

THREE-DIMENSIONAL STRUCTURES OF PARTICLES RECOVERED FROM THE ASTEROID ITOKAWA BY THE HAYABUSA MISSION AND A ROLE OF X-RAY MICROTOMOGRAPHY IN THE PRELIMINARY EXAMINATION.

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Introduction: Particles of regolith on S-type Asteroid 25143 Itokawa were successfully recovered by the Hayabusa mission of JAXA (Japan Aerospace Exploration Agency) [1]. Near-infrared spectral study of Itokawa's surface indicates that these particles are materials similar to LL5 or LL6 chondrites [2]. High-resolution images of Itokawa's surface suggest that they may be breccias and some impact products [3]. At least more than 1500 particles were identified as Itokawa origin at curation facility of JAXA. Preliminary analysis with SEM/EDX at the curation facility shows that they are roughly similar to LL chondrites [4]. Although most of them are less than 10 μm in size, some larger particles of about 100 μm or larger were also identified.

A part of the sample (probably several tens particles) will be selected by Hayabusa sample curation team, and sequential examination will start from January 2011 by Hayabusa Asteroidal Sample Preliminary Examination Team (HASPET) [5]. In mainstream of the analytical flow, each particle will be examined by microtomography, XRD and XRF first as nondestructive analyses, and then the particle will be cut by an ultra-microtome and examined by TEM, SEM, EPMA, SIMS, PEEM/XANES, and TOF-SIMS sequentially.

Three-dimensional structures of Itokawa particles will be obtained by microtomography sub-team of HASPET. The results together with XRD and XRF will be used for design of later destructive analyses, such as determination of cutting direction and depth, to obtain as much information as possible from small particles. Scientific results and a role of the microtomography in the preliminary examination will be presented.

Analytical techniques: X-ray tomography is the method to obtain internal structures by using signals that are obtained when an X-ray beam passes through

an object. Different signals, such as absorption, refraction, diffraction, and fluorescence, can give different information, such as absorption contrast, phase contrast, crystallography, and elements. Tomography using X-ray absorption is conventional method to give spatial distribution of X-ray linear attenuation coefficients (LACs) along a slice of an object as a digital image (CT image). Three-dimensional structure can be obtained by stacking successional CT images.

Synchrotron radiation (SR) X-ray beams with high flux density and high orientation gives CT images of high spatial resolution and high S/N ratio. High flux X-ray beams are easily monochromated, and this gives quantitative LAC values in CT images, which can use for identification of minerals and the chemical compositions, such as the Mg/Fe ratios of olivine and pyroxene [6]. In addition, nano-scale resolution can be obtained by X-ray imaging system using FZP (Fresnel zone plate) (imaging tomography).

In the preliminary examination, X-ray absorption imaging tomography will be used at BL47XU of SPring-8, Hyogo, Japan [7]. Three different imaging system settings will be prepared for samples with different sizes as follows: (1) voxel (pixel in 3-D) size: 44 nm, spatial resolution: 200-300 nm, FOV (field of view): 50 μm , (2) voxel size: 90 nm, spatial resolution: 300-400 nm, FOV: 80 μm , and (3) voxel size: 150 nm, spatial resolution: 300-400 nm, FOV: 200 μm . The sample size should be smaller than the FOV, and this determines the spatial resolution.

Each particle will be attached on a carbon fiber with a resin for TEM (EMbed812). The particle will be also covered entirely with a thin layer of the same resin to avoid oxidation as much as possible. Three-dimensional internal structures (three-dimensional distribution of LAC values) of the particle will be obtained. The external shape of the particle will be also

obtained by extracting solid portions using binarization. After the tomographic imaging, the samples will move on to the XRD and XRF analysis at BL3A of KEK-PF, Tsukuba, Japan and BL15XU of SPring-8, where mineral compositions and elemental compositions will be obtained. Based on the LAC values in CT images and the mineral compositions, three-dimensional distribution of mineral phases (three-dimensional phase map) will be obtained.

Examination Goals: The basic scientific goals of the microtomography sub-team are as follows.

(1) *Three-dimensional texture of each particle and its variation.* The spatial resolution of the microtomography is comparable or higher than that of a conventional SEM and is sufficient to examine textures of LL5 or LL6 chondrites, or even LL4 chondrites. Instead, the particle sizes are comparable to the typical grain sizes of these chondrites. Accordingly, statistical data should be required for comparison between textures of Itokawa particles and chondrites, especially for the case where Itokawa particles are a mixture of LL4 to LL6 chondrite polymict breccia. The FE-SEM and EPMA analysis can give higher spatial resolutions as well as the chemical compositions of minerals. However, the amount of information in two-dimensional areas may not be sufficient for the comparison. In contrast, the amount of information in three-dimensional volume is much larger than the two-dimensional one. Thus, this gives complimentary information, such as mode of minerals, and will help to reconstruct original textures of Itokawa materials before regolith formation.

(2) *Three-dimensional external shape of each particle of regolith and its variation.* If the external shapes of Itokawa particles are measured this is the first measurement on the shapes of regolith particles on an asteroid. Three-dimensional shapes of lunar regolith were measured by microtomography, and the effect of particle properties on bulk mechanical properties of lunar surface soil were elucidated by simulation using the three-dimensional shapes [8]. Similar application is possible for regolith on the Itokawa surface.

A Role of Microtomography in Preliminary Examination: Combination of non-destructive analyses, microtomography, XRD and XRF, used for design of the later destructive analyses is one of the key features in this preliminary examination. It is easy to obtain the priority of the samples to be analyzed. Furthermore, three-dimensional phase map together with external shape of each particle gives information where should be cut for the later destructive analyses to obtain suitable areas of specific minerals in cross sections of small particles. In fact, this procedure was very useful for obtaining a sufficient area of plagioclase section to measure the Al-Mg age for a cometary dust collected

by the Stardust mission [9]. In addition to specific mineral phases, carbonaceous materials in a particle can be identified by the microtomography if they are present. In this case, the particle will be cut for organic material analysis by PEEM/XANES and TOF-SIMS.

References: [1] http://www.jaxa.jp/press/2010/11/20101116_hayabusa_e.html. [2] Abe M. et al. *Science*, 312, 1334-1338. [3] Noguchi T. et al. (2010) *Icarus*, 206, 319-326. [4] Nakamura T. et al. (2011) abstract in this conference. [5] Tsuchiyama A. et al. (2011) abstract in this conference. [6] Tsuchiyama A. et al. (2005) *Am. Min.*, 90, 132-142. [7] Uesugi K. et al. (2006) *Proc. SPIE*, 6318, 63181F; Takeuchi A. et al. (2009) *J. Phys.: Conf. Ser.*, 186, 012020. [8] Matsu-shima T. et al. (2009) *Journal of Aerospace Engineering, ASCE*, 22, 1, 15-23. [9] Nakamura T. et al. (2008) *Science*, 321, 1664-1667.