

EXTRACTING QUANTITATIVE DATA FROM LUNAR SOIL SPECTRA. S. K. Noble^{1,*}, C. M. Pieters¹, and T Hiroi¹, ¹Brown University, Box 1846 Providence RI 02912. noble@porter.geo.brown.edu, *Currently the GSA Congressional Fellow, assigned to the House Committee on Science, H2-394 Ford Building, Washington DC 20515.

Introduction: Using the modified Gaussian model (MGM) developed by Sunshine et al. [1] we compared the spectral properties of the Lunar Soil Characterization Consortium (LSCC) suite of lunar soils [2,3] with their petrologic and chemical compositions to obtain quantitative data. Our initial work on Apollo 17 soils [4] suggested that useful compositional data could be elicited from high quality soil spectra. We are now able to expand upon those results with the full suite of LSCC soils that allows us to explore a much wider range of compositions and maturity states. The model is shown to be sensitive to pyroxene abundance and can evaluate the relative portion of high-Ca and low-Ca pyroxenes in the soils. In addition, the dataset has provided unexpected insights into the nature and causes of absorption bands in lunar soils. For example, it was found that two distinct absorption bands are required in the 1.2 μ m region of the spectrum. Neither of these bands can be attributed to plagioclase or agglutinates, but both appear to be largely due to pyroxene.

Methods: Using the continuum removal method developed by Hiroi *et al.* [5], the continuum is determined and removed and each absorption band is fit to a modified Gaussian shape which can be fully described by three terms; band center, band strength and band width (FWHM), as is shown in Fig. 1a. Additional bands are added as needed until the residual is small and there are no systematic features. These three parameters then provide quantitative information about each absorption band that can be directly compared to LSCC measured compositional data.

Results: Initially each soil was fit with only three bands centered near 1, 1.28 and 2 μ m. As demonstrated in Fig. 1a, these 3-band fits produced unacceptable systematic errors, indicating that additional bands are necessary. This was not unexpected, since the compositional data [2] indicate that both high- and low-Ca pyroxenes are present in all of the soils. The model was subsequently run using five bands: a 1.28 μ m band plus two bands near 1 μ m and two near 2 μ m to account for the high- and low-Ca pyroxene. With five bands the errors were considerably reduced, but an unacceptably large error consistently appeared in the 1.2-1.3 μ m region, so a 6th band was added. A typical 6-band fit is shown in Fig. 1b. In addition, a seventh band was needed for the four Apollo 17 soils at \sim 0.6 μ m. This additional band is required due to their Ti-rich pyroclastic glass content.

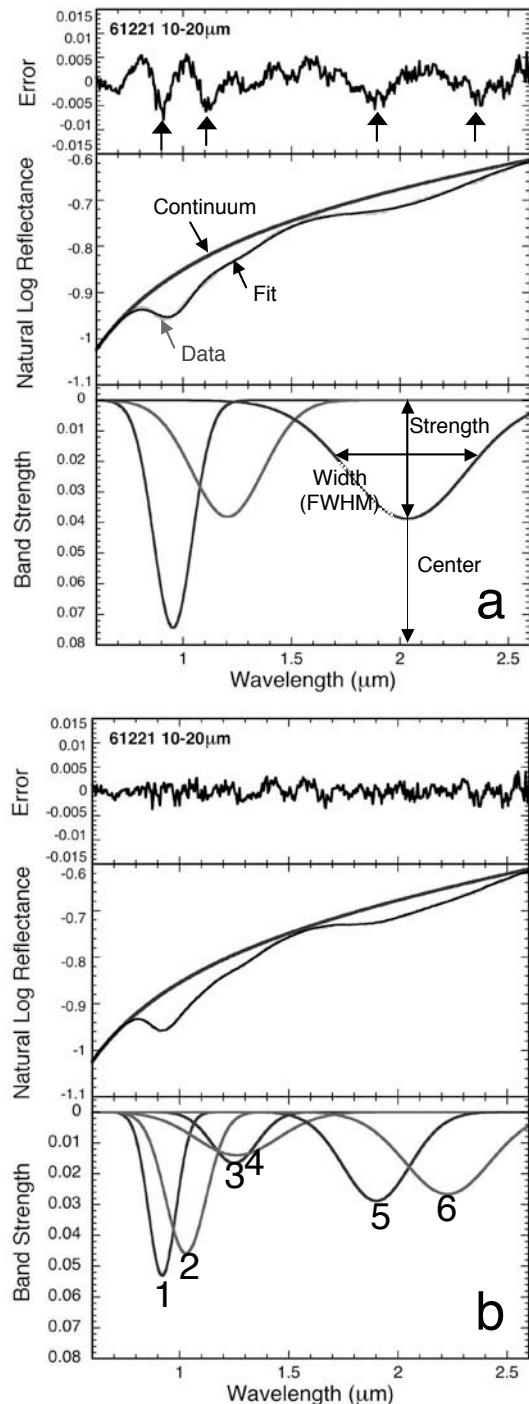


Figure 1. MGM deconvolution results for a representative lunar soil, the 10-20 μ m fraction of 61221: a=3-band fit, b=6-band fit. The residual in a exhibits systematic errors (arrows) indicating additional bands are required.

