Na-rich phase in Ryugu particle: Evidence for metasomatic agent in the parent asteroid?

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Introduction

Carbonaceous chondrites were derived from C-type asteroids. They represent remnants of primitive planetesimals that formed in the outer region of the early Solar System. These hydrated, organic-rich asteroids may have been responsible for the delivery of volatile components to the inner Solar System. Recent studies indicate that Ryugu particles are most similar to CI chondrites (e.g., Yokoyama et al. 2022; Ito et al. 2022). As a course of a consortium study by the Phase2 Kochi curation team, we found phases exceptionally rich in Na. Here, we discuss the origin of the Na-rich phases.

Analytical techniques

We found the Na-rich phases in a Ryugu particle, C0014. This particle was impregnated with epoxy resin, evacuated for ~30 min, and placed on a hot plate at ~50°C. All the procedures were done under purified nitrogen. The potted butt of the particle was polished by diamond lapping sheets (30-0.5 μm) without using any fluid under air. We minimized the exposure of this particle to air (<1 hour). We examined the polished section first using an FE-SEM (JEOL: JSM-7100F) equipped with an EDS (Oxford AZtec Energy) and then an EPMA (JEOL: JXA-8200) at NIPR. For crystallographic characterization, the section was processed using a FIB (FIB; Hitachi SMI-4050) at Kochi, JAMSTEC. The FIB section was examined by synchrotron X-ray diffraction at the beamline BL 20XU at SPring-8. The FIB section was further thinned by FIB and examined using a TEM (TEM; JEOL JEM-ARM200F) at Kochi, JAMSTEC.

Results and discussion

The polished section, C0014,1 (1.9 mm^2) is dominated by matrix and contains phyllosilicate clasts and various kinds of mineral grains. The section consists of phyllosilicates (85 vol%), magnetite (5 vol%), sulfide minerals (5 vol%), dolomite (3 vol%) and traces (<1 vol%) of pentlandite, cubanite, chromite, spinel, and apatite. The mineral mode and compositions are similar to that of the other particles we studied (Ito et al. 2022).

Na-rich phases occur as a Na-rich clast (Mg3) (41x32 μm) (Fig. 1) and tiny (<a few μm) Na-rich spots in the matrix. The Na-rich clast (Mg3) is subrounded and shows a feathery texture, similar to the low-Na phyllosilicates. This phyllosilicate clast (Mg3) is rich in Na_2O (~10-36 wt%) with the highest Na-spot (Na_2O 36.2 wt%) near the center. FE-SEM observations indicate that all the Mg3 clast we examined appear to be composed of phyllosilicate. Note that all phyllosilicate clasts in C0004 and other particles we examined contain less than 2 wt% Na_2O.

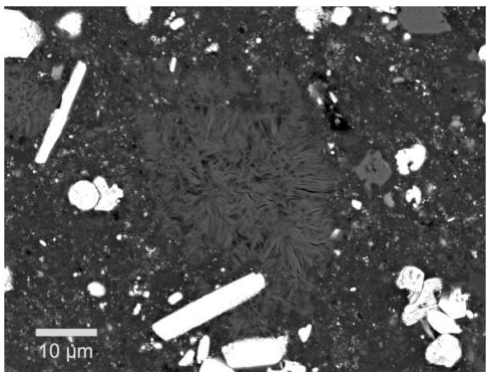

Fig. 1. BSE image of Na-rich clast (Mg3).

After detailed observations using an FE-SEM, we extracted a thick section from the Mg3 clast using a FIB and performed synchrotron X-ray diffraction (SXRD). A diffraction pattern from the section shows a reflection with d-spacing of 1.24 nm. The value is close to the basal layer spacing of saponite in the ambient condition. After the SXRD measurements, the FIB section was further processed into an ultrathin film, and TEM analyses were performed. The Na-rich clasts consist of interlayers with spacings of 0.7 nm and ~1.0 nm. The former likely corresponds to serpentine, and the latter corresponds to a saponite-like phase in which the interlayers have shrunk in the vacuum conditions in the TEM. The Na-rich spots observed in SEM could not be identified even under TEM.

Phyllosilicates that contain Na_2O>several wt% have been rarely found in chondritic meteorites. Ikeda (1991) and Kimura and Ikeda (1992) found Na-rich phyllosilicates ("sodian talc-rich clasts") in "CY" chondrites, Y-82162 and B-7904. However, Na_2O contents of these phyllosilicates are ~5-6 wt%, much lower than those of the Na-rich clast in C0014. Na-carbonate is suggested to occur on a C-type asteroid Ceres (De Sanctis et al. 2016). However, the presence of Na-carbonate is unlikely because we did not detect carbon by EDS. One may consider the presence of tiny non-silicate phases in the Mg3 phyllosilicate which are extremely rich in Na. Zolensky et al. (1999) found halite (NaCl) in the Monahans H chondrite. The lack of Cl (<0.02 wt%) rules out the presence of halite. Thus, the Na-rich phase is something hard to be identified by our analytical techniques and/or is extremely susceptible to short exposure to air. Among several candidates of metasomatic agents which were proposed on the basis of thermodynamic calculations (Zokotov 2012), we suggest that the Na-rich phases are sodium hydroxide (NaOH). NaOH is a deliquescent material and is easily decomposed during short exposure to the atmosphere. Although the origin of NaOH is unknown yet, we suggest that Na-rich fluid was introduced at the early stage of the evolution of the precursor body of Ryugu.

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