Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

U005-01 Room:IC Time:May 26 08:30-08:35

Introduction to ”New planetary science arising from ’HAYABUSA’ recovery sample” (session outline)

Toshifumi Mukai[1*], Masanao Abe[1], Makoto Yoshikawa[1]

[1]Japan Aerospace Exploration Agency

Return capsule of the asteroid exploration spacecraft ”HAYABUSA”, which tried the sample collection from the asteroid Itokawa for the first time and succeeded in the earth return, was recovered safely in June, 2010. In this session, we will discuss results of the curation work and preliminary analyses of the recovered samples in expectation of new planetary science.

Keywords: Hayabusa, Recovery sample, Planetary science

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U005-02 Room:IC Time:May 26 08:35-08:50

Hayabusa missions outline and capsule recovery

Masanao Abe[1*], Akio Fujimura[1], Hajime Yano[1], Chisato Okamoto[1], Tatsuaki Okada[1], Toru Yada[1], Yukihiro Ishibashi[1], Kei Shirai[1], Tomoki Nakamura[2], Takaaki Noguchi[3], Ryuji Okazaki[4], Michael Zolensky[5], Scott Sandford[6], Trevor Ireland[7], Munetaka Ueno[1], Toshifumi Mukai[1], Makoto Yoshikawa[1], Tesuya Yamada[1], Hitoshi Kunnaka[6], Junichiro Kawaguchi[1], Hayabusa Capsule recovery team[1]

[1]Japan Aerospace Exploration Agency, [2]Tohoku University, [3]Ibaraki University, [4]Kyushu University, [5]NASA Johnson Space Center, [6]NASA Ames Research Center, [7]Australian National University

On June 13, 2010, the Hayabusa spacecraft and its re-entry capsule returned to the Earth, and separation of the capsule occurred at 19:51(JST). At 22:51, both the spacecraft and the capsule entered the Earth's atmosphere and the spacecraft was burned up. After the thermal shields separated from the re-entry capsule and parachute deployed at 22:56, the capsule landed on the ground and began sending out a radio beacon at 23:08. A helicopter, assisted by information from four direction finding gound sites, discovered the capsule at 23:56. The landing point was almost the exact center of predicted ellipse within the Woomera Prohibited Area (WPA), thanks to mild wind. The final recovery of the capsule was performed on the following day, June 14, including special safety operations at the landing point.

At the landing point, acquisition of scientific do-cumentary photography, collection of the circumfe-rence soil samples, environmental measurements such as GPS positioning, temperature and humidity, and packaging the capsule into the temporally plastic bag and initial/temporary transportation box for the recov-ery activity only were performed. The recovery capsule was then transported to the WPA Instrument Building where both the headquarters (HQ) of the Hayabusa capsule recovery team and Quick Look Facility (QLF) for this purpose were temporally in-stalled. One day was spent on the removal of the ex-plosive device and the battery in the capsule. The next day was spent on the removal of contaminants adher-ing to the capsule and the packing the capsule into the another cleand transportation box for internal trans-port. The surface cleaning of the capsule and packing operation were both executed in the temporary cleanroom at the QLF installed in the building. The transportation box has a purge function of pure nitrogen gas, and can ease the shock under transportation. On the afternoon of June 17, the remaining capsule I/M was flown from Woomera's Airfield in Australia, which is the nearest airport from the WPA, to Haneda Airport in Japan in a direct flight.

Keywords: Hayabusa, Capsule, Recovery

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U005-03 Room:IC Time:May 26 08:50-09:10

Curation of the sample: Circumstances, present condition, and future schedule

Akio Fujimura[1*], Masanao Abe[1], Toru Yada[1], Tomoki Nakamura[2], Takaaki Noguchi[3], Ryuji Okazaki[4], Yukihiro Ishibashi[1], Kei Shirai[1], Tatsuaki Okada[1], Hajime Yano[1], Michael Zolensky[5], Scott Sandford[6], Tetsuya Yamada[1], Munetaka Ueno[1], Toshifumi Mukai[1], Makoto Yoshikawa[1], Junichiro Kawaguchi[1]

[1]Japan Aerospace Exploration Agency, [2]Tohoku University, [3]Ibaraki University, [4]Kyushu University, [5]NASA Johnson Space Cneter, [6]NASA Ames Research Center

Japanese spacecraft Hayabusa, which returned from the near Earth asteroid Itokawa, successfully returned its reentry capsule to the Woomera Prohibited Area (WPA) in Australia on June 13th, 2010. The capsule introduced into the Planetary Material Sample Curation Facility in the Sagamihara campus of JAXA in the early morning of June 18th.

Hereafter, we describe a series of processes for the returned capsule and the container to recover gas and materials samples inside.

Keywords: Hayabusa, Recovery sample, Curation

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U005-04 Room:IC Time:May 26 09:10-09:30

Preliminary examination of Hayabusa asteroidal samples: Overview by university consortium team

Akira Tsuchiyama[1*], Mitsuru Ebihara[2], Makoto Kimura[3], Fumio Kitajima[4], Masato Kotsugi[5], Shoichi Itoh[6], Keisuke Nagao[7], Tomoki Nakamura[8], Hiroshi Naraoka[4], Takaaki Noguchi[3], Ryuji Okazaki[4], Uesugi Kentro[5], Masayuki Uesugi[9], Hisayoshi Yurimoto[6], Trevor R. Ireland[10], Scott A. Sndford[11], Michael E. Zolensky[12], Akio Fujimura[13], Masanao Abe[13], Toru Yada[13], Toshifumi Mukai[13], Tatsuaki Okada[13], Yukihiro Ishibashi[13], Kei Shirai[13], Munetaka Ueno[13], Junichiro Kawaguchi[13], Makoto Yoshikawa[13]

[1]Graduate School of Sci., Osaka Univ., [2]Grad. Sch. Sci. Eng., Tokyo Met. Univ., [3]Coll. of Sci. at Ibaraki Univ., [4]Graduate School of Sci., Kyushu Univ., [5]JASRI, SPring-8, [6]Graduate School of Sci., Hokkaido Univ., [7]Graduate School of Sci., Univ. of Tokyo, [8]Graduate School of Sci., Tohoku Univ., [9]Graduate School of Eng., Osaka Univ., [10]Res. School of Earth Sci., ANU, [11]NASA Ames Research Center, [12]NASA Johnson Research Center, [13]JAXA

The Hayabusa spacecraft arrived at S-type Asteroid 25143 Itokawa in November 2006, and reveal astounding features of the small asteroid [1]. Near-infrared spectral shape indicates that the surface of this body has a material similar to that of LL5 or LL6 chondrites [2]. Many small particles (at least >1500 particles; mostly <10 micron and some larger particles of >~100 micron) were successfully collected from MUSES-C region. Tentative analysis with SEM/EDX at the curation facility of JAXA showed that olivine (Fa28;/-4), low-Ca pyroxene (Fs23+/-6), high-Ca pyroxene (Fs12+/-9Wo38+/-6), plagioclase (Ab86+/-7) are identified as major phases with minor amounts of Fe-Ni metal, chromite, Ca phosphate, silica minerals and K-bearing halite [3]. About fifty particles of 30-150 microns were allocated for the preliminary examination (PE) by university consortium team.

