

FROM MINERALS TO ROCKS: TOWARD MODELING LITHOLOGIES WITH REMOTE SENSING John F. Mustard, Jessica M. Sunshine, Carlé M. Pieters, Andrew Hoppin, Stephan F. Pratt, Dept. of Geol. Sci., Brown University, Providence, RI, 02912.

**Introduction:** High spectral resolution imaging spectroscopy will play an important role in future planetary missions. Sophisticated approaches will be needed to unravel subtle, super-imposed spectral features typically of natural systems, and to maximize the science return of these instruments. Carefully controlled laboratory investigations using homogeneous mineral separates have demonstrated that variations due to solid solution (1), changes in modal abundances (2,3), and the effects of particle size (4,5) are well understood from a physical basis. In many cases, these variations can be modeled quantitatively using photometric models (6), mixing approaches (7), and deconvolution procedures (3). However, relative to the spectra of individual mineral components, reflectance spectra of rocks and natural surfaces exhibit a reduced spectral contrast. In addition, soils or regolith, which are likely to dominate any natural planetary surface, exhibit spectral properties that have some similarities to the parent materials, but due to weathering and alteration, differences remain that cannot yet be fully recreated in the laboratory or through mixture modeling (e.g. 8). A significant challenge is therefore to integrate modeling approaches to derive both lithologic determinations and include the effects of alteration. We are currently conducting laboratory investigations in lithologic modeling to expand upon the basic results of previous analyses with our initial goal to more closely match physical state of natural systems. The effects of alteration are to be considered separately.

**Experimental Procedure:** We have chosen to begin with an igneous model consisting of five basic igneous rock forming minerals or mineral groups (olivine (OL), clinopyroxene (CPX), orthopyroxene (OPX), plagioclase (PL), and opaques (ilmenite)). These minerals can explain many volcanic and igneous exposures on the terrestrial planets. Each mineral was crushed and wet sieved to three particle sizes (<25 (S) 25-75 (M) 75-250 (L)  $\mu\text{m}$ ). The particle size separates were combined to form mono-mineralic soils in the following proportions: small soil (SS) (65% S 25% M 10% L), medium soil (MS) (25% S 50% M 25% L), and large soil (LS) (10% S, 25% M, 65% L). Particle size separates and soils were measured in RELAB and these data are presented in **Figure 1**. Mono-mineralic soils of CPX, OPX, and OL were combined with a constant mass fraction ratio of 3:1:1, similar to mafic mineral ratios in gabbroic rocks, but with three different soil combinations: 1) MS:MS:MS 2) SS:SS:LS 3) LS:LS:SS. These data are presented in **Figure 2**. The reflectances of all samples have also been measured at wavelengths out to 25  $\mu\text{m}$  and initial analyses of these data are reported in a companion abstract (9).

**Analysis:** The spectra of the particle size separates exhibit the well known and characterized particle size variation where the spectra of small particles are brighter and have weaker absorptions than larger particle sizes. The soil spectra show the same systematics where the SS is brightest and has the weaker absorptions than the MS and LS. This generally reflects the relative contributions of the various particles sizes used to construct the soils. However, modeling of these soil mixtures using a simplified intimate mixing model (2) generally shows that the small particles contribute to the measured soil spectra in excess of the known proportions that were used to construct the soil mixtures. This effect is expressed as a weaker absorption for a given brightness and can be seen in the spectra for OPX and OL where the LS has the same general brightness of M, but weaker absorptions. We hypothesize that the finest size fraction does not behave as an independent particle as required by theory, but coats the larger grains and therefore interacts with more photons than expected. In addition, Hapke's (6) treatment of bidirectional reflectance explicitly states that the particle diameters must be greater than the wavelength of light. The particle diameters of the smallest size fraction begin to approach this limit.

Although the endmember compositions and mass fraction ratios used to construct gabbroic soils are the same, the different particle size distributions dramatically affect the measured spectra (**Fig. 2**). Also note that the spectral contrast of the data in **Fig. 2** is much less than in the spectra of individual endmembers. Application of the intimate mixture model for these returns the results shown in **Table 1**. When the appropriate endmember soil spectra are used, good agreement between known and calculated abundances are found and the fitting error is low (1-3 times noise). Some of the discrepancies between known and calculated abundances are attributed to the settling of samples during preparation for measurement. However, even if the correct endmember compositions but inappropriate particle sizes are used, then the mass fraction estimates are in poor agreement, and there is a large fitting error (5-10 times noise). If endmembers of the wrong composition are used, we can expect even greater fitting errors and errors in fractional abundance estimates.

**Conclusion:** This investigation is the first to systematically study the effects of particle size distributions on the spectra of mineral separates and mineral mixtures. The analyses show that the finest particles dominate the mono-mineralic soil spectra in excess of theoretical expectations. For the mineral mixture spectra, the spectral

contrast of the mixture is less than the endmember spectra. However, one must use the appropriate soil endmembers, rather than size separates, to attain reasonable solutions. We expect natural surfaces to also be dominated by fine particles and photometric mixture modeling approaches must begin to accommodate not only particle size variations, but distributions. Deconvolution procedures, on the other hand, are less sensitive to particle size variations (10). Analyses of these data with deconvolution is being pursued in parallel. We believe that quantitative modeling of lithologies will be best approached with a combination of methods.

