

## ANORTHITE SYNTHESIS EXPERIMENTS WITH APPLICATIONS TO LUNAR SPECTROSCOPY.

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**Introduction:** The lunar crust is believed to be composed primarily of anorthosite, a rock consisting of > 90% plagioclase feldspar. Despite its abundance on the surface of the Moon, the controls on the spectral characteristics of plagioclase in the near-infrared remain incompletely understood. Iron-bearing crystalline plagioclase exhibits a diagnostic absorption band at  $\sim 1.3 \mu\text{m}$  due to electronic transitions of  $\text{Fe}^{2+}$  substituting for Ca in a poorly characterized site (Fig.1). Laboratory studies of this feature [1-3] have suggested that its characteristics may be composition-dependent, with band depth varying regularly according to Fe content.

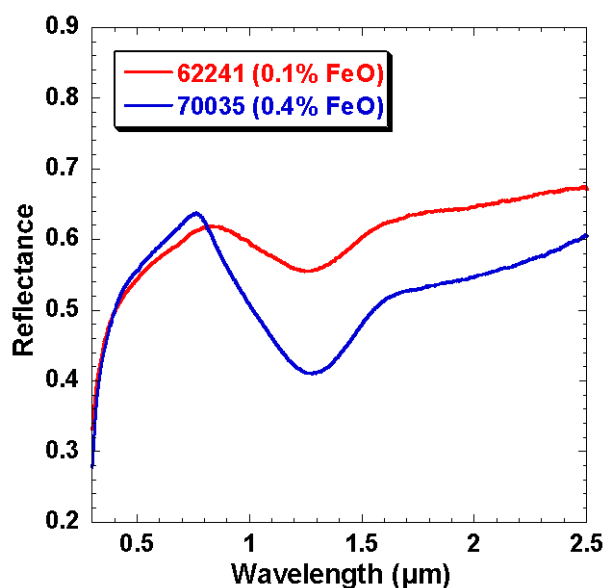


Fig. 1. Laboratory reflectance spectra of plagioclase mineral separates from a lunar basalt (70035) and a lunar soil (62241). Both have the diagnostic plagioclase absorption at  $\sim 1.3 \mu\text{m}$ , but the sample with more FeO has a deeper band. Particle size  $< 125 \mu\text{m}$ .

Historically, regions of pure plagioclase on the Moon have only been identified indirectly using the near-IR, based on spectra that lack a  $1 \mu\text{m}$   $\text{Fe}^{2+}$  band and have a high albedo, not by detection of the diagnostic  $1.3 \mu\text{m}$  feature [4,5]. Remote identification of plagioclase has proven challenging for a number of reasons: 1) the diagnostic  $1.3 \mu\text{m}$  plagioclase absorption feature is only present if trace amounts of  $\text{Fe}^{2+}$  has been incorporated into the mineral structure, 2) this feature disappears if plagioclase has been shocked above  $\sim 25$ - $30 \text{ GPa}$  [6, 7], and 3) olivine and pyroxene have strong

absorption bands near  $1 \mu\text{m}$  that dominate the near-infrared spectra.

Recently, however, the newest near-infrared orbiting spectrometers have unequivocally identified plagioclase on the lunar surface. The Spectral Profiler of the Japanese SELENE mission detected anorthosite in the central peak of Jackson crater and others on the farside [8], and Pieters et al. [9] have identified crystalline plagioclase in the Inner Rook mountains of the Orientale Basin with the Moon Mineralogy Mapper ( $\text{M}^3$ ) on Chandrayaan-1. Given these new datasets with the ability to identify the plagioclase absorption, a thorough characterization of the compositional controls on these spectra is essential to inform interpretations of remote measurements of the lunar crust.

