

SPECTRAL CHARACTERISTICS OF PLAGIOCLASE WITH VARIABLE IRON CONTENT: APPLICATIONS TO REMOTE SENSING OF THE LUNAR CRUST. L. C. Cheek,¹ C. M. Pieters,¹ S. W. Parman,¹ M. D. Dyar,² and E. A. Speicher,² and R. F. Cooper¹¹Brown Univ. Geol. Sciences, Box 1846, Providence, RI 02912 (Leah_Cheek@brown.edu) ²Dept. of Astronomy, Mount Holyoke College, South Hadley, MA 01075.

Introduction: Plagioclase is the most abundant mineral on the Moon's surface, comprising >90% of anorthositic rocks that dominate the crust as primary crystallization products of the lunar magma ocean. Returned highland plagioclase samples are both low in FeO (generally <0.2 wt%, indicating re-equilibration with associated mafics) and highly calcic compared to terrestrial samples [e.g., 1]. Characterization of lunar plagioclases on a global scale is now feasible with new high spatial- and spectral-resolution orbital data [2,3]. Global assessment will improve understanding of the large-scale spatial homogeneity of lunar evolution processes, such as magma ocean crystallization and low-grade metamorphism during prolonged cooling.

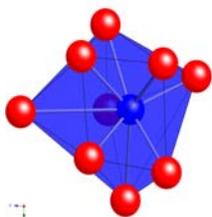


Fig. 1. Ca site in anorthite, showing many different bond angles and a wide range of Ca-O distances. Such extreme distortion makes it difficult to specify the coordination number for Ca and relate spectroscopic data to those of other minerals.

Plagioclase compositions can be obtained remotely from near-infrared (NIR) reflectance data, which are sensitive to the coordination environment of Fe²⁺ cations. Plagioclase exhibits a diagnostic absorption band at ~1.25 μm due to substitution of trace Fe²⁺ for Ca in a large, distorted site (Fig. 1). The strength of this feature varies regularly with FeO content [4-6]. The aim of this ongoing laboratory project is to use spectra of plagioclases with known compositions to calibrate remotely-acquired spectra and derive well-constrained plagioclase compositions for the lunar crust. Here we present initial results of experiments to synthesize a suite of plagioclase compositions examining the effect of FeO content on absorption band depth.

Experimental Approach: Powdered synthetic anorthite and albite glasses were combined to create a glass composition of ~An₈₅. The mixture was homogenized by melting at 1550° C in a Pt capsule, and quenching in air after 2 h. One wt% ⁵⁷Fe-enriched Fe₂O₃ was added to half of the sample, which was homogenized again by the same procedure. Electron microprobe analyses indicate that, after glassing, both samples were ~An₉₁, suggesting some amount of Na loss. The Fe-bearing glass was mixed with the Fe-free (<0.1 wt% FeO) glass in controlled proportions, pro-

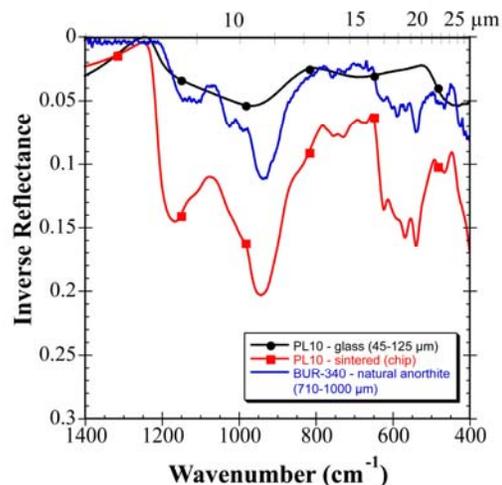


Fig. 2. MIR spectra of sample PL10 (~0.3% FeO) before (black, circles) and after (red, squares) sintering, compared to a spectrum of a natural anorthite (blue, no symbols), from the ASU spectral library. All samples are >An₈₅.

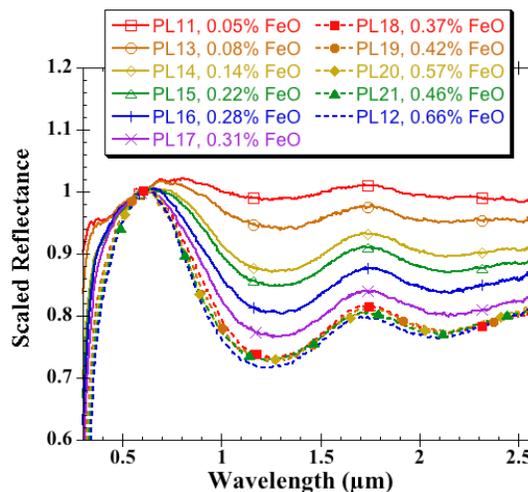


Fig. 3. NIR spectra of all samples (45-125 μm grain size), scaled at 600 nm for comparison.

ducing a series of 11 compositions ranging from 0-1 wt% FeO, in 0.1 wt% increments. Glasses were sintered in a gas-mixing furnace at pO₂ ~2⁻¹⁰ atm for 64 h. The target temperature was 1400° C, but the actual temperature may have ranged up to several tens of degrees hotter than anticipated. The presence of diagnostic plagioclase Reststrahlen bands in mid-IR (MIR) spectra of a sample that has undergone the sintering process (Fig. 2) indicates that the starting glasses were successfully transformed into the plagioclase structure.

