REMOTE COMPOSITIONAL ANALYSES OF LUNAR OLIVINE-RICH LITHOLOGIES USING MOON MINERALOGY MAPPER (M^3) DATA. P. J. Isaacson[1], C. M. Pieters[1], R. N. Clark[2], J. W. Head[1], R. L. Klima[1,3], N. E. Petro[4], M. I. Staid[5], J. M. Sunshine[6], L. A. Taylor[7], K. G. Thaisen[7], and S. Tompkins[8]. [1]Brown University Geological Sciences, Box 1846, Providence, RI 02912, [2]USGS Denver, [3]JHU/APL, [4]NASA Goddard, [5]PSI, [6]Univ. of MD, [7]Univ of Tenn., [8]DARPA [Peter_Isaacson@Brown.edu].

Introduction: Olivine is an important mineral with which to interpret the petrologic evolution and history of mafic igneous rocks. The composition of olivine (Mg#) indicates, generally, the degree of evolution of the source magma from which a particular sample crystallized. Mg-rich olivine is generally indicative of a relatively primitive source. Visible to near-infrared reflectance spectroscopy is sensitive to the Mg# of olivine, as absorption features shift in generally understood ways with changing major element (MgO and FeO) content [1-3].

Olivine reflectance spectra: Olivine reflectance spectra are characterized by a composite absorption near 1000 nm caused by crystal-field transitions in Fe^{2+} ions situated in distorted octahedral crystallographic sites. The central absorption is caused by iron in the M2 site, and the two "wing" absorptions by iron in the M1 site [4, 5]. These component absorptions shift to longer wavelengths as the iron content of the olivine increases. These regular shifts can be used to "predict" the Mg# of an olivine of unknown composition if the band centers of the component absorptions can be deconvolved, for example using quantitative deconvolution methods such as the Modified Gaussian Model (MGM) [2, 6].

Lunar Olivine: Lunar olivines typically contain inclusions of Cr-spinel [e.g., 7, 8]. Spinels have strong absorptions near 2000 nm [9], which complicate the standard approach used to deconvolve terrestrial and synthetic olivine reflectance spectra with the MGM. These spinel absorptions affect the continuum slope in particular and necessitate a modified approach for deconvolving lunar olivine spectra. Such an approach has been developed for laboratory spectra of lunar olivines [10], and involves truncating the spectra (to focus only on the 1000 nm region) and using a more interactive approach to selecting an appropriate, flat continuum slope for a given spectrum. Additionally, single absorptions are included at shorter and longer wavelengths than the principal olivine feature in order to account for residual spectral structure remaining after truncation. This modified approach is able to reproduce the trends in the principal absorption features expected from analysis of terrestrial olivine spectra, and in the ideal case of laboratory measurements, can be used to predict olivine Mg# of the mineral separate spectrum to within 5-10% [10].

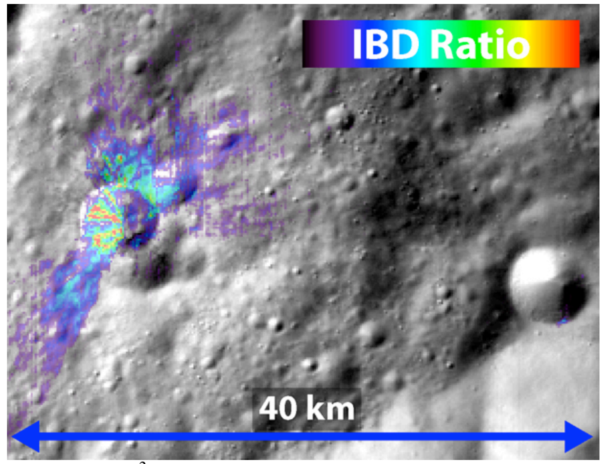

Fig. 1: M^3 image of a small crater NW of Mare Moscoviense from which olivine-dominated spectra analyzed in this study were extracted. Color overlay illustrates the ratio of integrated 1000 and 2000 nm band depths; high values are indicative of olivine-rich areas.

Remote-sensing data: Prior to 2008, the only global reflectance data for the Moon was multispectral, and determination of olivine composition by deconvolution was not possible. However, modern spectrometers collect data in tens to hundreds of spectral channels across visible to near-infrared wavelengths [11, 12]. Such spectral resolution and coverage allows the unambiguous detection of olivine-dominated lithologies, and also allows the variations in the principal olivine absorption features discussed above to be detected. By applying the techniques developed for analysis of laboratory spectra of lunar olivines, deconvolution of remotely-sensed data returned by the Moon Mineralogy Mapper (M^3) is enabling preliminary predictions of the composition of olivines exposed on the lunar surface.

