

MINERALOGY AND MAJOR ELEMENT ABUNDANCE OF THE DUST PARTICLES RECOVERED FROM MUSES-C REGIO ON THE ASTEROID ITOKAWA. T. Nakamura¹, T. Noguchi², M. Tanaka³, M. E. Zolensky⁴, M. Kimura², A. Nakato¹, T. Ogami¹, H. Ishida¹, A. Tsuchiyama⁵, T. Yada⁶, K. Shirai⁶, R. Okazaki⁷, A. Fujimura⁶, Y. Ishibashi⁶, M. Abe⁶, T. Okada⁶, M. Ueno⁶, T. Mukai⁶ ¹Department of Earth and Planetary Material Sciences, Faculty of Science, Tohoku University, Aoba, Sendai, Miyagi 980-8578, Japan (tomoki@m.tohoku.ac.jp), ²College of Science, Ibaraki University, 2-1-1 Bunkyo, Mito, Ibaraki 310-8512, Japan, ³WEBRAM, Spring-8, National Institute for Materials Science, Sayo, Hyogo 679-5198, Japan, ⁴KT NASA Johnson Space Center Houston, TX 77058, USA, ⁵Department of Earth and Space Science, Graduate School of Science, Osaka University, Toyonaka 560-0043, Japan, ⁶JAXA-ISAS, 3-1-1 Yoshinodai, Sagami-hara, Kanagawa 229-8510, Japan. ⁷Department of Earth and Planetary Science, Faculty of Science, Kyushu University, Hakozaki, Fukuoka 812-8581, Japan.

Introduction: Remote sensing by the spacecraft Hayabusa suggested that outermost surface particles of Muses-C regio of the asteroid Itokawa consist of centimeter and sub-centimeter size small pebbles [1]. However, particles we found in the sample catcher A stored in the Hayabusa capsule, where Muses-C particles were captured during first touchdown, are much smaller. i.e., most are smaller than 100 microns in size. This suggests that only small fractions of Muses-C particles were stirred up due to the impact of the sampling horn onto the surface, or due to jets from chemical thrusters during the lift off of the spacecraft from the surface.

X-ray fluorescence and near-infrared measurements by the Hayabusa spacecraft suggested that Itokawa surface materials have mineral and major element composition roughly similar to LL chondrites [2, 3]. The particles of the Muses-C region are expected to have experienced some effects of space weathering [3]. Both of these prospects can be tested by the direct mineralogical analyses of the returned Itokawa particles in our study and another one [4]. This comparison is most important aspect of the Hayabusa mission, because it finally links chemical analyses of meteorites fallen on the Earth to spectroscopic measurements of the asteroids.

Identification of Itokawa particles: On 13th of June, the Hayabusa return capsule successfully landed in the Woomera Prohibited Area of South Australia and was transported to Japan on 17th. One week later, the sample container was opened in the vacuum sample chamber and very small amounts of atmospheric gases were released from the container [5]. This indicated that a slow leak occurred into the sample container and that sample particles were exposed to air for a couple of days. However, sample particles have been subsequently kept in pure nitrogen atmosphere in the sample chamber.

Particles were removed from the room A of the sample catcher by applying several different methods; (1) picking up particles using an electrostatic manipulator, (2) separating particles using a small Teflon spatula, and (3) dropping particles onto a polished silica

glass plate. For particles (1), no analysis was performed so far, while for particles (2) and (3), FE-SEM/EDS analysis have been performed.

SEM analysis of the Teflon spatula: Many particles became attached to the surface of the Teflon spatula during sweeping of approximately 10% of the surface of sample catcher room A. The spatula was transferred from the sample chamber to the FE-SEM without exposure to atmosphere. Particles on one side of the spatula were analyzed individually without any conductive coat at 10KeV, a low electron current, low vacuum mode (60Pa ambient pure-nitrogen pressure), and low magnification of 600X. A higher voltage, lower ambient pressure, and higher magnification would have caused significant damage to the Teflon spatula and severe charging of the spatula surface. Each particle on the spatula was irradiated by a focused electron beam and a quantitative composition was obtained.

All particles on one side of the spatula were analyzed. Particles that could not be distinguished as discrete grains at 600X magnification (smaller than several microns) were excluded from analysis. Among particles analyzed, approximately 1800 particles are manmade including small bits of Al and stainless steel, but approximately 1500 particles are natural rocky particles. More than 90% of the rocky particles are smaller than 10 micron in size and the largest one is 40 microns (Fig. 1). Most particles are angular - they are probably broken pieces of larger rocks.

Among the rocky particles analyzed, 580 are olivine, 118 are low-Ca pyroxene, 56 are high-Ca pyroxene, 186 have feldspar compositions (172 plagioclase and 14 K-feldspar), 113 are Fe sulfide, 13 are chromite, 10 are Ca phosphate, 3 are FeNi metal, and 447 are mixtures of several mineral phases. Several particles of silica minerals and K-bearing halite were found. The average and one sigma variation of Fa# for olivine, Fs# for low-Ca pyroxene, Fs# and Wo# for high-Ca pyroxene, and Ab# for plagioclase are 28±4, 23±6, 12±9 and 38±6, and 86±7, respectively. Fe sulfide contains only Fe and S with an average Fe/S ratio of 1 and, in one particle, coexists with FeNi metal. There-

fore, Fe sulfide is probably troilite. Both kamacite and taenite are present as FeNi metal.

