ABRASION OF LUNAR REGOLITH PARTICLES.

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Introduction: 3D shape distribution of Itokawa regolith particles collected by the Hayabusa mission was examined using x-ray microtomography, and it was proposed that the particles are consistent with impact fragments on the asteroid surface [1, 2]. Lately, 3D shape distribution of fragments produced by a series of hypervelocity impact experiments using basalt targets were examined for small particles that have similar size with the Itokawa particles [3]. It was found that their average three-axial ratios are almost the same irrespective of impact conditions with a variety of the energy densities; the ratios are similar to the 2D silver ratio and that of Itokawa particles as well. 3D shape distributions of lunar regolith particles sampled by the Apollo and Luna missions have been also examined by microtomography [4-6]. In contrast to the impact fragments and Itokawa particles, the average axial ratios of the lunar particles are different from them and are more spherical than the 2D silver ratio.

The external 3D shapes and surface nano-micromorphologies of Itokawa particles examined by x-ray microtomography and SEM showed that some particles have rounded edges on the surfaces indicating that they were suffered by mechanical abrasion [1, 2, 7]. The mechanical abrasion was caused by a high-energy event on the asteroid surface, such as seismic induced grain motion [1] and/or YORP effect [8]. The average axial ratio of particles with rounded edges is slightly more equant than that of angular particles without rounded edges [2]. As mentioned above, the lunar particles are clearly more spherical than the impact fragments and Itokawa particles although the lunar particles must be impact fragments on the lunar surface. The cause for the spherical shapes may be mechanical abrasion as in the case of Itokawa particles, but it has not been known so far. In this study, the external 3D shapes and surface nano-micromorphologies of lunar particles were examined to elucidate whether or not mechanical abrasion also took place in the lunar regolith.

Experiments and analysis: The external 3D shapes of lunar regolith particles collected from Mare Tranquillitatis (Apollo 10084) and Descartes highland (Apollo 60501) that have been already imaged grain-by-grain using x-ray microtomography [4] were analyzed for detecting rounded edges without melting in this study. The image analysis was carefully made because lunar particles usually have partially melted portions. Then, the surfaces of particles with rounded and angular edges were observed by a field emission scanning microscope (FE-SEM: FEI Helios NanoLab Dual Beam) at Kyoto University. The SEM observation were made without any coating of an electrically conductive material, such as carbon, onto the particles. To avoid charge up, secondary electron images were taken at a low accelerating voltage (2 kV).

Results and Discussion: Some of the particles clearly have rounded edges in the CT images as in the case of Itokawa particles although some areas of the surfaces are partially covered with partially melted materials with small voids (agglutinates). SEM observation of one of the particles (Apollo 60501) with clearly rounded edges show that the surfaces are basically smooth in nano-meter scale, which is covered with many pancake-shaped glassy objects a few μm to <10 nm in size. Tiny crater-like structures ~10 nm in size, which should be formed by secondary impact, were rarely observed. Any objects similar to blisters formed by solar wind irradiation were not observed. Sharp steps were locally observed in concaved areas of the surface. Thus, this surface might be eroded by mechanical abrasion and the particle spended some short duration, when melt splashes produced by micro-impacts hit the surface, after the erosion in the regolith layer. In contrast, sharp steps were commonly observed on the surface of angular particles without rounded edges. Many melt splashes and rare nanocrater-like structures were also observed.

The present observation strongly suggests that some lunar regolith particles were mechanically abraded and became spherical, and thus the three-axial ratios are closer to that of a sphere than those of impact fragments. The cause of the abrasion might be grain motion due to gardening by repeated impacts onto regolith layers for much longer duration than the small asteroid Itokawa. The average three-axial ratios of the lunar particles are almost constant irrespective of their occurrence (mare and highland) and maturity [6]. This suggests that the three-axial ratios of the lunar particles became saturated by repeated abrasion and fracturing in the regolith layers. It was proposed that the regolith activity—including grain motion, fracturing, and abrasion—might effectively act as refreshing process of Itokawa particles against space-weathered rim formation [7]. However, the three-axial ratio of Itokawa particle was not saturated due to their younger age than lunar particles.

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