REPRODUCING VISIBLE AND NEAR-INFRARED REFLECTANCE SPECTRA OF LUNAR ROCKS DIRECTLY FROM THEIR END-MEMBER SPECTRA: IMPORTANCE OF ILMENITE IN ESTIMATING THE LUNAR SURFACE COMPOSITION. T. Hiroi[1], P. J. Isaacson,[1] R. L. Klima[1], C. M. Pieters[1], A. B. Sarbadhikari[2], Y. Liu[2], and L. A. Taylor[2], [1] Dept. Geological Sciences, Brown Univ., Providence, RI 02912 (takahiro_hiroi@brown.edu), [2] Dept. Earth & Planetary Science, Univ. Tennessee, Knoxville, TN 37996.

Introduction: The Lunar Rock and Mineral Characterization Consortium (LRMCC) [1,2] is currently being undertaken following the Lunar Soil Characterization Consortium which undertook detailed analyses of a suite of representative lunar soils with carefully coordinated mineralogy, petrology, and spectroscopy measurements [3,4]. Our goal is to obtain the ground-truth as a solid foundation for lunar science and exploration. The visible and near-infrared spectroscopy measurements especially will help interpreting recent and future high-quality observations such as those by Kaguya/SP and Chandrayaan-1/M3. Reported in this paper are the preliminary results of spectral mixing model calculations on the bulk samples and major mineral separates prepared from samples of two low-Ti Apollo 15 basalts and two high-Ti Apollo 17 basalts.

Experimental: A thin section and neighboring slab were prepared and studied for petrology and mineralogy [5]. Bulk particulate samples and mineral separates prepared from the slabs were used for spectroscopic measurements. Samples of four basalts 15058, 15555, 70017, and 70035 have been prepared for analysis. Bidirectional reflectance spectra (0.28-2.6 μm) of the <125 μm grain size fractions of the above samples were measured at 30° incidence and 0° emergence angles using the RELAB spectrometer [6].

Spectral Mixing Model Calculations: A scheme [7] of Hapke's model [8] was utilized to fit the reflectance spectrum of each bulk powder sample with those of its major component minerals by varying the volume abundance and grain size of each component, and the surface roughness of the bulk sample if necessary. Although the scattering phase function was assumed to be isotropic, anisotropic scattering was achieved naturally according to the grain size and opacity of each grain. The real refractive indices of component minerals at 0.55 μm in wavelength were assumed to be 1.57 for plagioclase, 1.78 for olivine, and 1.67 for pyroxene, except when prevented by the model limitations. Ilmenite was treated as an opaque mineral. For the purposes of the calculations, reflectance data were resampled to 10 nm intervals from 0.4 to 2.5 μm.

Results: Three representative results of spectral mixing calculations are described below.

15058. Two groups of pyroxene and plagioclase samples were separated from this rock, and their spectra were used for calculations. The results are shown in Table 1 and Fig. 1. Optimized mineral modal abundances are in reasonable agreement with those estimated from the full data [2], and the optimized effective grain sizes (μm) are near the center of the actual grain size range (<125 μm).

Table 1. Estimated mineral modal abundances of 15058.

Mineral modal abundances (vol %)	Green pyroxene	Brown pyroxene	Plagioclase
From thin section	29.3	33.8	30.1
By spectral fitting (Effective grain size)	29.1 (68.3)	45.9 (57.6)	25.0 (73.9)

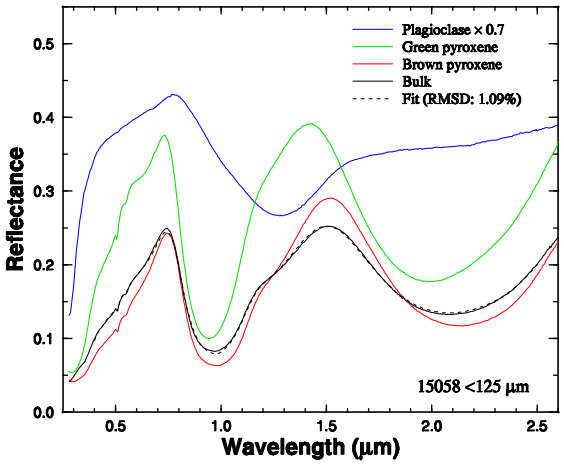

Fig. 1. Result of spectral fitting of 15058. Note that the plagioclase spectrum is scaled by a factor of 0.7.

15555. Olivine, two groups of pyroxene, and plagioclase samples were separated from this rock. The results are shown in Table 2 and Fig. 2. The abundance of olivine is overestimated by a factor of more than 2, and that of light-brown pyroxene is underestimated. The optimized effective grain size of plagioclase is less than half of those of other minerals.

Table 2. Estimated mineral modal abundances of 15555.

