MESSENGER GLOBAL COLOR OBSERVATIONS: IMPLICATIONS FOR THE COMPOSITION AND EVOLUTION OF MERCURY'S CRUST.

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Introduction: MESSENGER's first two flybys of Mercury provided near-global observations of the surface with the two cameras that comprise the Mercury Dual Imaging System (MDIS) [1]. Combined with Mariner 10 images [2], over 90% of the surface has now been viewed by spacecraft. These data provide the first opportunity to perform a global assessment of Mercury's major geologic units and their significance.

Mapping: Enhanced color mosaics created from the 11 color filters (430-1020 nm) of the Wide Angle Camera (WAC) at resolutions of 2.8-5.0 km/pixel were used in tandem with the higher-resolution (0.5 km/pixel) monochrome (750 nm) Narrow Angle Camera (NAC) mosaics to map surface units on the basis of both color and morphology. Areas of MDIS mosaics with high Sun illumination, disadvantageous for viewing morphology, were supplemented with the Mariner 10 clear-filter mosaic (1 km/pixel) [3] in regions of overlap; otherwise these high-Sun areas were excluded. Mercury's major surface units all share red-sloped spectra without strong crystal-field absorptions, and thus color variations among units are solely due to changes in the steepness of the red slope.

Major Units: The majority of Mercury's surface can be subdivided into three units based on color and morphology: smooth plains (SP), intermediate terrain (IT), and low-reflectance material (LRM).

Smooth plains. Areas mapped as smooth plains have a lower density of impact craters and typically are seen to fill low-lying areas. Their reflectance and spectral slope vary from unit to unit, and three type examples are identified: high-reflectance red plains (HRP), intermediate plains (IP), and low-reflectance blue plains (LBP). Reflectances at 750 nm range from 35% higher than the global mean (HRP) to 15% lower than the global mean (LBP), and a decrease in spectral slope of ~3% is observed from HRP to LBP (Fig. 1).

Intermediate Terrain. This unit includes areas with a higher crater density than smooth plains and generally corresponds to regions mapped as intercrater plains in Mariner-10-based work. The reflectance and color properties are similar to the global mean.

Low-reflectance material. The LRM is defined by its low reflectance (up to 40% below the global mean) and shallower spectral slope (~5% lower 430/1000 nm ratio than the HRP; Fig. 1). It occurs both as broad regions with diffuse margins and concentrated in "centers" typically comprised of crater or basin ejecta.

Global Stratigraphy: Smooth plains are widespread on Mercury, covering ~40% of the surface, and they are globally distributed. Individual deposits range from tens of km^2 to 1.7 million km^2 (Caloris interior plains), rivaling the size of the largest flood basalt units on the Earth or Moon. The majority of smooth plains are likely of volcanic origin [4], though impact melt and basin ejecta remain a plausible explanation for a subset of smooth plains. Vast expanses of smooth plains deposits with features diagnostic of volcanically emplaced materials, like those of the Caloris basin interior [4,5], demonstrate that volcanism was extensive on Mercury. In many areas a sequence of several generations of smooth plains can be observed, and intercrater plains of the IT may simply be older, degraded smooth plains. Crater excavation relationships demonstrate that smooth plains are greater than 5 km thick in some areas [6]; together with the widespread distribution of smooth plains, these observations suggest that much of the crust may have been built up through voluminous volcanic eruptions.

The LRM covers at least 15% of Mercury, and individual regions of LRM can be greater than four million km^2. Due to the diffuse nature of typical LRM deposits, most of its boundaries are mapped as approximate. At least 65 craters and basins greater than 20 km in diameter exhibit some form of LRM ejecta, implying depths of origin of the LRM from several km to greater than 25 km. The observation that regional LRM deposits are often without clear morphologic boundaries (aside from distinct margins in crater and basin ejecta, or where embayed by smooth plains) and occur as thin surficial deposits in many locations, indicates a subsurface origin through impact excavation and subsequent distribution across the surface as an ejecta veneer. LRM source material could originate as a component of the lower crust or upper mantle redistributed on the surface as basin ejecta. However, the absence of LRM in the ejecta of many large impact craters demonstrates heterogeneous distribution of its source material throughout the crust both horizontally and vertically (Fig. 2). Alternatively, the regional diffuse LRM deposits may have originally been volcanically emplaced as intrusive or extrusive (LBP-like) deposits, now degraded and mixed through impact gardening.

