

**MORPHOLOGIC AND SPECTRAL CHARACTERIZATION OF REGOLITH BREAKDOWN DUE TO WATER ICE.** A. Shackelford<sup>1</sup> and K. L. Donaldson Hanna<sup>1</sup>, <sup>1</sup>Department of Physics, University of Central Florida, 4111 Libra Drive Physical Sciences Bldg. 430, Orlando, FL 32816-2385 (A.Shackelford@Knights.ucf.edu).

**Introduction:** The permanently shadowed regions (PSRs) at the lunar poles are hypothesized to host trapped volatiles, namely OH and H<sub>2</sub>O, that may alter the regolith in ways that are seemingly unique to the higher latitudes on the lunar surface [e.g., 1, 2]. Polarimetric radar studies from Chandrayaan-1 and the Lunar Reconnaissance Orbiter (LRO) found anomalous craters, nearly all of which are found within PSRs, with high circular polarization ratio (CPR) values inside the craters (> 1) and low CPR values outside crater perimeters, which is likely indicative of water ice [e.g., 3, 4]. These studies, alongside the Lunar Crater Observation and Sensing Satellite (LCROSS) impact at Cabeus crater, revealed that the water ice present in PSRs could be in the form of discrete ice grains intermixed with the lunar regolith or as a thin coating of ice on rock grains [e.g., 4, 5]. Does this water ice have the capability to significantly change the nature of the lunar regolith? Temperature measurements from LRO's Diviner instrument and the Jet Propulsion Laboratory's proton fluence model were combined to investigate dielectric breakdown events in PSRs, and it was hypothesized that these events could explain the "fairycastle" regolith structures and increase the percentage of fine particulate materials within PSRs, indicating that solar wind and micrometeorite impacts may not be the only processes weathering the lunar surface [e.g., 6, 7]. The presence of water ice, the nature in which it exists within the regolith, and the breakdown of the regolith due to interactions with water ice may then be unique to the Moon's polar environment.

Understanding the uniqueness of the lunar polar environment, the presence of water there, and how it impacts regolith properties is essential in planning for successful, long-term lunar surface operations and science. Rovers, landers, and humans alike will face challenges regarding the geotechnical properties of the lunar soil [e.g., 8], and it is essential that we are able to create tools that will work effectively with the likely different regolith of the future polar landing sites.

To investigate the way water ice may change the polar regolith, we have characterized the morphologic and spectral changes of two high-fidelity lunar regolith simulants after exposing them to freezing temperatures and concentrations of water ice consistent with spectral observations [1] for varying lengths of time.

**Methods:**

*Lunar simulants and ice mixing.* In this experiment we used LHS-1 and LMS-1, which are lunar highlands and lunar mare simulants produced by the Exolith Lab

[9]. Each sample was created by freezing 2 grams of simulant for 24 hours in a small, air-tight container before mixing in deionized water from a vial suspended in an ice bath in concentrations of 1, 10, or 30 wt.% [1]. The samples were then placed in the freezer undisturbed for periods of either one, three, or six months. A reference frozen sample with no water added was also created for each time period for a total of 24 unique samples. Upon removal from freezer storage, samples were placed in a gravity convection oven and baked at 50° C to drive off any added water. Then, spectral and morphological analyses could begin. All data from the frozen samples were compared to those of the original, unaltered simulant.

*Spectral analysis.* Visible-to-near infrared (VNIR) and mid-infrared (MIR) reflectance spectra were collected of each sample using a Nicolet is50 FTIR spectrometer using the following detector, beam splitter, and standard calibration materials:

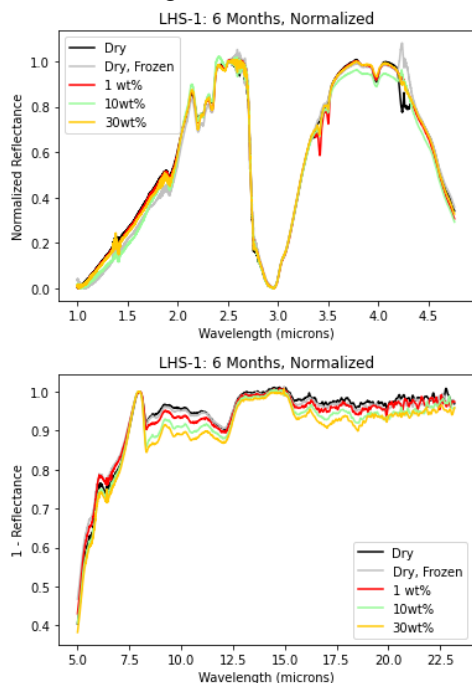
Wavelengths	Detector	Beamsplitter	Standard
1-2.5 μm	InGaAs	Quartz	Spectralon
2.5-5 μm	DTGS	CaF <sub>2</sub>	Gold
5-25 μm	DTGS	KBr	Gold

*Morphologic analysis.* To characterize changes in particle shape and size distribution, we used an AccuScope system with corresponding ExpertShape software to study individual particles. This method alone was not sufficient for characterizing all the clinging fine particulate material in our samples, so we supplemented the work with electron dispersive spectroscopy (EDS) and scanning electron microscopy (SEM) to analyze which mineral phases appeared to break down more efficiently and how the subsequently created fines interacted with one another.

