THREE-DIMENSIONAL STRUCTURES OF ITOKAWA PARTICLES USING MICRO-TOMOGRAPHY: COMPARISON WITH LL5 and LL6 CHONDRITES. A. Tsuchiyama[1], M. Uesugi[2], K. Uesugi[3], T. Nakano[4], R. Noguchi[1], T. Matsumoto[1], J. Matsuno[1], T. Nagano[1], Y. Imai[1], A. Shimada[1], A. Takeuchi[3], Y. Suzuki[3], T. Nakamura[5], T. Noguchi[6], T. Mukai[2], M. Abe[2], T. Yada[2], A. Fujimura[2], [1]Department of Earth and Space Science, Osaka University, Toyonaka, Japan (akira@ess.sci.osaka-u.ac.jp), [2]JAXA, Sagamihara, Japan, [3]JASRI/SPring-8, Sayo, Hyogo, Japan, [4]Geological Survey of Japan. AIST, Tsukuba, Japan, [5]Department of Earth and Planetary Material Sciences, Tohoku university, Aoba-ku, Sendai, Japan, [6]The collage of Science at Ibaraki University, Mito, Japan.

Introduction: Fine particles of S-type Asteroid 25143 Itokawa were successfully recovered by the Hayabusa mission [1-6]. This is the first sample recovered from an asteroid and returned to Earth, and the second extraterrestrial regolith to have been sampled, the first being the Moon, which was sampled by the Apollo and Luna missions. Preliminary examination of Itokawa particles revealed that the samples are mixture of LL chondrites [1-4], which was suffered by space weathering [5], as expected from remote sensing observation by the Hayabusa spacecraft [7], and brought an end to the origin of meteorites. Processes on the Itokawa surface and regolith chronology were elucidated by examining the samples that are regolith particles on Itokawa [2,5,6].

As a part of the preliminary examination, three-dimensional (3D) structures of forty particles (30-180 μm) were examined using x-ray micro-tomography in order to understand their internal structures and external shape features [2]. The particles were picked up from room-A of the sample chamber, which corresponds to sampling sequence at the spacecraft second touchdown. However, particles picked up from room-B, which corresponds to sampling sequence at the first touchdown, has not yet been examined. The sampling were made in the smooth terrain of MUSES-C Regio [8], but the two estimated touchdown locations are different from each other [9], and different materials, such as those with different degrees of space weathering, might be sampled.

The textures of the Itokawa particles show that most of them are LL5 and/or LL6 chondrites [1,2]. However, as 3D structures of LL chondrites have not been examined with the same method as the Itokawa particles, comparison with LL chondrites has not been made with the same resolution.

In the present study, 3D structures of additional particles, which were picked up from rooms-A and -B and newly allocated for the preliminary examination, were examined. In addition to the Itokawa samples, particles of LL5 and LL6 chondrite fragments were also examined using the same method to compare Itokawa samples with LL chondrites.

Analytical techniques: The Itokawa samples are four particles from room-A (RA-QD02-0017, 0033, 0049-2 and 0064) and four from room-B (RB-QD04-0006, 0023, 0025 and 0049). Fifteen particles of Tuxtuac meteorite (LL5), twelve particles of Kilabo meteorite (LL6) and fifteen particles of Ensisheim meteorite (LL6) were also examined. Fragments of the meteorites were crushed and particles of similar size as the Itokawa particles (~50-100 μm) were picked up.

X-ray absorption imaging tomography [10,11] was used at BL47XU of SPring-8, Hyogo, Japan. The experimental procedure was the same as that in the previous study [2]. Two different imaging system settings was used for samples with different sizes: (1) voxel (pixel in 3-D) size of ~100 nm (effective spatial resolution of ~200 nm) for smaller samples (<~100 μm) and (2) voxel size of ~250 nm (effective spatial resolution of ~500 nm) for larger samples (>~100 μm). Imaging at two X-ray energies of 7 and 8 keV made identification of minerals in CT images possible since the K-adsorption edge of Fe at 7.11 keV is present between the two energies (analytical dual-energy micro-tomography [12]). Chemical compositions of olivine, pyroxene and plagioclase were roughly obtained using this method [12]. A successive set of 3D CT images, which shows quantitative 3D mineral distribution, was obtained for each particle.

Results and discussion:

(1) *3D internal structures and mineralogy of Itokawa particles.* The total volume of the forty-eight Itokawa particles is 4.4×10^6 μm^3, which corresponds to a sphere of ~202 μm in diameter, and the total mass is ~15 μg. The modal mineral abundances in volume are 65% olivine, 19% low-Ca pyroxene, 3% high-Ca pyroxene, 11% plagioclase, 2% troilite, 0.2% kamacite, 0.01% taenite, 0.1% chromite, and 0.06% Ca phosphates, and the porosity is 1.4 vol.%. They are almost the same as the previous data for the forty particles in [2]. The abundance is similar to that of LL chondrites, and slight difference between them can be regarded as the result of sampling bias, which was indicated by statistical analysis of LL6 chondrite textures [13].

