

REGIONAL AND TEMPORAL VARIATIONS IN THE WESTERN MARE BASALTS: NEW OBSERVATIONS FROM THE MOON MINERALOGY MAPPER. M. I. Staid¹, C. M. Pieters², J. Boardman³, J. W. Head², J. Sunshine⁴, L. A. Taylor⁵, P. Isaacson², S. Besse⁴, R. Klima², G. Kramer⁶ and D. Dhingra². ¹Planetary Science Inst., Tucson, AZ, ²Brown Univ., ³AIG, LLC, ⁴Univ. MD, ⁵Univ. TN, ⁶Bear Fight Center; (staid@psi.edu)

Introduction and Background: The history of volcanism on the western near side of the Moon is unique in both its duration and the basaltic compositions it left behind on the lunar surface. Together, Oceanus Procellarum and Mare Imbrium compose the largest expanse of the lunar maria with deposits ranging from the early history of lunar volcanism through its last major phases. Various techniques have dated many of these flows as younger than 3.0 Ga [1] with some areas having erupted as recently as ~1.2 Ga [2, 3], or almost two billion years after the youngest basalts collected by sample return missions.

These last major phases of lunar volcanism produced spectrally unique, high-titanium basalts that cover large areas of Procellarum and Imbrium as well as smaller regions within several surrounding maria. The reflectance properties of soils and craters within these deposits display a relatively strong 1 μm feature and a weaker 2 μm absorption, suggesting the presence of abundant olivine [4, 5, 6]. However, previous telescopic and orbital measurements lack the combined spectral and spatial resolutions necessary for detailed mineralogical characterizations of these basalts.

In the current study, visible to near-infrared reflectance data acquired by the Moon Mineralogy Mapper (M^3) on Chandrayaan-1 are used to investigate the mineralogy of these late-stage basalts and implications for the heterogeneity and evolution of their source regions.

M^3 Data Analysis: The M^3 imaging spectrometer was a guest instrument on India's Chandrayaan-1 mission which launched on October 22nd, 2008 and mapped the lunar surface from a polar orbit through August of 2009. M^3 acquired visible to infrared reflectance data at spatial and spectral resolutions capable of measuring discrete basaltic flows within the lunar maria. This global data covers the wavelength range of ~430 to 3000 nm in 85 spectral bands at 140 to 280 m/pixel. Small amounts of data were also acquired of targeted regions in 259 spectral bands and at higher spatial resolutions.

To perform preliminary compositional assessments, global mosaics were created by reducing the spatial resolution of the M^3 data by a factor of 10 [7]. After calibration of the data to apparent reflectance and the application of thermal corrections [8, 9], a range of spectral parameters were calculated to explore broad mineralogical differences across the Moon. Figure 1 provides an example of a hemispheric color

composite image that distinguishes several near side mare regions based on their 1 and 2 μm integrated band depths (IBD) and near infrared albedo. The late-stage western maria are unique within this color composite due to their relatively weak 2 μm absorptions and strong 1 μm ferrous bands (distinguished by red hues in this color composite image).

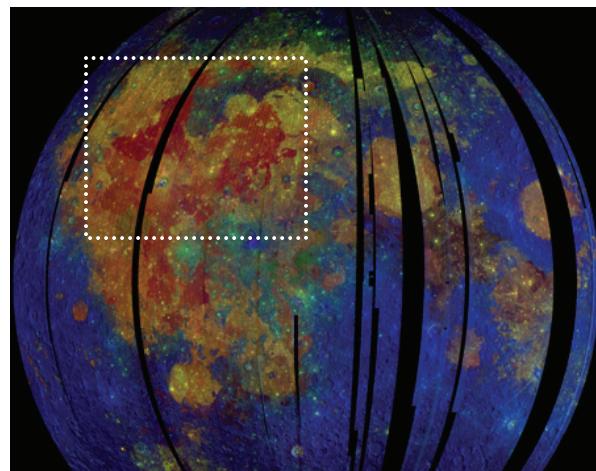


Figure 1: Late-stage lunar volcanism on the western near side appears as a distinct red hue in this M^3 color composite (red=1 μm IBD, green=2 μm IBD, blue=reflectance at 1.58 μm). Dashed white lines locate the study area shown in Figure 2.

Where spectral and stratigraphic boundaries are identified, the reflectance properties of optically immature ("fresh") mare craters and associated ejecta are being examined using full resolution global mode data to evaluate the spectral properties of crystalline materials associated with each basalt unit. Figure 2 shows a region of northern Oceanus Procellarum and western Mare Imbrium where spectra of mare craters have been sampled within several spectrally distinct basalt types. White outlines indicate the approximate boundaries of the late-stage high-Ti basalts within this region. In this figure, high titanium basalts are further separated based on the relative strengths of their 1 and 2 μm mafic absorptions (dashed lines). Spectra obtained from fresh mare craters in three spectrally distinct mare units are presented in Figure 3. These spectra, based on the full resolution global mode data, have not yet been thermally corrected and may exhibit an increased signal at longer wavelengths caused by thermal emission. As a result, spectra are only plotted to 2.5 μm in Figure 3.

