SPACE WEATHERING IN THE MERCURIAN ENVIRONMENT. S. K. Noble and C. M. Pieters, Brown University. Dept of Geological Sciences, Providence RI 02912. noble@porter.geo.brown.edu

Introduction: Space weathering processes are known to be important on the Moon. These processes both create the lunar regolith and alter its optical properties [1,2,3]. Like the Moon, Mercury has no atmosphere to protect it from the harsh space environment and therefore it is expected that it will also incur the effects of space weathering [3]. However, there are many important differences between the environments of Mercury and the Moon. These environmental differences will almost certainly affect the weathering processes and the products of those processes. It should be possible to observe the effects of these differences in Vis/NIR spectra of the type expected to be returned by MESSENGER. More importantly, understanding these weathering processes and their consequences is essential for evaluating the spectral data returned from MESSENGER and other missions in order to determine the mineralogy and the Fe content of the Mercurian surface.

Mercurian Environment: Because of its proximity to the Sun, Mercury has a flux of impactors 5.5 times that of the Moon [4]. This flux coupled with its greater density makes Mercury more efficient at creating melt and vapor. Per unit area, Mercury will produce 13.5 times the melt and 19.5 times the vapor than is produced on the Moon [4]. Mercury has a magnetic field that will protect its surface from charged particles, reducing the solar wind flux at the planet by a factor of 160 vs. the lunar environment [5]. The combination of these factors then means that melting and vaporization due to micrometeorites will dominate space weathering on Mercury with little or no solar wind sputtering effects [3]. Furthermore, agglutinitic glass-like deposits and vapor deposited coatings should be created much faster and more efficiently on Mercury.

The nanometer-scale metallic Fe particles ($npFe^0$) that are ubiquitous in the rims and agglutinates of lunar soil [6] should also be present on Mercury. In the lunar case formation of $npFe^0$ is largely derived by vapor fractionation and sputtering of local FeO-bearing material. Neither process requires a H-saturated surface [3]. Even for the endmember case where the surface of Mercury has no native FeO, the iron brought in by meteorites would be sufficient to make the formation of $npFe^0$ through vapor fractionation an important process on the planet. Amounts as small as 0.05wt % $npFe^0$ is enough to affect the optical properties [2]. The size distribution of metallic Fe particles in a soil strongly controls the effects on the Vis/NIR spectrum. The smallest particles (<5nm) will tend to redden the soil while larger particles (>10nm) will cause darkening [7,8].

The Mercurian environment is also unique in our solar system because of its extreme temperature range. Due to its slow rotation and proximity to the sun, equatorial regions of Mercury can achieve temperatures above 700K during the day, while nighttime temperatures can dip below 100K. These conditions have important effect on diffusion in glass and crystal growth.

Weathering on Mercury: What, if any, effects might Mercury's unique environment have on space weathering products? The possibilities fall into two groups: (1) *Formation processes* - What weathering products are formed on Mercury and how do they compare to those on the Moon? (2) *Evolution processes* - Do the products of space weathering change as they are exposed to the Mercurian thermal regime?

Formation Processes: Melt products produced from micrometeorites which impact in the night will look similar to those observed in lunar soil. The only difference should be the rate of formation. Agglutinitic glass and vapor should be forming at a much faster rate. In a mature lunar soil, agglutinates make up as much as 50-60% of the soil. A mature soil on Mercury probably has little, if any, original crystalline material remaining.

On the day side of Mercury, the cooling regime for micrometeorite impacts is going to be somewhat different. Because the base temperature during the day is significantly higher, the cooling rate will be slowed compared to the night side (and the Moon). The slower cooling rate will allow more time for crystallization and make it difficult to form quenched glass. "Agglutinates" as we understand them from lunar soil, may look very different under these conditions if there is sufficient time for the melt to crystallize. Likewise, we might expect rim material (vapor coatings) to be microcrystalline. Perhaps the most important effect that we should expect is that the Fe-particles in both the agglutinate-like material and vapor deposited rims formed during the elevated daytime temperatures will have time to grow to larger sizes.

Evolution processes: Lunar-like agglutinates and vapor deposits formed during the night will eventually be exposed to the heat of the Mercurian day. The thermal regime on Mercury may have significant effects on the $npFe^0$. Regardless of whether these products were created in the day or night, they will be exposed repeatedly to extended periods of the 400°C+ temperatures of Mercury's day.