All the new eight particles have equilibrated textures. We cannot distinguish the mineralogy and textures of the room-A particles form those of the room-B particles. A relatively coarse grain of Ca-phosphate was found in a room-B particle (RB-QD04-0025), which may be used for Pb-Pb age determination by SIMS.

(2) *Comparison with LL5 and LL6 chondrites.* The numbers of poly- and mono-mineralic particles of Itokawa sample (Figs. 1A and 1B, respectively) are 21 (18 room-A and 3 room-B) and 27 (26 room-A and 1 room-B), respectively. The proportion of the two particle types roughly corresponds to mineral grain size in the samples. The numbers of poly- and mono-mineralic particles of LL5 samples are 9 and 6, respectively, and those of LL6 samples are 13 (6 Kilabo and 7 Ensisheim) and 14 (6 Kilabo and 8 Ensisheim), respectively. The proportions of Itokawa and LL chondrite particles are similar, showing that the Itokawa particles are consistent with LL5 and/or LL6 chondrites, but we cannot distinguish between LL5 and LL6.

Two types of voids are recognized both in the Itokawa and LL chondrite particles. One is small voids (<~a few μm) with facets usually aligned in a plane (Fig. 1B in [2]) and may be void inclusions along healed cracks. The other is relatively large rounded voids (~5-20 μm). Particles having this type of voids are porous, and might be formed by impact. The numbers of Itokawa particles with abundant and rare/none voids are 19 (16 room-A and 3 room-B) and 29 (28 room-A and 1 room-B), respectively. All the void-rich particles have small voids, and 5 of them (5 room-A and 0 room-B) are porous with large voids. The numbers of LL5 particles with abundant and rare/none voids are 8 and 7, respectively. 6 of the void-rich particles have abundant small voids and 5 of them are porous. In contrast, all of LL6 particles have rare/none voids. The difference between the LL5 and LL6 samples may be due to heterogeneity of the meteorites. The difference of shock degree may not be the cause because Kilabo meteorite is a breccia.

Particles with abundant cracks (Fig. 1A in [2]) are also present both in the Itokawa and LL chondrite particles. The numbers of Itokawa particles with abundant and rare/none cracks are 7 (7 room-A and 0 room-B) and 41 (37 room-A and 4 room-B), respectively. The numbers of LL5 particles with abundant and rare/none cracks are 11 and 4, respectively, and those of LL6 particles are 8 (6 Kilabo and 2 Ensisheim) and 19 (6 Kilabo and 13 Ensisheim), respectively. The proportion of crack-rich particles in the LL5 sample is larger than those in the Itokawa and Ensisheim samples. The difference may be simply due to sample heterogeneity, but possibility of shock degree difference cannot be excluded.

(3) *3D external shape of Itokawa Particles.* The sphere-equivalent diameter of the new particles in rooms-A and –B are 25-49 μm and 23-30 μm, respectively. The cumulative size distribution of the forty-eight particles was almost similar to that of the previous data for forty particles with the log-slope of ~-2. The size distribution of particles of ~50-200 μm, which were picked up from quartz disks (tapping samples; 175 particles form room-A and 32 particles from room-B), has the log slope of ~-2.2. These data confirmed the dominance of ~cm size particles in the smooth terrain as the size distribution of boulders has the log slope of ~-3 [2]. The 3D shape (three axial length ratios) distribution are almost the same as that in the previous data and cannot be distinguished from that of fragments produced by impact experiments, showing that the Itokawa particles are consistent with impact fragments [2].

Particles with rounded edges were recognized in the Itokawa particles and considered to be formed by erosion from impact fragments with sharp edges [2]. The numbers of particles with sharp and rounded edges are 35 (32 room-A and 3 room-B) and 13 (12 room-A and 1 room-B), respectively. Micro-structure observation of Itokawa particle surfaces using FE-SEM suggests that surfaces with rounded edges are matured by processes on Itokawa and/or its parental body surfaces, such as space weathering [14]. The abundance of particles with rounded edges in A-room is similar to that in room-B although the number of the particles is small.

Conclusions: The present study shows that the Itokawa particles with equilibrated textures are consistent with LL5 and LL6 chondrites even if detailed structures, such as grain size, voids and cracks, are taken into consideration. The features of the 3D external shapes, such as size and shape distributions, were not changed from the previous data of [2]. The degrees of space weathering among particles from the two different touchdown sites cannot be distinguished.

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