The basic goals of PE are as follows. (1) Characterization of the surface material of Itokawa, such as classification, formation age, and formation process and conditions. (2) Understanding of processes on a preexisting parent body of Itokawa and accretion into Itokawa, such as examination of brecciation, degrees of impact, etc. (3) Understanding of interaction with space environment, such as space weathering, and isotopic compositions of oxygen and noble gases of the solar wind. (4) Finding foreign substances fallen onto the surface, such as carbonaceous and organic materials and differentiated materials (granitic materials and halite).

The policies of PE are follows. (1) As the sample is not suffered from terrestrial contamination, we make maximum consideration to avoid terrestrial contamination, and obtain data that cannot be obtained from meteorites, such as space weathering, solar wind isotopic compositions, and organic materials. (2) We have to obtain as much data as possible effectively even from a small amount of samples by systematic analyses from non-destructive to destructive ways with minimum contamination in upstream analysis.

We have seven sub-teams; (1) mineralogy and petrology, (2) 3-D structures, (3) elemental compositions, (4) isotopic and minor elemental compositions, (5) noble gas, (6) carbonaceous matter, and (7) organic compounds. PE flow chart is mainly divided into two parts: mainstream and individual analysis flows for specific purposes. In the mainstream, allocated particles have been already measured by non-destructive analyses at Spring-8 and KEK, Japan. 3-D structures, mineral compositions and elemental compositions will be determined by micro-tomography, XRD and XRF, respectively. Based on the non-destructive information, each particle will be cut for later destructive analyses by TEM, SEM, EPMA and SIMS. If carbon is present in the cross section, organic analyses will be made with X-PEEM/XANES and TOF-SIMS.

The following three individual analysis flows are scheduled. (i) Carbonaceous matter on the surfaces will be examined by micro-Raman/IR/fluorescence. Organic materials will be extracted form the particles and analyzed. After the extraction, the residual solid particles will move to the elemental analysis by INAA. If radioactivity is lower than the threshold, the particles will move to the mainstream. (ii) Noble gas analysis will be made using mass spectrometry without exposing particles into the air. (iii) Space weathering will be examined with a TEM. The samples were prepared carefully to avoid oxidation of Fe metal nano-grains. Potted butts will move to the mainstream. Any suitable sample for isotopic analysis of solar wind oxygen, such as a large single particle of metallic iron or iron sulfide, has not been found at this moment. Result of each analysis will be presented by CoIs of the sub-team in this conference.

[1] Fujiwara A. et al. (2006) Science, 312, 1330-1334. [2] Abe M. et al. Science, 312, 1334-1338. [3] Nakamura T. et al. (2011) abstract in 42nd LPSC.

Keywords: Hayabusa mission, preliminary examination, chondrite, asteroid, Itokawa, sample return

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Preliminary examination of Hayabusa asteroidal samples: 3-D structures of Itakawa particles using X-ray microtomography

Akira Tsuchiyama[1*], Masayuki Uesugi[2], Uesugi Kentaro[3], Tsukasa Nakano[4], Tomoki Nakamura[5], Takaaki Noguchi[6], Ryo Noguchi[1], Tooru Matsumoto[1], Junya Matsuno[1], Takashi Nagano[1], Takeuchi Akihisa[3], Suzuki Yoshio[3], Mitsuru Ebihara[7], Yuta Imai[1], Trevor R. Ireland[8], Fumio Kitajima[9], Matsushima Takashi[10], Tatsuhiro Michikami[11], Keisuke Nagao[12], Hiroshi Naraoka[9], Ryuji Okazaki[9], Scott A. Sndford[13], Hisayoshi Yurimoto[14], Michael E. Zolensky[15], Akio Fujimura[16], Masanao Abe[16], Toru Yada[16], Toshifumi Mukai[16], Tatsuaki Okada[16], Yukihiro Ishibashi[16], Kei Shirai[16], Munetaka Ueno[16], Junichiro Kawaguchi[16], Makoto Yoshikawa[16]

[1]Graduate School of Sci., Osaka Univ., [2]Graduate School of Eng., Osaka Univ., [3]JASRI, SPring-8, [4]AIST, [5]Graduate School of Sci., Tohoku Univ., [6]Coll. of Sci. at Ibaraki Univ., [7]Grad. Sch. Sci. Eng., Tokyo Met. Univ., [8]Res. School of Earth Sci., ANU, [9]Graduate School of Sci., Kyushu Univ., [10]Grad. Sch. Sys. Inf. Eng., Tsukuba Univ., [11]Fukushima National College of Technology, [12]Graduate School of Sci., Univ. of Tokyo, [13]NASA Ames Research Center, [14]Graduate School of Sci., Hokkaido Univ., [15]NASA Johnson Research Center, [16]JAXA

Particles on S-type Asteroid 25143 Itokawa were successfully recovered by the Hayabusa mission of JAXA [1]. This is the first regolith sample of asteroid. Forty-one particles of 30-150 microns has been allocated to mainstream flow of preliminary examination (PE) [2]. These particles were imaged using SR -based X-ray mirotomography to obtain their three-dimensional structures as the first analysis in sequential mainstream analyses.

X-ray absorption imaging tomography system was used at BL47XU of SPring-8, Hyogo, Japan [3]. Each particle was imaged using two X-ray energies at 7 and 8 keV. As these energies are smaller and larger than the K?adsorption edge of Fe (7.11 keV), respectively, we can recognize olivine, Ca-poor pyroxene, Ca-rich pyroxene, plagioclase, troilite, taenite, kamacite, chromite and Ca phosphate easily using the contrasts of CT images, which correspond to linear attenuation coefficient (LAC) obtained by tomographic reconstruction. Relatively smaller thirty-five particles were imaged with the voxel (pixel in 3-D) size of about 90 nm (effective spatial resolution: 300-400 nm), while 6 particles with the voxel size of about 210-250 nm (effective spatial resolution of $>\tilde{}$400 nm).

3-D internal structures (3-D distribution of LAC values) of the particle were obtained. Based on the LAC values, we recognized most of the mineral phases and their three-dimensional distribution. Nineteen particles are mono-mineralic or almost mono-mineralic, fifteen particles are poly-mineralic (some of them contains accessory minerals), and seven particles have specific textures, such as a particle containing a porous aggregate of sub-micron grains. Voids are usually observed. As the particle size is comparable to the typical mineral grain sizes of LL5 and 6 chondrites, candidates of Itokawa surface sample, information of 3-D volume will help to reconstruct original textures of Itokawa materials.

From now on, modes of the minerals will be obtained. By using and image analysis, the external shapes of the particles will be also extracted to obtain volume, porosity and three-axial lengths. These shape parameters will be compared with those of boulders on Itokawa [4], fragments of collisional experiments [5] and lunar regolith [6] to obtain information on formation process of Itokawa regolith. By combining the chemical compositions of the minerals [7], the chemical composition and density of each particle and bulk composition and density will be also obtained.