References: (1) Cloutis and Gaffey (1991) *JGR* 96, 22809-22826. (2) Mustard and Pieters, *JGR* 94, 13619-13634. (3) Sunshine et al., (1990) *JGR* 95, 6955-6966. (4) Crown and Pieters (1988), *Icarus* 72, 492-506. (5) Hiroi and Pieters (1991), *Proc. Lun. Plan. Sci. XXII*, 313-325. (6) Hapke *JGR* 86, 3039-3054. (7) Johnson et al. (1983) *JGR* 88, 2649-2658. (8) Lunar Source Book (1992). (9) Pieters et al. (1993), this volume. (10) Sunshine and Pieters (1993) Estimating modal abundance from the spectra of laboratory pyroxene mixtures..., *JGR*, (submitted).

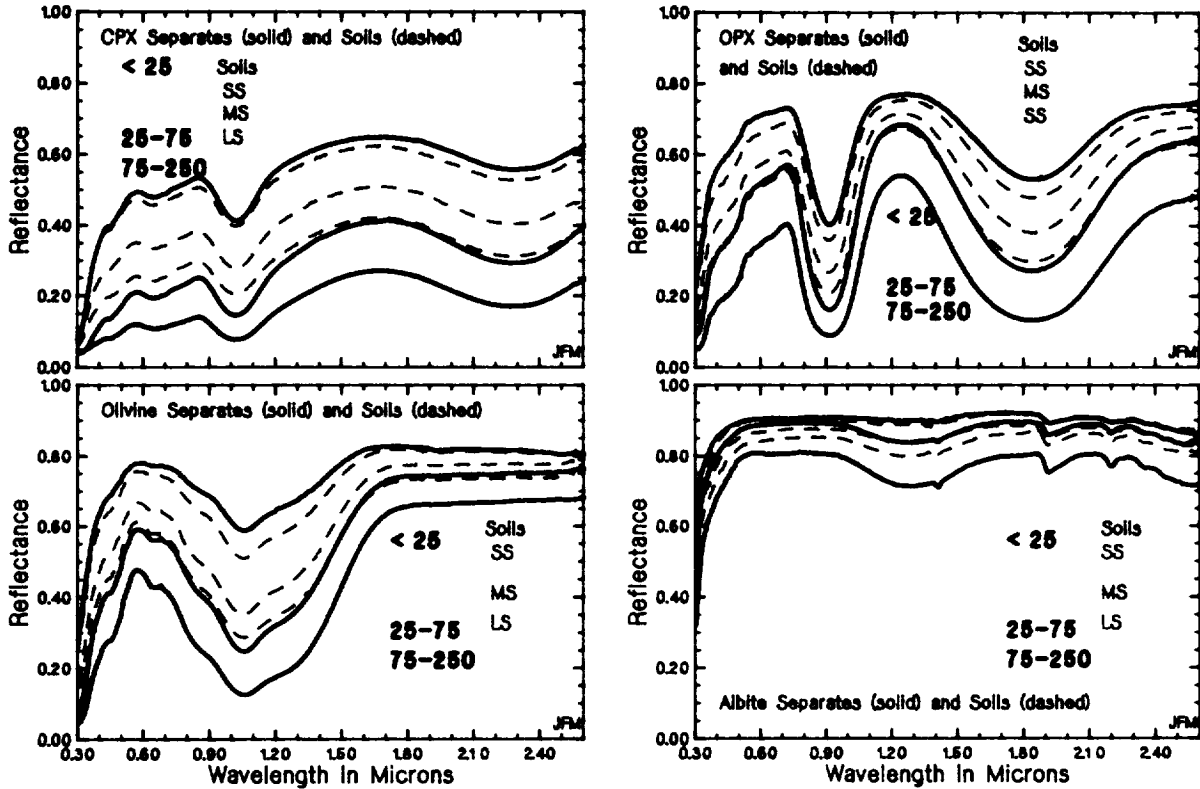


Figure 1

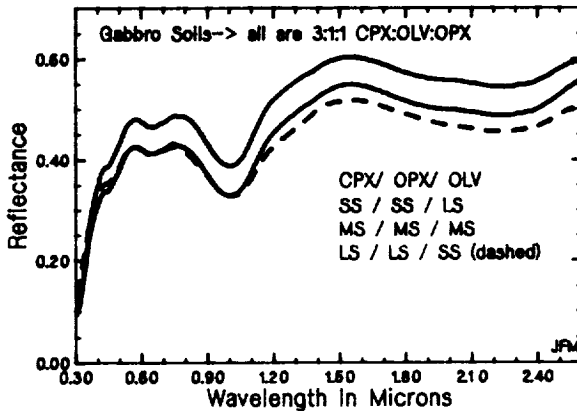


Figure 2

Table 1

	CPX	OPX	OLV	STD
Actual	0.60	0.20	0.20	
MS:MS:MS	0.534	0.203	0.263	0.32
SS:SS:LS	0.725	0.081	0.194	0.47
LS:LS:SS	0.554	0.200	0.246	0.56