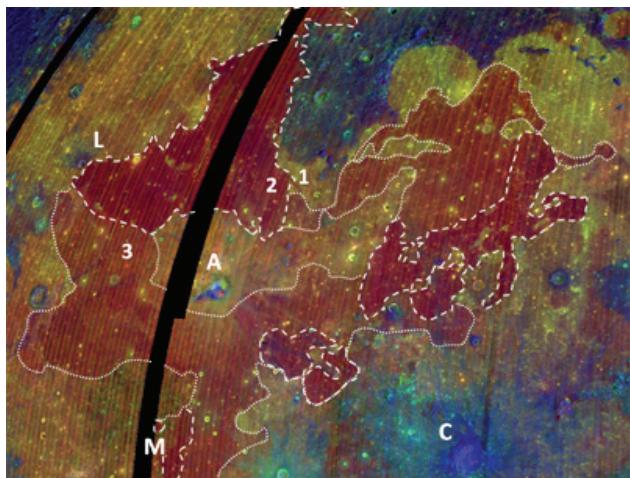


Figure 2: Subset of the spectral parameter image shown in Figure 1 centered over the mare deposits of NW Procellarum and Mare Imbrium. Approximate locations where fresh mare craters were sampled from different spectral units (Figure 3) are indicated with numbers. L= Lichtenberg, A= Aristarchus, C= Copernicus, M= Marius.

Olivine abundance and basalt stratigraphy:

Figure 3 compares an average fresh mare crater spectrum from three basalt types observed in Figure 2. Low Ti basalts that pre-date higher Ti flows (e.g. area 1) are dominated by 1 and 2 μm pyroxene absorptions typical of most pre-Eratostenian lunar basalts. M^3 spectra collected from craters within the younger high titanium basalts (areas 2 and 3) by comparison have strong but longer wavelength 1 μm absorptions and relatively weak 2 μm bands consistent with the presence of olivine within these basalts.

The strength of spectral properties associated with olivine is observed to vary stratigraphically, with the upper-most flows in several areas (dashed lines, Fig. 2) showing the broadest 1 μm absorptions and weakest relative 2 μm band strengths. This stratigraphic pattern is observed in a number of different regions with a wide range of inferred ages [3]. Some of the youngest basalts near Lichtenberg Crater [2, 3] are included in and contiguous with the most olivine rich group, represented by area 2 (green spectrum in Fig. 3). Additionally, the uppermost flows of basalts in some regions with older age estimates, such as in central Mare Imbrium and areas of southern Procellarum, also have similar spectral properties to these olivine-rich basalts. Basalts in Marius Crater that exhibit these olivine signatures are investigated in a companion study by Besse et al. [10]. Stratigraphically older high titanium flows within Imbrium and Procellarum (e.g. area 3) also appear to contain olivine, but at lower or more variable concentrations relative to their pyroxene abundances

and/or other mineral components absorbing near 2 μm , such as spinel. Together, these observations suggest that the late-stage basalts exhibit a pattern of increasing olivine abundance with subsequent emplacement, producing recognizable sequences of mare volcanism over more than a billion years of lunar history.

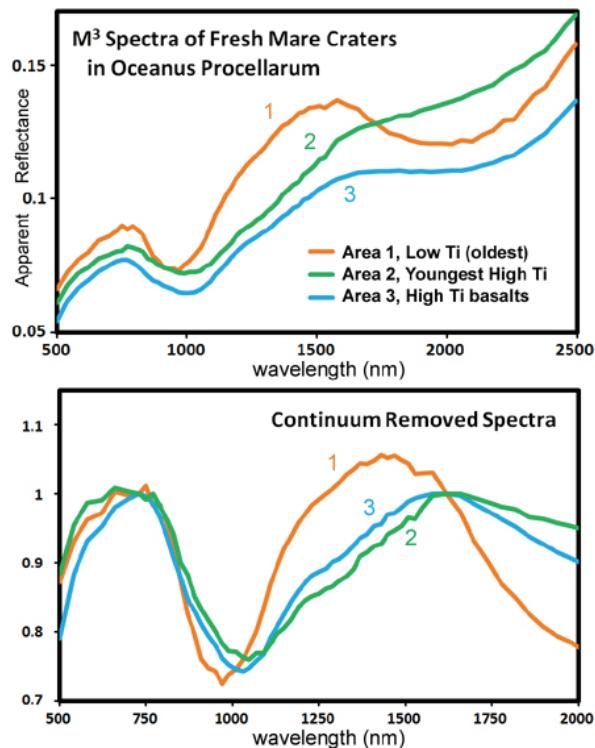


Figure 3. Spectra of fresh mare craters associated with the three distinct spectral groups identified in Fig. 2.

Future Work: Several concurrent studies of M^3 data have demonstrated the utility of quantitative techniques such as the Modified Gaussian Method (MGM) to interpret olivine and pyroxene compositions from M^3 data (e.g. [11,12]). Future work will attempt to provide estimates of the relative abundance and composition of pyroxene and olivine within these last products of lunar volcanism to provide further constraints on their source regions, temporal evolution and emplacement mechanisms.

References: [1] Boyce, J.M. (1976) PLPSC 4th, 3167. [2] Schultz, P.H. and P. Spudis (1983), Nature, 302, 233. [3] Hiesinger, H. et al. (2003), JGR, 108, E7, 5065. [4] Pieters et al. (1980), JGR, 85, 3913. [5] Staid, M.I. and C.M. Pieters (2001), JGR, 27,887. [6] Lucey, P.G., (2004), GRL, 31, LO8701. [7] Boardman, J.W. et al. (2009), Eos, 90, 52, P34A-01. [8] Green, R.O. et al. (2009), LPSC 40, 2307 [9] Clark, R. et al. (2009), LPSC 40, 2136 [10] Besse, S. et al. (2010), LPSC 41, [11] Isaacson, P. et al.(2010), LPSC 41, [12] Klima, R.L. et al. (2010), LPSC 41.