After the tomographic imaging, the samples moved on to the non-destructive XRD and XRF analysis at KEK-PF and SPring-8, and then will move on to destructive analyses, such as those by SEM, EPMA, SIMS and TEM. Combination of the non-destructive analyses, microtomography, XRD and XRF, used for design of the later destructive analyses is one of the key features in this PE. 3-D phase map gives information where should be cut for the later destructive analyses to obtain suitable areas of specific minerals in cross sections of small particles. Carbonaceous materials in a particle can be identified by the microtomography if they are present.

[1] Nakamura T. (2011) abstract in 42nd LPSC. [2] Tsuchiyama A. et al. (2011) abstract in this conference. [3] Uesugi K. et al. (2006) Proc. SPIE, 6318, 63181F. [4] Michikami T. et al. (2010) Icarus 207, 277, [5] Fujiwara et al., (1978) Nature, 272, 602. [6] Matsushima T. et al. (2009) J. Aerospace Eng., 22, 1, 15-23. [7] Nakamura T. (2011) abstract in this conference.

Keywords: Hayabusa mission, asteroid, regolith, SPring-8, three-dimensional structure, X-ray tomography

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Preliminary examination of Hayabusa asteroidal samples: mineralogy and mineral-chemistry

Tomoki Nakamura[1*], Takaaki Noguchi[2], Masahiko Tanaka[3], Mike Zolensky[4], Makoto Kimura[2], Aiko Nakato[1], Toshihiro Ogami[1], Hatsumi Ishida[1], Akira Tsuchiyama[5], Masayuki Uesugi[5], Toru Yada[6], Kei Shirai[6], Ryuji Okazaki[7], Akio Fujimura[6], Yukihiro Ishibashi[6], Masanao Abe[6], Tatsuaki Okada[6], Munetaka Ueno[6], Toshifumi Mukai[6]

[1]Tohoku University, [2]Ibaraki University, [3]WEBRAM, SPring-8, [4]NASA JSC, [5]Osaka University, [6]JAXA-ISAS, [7]Kyushu University

We have carried out (1) FE-SEM/EDS analysis of small particles (mostly smaller than 10 microns in diameter) collected by a Teflon spatula from room A of the sample catcher, and (2) FE-SEM and synchrotron X-ray diffraction analysis of particles with diameter from 30 to 150 microns that are collected from a silica glass placed at the bottom of the room A. All results show that the Hayabusa spacecraft succeeded to collect Itokawa surface dust particles upon the 2nd touchdown performed on 26th Nov. 2005.

Teflon spatula collected many particles during sweeping of approximately 10% of the surface of sample catcher room A. 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. Each particle on the spatula was irradiated by a focused electron beam and a quantitative composition was obtained. 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. 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. Therefore, Fe sulfide is probably troilite. Both kamacite and taenite are present as FeNi metal.

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. Many particles are angular and have very fine adhering particles. We have analyzed approximately 50 particles. 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.

Synchrotron X-ray diffraction analysis of approximately 40 particles with diameter from 30 to 150 microns indicates that silicates are very highly crystalline. Silicates are olivine, low-Ca orthopyroxene, high-Ca clinopyroxene, and plagioclase. Other phase detected is troilite.

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. Our results are consistent with the results of remote sensing measurements made of asteroid Itokawa by on-board instruments of Hayabusa [1-3]. However, our analysis indicates that the particles captured by Hayabusa are depleted in FeNi metal compared with typical LL chondrites (0.5~7.2%) [4].

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] Dunn et al. (2010) Meteoritics and Planetary Science 45, 123-145.

Keywords: Hayabusa Sapcecraft

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SEM AND STEM OBSERVATION OF THE SURFACES OF THE FINE-GRAINED PARTICLES RETRIEVED FROM THE ASTEROID ITOKAWA

Takaaki Noguchi[1*], Tomoki Nakamura[2], Makoto Kimura[1], Michael Zolensky[3], Masahiko Tanaka[4], Takahito Hashimoto[5], Mitsuru Konno[5], Aiko Nakato[2], Toshihiro Oogami[2], Akio Fujimura[6], Masanao Abe[6], Toru Yada[6], Toshifumi Mukai[6], Munetaka Ueno[6], Tatsuaki Okada[6], Kei Shirai[6], Yukihiro Ishibashi[6], Ryuji Okazaki[7]

[1]Ibaraki University, [2]Tohoku University, [3]JSC/NASA, [4]National Institute for Materials Science, [5]Hitach High-Technologies Corporation, [6]JAXA, [7]Kyushu University

Surface materials on airless solar system bodies exposed to interplanetary space are gradually changed their visible to near-infrared reflectance spectra by the process called space weathering, which makes the spectra darker and redder. Hapke et al. proposed a model of space weathering: vapor deposition of nanophase reduced iron (npFe^0) on the surfaces of the grains within the very surface of lunar regolith. This model has been proved by detailed observation of the surfaces of the lunar soil grains by transmission electron microscope (TEM). The npFe^0 was formed by a combination of vapor deposition and irradiation effects. In other words, both micrometeorite impacts and irradiation by solar wind and galactic cosmic ray play roles on the space weathering on the Moon.

Because there is a continuum of reflectance spectra from those of Q-type asteroids (almost the same as those of ordinary chondrites) to those of S-type asteroids, it is strongly suggested that reflectance spectra of asteroids composed of ordinary chondrite-like materials were modified over time to those of S-type asteroids due to space weathering. It is predicted that a small amount of npFe^0 on the surface of grains in the asteroidal regolith composed of ordinary chondrite-like materials is the main agent of asteroidal space weathering. Detailed global measurements of reflectance spectra of Itokawa were performed by Hayabusa revealed that a sub-kilometer-sized small asteroid Itokawa experienced space weathering. Hiroi et al. (2006) discovered that the dark areas are more space-weathering than the bright areas. They estimated the former contains 0.069 vol.% npFe^0 and the latter 0.031 vol.% npFe^0 if the surface of Itokawa is composed of LL5-6-like materials. The main purpose of this study is to identify the direct evidence of space weathering on the surface of the fine-grained particles retrieved from the MUSES-C regio on 19 and 25 November 2005 UTC.

Among the particles in the room A of the sample catcher of the Hayabusa sample container, we used several particles for this study. Ultrathin sections of a few particles are prepared by an ultramicrotome set in a N_2-purged grove box and transferred into a scanning TEM (STEM) at the Hitachi High-Technologies Corporation to prevent to contact them with the earth's atmosphere. The others are prepared by an ultramicrotome set in the earth's atmosphere. We also made ultrathin sections of a fine-grained lunar soil grain collected by Apollo 15 to compare the surface texture of the fine-grained Itokawa particles. We also observed the surfaces of about 20 lunar soil grains to compare their surface morphology with those of the Itokawa particles.

Back-scattered images of typical fine-grained particles from the asteroid Itokawa and the Moon show that both particles are angular and fragmental. However, the Itokawa particle does not show any evidence of remarkable melting. Some fine-grained particles of Itokawa have multiple steps (each step has about 1 micrometer in width and height), which are very similar to fresh fracture surfaces of olivine and pyroxene when we lightly crush them. Therefore, fine-grained particles retrieved from the MUSES-C regio seem to have experienced the least surface modification after their formation. On the other hand, lunar soil grains show vesicles or walls of vesicles and reduced iron globules in glass. The lunar soil grains investigated in this study are composed of a mixture of vesiculated glass and embedded mineral fragments. By our rehearsal STEM observation, we easily identified npFe^0 on the surface of the lunar soil grain. Initial STEM observation of the fine-grained particles retrieved from Itokawa is now on progress. We will show the comparison of the surface microstructure between the Itokawa grains and the lunar soil grains.