Composition: Mercury's average reflectance is similar to, or lower than, the reflectance of the integrated lunar nearside [e.g., 7], 30% of which is covered by high-Fe, high-Ti basalts. Mercury's reflectance cannot be ascribed to differential space weathering of a lunar-like anorthositic crust, as immature materials on Mercury are also up to 30% lower in reflectance than comparable material on the Moon [3,8], indicating that Mercury's crust is not anorthositic, but instead possibly rich in enstatite and/or forsterite (which have reflectances lower than that of anorthite). The spectral gradation from HRP to IP to LBP to LRM suggests the possibility that a single mineral is controlling the major variations in reflectance and color on Mercury, with HRP and LRM representing compositional end-members. What is this mineral?

Iron, titanium, and carbon are the most cosmochemically abundant elements that contribute to strong absorption at ultraviolet through near-infrared wavelengths. Carbon is unlikely to be responsible, as it is effectively sequestered to the core during early planetary differentiation and lost through volatilization in volcanic eruptions. Thus iron and titanium are the most likely constituents, though the lack of a 1-µm band [8-12] requires that the iron content of silicates is low (<6 wt%) [e.g. 13]. Fe-Ti oxides such as ilmenite ($FeTiO_3$), armalcolite ($MgFeTi_2O_5$), and ulvöspinel (Fe_2TiO_4) match the spectral characteristics of the LRM because of their Fe-Ti charge transfer absorptions, without exhibiting a 1-µm band. Early crystallization of ilmenite under reducing conditions (near iron-wüstite) from a Ti-rich, relatively FeO-poor melt limits FeO incorporation into later-crystallizing pyroxene. Preliminary radiative transfer modeling based on the equations of Hapke [14-17] suggests that abundances of up to 10-15% ilmenite are required to match MDIS spectra of the IT and up to 30-40% ilmenite for spectra of LRM centers, if modeled as a combination of HRP and ilmenite. Neutron Spectrometer (NS) measurements of thermal neutron absorption obtained during MESSENGER's first flyby of Mercury were initially interpreted to indicate less than 6 wt% Fe, if all absorption were due to Fe, and significantly lower if Ti, Sm, or Gd were also present [18], leading to the supposition that high abundances of ilmenite could not reflect the average composition of surface material [19]. However, initial NS results did not include a model of spacecraft interaction with neutrons, likely to have a major effect on the results [20], and the NS footprint was dominated by IT. Few minerals have both the low reflectance and neutral spectrum required to match the characteristics of the LRM. Until further geochemical data are in hand, Fe- and Ti-bearing oxides remain a possible cause of the low-reflectance and relatively blue nature of the LRM.

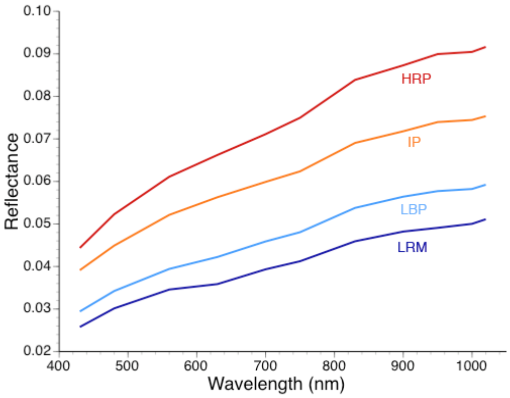

Fig. 1 Preliminary MDIS spectra (photometrically corrected to i=30°, e=0°) of the three type examples of smooth plains and the LRM.

If indeed the LRM centers, whose source material exists only as deposits at depth, have a significant abundance of Fe-Ti oxides, one can speculate that they are magmatic cumulates whose density inhibited their eruption to the surface. In this scenario the HRP-LBP lavas could be the residual melt containing a smaller fraction of the dense Fe-Ti oxides, facilitating their eruption to the surface.

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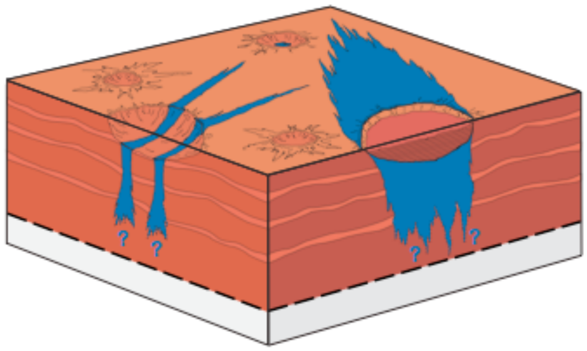

Fig. 2. Proposed excavation and surficial redistribution of material with relatively low reflectance and blue (less red) spectral slope. If this material contains significant amounts of ilmenite it may have formed as an early cumulate from high-TiO_2 and low-FeO melt. The sectioned crater on the left shows the morphology of LRM streamers, like those of Mozart crater. On the right, continuous LRM ejecta with lava fill of the basin (indicated in red) as observed at Tolstoj.