SPACE WEATHERING PRODUCTS FOUND ON THE SURFACES OF THE ITOKAWA DUST PARTICLES: A SUMMARY OF THE INITIAL ANALYSIS. T. Noguchi[1], M. Kimura[1], T. Hashimoto[2], M. Konno[2], T. Nakamura[3], A. Nakato[3], T. Ogami[3], H. Ishida[3], R. Sagae[1], S. Tsujimoto[1], A. Tsuchiyama[4], M. E. Zolensky[5], M. Tanaka[6], A. Fujimura[7], M. Abe[7], T. Yada[7], T. Mukai[7], M. Ueno[7], T. Okada[7], K. Shirai[7], Y. Ishibashi[7], and R. Okazaki[8] [1]Ibaraki University (2-1-1 Bunkyo, Mito, Ibaraki 310-8512, Japan, tngc@mx.ibaraki.ac.jp), [2]Hitachi High-Technologies Corporation (882 Ichige, Hitachinaka, Ibaraki 312-8504 Japan), [3]Tohoku University (Aoba, Sendai, Miyagi 980-8578, Japan), [4]Department of Earth and Space Science, Osaka University (1-1 Machikaneyama, Toyonaka, Osaka 560-0043, Japan), [5]NASA/JSC (Houston, Texas 77058, USA), [6]National Institute for Materials Science (1-1-1 Kouto, Sayo, Hyogo 679-5148, Japan), [7]ISAS/JAXA (3-1-1 Yoshinodai, Sagamihara, Kanagawa 252-5210, Japan), [8]Kyushu University (Hakozaki, Fukuoka 812-8581, Japan).

Introduction: Surfaces of airless bodies exposed to interplanetary space gradually have their structures, optical properties, chemical compositions, and mineralogy changed by solar wind implantation and sputtering, irradiation by galactic and solar cosmic rays, and micrometeorite bombardment. These alteration processes and the resultant optical changes are known as space weathering [1, 2, 3]. Our knowledge of space weathering has depended almost entirely on studies of the surface materials returned from the Moon and regolith breccia meteorites [1, 4, 5, 6] until the surface material of the asteroid Itokawa was returned to the Earth by the Hayabusa spacecraft [7]. Lunar soil studies show that space weathering darkens the albedo of lunar soil and regolith, reddens the slopes of their reflectance spectra, and attenuates the characteristic absorption bands of their reflectance spectra [1, 2, 3]. These changes are caused by vapor deposition of small (<40 nm) metallic Fe nanoparticles within the grain rims of lunar soils and agglutinates [5, 6, 8].

The initial analysis of the Itokawa dust particles revealed that 5 out of 10 particles have nanoparticle-bearing rims, whose structure varies depending on mineral species. Sulfur-bearing Fe-rich nanoparticles (npFe) exist in a thin (5-15 nm) surface layer (zone I) on olivine, low-Ca pyroxene, and plagioclase, suggestive of vapor deposition. Sulfur-free npFe exist deeper inside (<60 nm) ferromagnesian silicates (zone II). Their texture suggests formation by amorphization and in-situ reduction of Fe^{2+} in ferromagnesian silicates [7]. On the other hand, nanophase metallic iron ($npFe^0$) in the lunar samples is embedded in amorphous silicate [5, 6, 8]. These textural differences indicate that the major formation mechanisms of the $npFe^0$ are different between the Itokawa and the lunar samples. Here we report a summary of the initial analysis of space weathering of the Itokawa dust particles.

Samples and methods: We investigated twelve particles in the room A of the sample catcher of the Hayabusa sample container, in which samples collected on 25 November 2005. Eleven of them were embedded in epoxy resin and ultramicrotomed into ~100 nm-thick ultrathin sections. About 100 nm-thick sections were lifted out from one of the potted butts after ultramicrotomy and from a polished cross sectional sample using a focused ion beam (FIB) machine. All the samples were investigated using a spherical aberration corrected scanning transmission electron microscope (Cs corrected STEM) to investigate space weathering products on the samples. Three samples were investigated by a field emission TEM to search for solar flare tracks.

