WEATHERING EFFECTS OF DIELECTRIC BREAKDOWN IN THE LUNAR POLAR REGIONS. Morgan L. Shusterman[1], Noam R. Izenberg[1], Charles A. Hibbitts[1], Andrew P. Jordan[2,3], Tim J. Stubbs[3,4], and Jody K. Wilson[2,3], [1]The Johns Hopkins University Applied Physics Laboratory, Laurel, Maryland. [2]EOS Space Science Center, University of New Hampshire, Durham, NH, [3]Solar System Exploration Research Virtual Institute, NASA Ames Research Center, Moffett Field, California, USA, [4]NASA Goddard Space Flight Center, Greenbelt, MD.

Introduction: The bombardment of solar energetic particles (SEP), accelerated by coronal mass ejections and solar flares, create a charge buildup in permanently shadowed regions (PSRs) of the Moon, leading to dielectric breakdown in the top 1 mm of regolith [1]. Lunar soil properties such as jagged grain edges and inclusions of materials with different dielectric properties can increase local electric fields, thus increasing the likelihood of breakdown between the grains [2]. Because the conductivity of cold lunar soils in PSRs is very low, deposited charges remain separated long enough for the fluence from large SEP events to exceed the threshold for breakdown [1].

This stepwise study aims to characterize the physical, chemical and optical effects that dielectric breakdown has on lunar soils. We anticipate breakdown effects to include melting, fraturing along mineral (dielectric) boundaries, and vapor deposition (Fig. 1). The first 'laboratory' iteration of an analog experiment (Fig. 2) was conducted in terrestrial conditions. Breakdown was induced in JSC-1A lunar regolith simulant by applying sufficient potential from a 9V DC source. Some of the anticipated results such as melting and vapor deposition did occur.

In a similar experiment performed under ultra high vacuum, the researchers found evidence for degradation of the dielectric properties of the soil resulting in breakdown at lower voltages after repeated pulsed breakdown experiments conducted on a single sample. It was also expected that some breakdown channels formed in the soil analog. However, the soil was never analyzed for physical, chemical, nor mineralogical alteration [3]. Also, no experiments to date have ideally replicated the environment of PSRs, which requires not only high vacuum but also cold temperatures. More analogous conditions are required to test the validity of potential breakdown observations and results for the Moon.

Experimental design: To mitigate the breakdown pathway through the atmosphere so conditions are more similar to PSRs, the second iteration of laboratory experiments is testing dielectric breakdown of JSC-1A in vacuum at ~ $1e^{-4}$ torr. Samples will be placed in a ceramic well and two copper electrodes set into the grains at approximately 1 mm depth and separated initially by 1 mm. We will supply a large potential to force dielectric breakdown and then examine both intact and cross sectional grains under a scanning electron microscope (SEM).

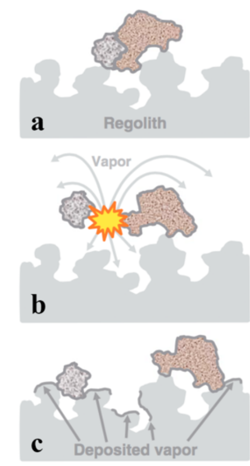

Fig. 1. Illustration of possible weathering effect of dielectric breakdown from [2]. a) Grain at regolith's surface.
b) Breakdown vaporizes some of grain's material and splits grain.
c) Grain fragments move, changing regolith's porosity; some vaporized material is deposited onto surrounding regolith.

SEM evaluation: To prepare for interpreting our results, we have searched for diagnostic signs of dielectric breakdown in Apollo soil samples. We examined prepared SEM-ready samples from 12001, 15231, and 61221 in cross-section under SEM. The extent of fracturing within grains varies with each sample but often occurs along grain boundaries. A few grains exhibited vapor deposition features (Fig. 3) in which an entire grain is coated with a 3-10 micron layer of melt. Fig. 3a and 3d for example, could be representations of the cross-sectional view of the melted grain pictured in Fig. 2d. Melting, fracturing, and vapor deposition are not themselves diagnostic of dielectric breakdown, as micrometeorite impact events will produce similar features. However, fracturing and melting within a grain due to dielectric breakdown might produce physical effects distinguishable from fracture and melting from an impact. Further inventorying lunar soils and examining materials subjected to breakdown will determine if discrimination is possible. Furthermore, analyses of our laboratory experiments may also test this hypothesis for internal grain dielectric discharge and grain alteration.

