**CHARACTERIZATION OF APOLLO SOIL SAMPLES UNDER SIMULATED LUNAR CONDITIONS.**
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**Introduction:** Apollo mare and highland soils [e.g. 1-3] as well as basaltic rocks [4] have been well-characterized across the visible- to near-infrared (VNIR) wavelengths including the effects of mineralogy, mineral chemistries, ilmenite content and space weathering on their spectra. These laboratory analyses provided ground truth to remote sensing observations from Earth-based telescopic observations and spacecraft observations like those from Clementine, Galileo, Lunar Prospector, SELENE, and Chandrayaan-1 as well as providing key insights into the composition and evolution of the lunar surface. Recently the Diviner Lunar Radiometer, a thermal infrared (TIR) radiometer, was launched onboard the Lunar Reconnaissance Orbiter (LRO) making it necessary for the characterization of Apollo samples across TIR wavelengths. The near-surface vacuum environment of airless bodies like the Moon creates a thermal gradient in the upper hundred microns of regolith. Lab studies of particulate rocks and minerals as well as selected lunar soils under vacuum and lunar-like conditions have identified significant effects of this thermal gradient on thermal infrared (TIR) spectral measurements [e.g. 5-10]. Such lab studies demonstrate the high sensitivity of TIR emissivity spectra to environmental conditions under which they are measured.

In this work, an initial set of thermal infrared emissivity measurements of the bulk lunar soil samples will be made in three of the laboratories included in the Thermal Infrared Emission Studies of Lunar Surface Compositions Consortium (TIRES-LSCC): the Asteroid and Lunar Environment Chamber (ALEC) in Reflectance Experiment Laboratory (RELAB) [11] at Brown University, the Simulated Lunar Environment Chamber in the Planetary Spectroscopy Facility at the University of Oxford, and the Simulated Airless Body Emission Laboratory (SABEL) at the Jet Propulsion Laboratory (JPL). These laboratory measurements of bulk lunar soil samples are compared with Diviner data to understand: (1) how to accurately simulate conditions of the near-surface environment of the Moon in the lab and (2) the difference between returned samples and undisturbed lunar soils in their native setting. Both are integral for constraining thermally derived compositions and properties of the lunar surface from current (Diviner) and future TIR datasets.

**Experimental Setups:** ALEC is a vacuum chamber in Brown University's RELAB designed to simulate the space environment experienced by the near-surface regolith of the Moon and asteroids. The design details of the vacuum chamber have previously been discussed [12]. ALEC is connected to RELAB's Thermo Nicolet 870 Nexus FTIR spectrometer which allows laboratory emissivity spectra to be collected at a resolution of 4 $cm^{-1}$ over the ~400 – 2000 $cm^{-1}$ spectral range. The Simulated Lunar Environment Chamber (SLEC) at the University of Oxford is described in more detail elsewhere [8]. Radiation emitted from the sample is reflected into a Brüker IFS-66v/S FTIR spectrometer by a cooled collecting mirror positioned above the sample. Spectral measurements are collected at a resolution of 4 $cm^{-1}$ over the ~400 – 2400 $cm^{-1}$ spectral range.

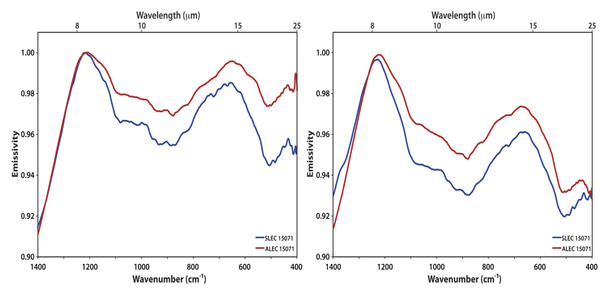


**Figure 1. (Left)** Ambient emissivity spectra of Apollo 15071 measured under ambient conditions (sample heated from below, pressure ~ 1000 mbar, and no chamber cooling or solar heating) in ALEC and SLEC. **(Right)** Simulated lunar environment emissivity spectra of 15071 (sample heated from below and above, pressure < $10^{-3}$ mbar and chamber cooled < 150 K).

