DETECTING OLIVINE COMPOSITION IN TROCTOLITIC MIXTURES IN THE “CROSS-OVER” INFRARED RANGE (4-8 µm).

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Introduction: Recent work has demonstrated that infrared spectra measured in the 4-8 µm “cross-over” range are a useful tool for determining the Mg# of olivine [1]. Olivine has two strong, distinct bands at 5.6 and 6.0 µm (Fig. 1) that shift systematically to longer wavelengths with increasing Fe content, allowing Mg# to be determined for reflectance spectra of pure olivine samples in a laboratory setting within +/-10 mol% [1]. Although Mg# trends have been studied in pure olivine in the “cross-over” region, it remains unknown how the presence of other minerals affects these spectral bands and their use as a diagnostic tool for Mg#. Investigating “cross-over” spectra of olivine-bearing particulate mixtures is therefore essential for constraining the opportunities and limitations of this technique in the lunar context as detectors become available for lunar missions.

We are preparing a suite of particulate mixtures of forsterite and anorthite with particle size distributions approximating those of the lunar regolith, which we will measure in reflectance and in emissivity in a simulated lunar environment. Measurements of these samples will provide a strong foundation for interpretation of spectra measured from future spacecraft instruments. As a proof of concept for this study, we also examine emissivity measurements of a similar suite of fine-particulate (<32 µm) anorthite-forsterite mixtures.

Background: The “cross-over” region is the wavelength range of the infrared where the volume scattering of photons in the visible-near infrared (VNIR 0.5-3 µm) transitions to the surface scattering of photons in the mid-infrared (MIR 8-15 µm). In the inner Solar System, the “cross-over” region for silicate minerals also generally coincides with the transition between the dominance of reflected solar photons in VNIR and thermally emitted photons in the MIR. The “cross-over” signatures of silicate minerals are hypothesized to arise as overtone-combination bands of fundamental vibrations at longer wavelengths [2].

Since both reflection and emission are expected to contribute to the radiance measured on the Moon in the 4-8 µm range [3], it is necessary to examine both reflectance and emissivity spectra when assessing the “cross-over” character of mineral samples. It has been demonstrated that features seen in emissivity and reflectance spectra of identical samples in the “cross-over” region can be related to each other through Kirchhof’s law (E=1–R, where E is emissivity and R is reflectance), meaning that reflectance and emissivity spectra may be directly compared with each other [1].

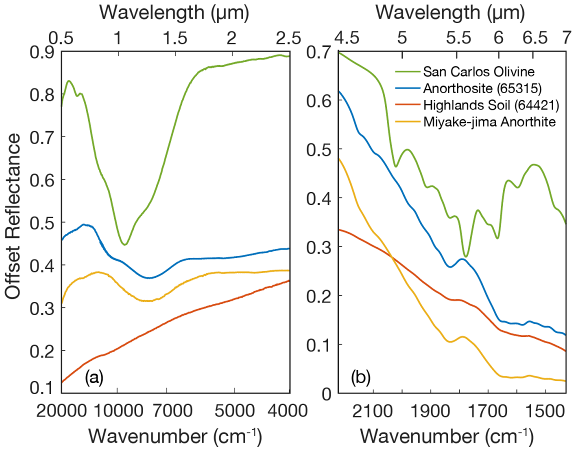

Figure 1. *(a) VNIR and (b) “cross-over” reflectance spectra of San Carlos forsterite, Miyake-jima anorthite, a lunar anorthosite, and a highlands soil. Spectra are offset for clarity.*

In the lunar context, olivine is likely to be found in rocks containing anorthite, such as troctolite, troctolitic anorthosite, or basalt [e.g., 4]. Studies of plagioclase-bearing mixtures in the VNIR and MIR have demonstrated that plagioclase can influence the spectral character of mineral mixtures [e.g., 5]. However, the effect of plagioclase on spectra of mineral mixture remains unknown in the “cross-over” range. Although previous laboratory studies have generally used bytownite or labradorite in artificial mixtures [e.g., 5], our study uses Miyake-jima anorthite (~An_{95}), which is similar in Ca content to plagioclase on the Moon [6]. In the “cross-over” spectral region, lunar and Miyake-jima anorthite is generally characterized by a broad spectral slope, similar to bytownite and labradorite, and also exhibits two weak spectral bands at ~5.3 and ~6.2 µm (Fig. 1), which appear more subdued than the “cross-over” bands in olivine. The spectral character of Miyake-jima anorthite is generally similar to lunar anorthite separates and highlands soils in the “cross-over” range (Fig. 1).

