

NEW DISCOVERIES AND OBJECTIVES OF THE LUNAR RECONNAISSANCE ORBITER'S EXTENDED MISSION: VOLCANISM AND INTERIOR J. Stopar¹, T. Watters², N. Petro³, G. Morgan⁴, S. Lawrence⁵, J. Keller³, B. Jolliff⁶, B. Greenhagen⁷, J. Cahill⁷, K. Bennett⁸, and the LRO Team, ¹Lunar and Planetary Institute, USRA, Houston, TX; ²National Air and Space Museum, Smithsonian Institution, Washington, D.C.; ³Goddard Space Flight Center, Greenbelt, MD; ⁴Planetary Science Institute, Washington, DC; ⁵NASA/Johnson Space Center, Houston, TX; ⁶Washington Univ. in St. Louis, St. Louis, MO; ⁷Johns Hopkins University Applied Physics Laboratory, Laurel, MD; ⁸USGS Astrogeology, Flagstaff, AZ.

Introduction: Data from LRO has formed a cornerstone in our understanding of many fundamental aspects of lunar geology. However, as LRO approaches its 10th year of lunar discovery, key questions about volcanic, tectonic, and interior processes and composition still remain.

Mafic Rocks in the Primary Crust: “Purest anorthosite” (PAN) was spectrally detected in basin ring massifs and central peaks of craters ≥ 30 km in diameter, suggesting a nearly pure anorthositic layer in the upper 3 to 30 km of the crust (the crust is on average only 40 to 50 km thick) and efficient magma-ocean differentiation and aluminum sequestration [1-6]. However, mafic minerals (pyroxene and olivine) are detected alongside PAN in many of the same central-peak and fresh-highlands rock exposures [6-9]. *Thus, what is the possible relationship of the mafic rocks to primary anorthositic crust?*

Methods: New LROC NAC geometric stereo image pairs and photometric sets (stacks of images covering the same ground but with a range of phase, emission, and incidence angles) will aid in classification of rock type occurrences. Variations in albedo derived from NAC photometry (including effects of topography and illumination geometry) will be correlated to spectral variations (e.g., M³, Kaguya MI, Clementine).

Non-Mare Volcanism: The unambiguous identification of highly silicic volcanic features on the lunar surface is a major result of the LRO mission [10-13]. The compositions present in these features cannot be produced through primary crustal formation and are fundamentally different from the magmatic processes that gave rise to the mare basalts. During the next extended mission several silicic features are identified for targeted, multi-instrument observations, one of which is Wolf crater (**Fig. 1**). *Are light-toned massifs of unusual composition (e.g., Wolf crater) related to silicic volcanism?*

Methods: New targeted NAC high- and low-phase observations and Diviner noon-time observations will aid in determinations of absolute reflectance and composition, including the concavity index and CF positions (both measures of the polymerization of silicate minerals [14]). Combined with high-incidence NAC images, NAC stereo images, off-nadir Diviner thermal IR and

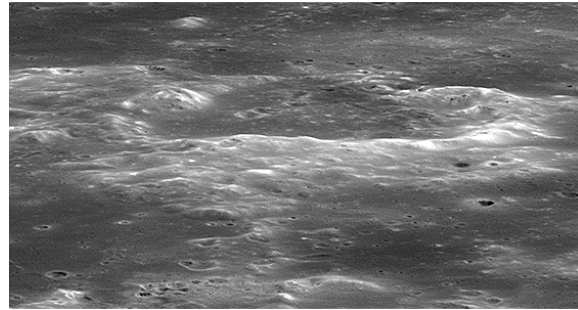


Fig. 1. West-looking oblique view of Wolf crater, diameter ~50 km, is an example of light-toned massifs with unusual composition. (NAC M1267220207)

Mini-RF bistatic observations, composition can be interpreted along with morphology and surface roughness to discern geologic origins of the silicic deposits.

