Ivuna 隕石および Ryugu, Bennu サンプルに含まれる無水一次鉱物の起源

Anhydrous primary minerals in Ryugu, Ivuna, and Bennu

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Samples returned from asteroid Ryugu are chemically and mineralogically similar to CI chondrites [e.g., 1–3]. Both are predominantly composed of low-temperature aqueously formed secondary minerals, whereas high-temperature anhydrous primary minerals, such as olivine, low-Ca pyroxene, spinel, and hibonite, are rarely present. Using secondary ion mass spectrometry (SIMS; Cameca ims-1280HR at Hokkaido University), we performed O [4] and Al–Mg [5] isotope measurements of anhydrous primary minerals in samples of Ryugu and the Ivuna CI chondrite to constrain their origin.

Anhydrous primary minerals in our samples of Ryugu and Ivuna occur mostly as monomineralic isolated grains embedded in hydrated matrix. Their O-isotope compositions are distributed along the slope-1 line on the O three-isotope diagram and range from $\Delta^{17}O \sim -23$ to 0‰. Mg-Al spinel grains are ^{16}O-rich ($\Delta^{17}O \sim -23$‰). Low-Ca pyroxene grains are ^{16}O-poor ($\Delta^{17}O \sim -5$‰). Olivine grains show a bimodal distribution of O-isotope composition: 10 of 34 grains measured are ^{16}O-rich ($\Delta^{17}O \sim -23$‰) and 24 grains are ^{16}O-poor ($\Delta^{17}O \sim -7$ to 0‰).

We found refractory inclusions composed of Mg-Al spinel and hibonite, one from Ryugu and one from Ivuna. Also, in Ivuna, we found an amoeboid olivine aggregate (AOA) composed of olivine, diopside, anorthite, and Mg-Al spinel and an inclusion composed of olivine and Mg-Al spinel. The minerals in all of these inclusions are ^{16}O-rich ($\Delta^{17}O \sim -24$‰).

The ^{16}O-rich grains and inclusions are mineralogically and O-isotopically similar to calcium-aluminum–rich inclusions (CAIs) and AOAs reported in other carbonaceous chondrites [6, 7]. In addition, the initial $^{26}Al/^{27}Al$ ratios of the two spinel-hibonite inclusions are inferred as ~4.4×10^{-5}, also similar to most CAIs in carbonaceous chondrites [6, 8]. The range of $\Delta^{17}O$ values for the ^{16}O-poor olivine and low-Ca pyroxene grains is consistent with that of these minerals in chondrules in most carbonaceous chondrites [9]. Moreover, the most frequent $\Delta^{17}O$ value (–6‰) for Mg-rich (Mg# > 97) olivine grains is identical to those for chondrules. Although CI chondrites and Ryugu samples are devoid of chondrules, the ^{16}O-poor grains most likely represent fragments of chondrule-like objects. The presence of both ^{16}O-poor chondrule-like and ^{16}O-rich refractory inclusion–like minerals in Ryugu and Ivuna suggests that some of their building blocks are similar to those of other carbonaceous chondrite groups. They both probably formed in the inner solar protoplanetary disk and were subsequently transported outward.

Preliminary data for petrography of asteroid Bennu samples and chemical and isotopic compositions of their anhydrous primary minerals will also be presented in the meeting.

References: [1] Yokoyama et al. (2023) *Science* 379, eabn7850. [2] Nakamura et al. (2023) *Science* 379, eabn8671. [3] Noguchi et al. (2023) *Nat. Astron.* 7, 170–181. [4] Kawasaki et al. (2022) *Sci. Adv.* 8 (50), eade2067. [5] Miyamoto et al. (2024) this meeting. [6] Ushikubo et al. (2017) *GCA* 201, 103–122. [7] Fukuda et al. (2021) *GCA* 293, 544–574. [8] Kawasaki et al. (2020) *GCA* 279, 1–15. [9] Tenner et al. (2018) In *Chondrules*, 196–246.