INTENSE SPACE WEATHERING ON MERCURY: ARE THERE ANY SURFACE EXPOSURES OF IMMATURE MATERIAL?

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Introduction: Mercury is surprisingly dark given known constraints on the surface composition. Mercury is as dark as the lunar maria, yet multiple lines of evidence sigguest low surface iron abundances (≤ 4 wt. % average Fe) [1-2]. In the absence of abundant iron, explanations of Mercury's low albedo have been elusive. Here we report on appication of a new space weathering model to multispectral images of Mercury's surface. By isolating composition and maturity effects based on geologic context we are able to further constraint the composition and space weathering effects on Mercury. We find that despite low surface iron abundance, the total accumulation of space weathering derived iron is substantially higher on Mercury than on the Moon. Even exposures of immature crater ejecta require abundanct space weathering derived iron to explain their low albedo suggesting there are no large deposits of truly immature material on Mercury.

The albedo of Mercury can be investigates along two lines of reasoning. First understanding the low albedo of Mercury relative to known properties of plausible materials and second understanding albedo and color variations between different crustal terrains on Mercury. Three major crustal terrains have been identified [1]. The high reflectance plains (HRP), intermediate terrain (IT) and low reflectance materials (LRM) span a continuum of bright materials with a steep spectral slope (red) to dark materials with a relatively blue, or shallower, spectral slope (Fig. 1-2). It has been proposed that a single opaque component controls the spectral and albedo variations between the major crustal terrains [3]. However, the identity of the opaque component is highly uncertain and a subject of ongoing research.

Fig 1 – MDIS image used in this study phtometrically corrected to 30° phase angle (30° inc., 0° inc.) relative to an identically illuminated Lamertian surface. R=1020nm, G=750nm, B=430nm. (EW0108829678 - EW0108829728C).

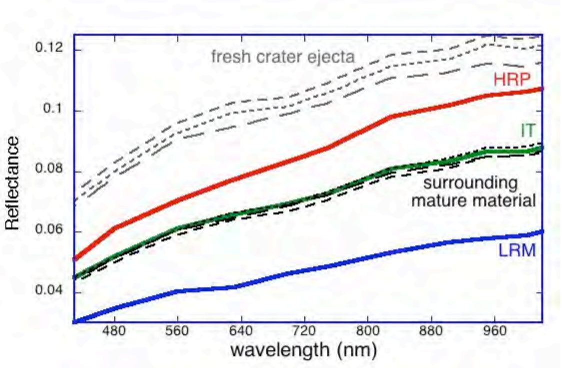

Fig 2 – Representative spectra of three major crustal terrains (HRP, IT, LRM) and pairs of mature/immature IT terrain taked from the image in Fig. 1.

Space weathering describes the chemical and physical changes to a surface exposed to the vacuum of space. Micrometeorite bombardment and particulate and electromagnetic radiation cause a darkening and reddening of lunar soils as they mature. These optical effects have been attributed to submicroscopic metallic iron (SMFe) produced by solar wind sputtering and impact vaporization.

Space weathering derived iron (SMFe) comes in two forms with different spectral effects. Vapor deposited nanophase iron (npFe, < 50 nm) occurs in thin patinas on grain surfaces and darken and redden the soil spectrum while Britt-Pieters particles are larger (> 50 nm) iron blebs occurring impact glass welded aggregates of mineral grains, called agglutinates. Britt-Pieters particles darken but do not redden the soil spectrum [4].

Approach: Hapke [5] presented a model to describe the optical properties of lunar soils with theoretical treatment of npFe. This model is able to reproduce the effects of npFe but does not explicitly model Britt-Pieters particles. Lucey and Riner [4] added a Mie scattering component to the Hapke [5] model to explicitly model the optical effects of these particles. The model is able to reproduce laboratory data of iron metal particles of varying sizes and abundances in a transparent silica gel matrix. The model also successfully predicts the laboratory spectra of 19 lunar soil samples based only on the measured chemical, mineralogical, npFe and Britt-Pieters particle abundances. Finally the model can reproduce the low albedo and spectral slope of the MESSENGER MASCS spectra [4]. However the darkening effects of the opaque component cannot be unambiguously separated from the darkening effect of Britt-Pieters particles.

We address these ambiguities using the geologic context of 11-band spectra from the MESSENGER MDIS multispectral imager. Current constraints do not allow a unique solution, so we complete a grid search over the plausible input parameter space and consider a weighted measure of the reflectance error (rms error) and the spectral shape error (rms error of spectra normalized to 430nm). We then interpret the range of solutions that can match the observed representative spectra of mature crustal terrains and mature/immature spectral pairs (Fig. 2).

Results: The additional of a single opaque component cannot explain the spectral and albedo variations between the major crustal terrains without grain size variations or some other unknown process. The darkest known opaque minerals have reflectances of 4-5% in the UV-VIS. Over 20% of the pixels in the MDIS image are < 4% reflectance (80% are less than 5% reflectance).

