POSSIBLE OBSERVATIONAL EVIDENCE FOR DIELECTRIC BREAKDOWN WEATHERING ON THE MOON. A. P. Jordan[1,2], J. K. Wilson[1,2], [1]EOS Space Science Center, University of New Hampshire, Durham, NH, USA (first author email address: a.p.jordan@unh.edu), [2]Solar System Exploration Research Virtual Institute, NASA Ames Research Center, Moffett Field, CA, USA.

Introduction: To interpret remote sensing observations of lunar regolith, it is important to understand how space weathering has affected the surface. Much work has focused on how bombardment by solar wind and micrometeoroids changes the reflectance spectrum of lunar soil. These processes, however, may not cause all reflectance features seen in lunar swirls and latitudinal trends. Instead, a newly predicted process—dielectric breakdown weathering—may be responsible.

Puzzling observations: Swirls are high albedo, sinuous features associated with localized regions of magnetic fields. The transitions of various swirls' backgrounds to their brightest regions have similar slopes on a plot of the 950 nm-to-750 nm reflectance ratio versus the reflectance at 750 nm [1]. In addition, these slopes are similar to those of the latitudinal trends of much of the lunar surface, when binned by iron content [2].

The similarity in slopes suggests that the same process creates both the swirl trend and the latitudinal trends, and the most likely cause in common seems to be the average flux of solar wind [2]. The magnetic fields colocated with swirls may reduce the average flux at the swirl. Similarly, the average flux of solar wind impinging on the surface decreases with latitude as its angle of incidence increases. Consequently, changes in the average flux of solar wind seem to explain why the slope of the swirl trend is similar to those of the latitudinal trends.

In the case of iron-rich (>20 wt% FeO) soils, however, this explanation creates three puzzles. First, the maria's soils that are richest in iron tend to have latitudinal slopes that are steeper (more negative) than the swirl slopes [2]. It is unclear how the solar wind could create both the flatter, swirl-like slopes and these steeper slopes. This suggests that another process may affect these iron-rich soils.

Second, a high-iron (~21 wt%) swirl, Reiner Gamma, appears to be brighter than expected for soil that receives no solar wind [3]. This is based on extrapolating, for that iron content, the latitudinal trend in brightness to the poles, where the average solar wind flux is zero. The extrapolated difference in brightness between equatorial and polar soil is about half the observed difference between the equatorial soil and the swirl. This suggests that a space weathering process affects the equatorial and polar regions but not the swirl, perhaps because this process is inhibited by the swirl's magnetic field.

Finally, in 1064 nm, there is evidence that the soils richest in iron *darken* with increasing latitude [3]. In 750 nm, all maria soils brighten with increasing latitude, but the highest-iron soils have slopes that are almost flat. This trend with iron content is also clear in 1064 nm, except that the slope of the highest-iron soils is not flat but positive. These soils darken toward the poles. Again, this implies another space weathering process may play a role.

Dielectric breakdown weathering: A newly predicted process may explain these observations. Dielectric breakdown is predicted to occur in the top ~1 mm of lunar soil during large solar energetic particle (SEP) events [4-7]. These charged particles cause significant deep dielectric charging in cold (≤120 K) soil; at these temperature, the soil's electrical conductivity is so low that the soil cannot dissipate the charging.

Experiments in space and in the laboratory show that, under such conditions, solid dielectrics undergo dielectric breakdown. During this process, small (≤1 μm) channels of vaporized material form in the dielectric. These channels explosively cross the dielectric—the top ~1 mm of soil—and dissipate the local charging. After breakdown, the material returns to being electrically insulating, and charging can begin again [e.g., 7 and references therein].

The conditions for breakdown are well-understood and have been predicted to be met on the nightside of the Moon and in permanently shadowed regions [4, 7]. Globally, breakdown weathering is predicted to melt and vaporize ~3-10% of all impact-gardened soil on the Moon. This would make it comparable to micrometeoroid impact weathering [7].

Like impacts, breakdown could create melt and vapor deposits on grains [5, 7] and create submicroscopic iron particles [8-10]. These iron particles would be limited in size, however, because the breakdown channels have a diameter ≤1 μm. Consequently, the submicroscopic iron would be no more than tens of nm.

