INVESTIGATIONS INTO THE ORIGIN OF MERCURY'S HIGH-MAGNESIUM REGION. Elizabeth A. Frank[1*], Ross W. K. Potter[2], Oleg Abramov[3], Stephen J. Mojzsis[4], Larry R. Nittler[1]. [1]Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, DC 20015, USA. [2]Department of Earth, Environmental and Planetary Sciences, Brown University, Providence, RI 02912, USA. [3]United States Geological Survey, Astrogeology Science Center, Flagstaff, AZ 86001, USA. [4]Department of Geological Sciences, University of Colorado, Boulder, CO 80309, USA. *email: efrank@ciw.edu

Introduction: During its three flybys and four years in orbit around Mercury, the MESSENGER (MErcury Surface, Space ENvironment, GEochemistry, and Ranging) spacecraft mapped Mercury's surface chemistry primarily using an X-Ray Spectrometer (XRS). The XRS measured Mg, Al, Si, S, Ca, Ti, and Fe and revealed a surface that is less chemically diverse than that of the Moon yet surprisingly S-rich and Fe-poor [1-3].

Despite its narrow range of compositions, Mercury's surface still shows clear chemical heterogeneities [4] that are indicative of the presence of more than one chemical mantle reservoir [5]. In particular, several "geochemical terranes" of distinct composition have been identified, including the high-Mg region (HMR), a large area in the northern hemisphere that hosts the highest Mg/Si, S/Si, Ca/Si, and Fe/Si and lowest Al/Si ratios on the planet [4]. This vast area covers roughly 10^7 km^2, ~15% of Mercury's surface, and we arbitrarily define it as the large, contiguous region in the northern hemisphere with Mg/Si >0.5 (Figure 1). Using the finalized XRS maps presented at this meeting by [6], here we will explore and test possible scenarios for how Mercury's high-Mg region may have formed.

Comparison with other datasets: The origin of the HMR was first considered in [4]. It was noted that there is a sharp topographic boundary in the north with a plateau that is adjacent to the northern volcanic plains. Additionally, the HMR has an inferred crustal thickness lower than the global average, ~25 km versus a global average of ~35 km [7]. This evidence was used by [4] to suggest a possible impact origin for the HMR, wherein the topographic boundary is a remnant basin rim.

The other MESSENGER datasets provide few additional constraints on the origin of this region. There are no clear correlations with albedo, reflectance, or color [8]; there are no mascons lurking beneath the surface [9]; and the crater density of the HMR spans a wide range [10]. It is important to note, however, that given how early in Mercury's history this impact would have occurred (at least ~3.8 Ga [11]), it is possible that evidence of an impact basin in these observations would have been erased over the following several billion years.

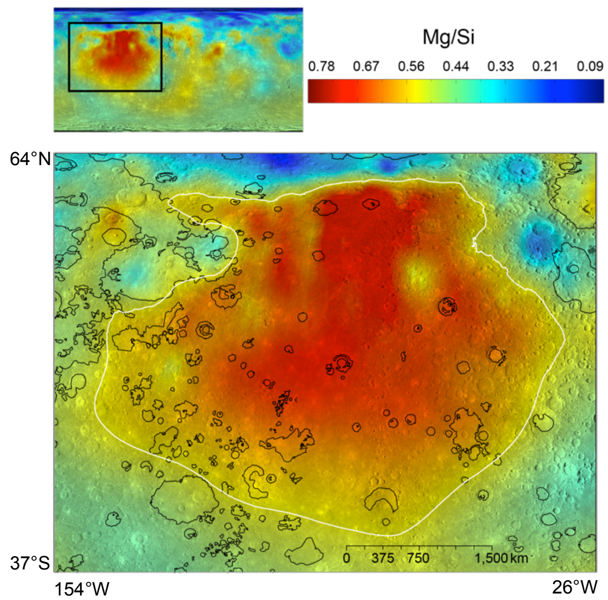

Figure 1. Mercury's high-Mg region (HMR). The top left map shows the global Mg/Si coverage [6], with the HMR indicated by the box. In the bottom map, the black lines are smooth plains, while the white line indicates the HMR boundary defined by Mg/Si >0.5.

Origin scenarios: We pose several different scenarios for the origin of the HMR, some aspects of which are testable.

(1) *Mantle excavation*. A large and/or high-velocity impactor hit Mercury prior to its global resurfacing 4.0 to 4.1 Ga [12], penetrating the crust and excavating the upper mantle. Mg-rich mantle material contaminated the surface, perhaps becoming mixed into the uppermost crust via impact gardening.