Keywords: Itokawa, SEM, STEM, Space weathering

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Preliminary examination of Hayabusa asteroidal samples: Noble gases

Keisuke Nagao[1*], Ryuji Okazaki[2], Tomoki Nakamura[3], Yayoi N. Miura[1], Takahito Osawa[4], Ken-ichi Bajo[1], Shintaro Matsuda[1], Mitsuru Ebihara[5], T.R. Ireland[6], Fumio Kitajima[2], Hiroshi Naraoka[2], Takaaki Noguchi[7], Akira Tsuchiyama[8], Masayuki Uesugi[8], Hisayoshi Yurimoto[9], M. Zolensky[10], Kei Shirai[11], Masanao Abe[11], Toru Yada[11], Yukihiro Ishibashi[11], Akio Fujimura[11], Toshifumi Mukai[11], Munetaka Ueno[11], Tatsuaki Okada[11], Makoto Yoshikawa[11], Junichiro Kawaguchi[11]

[1]University of Tokyo, [2]Kyushu University, [3]Tohoku University, [4]Japan Atomic Energy Agency, [5]Tokyo Metropolitan University, [6]The Australian National University, [7]Ibaraki University, [8]Osaka University, [9]Hokkaido University, [10]NASA Johnson Space Center, [11]JAXA-ISAS

Samples of the asteroid 25143 Itokawa were successfully recovered by the Hayabusa spacecraft. Near-infrared spectroscopic observation by the Hayabusa indicated that the surface materials of the asteroid are similar to the LL5-6 chondrites [1]. Because this is the first chance to measure samples from a known asteroid, we have improved analytical techniques and mass spectrometry system available to noble gas analysis of small grains. Because the returned materials were free from terrestrial noble gas contamination, which is essentially different from meteorites and cosmic dust particles collected on the Earth, the Itokawa samples were treated under condition of nitrogen gas with low concentration of noble gases in the curation facility [2]. Accordingly, we can expect low contamination of terrestrial noble gases for the samples.

Surface materials of asteroids are exposed to solar gases, and the gases are implanted into surface layer of the materials. The asteroidal surface materials are also bombarded by galactic cosmic-rays, producing cosmogenic noble gases with characteristic isotopic compositions through nuclear reactions. Therefore, noble gases of the Itokawa samples would be a mixture of several different origins, e.g., trapped, radiogenic, cosmogenic, and solar gases. The cosmogenic and solar noble gases will provide us with information about the cosmic-ray irradiation, surface gardening, and surface erosion histories of small asteroids.

Detection limits for ^{3}He and ^{132}Xe with our mass spectrometers are ca. 1x10^{-15} and 1x10^{-16} cm^{3}STP, respectively, which correspond to the number of atoms in the order of 10^{4} and 10^{3}. Noble gas extraction system using a Nd-YAG laser performs extremely low blank levels (in cm^{3}STP), e.g., 7x10^{-12} (^{4}He), 1x10^{-13} (^{20}Ne), 5x10^{-12} (^{40}Ar), 2x10^{-16} (^{84}Kr), and $<$1x10^{-16} (^{132}Xe). The analytical techniques have been applied to a large number of micrometeorites from Antarctica to measure all noble gases (He, Ne, Ar, Kr, and Xe) extracted from single grains weighing ca. 1 micro-g or less each [3-8]. Measured amounts of noble gases extracted from single grains with carbonaceous chondritic character were (10-10000)x10^{-12} cm^{3}STP for ^{4}He and (1-10)x10^{-15} cm^{3}STP for ^{132}Xe. The results showed high concentrations of solar noble gases implanted in most micrometeorites, suggesting an importance of solar gas implantation for small grains in space. Histories of crystallization, accumulation of radiogenic noble gases, cosmic-ray irradiation, and solar gas implantation are expected to be variable among the grains as indicated by the single grain analysis of micrometeorites [3-7].

The Hayabusa samples have been analyzed for noble gases as a member of the university consortium team. We used our laser extraction system to extract noble gases from single grains, and measured noble gases on the modified-VG5400 (MS-III) at the Geochemical Research Center, University of Tokyo. The samples were heated stepwisely, two steps at low temperatures and at high temperature to melt. Results will be presented at the meeting.

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Keywords: noble gases, Hayabusa, preliminary examination, sample return

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Preliminary examination of Hayabusa asteroidal samples: oxygen and magnesium isotopic compositions

Shoichi Itoh[1*], Masanao Abe[2], Mitsuru Ebihara[3], Akio Fujimura[2], Ko Hashizume[4], Trevor R. Ireland[5], Junichiro Kawaguchi[2], Fumio Kitajima[6], Toshifumi Mukai[2], Keisuke Nagao[7], Tomoki Nakamura[8], Hiroshi Naraoka[6], Takaaki Noguchi[9], Ryuji Okazaki[6], Naoya Sakamoto[1], Yusuke Seto[10], Akira Tsuchiyama[4], Masayuki Uesugi[4], Toru Yada[2], Makoto Yoshikawa[2], Hisayoshi Yurimoto[1], Michael Zolensky[11]

[1]Hokkaido University, [2]JAXA, [3]Tokyo Metropolitan University, [4]Osaka University, [5]The Australian National University, [6]Kyushu University, [7]University of Tokyo, [8]Tohoku University, [9]Ibaraki University, [10]Kobe University, [11]NASA

Introduction: The Hayabusa spacecraft made two touchdowns on the surface of Asteroid 25143 Itokawa on November 20th and 26th, 2005. The Asteroid 25143 Itokawa is classified as an S-type asteroid and inferred to consist of materials similar to ordinary chondrites or primitive achondrites. Near-infrared spectroscopy by the Hayabusa spacecraft proposed that the surface of this body has an olivine-rich mineral assemblage potentially similar to that of LL5 or LL6 chondrites with different degrees of space weathering.

The spacecraft made the reentry into the terrestrial atmosphere on June 12th, 2010 and the sample capsule was successfully recovered in Australia on June 13th, 2010. Although the sample collection processes on the Itokawa surface had not been made by the designed operations, more than 1,500 grains were identified as rocky particles in the sample curation facility of JAXA, and most of them were judged to be of extraterrestrial origin, and definitely from Asteroid Itokawa on November 17th, 2010. Although their sizes are mostly less than 10 micrometers, some larger grains of about 100 micrometers or larger were also included. The mineral assembly is olivine, pyroxene, plagioclase, iron sulfide and iron metal. The mean mineral compositions are consistent with the results of near-infrared spectroscopy from Hayabusa spacecraft, but the variations suggest that the petrologic type may be smaller than the spectroscopic results.

Several tens of grains of relatively large sizes among the 1,500 grains will be selected by the Hayabusa sample curation team for preliminary examination. Each grain will be subjected to one set of preliminary examinations, i.e., micro-tomography, XRD, XRF, TEM, SEM, EPMA and SIMS in this sequence. The preliminary examination started from January 21th, 2011. Samples for isotope analyses in this study will start from the last week of February 2011. By the time of this meeting we will have measured the oxygen and magnesium isotopic composition of several grains.