Due to differences in free energy between curved surfaces, $npFe^0$ particles in a glass matrix will tend to coarsen via a process well known in material sciences, Ostwald ripening. This process could be acting on the Moon as well, although, in the lunar case the rate of growth is probably much to slow to be perceptible. Because the growth rate is dependent on temperature, the process should be considerably faster on the day side of Mercury than it is on the Moon. During the course of a Mercurian day, the soil at the hottest parts of Mercury will stay above 400°C for about 2 weeks. This increased temperature may be enough to allow the $npFe^0$ particles to grow significantly. A vapor deposition experiment of Hapke *et al.* [9] demonstrated that heating $npFe^0$-rich vapor coatings to a temperature of 650°C for just one hour is sufficient to remove the ferromagnetic resonance. This presumably occurs because particles of the $npFe^0$ have grown to be larger than the range that is measured by FMR techniques (4 - 33 nm in dia. [10]), suggesting that the size of those particles tripled or quadrupled in the course of the experiment.

Determining the rate of Ostwald ripening on Mercury is difficult due to a lack of experimental data. The equation for this process is given below along with estimations of values for each variable. The least constrained, and most important variables are D, the diffusion coefficient, and σ, the surface energy. Considering a wide range of values for these, we have attempted to bound the possible range of grain growth through time (figure 1).

$$r^3 - r_0^3 = \frac{8}{9} \times \frac{x_{IL}(1-x_{IL})}{(x_{IS}-x_{IL})^2} \times \frac{D\Omega\sigma}{RTI} \times (t - t_0)$$

r_0 = original size of Fe particles ≈ 3 nm = 3×10^{-9} m [6]
x_{IL} = fraction of $npFe^0$ in rim coating = 0.1 [3] - 0.01
x_{IS} = fraction of glass = 1
D = diffusion coef. of Fe in glass = 10^{-17}-10^{-19} m^2/s
Ω = molar volume of Fe = 7.09×10^{-6} m^3/mol
σ = surface energy = 0.01-100 mJ/m^2
T = average temperature on Mercury = 400K
I = thermodynamic factor ≈ 1
$t-t_0$ = time of exposure

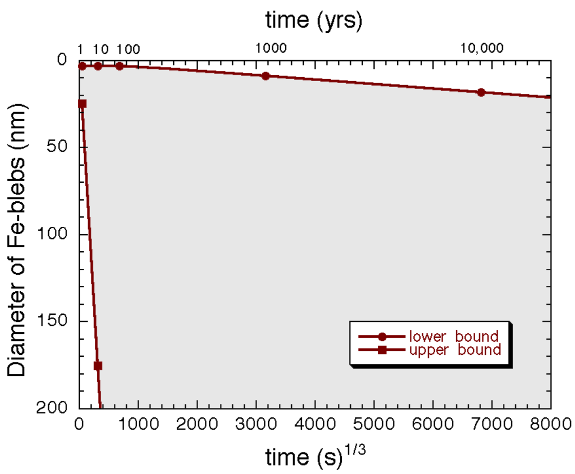

Figure 1. Possible range of effects of Ostwald ripening with time at the equator of Mercury.

Even our most conservative estimates indicate that Ostwald ripening should have a significant effect on some Mercurian soils, doubling the size of the $npFe^0$ in a matter of centuries. Of course, with increasing latitude, there is less heat available and the thermal regime becomes much more lunar-like where Ostwald ripening will have little or no effect. Our data is too limited at this point to predict the latitude where that transition will occur. Clearly work needs to be done to constrain the rate of growth and to understand the temperature dependence of this process.

Discussion: Ostwald ripening and the earlier described effects of slower cooling for day side impacts should combine to result in larger Fe particles, on average, near the equator. Since smaller $npFe^0$ particles cause reddening and larger ones result in darkening, if Ostwald ripening dominates over $npFe^0$ production, we should expect the spectral continuum to be darkest near the equator and become somewhat redder with increasing latitude.

Our current spectral data set for Mercury is very limited. Most of our spectral data is telescopic [11], largely providing an integrated disk view, masking any possible latitudinal variations, as well as regional differences. Also hidden are maturity differences that we might expect to find at young craters. Recently, though, the surface was mapped over the wavelength range 550-940nm at roughly 200km resolution by the Swedish Vacuum Solar Telescope [12]. Also, two filter data was taken during the Mariner 10 flyby, which confirms that spectral differences exist on a regional scale [13]. These data do not reveal major latitudinal trends, which is not surprising given the limited spatial and spectral resolution of the data.

The shape of the continuum influenced by $npFe^0$ can provide information about the Fe-content of a soil. Observational [2], experimental [14], and theoretical [3] data show that the shape of the spectral continuum of lunar soils changes systematically with $npFe^0$ content. Thus, for high latitude areas that have not been significantly affected by the processes described above, it should be possible to determine the amount of $npFe^0$ present. The amount of $npFe^0$ can then be used to constrain the total amount of iron in the soil.

Conclusions: If we can understand the weathering environment on Mercury, than we can predict what the space weathering products will be. By combining these predictions with an understanding of the optical effects of weathering gleaned from laboratory studies of lunar soil, we hope to estimate the total Fe on the surface of Mercury and to provide the necessary tools for evaluation of mineralogy for future missions.

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