CHARACTERIZATION OF LUNAR SOILS USING INFRARED MICROSCOPIC HYPERSPECTRAL IMAGING.

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Introduction: Our understanding of the geology of the Apollo landing sites can be enhanced by a comprehensive characterization of the mineralogy of a wide range of lunar soil samples. Microscopic analysis of lunar soils using hyperspectral imaging is one way to perform this study, and allows direct characterization of the mineralogy of each individual grain in a sample.

This work is to characterize the 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 infrared hyperspectral imaging systems developed for remote sensing under funding from the Planetary Instrument Definition and Development and Mars Instrument Development Program to enable resolved microscopic spectral imaging at thermal and near infrared wavelengths.

Instruments and methods: We have implemented thermal emission spectroscopy using a microscopic imager based on a Sagnac interfometer equipped with a 320x256 element microbolometer array detector 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. For emission spectroscopy, the samples are arrayed on a heated substrate in a single layer to prevent spectral interactions between grains. We have now added a reflectance attachment that improves our sensitivity at the shortest wavelengths (Figure 1) and allows for use on more temperature sensitive (non-lunar) samples. An advantage of the reflectance attachment is that it allows better differentiation of spectrally neutral grains from the background.

To date we have scanned with this system four individual soils (10084,97 12001,893, 14163,882, and 61221,175) prepared at different grain sizes (45-75 microns, 75-150 microns, 75-125 microns, and >75 mcrons) and either unwashed or washed to removed small grains 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 measures the correlation between the test spectrum and library spectra, as well as a measure of the relative intensity of the test spectrum and library 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.

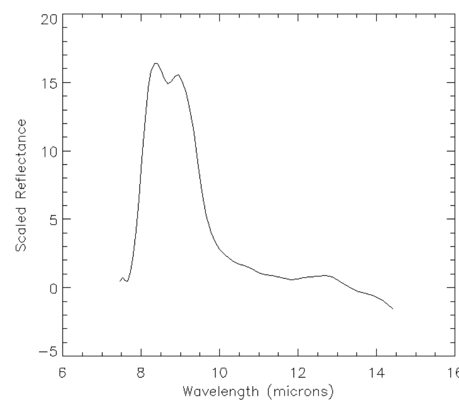

FIGURE 1: Quartz reflectance spectrum in the thermal wavelengths obtained using the new reflectance attachment.

We have also added 0.9-2.5 micron capability using a microscopic imager based on an Offner spectrograph equipped with a cooled 320x256 HgCdTe array. Similar to the thermal infrared microscope, it images a field of view approximately 10 millimeters wide at 30 micron spatial resolution and a scan rate of about 1mm/second. Taking the cautions of [1] regarding near-IR spectroscopy, the samples are arrayed on a glass slide above a first surface mirror to allow dark field measurements that limit the signal to transmitted light. We have taken data on wet-seived samples of 12001,893, 14163,882, and 61221,175 in size fractions <25 microns, 25-45 microns, 45-90 microns, 90-150 microns, and >150 microns. Figure 2 shows an example dark field image of the >150 micron size fraction of soil 14163,882. The infrared illuminators currently being used for reflectance provide little flux near 1 microns, so we are adding halogen lights to our ring illuminator that will enhance the quality of data collected in this wavelength range.

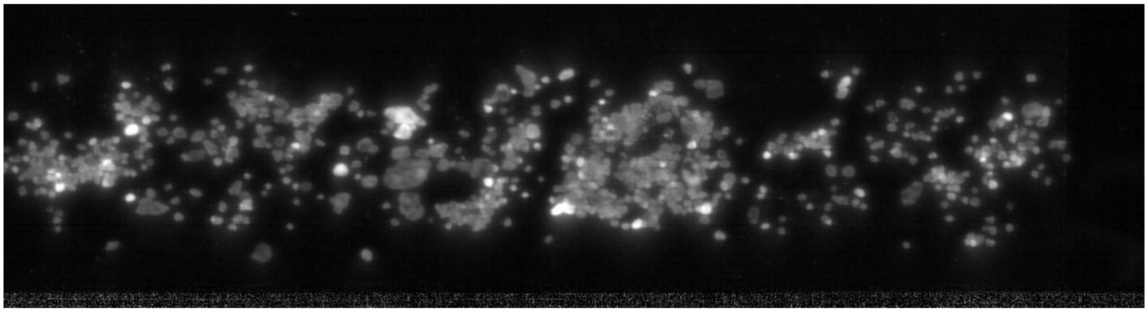

FIGURE 2. Near infrared dark field image of soil 14163,882 wet sieved to >150 microns.

Preliminary Results:

Mineral Detections. Using the thermal emission microscope, 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. Grains of olivine, pyroxene, and feldspar were detected in all soils studied. Quartz was detected in small quantities in soils from Apollo 12 and Apollo 14, and apatite was detected in Apollo 14 soil. Figure 3 shows spectra of minerals detected in lunar soils compared with library spectra. 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 visited by Apollo and Luna missions.

Conclusions: We have used a thermal infrared spectral microscope to successfully isolate minerals and agglutinates in lunar soil samples using emission, and have added a reflectance attachment that improves sensitivity at the shortest wavelengths. The characterization of lunar soil mineralogy at the individual grain level will help provide insight into the geology of the landing sites. The ability of our methods to detect rare mineral components of lunar soils also demonstrates its value as a method for possibly isolating meteoritic or other exotic material in samples. We have also added 0.9-2.5 micron capability in dark field for improved cross-calibration with the landing sites. Future work includes adding 0.5-1 micron capability, as well as expansion and corroboration of the setup using a point Raman spectrometer. The ultimate goal is to do a comprehensive study of soils from each landing site without disturbing the samples, allowing selection and removal of grains of interest for further study.

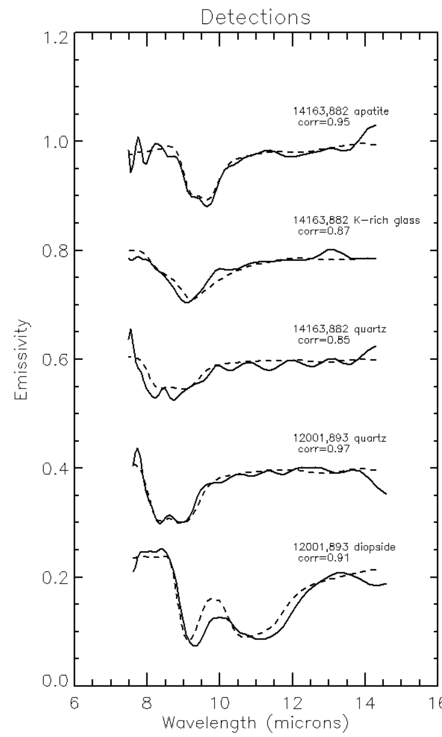

FIGURE 3: Spectra of selected minerals identified using thermal emission. *Corr* is a parameter describing the strength of the correlation with a reference spectrum.

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.