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Surface processes on the asteroid deduced from the external 3D shapes and surface features of Itokawa particles.

A. Tsuchiyama (1) and T. Matsumoto (2)
(1) Kyoto University, Japan, (2) ISAS/JAXA, Japan (atsuchi@kueps.kyoto-u.ac.jp / Fax: +81-75-753-4189)

Abstract

1. Introduction

Particles on the surface of S-type Asteroid 25143 Itokawa were successfully recovered by the Hayabusa mission of JAXA (e.g., [1,2]). They are not only the first samples recovered from an asteroid, but also the second extraterrestrial regolith to have been sampled, the first being the Moon by Apollo and Luna missions. The analysis of tiny sample particles (20-200 μm) shows that the Itokawa surface material is consistent with LL chondrites suffered by space weathering as expected and brought an end to the origin of meteorites (e.g., [2-4]). In addition, the examination of Itokawa particles allow studies of surface processes on the asteroid because regolith particles can be regarded as an interface with the space environment, where the impacts of small objects and irradiation by the solar wind and galactic cosmic rays should have been recorded.

External 3D shapes and surface features of Itokawa regolith particles were examined. Two kinds of surface modification, formation of space-weathering rims mainly by solar wind implantation and surface abrasion by grain migration, were recognized. Spectral change of the asteroid proceeded by formation of space-weathering rims and refreshment of the regolith surfaces.

External 3D shapes and surface morphologies of the regolith particles can provide information about formation and evolution history of regolith particles in relation to asteroidal surface processes. 3D shapes of Itokawa regolith particles were obtained using microtomography [3]. The surface nano-miromorpholgy of Itokawa particles were also observed using FE-SEM [5]. However, the number of particles was limited and genial feature on the surface morphology has not been understood. In this study, the surface morphology of Itokawa regolith particles was systematically investigated together with their 3D structures.

2. Experiments

Eleven and nine particles picked up from Rooms-A and –B of the sample catcher, respectively. They were examined by analytical dual-energy microtomography [6] with the voxel size of about 100 nm at BL47XU of SPring-8 for 3D structures and by FE-SEM (JEOL JSM-7001F, JSM-7800F, Hitachi S-5500, SU-8220) for micro-nanaomorphology. In the SEM observation, the samples were not coated with any conducting materials to avoid possible decoration by the coating. To avoid charge up by electron irradiation, observation was made at a low accelerating voltage (1 or 2 kV) in vacuum.

After the tomography and SEM observation, ultra-thin sections were prepared using focused ion beam (FIB: FEI Quanta 200 3DS FIB) from one of the particles (RB-QD04-0043) for TEM/EDX analysis (JEM-2100F). A high-angle annular dark-field (HAADF) imaging in STEM mode was performed to observe distribution of materials with heavy elements in the sample.

3. Results and Discussions

Based on the SEM observation, the regolith surfaces can be classified into three-types. Type 1 surfaces are represented by nearly parallel and sometimes branched steps. They are regarded as fractured or cleaved surfaces by comparing with fractured and cleaved surfaces of terrestrial olivine and pyroxene grains. These surfaces were formed by impact on the

Itokawa surface. Type 2 surfaces are represented by parallel and/or concentric steps with polygonal shapes. Type 3 surfaces are covered with many micron-submicron mineral grains, which are connected to the substrates based on the CT observation. These grains usually have facets and show euhedral shapes. Type-2 and -3 surfaces resemble to products in vapor condensation experiments of olivine [7], and thus can be regarded as condensates from vapor. Particles having these surface types are porous in the CT images. They should be walls of closed cavities or "micro-druses", which were formed from originally porous aggregates of fine materials such as matrix or fine regolith breccia at high temperatures during thermal metamorphism or post-shock heating.

The surfaces can be also categorized into two different types; fresh surfaces having sharp edges, and matured surfaces having rounded edges. They are consistent with the external 3D shapes observed by the microtomography. The fresh and matured surfaces were observed regardless of Types 1-3. A single grain sometimes has the both surface types. The matured surfaces were considered to form from fresh surfaces by abrasion processes on Itokawa [3].

Blister structures were formed by solar wind implantation as a part of space-weathering rims [8]. The SEM and TEM studies of the same location of the same particle showed that blister structures, which were originally observed by TEM [8], were recognized as spotted structures on the particles surfaces by SEM. Eleven out of twenty regolith particles have space-weathered rims with blisters. These rims are heterogeneously distributed in a single particle and the rims often present in opposite surfaces of the same particle, suggesting migration of regolith particles on Itokawa. In addition, the blister distribution and the roundness of the particle surface are not correlated with each other. Thus, the abrasion process can be regarded as a different type of space weathering with a longer timescale, and should be called "space micro-erosion." The abrasion is probably the result of grain migration, which is caused by seismic waves repeatedly reflecting off the surface of Itokawa after impacts [3]. Different potential mechanisms for the physical weathering, tidal disruption and YORP effect, was also proposed [9].

The present results indicate that space-weathering process of Asteroid Itokawa proceeded as follows. Space-weathered rims were developed on local surfaces of individual regolith particles, promoting the spectral change of Asteroid Itokawa, while refreshment of the regolith surfaces occurred, suppressing the spectral change, by mechanical abrasion due to grain migration and fragmentation due to impact.

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