Also, breakdown weathering should be more significant in regions that are, on average, colder. Consequently, its importance would grow toward the poles [7]. This may be opposite to micrometeoroid impacts, which likely decrease with latitude [3, 11-14].

Puzzles explained: The three observational puzzles may all be explained by dielectric breakdown weathering. The puzzles all occur in soils richest in iron. Experiments show that dielectric breakdown is more likely when a mineral contains iron than when it does not [8] and that a larger fraction of metallic inclusions makes a material more susceptible to breakdown [15]. Iron-rich soils may thus undergo breakdown during SEP events that are too small to cause breakdown in soils with less iron; in other words, they would experience enhanced space weathering, as all three observations suggest.

In addition, these soils would experience more breakdown weathering near the poles. Their net weathering, however, would depend on how much breakdown weathering increases with latitude and solar wind and micrometeoroid weathering decreases with latitude. When comparing the expected trends in breakdown and micrometeoroid weathering, it seems that the net latitudinal trend should be nearly flat, as is observed for some soils. But, consistent with the previous point, the weathering of iron-rich soils could be slightly more dominated by breakdown. If so, then this would explain the puzzle of such soils getting darker in 1064 nm with increasing latitude.

Breakdown weathering may also explain the unexpected brightness of Reiner Gamma. While the swirl's magnetic field is unlikely to block SEP protons and the most energetic electrons, lower-energy (≤30 keV) SEP electrons may be unable to reach the surface, as their gyroradii are much smaller. But these electrons tend to dominate charging during SEP events [7, 16]. If they are blocked by Reiner Gamma's magnetic fields, then breakdown weathering would be reduced. The polar regions would experience more breakdown weathering than the swirl and could thus be more weathered (Fig. 1).

This could be tested by an energetic charged particle sensor on the surface at Reiner Gamma. This instrument could measure the cutoff energy for SEP protons and electrons at the surface, if it detected multiple SEP events at the swirl, perhaps over a number of months. This is similar to the proposed rover Intrepid, which would spend a significant period at Reiner Gamma and carry a radiation environment sensor [17]. Such a mission would provide an excellent opportunity to test the viability of breakdown weathering to explain these puzzles.

Conclusion: Soils richest in iron exhibit some puzzling characteristics, but these are consistent with dielectric breakdown weathering. Consequently, this process should be considered in analyzing remote sensing observations of lunar regolith and in developing future missions.

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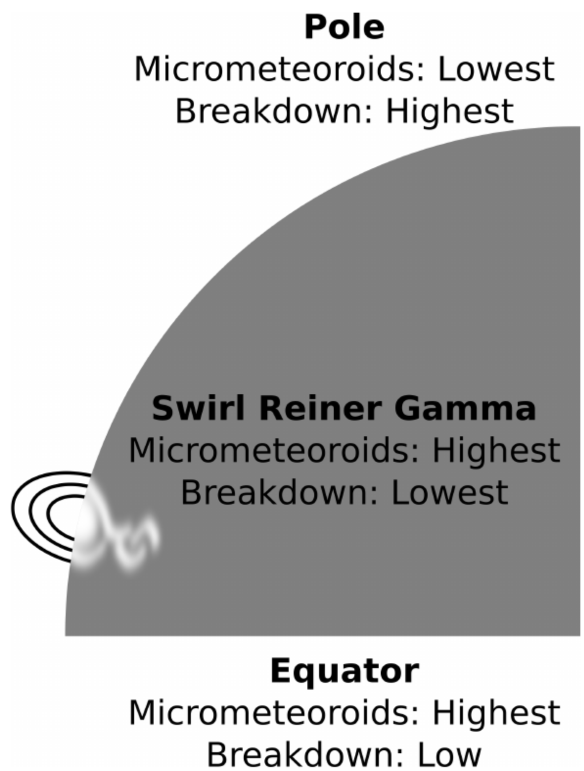

Fig. 1. Cartoon showing how the swirl Reiner Gamma could be less weathered than the poles, depending out how breakdown weathering and micrometeoroid weathering depend on latitude.