MGM ANALYSIS OF PYROXENE MINERAL SEPARATES FROM APOLLO 15 AND 17. R.L. Klima[1] and C.M. Pieters[1], [1]Dept. of Geol. Sciences, Brown University, Providence, RI 02906 (Rachel_Klima@Brown.edu).

Introduction: With the new generation of missions flying high spectral resolution spectrometers to the Moon, it is crucial to strengthen the laboratory framework for remote mineralogical analyses. While mafic minerals are readily identifiable in the near-infrared, methods to better quantify specific chemistry and mineralogy are being improved.

Pyroxenes, in particular, offer exciting possibilities for characterizing the thermal history of outcrops on the lunar surface. In laboratory studies, the chemistries of coexisting pyroxenes have been used to characterize the phase equilibria of igneous systems, which can be used for geothermometry [1]. Detailed analyses of Mg-Fe ordering between crystallographic sites in a pyroxene provide further constraints on the cooling rates and history of pyroxene-bearing rocks [e.g., 2-5]. New methods are under development to address these issues using high-quality reflectance spectra [6].

Methods: Pyroxene separates from slabs of four mare basalts (15058, 15555, 70017 and 70035) were prepared by the Lunar Rock & Mineral Characterization Consortium at the University of Tennessee. The preparation methods, petrology and chemistry for these samples are decribed in [7]. Coordinated reflectance spectra of bulk samples and mineral separates were obtained using the NASA/Keck RELAB at Brown University and are described in [8]. Bidirectional reflectance spectra of pyroxenes, collected from 0.35-2.6 μm at 5 nm resolution, are deconvolved here using the MGM which separates a spectrum into a continuum slope and a series of modified Gaussian curves that can be associated with specific electronic transitions [9]. In two pyroxene mixtures, MGM allows derivation of relative amounts of high and low calcium pyroxene [10]. The MGM also derives relative intensities of pyroxene absorption features caused by iron in the M1 and M2 cation sites, allowing a remote assessment of Fe-Mg ordering [6]. MGM analysis of lunar olivine separates from these basalts is presented in [11].

Preliminary Results: Pyroxenes in slab 15555,965 are compositionally zoned, ranging from a pigeonite core through an Mg-rich inner core to an Fe-rich outer augite rim [8]. The pyroxene mineral separates of this sample, referred to here as 'reddish-brown pyroxene' and 'light brown pyroxene' can be broadly classified as rims and cores, though the compositions of both separates overlap slightly. The reddish-brown pyroxene has an overall higher iron content than the light brown pyroxene, but the iron contents of individual grains range from ~14-32% FeO [8]. The calcium content of the reddish brown pyroxene is less variable, ranging from ~6-16% CaO. In contrast, the light brown pyroxene shows less variability in iron content (~13-26%), but more variability in calcium (~3-15%) [8].

Shown in Fig. 1 are spectra of the reddish-brown and light brown pyroxene mineral separates from slab 15555,965. For comparison, the spectrum of a pyroxene separate from 12063,199 is also presented. The strong absorption feature near 2 μm in all spectra is caused by Fe^{2+} in the M2 pyroxene site, and moves to longer wavelengths with increasing Fe or Ca content. The absorption near 1 μm is caused by Fe^{2+} in the M1 and M2 sites, and also shifts with composition. All spectra exhibit another weaker absorption band near 1.2 μm, caused by Fe^{2+} in the M1 pyroxene site.

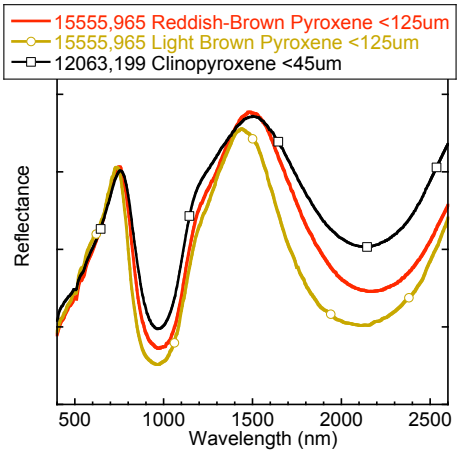

Fig. 1. Pyroxene mineral separates from slab 15555,965 compared with Apollo 12 pyroxene separate 12063,199.

Modified Gaussian Modeling. MGM deconvolutions of both 15555 pyroxene samples were first performed using a single pyroxene fit, with one absorption near 1 μm, one near 1.2 μm, and one near 2 μm. Previous MGM modeling of zoned pyroxene 12063,199 required only one pyroxene for a model fit [6]. This is in contrast to pyroxenes that are exsolved into two distinct compositions, which require absorption bands for two pyroxenes to produce an acceptable model fit [6]. Single pyroxene fits also facilitiate calculation of the M1 intensity ratio (the intensity of the 1.2 μm M1 absorption divided by the sum of the intensities of the 1.2 μm M1 and the 2 μm M2 absorptions). This ratio provides an estimate of the ordering in the pyroxene, which is related to the last thermal event experienced by the mineral [7].

