

LSCC SAMPLES AS GROUND TRUTH: USING SPECTRAL PARAMETERS DEVELOPED FOR M³ DATA TO ASSESS COMPOSITION AND MATURITY. D. P. Moriarty III¹ and C. M. Pieters¹, ¹Dept. of Geol. Sci., Brown Univ., Providence, RI [Daniel_Moriarty@Brown.edu]

Background: In reflectance spectra, common lunar minerals exhibit diagnostic absorption bands across the near-infrared (NIR) [1]. The character of these absorption bands (wavelength position, depth, and shape) can be used to infer the mineralogy of the lunar surface from remote measurements. The lunar surface exhibits a red-sloped spectral continuum across the NIR that is dependent on both composition and space weathering processes, which also tend to darken spectra and weaken absorption bands [e.g., 2]. These optical effects arise from the accumulation of nanophase metallic Fe (npFe⁰) on the surface of mineral grains [e.g., 3]. Relative maturity can be inferred from the magnetic response of a soil due to npFe⁰ (I_s) normalized to total iron content (I_s/FeO) [4].

Soils from several locations on the lunar surface sampled by the Apollo missions were studied by the Lunar Soil Characterization Consortium (LSCC) to document the relationships between mineralogical, optical, chemical, and physical properties [5-7]. These integrated analyses provide a rich source of information on lunar composition and evolution, and also serve as important groundtruth for remote sensing. We extend the LSCC analyses to include tools developed for use with M³ data [8].

Methods: In [9], NIR spectra of LSCC were investigated using the Modified Gaussian Model (MGM) [10]. Since lunar soils are a natural mixture of multiple minerals (including both low-Ca and high-Ca pyroxene [LCP and HCP]), each spectrum was modeled using multiple modified Gaussian functions. The soil spectra were well fit using superposed Gaussians representing two distinct pyroxene compositions [9].

Although MGM is an excellent approach when working with high-quality laboratory data, it is not always appropriate for remote sensing data that contain significant noise or artifacts. Here, we analyze the LSCC soil spectra using a somewhat simpler approach initially developed for use with M³ data [8].

A two-part linear (in wavelength) continuum is fit to each spectrum using three tiepoints bounding the primary 1 μ m and 2 μ m absorption bands. This approximation serves as an average continuum over the 1 μ m and 2 μ m regions. Continuum removal is performed by dividing the reflectance spectrum by the derived continuum. Continuum slope is a useful parameter related to both composition and optical maturity. Since spectral slopes are also sensitive to signal level (due to illumination, albedo, etc.), continuum slopes are first normalized to the reflectance value at

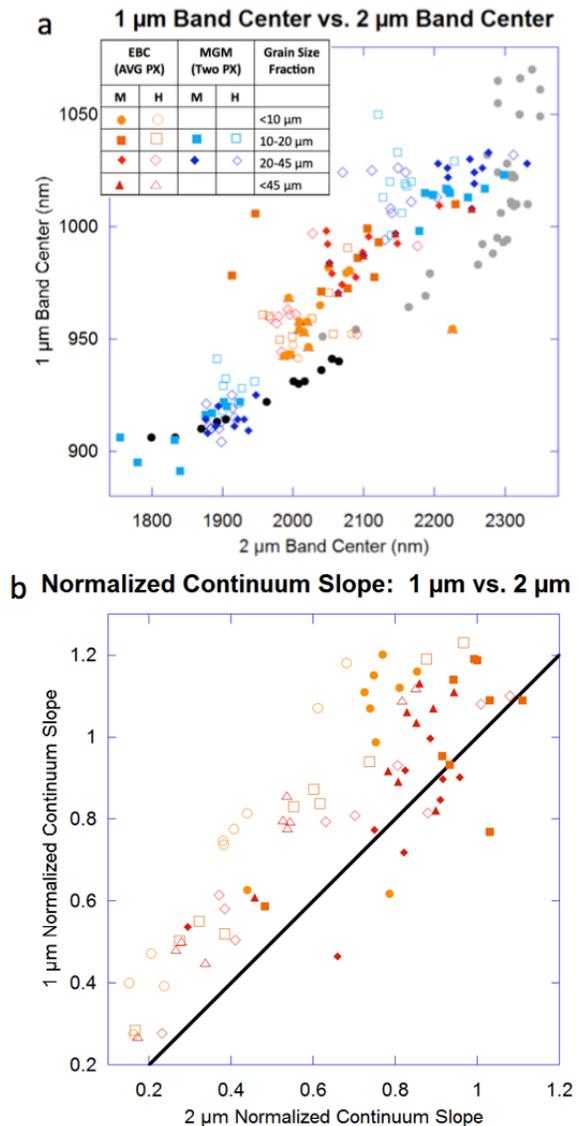


Fig. 1: Comparison of 1 and 2 μ m parameters for each soil separate. For LSCC soils M=mare; H=highland. (a) Band centers derived from MGM [9] and parabola fits. MGM fits for a range of pure, pyroxene compositions are given by black (OPX) and gray (CPX) circles [11,12]. (b) Normalized continuum slope. The black line gives NCS1=NCS2.

