

**MODAL ANALYSES OF APOLLO SOILS BY X-RAY DIFFRACTION AND MICROSCOPIC SPECTRAL IMAGING.** Sarah Crites<sup>1</sup>, G. Jeffrey Taylor<sup>1</sup>, Linda M.V. Martel<sup>1</sup>, Paul G. Lucey<sup>1</sup>, and D.F. Blake<sup>2,1</sup> Hawai'i Institute of Geophys. & Planetology, 1680 East-West Rd., Honolulu, HI 96822, gjtaylor@higp.hawaii.edu, <sup>2</sup>NASA Ames Research Center, Moffett Field, CA.

**Introduction:** We have launched a project to determine the modal mineralogy of over 100 soils from all Apollo sites using quantitative X-ray diffraction (XRD) and microscopic hyperspectral imaging at visible, near-IR and thermal IR wavelengths. The two methods are complementary: XRD is optimal for obtaining the major mineral modes because its measurement is not limited to the surfaces of grains, whereas the hyperspectral imaging spectroscopy method allows us to identify minerals present even down to a single grain, well below the quantitative detection limit of XRD. The goal is to use this quantitative mineralogy in comparison with reflectance and thermal emission spectra of the same soils and with remote sensing data of the sampling stations to improve our ability to extract quantitative mineralogy from remote sensing observations.

We report here our initial results from analysis of the <150 μm fraction of 30 Apollo 16 soils. We also analyzed 90–150, 45–90, 25–45, and <25 μm fractions from Apollos 12, 14, and 16 for comparison with previous data [1-3]. A bonus of analyzing numerous soils from one site is that it allows us to test ideas for the petrologic character of geologic terrains such as at the Apollo 16 site, specifically the Descartes Mountains and the Cayley Plains.

**Methods:** For XRD, samples were dry-sieved to obtain >150 and <150 μm fractions. Samples were analyzed in an InXitu Terra XRD instrument using sample masses of ~35 mg; we did replicate analyses of each sample and averaged them. We reduced the data using Reitveld refinement as implemented by the Jade program. Glass abundances were determined by fitting a broad Gaussian to the scattering hump above a linear background. We calibrated the instrument by using mineral mixtures and results from the Lunar Sample Characterization Consortium (LSCC [1–3]). A comparison of our data for three soil samples (25–45 μm fraction) and data from the LSCC are shown in Fig. 1. The dashed line is simply a 1:1 line; a line fitting to the

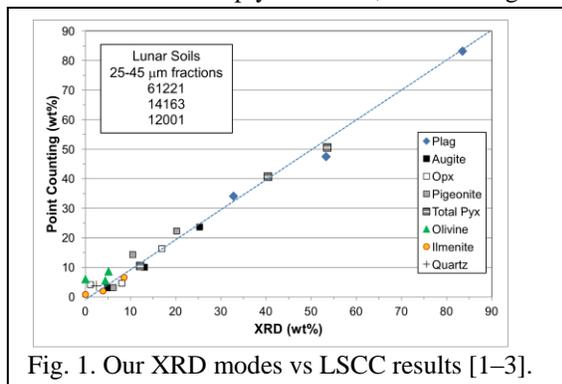


Fig. 1. Our XRD modes vs LSCC results [1–3].

data has a slope of 0.97. The standard deviation of the dataset is 2.8 wt%, which is acceptable for improving remote sensing data, and we expect it to decrease as we analyze more samples that were also studied by the LSCC.

For microscopic thermal imaging we measure wet-sieved soils at a variety of grain sizes as we develop our methodology, to date using 45-75 microns, 75-150 microns, 75-125 microns, and >75 microns. Spectral images at 30 micron resolution are measured over fields of 8x30 mm at both near and thermal IR wavelengths using spectrometers built by us. Near-IR data are collected at 10 nm resolution from 900–2500 nm, and thermal IR data at 20 wavenumber resolution from 8 to 14 microns.

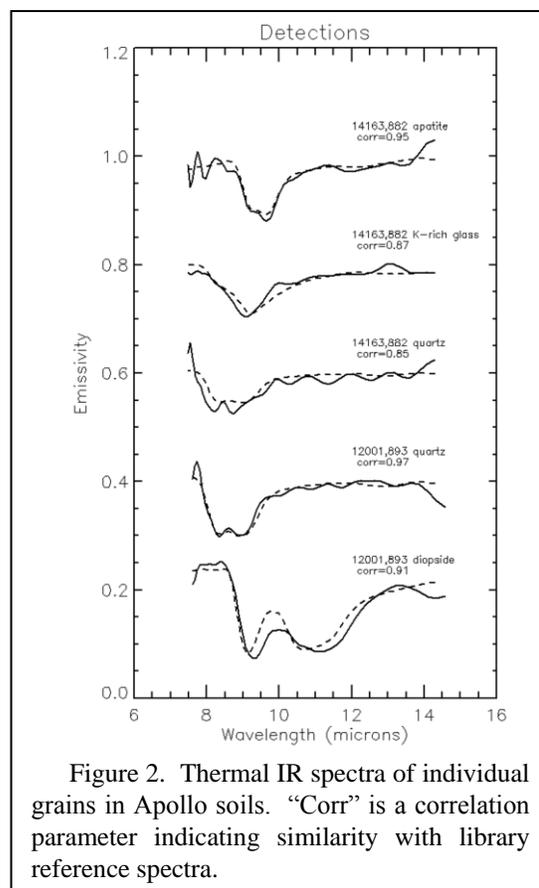


Figure 2. Thermal IR spectra of individual grains in Apollo soils. “Corr” is a correlation parameter indicating similarity with library reference spectra.