Results and discussion: In the first report, we did not use ultrathin sections prepared by FIB to avoid the possibility that surface textures were greatly modified during sample preparation because FIB introduces ~20 to ~30-nm amorphous surface layers during sample preparation. To investigate the mineralogy of the Itokawa samples, we prepared 8 thin sections from 6 Itokawa particles by FIB [9]. We found three thin sections contain their surfaces and two of them have nanoparticle-bearing rims that are indistinguishable from those prepared by ultramicrotomy. Because the surfaces of the three samples faced to the opposite direction of the incident Ga^+ ion beam and because the surfaces of the samples were enclosed by epoxy resin, it is unlikely that their surface texture was modified considerably during FIB processing. We found that low-Ca pyroxene in RA-QD02-0009 has a vesiculated rim (Fig. 1). Most of the vesicles seem to have formed at or near the boundary between the amorphous surface layer and the $npFe^0$-bearing layer, which correspond to the zone I and zone II in [7] although this zone I does not contain nanoparticles abundant in Fe, S, and Mg, in spite of the presence of sulfur. After that, we found a vesicular rim on the surface of olivine in an ultramicrotomed section. Therefore, the vesicular rim found in the FIB sample is not artifact from sample preparation. Their texture suggests that implanted gases segregated from the $npFe^0$-bearing layer to the surface by diffusion and formed vesicles. Further studies are needed to investigate formation mechanisms of the vesicular rims on the Itokawa samples [5, 10, 11].

We re-examined two ultramicrotomed samples that did not contain nanoparticle-bearing rims by STEM. They have quite thin (2-3 nm) surface layers with elements that are not included in the substrate minerals (Fig. 2). In Fig. 2, the surface layer is enriched in Si and contains Na, Al, (Cl,) K, and Ca, as well as Mg and Fe, suggestive of vapor deposition from the surrounding minerals. Sulfur was not detected in the quite thin layers. We also sought solar flare tracks in three ultramicrotomed samples containing nanoparticle-bearing rims by FE-TEM. However, tracks are apparently quite rare in these samples.

Because crystal structures just beneath the quite thin deposition layers are intact, the exposure duration of these particles would have been considerably shorter than the particles having nanoparticle-bearing rims. We think that the quite thin layers are the immediate-early product of space weathering. The total thickness of $npFe^0$-bearing rims seldom reaches 100 nm, which is similar to the penetration depth of solar wind (20-100 nm in olivine) [12, 13]. This observation may suggest that the major agent to form the $npFe^0$-bearing layer (zone II) is implantation of solar wind hydrogen.

On the other hand, even the exposure duration in the $npFe^0$-bearing samples was too short to accumulate solar flare tracks because solar flare tracks in them are quite rare. The time necessary to accumulate the ^{20}Ne abundances in three Itokawa particles was estimated to be 150-550 years by assuming single-stage irradiation, no erosion of grain surface, and backscatter effects of Ne ions [14]. Their estimation may be consistent with our observation. However, because the release profiles of noble gases indicate rather complex solar wind implantation and loss histories [14], there may yet be particles that contain abundant solar flare tracks. Future searches for solar flare tracks combined with noble gas analysis are needed to understand the details of the exposure history of each Itokawa dust particle.

