GLOBAL MINERALOGY OF THE MOON: A CORNERSTONE TO SCIENCE AND EXPLORATION

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The history of the Earth and the Moon are intimately linked since their formation 4.5 Gy ago. The Apollo era allowed recognition of major planetary processes such as formation of a magma ocean and pervasive differentiation, and these early events were dated with lunar rocks. We have learned that many processes active on the early Moon are common to most terrestrial planets, including the record of early and late impact bombardment [1,2]. Since most major geologic activity ceased on the Moon ~3 Gy ago, the Moon's surface provides a record of the earliest era of terrestrial planet evolution. The type and composition of minerals that comprise a planetary surface are a direct result of the initial composition and subsequent thermal and physical processing. Lunar mineralogy seen today is thus a direct record of the early evolution of the lunar crust and subsequent geologic processes. Specifically, the distribution and concentration of specific minerals is closely tied to magma ocean products, lenses of intruded or remelted plutons, basaltic volcanism and fire-fountaining, and any process (e.g. cratering) that might redistribute or transform primary and secondary lunar crustal materials.

Of the various missions and instruments that will reopen exploration of the Moon in the next decade, only one will both characterize and map the mineralogy of the Moon in geologic context at high spatial resolution, the Moon Mineralogy Mapper (M3, or "m-cube"). M3 is a state-of-the-art imaging spectrometer that will fly on Chandrayaan-1, the Indian Space Research Organization (ISRO) mission to be launched in early 2008. M3 is one of several foreign instruments chosen by ISRO to be flown on Chandrayaan-1 to complement the strong ISRO payload package. After NASA peer-review, M3 was selected for funding through NASA's Discovery Program as a Mission of Opportunity. M3 is under the oversight of PI Carlé Pieters at Brown University. It is being built by an experienced and committed team at JPL led by Tom Glavich as Project Manager and Rob Green as Instrument Scientist. Each member of the M3 Science Team is uniquely experienced and has a specific responsibility for data calibration, analysis and/or interpretation.

The primary *science* goal of M3 is to characterize and map lunar surface mineralogy in the context of its geologic evolution as outlined above. This translates into several sub-topics that focus on exploring the mineral character of the highland crust, characterizing the diversity basaltic volcanism, and identifying potential volatile concentrations near the poles. The primary *exploration* goal is to assess and map lunar mineral resources at high spatial resolution to support planning for future, targeted missions.

These goals translate directly into requirements for accurate measurement of diagnostic absorption features of rocks and minerals, with sufficient spectral resolution for deconvolution of superimposed features, and sufficient spatial resolution for geologic context. M3 spectral requirements are for a 0.7 to 3.0 µm range (optional to 0.43 µm is the baseline) measured at a continuous 10 nm spectral resolution. Spectra of lunar soils and minerals that exhibit highly diagnostic features over the spectral range of M3 are shown in Figure 1.

