AN IMPACT-VAPOR CONDENSATE FROM ASTEROID ITOKAWA: EVIDENCE FROM O AND Si ISOTOPES

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Introduction: Bulk lunar regolith is enriched in the heavy isotopes of O, Si, S, and K [1]. Vaporization of regolith during micrometeoroid impact causes Rayleigh distillation of the target material, resulting in isotopically heavy residue and light vapor. The vapor is thought to be mostly lost to space. However, volatile-rich alumina-poor (VRAP) glass that is complementary to high-alumina, silica-poor (HASP) evaporation residue is found in mature Apollo 16 regolith [2]. Regolith from asteroid Itokawa, an S-type asteroid sampled by JAXA's Hayabusa mission, also contains evidence of micrometeoroid impacts [3, 4]. Previously, we identified two adhering, μm-sized amorphous SiO_2 particles with multi-droplet porous textures, as well as nearby Ni-free metallic Fe, on the surfaces of two 30 μm regolith grains from Itokawa [4]. We hypothesize that the porous particles and metallic Fe are vapor condensates from an impacted ferromagnesian silicate target. To help test this hypothesis, we measured O and Si isotopes in the larger porous Itokawa particle and the underlying host olivine. We also measured a VRAP-like Al-poor, SiO_2-rich region in a 30 μm grain from Apollo 16 mature lunar regolith (61141).

Methods: A 5×5 μm FIB section containing the 1.5 μm porous adhering particle was removed from Hayabusa grain RB-DQ04-0091. The section was milled to a thickness of ∼1 μm and attached to a Cu TEM grid. A 10×10 μm FIB section of a quartz isotope standard was attached to the same grid. After TEM analysis, this grid was attached to a stainless steel bullet using C paint and coated with 15 nm of C for ion probe analysis. Apollo 16 lunar soil grains were attached to C tape along with isotope standards, embedded in epoxy, and polished, exposing the grains and standards in cross section. Using the UH Cameca ims 1280, we multicollected $^{16}O^-$, $^{17}O^-$, and $^{18}O^-$ for 30 s, jumped to $^{28}Si^-$, $^{29}Si^-$, and $^{30}Si^-$ for 30 s, then jumped to $^{56}Fe^{16}O^-$ for 4 s. We used a <3 pA Cs^+ primary beam focused to 250 nm and ∼5500 mass-resolving power for the monocollector EM ($^{17}O^-$, $^{30}Si^-$) to minimize interference from $^{16}OH^-$. We collected 128×128 pixel maps over a 5×5 μm raster for 100 cycles (2.5 hrs per analysis) for standards and unknowns.

Results: The porous Itokawa adhering particle has O and Si isotopic composition: $\delta^{18}O = -101 \pm 31‰$, $\delta^{17}O = -57 \pm 71‰$ and $\delta^{30}Si = -43 \pm 38‰$, $\delta^{29}Si = 6 \pm 30‰$. The Apollo 16 lunar soil SiO_2-rich region has O and Si isotopic composition: $\delta^{18}O = 34 \pm 12‰$, $\delta^{17}O = 43 \pm 29‰$ and $\delta^{30}Si = 4 \pm 13‰$, $\delta^{29}Si = -1 \pm 10‰$. All errors are 2σ.

Discussion: The porous Itokawa adhering particle has isotopically light O composition, consistent with a recondensed, Rayleigh-distilled vapor. The host Itokawa olivine, which the porous grain adheres to, was simultaneously measured to have normal O isotopic composition. The SiO_2-rich region of an Apollo 16 lunar regolith grain has isotopically heavy O composition, consistent with a residue fractionated by the Rayleigh process. The uncertainties in our silicon isotope measurements were slightly larger than the expected Rayleigh effect for both samples based on the O measurements. We conclude, based on its morphology, mineralogy, and isotopic composition, that the porous Itokawa particle is an impact-vapor condensate. The SiO_2 region of the Apollo 16 regolith is likely an evaporative residue, not VRAP glass.

References: [1] Clayton, R. N. et al. 1974. *5th LPSC* 1801. [2] Keller, L. P. & McKay, D. S. 1992. *22nd LPSC* 137. [3] Nakamura, E. et al. 2012. *PNAS* 109, E624. [4] Ogliore, R. C. & Dobrică, E. 2015. *46th LPSC* #1631.