INTEGRATED ANALYSES OF LUNAR METEORITES: EXPANDED DATA FOR LUNAR GROUND TRUTH. P. J. Isaacson[1], Y. Liu[2], A. Patchen[2], C. M. Pieters[1], and L. A. Taylor[2], [1]Dept. of Geological Sciences, Brown University, Providence, RI, 02912 [Peter_Isaacson@Brown.edu], [2]Planetary Geosciences Institute, Dept. of Earth & Planetary Sciences, University of Tennessee, Knoxville, TN, 37996.

Introduction: Analysis of the samples returned by the Apollo and Luna programs has revolutionized our understanding of lunar geology [1-3]. However, data collected after the return of these samples seem to suggest that they were collected from a geochemically anomalous region, and that they may thus present an incomplete picture of global lunar geology [4-6]. This region, known as the Procellarum KREEP Terrane (PKT), contains elevated abundances of Th and other incompatible elements [7-10]. The small collection of lunar meteorites [5, 11] should represent a more diverse sampling of the lunar crust, as the impact process is stochastic. While these samples can help provide a more complete understanding of lunar geologic evolution, their geologic context is unknown, which limits their value.

Several current and imminent international missions carry a range of sophisticated instruments that will map the Moon in unprecedented detail. The highest resolution compositional data will be provided by optical instruments sensitive to surface mineralogy. These instruments will rely in large part on ground truth measurements of lunar samples to perform their mapping [12, 13]. The lunar meteorite collection represents a valuable opportunity to expand our library of well-characterized lunar samples for use as ground truth for exploration [14]. While broadly similar to samples from the Apollo collection, lunar meteorites have distinct mineralogical and chemical differences from the Apollo samples, and these differences can be detected with remote sensing techniques. In addition to enabling the use of lunar meteorites as ground truth, laboratory analysis of these samples will provide the groundwork necessary for using remote data to evaluate the source regions of the meteorite samples and thus to constrain their geologic context. We have begun the steps to obtain these critical measurements by conducting paired mineralogy/petrology and initial reflectance spectroscopy measurements of a set of lunar meteorite samples. However, determining the geologic context of these samples will likely require the application of a number of diverse datasets, because while optical spectrometers are sensitive to mineralogy, an important distinguishing characteristic of the meteorites, they are not sensitive to elemental abundances, another critical property of the samples. [1, 2, 5, 13].

Lunar Samples: Six meteorite chip samples were provided by the NASA lunar meteorite working group.

The samples are as follows: two feldspathic breccias (ALHA81005, QUE93069), two unbrecciated basalts (LAP02205, MIL05035), and two basaltic breccias (EET87521, EET96008). The samples and their petrology have been analyzed by a number of previous studies on different parts of the stones [15-34]. We report data on the first four samples here.

Mineralogy/Petrography Analyses: As it is well known that mineralogy can vary greatly within a single stone, we conducted mineralogy/petrography analyses on our samples. Results obtained using an electron microprobe (EMP) at the University of Tennessee are consistent with previous studies [15-34]. As an example, mineral compositions for LAP02205 are illustrated in Fig. 1. Pyroxenes in LAP02205 are quite Fe-rich. Plagioclases are Ca-rich (~An_{88}-An_{90}), typical for mare basalts. Olivines are mainly fayalitic and volumetrically minor (<1.5 vol.%, [27-30]),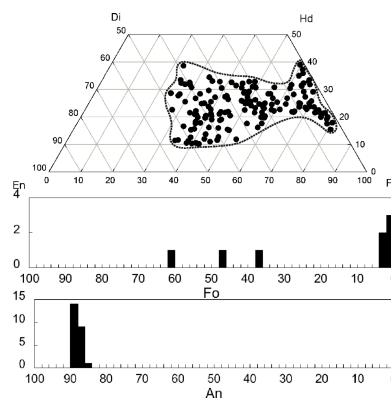 often associated with late-stage crystallization products. These minor occurrences are geochemically significant but not detectible by reflectance spectroscopy, which is an important consideration in interpreting remotely acquired reflectance spectra.

Fig. 1: Composition of pyroxene, olivine, and plagioclase in LAP02205.

