NaCl in an Itokawa Particle: Terrestrial or Asteroidal?

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Introduction. The detailed mineralogies and compositions of the particles returned from asteroid Itokawa collected by the Hayabusa mission were extensively studied over the past decade [e.g., 1-3]. However, the full range of nanoscale features of these returned samples are still not well understood. We previously reported NaCl grains in a focused-ion-beam (FIB) section extracted from particle RA-QD-02-0248 [4]. In this study, these NaCl grains are re-examined to better understand their origins and potential implications for the alteration processes on Itokawa.

Methods. The characterization work was conducted on the 200 keV Hitachi HF5000 scanning transmission electron microscope (S/TEM) located at the Kuiper Materials Imaging and Characterization Facility, Lunar and Planetary Laboratory, University of Arizona (Tucson, AZ, U.S.A.). The HF5000 is equipped a cold-field emission gun, third-order spherical aberration corrector for STEM mode, and an Oxford Instruments X-Max N 100 TLE energy-dispersive X-ray spectroscopy (EDS) system with dual 100 mm^2 windowless silicon-drift detectors providing a solid angle (Ω) of 2.0 sr.

Results. A total of five FIB sections were lifted out from RA-QD-02-0248 during the initial examination in August and September 2016. [4] reported that Section #3 is composed of plagioclase and olivine with abundant NaCl grains, most of which were randomly distributed on the plagioclase surfaces while some appeared be within the thickness of the section. The NaCl grains were reported to vary in size from <20 nm to 200 nm and some of the large grains appeared euhedral, with cubic or elongate shapes. No NaCl grains were found on the adjacent olivine. The plagioclase was also reported to contain thin (<15 nm) K-feldspar lamella along its interface with olivine. We recently re-visited this FIB section to evaluate if the NaCl grains were modified. Our STEM results show that the overall distribution of the grains did not change (Fig. 1). To better compare the NaCl grains analyzed in 2016 and now, we overlaid the secondary electron (SE) images with each other (Fig. 2). The data suggest that some grains grew larger and more euhedral and some adjacent grains merged into larger ones. We also re-examined the Section #4 containing plagioclase and olivine. STEM analysis shows abundant high-Z grains (~30 nm in size) and many of them are on the surface of the FIB section. The EDS elemental mapping of these grains shows a clearly resolved Cl K peak in a summed spectrum. Similar to Section #3, NaCl grains do not occur within the olivine in this Section #4.

Discussion. Halite crystals were previously reported in two ordinary chondrites, Monahans (H5) and Zag (H3-6) [5-6]. Several lines of evidence, such as the widespread distribution of halite in the matrices and the ancient ages derived from the radiogenic isotope dating methods, suggest a pre-terrestrial origin of halite in these meteorites. Micrometer-sized halite is also a ubiquitous phase on the external surfaces of many Itokawa particles [7], and a recent TEM study of two Itokawa particles [8] showed that submicrometer-sized NaCl grains were present on the top surface of plagioclase below the capping layer. These authors also described an outer NaCl rim surrounding plagioclase. Contrary to the halite grains in Monahans and Zag, those in Itokawa particles do not show strong textural or compositional evidence for a pre-terrestrial origin, partly due to their small sizes and extremely reactive nature [7]. Textural modifications of halite in the N_2-filled storage box were previously observed [7].

The NaCl grains in the Itokawa sample RA-QD-02-0248 that we report on here could be contaminants introduced during the ultramicrotomy or FIB sectioning. However, this scenario has difficulty in explaining why NaCl grains only occur on the plagioclase, instead of randomly dispersed in both plagioclase and olivine. Alternatively, NaCl grains might have formed during the TEM analysis. Na in plagioclase could be mobilized by the high-voltage electron beam providing a potential Na source for NaCl grains. However, this scenario has trouble explaining the source of Cl. The coarsening and change of shapes of NaCl grains could be driven by Ostwald ripening due to the relative low humidity in the N_2-filled desiccator. Nonetheless, the lack of changes in the distribution and amount of NaCl grains after 5-year storage in the desiccator proves that significant alteration did not occur during sample preservation.

If the NaCl grains in our FIB sections are native to the asteroid, which the TEM data supports, then such grains could have formed through in situ alteration of plagioclase on Itokawa. Previous studies of phosphates and plagioclase in ordinary chondrites suggest that the initial fluid altering primary merrillite and anorthite was a hydrous brine containing Na, K, Cl and F, and at the waning stage of alteration, the fluid could have become very dry and halogen-rich [9-11]. The saturation of NaCl in the dry fluid could have subsequently resulted in the precipitation of halite [11,12].

Conclusion and further work. Our TEM investigation of Itokawa particle RA-QD-02-0248 suggests that the NaCl grains might be native to Itokawa. We plan to conduct atomic-scale imaging with EDS to further investigate the structure and chemical composition of the NaCl grains in Section #3. We will also search for NaCl in another FIB section #5 that contains twinned plagioclase.