Methods: The spectra analyzed in the current study were extracted from a single strip of M^3 data from the lunar farside. This strip covers the western portion of the inner ring of the Moscoviense basin. We attempted to avoid the steep slopes of crater walls when selecting spectra to model. All spectra were extracted as individual (1x1) pixels. Residual band-to-band artifacts in the spectra were suppressed using a laboratory reflectance spectrum of mature Apollo 16 soil as ground truth. Deconvolutions of laboratory lunar olivine spectra relied on linear continuum slopes [10]. However, such a choice is impractical for remotely-sensed lunar spectra, which exhibit a notable continuum slope even for relatively immature materials. We chose to use a tangential continuum fitted on either side of the principal olivine absorptions (730 and 1700 nm in M^3 low-resolution spectra with 20-40 nm spectral resolution), a modification of the approach of [13]. Our present focus has been on olivine-dominated spectra that lack "competing" mafic 1000 nm absorptions such as those caused by pyroxene. Thus, the spectra analyzed here are likely to represent mixtures of olivine ± plagioclase. The olivine Mg# is estimated from the band centers of the MGM deconvolution by minimizing the deviation from the trends calculated by [2, 10] across all three bands.

Results: Here we present the results of deconvolutions performed on a suite of spectra extracted from the region of a single olivine-rich crater located within the M^3 "strip", illustrated in Fig. 1. We are actively investigating other olivine-rich regions. Results for additional suites of spectra will be presented. Fig. 2 presents an example fit to one of the olivine-dominated spectra extracted from this region. The quality of the fit is generally good and consistent with an olivine-dominated lithology. However, despite the smoothing correction, several notable "noisy" regions are apparent in the spectrum, particularly at ~900 nm and near 1500 nm. The MGM can deconvolve "noisy" spectra, though the accuracy of the fit and consequently of the compositional prediction are compromised.

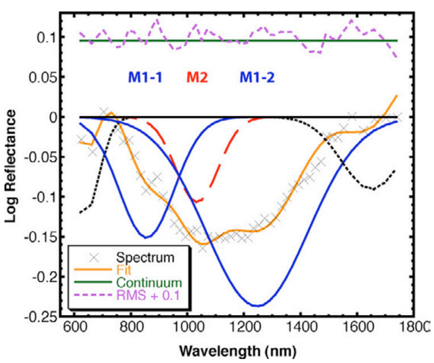

Fig. 2: Example MGM deconvolution of olivine-dominated reflectance spectrum. Note broad-scale quality but local errors in fit.

Predictions of olivine Mg# from M^3 spectra are shown in Fig. 3. The derived band centers produce predictions lying within a reasonably narrow compositional range from ~Fo_{55} to ~Fo_{65}. This range is toward the low end of, but not inconsistent with, olivine compositions observed in feldspathic lunar meteorites, which represent the best proxy for this farside feldspathic highlands region [e.g., 14, 15]. The predicted Mg#'s are less Mg-rich than those found in primitive Mg-suite rocks (e.g. 72415 and 76535, ~$F0_{88}$). The

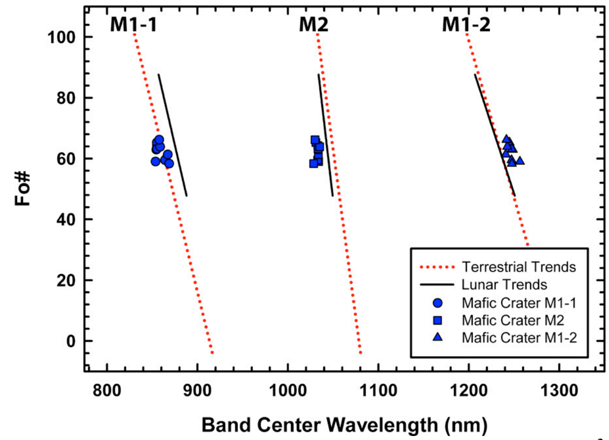

Fig. 3: Band center vs. predicted Fo# (Mg#) for M^3 spectra analyzed in this study. Terrestrial trends are from [2], lunar trends from [10]

band centers of the fits plotted here deviate from the anticipated trends for lunar olivine spectra (M1-1 and M2 bands fall at shorter-than-anticipated wavelengths, and M1-2 bands at slightly longer-than-anticipated wavelengths). The anticipated trends in band positions are based on deconvolutions with a flat continuum slope, quite different from our tangential continuum slope. The compositional trends in the olivine absorption band centers are likely affected by this alternate continuum slope, though the effect on Mg# prediction is presently unknown. The estimates are likely true in a relative sense, but may require adjustment in an absolute sense.

Conclusions and Future Work: Even in its low-resolution mode, M^3 collected spectra of sufficient spectral resolution and signal-to-noise ratio to enable quantitative deconvolution of mineral absorption features. Preliminary analyses of a select suite of olivine-dominated reflectance spectra suggest that the composition of the olivine present in those pixels is consistent with compositions of olivines found in feldspathic lunar meteorites. However, accuracy of the absolute compositional prediction may be compromised by our choice of continuum slope. The effect of the choice of continuum slope on the accuracy of the compositional predictions for lunar olivine-dominated spectra represents an important area of ongoing work.

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