

Using mercury isotopes to trace the origin of volatile elements in terrestrial planets

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Variations in the abundances of moderately volatile elements (MVE) are key geochemical signatures distinguishing the terrestrial planets. The origins of these variations—whether due to nebular processes, planetary volatilization, differentiation, or late accretion—remain uncertain. Mercury (Hg), one of the most volatile MVEs and a strongly chalcophile element, exhibits significant mass-dependent (MDF) and mass-independent (MIF) isotopic fractionations. Traditionally used to trace biogeochemical cycling in surface environments, Hg is also among the few elements for which the solar composition is poorly constrained and its concentration highly variable in primitive meteorites, likely due to terrestrial contamination.

At the conference, we will present the Hg isotopic and elemental data obtained from Ryugu samples returned by the Hayabusa2 mission. To establish the Hg isotopic composition of the bulk silicate Earth (BSE), we analyzed samples least affected by crustal recycling—high ³He / ⁴He lavas from Samoa and Iceland—yielding $\Delta^{199}\text{Hg} = 0.00 \pm 0.10$, $\Delta^{201}\text{Hg} = -0.02 \pm 0.09$, and $\delta^{202}\text{Hg} = -1.7 \pm 1.2$ (2SD). We further demonstrate that Hg isotopes can be used to trace crustal recycling: terrestrial subaerially-derived materials exhibit negative $\Delta^{199}\text{Hg}$, whereas subaqueously-derived marine sediments show positive values. For example, HIMU-type lavas display positive $\Delta^{199}\text{Hg}$, reflecting the influence of altered oceanic crust in their mantle source.

Our extensive dataset on meteorites reveals that the BSE falls within the chondritic range for both MIF and MDF. Given that planetary differentiation is expected to fractionate Hg isotopes from chondritic compositions, we suggest that the mantle's Hg budget is primarily shaped by late accretion of chondritic material—consistent with the behavior of other volatile chalcophile elements (S, Se, Te). Distinct isotopic fractionation mechanisms—kinetic (magnetic isotope effect) and equilibrium (field shift effect)—produce different trends in a $\Delta^{199}\text{Hg}$ vs. $\Delta^{201}\text{Hg}$ diagram, enabling us to infer the mechanisms of volatile loss. Applying this approach to eucrite meteorites, we find that volatile depletion occurred under equilibrium conditions, consistent with loss during a magma ocean phase on the surface of the eucrite parent body, likely asteroid 4 Vesta.