**Results:** XRD: On a glass-free basis, plagioclase ranges from 78 to 94 wt%, with the sites on the Descartes Mountains (Stations 4, 11, and 13) tending to contain more plagioclase (Fig. 3). This is consistent

with previous conclusions that the Descartes highlands are more feldspathic than the Cayley Plains [e.g., 5]. The relative abundance among pyroxenes and between pyroxene and olivine varies throughout the site, with little correlation with sampling location (Figs. 3–5).

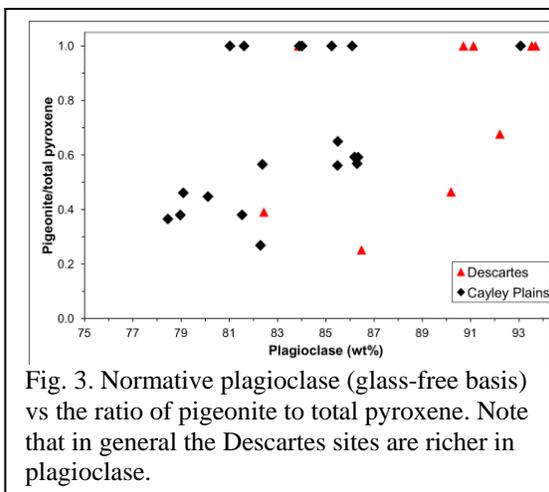


Fig. 3. Normative plagioclase (glass-free basis) vs the ratio of pigeonite to total pyroxene. Note that in general the Descartes sites are richer in plagioclase.

Modal plagioclase is systematically greater than normative plagioclase (Fig. 5). A difference between modes and norms is not unusual, but this substantial difference indicates that the glass in the Apollo 16 regolith is more mafic than the crystalline material. This is consistent with the average composition of impact glass in Apollo 16 samples compared to bulk soils [3]. For example, bulk regolith contains 26–30 wt%  $Al_2O_3$  [literature values], whereas impact glasses on average contain 23–27 wt% [3,6].

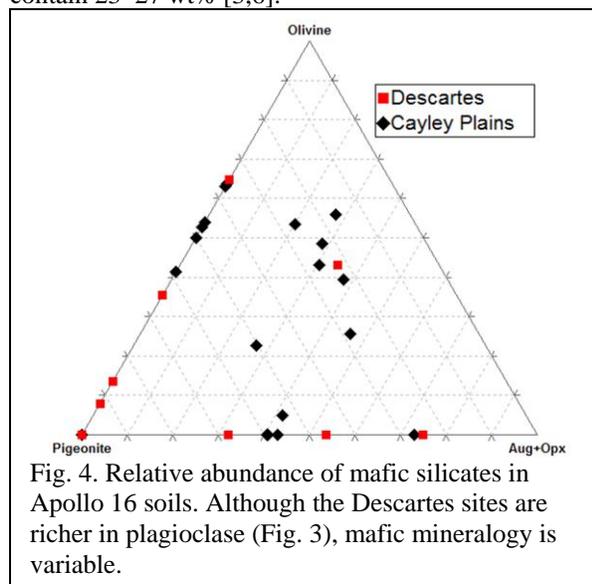


Fig. 4. Relative abundance of mafic silicates in Apollo 16 soils. Although the Descartes sites are richer in plagioclase (Fig. 3), mafic mineralogy is variable.

**Spectroscopy:** The high resolution imaging capability enables detection of relatively rare components in the soils. To date we have identified quartz, K-rich

glass and apatite in soils from various landing sites using thermal IR spectroscopy. Taking the cautions of [4] regarding near-IR microscopic spectral imaging, 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. High contrast near-IR spectra are obtained using this method.

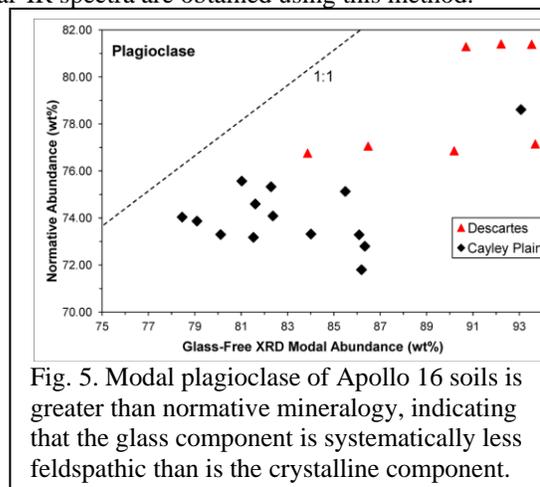


Fig. 5. Modal plagioclase of Apollo 16 soils is greater than normative mineralogy, indicating that the glass component is systematically less feldspathic than is the crystalline component.

**Discussion:** Our XRD results are consistent with previous studies that concluded that the Descartes highlands, as represented particularly by ejecta from North Ray Crater, are more feldspathic than the Cayley Plains [5–9]. The Cayley Plains are more mafic, probably because of addition from Imbrium [6,10] and other basin [11] ejecta. Additional mafic components may have been added to the site from mare sources [3].

This work re-emphasizes the difference in chemistry between the minerals and glass components of the soils recognized by [1-3]. This has important implications for using these data for calibration of remote sensing data. Methods must be developed to decide how ground truth measurements such as being developed here are to be applied to remote data.

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