Analytical Techniques: The oxygen and magnesium isotope analyses for the collected grains will be investigated by the Hokudai isotope microscope system, consisting of Cameca ims-1270 SIMS instrument and SCAPS ion detector. The grains used in this study will have had their mineral compositions and petrographic textures determined by EPMA/SEM analyses. The SIMS procedures will be applied to the measurements for oxygen isotopes and magnesium isotopes, respectively. The analytical precisions will be expected to be ca. 0.6 permil for oxygen isotopes and ca. 0.1 permil for 26Mg-excesses using 10 micrometer primary beam although the primary beam size and measurement precisions will be adjusted to the mineral species and the crystal sizes in each grain.

Examination Goals: The basic goals of the preliminary examination of isotope sub-team are as follows:
(1) Determination of oxygen isotopic compositions of each mineral and their variation.
(2) Determination of magnesium isotopic compositions and search for 26Al.
(3) Determination of oxygen isotopic composition of solar wind.

What totally unexpected features have we encountered, and how will we learn to deal with them? We can expect to be surprised.

Acknowledgements: We thank Hayabusa sample curation team and Hayabusa project team for close cooperation.

Keywords: Hayabusa, asteroid, isotope, oxygen, magnesium

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U005-10 Room:IC Time:May 26 11:25-11:40

Preliminary examination of Hayabusa asteroidal samples: Neutron activation analysis of single grain

Mitsuru Ebihara[1*], Shun Sekimoto[2], Yasunori Hamajima[3], Masayoshi Yamamoto[3], Kazuya Kumagai[1], Yasuji Oura[1], Hiroshi Naraoka[9], Naoki Shirai[1], Trevor R. Ireland[4], Fumio Kitajima[5], Keisuke Nagao[6], Tomoki Nakamura[7], Takaaki Noguchi[8], Ryuji Okazaki[5], Akira Tsuchiyama[9], Masayuki Uesugi[10], Hisayoshi Yurimoto[11], Michael E. Zolensky[12], Masanao Abe[13], Akio Fujimura[13], Toshifumi Mukai[13], Toru Yada[13]

[1]Grad. School of Sci., Tokyo Met. Univ., [2]Kyoto Univ. Research Reactor Institute, [3]Low Level Radioactivity Lab. Kanazawa U., [4]Res. School of Earth Sci., ANU U., [5]Grad. School of Sci., Kyushu Univ., [6]Grad. School fo Sci., Univ. of Tokyo, [7]Grad. School of Sci., Tohoku Univ., [8]Coll. of Sci., Ibaraki Univ., [9]Grad. School of Sci., Osaka Univ., [10]Grad. School of Eng., Osaka Univ., [11]Grad. School of Sci., Hokkaido Univ., [12]Johnson Space Center, NASA, [13]ISAS, JAXA

The Hayabusa spacecraft was launched on May 9, 2003 and reached an asteroid Itokawa (25143 Itokawa) in September 2005. After accomplishing several scientific observations, the spacecraft tried to collect the surface material of Itokawa by touching down to the asteroid in November. The spacecraft was then navigated for the earth. In encountering several difficulties, Hayabusa finally returned to the earth on June 12, 2010 and the entry capsule was successfully recovered.

When the Hayabusa mission was designed, a g-scale of solid material was aimed to be captured into the entry capsule. Although the sample collection was not perfectly performed, it was hoped that some extraterrestrial material was stored into the capsule. After careful and extensive examination, more than 1500 particles were recognized visibly by microcopes, most of which were eventually judged to be extraterrestrial, higly probably originated from Itokawa [1].

Several years before the launching of the Hayabusa spacecraft, the initial analysis team was officially formed under the selection panel at ISAS. As a member of this team, we have been preparing for the initial inspection of the returned material from many scientific viewpoints [2]. Once the recovered material had been confirmed to be much less than 1 g, a scheme for the initial analysis was updated accordingly [3]. In this study, we aim to analyze tiny single grains by instrumental neutron activation analysis (INAA). As the initial analysis is to be started in mid-January, 2011, some progress for the initial analysis using INAA is described here.

Initially, we planned to apply prompt gamma ray analysis (PGA) at the beginning of whole scheme for the initial analysis of g-sized material [4]. As this was not the case, PGA was canceled. In place of PGA, a conventional method of INAA was introduced at the last stage of the analytical flow scheme. In INAA of this study, a single grain is to be analyzed. A rocky grain sample (mostly silicate) is placed into a pit of synthesized clean quartz plate, which is covered with a plane quartz plate. An assembly of quarts plates with a sample grain in-between is wrapped with pure aluminum foil. The sample is irradiated by reactor neutron at Kyoto University Reactor Research Institute (KURRI). Assuming that a grain of diameter of 100 micro-m and density of 3 g/cm^3 is similar to CI chondrite in chemical composition and irradiated with neutron flux of $3x10^{13}$ n/cm^2 for 50 h, calculated radioactivity (in parentheses in Bq) of neutron-captured nuclides of some constituent elements are as follows; ^{46}Sc (1.7), ^{51}Cr (51), ^{59}Fe (11), ^{60}Co (2.5) and ^{192}Ir (0.83). The gamma ray measurement is to be done both at KURRI and at the low level Radioactivity Laboratory (LLRL), Kanazawa University, where a well-type Ge semiconductor detector is heavily shielded from environmental radioactivity.

Considering the background radioactivity at LLRL, a grain of 1micro-m can be analyzed for the elements mentioned above. If a metal grain of this size is included in a sigle silicate grain, we are confident that the source material for such a metal (and further silicate) is able to be identified.

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Keywords: Hayabusa space mission, Itokawa, asteroids, neutron activation analysis, elemental composition

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Preliminary examination of Hayabusa asteroidal samples: Micro-spectroscopic analyses of carbonaceous matter

Fumio Kitajima[1*], Masato Kotsugi[2], Takuo Ohkochi[2], Hiroshi Naraoka[1], Yukihiro Ishibashi[3], Masanao Abe[3], Akio Fujimura[3], Ryuji Okazaki[1], Toru Yada[3], Tomoki Nakamura[4], Takaaki Noguchi[5], Keisuke Nagao[6], Akira Tsuchiyama[7], Toshifumi Mukai[3], Scott A. Sandford[8], Tatsuaki Okada[3], Kei Shirai[3], Munetaka Ueno[3], Makoto Yoshikawa[3], Junichiro Kawaguchi[3]

[1]Kyushu University, [2]JASRI/SPring-8, [3]JAXA, [4]Tohoku University, [5]Ibaraki University, [6]University of Tokyo, [7]Osaka University, [8]NASA Ames Research Center

Introduction The main target of the carbonaceous matter sub-team is the insoluble organic matter (IOM) in the returned sample by the HAYABUSA mission. We are planning to analyze the matter by micro-spectroscopic techniques, such as Raman, fluorescence, infrared (IR) spectroscopy. And in addition to these techniques, we are also planning to use photoemission electron microscopy (PEEM).