We present to total range of model parameter results as plots of SMFe versus opaque abundance. We use the opaque abundance, in conjunction with x-ray spectrometer (XRS) limits on major element abundance on Mercury, to evaluate the plausibility of spectral matches. For example, using the major element abundances [2] and a variety of proposed opaque minerals, we estimate a conservative maximum opaque abundance of 15 wt.% in average IT. The actual opaque abundance is likely must less because we assumed all sulfide minerals are opaque, regardless of Fe content, and we maximized the opaque abundance by allowing a variety of opaque minerals without regard to geochemical plausibility.

The model cannot match representative spectra of the three major crustal terrains (mature) at the same SMFe abundance (Fig. 3) without unrealistic abundances of an opaque component (> 40 wt. %). Mature IT with opaque abundance < 15 wt.% requires 2.5-3.1 wt.% SMFe (compared to 0.48 and 0.80 wt.% average SMFe in lunar highlands and mare soils [6]). Spectra of IT fresh crater ejecta (immature) cannot be matched by the model without substantial SMFe (Fig. 3). Assuming <15 wt.% opaque in the IT, *immature* IT requires a minimum of 1.6 wt. % SMFe.

The ratio of Britt-Pieters particles to npFe (BP:npFe) on the Moon is ~2 [6]. On Mercury, mature HRP spectra cannot be matched by the model with BP:npFe > 6. However, immature IT spectra require BP:npFe ≥ 6 for opaque abundances ≤ 15 wt.%. However, an exact BP:npFe ratio = 6 is unable to match ~25% of the pixels in the MDIS image (particularly immature HRP), suggesting that there is some varaiblility in the ratio across the surface. However, the relative abundance of Britt-Pieters particles on Mercury is substantially higher than on the Moon.

Discussion: The low albedo of Mercury can be explained by intense space weathering that results in greater abundance of space weathering derived iron across the surface, including immature crater ejecta. Model results suggest that few, if any, areas on the planet are truly immature at this spatial resolution.

Mature LRM, IT, and HRP have progressively lower SMFe. In the absence of systematic exposure age differences between the major crustal terrains, this suggests that compositional (Fe) variations are controlling the abundance of SMFe. The albedo variations observed on the surface of Mercury are not simply the result of binary mixtures of mature HRP with an opaque component but also include SMFe abundance variations due to the availability of Fe to alter in the unweathered host material (similar to differences between SMFe in the lunar highlands and maria).

The modeled abundance of SMFe is consistent with Fe abundance limits determined by the MESSENGER XRS (<= 4 wt. %). However, the SMFe abundance suggested by the model requires much more efficient conversion of iron in the unweathered host rock to SMFe on Mercury than we see on the Moon. This could be due to the lower abundance of iron, the oxidation state of the iron (Fe^0 versus FeO), or higher impact velocities on Mercury. This is an important problem to address via laboratory experiments.

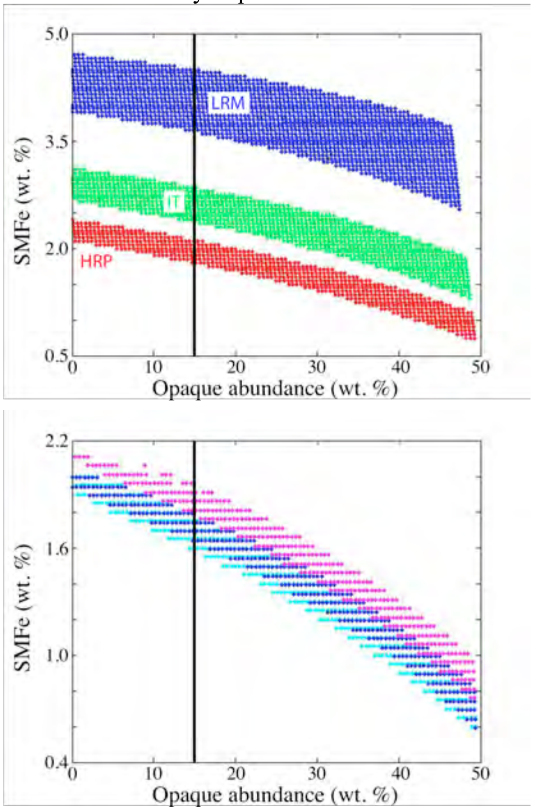

Fig 3 - Modeled opaque abundance versus total space weathering derived iron for all model inputs matching (top) each crustal terrain or (bottom) each immature IT spectrum (Fig 2.) The vertical black line represents the plausible upper limit of opaque component in the IT.

Conclusions:

- Binary mixtures of plausible opaque minerals with mature HRP cannot explain albedo variations between major crustal units on Mercury.
- The abundance of space weathering derived iron (SMFe) on Mercury is substantially higher than on the Moon (by a factor ≥ 3-6).
- Even immature IT crater ejecta has substantially more SMFe than average lunar soils suggesting large deposits of truly immature material are not exposed on Mercury.

References: [1] Robinson et al. (2008) *Sci.*, 321, 66-69. [2] Nittler et al. (2011) *Sci.* 333, 1847-1850. [3] Denevi et al. (2009) *Sci.* 324, 613-618. [4] Lucey and Riner (2011) *Icarus*, 212, 451-462. [5] Hapke (2001) *JGR* 106(E5), 10039-10073. [6] Morris (1980) *LPSC XI,* 1697-1717.