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Estimation of space weathering morphologies of Itokawa regolith particles by comparison with ion irradiation experiments

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Itokawa regolith particles recovered by the Hayabusa missions have important information about surface processes on a small asteroid without atmosphere. Analysis on the three-dimensional micro-morphology of the Itokawa particles by micro-tomography (CT) revealed that some particles (~25 %) have rounded edges [1]. Transmission electron microscope (STEM) analysis found space weathering rims caused by solar wind irradiation [2,3]. 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 [4], indicating that the surfaces with rounded edges can have formed by mechanical abrasion due to micrometeoroid impacts on Itokawa. On the other hand, a possibility of solar wind sputtering cannot be excluded [1,4]. The comparison between the surface structures observed by TEM with nm-scale resolution and by CT with several um-scale resolution is not enough for detailed discussion. In this study, the surface morphologies of Itokawa particles and experimentally ion irradiated olivine particles were compared using FE-SEM, which can identify structures of several tens nm to few um, and TEM. Experiments simulating solar wind irradiation to mineral grains were performed at the Wakasa Wan Energy Research Center. An olivine sample of 100 um in size from Sri Lanka with the composition of Fa_{30}, which is almost the same as the composition of olivine in Itokawa regolith, was chosen as an analog of Itokawa regolith. The olivine fragments were irradiated with H^+, and $^4He^+$ ions accelerated at 10 to 50 keV with fluences of 1 x 10^{16} to 1 x 10^{18} ions/cm^2. The olivine surfaces were observed using field-emission secondary electron microscope (JSM7001F) before and after the irradiation. TEM samples were prepared by focused ion beam (FEI Quenta 200 3DS) and observed by transmission electron microscope (H8000k) at Kyoto University. Samples irradiated with H^+ and He^+ ions at fluence of 1 x 10^{18} ions/cm^2 show numerous blister structures of several hundreds nm to 3 um in size on their surfaces. Observation by TEM showed that appearance of abundant vesicles beneath the surfaces. Blisters have vesicles structures in similar sizes as the blisters beneath the surface. The vesicles were suggested to be filled with H of He gas. In the previous study, vesicles were observed in thick space weathering rims [3] and blisters were observed by FE-SEM [5]. 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. The fluence of 3 x 10^{18} ions/cm^2 correspond to the solar wind He irradiation duration of 1540 years. The blisters on the Itokawa particles should be formed between approximately in the order of 1000 years. The results indicate 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 [6]). Mechanical abrasion by seismic vibration might occur for a long duration (<~3 Myr [5]) during the particles had been staying in the regolith. [1] Tsuchiyama A. et al. (2011) Science, 333, 1125-1128. [2] Noguchi T. et al. (2011) Science, 333, 1121-1125. [3] Noguchi T. et al. (2012) Met. Planet. Sci. submitted. [4] Tsuchiyama A. et al. (2013) LPSC XLIV,2169. [5] Matsumoto T. et al. (2013) LPSC XLIV, 11441. [6] Nagao K. et al. (2011) Science, 333, 1128-1131.

Keywords: Itokawa, regolith, space weathering