CHARACTERIZATION OF LUNAR SOILS USING A THERMAL INFRARED MICROSCOPIC SPECTRAL IMAGING SYSTEM.

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Introduction: Lunar Reconnaisance Orbiter's Diviner radiometer has provided the planetary science community with a large amount of thermal infrared spectral data. This data set offers rich opportunities for lunar science, but interpretation of the data is complicated by the limited data on thermal infrared spectral properties of lunar materials. Lunar minerals and glasses have been affected by space weathering processes that may alter their spectral properties in important ways. For example, mineral grains acquire vapor deposited coatings, and soils contain large amounts of agglutinate glass that contains abundant nanophase iron as a result of exposure to the space environment. In both of these cases the thermal IR spectral effects are unknown.

This work is to characterize the thermal infrared spectral properties of individual grains in lunar soils, enabling a wide range of spectral behaviors of componenets to be measured rapidly. Pieters and Klima [1] showed the value of infrared microscopy for characterizing spectral properties of materials; following that lead, we have altered an infrared hyperspectral imaging system developed for remote sensing under funding from the Planetary Instrument Definition and Development Program to enable resolved microscopic spectral imaging at thermal wavelengths.

Instrument and methods: The microscopic imager is based on a Sagnac interfometer equipped with a 320x256 element microbolometer array detector and is sensitive from 8 to 15 microns at 40 wavenumber resolution. It images a field of view of 8 millimeters at 30 micron spatial resolution and scans at a rate of about 1mm/second enabling relatively large areas to be scanned rapidly. The samples are arrayed on a heated substrate in a single layer to prevent spectral interactions between grains. We limit individual grain sizes to a range between 30 and 200 microns for best compatibility with our spatial resolution and depth of field.

To date we have scanned four individual soils prepared at different grain sizes and either unprepared, or washed to removed small grains (Table 1) with final data sizes of 256 x1000 pixels (8 by 40 mm).

Detection of specific minerals is based upon the correlation described in [3], which is a part of the Tetracorder algorithm. The algorithm provides a measure of relative intensity of the test spectrum to members of a reference library as well as the correlation between the spectra.

The reference library includes samples measured by us (pure mineral separates, wet-sieved to a 90-150 μm size fraction) as well as spectra from the Arizona State University spectral library [2] to build a reference set of relevant lunar minerals. We also used these data to confirm that the emission spectra of individual mineral grains of a wide range of silicates are very similar to spectra of coarse grained powders. Effects of grain orientation on spectra of individual grains were mitigated before insertion into the spectra library by averaging the spectra of all pure mineral grains in a reference scan.

TABLE 1. Lunar soil samples scanned

Soil	Size fraction	
10084,97	>75	Washed
12001,893	>75	Washed
14163,882	75-150	Washed
14163,882	75-150	Unwashed
14163,882	75-125	Unwashed
14163,882	45-75	Washed
14163,882	45-75	Unwashed
61221,175	75-150	Unwashed
61221,175	75-150	Washed

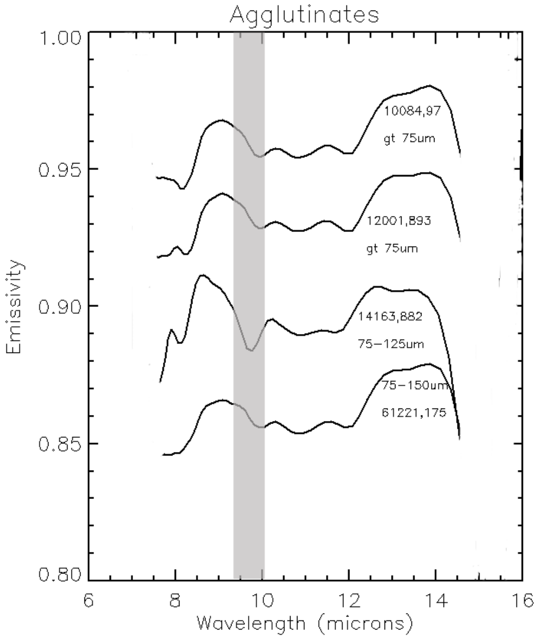
Preliminary Results:

Mineral detections. We identified minerals expected to be present in lunar soils, and using the thermal images created by the spectrometer , built spatial maps of the minerals in the soil (Figure 1). Grains of olivine, pyroxene, and feldspar were detected in all soils. Quartz was detected in small quantities in soils from Apollo 12 and Apollo 14, and apatite was detected in an Apollo 14 soil. The identification of minerals thought to be present in very small quantities demonstrates the potential of a grain-by-grain survey of lunar soils to locate and analyze rare components of the soils including rare minerals, meteoritic material, and material from areas of the moon not directly sampled by Apollo and Luna missions.

FIGURE 1. Thermal image of soil 61221,175 with mineral detection inset. Blue: feldspar; cyan: pyroxene; yellow: glass

Space weathering. Agglutinate particles are a space weathering product that compose up to 60% of lunar soils [4], but the thermal infrared spectra of these particles have not been well characterized. To characterize the spectra of agglutinate particles, we excluded all grains identified as minerals and extracted an average spectrum for the remaining grains in each soil measured. These spectra are shown in Figure 2. They show a distinctive shape, with about 2% spectral contrast. Each spectrum has an emission peak near 9 µm, which may be the Christiansen Frequency. The absorption feature just below 10 µm (highlighted in grey) is an artifact introduced by the sample cup that is being altered for future measurements. We predicted that differing sample site compositions would lead to differing spectra of agglutinates formed from the minerals at each site. On a gross scale, they appear to behave spectrally as mixtures of minerals and glasses; however, there is a surprising and unexplained similarity between sample sites.

FIGURE 2. Spectra of isolated agglutinate glasses in lunar soils



Another expected effect of space weathering is a loss of spectral contrast due to vapor coatings. We have performed preliminary comparisons between the absorption feature strengths of identified lunar minerals and those of reference mineral separates which have demonstrated that the spectral features of the lunar soils are distinctively weaker; however, our reference mineral sets are not sieved to the exact same size range of the lunar soils, so grain size effects may be contributing. We are currently scanning mineral separates in the same size ranges as our lunar soil samples in order to fully characterize the effects of space weathering on spectral contrast.

Conclusions: We have used a thermal infrared spectral microscope to successfully isolate minerals and agglutinates in lunar soil samples. The ability of our methods to detect rare mineral components of lunar soils demonstrates its value as a method for characterizing soil compositions at a single grain level, and possibly isolating meteoritic or other exotic material in samples. Improvement of the system's spectral resolution will enhance our ability to confidently identify ambiguous minerals found in the soils, and allow us to do quantitative abundance measurements of the soils' mineral components. Future work includes improving our analysis of space weathering by creating a reference set of pure mineral spectra of the same size fractions as the lunar soils scanned, implementation of linear unmixing in our analyses, and expansion and corroboration of the setup using other mineral detection methods including Raman spectroscopy.

References:

[1] Klima R.L. and Carle M. Pieters (2006), Near- and mid-infrared microspectroscopy of the Ronda peridotite, *JGR, 111,* E01005. [2] Spectral Library. V1.0. Arizona State Library, (Mars Space Flight Facility). Web. 31 Aug. 2010. [3] Clark, R.N., et al. (2006), Imaging spectroscopy: Earth and planetary remote sensing with the USGS Tetracorder and expert systems, *JGR, 108(E12),* 5-1 to 5-44. [4] Taylor, L.A. et al., (2003) *LPS XXXIV*, Abstract #1774.