While the design and workings of each chamber is slightly different, the chambers are functionally the same. In each chamber, we simulate the lunar environment by: (1) pumping the chambers to vacuum pressures (<$10^{-3}$ mbar), which is sufficient to simulate lunar heat transport processes within the sample, (2) cooling the chambers with liquid nitrogen to simulate the cold space environment that the Moon radiates into, and (3) heating the samples from below, above, or both to set-up thermal gradients similar to those experienced in the upper hundreds of microns of the lunar surface. Samples are heated from below using heaters embedded in the base of each sample cup and from above using solar-like halogen lamps. Each laboratory and chamber has its own strengths and collaborating amongst multiple laboratories will provide us the unique opportunity to do a rigorous characterization of the lunar samples as well as cross-laboratory calibrations.

**Results:** To best constrain the regolith properties on the lunar surface, initial measurements were made of bulk lunar samples 15071. Spectral measurements under ambient (or 'Earth-like') and simulated lunar environment conditions were made to characterize spectral changes due to the changes in environmental conditions. Ambient conditions in ALEC are created by heating the sample from below to 405K and filling the chamber with ~1000 mbar of dry air. Ambient conditions in SLEC are created by heating the sample from below to 353K and filling the chamber with ~1000 mbar of nitrogen. In both chambers under ambient conditions, the solar-like halogen lamps are not used to illuminate the surface of the samples and the chambers are not cooled. Full resolution spectral measurements of Apollo 15071 under ambient conditions are shown in the plot on the left of Figure 1. Slight differences in the spectral contrast and slope are observed between the two ambient spectral measurements. These differences could arise from sample preparation as packing plays an important role in the spectral contrast of the reststrahlen bands [e.g. 13] and/or from the calibration procedures of the two chambers (including the accounting for downwelling radiance).

Lunar conditions in ALEC are simulated by heating the sample from below to 405K, the surface of the sample is illuminated by a solar-like halogen lamp, the chamber pressure is held to < $10^{-4}$mbar and the chamber is cooled to ~85K. In SLEC, the sample is heated from below to 393K, the surface of the sample is illuminated by a solar-like halogen lamp, the chamber pressure is held to < $10^{-4}$mbar and the chamber is cooled < 150K. Full resolution spectral measurements of Apollo 15071 under simulated lunar conditions are shown in the plot on the right of Figure 1. Again we observe spectral features at the same wavelength positions, but slight differences in the spectral contrast and slope are observed between the two simulated lunar conditions spectra. These differences could arise from differences in the thermal environment in the chambers, sample preparation, and/or from the calibration procedures of the two chambers and will be investigated further

Full resolution laboratory spectra of Apollo 15071 were re-sampled to the three Diviner spectral bands and compared with an average Diviner emissivity spectrum [14] from a 400 m box surrounding the location sample 15071 was collected (sampling station 1) as seen in Figure 2. Re-sampled ALEC and SLEC emissivity spectra are similar to the Diviner emissivity spectrum and fit within two standard deviations of the Diviner measurements (as shown by the y-error bars in Figure 2). Differences between Diviner and lab measured spectra will be investigated further.

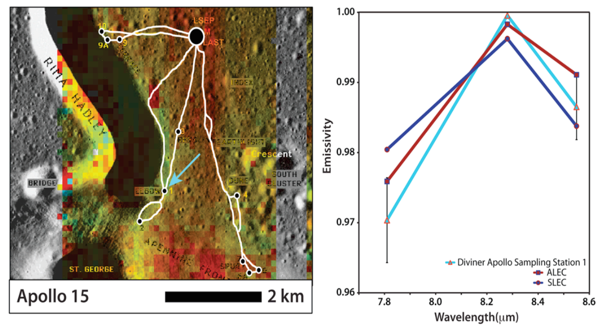


**Figure 2. (Left)** Diviner Christiansen Feature (CF) map of the Apollo 15 landing site [14]. Blue/green pixels highlight feldspathic materials with shorter CF positions and red pixels highlight more mafic materials with longer CF positions. The cyan arrow highlights sampling station 1 where Apollo 15071 was collected. **(Right)** Average Diviner emissivity spectrum for sampling station 1 as well as ALEC (red) and SLEC (blue) spectra resampled to the Diviner spectral bands.

**Discussion:** Future work will focus on the measurement of a suite of Apollo bulk lunar soil samples that encompass a range of compositions and maturities. In addition, we will further characterize the spectral differences observed in ALEC and SLEC measurements to (1) understand where the differences arise and (2) minimize those differences as much as possible. Samples will also be measured under simulated lunar conditions at JPL's SABEL in an effort to better characterize the near surface environment of the Moon as well as understanding cross laboratory measurement differences.

**Acknowledgments:** This work was supported by NASA NLSI Grant ID NNA09DB34A. This work was also funded by a Leverhulme Trust research grant RPG-2012-814.

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