GROUNDTRUTHING DIVINER LUNAR RADIOMETER OBSERVATIONS WITH APOLLO SAMPLES.

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Introduction: The Moon is the only planetary body for which we have extraterrestrial samples with known spatial context collected at a diverse range of sampling sites. These samples, an enduring legacy of the Apollo missions, provide a unique opportunity to validate planetary remote sensing datasets. Here we present results of a comprehensive study to best replicate a lunar environment in the laboratory, evaluate the most appropriate sample and measurement conditions, collect thermal infrared spectra of a representative suite of Apollo soils, and correlate these measurements with thermal infrared observations of the lunar surface.

Diviner: NASA's Lunar Reconnaissance Orbiter Diviner Lunar Radiometer (Diviner) instrument has produced the first global, high resolution, multispectral thermal infrared observations of an airless body. Diviner is a nine-channel, pushbroom mapping radiometer that measures broadband reflected solar radiation with two channels, and emitted thermal infrared radiation with seven infrared channels [1]. The three shortest wavelength thermal infrared channels near 8 μm were specifically designed to characterize the mid-infrared Christiansen feature (CF), an emissivity maximum, sensitive to silicate composition [2,3]. The Diviner dataset includes all six Apollo sites at approximately 200 m spatial resolution (Figure 1).

Simulated Lunar Environment: In nearly 50 years of laboratory experiments, it has been established that thermal emission spectra measured in a simulated lunar environment (SLE) are significantly altered from spectra measured under terrestrial conditions [e.g. 3, 4, 5, 6]. The data for this study were collected in the Planetary Analogue Surface Chamber for Asteroid and Lunar Environments (PASCALE) at University of Oxford. The lunar environment is simulated by (1) pumping the chamber to vacuum pressures ($<10^{-4}$ mbar), which is sufficient to simulate lunar heat transport processes within the sample, (2) cooling the chamber (<125 K) with liquid nitrogen to simulate a surface radiating into a cold space environment, and (3) simultaneously heating the sample cups with heaters and illuminating the surface with a lamp to set up thermal gradients similar to those experienced in the upper hundreds of microns of the lunar surface.

Lunar Soils: Our reference sample suite is composed of bulk lunar soils from two NASA Curation and Analysis Planning Team for Extraterrestrial Materials (CAPTEM) requests: (1) the UCLA Bi-Directional Reflectance Function (UCLA-BDRF; 5 g mass; PI Paige) and (2) the Thermal Infrared Emissions Studies Lunar Soil Compositions Consortium (TIRES-LSCC; 3.5 g mass; PI Pieters) shown together in Table 1.

Results: We conducted a preliminary suite of experiments on Apollo soils 15071 (maria) and 61141 (highland) using different environmental conditions and found spectral changes similar to [6]. We determined that the spectral effects causing by variable thermal enfironments were significant enough to reconsider our measurement methodology. For our new methodology, we heated each sample to the brightness temperature observed by Diviner at each sampling station for a 50° solar incidence angle (similar to the lamp incidence angle in PASCALE). For comparision, we also heated each sample to the average noontime temperature of all the observed sampling stations.

We found that analyses of Diviner observations for individual sampling stations and PASCALE measurements of the returned Apollo soils in a relevant environment generally show good agreement. Furthermore, the agreement was improved when the illumination geometry of the laboratory experiments and Diviner observations are similarly constrained. In contrast, comparisons between Diviner observations and thermal infrared emission and reflectance measurements under terrestrial conditions do not agree well. These analyses underscore the need for SLE measurements to validate thermal emission datasets from the Moon and other airless bodies.

Table 1: Apollo soils available for this study.

Apollo Site	Station	Soil	Mass	Is/FeO
Apollo 11	LM	10084	5g	78
Apollo 12	LM	12001	5g	56
Apollo 14	LM	14259	3.5 g	85
Apollo 15	LM	15021	3.5 g	70
Apollo 15	Sta. 1	15071	5g	52
Apollo 15	Sta. 7	15411	3.5 g	43
Apollo 15	Sta. 9a	15601	3.5 g	29
Apollo 16	Sta. 1	61141	5g	56
Apollo 16	Sta. 6	66031	3.5 g	102
Apollo 16	Sta. 11	67701	3.5 g	39
Apollo 17	LM	70181	5g	47
Apollo 17	Sta. 2	72501	3.5 g	81
Apollo 17	Sta. 9	79221	3.5 g	81

References: [1] Paige D.A. et al. (2010) SSR, 150. [2] Greenhagen B.T. et al. (2010) Science, 329, 1507. [3] Logan L.M. et al. (1973) JGR, 78, 4983. [4] Henderson B.G. et al. (1996) JGR, 101. [5] Thomas I.R. et al. (2012) Rev.Sci.Inst., 83 (12), 124502. [6] Donaldson Hanna K.L. et al. (2017) Icarus, 283, 326-342.

Figure 1: Diviner CF maps overlain on Apollo traverse maps illustrate compositional and soil maturity variations observed between different Apollo site and sample stations. The diversity of the samples collected at these stations and excellent coverage by Diviner enables a meaningful grountruth.