Although both 15555 pyroxene separates are compositionally diverse [8], an adequate single pyroxene fit was obtained for the reddish-brown pyroxene. The resulting band widths are broader than expected for a single pyroxene, similar to results derived in fitting the 12063 clinopyroxene [6]. As illustrated in Fig. 2., the centers of the 1 and 1.2 μm bands are also slightly misfit. The MGM could not arrive at a single pyroxene fit for the light brown pyroxene without constraining the continuum. With the continuum held constant, the resulting fit for the light brown pyroxene had significant RMS error in both the 1 and 2 μm regions. The M1 intensity ratio is calculated at 0.24 for the reddish-brown pyroxene (~rim) and 0.18 for the light brown pyroxene (~core).

Two pyroxene fits were also derived for both 15555 pyroxene separates, and are presented in Figs. 3 and 4. In both figures, bands associated with the pyroxene that is lower in iron and calcium are dark blue, with the higher iron/cacium pyroxene bands in light blue. Near 1.2 μm, the M1 bands for both pyroxenes in each separate occur almost the same wavelength and have thus been modeled as one band (shown in purple) for simplicity. The band parameters for the two band fits are presented in Table 1.

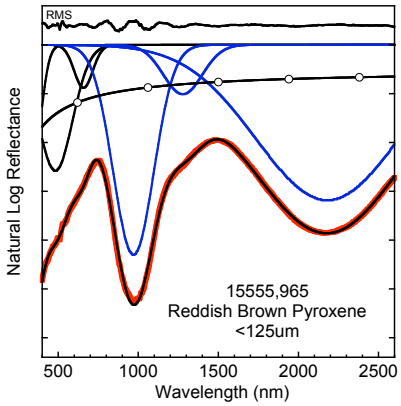

Fig. 2. Single pyroxene MGM fit to the spectrum of the reddish-brown pyroxene separate.

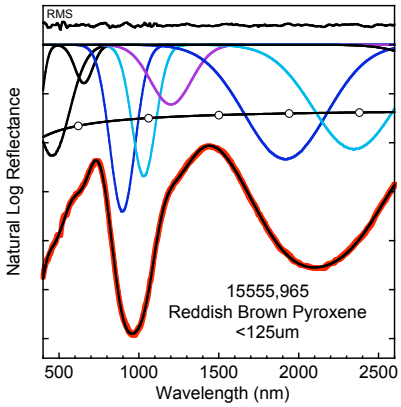

Fig. 3. Two pyroxene MGM fit to the spectrum of the reddish-brown pyroxene mineral separate.

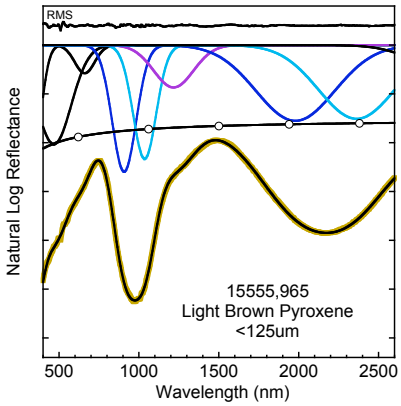

Fig. 4. Two pyroxene MGM fit to the spectrum of the light brown pyroxene mineral separate.

Table 1. MGM parameters for two pyroxene fits.

Reddish-Brown Pyroxene	**Center**	**Width**	**Intensity**
Px1 – 1 μm	908	176	-1.30
Px2 – 1 μm	1036	170	-1.17
Px1 – 2 μm	1979	579	-0.78
Px2 – 2 μm	2363	561	-0.75
Light Brown Pyroxene			
Px1 – 1 μm	897	185	-1.70
Px2 – 1 μm	1031	174	-1.34
Px1 – 2 μm	1918	604	-1.17
Px2 – 2 μm	2346	603	-1.07

Discussion and Ongoing Work: The difficulty experienced in obtaining a single pyroxene fit for the light brown pyroxene is consistent with the petrology of the separate. Though the sample is dominated by pigeonites, a portion of the grains are Mg-rich augite [8]. The difference in structure caused by the higher Ca content results in the spectral separation of two distinctive pyroxenes. In contrast, in the case of the reddish-brown pyroxene, which is almost strictly augite of varying Fe content, a single pyroxene fit provides allows estimation of a reasonable average composition.

The M1 intensity ratios calculated from single pyroxene fits suggest that overall the light brown pyroxene (lower ratio) has experienced a higher degree of Mg-Fe equilibration than has the reddish-brown pyroxene. Both, however, are slightly more ordered than the 12063 clinopyroxene, which has an M1 intensity ratio of 0.28. This suggests that the pyroxenes in mare basalt 12063 may have cooled more rapidly than those in 15555.

The 2 μm band position for the shorter wavelength pyroxene in the two pyroxene fit of the light brown pyroxene is consistent with a pigeonite of around Mg70. For the reddish-brown pyroxene, the 2 μm band occurs at a longer wavelength, suggesting that is it either much more ferrous (~Mg40or50) or richer in Ca (Wo10 or higher). The second pyroxene in both cases is an augite.

Our MGM fits to pyroxene separates from 15555 provide compositional estimates that are consistent with the mineralogy as determined by electron microprobe. Though the separates are compositionally diverse, single pyroxene fits provide a rough average of the composition, and two pyroxene fits allow boundaries to be set on the low and high calcium pyroxene compositions. Similar analyses are underway for the pyroxene separates from 15058, 70017 and 70035.

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