EXAMINING LOCALIZED OCCURRENCES OF LOW-REFLECTANCE MATERIAL ON MERCURY.

R. L. Klima[1] (Rachel.Klima@jhuapl.edu), B. W. Denevi[1], C. M. Ernst[1]. [1]The Johns Hopkins Applied Physics Laboratory, Laurel, Maryland, U.S.A.

Introduction: Low reflectance material (LRM) is found across the surface of Mercury, and has been interpreted as being darkened by carbon. In global mapping efforts, LRM is associated with a broad, shallow ~600 nm absorption band, that correlates with carbon content in the regions that have been measured directly with the neutron spectrometer. However, because LRM is often associated with hollows, it is possible that the spectral signature of LRM that is observed on a global scale actually consists of a mixture of a dark, flat spectrum, characteristic of carbon, and an absorption in the hollows spectrum, perhaps due to sulfides or another phase. We examine high-resolution Mercury Dual Imaging System (MDIS) color images of prominent LRM deposits, with and without prominent hollows inside of them, to investigate the origin(s) of the 600-nm feature.

Low Reflectance Material: Distinctive LRM was first observed on Mercury in Mariner 10 flyby images [1]. Visible to near-infrared reflectance spectra of LRM are flatter than the average reflectance spectrum of Mercury, which is strongly red sloped (increasing in reflectance with wavelength). From Mariner 10 and early MErcury, Surface, Space, ENvironment, GEochemistry, and Ranging (MESSENGER) flyby observations, it was suggested that a higher content of ilmenite, ulvöspinel, carbon, or iron metal could cause both the characteristic dark, flat spectrum of LRM and the globally low reflectance of Mercury [1,2]. Once MESSENGER entered orbit, low Fe and Ti abundances measured by the X-Ray and Gamma-Ray Spectrometers ruled out ilmenite and ulvöspinel as important surface constituents [3,4] and low-altitude thermal neutron measurements confirmed an enhancement of 1–3 wt% carbon in LRM compared to the global abundance, supporting the hypothesis that the darkening agent in LRM is carbon [5].

Mapping LRM on Mercury: LRM is distributed across Mercury, typically having been excavated from depth by craters and basins. In contrast to the high-reflectance plains (HRP), many of which exhibit morphological evidence of volcanism [e.g., 6-8], LRM is not associated with flow features or other evidence of a volcanic origin. LRM boundaries are generally diffuse, and grade into low-reflectance blue plains (LBP). Because of the common lack of sharp geologic boundaries, LRM has been defined primarily based on low albedo and spectral shape, isolated through principal components (PC) analyses of MDIS color images [9].

Because PC analyses (PCA) are calculated using the spectral range over a given data set, a PC2 constraint cannot be directly translated to individual targeted color images, except in the rare case of images that contain the full range of Mercury's spectral diversity. The broad, shallow band centered near 600 nm that is observed in LRM (and also often in hollows material) can be isolated directly by dividing the planet as a whole by a reference spectrum and then calculating a band depth ratio. Murchie et al. [10] found that the most successful ratio for mapping the LRM was calculated by first dividing the full mosaic by a reference spectrum of the northern volcanic plains, and then calculating the ratio as:

$$\boxed{\sim 600\ nm\ band\ depth = 1 - \left[\frac{(R560 + R630 + R750 + R830)/4}{(R900 + R480)/2}\right]}$$

where R is photometrically corrected reflectance in each of the given filters. Figure 1 presents a comparison between a simple 3 band color image, a 3-band enhanced color image using PC1 and PC2, and an enhanced color image using 600 nm band depth, albedo at 560 nm, and 430/1000 nm slope.

Global Results: Unlike the PCA-derived enhanced color composite, which separates all spectral diversity on Mercury and highlights the full diversity of the planet, the enhanced color composite shown in Fig. 1b focuses on examining properties of the LRM and hollows material. Both types of material exhibit a shallower spectral slope than average Mercury, and a curvature that is captured in the 600-nm band depth. The obvious difference is in the albedo, with hollows being extremely bright and LRM extremely dark, resulting in hollows appearing cyan, and LRM appearing blue. An example of Basho crater is shown in Fig. 2. The similarity in the band depths for hollows and LRM does not necessarily imply that the 600-nm curvature has to be due to hollows, however. As can be seen in Fig. 1, fresh deposits such as crater ejecta is clearly cyan as well, due to the bluer slope of fresh material.

Initial Findings: Shown in Fig. 2a are spectra from several regions with strong 600-nm signatures, including LRM as well as hollows and a distinctive impact melt flow. The LRM spectra are remarkably similar in slope and albedo, though subtle differences can be seen when ratioed to a Northern Volcanic Plains (NVP) spectrum to remove some slope effects and residual filter-to-filter artifacts (Fig. 2b). The regions with strong 600-nm bands that are not obviously rich in LRM are shown in Fig. 3. In the case of Basho, both the LRM ejecta and the hollows in the crater floor and walls exhibit strong 600-nm features, though the LRM forms a distinct region when albedo and band depth are examined as a function of one another.

