SURFACE NANO-MORPHOLOGIES OF ITOKAWA REGOLITH PARTICLES FORMED BY SPACE WEATHERING PROCESSES: COMPARISON WITH ION IRRADIATION EXPERIMENTS.

T. Matsumoto[1] A. Tsuchiyama[2], A. Takigawa[2], K. Yasuda[3], Y. Nakata[3], J. Matsuno[2], T. Nagano[1], A. Shimada[1], T. Nakano[4], K. Uesugi[5], [1]Osaka University (tmatsumoto@kueps.kyoto-u.ac.jp), [2]Kyoto University, [3]The Wasaka Wan energy research center, [4]JASRI/SPring-8, [5]Geological Survey of Japan. AIST

Introduction:

Itokawa regolith particles recovered by the Hayabusa missions have important information about surface processes on a small asteroid without atmosphere. X-ray micro-tomography (CT) analysis on the three-dimensional (3D) micro-morphology of the Itokawa particles with the spatial resolution of a few μm revealed that some particles (~25 %) have rounded edges as well as angular edges [1]. Micro-nano morphologies of Itokawa particle surfaces were also observed using a field emission scanning electron microscope (FE-SEM) [2]. It was revealed that the particle surfaces with angular edges have distinct structures such as sharp fine steps, while surfaces with rounded edges have fainted structures such as ambiguous steps. These surfaces can be regarded as "fresh" and "matured" surfaces, respectively.

On the other hand, transmission electron microscope (TEM) analysis found space weathering rims on the particle surfaces within 100 nm in depth caused by solar wind irradiation [3,4]. Implantation of noble gases to Itokawa particles was also detected by noble gas isotope analysis [5]. Comparison between the CT and TEM analyses showed that there was no correlation between the edge roundness and the thickness of the space-weathering rim [6]. Thus, the surfaces with rounded edges can have formed by a different type of space weathering that formed the space-weathering rim. This type of space weathering, named "surface erosion", should relate to mechanical abrasion during migration of regolith particles due to micrometeoroid impacts on Itokawa, which induced seismic vibration, although a possibility that the surfaces with rounded edges were formed by solar wind sputtering cannot be excluded [1,6].

Comparison between the surface structures observed by TEM with nm-scale resolution and by CT with several μm-scale resolution is not enough for detailed discussion. It is thus necessary to observe surface morphologies in relation to solar wind irradiation using FE-SEM, which can identify structures of several tens nm to few μm. In this study, the surface micro-nano morphologies by FE-SEM [2] were compared with the space-weathering rim observed by TEM [4]. Ion irradiation experiments to mineral grains were also performed to compare surface morphological features of the Itokawa regolith particles.

Experiments:

The irradiation experiments were performed at the Wakasa Wan Energy Research Center, Tsuruga, Japan. An olivine sample from Sri Lanka with the composition of Fa_{30}, which is almost the same as the composition of olivine ($Fa_{28.6\pm1.1}$) in Itokawa regolith [7], was chosen as an analog of Itokawa regolith. A clear single crystal of the olivine sample was crushed in a tungsten carbide mortar and fragments with similar sizes as the Itokawa particles (~50 to 100 μm) were picked up. The olivine fragments were placed on an Au plate and irradiated with H^+, H_2^+ and He^+ ions accelerated at 10 to 50 keV with fluences of 1×10^{16}, 1×10^{17} ions/cm^2 for all ions and 1×10^{18} ions/cm^2 for H_2^+ and He^+ ions. The olivine surfaces were observed using FE-SEM (JSM7001F at Kyoto University) before and after the irradiation to examine their morphological changes. The samples were not coated with any electric conductors such as carbon. To avoid charge up effect during the FE-SEM observation, secondary electron (SE) images were obtained at a low accelerating voltage (2 kV) in vacuum for observation with high-spatial resolution.

Results and Discussions:

No noticeable morphological changes are observed on the secondary electron images of olivine samples irradiated at fluences of 1×10^{16} and 1×10^{17} ions/cm^2. On the other hands, samples irradiated with H_2^+ and He^+ ions at fluence of 1×10^{18} ions/cm^2 show numerous blister structures on their surfaces (Fig. 1). The blister sizes are several hundreds nm to 3 μm. Observation on cracked blisters indicated that the blisters have vesicle structures beneath the surface. In previous irradiation experiments to a thin section of San Carlos olivine, appearance of abundant bubbles or voids beneath the surfaces was reported after He^+ irradiation [8]. The bubbles were suggested to be filled with He gas. Blisters observed in this study should have been also formed by nucleation and growth of vesicles filled with the gas beneath the surfaces.

In the previous TEM observation for ultra-thin sections of Itokawa regolith particles, vesicles were observed in thick space weathering rims [4]. The morphology of the vesicles is similar to the blister structures. They were probably formed by solar wind He implantation because their depth (~50 nm) is consistent with implantation depth by solar wind He with typical energy of 4 keV [4]. In the FE-SEM observation on Itokawa particle surfaces, some surfaces are covered with numerous convex spotted structures of several tens nm in size (Fig. 2). These structures are similar to blisters formed on the olivine sample by the He^+ irradiation in this study, although the blister size on the olivine sample is larger than that of Itokawa particles. Previous irradiation experiments showed that the blister size increases with increasing the ion energy, where tungsten plates were irradiated with deuterium ions [9]. Therefore, the size difference between blisters on Itokawa regolith particles and experimental samples is due to the difference in the ion energy (~4 keV in the solar wind and 20-50 keV in the experiments). It should be also noted that the vesicle size observed by TEM [4] is similar to the size of the spotted structures on the Itokawa particle and these sizes are almost same as those formed in the previous irradiation experiments of 4keV He [8].