As plagioclase is expected to weather more quickly than pyroxene, we used EDS to pick out individual plagioclase (Ca/Al) and pyroxene (Mg) particle targets and separately imaged them by defining two classes of fine particulate SEM images: "Clumps" and "Fines." "Primary clumps" refer to a conglomerate of particles *greater than* 2 μm in diameter comprised of either a unit of more than one particle that features at least ten visible clinging sub-micron fines or a unit of at least four clinging particles. "Secondary clumps" are *less than* 2 μm in diameter and consist of a unit of at least four clinging particles. The maximum Feret diameter, or the maximum diameter of a particle between two bounding

parallel, tangential lines, and area of these clumps are measured to determine how the fines are interacting with one another with increasing water content. “Fines” in this case are defined as any individual particle less than 2  $\mu\text{m}$  in diameter, and for each “Fines” image, all fine particulates are counted to determine whether significantly more fines are generated with increasing water concentration and time during the breakdown process.

**Spectral results:** The samples of LHS-1 plotted in **Figure 1** were each frozen for six months. The VNIR spectra were normalized at 2.5  $\mu\text{m}$ , whereas the MIR spectra were normalized in  $(1 - \text{Reflectance})$  space at the reflectance maximum near 8  $\mu\text{m}$ . Compared to the ‘Dry’ (unaltered) simulant MIR spectra, we see a trend of increasing feature depth with increasing water ice concentration. This trend correlates to an observed increase in the abundance of fines and clumps as a function of increasing water ice concentration and time.

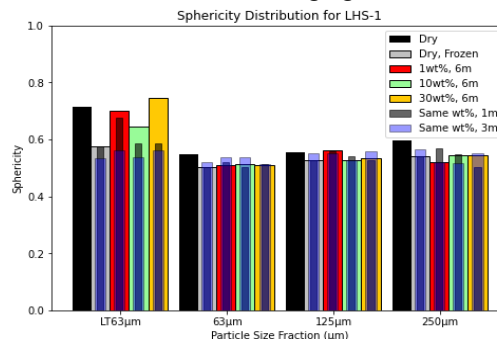


**Figure 1.** VNIR (top) and MIR (bottom) spectra of six-months LHS-1.

**Morphologic results:** Here we present individual particle analyses for weathered LHS-1 and LMS-1 performed with the AccuScope and ExpertShape.

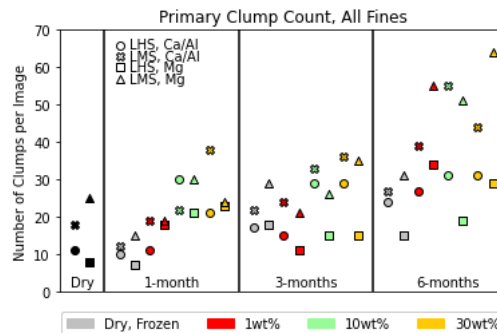
Sphericity of particles in the < 63  $\mu\text{m}$  particle size fraction of LMS-1 mixed with 30 wt% of water increased by  $\sim 30\%$  over the course of a six-month freezing period when compared to unaltered simulant. Particle elongation decreased  $\sim 24\%$  for the same sample, and equivalent circular diameter decreased by  $\sim 22\%$ . For LMS, we observed increasing particle degradation with increasing added water content.

No apparent trends were observed as a function of water ice content using this method for LHS-1, as shown in **Figure 2**. This prompted us to begin EDS/SEM characterization of clinging fines.



**Figure 2:** Sphericity distribution of LHS-1 after six months of freezing. The smaller dark grey and blue bars designate the weathering status after one and three months, respectively.

**Current and Future Work:** The SEM/EDS analyses of the bulk weathering properties of the samples’ fine particulate material are currently underway. Thus far, we see that Mg-rich particles host more primary and secondary clumps, and that the abundance of clumps increases with time and concentration of water, as shown in **Figure 3**. Further analyses on the clumps and fines will be presented at the conference.



**Figure 3:** Primary clump count for both Ca/Al and Mg particles of LMS-1 and LHS-1. Data points are offset for ease of reading.

**References:** [1] Li, S., et al. (2018) *Proceedings of the National Academy of Sciences*, 115, no. 36, 8907–8912. [2] Fisher, E., et al. (2017) *Icarus*, 292, 74-85. [3] Spudis, P. D., et al. (2010) *Geophys. Res. Letters*, 37, no. 6. [4] Neish, C.D., et al. (2011) *JGR Planets*, 116, no. E1. [5] Colaprete, A., et al. (2010) *Science*, 330, no. 6003, 463-468. [6] Hapke, B., van Horn, H., (1963) *J. Geophys. Res.*, 68, 4545-4570. [7] Jordan, A. P., et al. (2015) *JGR Planets*, 120. [8] He, C. (2010) *Doctoral Dissertation*. [9] Exolith Lab, Center for Lunar and Asteroid Surface Science (2020).