The mineralogy and mineral chemistry of the rocky particles on the Teflon spatula are very similar to LL chondrites, suggesting that the small particles of the Muses-C regio are mostly LL-chondrite materials. The mineral chemistry suggests that silicates are virtually homogeneous in compositions. This implies that the particles are thermally processed as a single large rock (or body) prior to breaking into small pieces. The intensity of thermal metamorphism (i.e., petrologic type) is usually estimated based on compositional variations of silicates, but we did not estimate it yet. Because the particles were analyzed as grains with rough surfaces (without any polishing for flat surface), the chemical variations observed in Fa#, Fs#, Wo#, and Ab# are probably larger than true variations. For precise estimation of the petrologic type, we need to have quantitative chemical compositions obtained by analysis of flat surface of silicates and this analysis will be done in the near future as is described in the next section.

Our results are consistent with the results of remote sensing measurements made of asteroid Itokawa by on-board instruments of Hayabusa. However, our analysis indicates that the particles captured by Hayabusa are depleted in FeNi metal compared with typical LL chondrites (0.5~7.2%) [6]. Possible explanations for the low abundance of FeNi metal are (1) the metallic particles are rare on the topmost surface of Muses-C regio, (2) they could not reach the sample catcher during capture due to some sorting effects, or (3) they were not efficiently transferred from the sample catcher to the Teflon spatula during sweeping in the catcher.

SEM analysis of the particles from the silica plate: Many particles were recovered on a silica plate that was placed on the bottom of the room A of the sample catcher, after gentle beating by a metallic rod. Many of the particles are 100 microns or larger in size and thus they are larger than those on the Teflon spatula. Particles were removed from the glass plate one by one and put on an SEM sample holder made of pure metallic copper using the electrostatic manipulator and analyzed by FE-SEM/EDS. Currently we have identified 32 particles with sizes from 30 to 130 microns as Itokawa particles. Many particles are angular and have very fine adhering particles (Fig. 2). They are usually composed of multi-mineral phases such as olivine-low Ca pyroxene and olivine-plagioclase. Fe sulfides and FeNi metal are found as small inclusions in the particles, but not identified as discrete single particles. These analyses are still in work, and probably 40 to 50 particles will be identified by the end of January 2011 whereupon they will be analyzed sequentially by the initial analysis team.

Mineralogy-Petrology analysis as a part of initial analysis: The particles recovered from the silica glass plate will be analyzed in late January and February 2011 in the following sequences. (a) Synchrotron X-ray diffraction and fluorescence analysis at KEK and SPring-8 for bulk mineral and chemical compositions, (b) TEM observation after ultramicrotomy and FIB for micro-textures, mainly of silicates, (c) FE-SEM/EDS/EBSA analysis for petrography and crystallographic features, and (d) FE-EPMA/WDS analysis for quantitative chemical compositions of each mineral phase. The experimental conditions will be very similar to those applied for Stardust particles [7], but we will take special precautions during sample preparation and polishing to not expose samples to terrestrial atmosphere in order to minimize sample degradation.

References: [1] Yano H. et al. (2006) *Science* 312, 1350-1353. [2] Okada T. et al. (2006) *Science* 312, 1338-1341. [3] Abe M. et al. (2006) *Science* 312, 1334-1338. [4] Noguchi et al. (2011) in this volume. [5] Okazaki et al. (2011) in this volume. [6] Dunn et al. (2010) *Meteoritics and Planetary Science* 45, 123-145. [7] Nakamura et al. (2008) *Science* 321, 1664-1667.

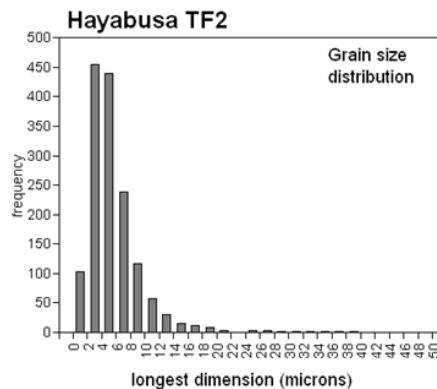


Fig. 1. Size distribution of the Itokawa particles on one side of the Teflon spatula. The total number of the particles measured is 1574.

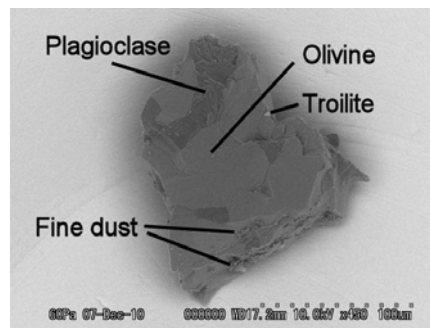


Fig. 2. A large Itokawa particle captured during first touchdown onto the surface of Muses-C regio.