DETECTING A BROADER LUNAR MAGNESIAN SUITE WITH ORBITAL SPECTROSCOPY. P. J. Isaacson and C. M. Pieters, Dept. of Geological Sciences, Brown University, Providence RI, 02912 [Peter_Isaacson@Brown.edu].

Introduction: Rocks of the lunar Mg-suite (the dunites, troctolites, norites, and gabbros) were found at all Apollo landing sites, often occurring in mafic impact-melt breccias (MIMB's) derived from depth [1, 2]. The Apollo Mg-suite rocks also appear to have a genetic relationship to KREEP, as they have enhanced rare-earth element (REE) concentrations which were likely caused by interaction with a KREEP-rich suite of rocks [3-5]. Taken together, these observations were the basis of the hypothesis that a global KREEP-rich layer exists at the base of the lunar feldspathic crust [6], and that the Mg-suite was formed by intrusions of a primitive magma through this layer and into the overlying feldspathic crust [2, 4]. We address how this hypothesis will be evaluated with high resolution orbital spectroscopy data.

The KREEP Anomaly. Orbital data indicate that the areas from which the samples were returned are in a geochemically unique region [7-9]. This region has been termed the Procellarum KREEP terrane, and is enhanced in Th and other incompatible elements [10, 11]. The concentration of KREEP in this region, combined with the relationship of Mg-suite rocks to KREEP, suggests that these types of Mg-suite rocks may be unique to this region [12, 13]. In other words, the Apollo samples may not be wholly representative of the Mg-suite and by extension of the broad feldspathic highlands in other regions [12].

Meteoritic Mg-suite. Feldspathic lunar meteorites also often contain similar Mg-rich lithologies. Because impacts onto a planetary surface are by nature a stochastic process, these meteorites should represent a broader sampling of the lunar crust [13, 14]. However, many of the meteoritic Mg-suite materials have much lower REE abundances than the Apollo Mg-suite [13, 15], suggesting a separate, or at least distinct, origin.

This broader Mg-suite is characterized by subtle but important mineralogical properties. The meteoritic Mg-suite lithologies are typically more feldspathic (e.g., anorthositic troctolites and troctolitic anorthosites rather than dunites and troctolites), and the minerals which carry the magnesian signature are typically more magnesian than comparable minerals in the Apollo Mg-suite. In summary, the meteoritic Mg-suite is characterized by more feldspathic magnesian clasts containing minerals with high Mg*, which distinguish it from other highland lithologies and from more mafic and often more Fe-rich Apollo Mg-suite lithologies [13, 16].

Motivation: Reflectance spectroscopy from high spatial and spectral resolution instruments such as M^3 [17] will allow Mg-suite materials to be identified and placed in geologic context. While not sensitive to REE abundances, high spectral resolution spectroscopy is capable of detecting the different mineral compositions that distinguish the range in the lunar Mg-suite [18-20]. When used in conjunction with lower-resolution measurements such as gamma ray spectroscopy [e.g., 21], which are sensitive to KREEP components, M^3 imaging spectroscopy not only identifies the diagnostic minerals and mineral compositions of the Mg-suite, but the high spatial resolution allows the geologic evolution of these important crustal components to be better defined.

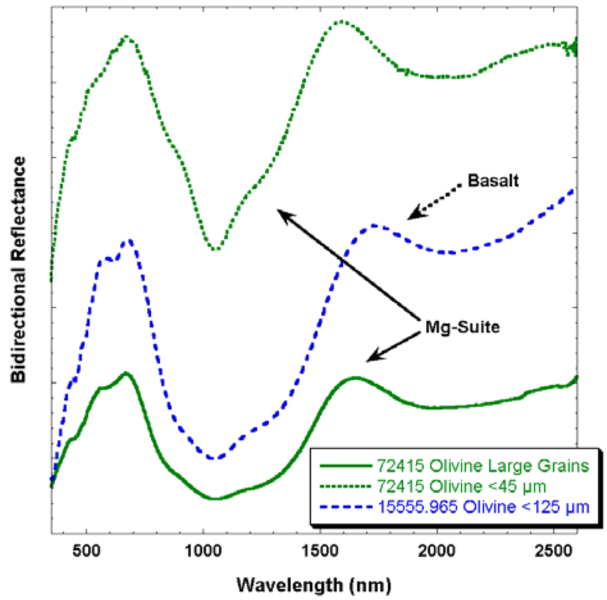

Figure 1: Bidirectional reflectance spectra of lunar olivine. The upper two spectra were analyzed with the MGM. The bottom spectrum is of an olivine from the same sample as the top spectrum, but at a much larger grain size, illustrating the effect of grain size on reflectance spectra.

