**DIELECTRIC BREAKDOWN WEATHERING RATE OF THE MOON'S POLAR REGOLITH.** A. P. Jordan[1,2], T. J. Stubbs[3,2], J. K. Wilson[1,2], N. A. Schwadron[1,2], [1]EOS Space Science Center, University of New Hampshire, Durham, NH (first author email address: a.p.jordan@unh.edu), [2]Solar System Exploration Research Virtual Institute, NASA Ames Research Center, Moffett Field, California, USA, [3]NASA Goddard Space Flight Center, Greenbelt, MD.

**Introduction:** Large solar energetic particle (SEP) events may cause dielectric breakdown in the upper ~1 mm of regolith within the Moon's permanently shadowed regions (PSRs) [1]. Regolith gardened by meteoritic impacts is estimated to have experienced about $10^6$ SEP events capable of causing breakdown, and, in the past few years, at least two SEP events detected by the Cosmic Ray Telescope for the Effects of Radiation (CRaTER) onboard the Lunar Reconnaissance Orbiter (LRO) may have had the necessary fluence to cause breakdown [2]. We build on this previous work to estimate how breakdown weathering might affect the regolith in the Moon's polar regions, and we compare breakdown and meteoritic weathering to determine their relative importance.

**Conditions for breakdown:** Dielectric breakdown occurs if the electric field within a material exceeds a threshold that is dependent on the material's characteristics. Once this threshold is surpassed, the material ionizes along one or more channels of ~10 μm in diameter [3] (this process is also called sparking; see Figure 1). The threshold field typical for most solids is $\sim10^7$ V m$^{-1}$ [4], although it can occur at field strengths an order of magnitude lower [5].

Such an electric field requires a fluence (time-integrated flux) of charged particles of $\sim10^{10}$ cm$^{-2}$ [6]. This particle fluence needs to be deposited well within the material's discharging timescale; otherwise the material will be able to dissipate the charge build-up before the electric field becomes strong enough to cause breakdown. One way for a material to have a very long discharging timescale is for it to have a very low conductivity.

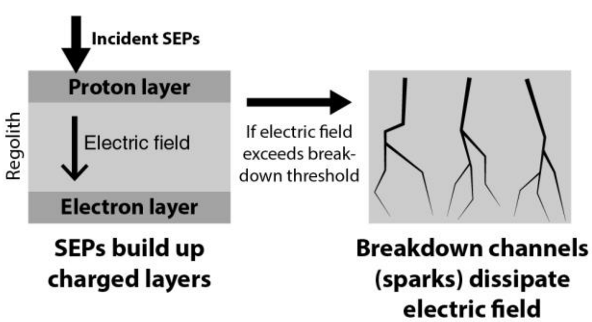


***Figure 1.*** *SEP protons and electrons can create a subsurface electric field that eventually causes breakdown.*

Regolith conductivity is expected to be very low ($\sim10^{-17}$ S m$^{-1}$) within PSRs, thus giving a discharging timescale of about 20 days—much longer than a single SEP event [1]. Therefore, an SEP event with sufficient fluence could deposit enough particles to cause breakdown. Such events are estimated to occur roughly once per year over the long term [1], and two have been detected throughout LRO/CRaTER's roughly 4 year mission to date [2].

**Average breakdown weathering rate:** Gardened regolith within PSRs has experienced about $10^6$ breakdown-causing SEP events [1]. These events dissipate the energy contained in the electric field by ionizing and heating the material to create the plasma channel(s). This explosive process can cause the material to crack, particularly along mineralogical boundaries [7,8]. Note that this rapid dissipation of the electric field likely affects lunar surface charging measurements—a scenario considered in a study using electron reflectrometry measurements from the ARTEMIS mission [9].

We first estimate the energy density released by a breakdown-inducing SEP event like those detected by LRO/CRaTER and find that it is $\sim10^3$ J m$^{-3}$. We also estimate that the energy density needed to split all the grains per unit volume is at most $\sim10^5$ J m$^{-3}$. Therefore, an SEP event capable of causing breakdown can deposit enough energy in the upper ~1 mm of regolith to fragment roughly 1% of the grains.

We then consider how repeated breakdown-causing SEP events (up to $10^6$ events) affect the regolith. To do this, we consider how large an area of regolith is discharged by the formation of a single breakdown channel. This enables us to estimate how many breakdown channels form per unit area within a PSR (see the right hand panel in Figure 1). We also use this information to determine the rate of breakdown-driven comminution of regolith within PSRs.

**Comparison of breakdown and meteoritic weathering:** In addition to breakdown, meteoritic impacts also weather regolith within PSRs. Observations at 1 AU indicate that the incident meteoritic energy flux is ~10 J m$^{-2}$ yr$^{-1}$, deposited over all depths to which meteoroids penetrate [10]. Our preliminary estimates indicate that the breakdown energy flux to be at least ~1 J m$^{-2}$ yr$^{-1}$, but this energy is deposited only within the top ~1 mm of regolith. Therefore, it seems possible that breakdown weathering due to SEP events is an important driver of regolith maturation and may even be comparable to meteoritic weathering. Because of this, breakdown weathering may also be important at the surface of other airless bodies in elevated radiation environments throughout the solar system.

**References:** [1] A. P. Jordan et al. (2014), *JGR-Planets*, *119*, 1806-1821. [2] A. P. Jordan et al. (under review), "Dielectric breakdown weathering of the Moon's polar regolith," *JGR-Planets*. [3] P. P. Budenstein et al. (1969), *J. Vac. Sci. and Technol.*, *6*, 289-303. [4] N. W. Green and A. R. Frederickson (2006), *Space Tech. & App. Internat. Forum – STAIF 2006*, *813*, 694-700. [5] J. Sørenson et al. (2000), *5th European Conf. on Rad. Effects on Comp. and Sys.*, 27-33. [6] A. R. Frederickson et al. (1992), *ICCC. T. Nucl. Sci.*, *39*, 1773-1782. [7] I. V. Lisitsyn et al. (1998), *J. Appl. Phys.*, *84*, 6262-6267. [8] U. Andres et al. (2001), *Miner. Process. Extr. M.*, *110*, 149-157. [9] R. M. Winslow et al. (2015), *LPSC* abstract, March. [10] E. Grün et al. (1985), *Icarus*, *62*, 244-272.