solar wind, if they can be located, and comparing their spectra with swirl spectra.

One particularly useful test of the dust transport model at lunar swirls would be inferences about particle size differences. Because any fine dust at swirls would likely affect the density, conductivity, and heat capacity of the soil, soil at swirls should exhibit a difference in thermal inertia compared to background values. The thermal inertia can be derived from measurements of infrared temperatures and surface albedos. Ultimately, perhaps the best test of the dust transport model and solar wind stand-off model would be measurements of particle fluxes, electric fields, and dust movement at the surface.

An alternative to the dust transport explanation for swirl spectral properties is that the solar wind stand-off model is at least partially correct, and we do not understand the combined effects of solar wind and micrometeoroid weathering. For example, the solar wind can produce nanophase iron (Hapke, 2001), but micrometeoroid weathering can produce both nanophase iron (Yamada et al., 1999) and change the grain size distribution through comminution. If the solar wind is responsible for a significant portion of the nanophase iron observed in normal soils, and if the solar wind is indeed kept from the surface at magnetic anomalies, then the extreme right portion of Trend 1 may represent fully developed soil produced by micrometeoroid bombardment. This nearly nanophase iron-free soil would be bright, but have the same high abundances of glass welded aggregates and particle size distribution as normal mature soils. Trend 2 is then superimposed on Trend 1 as small craters expose fresh, bright material that is mixed with the local, older and darker soil from Trend 1. Displacements of Trend 1 to the left and right would occur due to increased and decreased solar wind exposure.

The above spectral, topographic, and thermophysical tests may be able to distinguish between the two models, or a combination of the two. Regardless of which model is correct, swirls clearly provide an excellent laboratory to understand the nature of space weathering.

### 4.2. Applications to other bodies

Other airless solar system objects may produce albedo anomalies like lunar swirls if they have crustal magnetic anomalies. For example, Schultz and Srnka (1980) proposed that albedo anomalies on Mercury may be swirls, and Blewett et al. (2009) have reexamined these anomalies with Messenger data. Vernazza et al. (2006) suggested that Vesta may have a sufficient magnetic field to either stand off the solar wind from the entire body, or to form swirls.

For two reasons, Mercury may not exhibit swirl features under either the solar wind stand-off model or the dust transport model. The first reason is that Mercury has a weak global magnetic field that produces a magnetosphere that is substantially different from the daytime plasma environment on the Moon (Anderson et al., 2009). If the solar wind cannot reach the surface in significant quantities, the generation of electric fields at magnetic anomalies will not occur in the dust transport model, and the local difference in weathering under the solar wind stand-off model will be absent. The actual rate of solar wind weathering on Mercury is, however, still unknown (Noble and Pieters, 2003; Slavin et al., 2007; Denevi and Robinson, 2009). A second, probably less significant reason is that the subsurface temperature on Mercury is higher than on the Moon. For example, the mean diurnal near-surface temperature at Mercury's equator (100–200 °C) is about 120–220 °C higher than on the Moon (−20 °C) (Vasavada et al., 1999). Therefore, after billions of years, magnetic minerals may thermally unblock greater amounts of magnetization on Mercury than on the Moon, and any local crustal magnetic anomalies may be relatively weaker.

Swirls on asteroids do not suffer from the above two difficulties for Mercury. However, the mechanisms by which crustal magnetic anomalies are generated, such as the antipodal convergence of impact ejecta in a magnetic field (Hood and Artemieva, 2008), and cooling of magnetic material in a dynamo field (Weiss et al., 2008), are less well-explored on asteroids than for the Moon. It remains to be seen if swirls will be located on asteroids.

## 5. Conclusions

We have shown (1) swirls exhibit linearly displaced spectral weathering trends, unlike a normal immature surface, which may suggest an increased feldspathic component, (2) dark lane widths and estimated proton gyrodiameters suggest volume magnetizations at least as strong as the most magnetic Apollo samples, if the solar wind stand-off model is correct, (3) fine, electrostatically lofted dust can be transported horizontally by weak electric anomalies created by the solar wind interaction with magnetic anomalies, over distances comparable to swirl length scales, within the solar wind weathering timescale of 100,000 years, assuming parameters derived from Apollo surface measurements and theory, (4) horizontal transport of fine dust can alter the surface spectral properties because it is bright and slightly enriched in feldspathic material. An alternative explanation for the spectral observations is that the solar wind stand-off model is correct, and our understanding of space weathering is incomplete. More swirls on the Moon, and possibly Mercury and asteroids, may be discovered using our results.

The dust transport model for swirl formation accommodates magnetic fields, permits micrometeoroid and solar wind weathering, and can be tested with high-resolution topography data, spectral data, and thermal inertia studies. Ultimately, the best test may be to obtain measurements of magnetic fields, electric fields, dust movement, and particle fluxes at the surface.

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