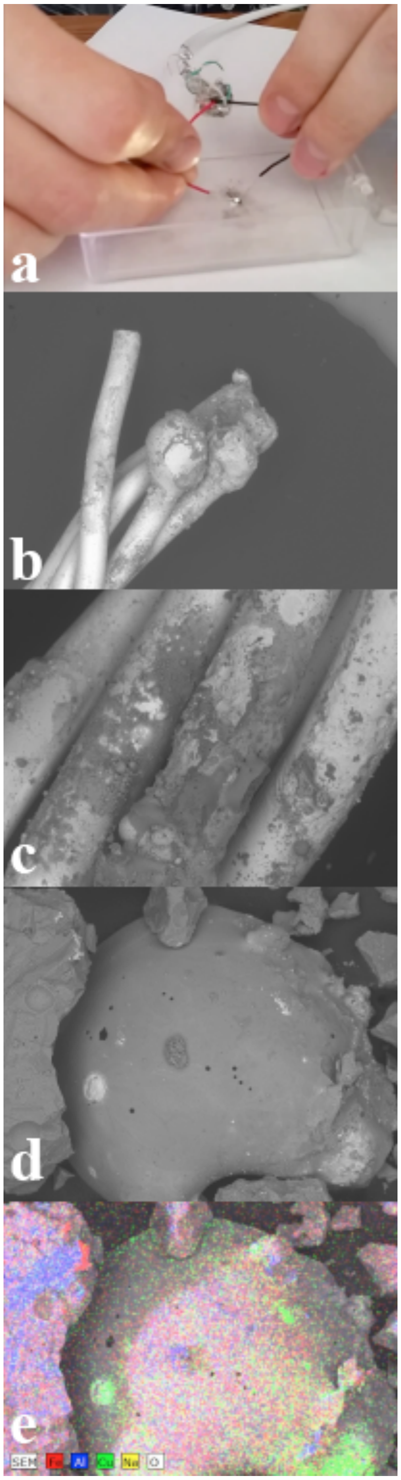

Fig. 2. Pilot breakdown experiment and results: a) Sparking experiment using JSC-1A simulant between electrodes with voltage supplied by parallel 9-volt batteries. b) SEM image of electrode tip showing melted copper mixed with melted simulant. c) Melted simulant spatter on copper wire near electrode tip. d) SEM image of JSC-1A melt. e) X-ray spectrometry elemental abundances within the JSC-1A melted nodule show greater mixing than unmelted grain to the left, and incorporated copper (green) from the electrodes.

Conclusions and Implications: There are several implications of breakdown weathering in PSRs. First, if breakdown weathering significantly affects regolith in PSRs, then the overall rate or extent of weathering when combined with impact weathering may be greater or different within these regions than outside them. Even if a discharge produces a fracture rather than complete fragmentation, the grains become more susceptible to comminution by micrometeorite impacts [2]. It is therefore expected that the bulk grain size in areas where breakdown weathering occurs may be finer than in other regions. An increase in the abundance of fine grains may also increase the porosity to more readily form "fairy castle" structures, potentially explaining the far-ultraviolet low albedo detected in many PSRs and consistent with higher porosities in Cabeus Crater from the LCROSS impact experiments [4,5].

The prior study showing that dielectric properties of a soil can change under ultra high vacuum when subjected to repeated pulsed breakdown events [3] indicates the possibility of dielectric breakdown as a weathering process on other airless bodies and motivates the need to analyze grain alterations that result from dielectric breakdown events. At the time of this writing the second iteration of this experiment is being conducted under low vacuum. Future experimentation will analyze the alteration of grains when breakdown occurs under high vacuum and at low temperatures.

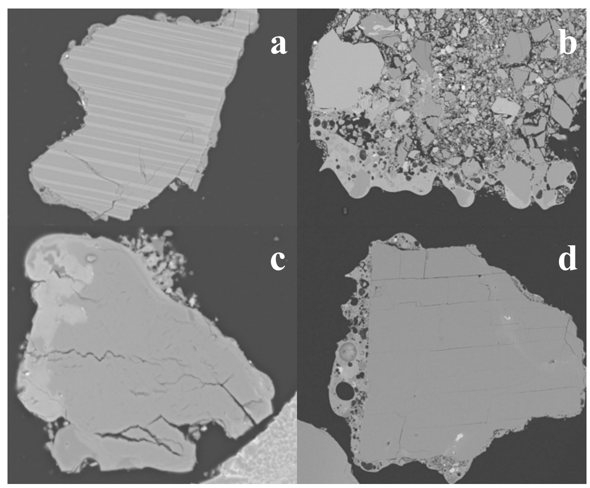

Fig. 3. SEM images of lunar grains with melt and fractures. Lunar sample numbers: a) 12001, 611. b) 15231, 206. c) 15231, 203. d) 12001, 615.

References: [1] Jordan A. P. et al. (2014) *JGR Planets, 119*, 1806-1821. [2] Jordan A. P. et al. (2015) *JGR Planets, 120*, 220-225. [3] Kirkici H. et al. (1996) *IEEE,* 3,119-125. [4] Gladstone G. R. et al. (2012) *JGR Planets, 117,* E00H04. [5] Schultz P. B. et al. (2010) *Science* 330, 468-472.

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