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Regional-scale chemical heterogeneity on Mercury

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1. Introduction

The MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft's geochemical payload includes the X-Ray Spectrometer (XRS) and Gamma-Ray Spectrometer (GRS). Since MESSENGER entered into orbit around Mercury in March 2011, data from these sensors have been used to characterize the chemical composition of Mercury's surface in detail for the first time. Early orbital results revealed that the surface is rich in Mg, but Al- and Ca-poor compared with typical terrestrial and lunar crustal materials [1–3]. In addition, detections of abundant S, Na, and K revealed that Mercury is not volatile-depleted compared with the other terrestrial planets [1, 3, 4]. Low total Ti and Fe contents for surface materials have also been confirmed [1, 3]. These results suggest that Mercury formed via the accretion of highly reduced materials at conditions of high temperature and pressure. The planet may have experienced a subsequent giant impact event that resulted in the planet's large metal-to-silicate ratio.

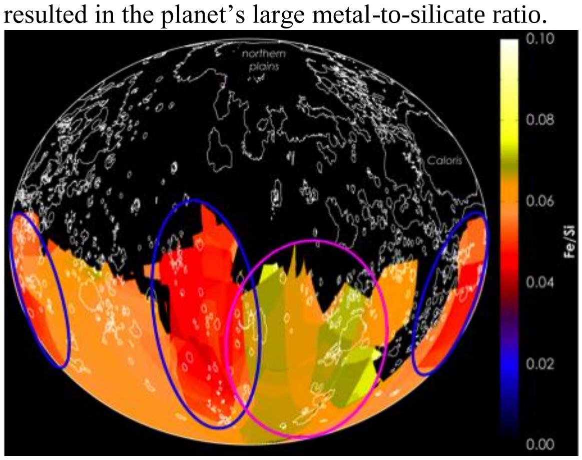

Figure 1. Map of Fe/Si on Mercury's surface (Mollweide projection centered on 0° E) derived from 66 flare observations. Smooth plains deposits [6] are outlined in white. Large-scale regions with lower (blue) or higher (pink) Fe/Si than average are marked by ellipses.

2. Mapping chemical heterogeneity

As the MESSENGER mission progresses, the XRS continues to collect data that can be used to investigate chemical variations across Mercury's surface. During solar flares, X-rays emitted from plasma high in the Sun's atmosphere excite atoms on Mercury's surface and cause characteristic X-ray fluorescence emission. During weak solar flares, or "quiet-Sun" periods (plasma temperature T_p <8 MK), only Mg, Al, and Si can be measured by the XRS. As the strength of the solar activity increases, elements of higher atomic number, Z, can be detected, i.e., S and Ca; during the strongest solar flares (T_p>13.5 MK), data for elements with Z up to that of Fe can be obtained. Through a combination of flare and quiet-Sun data analyses, we can now map the abundances of several elements over a substantial fraction of the planet's surface.

XRS results [5] so far have shown that large expanses of volcanic smooth plains in the northern lowlands and the Caloris basin are compositionally different (with lower Mg/Si, S/Si, and Ca/Si, and higher Al/Si) from the older intercrater plains and heavily cratered terrain (IcP-HCT) that surround them. These different compositions are thought to be due to different degrees of partial melting of separate, chemically distinct mantle source regions at different stages in Mercury's evolution [5].

A map of the Fe/Si ratio across Mercury's surface, constructed from over 65 of the strongest solar flare analyses is shown in Figure 1. The mean Fe/Si value is ~0.06 (~1.5 wt % Fe); we assume a bulk Si abundance of 25 wt %. Although absolute Fe/Si values may be underestimated because of systematic uncertainties in the XRS Fe analysis, relative differences are more robust. There is no coverage for the northern hemisphere in this map, but modest, yet significant (at greater than two standard deviations) large-scale variations are evident in the southern hemisphere. Two regions have Fe/Si ~20% lower than average, and a separate region has Fe/Si ~10% higher than average. Maps of Mg/Si, Al/Si, S/Si, and Ca/Si, include data from several flares (including those previously analyzed [5]) and 10 months of quiet-Sun analyses, are shown in Figure 2. A region of high Mg/Si, S/Si, and Ca/Si, and low Al/Si (representing mainly the region of IcP-HCT reported earlier [5]) is not representative of all the older terrain (i.e., older than smooth plains [6]) on Mercury. The extent of this region does not obviously correlate with any geological units or distinctive spectral characteristics determined from MESSENGER images.