References: [1] Hapke, B. (2001) *JGR*, *106*, 10039-10073. [2] Clark, B. E. et al. (2002) In *Asteroids III*, Tucson, Univ. Ariz. Press. [3] Chapman, C. R. (2004) *Ann. Rev. Earth. Planet. Sci.*, *32*, 539-567. [4] Hapke, B. *Moon*, *13*, 339-354. [5] Keller, L. P., McKay, D. S. (1997) *GCA*, *61*, 2331-2341. [6] Noble, S. K. et al. (2005) *MAPS*, *49*, 397-408. [7] Noguchi, T. et al. (2011) *Science*, *333*, 1121-1125. [8] Pieters, C. M. et al. (2000) *MAPS*, *35*, 1101-1107. [9] Nakamura, T. et al. (2011) *Science*, *333*, 1113-1116. [10] Zhang, S., Keller, L. P. (2010) *LPS XXXI*, 1432 (2010). [11] Brownlee, D. E. Et al. (1998) *LPS XXIX*, 1869. [12] Wieler, R. (2002) *Rev. Mineral. Geochem. 47*, 21-xx. [13] Parker, E. N. In *Cosmic Winds and the Heliosphere*, Tucson, Univ. Ariz. Press. [14] Nagao, K. et al. (2011) *Science*, *333*, 1128-1131.

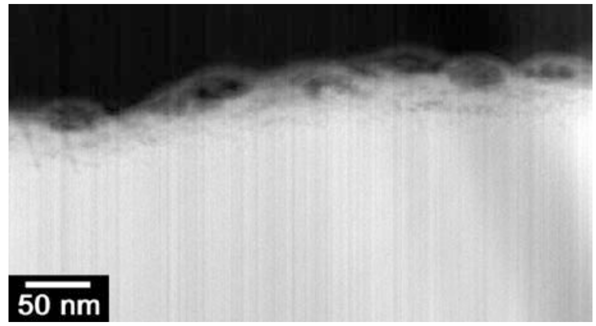

Fig. 1 HAADF-STEM image of a vesicular rim on low-Ca pyroxene in RA-QD02-0009.

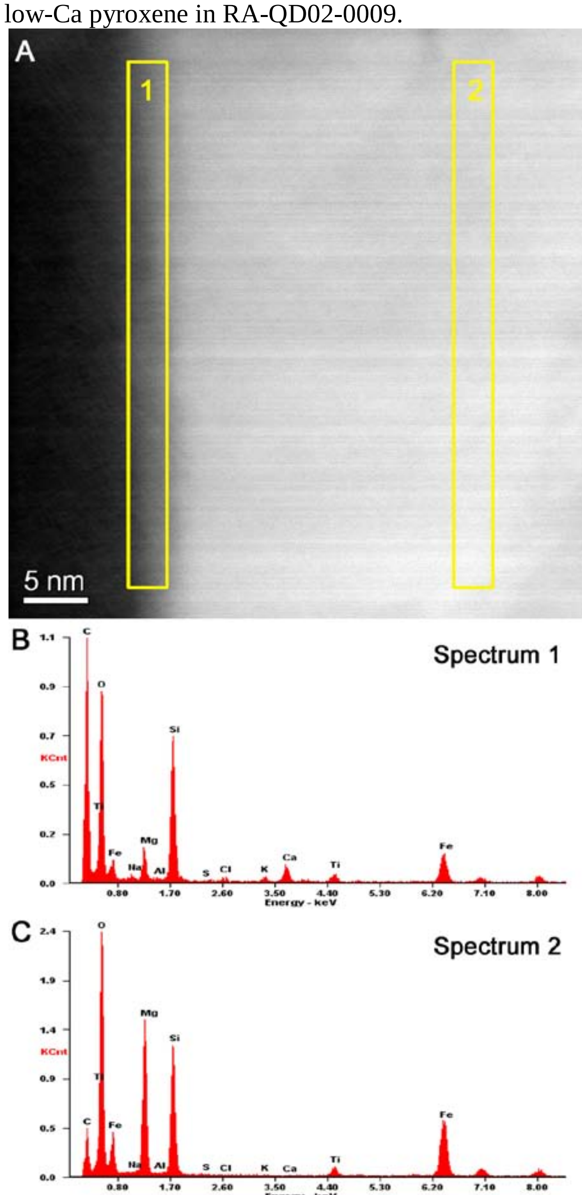

Fig. 2 A thin deposition layer on olivine in RA-QD02-0050. A) HAADF-STEM image, B) and C) EDX spectra of the boxed areas 1 and 2 in A). Peaks of Titanium were derived from the TEM sample holder.