Results: Electron microprobe analyses (10 μm spot

size, 15kV) show that, with the exception of the varied FeO content (described below), all 11 samples are texturally and compositionally similar. Plagioclase grains (5-15 μm) are stoichiometric, and all samples are between An_{85} to An_{87} . FeO content for the entire suite ranges from 0.05 to 0.66 wt% (2σ s.d. on standard was 0.06 wt%). Microprobe analyses using a 2 μm spot size show that individual plagioclase grains lack strong compositional zoning. In particular, for samples with <0.4 wt% FeO, within-grain FeO variation in was <0.05 wt% (2σ s.d. on standard was 0.04 wt%).

In general, microprobe data show that the plagioclase did not incorporate all of the FeO from the starting glasses (the highest-Fe glass contained 1% FeO). This is likely due to the presence of a melt phase, which comprises ~20% of each sample. Melt is easily distinguished from plagioclase by major element chemistry, and is likely due to the temperature control issues mentioned above. No other contaminating phases with NIR absorption bands, such as pyroxenes or spinels, were identified.

Reflectance spectra of the powdered samples are shown in Fig. 3. An increase in strength of the ~1.25 μm absorption is well-resolved, particularly for low-Fe samples. For samples containing >0.4 wt% FeO, absorption band depth is approximately constant, despite further increases in FeO content (Fig. 4). Also apparent in Fig. 3 is a second, broad, absorption band, centered near 2.1 μm . Although not typically noted in NIR reflectance data of plagioclase, this band has been reported in transmission spectra [7], and is consistent with Fe^{2+} in multiple coordination environments [8-

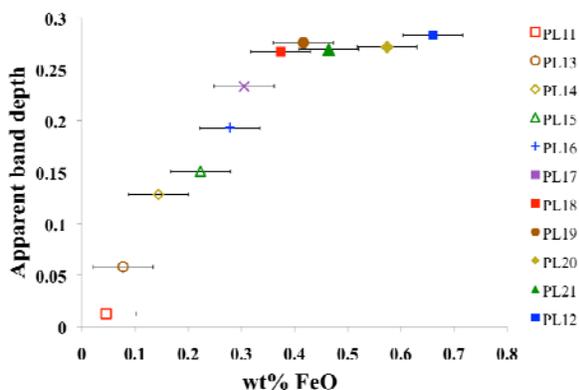


Fig. 4. Band depth vs. FeO. Depths calculated relative to a horizontal continuum at 600 nm (1-R1250/R600). Error bars correspond to 2σ s.d. on the standard.

10].

Mössbauer spectra of samples show three broad distributions, each corresponding to Fe^{2+} cations in the Ca site, at 295K (Fig. 5). Varying locations of the Fe^{2+} cation within the highly-distorted polyhedron apparently results in these multiple local environments.

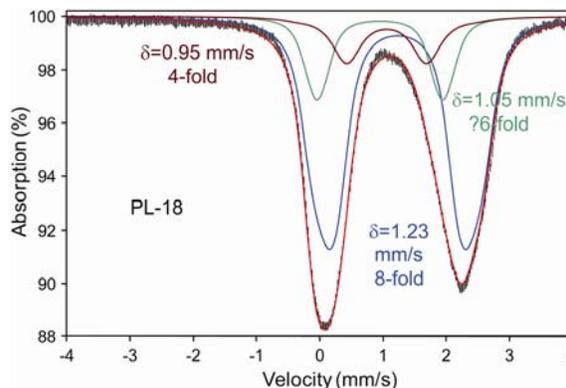


Fig. 5. 295K Mössbauer spectra of sample PL-18, showing three distributions of Fe^{2+} in sites corresponding to coordination numbers ranging from 4-8. These likely correspond to local site differences within the Ca site polyhedron.

Conclusions: These preliminary experiments indicate that the anorthite and albite starting glasses can be combined with sufficient accuracy to generate well-controlled, homogeneous plagioclase compositions. The correlation of band depth to FeO content is well-resolved in the An_{87} series, indicating that, even at low FeO contents, differences plagioclase compositions can be identified using reflectance spectroscopy. Additionally, a second, long-wavelength plagioclase absorption is observed in all samples, which should be considered in interpretations of new remote spectroscopic measurements of the lunar highlands.

Future Work: To constrain the effect of associated mafic minerals on plagioclase absorption strengths, laboratory mixtures will be created using these synthetic samples. Preliminary non-linear mixing analyses suggest that the ~1.25 μm plagioclase absorption is detectable in binary mixtures containing at least 5% pyroxene. Additional work with the pure An_{87} sample suite will include accurately determining absorption centers and depths using MGM [11]. Future experiments will be run at lower temperatures to avoid creation of melt, and will include a series of higher-An plagioclases, as well as a suite with variable An# at a constant FeO.

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References: [1] McGee J. J. (1993) *JGR*, 98, 9089-9105. [2] Ohtake M., et al. (2009) *Nature*, 461, 236-240. [3] Pieters C. M., et al. (2009) *LPS XL*, Abstract #2052. [4] Adams J. B. and McCord T. B. (1971) *PLPSC*, 2, 2183-2195. [5] Bell P. M. and Mao H. K. (1973) *GCA*, 37, 755-759. [6] Adams J. B. and Goullaud L. H. (1978), *PLPSC*, 3, 2901-2909. [7] Hofmeister, A. M. and Rossman G. R. (1984) *Phys. Chem. Minerals*, 11, 213-224. [8] Appleman, D. E. et al. (1971) *PLPSC*, 2, 117-133. [9] Hafner S. S., et al. (1971) *EPSL*, 12, 159-166. [10] Dyar, M. D. et al. (2002) *LPS XXXIII*, Abstract #1725. [11] Sunshine, J. M. et al. (1990) *JGR*, 95, 6955-6966.