**Approach:** We have begun experiments to synthesize plagioclase in order to produce a well-constrained sample suite for near-IR reflectance studies. Synthesizing plagioclase in the laboratory will allow us to vary iron content while controlling the An number and limiting the amount of contamination by other phases that complicate interpretation of spectral features [10]. Further, since the  $1.3 \mu\text{m}$  absorption is due solely to  $\text{Fe}^{2+}$ , the ability to control oxygen fugacity in a laboratory setting is crucial for modeling the relationship between iron content and band depth.

**Methods:** For the initial experiments presented here, we have mixed a powdered synthetic anorthite glass (An100) with controlled amounts of  $\text{Fe}_2\text{O}_3$ . Samples were sintered at  $1400^\circ\text{C}$  for 24 hours and analyzed by electron microprobe and powder X-ray diffraction at Brown University to verify composition and structure. Spectra were acquired as diffuse reflectance in the near-infrared ( $0.3$ - $2.6 \mu\text{m}$ ) and mid-infrared ( $5$ - $25 \mu\text{m}$ ) in the RELAB.

**Preliminary Results:** Microprobe analyses (Fig 2) indicate that samples LC006 and LC007 consist of homogenous anorthite grains approximately  $5$ - $10 \mu\text{m}$  in size, with minor excess  $\text{Al}_2\text{O}_3$ . Both appear to have incorporated FeO. X-ray diffraction (Fig. 3) and Mid-IR reflectance (Fig. 4) confirm an anorthite crystal structure.

The near-IR reflectance spectra (Fig. 5) of both samples have very weak, broad absorptions between  $1$  and  $1.5 \mu\text{m}$  rather than distinct, strong bands at  $\sim 1.3 \mu\text{m}$  as observed natural samples. Interestingly, there is also a weak absorption at longer wavelengths, between  $\sim 2$  and  $2.5 \mu\text{m}$ . Both absorptions may be composite features.

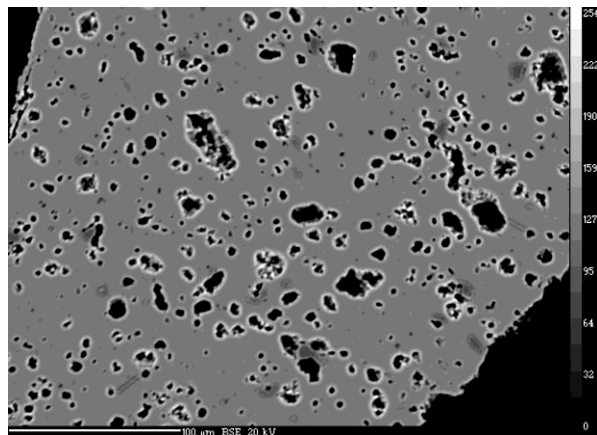


Fig. 2. Electron microprobe BSE image of anorthite LC007 (0.4 wt% FeO). Black spots are pore spaces in the sample and are artifacts of the sintering process. The dark grey phases are excess  $\text{Al}_2\text{O}_3$ .

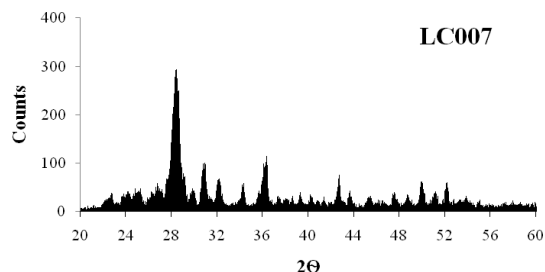


Fig. 3. Power x-ray diffraction analysis of LC007 (0.4 wt% FeO). The anorthite peak near  $2\theta=27$  is apparent.