IOM is the major fraction of the chondritic carbonaceous matter, and generally assumed to be completely indigenous due to their high molecular weight and immobility. It is characterized by condensed aromatic moieties cross-linked by aliphatic and ether linkages, with various functionality external to the aromatic structure [1]. It converts gradually to graphitic matter during thermal metamorphism, and suggests to what extent thermal metamorphism has proceeded [2]. Raman spectroscopy is a useful tool to evaluate the structural ordering of the matter and the degree of thermal metamorphism [3, 4, 5]. Carbon X-ray Absorption Near Edge Structure (C-XANES) spectra [6] and infrared spectral band of aliphatic C-H stretching [7] are alternative methods to evaluate thermal process of IOM.

The asteroid Itokawa belongs to S-type and its surface is similar to that of LL5 or LL6 chondrite. However, it is a rubble-pile object and experienced collisional breakup and re-agglomeration, suggesting the possible fragments of carbonaceous materials in Itokawa samples. If such particles are found, it can be a clue to the thermal process involved in the formation history of Itokawa.

Methods We hope to analyze the samples as intact as possible by non-destructive method without using organic resin or adhesives. And, because recovered samples by HAYABUSA mission are considered to be small grains, we designed a sample holder made from diamond plates for Raman, fluorescence, and IR spectroscopy (PEEM analysis will be performed using potted butt, as it is located at downstream of the examination flow). One diamond plate has some hollows and each individual sample particle shall be put in a hollow at the curation facilities. This plate can be covered by another flat diamond plate, and we can carry it without using organic adhesives. This sample holder can be put directly on the sample stages of micro-Raman or micro-IR spectrometers, and we can obtain the spectra without taking out the sample grains from the holder.

Discussion The first question is whether some particles recovered by the HAYABUSA mission contain extraterrestrial carbonaceous matter. If such carbon-containing particle is found, characterization of IOM will be performed. Micro-Raman spectroscopy is sensitive to skeletal aromatic network and it gives maturity level of IOM. The G-band position of the chondritic carbonaceous matter shifts up with increasing metamorphic grade, and the FWHM-G (Full width at half maximum of G-band) decreases [3, 4, 5]. Fluorescent background reflects overall compositional differences of IOM [4]. External functional groups will be determined by IR spectroscopy, and element-selective analysis of functional groups can be performed by PEEM. These different analytical spectroscopic features also indicate the record of thermal evolution of IOM in individual grains. Such approach can be a clue to an asteroid formation history.

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Keywords: Hayabusa, Carbonaceous matter, Micro-spectroscopic analyses

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U005-12 Room:IC Time:May 26 11:55-12:10

Preliminary examination of Hayabusa asteroidal samples: Organic compound analyses

Hiroshi Naraoka[1*], Hajime Mita[2], Kenji Hamase[3], Masashi Mita[4], Hikaru Yabuta[5], Kaori Saito[6], Kazuhiko Fukushima[6], Fumio Kitajima[1], Scott A. Sandford[7], Tomoki Nakamura[8], Takaaki Noguchi[9], Ryuji Okazaki[1], Keisuke Nagao[10], Mitsuru Ebihara[11], Hisayoshi Yurimoto[12], Akira Tsuchiyama[5], Masanao Abe[13], Toru Yada[13], Yukihiro Ishibashi[13], Kei Shirai[13], Munetaka Ueno[13], Tatsuaki Okada[13], Akio Fujimura[13], Toshifumi Mukai[13], Makoto Yoshikawa[13], Junichiro Kawaguchi[13]

[1]Dept. Earth & Planet. Sci., Kyushu Univ., [2]Fukuoka Inst. Technol., [3]Grad. School Pharm. Sci., Kyushu Univ., [4]Frontier Sci. Dev. Shiseido Co. Ltd., [5]Grad. School Sci., Osaka Univ., [6]Grad. School Agricul. Sci., Nagoya Univ., [7]NASA-Ames Research Center, [8]Fac. Sci., Tohoku Univ., [9]Fac. Sci., Ibaraki Univ., [10]Grad. School Sci., Univ. Tokyo, [11]Fac. Sci. & Tech., Tokyo Metro. Univ., [12]Dept. Nat. History Sci., Hokkaido Univ., [13]ISAS/JAXA

Many organic molecules have been observed in the interstellar medium as well as extraterrestrial materials. In particular, various organic compounds including amino acids are reported from carbonaceous chondrites, which may have connections to emergence of life on the primitive Earth. By the Hayabusa mission, the existence of organic matter at the surface of Asteroid 25143 Itokawa can be examined without terrestrial contaminants. Ordinary chondrites, which seem to have an origin of S-type asteroid including Itokawa [1] [2], are generally depleted in not only volatile organic compounds but also carbonaceous materials due to their relatively high formation temperature. However, the existence of organic compounds is possible at the surface of Itokawa, because indigenous amino acids are found in lunar soils by Harada et al. [3] and Brinton and Bada [4] and interplanetary dust particles (IDPs) by Brinton et al. [5]. In addition, polycyclic aromatic hydrocarbons (PAHs) are reported in a Martian igneous meteorite [6] and IDPs [7]. In this study, we will perform a preliminary organic compound analysis on particles from asteroid Itokawa returned by the Hayabusa mission.

The particles are rinsed with small amount of methanol/dichloromethane on the plate. The extract is hydrolyzed with HCl followed by separation into amino acid and other organic compound fractions. Amino acid analysis with enantiomeric separation is carried out using two-dimensional high-performance liquid chromatography with highly sensitive fluorescence detectors (2D-HPLC/FD) [8]. The other organic fraction including PAHs is subjected to time of flight-secondary ion mass spectrometry (ToF-SIMS) analysis. The ToF-SIMS analysis is also applied directly to the carbonaceous materials in the particles.

Detection of amino acids and PAHs is highly dependent on the concentrations of these compounds in particles as well as the sample amount available for the analyses. If the particles yield glycine, one of the abundant amino acids in extraterrestrial materials, as much as the concentration in carbonaceous chondrites (~10-500 fmol/micro gram) [9] [10], the 2D-HPLC/FD can reveal the amino acids distribution. If the particle contains glycine as the similar amount as lunar soils (~0.1 fmol/micro gram) [3] [4], the quantification competes against the detection limit. The ToF-SIMS analysis can identify various organic compounds including PAHs in a ppm level [12]. The compound distributions may clarify origins of organic compounds at the surface of Itokawa. If glycine is the most abundant as observed in lunar soils [3] [4] and cometary dusts [11], hydrogen cyanide (HCN) may contribute to the amino acid precursors. In the case of anhydrous minerals, the HCN may be implanted by solar wind. If alpha-aminoisobutyric acid (AIB) is abundant as observed in some CM chondrites, meteoritic source derived from aqueous altered parent body is considered after a Sterecker-type reaction with ketones. In such a case, the organic compounds survived upon impact. The particle amount available for the preliminary organic analysis is very limited. Further investigations are necessary on the second stage of analysis with much sample by direct extraction with hot water.