GRS abundance results for K and Na also reveal variations across Mercury's northern hemisphere. Rather than being solely a function of underlying lithology, however, the abundances of these volatile elements are also likely subject to a surface heating process that mobilizes and redistributes these elements from equatorial and hot-pole regions to the exosphere and/or the polar regions [7, 8].

3. Summary

We continue to investigate the compositional heterogeneity of Mercury's surface, which provides important clues to the contributions of endogenous and possibly exogenous components, as well as surface processes that may have modified the distribution of several of the more volatile elements.

References

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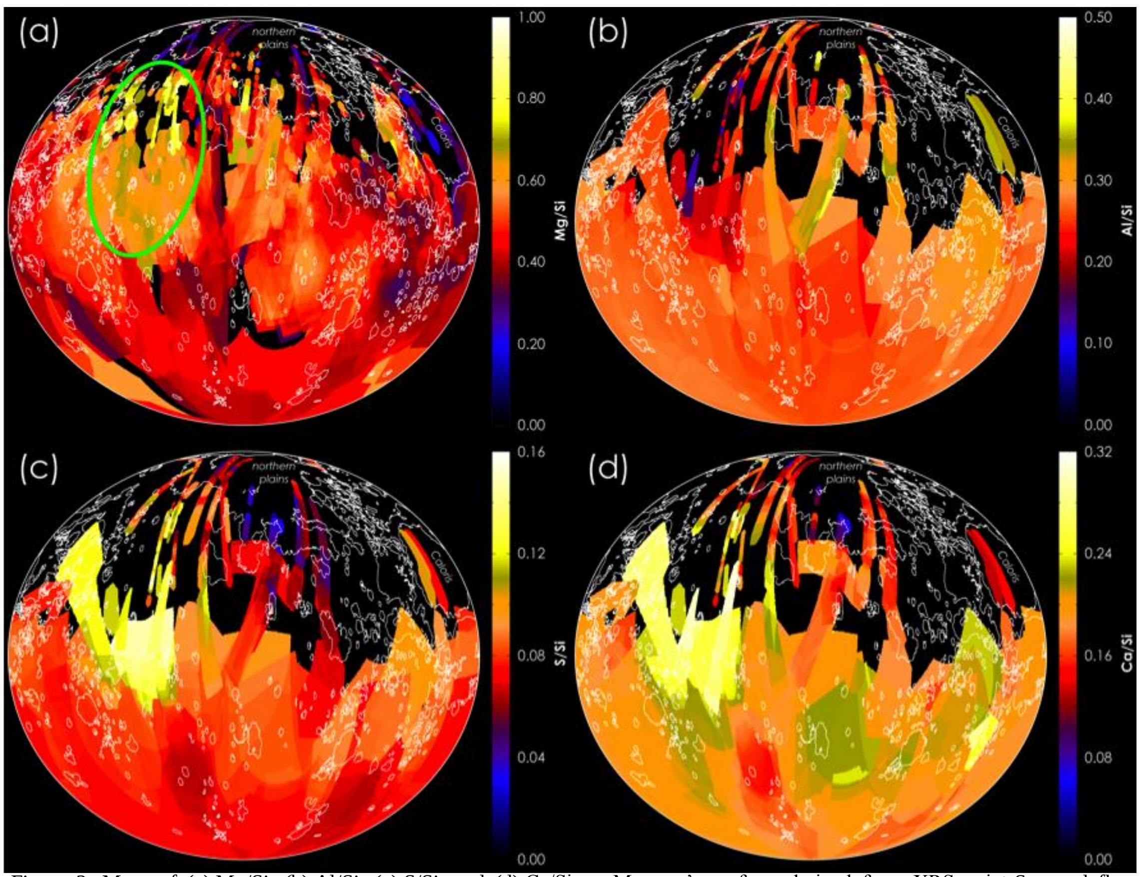

Figure 2. Maps of (a) Mg/Si, (b) Al/Si, (c) S/Si, and (d) Ca/Si on Mercury's surface, derived from XRS quiet-Sun and flare analyses. A region of high Mg/Si, S/Si, and Ca/Si, and low Al/Si outside the northern plains is marked by a green ellipse. Projection and smooth plains boundaries are the same as in Figure 1.