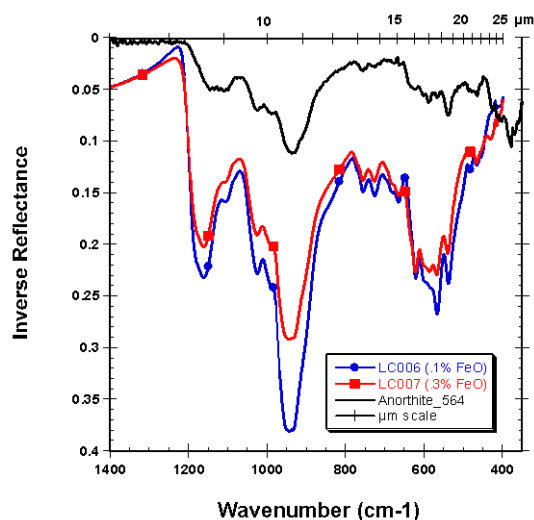


Fig. 4. Mid-IR spectra of LC006 and LC007 (0.1 and 0.4 wt% FeO, respectively). Anorthite sample 564 from the ASU emissivity database is shown for comparison.

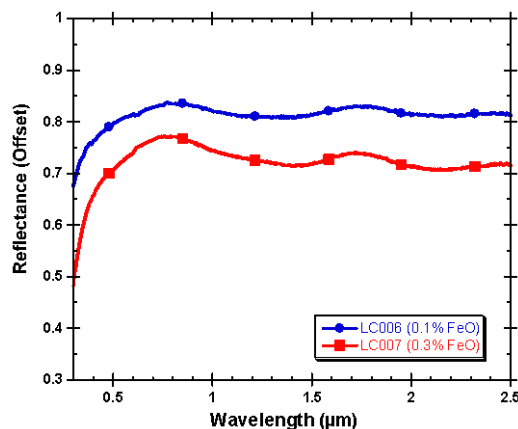


Fig. 5. Near-IR spectra of LC006 and LC007 (0.1 and 0.4 wt% FeO, respectively).

**Discussion:** There are a number of possible hypotheses for the observed shape of the 1-1.5  $\mu\text{m}$  absorption and the presence of a 2-2.5  $\mu\text{m}$  feature that is not typically noted in plagioclase. First, some Na may be required in the crystal structure to facilitate the substitution of Fe into the larger cation sites. The broad shape of the shorter-wavelength band observed here could be attributed to the lack of Na causing a distortion in the lattice. Second, a broad composite absorption near 2  $\mu\text{m}$  has been reported previously in transmission spectra of terrestrial plagioclase [11], so we must consider that the long-wavelength feature in the samples presented here may be due to absorptions occurring in the plagioclase itself. Third, although no other contaminating phases were observed that would preferentially incorporate  $\text{Fe}^{2+}$ , it is possible that sub-micron spinel may have formed finely dispersed throughout the sample causing a broad absorption around 2  $\mu\text{m}$ . Additionally, any unreacted glass remaining in the sintered sample could contribute to the observed long-wavelength absorption.

**Future work:** Additional analyses of these samples, including transmission spectroscopy and SEM, should clarify interpretations of both absorptions. In future experiments we will add controlled amounts of Na in addition to Fe in order to more accurately represent the compositions of most lunar samples.

**References:** [1] Adams J.B. and McCord T.B. (1971) *PLPSC* 3, 2183-2195. [2] Bell P.M. and H.K. Mao (1973) *GCA* 37, 755-759. [3] Adams J.B. and Goulland L.H. (1978) *PLPSC* 9, 2901-2909. [4] Pieters C.M. (1986) *Rev. Geophys.* 24, 557-578. [5] Hawke, B.R. et al. (2003) *JGR* 108, 5050. [6] Adams J.B. et al. (1979) *LPSC* X, 1-3. [7] Johnson J.R. and Hörz F. (2003) *JGR* 108, 5120. [8] Matsunaga et al. (2008) *GRL* 35, 23201. [9] Pieters C.M. et al. (2009) *LPSC* XL 2052. [10] Cheek L.C. et al. (2009), *LPSC* XL 1928. [11] Hofmeister and Rossman (1984) *Phy. Chem. Min.* 11, 213-224.

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