Initial Reflectance Spectroscopy: The chip samples have been analyzed in bidirectional reflectance (BDR) from 280 – 2600 nm, and with biconical reflectance by FT-IR to 50 μm. Measurements were made in the RELAB at Brown University. BDR spectra for the two feldspathic breccias and the two mare basalts are presented in Fig. 2. Because the samples were measured as chips rather than particulates, the spectra have a distinct negative or "blue" continuum slope [35]. This is most apparent for the feldspathic breccias, which were measured as flat slabs, while the basalts were measured in a more favorable orientation. Despite the unusual continuum slopes, significant spectral diversity can be seen in the chip samples.

The basal samples have strong, long-wavelength 1 and 2 μm pyroxene absorption features indicative of abundant high-Ca pyroxene [36-38]. The ALHA81005 spectrum has short-wavelength, relatively weak 1 and 2 μm absorptions, indicating relatively low abundances of low-Ca pyroxene [36-38]. These observations are consistent with the petrography of the samples [15-23]. The LAP02205, MIL05035, and ALHA81005 spectra have a feature near 1.3 μm for which the interpretation is not directly obvious; both pyroxene and crystalline plagioclase could produce such a feature [39-42].

QUE93069 has a relatively featureless, blue-sloped spectrum. This sample is the most shocked and glass-rich of the four, so it is likely that light interacts with the sample to a lesser degree and that the reflected radiation is dominated by surface reflection compared to the other three samples. The combined effects of geometry and the matrix composition and abundance also lead to this spectrum having a proportionally higher level of noise. The spectrum has a hint of an absorption near 1.3 μm, possibly indicative of a broad glass/maskelynite band [43], though this interpretation must rely on quantitative assessments. Strong pyroxene absorptions are not observed for this spectrum.

Planned Analytical Tasks: Where possible and appropriate, these samples will be prepared in particulate form at a range of grain sizes. Additionally, they will be separated according to clast type where possible, and these separations will be prepared as particulate samples. Spectra of particulate samples will be acquired in a manner similar to that used for the chip samples. The acquired spectra will be deconvolved with the Modified Gaussian Model (MGM), which will enable quantification of the absorption features observed and thus of the spectral diversity of the samples [44]. This quantification is an essential step toward application of these spectra as ground truth and to constrain the geologic context of the samples; the quantitative properties of the absorption features must be compared between laboratory and remotely acquired spectra.

Summary/Significance: Coordinated analyses of the mineralogy/petrography and reflectance spectra of a suite of lunar meteorite samples are underway. These coordinated analyses significantly enhance the value of the acquired spectra as ground truth, and allow for more certain interpretation of the observed spectra. The meteorite samples will increase the diversity of the library of well-characterized lunar materials, which are essential for interpretation of remotely acquired data. The detailed characterizations being performed will lay the groundwork needed to place these valuable samples in their proper geologic context with remote datasets.
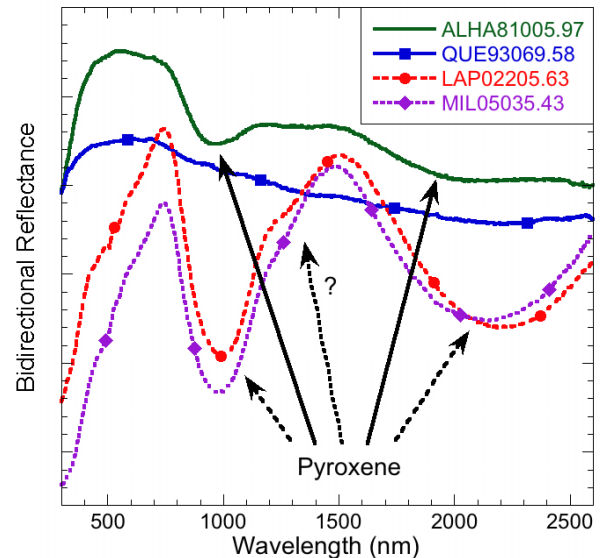
Fig. 2: Bidirectional reflectance spectra of lunar meteorite chip samples. Spectral diversity between the samples is readily apparent, most prominently in the strength and position of the 1 and 2 μm pyroxene features. The basalts have longer-wavelength and stronger pyroxene absorption features than the feldspathic breccias. The "blue" continuum slope is caused by the specular reflectance component introduced by collecting the spectra from chip surfaces.

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