Olivine: While the lunar Mg-suite is diverse, olivine is often a primary carrier of the magnesian component in Mg-suite clasts. Our current emphasis is thus on remote characterization of olivine-rich lithologies. Exposures of olivine-dominated lithologies have been identified with limited spectroscopy measurements [22-24], but the composition and abundance remain unknown. As discussed below, the diagnostic absorption features of olivine to which reflectance spectroscopy is sensitive vary as a function of mineral composition [19, 25], providing a valuable tool for assessing the diversity of the expanded lunar Mg-suite with orbital spectroscopy.

While not presented here, coordinated analysis of separates of lunar plagioclase [26] and pyroxene [26, 27] is ongoing. We expect unmixing algorithms to place constraints on plagioclase abundance of Mg-suite lithologies due to its effect on overall albedo [26, 28].

Previous Work: The MGM has been used to deconvolve spectra of terrestrial and synthetic mineral suites, and has been shown to detect accurately the changes in absorption features with mineral composition [18-20]. Comparable analyses have not been applied to lunar materials. In the case of olivine, the three absorption features that comprise the combined absorption feature near 1 μm [29] have been shown to shift to longer wavelengths with increasing Fe content (decreasing Fo#), with the middle-wavelength (M2) absorption shifting more slowly than the exterior (M1) absorptions [19, 25]. The MGM has also been shown to be effective at deconvolving absorption features in spectra of intimate mixtures [e.g., 18].

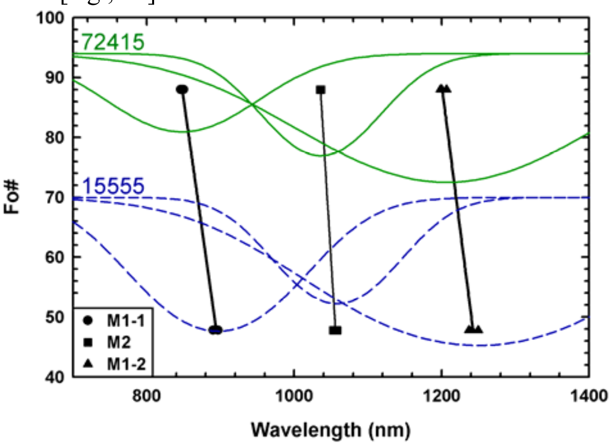

Figure 2: MGM-derived absorption band centers (black symbols) and Fo# for the three crystal-field absorption bands of the two olivine sample spectra in Figure 1. Superimposed are representative Gaussian absorptions for each spectrum (scaled maintaining relative band strength within each spectrum). The multiple symbols indicate results of different MGM fits with slightly different starting parameters or model constraints. Solid black tie lines illustrate the compositional trends of these diagnostic bands.

Samples and Methods: To demonstrate analytical procedures for lunar materials, we have analyzed bidirectional reflectance spectra of olivine separates which differ significantly in their composition. One olivine is prepared from a mare basalt (15555.965, part of the Lunar Rock & Mineral Characterization Consortium [26, 30]) at <125 μm grain size, and a second olivine from a Mg-suite dunite (72415.64), at <45 μm grain size. The basalt olivine has an average composition of $Fo_{47.8}$ [30], while the dunite olivine has an average composition of Fo_{88} [2, 16, 31]. Spectra for these olivines are shown in Figure 1. Although grain size differences will have a strong influence on the strengths of absorption features and on absolute albedo, they do not influence the positions of the absorption features [18], which is the parameter most critical to deriving composition from the spectra [19]. We analyzed these spectra using the MGM to obtain precise quantitative values for the diagnostic individual absorption bands [32]. For consistency, we elected to use flat-line continuum slopes. We also used the same set of starting parameters, roughly adjusted for composition based on previous work [19], for fits to the different olivine spectra.

MGM Fits: The results of MGM fits to lunar olivine are shown in Figure 2, which includes the absorption band centers vs. Fo# for our lunar olivine spectra, along with representative deconvolved MGM Gaussians for each spectrum. The results illustrate that the band centers shift to longer wavelengths with increasing Fe content, and that the trend is readily detectible with quality spectra.

Summary: The absorption bands of lunar olivines are shown to move in predictable ways with mineral composition, in a manner consistent with previous results. Although we have not directly tested mineralogies similar to those found in the meteoritic magnesian materials, the predictable manner in which these absorptions shift indicates that this technique should be able to detect reliably the different mineral compositions across the range of lunar Mg-suites. Furthermore, reflectance spectroscopy is expected to provide constraints on the feldspar content of the various Mg-suite lithologies. Together, such data will allow us to place these expanded Mg-suite materials in their geologic context. Our overall goal is to broaden constraints on models for lunar crustal petrogenesis, which have to date been based (by necessity) principally on knowledge gained from the Apollo sample collection.

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Acknowledgments: The spectra used in this analysis were measured by Takahiro Hiroi in the RELAB at Brown University, a multi-user facility supported by NASA Grant NNG06GJ31G. The mare basalt olivine separate was prepared by Amit Basu Sarbadhikari, Yang Liu, and Lawrence Taylor at the University of Tennessee. The support of NASA Grants NNM05AB26C and NNG05GG15G is greatly appreciated.