700 nm. The Normalized Continuum Slopes (NCS1 for the 1 μ m region; NCS2 for the 2 μ m region) are derived for each spectrum.

After continuum removal, parabolas are fit to the 1 μ m and 2 μ m absorption features. From the parabola minima, absorption band depths (EBD1 and EBD2) and centers (EBC1 and EBC2) are calculated. Together, this suite of six spectral parameters provides an overview of compositional properties of the sample.

The LSCC soil collection contains 19 highland and

mare soils. In [9], MGM analyses were obtained for two grain size separates from each soil: 10-20 μm and 20-45 μm . Using these existing spectra from the RELAB database (plus two additional grain sizes), we calculate the spectral parameters described above. Two primary issues are investigated: (1) compositional information derived from comparison of EBC and MGM band centers, and (2) optical maturity and compositional links associated with several other parameters.

Results: Band Centers - EBC vs. MGM: Fig. 1a compares EBC band center values to the MGM values reported in [9]. For all soils, the single EBC value is bracketed by the two reported MGM band centers. This is an expected result, since MGM assumes a two-pyroxene mixture while EBC fits a single parabola to the composite band and thus represents a mean pyroxene composition for the mixture.

Using MGM, the proportion of each pyroxene endmember is inferred from the relative depths of each component band. The EBC analysis is sensitive to the mean pyroxene composition, and the relative proportion of each endmember is related to the band center of the composite band (for binary mixtures).

However, either approach is nonunique since it is difficult to distinguish a mixture of HCP and LCP from a single pyroxene of intermediate composition. Nevertheless, both allow compositional trends to be evaluated. When a single pyroxene component is present, the composition inferred by EBC values may be more accurate than MGM analyses that assume two components. Results from both approaches tend to fall above the pure pyroxene sequence [*Klima 2008 2011*]. This is likely due to other components in the soil or alteration effects.

Continuum Slope, Composition, and Maturity: A comparison of NCS1 vs. NCS2 values for each soil separate is given in Fig. 1b. With the exception of a few (mostly mare) soil separates without fines, most soils exhibit a flatter 2 μm continuum than the 1 μm . LSCC highlands soils exhibit a wide range of NCS1 and NCS2 values and are distinctly lower (flatter) than mare soils. This indicates that composition contributes significantly to spectral slope.

For both mare and highlands soils, the <10 μm fraction exhibits the highest NCS1/NCS2 ratio, i.e. the 1 μm slope is steepest compared to the 2 μm slope. The 20-45 μm fraction exhibits the lowest NCS1/NCS2 ratio. The ratio is somewhat higher for highlands soils than for mare soils.

Although not shown here, relations of measured parameters to I_s and I_s/FeO values [13,14] were also investigated. The NCS1/NCS2 ratio appears uncorrelated with the measured I_s and I_s/FeO values for these

soils. This implies that the NCS1/NCS2 ratio is dominated by grain size and/or composition, not maturity. Since the composition of lunar soils varies with grain size, differentiating between these variables is not possible using this data.

Both NCS1 and NCS2 tend to increase with increasing maturity (I_s/FeO), but exhibit higher values for mare soils than for highlands soils. NCS1 exhibits a tighter correlation than NCS2, especially for mare soils. Tighter correlations are observed between NCS and I_s than for NCS and I_s/FeO . This indicates that it is specifically npFe^0 content rather than exposure time that contributes to spectral continuum slopes, in agreement with [9]. This relationship is useful for remote sensing observations, as it shows that the relative maturity of materials with similar compositions can be assessed using spectral slopes.

Several additional maturity-related trends were observed. Albedos (reflectance at 1450 nm) are negatively correlated with steepening NCS1 and NCS2. Band depths exhibit only weak negative correlations with I_s and I_s/FeO , but also exhibit a “zone of avoidance” where strong bands do not exist for high I_s and I_s/FeO values.

Conclusions: We have shown that the approximations of a two-part linear continuum and parabola fitting produces band center results consistent with earlier MGM analysis of LSCC soils [9]. EBC values are sensitive to the mean pyroxene composition rather than individual components of a mixture. The EBC methods tested here are valid for remote sensing use.

Correlations between previously reported optical maturity effects (darkening, reddening, and weakening of absorption bands) are captured using the spectral parameters described here. Additionally, the npFe^0 content of soil separates (as measured by I_s) is better correlated with several spectral parameters than maturity parameter I_s/FeO . This indicates that absolute npFe^0 content is more important than degree of weathering in determining the optical properties of lunar soils.

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