Since using only 3 bands produced such poor fits to the data (Fig. 1a), it is clear that both types of pyroxene significantly affect soil spectra. In measuring soil composition, pyroxenes were divided into 4 categories by the LSCC: orthopyroxene, pigeonite, a Mg-rich pyroxene (augite), and an Fe-rich pyroxene [2]. To simplify our analyses we have combined the measured abundances of orthopyroxene and pigeonite into a “low-Ca pyx” category and the Mg- and Fe-rich pyroxenes into a “high-Ca pyx” category. The relative band strength of bands 1 and 2 (near $1\mu\text{m}$, as labeled in Fig. 1) are expected to be directly proportional to the ratio of low to high Ca pyroxene in a given soil [6]. The same should also be true of bands 5 and 6 (near $2\mu\text{m}$). The measured ratio of low to high Ca pyroxene is compared to the ratio of the strength of band 1 to band 2 in Fig. 2 and the combined strength of these bands are compared to the combined pyroxene abundance in Fig. 3.

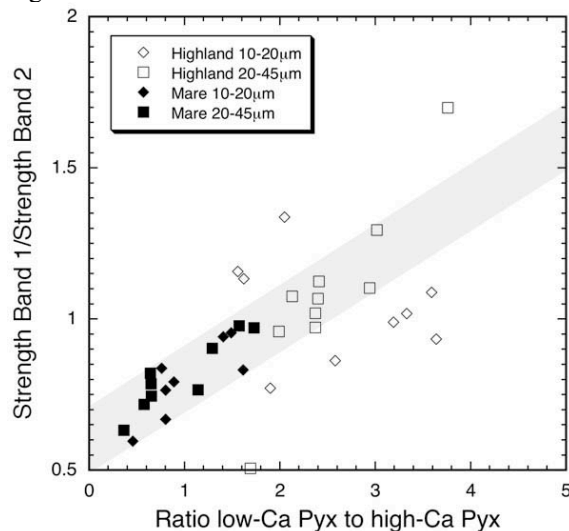


Figure 2. Ratio of low-Ca to high-Ca pyroxene compared to the ratio of a) the band strength of band 1 vs. band 2 and b) the band strength of band 5 vs. band 6.

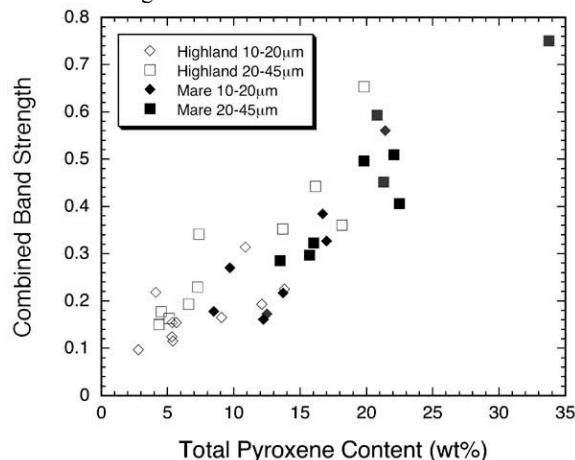


Figure 3. Combined strength of the bands near $1\mu\text{m}$ compared to the measured pyroxene abundance in the soils.

The model is clearly doing a good job of measuring both total pyroxene abundance as well as the relative abundance of high and low Ca pyroxene from absorptions in the $1\mu\text{m}$ region. Both the $10\text{-}20\mu\text{m}$ and the $20\text{-}45\mu\text{m}$ fractions of mare soil as well as the $20\text{-}45\mu\text{m}$ fraction of highland soils show strong correlations between band strength and composition. The $10\text{-}20\mu\text{m}$ fraction of highland soils, however, are considerably more scattered, most likely due to a combination of low total pyroxene content and the tendency for weathering products to increase in the finer fractions. If the highland $10\text{-}20\mu\text{m}$ soils are ignored, the fit is remarkably good. In contrast to the results in the $1\mu\text{m}$ region, a comparable relationship between composition and band strength is not seen in the $2\mu\text{m}$ region. We have found that for lunar soils, the MGM's ability to deconvolve individual bands is currently less accurate in the $2\mu\text{m}$ region.

Conclusions: Our MGM analyses demonstrate both the capabilities and the limitations of this method of deconvolution as a quantitative tool for lunar soils. The model does a good job eliciting data from the 1 and $1.2\mu\text{m}$ regions. It is currently less useful in the $2\mu\text{m}$ region where the bands are weaker. Low pyroxene abundance and high degrees of space weathering can also limit the accuracy of pyroxene assessment.

As a method of spectra deconvolution, the Modified Gaussian Model is able to identify both high- and low-Ca pyroxene in a suite of lunar soils. In addition to the pyroxene absorption bands, it was discovered that two distinct $\sim 1.2\mu\text{m}$ bands (bands 3 and 4) are required by the data. Although not discussed here, plagioclase and agglutinates have been eliminated as possible causes of the $1.2\mu\text{m}$ bands. Rather, pyroxenes, particularly pigeonite and Fe-rich clinopyroxene, appear to be largely responsible for those bands.

The strong association between band strength and pyroxene content indicates that for high quality spectra, the MGM allows quantitative predictions. In addition to identifying total pyroxene content, the MGM also allows the ratio of high- to low-Ca pyroxene to be derived from high quality lunar soil spectra.

References: [1] Sunshine, J. M., Pieters C. M. and Pratt S. F. (1990) *JGR*, **95**, 6955-6966. [2] Taylor L. A., Pieters C. M., Keller L. P., Morris R. V. and McKay D. S. (2001). *JGR*, **106**, 27985-27999. [3] Taylor L. A., Pachen A., Cahill J., Pieters C. M., Morris R. V., Keller L. P. and McKay D. S. (2002) *LPSCXXXIII*, ab#1302. [4] Noble S. K. *et al.* (2000) *LPSCXXXI*, ab #1880. [5] Hiroi T., Pieters C. M. and Noble S. K. (2000) *LPSCXXXI*, ab#1548. [6] Sunshine, J. M., McFadden L. A. and Pieters C. M. (1993) *Icarus*, **105**, 79-91.

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