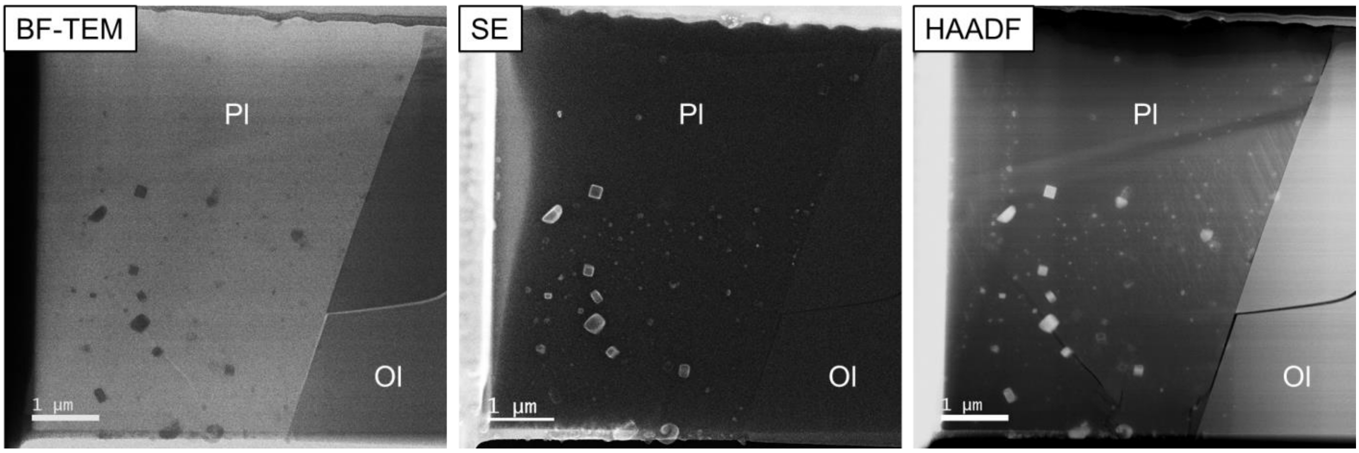

Figure 1. TEM images showing the distribution of NaCl grains on the side surface of plagioclase. The images were obtained on September 10th, 2021.

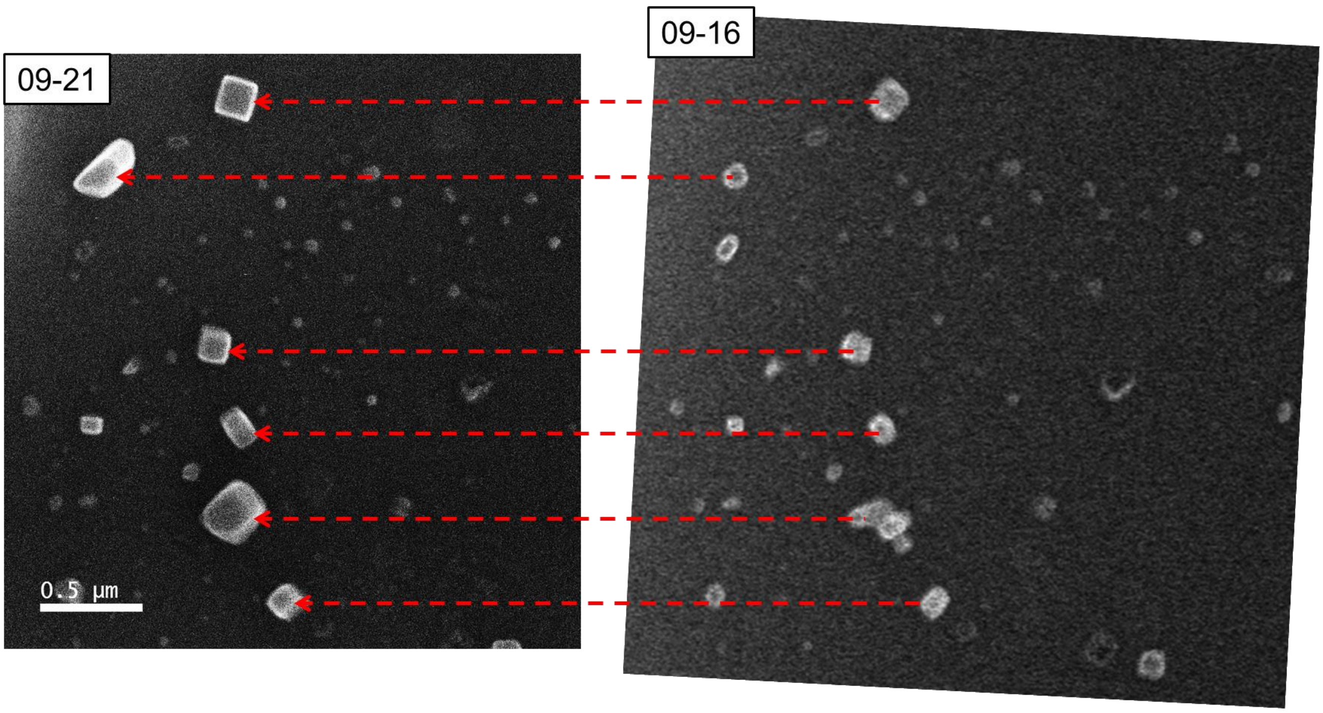

Figure 2. The SE image taken in September 2021 (left) is compared with that taken in September 2015 (right). The NaCl grains have been well preserved, except some of them show changes in size and shape.

References

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