COMPOSITIONAL HETEROGENEITY ON MERCURY'S SURFACE REVEALED BY MESSENGER'S X-RAY SPECTROMETER

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Introduction: The X-Ray Spectrometer (XRS) [1] on MESSENGER uses the technique of planetary X-ray fluorescence (XRF) [2,3] to measure the abundances of major rock-forming elements (*e.g.*, Mg, Al, Si, S, Ca, Ti, Fe) in the uppermost ~100 µm of Mercury's regolith. XRF data are obtained both under quiet-Sun conditions and during solar flares; larger flares induce XRF of heavier elements. Results published so far [4] were obtained mainly during solar flares that occurred when the spacecraft was at high altitudes, so the XRS footprints on the planet's surface were large and incorporated regions of mixed terrain. These results [4] revealed that Mercury's surface is relatively Mg-rich, but Al- and Ca-poor compared to typical terrestrial and lunar crusts. In terms of these elements, the bulk surface composition is intermediate between basaltic and komatiitic compositions. The XRS results also revealed a surface rich in S (up to ~4 wt %) and poor in Ti and Fe. These results are consistent with a scenario whereby Mercury formed under highly reducing conditions, perhaps from material akin to the enstatite chondrites. More recently, solar-flare-induced XRF data have been obtained at lower altitude and thus for smaller, spatially resolved regions. In early results [4] from one spatially resolved flare (16 April 2011) compositional variation was seen along the XRS ground track. With these new data, it is possible to investigate in more detail if different geological terrains are compositionally distinct.

Geological terrains. Three major geological terrain types have been identified on Mercury [5] including the smooth plains that cover ~40% of the surface and are thought to be mostly volcanic in origin. This category includes the northern volcanic plains, a product of flood volcanism at high northern latitudes covering ~6% of Mercury's surface [6].

Data: Using the forward modeling procedure of Nittler et al. [4] to fit the observed XRS spectra, we report compositional results from five solar flares that occurred during September 2011 as examples from the continually growing XRS dataset. The ground tracks for these flares are shown in Fig. 1. Each flare (represented in Fig. 1 by a different color) has been divided into a number of individual integrations (each <100 s in duration; for the majority the integration time is 40 s), as illustrated by the small circles. The individual footprints can be split into two groups: those that fall within the northern volcanic plains (NVP) and those that are outside this unit. Results from footprints that straddle the boundary are not included here.

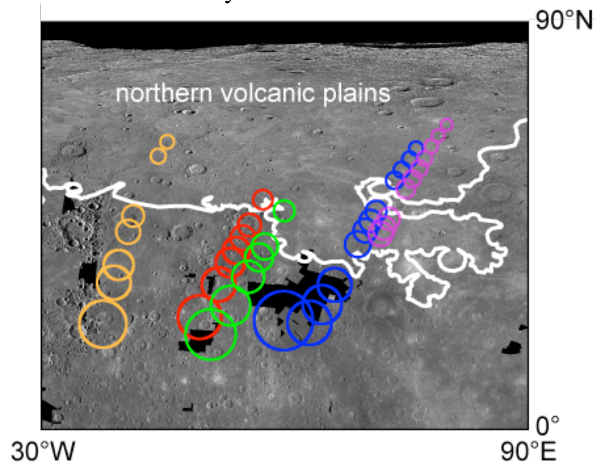

Figure 1. Approximate footprints of five solar flares (15 Sep 2011: pink, 16 Sep 2011: blue, 19 Sep 2011: green, 20 Sep 2011: red, 25 Sep 2011: orange) along ground tracks that cross the boundary of the northern volcanic plains (white line). Each circle represents an individual integration from which data are presented.

Results: Elemental ratio results (the Si abundance is fixed in the spectral modeling to 25 wt %) for the five solar flares are illustrated in Fig. 2. The plot of Mg/Si vs. Al/Si (Fig. 2a) illustrates that the composition of NVP areas are generally offset (lower Mg/Si) from those outside the NVP (non-NVP). This result suggests that the younger NVP are compositionally different (and more similar to typical basalts) from the non-NVP terrain immediately to its south (more ultramafic). These findings are consistent with the previously published results [4] but incorporate a wider range of compositions in terms of both Mg/Si and Al/Si ratios. The correlation first reported [4] between Ca and S is amply confirmed by these latest observations (Fig. 2b) and provides evidence that the abundant S on Mercury's surface may be contained within sulphides such as oldhamite (CaS).

The short integration times of the spectra analyzed here, combined with the relatively weak nature of the solar flares (maximum flare temperature here is ~17 MK), means that the signal-to-noise (S/N) ratio for elements heavier than Ca (*e.g.*, Ti, Mn, Fe) in the spectra is low, and reliable quantitative estimates of the abundances of these elements cannot be made.