Samples and Measurements: We are preparing two suites of particulate mixtures consisting of San Carlos olivine (Fo_{90}) and Miyake-jima anorthite (Table

1). The two suites will have particle size distributions representative of immature and mature lunar regolith, respectively [7,8]. We use 5 sieve sizes ranging from 20 to 250 µm (Table 2). Each suite ranges from 100 wt% olivine (0 wt% anorthite) to 50 wt% olivine (50 wt% anorthite), with abundance increments of 10 wt% between samples.

Table 1. Mixtures of forsterite and anorthite

Sample Suite	Sieve Sizes (µm)	Olivine Wt% Abundances
Uniform Fine-Grained	32	100, 97, 88, 75, 50, 25, 12, 6, 0
Mature Distribution	20, 45, 75, 150, 250	0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100
Immature Distribution	20, 45, 75, 150, 250	0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100

Table 2. Sieve Sizes for Particle Size Distributions

Sieve Sizes (µm)	250	150	75	45	20	<20	Total
Mature (wt%)	8	9	13	15	24	31	100
Immature (wt%)	12	11	14	14	20	29	100

We are also investigating a suite of forsterite-anorthite mixtures (Table 1) from which emissivity spectra have already been measured [9]. These mixtures have a uniform particle size of <32 µm and range from 100 wt% to 50 wt% forsterite by varying increments. The particle size of this suite roughly approximates the average particle size of mature lunar regolith [7,8] and therefore offers preliminary insight into the spectral character of olivine-bearing regolith.

Emissivity spectra of the uniform, fine-particulate suite of mixtures were measured at the Johns Hopkins University Applied Physics Laboratory, in both ambient and simulated lunar environment (SLE) conditions (Fig. 2). SLE spectra were measured in the Simulated Airless Body Emission Laboratory (SABEL). Reflectance spectra of the uniform, fine-grained suites, as well as two sample suites with particle size distributions, will be collected in the NASA Reflectance Experiment Laboratory (RELAB) at Brown University [10]. A subset of the suites with particle size distributions will be measured in SABEL.

Preliminary Results: Strong, distinctive olivine bands appear in SLE spectra of uniform, fine-particulate samples with up to 50 wt% anorthite, decreasing in optical contrast with increasing anorthite content. The olivine band minima do not appear to shift position, and the bands do not change significantly in shape with increasing anorthite content.

Conclusion: Our results suggest that olivine should be detectable in anorthite-forsterite mixtures containing 50 wt% anorthite (and possibly more). The consistency in position of the olivine band centers in the spectra indicate that the spectral signatures of anorthite do not interfere with the interpretation of Mg# of olivine. Together, these results suggest it should be possible both to detect olivine and determine its Mg# in regolith derived from troctolite. Ongoing work on anorthite-olivine mixtures with lunar-like particle size distributions will allow us to more definitively determine the detectability limits of olivine in mixtures with anorthite.

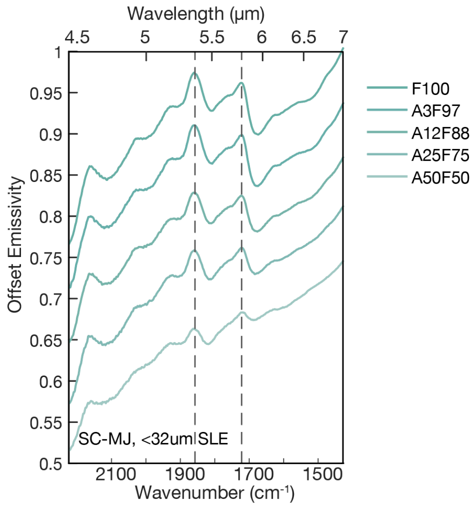

Figure 2. *Emissivity spectra of mixtures of San Carlos forsterite and Miyake-jima anorthite collected in a simulated lunar environment. Dashed lines indicate the positions of the 5.6 and 6.0 µm compositionally diagnostic bands of olivine [1]. Spectra offset for clarity. Proportions of anorthite and olivine in mixtures indicated in the legend.*

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