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Keywords: Hayabusa, Itokawa, Organic compounds

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U005-13 Room:IC Time:May 26 12:10-12:30

Initial analysis of the Hayabusa recovery materials: Overview and highlights at Misasa

Eizo Nakamura[1*], Katsura Kobayashi[1], Akio Makishima[1], Tak Kunihiro[1], Ryoji Tanaka[1], Tatsuki Tsujimori[1], Takuya Moriguti[1], Tsutomu Ota[1], Hiroshi Kitagawa[1], Chie Sakaguchi[1], Masanao Abe[2], Akio Fujimura[2], Toshifumi Mukai[2]

[1]PML, ISEI, Okayama University at Misasa, [2]Japan Aerospace Exploration Agency

A geochemistry group in the Institute for Study of Earth's Interior (ISEI), Okayama University at Misasa, has been designated one of the initial analysis groups for particles from the sample container, which was returned by the instrumental module of the asteroid exploration space craft "Hayabusa". By JAXA (Press Releases, January 17, 2011), "Initial analysis" is defined as the description of typical particles. This includes the numbering, identification and classification of individual particles in preparation for curation, preservation and allocation for further analysis.

In the initial analysis, our group at ISEI will have undertaken the description of individual return particles that are larger than 5 micron in diameter. The description will employ a comprehensive set of analytical techniques employing the optical and scanning electron microscope, electron probe micro-analyzer, secondary ion mass spectrometer, and transmission electron microscope. To enhance the accuracy of major and trace element and isotope analyses, in-house standard materials have been precisely characterized at ISEI by thermal ionization mass spectrometers, inductively-coupled plasma mass spectrometers and stable isotope mass spectrometers.

These comprehensive data sets for individual particles will provide general mineralogical and geo- and cosmo-chemical characteristics of the particles associated with components of the asteroid "Itokawa". This information will also help determine the direction in which any subsequent secondary analysis should follow.

Keywords: Hayabusa, MUSES-C, Asteroid Itokawa, initial analysis

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U005-14 Room:IC Time:May 26 12:30-12:50

Initial analysis of the Hayabusa recovery materials: Laboratory processing of individual grains

Katsura Kobayashi[1*], Tak Kunihiro[1], Ryoji Tanaka[1], Tatsuki Tsujimori[1], Takuya Moriguti[1], Tsutomu Ota[1], Hiroshi Kitagawa[1], Chie Sakaguchi[1], Akio Makishima[1], Eizo Nakamura[1], Masanao Abe[2], Akio Fujimura[2], Toshifumi Mukai[2]

[1]PML, ISEI, Okayama University at Misasa, [2]Japan Aerospace Exploration Agency

In the initial analysis stage, one of our major objectives is the petrological and geochemical description of the Hayabusa recovery materials, thus providing the foundation upon which to base further scientific studies. According to the initial observations conducted during sample curation by JAXA, the recovery materials are different types of small lithic particles typically less than several tens of microns in diameter. It is, therefore, quite important to apply grain-by-grain comprehensive analysis and make a catalog of grains based on these data-sets. These data will provide fundamental information that will assist in future studies directed towards understanding the asteroid ITOKAWA.

One of the challenges in our initial analysis is the establishment of a sequence of laboratory processing techniques applicable for such tiny particles. A sequential protocol has been developed that is composed of simple and robust techniques for handling tiny free-particles with minimum contamination and, at the same time, minimizes the amount of sample consumption. Therefore, the techniques established in this study will be easily applicable for general micro-petrology and geochemistry.

In this presentation, we focus on newly developed techniques and methods, associated sample handling, fabrications and treatment in the initial analysis. The following topics are reported on;

1) particle handling procedure in a transporting vessel.
2) sample fabrication procedure by Focused Ion Beam System (FIB).
3) sample preparation procedure for in-situ descriptions by SEM, EPMA and ion probes.
4) protocol to preserve an individual sample portion for further studies.

The detailed analytical sequence and background of our processing techniques will be also presented.

Keywords: Hayabusa, MUSES-C, Asteroid Itokawa, initial analysis, sample fabrication

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U005-15 Room:IC Time:May 26 14:15-14:35

Initial analysis of the Hayabusa recovery materials: Petrographical characterization

Tatsuki Tsujimori[1*], Tak Kunihiro[1], Katsura Kobayashi[1], Ryoji Tanaka[1], Takuya Moriguti[1], Tsutomu Ota[1], Hiroshi Kitagawa[1], Chie Sakaguchi[1], Akio Makishima[1], Eizo Nakamura[1], Masanao Abe[2], Akio Fujimura[2], Toshifumi Mukai[2]

[1]PML, ISEI, Okayama University at Misasa, [2]Japan Aerospace Exploration Agency

Characterization of the structural, textural and petrographical features of terrestrial and extraterrestrial materials is a fundamental and crucial approach to understanding natural physical phenomena. In particular, understanding the relationship between texture and chemical compositions of the constituent phases in lithic fragments and particles is of considerable importance as it quickly provides the first-order information necessary to assess their origin and evolutionary history.

In preparation for the initial petrographical characterization of the Hayabusa recovery materials, an analytical protocol for studying particle samples has been developed at ISEI (Kobayashi et al., this meeting) and has been repeatedly tested and rehearsed. We are now ready to apply our knowledge of geology, petrology and geochemistry to the study of the Hayabusa recovery materials.

In our petrographical characterization, we will (1) determine optical properties of the individual grains, (2) use FE-SEM observation and semi-quantitative analyses to identity constituent phases and to characterize their surface texture, (3) carry out FIB milling of grains investigated in step (2), (4) determine the major element composition and elemental distribution of FIB-milled micro-slices in step (3) by FE-SEM (equipped with EDS, WDS, and CL) and EPMA, and (5) perform ATEM study of FIB-milled foil in step (3). These data will then be used to decide analytical points for in-situ trace element and isotope analyses by HR-SIMS (Kunihiro et al., this meeting).

In this presentation, we will report some results from our micro petrographic study of meteorite particles. We also hope to show some petrographic characteristics of particles from Asteroid Itokawa.

Keywords: Hayabusa, MUSES-C, Asteroid Itokawa, initial analysis

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U005-16 Room:IC Time:May 26 14:35-14:55

Initial analysis of the HAYABUSA recovery materials: Trace-element and isotope abundance

Tak Kunihiro[1*], Katsura Kobayashi[1], Ryoji Tanaka[1], Tatsuki Tsujimori[1], Takuya Moriguti[1], Tsutomu Ota[1], Hiroshi Kitagawa[1], Chie Sakaguchi[1], Akio Makishima[1], Eizo Nakamura[1], Masanao Abe[2], Akio Fujimura[2], Toshifumi Mukai[2]

[1]PML, ISEI, Okayama University at Misasa, [2]Japan Aerospace Exploration Agency

After the analytical competition for the sample return mission MUSES-C in 2000 (Nakamura et al., 2003, ISAS Rep SP), we are expanding and further developing our Comprehensive Analytical System for Terrestrial and Extraterrestrial Materials (CASTEM). As part of the system we have developed in-house reference standard materials by coupling wet-chemical techniques with mass spectrometry including TIMS, ICPMS, and laser-fluorination assisted IR-MS. These reference materials will be used for in-situ trace-elemental and isotopic analyses including oxygen isotopes by secondary ion mass spectrometry (SIMS) and LA-ICPMS. We are now positioned to fully utilize the advanced analytical system and plan to determine precise and accurate elemental and isotopic abundances in small (several tens of micron diameter) particles delivered by the spacecraft Hayabusa.

