

**NACL IN AN ITOKAWA PARTICLE: TERRESTRIAL OR ASTEROIDAL?** S. Che<sup>1</sup> and T. J. Zega<sup>1,2</sup>, <sup>1</sup>Lunar and Planetary Laboratory, University of Arizona, Tucson AZ, <sup>2</sup>Department of Materials Science and Engineering, University of Arizona, Tucson AZ. (sche@arizona.edu)

**Introduction:** Ordinary chondrites (OCs) were affected by thermal metamorphism to varied degrees on their parent bodies, which is manifested by their progressive textural and chemical equilibration with increasing petrologic types [e.g., 1]. In addition, fluid alteration has modified the primary features of unequilibrated OCs [e.g., 2-3]. However, the role of these fluids in thermally heated OCs and the full range of alteration features are still not well understood. The Itokawa particles collected by the Hayabusa mission provide additional insights into the fluid alteration processes on the parent bodies of OCs. We previously reported NaCl grains in a focused-ion-beam (FIB) section extracted from a particle RA-QD-02-0248 [4]. Here we re-examine these NaCl grains and report new transmission electron microscopy (TEM) data from this Itokawa particle. The goal of this study is to better understand the origin of NaCl grains 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. The HF5000 is equipped with 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<sup>2</sup> windowless silicon-drift detectors providing a solid angle ( $\Omega$ ) of 2.0 sr.

**Results:** A total of five FIB sections were extracted from RA-QD-02-0248 during the initial examination in August and September 2016. Three of the FIB sections (#3 to #5) contain plagioclase, which we describe below.

*Section #3.* This FIB section is composed of plagioclase and olivine. [4] previously reported abundant NaCl grains on the plagioclase. Based on the secondary-electron (SE) images, most of the NaCl grains were randomly distributed on the plagioclase surfaces while some appeared to occur within the thickness of the section. The NaCl grains were reported to vary in size from <30 nm to 300 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 to 60 nm) K-feldspar exsolution lamellae along its interface with olivine. No textural relationship was observed between NaCl and K-feldspar exsolution

lamellae. We recently re-visited this FIB section to evaluate if the NaCl grains were modified during storage in an N<sub>2</sub>-filled desiccator. Our STEM results show that the overall distribution of these grains did not change, although minor modifications have been found: some grains grew larger and more euhedral, and some adjacent grains merged into larger ones (Fig. 1).

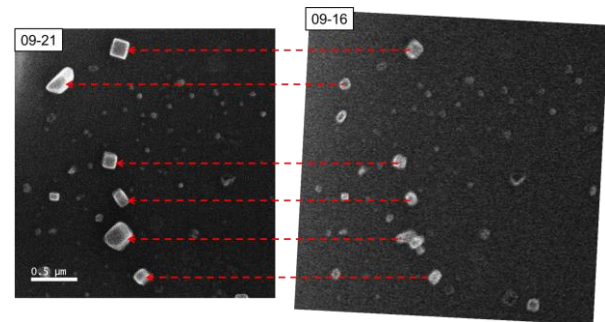


Fig. 1. The STEM-SE image of Section #3 taken in September 2021 (left) is compared with that taken in September 2016 (right). The NaCl grains have been well preserved, except minor changes in size and shape.

*Section #4.* This FIB section also transects plagioclase and olivine domains. STEM analysis shows abundant high-Z grains (<30 nm in size) on plagioclase. The EDS elemental mapping of these grains shows that they are enriched in Cl. It is thus very likely that these high-Z grains are NaCl, although their Na signals cannot be clearly resolved from the Na map due to their fine-grained sizes.

*Section #5.* This FIB section samples a single crystal of plagioclase which contains several twin lamellae (50 to 100 nm in width). The most interesting feature of this FIB section is a vein that transects the section (Fig. 2). The width of this vein varies from 300 to 500 nm. NaCl grains are found to decorate the interfaces between the vein and plagioclase. There are also some NaCl grains that are randomly distributed on plagioclase. Because the vein is sampled by the FIB section at an angle, it appears to be crosscut by the twin lamellae on the TEM images. Therefore, the apparent crosscut relationship between the vein and twin lamellae does not bear information of their relative formation times. We acquired EDS maps of the vein that show it is depleted in Na compared with the surrounding plagioclase (Fig. 2). EDS spectra of the vein show that it has a plagioclase-like composition. To reveal the compositional difference between the vein and

plagioclase quantitatively, we compare their EDS spectra after normalizing to the Si K $\alpha$  peak. The EDS data confirm the Na depletion of the vein which contains an average Na/Si atomic ratio of 0.18 compared to 0.25 for plagioclase. Such a Na depletion of the vein also results in a significant deviation from the plagioclase stoichiometry. The average (Na+K+Ca)<sub>total</sub> of the vein is 0.57 compared to 0.84 for plagioclase. Additionally, we compare selected area diffraction patterns obtained from the vein and plagioclase at the same tilt angles, which shows that the two patterns are very similar, but some of the diffraction spots for the vein are fainter.

