SEM AND TEM OBSERVATION OF THE SURFACES OF THE FINE-GRAINED PARTICLES RETRIEVED FROM THE MUSES-C REGION ON THE ASTEROID 25413 ITOKAWA.

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Introduction: Surface materials on airless solar system bodies exposed to interplanetary space are gradually changed their visible to near-infrared reflectance spectra by the process called "space weathering", which makes the spectra darker and redder [1, 2, 3]. Hapke et al. [4] proposed a model of space weathering: vapor deposition of nanophase reduced iron ($npFe^0$) on the surfaces of the grains within the very surface of lunar regolith. This model has been proved by detailed observation of the surfaces of the lunar soil grains by transmission electron microscope (TEM) [5, 6]. They demonstrated that $npFe^0$ was formed by a combination of vapor deposition and irradiation effects. In other words, both micrometeorite impacts and irradiation by solar wind and galactic cosmic ray play roles on the space weathering on the Moon.

Because there is a continuum of reflectance spectra from those of Q-type asteroids (almost the same as those of ordinary chondrites) to those of S-type asteroids [7], it is strongly suggested that reflectance spectra of asteroids composed of ordinary chondrite-like materials were modified over time to those of S-type asteroids due to space weathering [1, 2, 3, 7]. It is predicted that a small amount of $npFe^0$ on the surface of grains in the asteroidal regolith composed of ordinary chondrite-like materials is the main agent of asteroidal space weathering [6].

In-situ measurements of reflectance spectra of asteroids have been performed since 1991 when Galileo flew by Gaspra. Among them, detailed global measurements of reflectance spectra of Eros and Itokawa were performed by NEAR Shoemaker and Hayabusa, respectively [8, 9]. These observations revealed that not only a large asteroid Eros (34.4x11.2x11.2 km) but also a small asteroid Itokawa (535x294x209 m) experienced space weathering [10]. Hiroi et al. [10] discovered that the dark areas are more space-weathering than the bright areas. They estimated the former contains 0.069 vol.% $npFe^0$ and the latter 0.031 vol.% $npFe^0$ if the surface of Itokawa is composed of LL5-6-like materials.

First purpose of this study is (1) to identify the direct evidence of space weathering on the surface of the fine-grained particles retrieved from the MUSES-C regio, where Hayabusa was landed on 19 and 25 November 2005 UTC [11]. Second one is to estimate the most efficient mechanism of space weathering for a small asteroid such as Itokawa. Although both micrometeorite bombardment and solar wind irradiation produce $npFe^0$ on the surfaces of grains in regolith, both mechanisms have quite different time scales for development of significant space weathering: ~10^8 years [12] and ~10^6 years [13], respectively.

Samples and methods: Particles in the room A of the sample catcher of the Hayabusa sample container, in which samples collected on 25 November 2005, were collected on a silica glass plate. A few tens of particles were observed by field emission scanning electron microscope (FE-SEM) equipped with energy dispersive spectrometer (EDS) at the sample curation facilities, ISAS/JAXA. Details of the FE-SEM observation are described in elsewhere [14]. We prevented earth's atmosphere from acting on the Itokawa samples during sample handling. To compare surface morphology of fine-grained Itokawa particles with lunar soil grains, we also performed by using SEM equipped with EDS at Ibaraki University. In both cases, acceleration voltage is 10 kV and low-vacuum mode was used (60 Pa for FE-SEM and 40 Pa for SEM).

Results and discussion: Figure 1 show enlarged back-scattered (BSE) images of typical fine-grained particles from the asteroid Itokawa and the Moon. Although both particles are angular and fragmental, the Itokawa particle does not show any evidence of remarkable melting. As indicated by a yellow arrow in Fig. 1a, some fine-grained particles of Itokawa have multiple steps (each step has ~1 µm in width and height). These steps are very similar to fresh fracture surfaces of olivine and pyroxene when we lightly crush them. Therefore, fine-grained particles retrieved from the MUSES-C regio seem to have experienced the least surface modification after their formation. It is in stark contrast to lunar soil grains as shown in Fig. 1b, which shows vesiclues or walls of vesicules (indicated by red arrows) and reduced iron globules (indicated by a green arrow) in glass. The lunar soil grains investigated in this study are composed of a mixture of vesiculated glass and embedded mineral fragments. However, $npFe^0$ was not identified in both samples because the grain sizes of $npFe^0$ are expected to be smaller than 50 nm in diameter [5], well below the spatial resolution at these magnifications.

