically the ferroan anorthosites (FANs) and the Mg-suite, was known at the time of writing for NVM. However, more recent efforts have greatly improved the precision of radiogenic systems used to date these lithologies [e.g., 1-3]. These new, high-precision ages for FANs and Mg-suite samples have shown that the age overlap is not an artifact, but rather records rapid differentiation of the Moon and complex relationships between magmatic events.

Alteration of Lunar Crustal Lithologies, Elemental Mobility, and Crustal Volatiles: The discovery of abundances of magmatic volatiles in lunar samples that far exceeded previous estimates and the renewed focus on crustal chronology has led to new studies of the alteration of crustal samples. These studies have proposed alteration processes that had not been extensively considered in the past. These processes include metasomatism by basaltic melts [4], halogen-rich fluids [5], and sulfur-rich vapors [6]. These advances have increased our understanding of the processes that can alter pristine lunar crustal samples and transport volatile elements throughout the crust. Additionally, the quantification of magmatic volatile abundances in lunar crustal rocks [7] and determinations of isotopic compositions of volatile elements [e.g., 5, 8] have provided an entirely new window into magmatic processes contributing to crust formation in the lunar magma ocean and during subsequent magmatism.

Lithologic Diversity in Lunar Crustal Rocks: Our understanding of the geologic diversity in the lunar crust has significantly advanced since NVM and is an area of lunar science that has brought together new remote and sample observations in a meaningful way. Advances from laboratory observations have largely come from the plethora of lunar meteorites that have been discovered and studied since NVM. New analyses of lunar meteorites have challenged the concept of a clear compositional distinction between the FANs and the Mg-suite [e.g., 8, 9] and provided a sample-based context in which to interpret remote observations of spinel-rich lithologies [e.g., 10] that has been complemented by laboratory experiments [11].

The Youngest Known Mare Basalts: Lunar meteorites have provided the lunar science community with samples of mare basalts that are younger than any of those sampled by Apollo/Luna [12-15]. These (relatively) recent additions to the lunar crust have opened up a new period in lunar history to detailed sample-based study and have led to the refinement of models for lunar magmatic and crustal evolution.

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