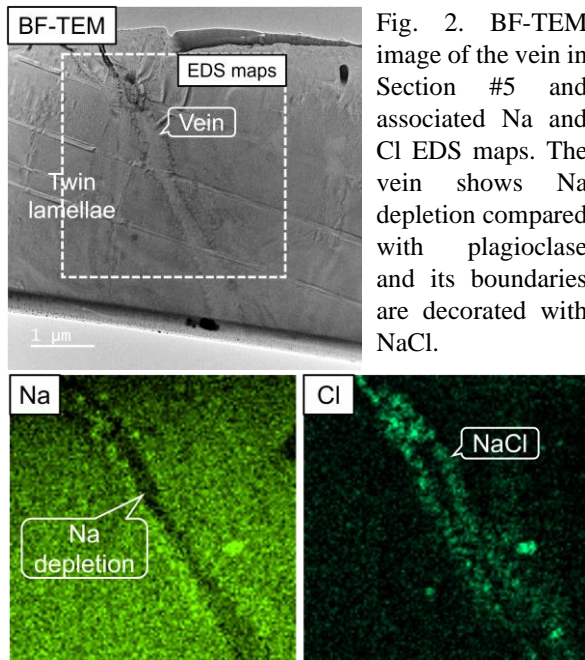


Fig. 2. BF-TEM image of the vein in Section #5 and associated Na and Cl EDS maps. The vein shows Na depletion compared with plagioclase and its boundaries are decorated with NaCl.

**Discussion:** NaCl was previously reported in several Itokawa particles. [5] reported halite and sylvite on the external surfaces of two particles separately. In addition, two recent studies [6-7] discovered NaCl crystals in FIB sections of three other Itokawa particles. Therefore, NaCl and KCl crystals may be common phases in Itokawa particles. However, due to the reactive nature of these salt crystals [5], unambiguous evidence for an asteroidal origin is lacking.

For the Itokawa particle RA-QD-02-0248, the textural observation that many NaCl crystals are adhered to the surfaces of FIB sections suggest that these crystals might be contaminants introduced after ion milling on the FIB. For example, NaCl could be introduced as contaminants via precipitation from moisture in the desiccator. However, our comparative investigation of the distribution of NaCl crystals in Section #3 implies that these crystals were well preserved in the desiccator for five years, though minor

changes to their size and shape occur due to Ostwald ripening. Alternatively, NaCl crystals could be reaction products between plagioclase and epoxy. One way for such a reaction to happen is that Na in plagioclase was mobilized by high-voltage electron beam in TEM and then reacted with the trace amount of Cl in epoxy. We will carry out an experiment using terrestrial albite to test this hypothesis, although based on our experience, the probability of this reaction is low. A more likely explanation for the surface adhering NaCl is migration of NaCl inclusions that were originally present within the thickness of the FIB sections. Such migration could be driven by dissolution and reprecipitation of NaCl in the presence of water vapor in the desiccator, a process that may be similar to efflorescence.

Several lines of evidence could support an indigenous origin of NaCl crystals in our Itokawa particle. First, sulfates, which are common terrestrial efflorescence products, are absent in Itokawa particles [5]. Second, the sample was handled carefully and no significant modifications to NaCl during the storage in the desiccator were found. Third, NaCl grains are observed only on plagioclase, indicating that their formation might be coupled with the alteration of plagioclase on the Itokawa asteroid. Pre-terrestrial halite crystals were previously reported in two OCs, Monahans (H5) and Zag (H3-6) [8-9]. Moreover, recent studies of fluid alteration of OCs [10-11] suggest halite and Cl-rich apatite in OCs may be genetically related. Finally, NaCl crystals along the alteration vein in Section #5 could have formed via precipitation from fluid. The Na-depleted phase in the vein might be a transient phase that formed during the alteration of plagioclase on Itokawa. The formation of such an alteration assemblage can be attributed to a coupled interfacial dissolution-reprecipitation mechanism [12-13].

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