Mineral modal abundances (vol %)	Olivine	Light-brown pyroxene	Reddish-brown pyroxene	Plagioclase
From thin section	11.8	42.0	14.7	27.3
By spectral fitting (Effective grain size)	27.0 (75.3)	31.3 (56.1)	16.1 (64.4)	25.6 (28.0)

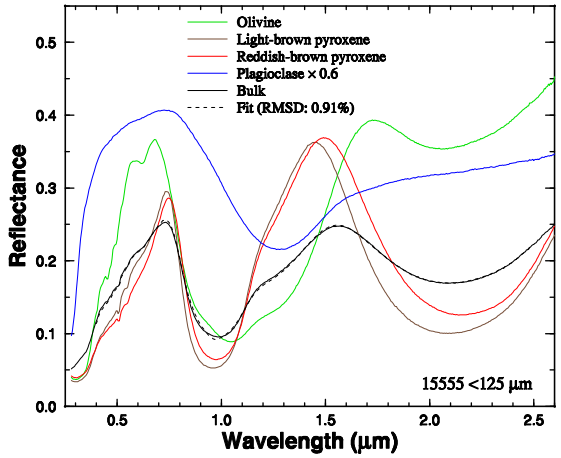

Fig. 2. Result of spectral fitting of 15555.

70017. Two groups of pyroxene, plagioclase, and ilmenite samples were separated from this rock. The results are shown in Table 3 and Fig. 3. The effective grain sizes of these component minerals are significantly smaller than those in Apollo 15 rocks above, and that of ilmenite is even smaller.

Table 3. Estimated mineral modal abundances of 70017.

Mineral modal abundances (vol %)	Light-brown pyroxene	Dark-brown pyroxene	Plagio-clase	Ilmen-ite
From thin section	17.7	34.8	25.7	17.3
By spectral fitting (Effective grain size)	27.0 (38.7)	25.2 (44.0)	16.9 (35.1)	31.1 (16.8)

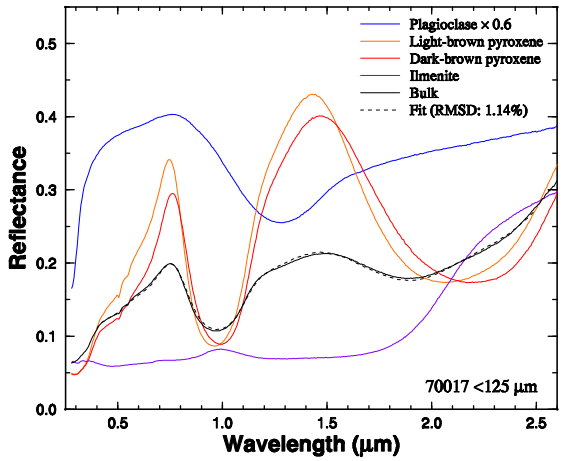

Fig. 3. Result of spectral fitting of 70017.

Discussion: With three distinct component mineral spectra as in 15058, this spectral mixing calculation seems to give reasonable estimates of the modal abundances and effective grain sizes. However, having an additional olivine component in 15555 incurred a large error in the abundance of olivine and a much smaller effective grain size of the plagioclase component. It is evident from the 2-μm feature of this olivine spectrum that this sample contains spinel and/or pyroxene, which may partially contribute to the abundance error. Note that the model has a restriction on the allowable effective grain size range which could either be tightened, sacrificing the quality of the spectral fit, or loosened, leading to better spectral fits. More study would be required to find an optimal balance in that procedure.

The ilmenite component in 70017 has significant effects on the spectral fit and modal abundance estimates. Because ilmenite is generally darker than other components, when it is overestimated, it requires the other mineral components to become brighter by reducing their grain sizes to maintain the same bulk sample reflectance. Because of its rapidly increasing reflectance with wavelength starting around 1.8 μm, a coexisting ilmenite component causes the 2-μm pyroxene band to appear centered toward shorter wavelengths and disproportionately stronger than the 1-μm band.

Estimating the pyroxene composition of the lunar rock 70017 without considering the possibility of coexisting ilmenite would lead to errors, as the apparent 1.9-μm feature would be attributed to a significant enstatite or bronzite component. In addition, if the reflectance spectrum of this rock powder on the Moon were measured remotely, the red continuum over the 2-μm band could be misinterpreted as due to thermal emission. This ilmenite issue is a serious one, and could be complicated by possible influences from other coexisting oxides such as ulvöspinel. The reflectance spectra of ilmenite and other minor components should be characterized, including their grain size dependencies.

Conclusions: While our spectral mixing calculations show some usefullness, there are outstanding issues, especially those related to ilmenite. This study has revealed the importance of considering coexisting ilmenite in estimating the grain sizes, chemical compositions, and modal abundances of lunar silicates.

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