It has been pointed out that formation of regolith on asteroids should be different from that on the Moon due to major differences in gravity on their surfaces [15, 16]. On the Moon, repeated impacts form impact melts and locally concentrated, size-sorted regolith. On the other hand, impact ejecta formed on the small asteroid Itokawa can easily escape from Itokawa due to quite low escape velocity (10 to 20 cm/s) [17]. Therefore, fine-grained particles in the MUSES-C regio may have been formed on the parent body of Itokawa or during aggregation of gravels to form Itokawa and segregated into the low potential MUSES-C regio [17]. Therefore, the absence of remarkable impact melts on the Itokawa particles may be consistent with the different formation mechanisms of regolith on the Moon and asteroids.

Although there is a variation in the degrees of space weathering on Itokawa, Itokawa accumulated space-weathered materials globally [10]. Miyamoto et al. [16] indicated that fine-grained gravels were sorted and migrated to the low potential MUSE-C regio by impact induced seismic shaking. If the resurfacing processes such as sorting and migration of gravels were more rapid than the space weathering rate, the thin (~100 nm thick or so [5, 6]) space weathered surfaces on the gravels would be removed by grinding against other gravels during sorting and migration. If reverse were true, space weathering products would be formed rapidly on the surface of gravels after the removal of the surface by the resurfacing processes. However, if space weathering rate would be much faster than the sorting and migration rates, there would be much less variation of space weathering on Itokawa than in reality. Therefore, the space weathering rate on Itokawa may be slightly more rapid than the resurfacing rate.

Initial analyses and predicted results: From the middle of January, initial analyses of these fine-grained particles will start [18]. TEM study of the surfaces of a few Itokawa particles will be performed. We will prevent the samples from exposure to earth's atmosphere during embedding, ultramicrotomy, transportation of samples, and TEM observation, to avoid oxidation of $npFe^0$ on the surfaces of the Itokawa particles. If the fine-grained particles from the MUSES-C regio contain $npFe^0$ on their surfaces, it indicates that solar wind irradiation is the important rapid agent of space weathering on small near-earth asteroids.

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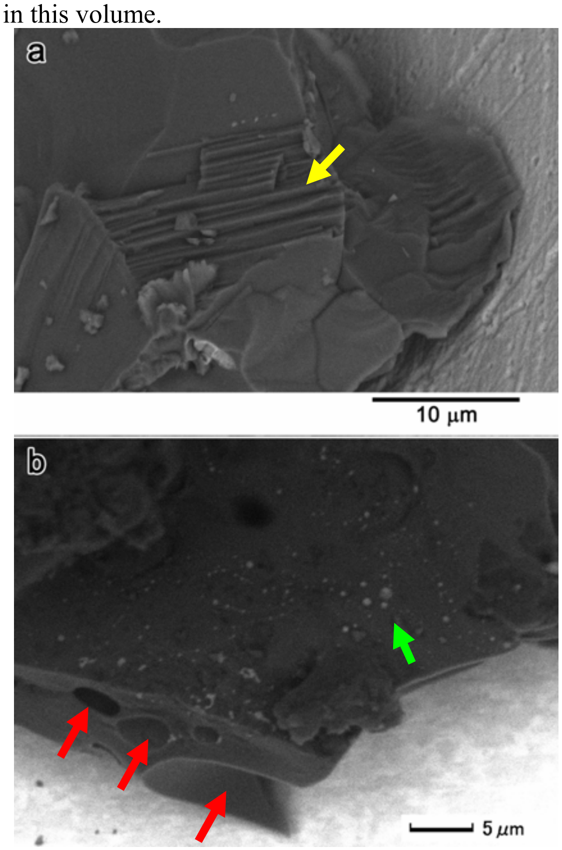

Figure 1 Enlarged BSE images of unconsolidated fine-grained particles from the surfaces of (a) Asteroid Itokawa and (b) Moon.