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Partitioning of sulfur between core and mantle on early Mercury and its building materials

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Owing to its large density, the planet Mercury is believed to have a large metallic core covered with a relatively thin rocky mantle. Recently, measurements by MESSENGER's X-ray and gamma-ray spectrometers have revealed the Mercury's surface composition (Nittler et al., 2011, Evans et al., 2012). One of its most unexpected findings is the high sulfur abundance as much as 1.9-2.7 wt% because sulfur is in general depleted in the lithosphere of a rocky planet due to the preferential partitioning to molten metal that segregated to form a planetary core. Therefore, it is an open question why Mercury has such a large amount of sulfur in its surface material. On the other hand, the measured surface iron abundance is 1.6-2.2 wt%. If all iron forms oxide, this abundance is equivalent to 2.1-2.8 wt% of FeO, which is much smaller than those in the crusts of Earth and Mars and consistent with ground-based observations of Mercury's reflectance spectra. From the comparison of the oxidation state of iron, Mercury has been speculated to be formed from FeO-depleted building materials like enstatite chondrite (EC) (Wasson, 1988).

If Earth's geochemistry is simply applied for Mercury, the sulfur abundance in the lithosphere is expected to be very low. However, it has been known that sulfur becomes more soluble into silicate melt under reduced conditions depleted in FeO. Therefore, the extremely high abundance of sulfur on the surface of Mercury might come from sulfur partitioned to silicate melt when the Mercury's core formed.

Here, we study partitioning of sulfur between core and mantle during the formation of Mercury by using an empirical sulfide capacity model (Taniguchi et al. 2010) and attempt to estimate the Mercury's building materials from its surface composition. For the description of sulfur partitioning, the oxygen fugacity fO_2 and sulfur fugacity fS_2 are important. They are calculated by considering chemical equilibrium between silicate melt and metallic melt. The starting composition of Mercury's building material is prepared from the mean composition of EC. The silicate melt is the mixture of oxides and non-Fe sulfide components and the metallic melt is the mixture of metallic iron and iron sulfide components with keeping relative elemental abundances in EC, respectively. This will be referred to as the standard composition. In order to analyze compositional dependence, the ratios of FeO/S, [non-Fe sulfide]/Si in starting silicate melt and S content in starting metallic melt are varied, respectively. The pressure dependence is also estimated over 1-10 GPa from the volume changes of the partitioning reaction. The temperature is assumed to be 2000 K.

Given the standard composition, the equilibrium sulfur and FeO concentrations in silicate melt are estimated to be 1.6 wt% and 0.024 wt%, respectively. Compared with the Mercury's surface composition, the calculated sulfur content is fairly consistent whereas the FeO content is too small to account for the observed iron content. The sulfur content in silicate melt decreases when FeO/Si ratio increases and FeO content decreases when [non-Fe sulfide]/Si ratio increases. Furthermore, FeO content increases up to about 0.06 wt% when the sulfur content in metallic melt increases to about 50 mol% while the sulfur content in silicate melt little changes. The sulfur content in silicate melt is almost independent of pressure but the FeO content decreases as the pressure increases.

The sulfur content observed in Mercury's surface can be explained by wide range of building material compositions near EC. This supports the idea that Mercury was made from EC -like materials whereas the corresponding FeO content is too small to account for the observed iron content. Iron might have been additionally accreted on the surface of Mercury after core formation. Alternatively, a large impact might excavate metallic iron beneath the thin mantle and disperse its fragments over the Mercury's surface.

Keywords: Mercury, sulfur, partitioning