The fluences of 1 × 10^{17} and 1 × 10^{18} He^+ ions/cm^2 correspond to the solar wind He^+ irradiation duration of ~500 and ~5000 years, respectively [10]. As the blister structure was not formed by He^+ irradiation at the fluence of 1 × 10^{17} ions/cm^2, the blisters on the Itokawa particles should be formed between 500 and 5000 years. Solar track density observed in an Itokawa particle with a thick space weathering rim and vesicles suggests that the irradiation duration is the order of 10^3 years [4]. The irradiation durations deduced from the blister formation is consistent with this duration, which confirms that the space weathering rim should be produced in a very short duration compared with the estimated residence time of regolith on the smooth terrain of Itokawa (<~3 Myr [5]).

The blister structures are present on the Itokawa particles both with rounded and angular edges, and their existence does not correlate to roundness of the edges. In the present irradiation experiments, cleavage steps remain sharp even after irradiation that results in blistering (Fig.1), which suggests that the rounded shapes of Itokawa particles would not have been caused by solar wind sputtering, although sputtering efficiency by solar wind H at ~1 keV should be examined. Mechanical abrasion by seismic vibration on Itokawa might be the main cause of the rounded edges of Itokawa particles, and this might occur for a long duration (<~3 Myr [5]) during the particles had been staying in the regolith. For future work, we plan to perform abrasion experiments using a shaker to evaluate the rate of ablation by seismic vibration on Itokawa.

Acknowledgements: We are grateful to Dr. T. Noguchi of Ibaraki University for fruitful discussion.

References: [1] Tsuchiyama A. et al. (2011) *Science, 333*, 1125-1128. [2] Matsumoto T. et al. (2012) *LPSC XLIII,* 1659. [3] Noguchi T. et al. (2011) *Science, 333*, 1121-1125. [4] Noguchi T. et al. (2012) *Met. Planet. Sci. submitted.* [5] Nagao K. et al. (2011) *Science, 333*, 1128-1131. [6] Tsuchiyama A. et al. (2013) *LPSC this volume.* [7] Nakamura T. et al. (2011) *Science, 333*, 1113-1116. [8] Carrez P. et al. (2002) *Met. Planet. Sci, 37,* 1599-1614 [9] Wang W. et al., (2002) *Jornal of Nuclear Materials, 299*, 124-131 [10] Goldstein B.E. et al.(1996) *Astron. Astrophys*. 316: 296–303.

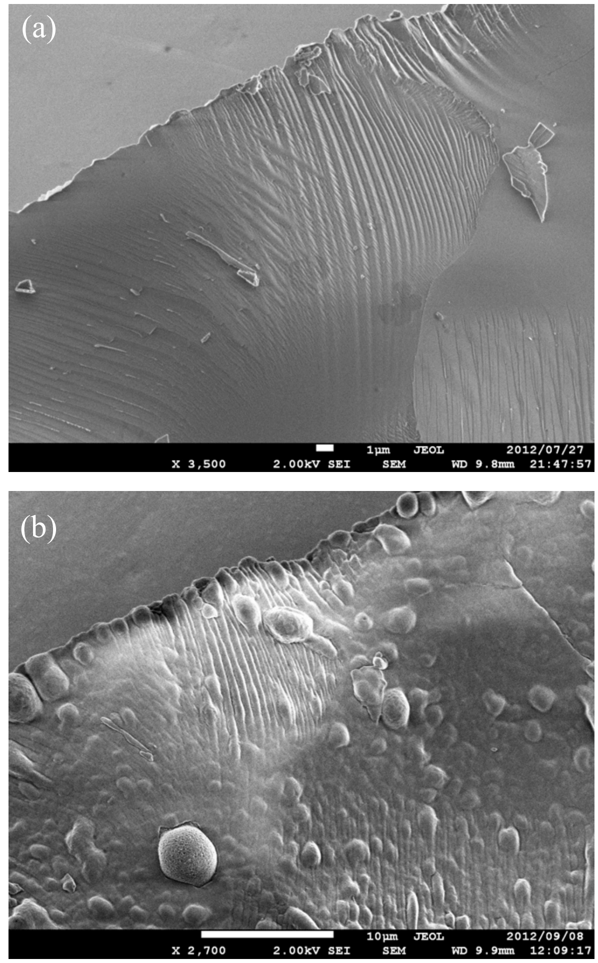

Figure 1: FE-SEM images (SEI) of an olivine particle surface. (a) Surfaces before irradiation. Cleavage steps are seen. (b) Surfaces with blister structure after irradiation of 20 keV He^+ at fluence of 1 × 10^{18} ions/cm^2.

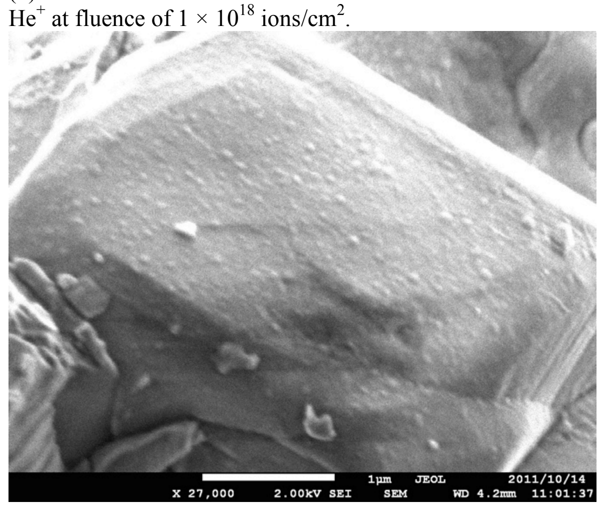

Figure 2: A FE-SEM image (SEI) of blister structure on olivine of an Itokawa particle surface (RA-QD02-0033).