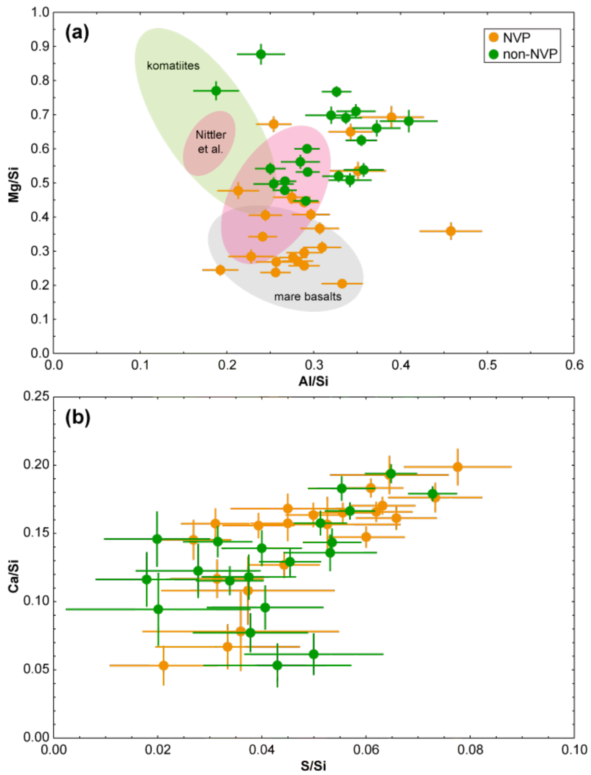

Figure 2. Mg/Si vs. Al/Si and Ca/Si vs. S/Si for the areas shown in Fig. 1. Footprints within and outside the northern volcanic plains (NVP) are grouped. The top panel also shows the fields of terrestrial komatiites, lunar mare basalts, and the results presented by Nittler et al. [4]. Error bars denote one-standard-deviation (1-σ) fitting errors.

Discussion: A potential compositional difference between the NVP and non-NVP footprints is most evident in terms of Mg/Si. For the other three elemental ratios (Al/Si, Ca/Si, S/Si) derived and presented here, the two populations show a similar range in values. The relationship between derived Mg/Si and solar temperature for each of the individual spectra is shown in Fig. 3. This plot illustrates that the inter-flare variation in Mg/Si is generally greater than the intra-flare variation, which often includes a difference in underlying geological terrain. It must therefore be considered whether the Mg/Si results have a dependence on flare temperature, which would have to be addressed prior to making conclusions regarding compositional differences. Earlier results [4] were presented as averages of several individual footprints for each flare. The intra-flare variability was taken as a measure of the systematic uncertainties in the analysis. Of the elemental ratios derived from the XRS spectral fitting, Mg/Si is the most sensitive to uncertainties in the solar spectrum modeling (for temperatures <10 MK). This may be the reason why only the Mg/Si results hint at a temperature dependence in the data presented here.

Three flares (19 Sep, 20 Sep, 25 Sep) have a similar range in temperature (~9 – 11 MK) and have the highest derived Mg/Si ratios. Most of these footprints are outside the NVP; the few points that correspond to NVP footprints do not display any consistent offset in terms of Mg/Si. Two flares (15 Sep, 16 Sep) with higher temperatures (up to ~17.5 MK) have lower Mg/Si values. The 16 Sep flare includes both NVP and non-NVP footprints, and the non-NVP points tend toward higher Mg/Si (if this were a temperature effect, the lower temperature points would have higher Mg/Si values). The 15 Sep flare contains only NVP footprints, but those that are derived from solar temperatures similar to those of the non-NVP footprints during the 16 Sep flare have substantially lower Mg/Si.

The Mg/Si offset between NVP and non-NVP footprints is clearer in the data from the higher-temperature flares. It may therefore be necessary to discount, or correct, flares below a certain temperature (*i.e.*, those with poorer S/N ratios) in order to confidently ascribe differences in derived Mg/Si ratios to true compositional variability. This issue should become clearer as the amount of suitable data analyzed increases.

The stronger solar flare results support the original observation, made from Fig. 2 and the 16 Apr flare data [4], that the NVP have lower Mg/Si than their surroundings. A compositionally distinct NVP is also observed in terms of K by the MESSENGER Gamma-Ray Spectrometer [7].

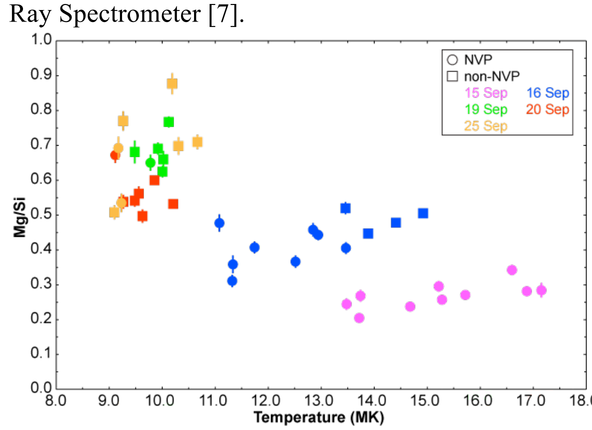

Figure 3. Mg/Si for each of the footprint areas from the five solar flares, as a function of solar temperature (in millions of Kelvins). The areas are split between those within the NVP and those outside (non-NVP) and by solar flare date. Error bars denote the 1-σ fitting errors only.

References: [1] Schlemm C.E., II et al. (2007) *Space Sci. Rev., 131,* 393-415. [2] Yin L.I. et al. (1993), in Pieters C.M. and Englert P.A. (Eds), *Remote Geochemical Analysis, Elemental and Mineralogical Composition*, Cambridge, 199-212. [3] Clark P.E. and Trombka J.I. (1997) *JGR, 102,* 16,361-16,384. [4] Nittler L.R. et al. (2011) *Science,* 333, 1847-1850. [5] Denevi B.W. et al. (2009) *Science, 324,* 613-618. [6] Head J.W. et al. (2011) *Science, 333,* 1853-1859. [7] Peplowski P.N. et al. (2012) *LPS, 43,* this mtg.