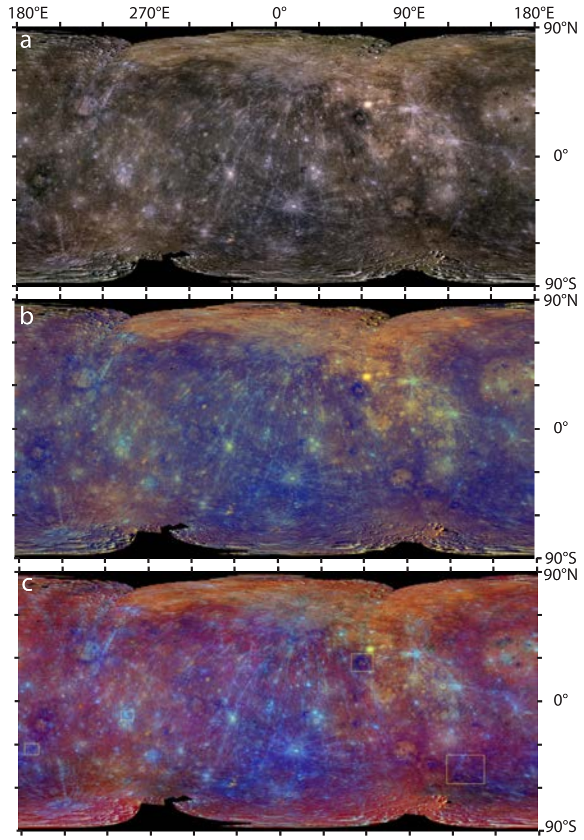

Fig. 1. (a) False color global map of Mercury with R=1000 nm, G=750 nm and B=430 nm. LRM shows up as dark bluish-black material, and grades into the slightly brighter LBP. (b) Enhanced color composite of Mercury with R=PC1, G=PC2, B=430/1000 nm slope. (a&b adapted from [10]). (c) Enhanced color composite of Mercury with R= ~600-nm broad band depth (inverted, stretched from 0-6% band depth), G=560 nm albedo (stretched from 0-10% albedo), B=430/1000 nm slope (stretched from 0.396-0.593). From left to right, boxes show the locations of Basho crater, Waters crater, Rachmaninoff basin, and the region around Neruda and Sher-Gil craters.

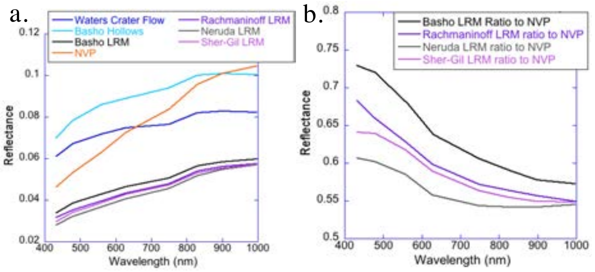

Fig. 2. (a) Spectra from each of the four regions from Fig. 1, including LRM, the "blue tongue" flow at Waters crater, and hollows in Basho crater. Also included is a reference spectrum of a typical region of the northern volcanic plains (NVP). (b) Comparison of LRM spectra ratioed to the NVP spectrum.

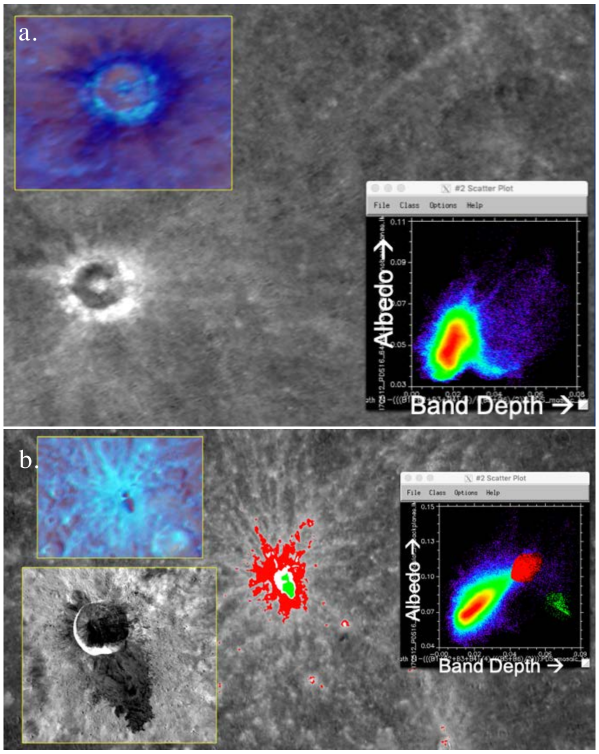

Fig. 3. Band depth map and scatter plot of (a) Basho and (b) Waters craters. The insets for each include an enhanced RGB of the crater and a scatter plot of albedo vs. band depth. For Waters, a high-resolution monochrome image of the flow is also shown. The tail on the Basho scatter plot is LRM ejecta.

At Waters, the region is generally free of obvious LRM, though the melt tongue exhibits a strong 600-nm signature and a lower albedo than the crater ejecta. The proximal ejecta exhibits the highest 600-nm band depth outside of the impact melt flow, but band depth and albedo are almost perfectly correlated throughout this whole region. We will present these and other areas that contain both hollows and LRM at high resolution, testing different hypotheses for the cause of the 600-nm feature.

Acknowledgments: We are grateful to the NASA PMDAP program for supporting this work (#NNX14AM93G).

References: [1] Hapke, B. et al. (1975) *JGR* 80, 2431. [2] Robinson, M.S. et al. (2008) *Science* 321, 66. [3] Nittler, L.R. et al., (2011) *Science* 333, 1847. [4] Evans, R.G. et al. (2012) JGR 117, E00L07. [5] Peplowski, P.N. et al. (2016) *Nat. Geosci*. 9, 273-278. [6] Head, J.W. et al., (2011) *Science* 333, 1853–1856. [7] Whitten, J. L., et al. (2014) *Icarus* 241, 97-113. [8] Denevi, B.W. et al., (2013) *JGR Planets* 118, 891–907. [9] Klima et al. (2018) *GRL*. [10] Murchie, S.L. et al. (2015) *Icarus* 254, 287.