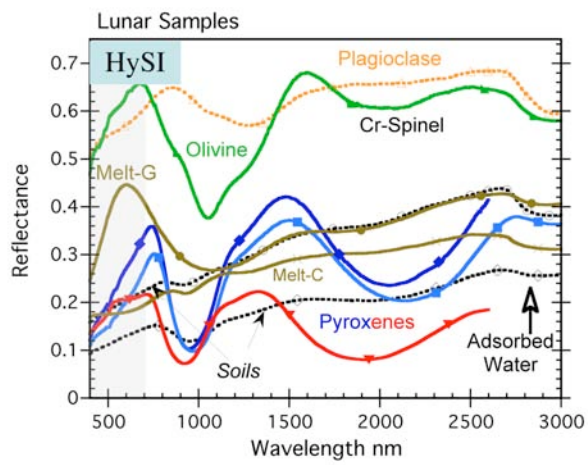
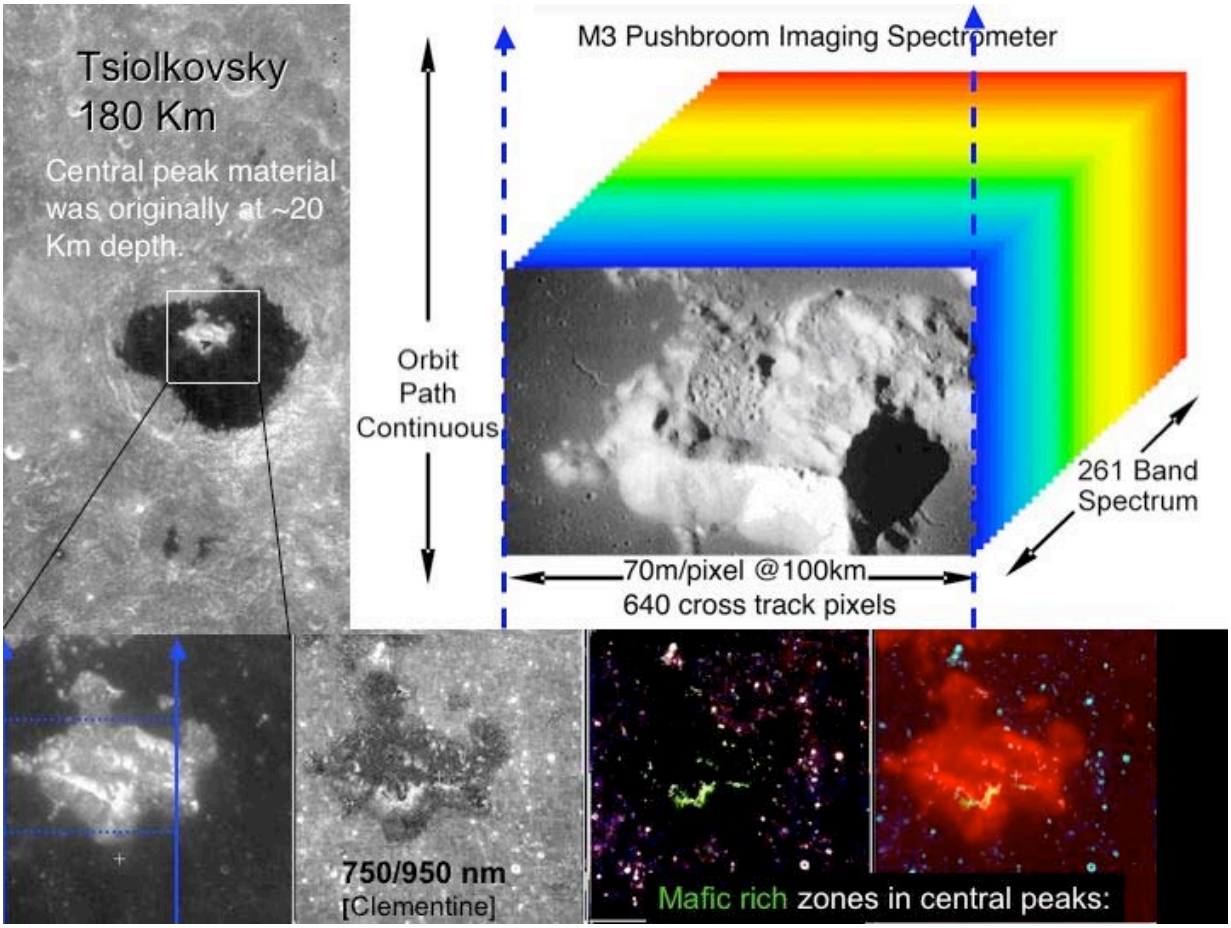


Figure 1. Reflectance spectra of lunar minerals and soils over the spectral range of M3. High spectral resolution allows superimposed features to be deconvolved for identification. M3 is coordinated with ISRO's HySI instrument which operates at shorter wavelengths. [The weak feature near 2900 nm is due to trace amounts of terrestrial water remaining on the samples in a purged laboratory environment.]

M3 operates as a pushbroom spectrometer with a slit oriented orthogonal to the S/C orbital motion. Measurements are obtained simultaneously for 640 cross track spatial elements and 261 spectral elements. This translates to 70 m/pixel spatial resolution from a nominal 100 km polar orbit for Chandrayaan-1. The design has exceptionally high uniformity: spectral elements are co-registered to within 0.1 pixel. The M3 FOV is 40 km in order to allow contiguous orbit-to-



orbit measurements at the equator that will minimize variation in lighting conditions.

The M3 instrument concept is shown above using the central peaks of the 180 km farside crater Tsiolkovsky as an example science target. Lower resolution Clementine images [3] show that the central peaks (excavated from ~20 km depth) contain an iron-rich material in very sharp contact with an iron-poor material. Continuous high spectral resolution reflectance measurements across the near infrared are required to identify the type and composition of minerals exposed. High spatial resolution and broad coverage is required to understand the geologic context and, ultimately, the processes involved. Has this crater tapped a layered pluton? Do the iron-rich materials represent a large subsurface dyke? Either possibility implies a buried thermal event – what accessory minerals are present?

Over the two-year Chandrayaan-1 mission lifetime, there are four periods of optimal lighting conditions for M3 spectroscopic measurements (two 2-month periods/year). Our current measurement plan includes one period that will be devoted to global assessment at moderate resolution (320 spatial elements, 87 spectral) and the other three will be devoted to obtaining full resolution data for prioritized target regions (10-30% of the surface).

In addition to exploring the global mineralogy of the Moon for the first time from orbit, M3 is designed to address the issue of whether the H at the poles [4] is in the form of water ice. If H is in the form of H_2O within the upper mm or two of the surface, the highly diagnostic fundamental absorption near 2.8 μm will allow its detection even in trace amounts. Normal gardening would expose near-surface materials. Scattered light from crater walls provide faint illumination in the shadowed areas that is expected to allow sufficient signal over the course of the mission to test the hypothesis of H_2O presence. Detection of H_2O would be unambiguous. On the other hand, lack of detection (the null hypothesis) places stringent limits on the uppermost surface but leaves the character of the lunar poles a mystery to be solved by other techniques.

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