(2) *Impact-related volcanism*. In much the same way that smooth plains are found in even small impact craters [13], an impact (not necessarily of the same size as the HMR) can reset the stress regime of the underlying crust, permitting volcanism at some later time despite global contraction otherwise constricting the flow of magma to the surface.

(3) *Volcanism unrelated to an impact*. Large volcanic provinces on Mercury, such as the northern volcanic plains, demonstrate that the emplacement of large igneous provinces took place at least ~3.8 Ga

[10]. It is highly probable that similar activity would have taken place at earlier times.

(4) *Chemically heterogeneous mantle*. Given how thin Mercury's silicate shell is (420 km [14]), it would be difficult to fully homogenize Mercury's mantle, leading to both vertical and lateral heterogeneities [15]. Indeed, petrological experiments and modeling show that more than one mantle chemical reservoir is required to explain Mercury's surface composition [5].

These scenarios are not mutually exclusive, and the HMR emplacement almost certainly involved volcanism and mantle chemical heterogeneities. The involvement of an impact, however, remains an open question.

Impact modeling: To test the physical plausibility of an impact origin for the HMR, we have employed the shock physics code iSALE, which has been used to model the Caloris impact on Mercury [16] and, more extensively, impacts on the Moon [e.g. 17]. The target was modeled as a half-space using crusts between 10 and 35 km thick, with the remainder of the 420-km-thick silicate shell [14] designated as mantle with an iron core below. Crustal thickness was varied under the supposition that Mercury's crust would have been thinner prior to volcanic resurfacing. Following [16], semi-analytical equations of state for basalt, dunite, and iron were used to simulate Mercury's crust, mantle and core, respectively. The impactor's diameter was varied between 100 and 300 km, and its velocity varied between 20 and 42 km/s. A grid cell size of 5 km was used.

Discussion: Preliminary shock physics simulations indicate that the magnitude of an impact is such that crustal thickness is irrelevant. Mantle material is easily excavated; even the core-mantle boundary is affected (Figure 2). Further work using tracer particles to track the precise flow of material is required for more quantitative results, but the ease of excavation is expected to hold true with additional testing.

The primary challenge with the HMR mantle excavation hypothesis is that a region of thin crust and a possible rim would be all that currently remains of the basin; volcanic resurfacing is presumably required to erase other clear morphological features. Yet at the same time, the chemical signature of deposited mantle material must be preserved despite resurfacing with perhaps kilometers of lava. The signal must also be detectable by the XRS, which only penetrates a few tens of microns into the surface. Furthermore, the HMR is fairly homogeneous, not showing any radial variation in composition as expected from impact ejecta [18]. Thus, mantle excavation from an impact is unlikely to be the primary cause of the HMR.

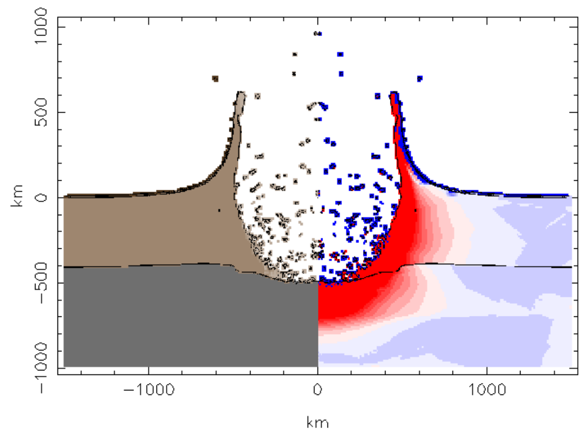

Figure 2. Frame from an iSALE simulation 4.33 minutes following the impact of a projectile with a diameter of 200 km and velocity of 42 km/s. The left side shows material: crust (not visible on this scale), mantle (beige), and core (gray) The right side shows temperature (blues are lows; reds are highs). This frame shows the transient crater, which not only penetrates the mantle but also perturbs the core-mantle boundary.

Due to the aforementioned detection issue, the unique chemistry of the HMR is probably tied to ancient volcanic plains of an ultramafic composition. It is difficult to definitively rule out the influence of an impact on the HMR since volcanism is required to hide most, if not all, structural evidence of it; indeed, perhaps an impact delivered the required thermal boost required to attain such anomalously high degrees of partial melt. While it is clear that an impact can set the stage for later volcanism [11], quantifying that effect remains an area for further study.

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