Pyroclastics: Low-albedo pyroclastic deposits preserve a partial record of the composition of the Moon's interior composition and volatile content, with some regional deposits containing 150-400 ppm water [15]. Earth-based radar studies indicate that regional pyroclastic deposits of the Aristarchus plateau are thicker than previously thought, but vary in thickness, ranging from meters to tens of meters [16]. Regional deposits (e.g., Aristarchus) are thought to be sourced from near the lunar crust-mantle boundary [17], whereas smaller, localized deposits typically occur in pre-existing craters overlying mafic intrusions [e.g., 18]. LRO data combined with M³ spectra recently suggested a greater juvenile (magma) component – either olivine and/or volcanic glass – than previously recognized, as well as variations in mineralogy within a single deposit, implying larger volumes or denser plumes of juvenile erupted materials [19-20] as well as changes in eruptions over time [19,21]. *Thus, do pyroclastic deposits preserve evidence of mantle heterogeneities as well as local, near-surface magmatism?*

Methods: Pyroclastic deposits lend themselves to new targeted, multi-instrument investigations. Generation of a new phase function of pyroclastic deposits across visible and thermal IR wavelengths requires improved Diviner temporal resolution and NAC photometric sets to constrain glass abundance, crystallinity, and particle sizes. LROC NAC image mosaics with consistent illumination will enable studies of superposed ejecta patterns to constrain deposit thicknesses. LAMP

daytime observations might reveal fine-scale pyroclastic deposit porosity [22], maturity, and an independent far-UV measure of hydration [e.g., 23]. Comparing Mini-RF X- and S-band bistatic radar observations will constrain the thickness variations (cms to >1m), physical properties, and morphologies. Radar will also help constrain Ti content in the shallow subsurface [e.g., 24]. Very high phase angle (up to $\sim 165^\circ$) 532-nm reflectance measurements will be acquired with the LOLA Laser Ranging telescope [25], providing surface roughness determinations in the sub-mm to cm range (relevant to photometric interpretations).

Revised Stratigraphy of Young Mare: A full appreciation of the thermal evolution of the Moon requires clear definition of the terminal stage of volcanism. Identification and delineation of the individual mare flows erupted during the final volcanic phase would provide a record with which to define and explore this important period in lunar history. However, the subtlety of mare flow margins presently limits mare mapping efforts to the definition of broad units (10s -100s km) delineated based on spectral properties derived from UV-NIR data [e.g., 26-27]. High spectral resolution M^3 data has enabled further subdivision of these units in restricted regions [e.g., 28] and revised unit ages based on NAC images reveal that compositional units may indeed contain a number of smaller units of different ages [29]. *Thus, how were final mare eruptions distributed in space and time, and what was their compositional range?*

Methods: Earth-based radar data have shown that individual volcanic flow features can be mapped based on titanium content (a critical elemental index for classification of mare basalts) [e.g., 30]. More recently, the LROC WAC UV data were incorporated within a new methodology to derive TiO_2 for the lunar maria [31]. The Ti information from radar and UV wavelengths combined with new targeted NAC images, photometric sets, stereo pairs, and mosaics (for mapping units, characterizing surface properties, and determining surface ages) as well as Mini-RF bistatic collects (to identify flow boundaries) of young maria will enable the critical stratigraphic refinements.

Recent Tectonic Activity: The young ages of small, globally distributed, lobate thrust fault scarps [32] raise the possibility that some may still be active [33]. Furthermore, models of the current stress state that include tidal forces make ongoing tectonism likely [33]. Continued slip events on the young faults has implications for current lunar seismicity and the potential for strong ground shaking in proximity to the scarps. A complete global view of recent tectonism is critical to an accurate estimate of the amount of radius change and compressional stresses from global contraction over time. Ultimately, estimates of contraction and stress are critically

important in determining the Moon's early thermal state and evolution. *Thus, is the Moon tectonically active in the present day and can ongoing events be detected?*

Methods: New NAC images at high-incidence angles in current coverage gaps will be used to any as yet undetected tectonic landforms [e.g., 32-34]. New NAC stereo pairs will provide the landform dimensions necessary to determine the nature and geometry of underlying faults. Finally, a NAC temporal imaging campaign during the next extended mission, in addition to limited NAC targeted re-imaging of specific lobate scarps, will permit a search for evidence of measurable changes, leveraging up to 9 years of previous LRO observations.

Summary: Our collective understanding of the Moon as a geologic body in the Solar System will evolve as prior accomplishments and new data are leveraged to address outstanding science questions. LRO's multi-instrument observations and targeted campaigns will provide data highly suited to interpreting the composition and structure of the lunar interior, the primary and secondary crusts, and their structural and compositional evolution over time.

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