Specifically, after sample preparation and petrological description, we plan to determine oxygen-isotope and trace-element abundances by SIMS, consuming approximately 10ˆ3 micronˆ3 of material for each particle. For olivine grains, we plan to estimate [H], [Li], [B], [F], [Na], [Cl], [Ca], [Al], [Ti], [Cr], and [Ni]. Additionally [Ba], [Sr], [Y], [Zr], [Nb], [Ba], [REE], and [Hf] will be determined for pyroxenes. For particles larger than 20 micron, we also plan to determine lithium-isotopic abundances.

In this presentation, we plan to demonstrate our analytical results obtained by the in-situ technique applied to the particles of an asteroid Itokawa.

Keywords: Hayabusa, MUSES-C, Asteroid Itokawa, initial analysis

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U005-17 Room:IC Time:May 26 14:55-15:15

Hayabusa recovery, curation and preliminary sample analysis: Lessons learned from recent sample return missions

Michael Zolensky[1]*

[1]NASA Johnson Space Center

Introduction: I describe lessons learned from my participation on the Hayabusa Mission, which returned regolith grains from asteroid Itokawa in 2010 [1], comparing this with the recently returned Stardust Spacecraft, which sampled the Jupiter Family comet Wild 2.

Spacecraft Recovery Operations: The mission Science and Curation teams must actively participate in planning, testing and implementing spacecraft recovery operations. The crash of the Genesis spacecraft underscored the importance of thinking through multiple contingency scenarios and practicing field recovery for these potential circumstances. Having the contingency supplies on-hand was critical, and at least one full year of planning for Stardust and Hayabusa recovery operations was necessary. Care must be taken to coordinate recovery operations with local organizations and inform relevant government bodies well in advance. Recovery plans for both Stardust and Hayabusa had to be adjusted for unexpectedly wet landing site conditions. Documentation of every step of spacecraft recovery and deintegration was necessary, and collection and analysis of launch and landing site soils was critical. We found the operation of the Woomera Text Range (South Australia) to be excellent in the case of Hayabusa, and in many respects this site is superior to the Utah Test and Training Range (used for Stardust) in the USA. Recovery operations for all recovered spacecraft suffered from the lack of a hermetic seal for the samples. Mission engineers should be pushed to provide hermetic seals for returned samples.

Sample Curation Issues: More than two full years were required to prepare curation facilities for Stardust and Hayabusa. Despite this seemingly adequate lead time, major changes to curation procedures were required once the actual state of the returned samples became apparent. Sample databases must be fully implemented before sample return. For Stardust we did not adequately think through all of the possible sub sampling and analytical activities before settling on a database design. Hayabusa has done a better job of this. Also, analysis teams must not be permitted to devise their own sample naming schemes. The sample handling and storage facilities for Hayabusa are the finest that exist, and we are now modifying Stardust curation to take advantage of the Hayabusa facilities. Remote storage of a sample subset is desirable.

Preliminary Examination of Samples: There must be some determination of the state and quantity of the returned samples, to provide a necessary guide to persons requesting samples and oversight committees tasked with sample curation oversight. Hayabusas sample preliminary examination, which is called HASPET, was designed so that late additions to the analysis protocols were possible, as new analytical techniques became available. A small but representative number of recovered grains are being subjected to in-depth characterization. The bulk of the recovered samples are being left untouched, to limit contamination. The HASPET plan takes maximum advantage of the unique strengths of sample return missions.

Keywords: Hayabusa, Stardust, Comets, Asteroids

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U005-18 Room:IC Time:May 26 15:15-15:30

Outline of Hayabusa-2, next asteroid sample return mission of Japan

Makoto Yoshikawa[1*], Minamino Hiroyuki[1], Satoru Nakazawa[1], Masanao Abe[1], Tsuda Yuichi[1], Junichiro Kawaguchi[1]

[1]JAXA

Hayabusa spacecraft finally came back to the earth on June 13, 2010. It has a quite dramatic story and we had a lot of experiences about planetary mission. And now we have started Hayabusa follow-on mission, Hayabusa-2. It is an asteroid sample return mission again, but the type of the target asteroid is C-type, which is different from the target of Hayabusa, Itokawa (S-type). The scale of the spacecraft is similar to Hayabusa, but many parts will be modified so that we will not have the troubles that we experienced in Hayabusa. Also the spacecraft has new equipment, which is called impactor. The impactor will make an artificial crater on the surface of the asteroid, and we will try to get the sample inside the crater. Then we can get much fresh material. The planned launch year is 2014 or 2015, arriving at the target asteroid 1999 JU3 in 2018, and coming back to the earth 2020. The budget of Hayabusa-2 has been approved by the Japanese government, so we can start manufacturing it from April 2011.

Keywords: Asteroid, Sample return, Hayabusa

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Hayabusa-2, sample-return mission to the C-type asteroid 1999JU3, and its scientific goals

Shogo Tachibana[1*], The Hayabusa-2 sampling team[1]

[1]Dept. Earth Planet. Sci., Univ. Tokyo

Recent progresses in research of extraterrestrial materials have revealed that the most pristine materials in the solar system are an interacted mixture of minerals, ice, and organic matter. It is accordingly important to study the interactions between minerals, ice, and organic matter within the pristine materials in the dynamically active protosolar disk to understand the very early evolution of minerals, ice, and organic matter, which would have later evolved to the Earth, ocean, and life, respectively. However, there have been no returned samples keeping the interactions between inorganics, ice and organics intact. In this talk, we will illustrate the importance of sample-return return missions from undifferentiated asteroids and comets, which preserve pristine minerals, ice, and organics, and introduce the scientific goals in the future Japanese asteroidal sample return mission, Hayabusa-2, to the C-type asteroid 1999 JU3.

Keywords: Hayabusa-2, sample return, asteroid, mineral, ice, organics

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Future of planetary material science

Hiroko Nagahara[1]*

[1]Dept. Earth Planet. Sci., The Univ. Toky

Recent success in collecting solid materials from inerplanetary space (the Stardust mission) and a small body (the Hayabusa mission) show the coming of new era, when we will be able to understand the evolution of the protoplanetary disc through studies on solid materials which had interacted with the gas. We are realizing that the evolution has been largely affected by interactions among silicates, organic materials, and water (ice), among which organics and ice had been hardly observed in situ, and only information about isotopic signature were recorded. The collected samples from the interplanetary space of primitive small bodies could retain information on the primitive materials. If we know the initial condition of the solid materials, such as phase, size, and occurrence of multiple phases, we will be able to predict the evolution of those materials as a function of pressure, temperature, and time, for which systematic experiments are required. One of the most important roles of the planetary material science in future is to give information that are applied to physics and dynamics of a protoplanetary disc. In order to do so, we need to develop a tool to convert qualitative information into quantitative information. The work will predicts the simultaneous evolution of solid materials and disc, which is crucial for the composition of precursor materials of planets as a function of distance from the central star.

Keywords: solid materials, star, origin, planets, evolution