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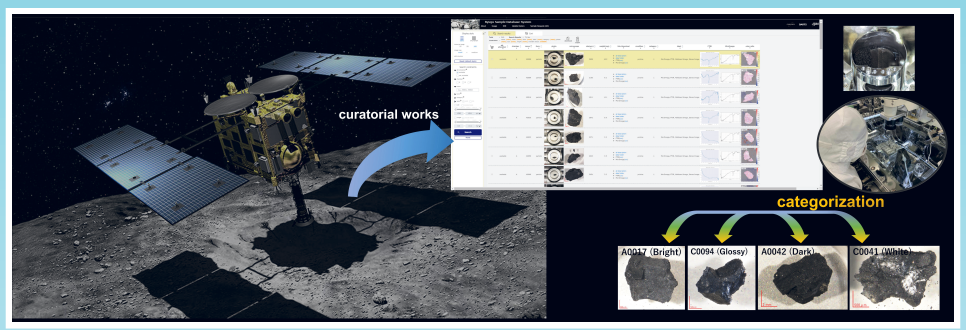
New Insights in Planetary Science with Hayabusa, Hayabusa2, and Future Space Missions



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Prof. Masahito Nosé
Editor-in-Chief, *Earth, Planets and Space*
eic-2025@earth-planets-space.org

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PREFACE

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Special issue "New insights in planetary science with Hayabusa, Hayabusa2, and future space missions"

Tatsuaki Okada[1,2*], Kevin Righter[3], Rosario Brunetto[4], Toru Yada[1] and Harold C. Connolly Jr.[5,6]

Great progress has been achieved in the recent years in understanding the Solar System evolution process by the results from observations during space missions and analyses of returned samples. Hayabusa (e.g., Kawaguchi et al. 2003; Fujiwara et al. 2006; Yano et al. 2006) was the first asteroid sample return mission that successfully delivered its precious cargo from S-type asteroid 25,143 Itokawa to Earth in 2010. The Itokawa samples have been curated in the Extraterrestrial Sample Curation Center of Japan Aerospace Exploration Agency (JAXA) in a nondestructive and noncontaminated manner (Yada et al. 2014) and characterized and analyzed in detail by the Hayabusa initial analysis teams and later by researchers worldwide (e.g., Nakamura et al. 2011; Noguchi et al. 2011; Tsuchiyama et al. 2011; Nagao et al. 2011; Yurimoto et al. 2011; Ebihara et al. 2011; Nakamura et al., 2012). Hayabusa2 (e.g., Tsuda et al. 2013; Tachibana et al. 2014) explored the C-type asteroid 162,173 Ryugu (e.g., Watanabe et al. 2019; Sugita et al. 2019; Kitazato et al. 2019; Arakawa et al. 2020; Okada et al. 2020; Tachibana et al. 2022; Jaumann et al. 2019; Grott et al. 2019) and collected samples from two sites on its surface, one from the equatorial region and the other from the near an artificial impact crater that caused fresh material to be ejecta around the crater area (Tsuda et al. 2020). Hayabusa2 returned the sample to Earth in 2020, and its initial characterization was carried out by the sample curation team (e.g., Yada et al. 2022; Pilorget et al. 2022; Ito et al. 2022) with detailed analysis having been performed by the initial analysis teams (e.g., Yokoyama et al. 2022; Nakamura et al. 2022b; Okazaki et al. 2022a; Okazaki et al. 2022b; Noguchi et al. 2022; Naraoka et al. 2023; Yabuta et al. 2023; Nakamura et al. 2022a).

Both of the above JAXA missions carefully characterized the surface of each asteroid with a suite of spacecraft instruments and robotic landers that provided data on the surface of Ryugu in situ. Such multiscale observations have proven to be effective and essential for providing detailed geologic context for the samples collected and providing science with a better understanding of the asteroid-meteorite connection. Following these two missions, the NASA OSIRIS-REx mission (e.g., Lauretta et al. 2019) successfully explored the B-type asteroid 101,955 Bennu and returned the sample to Earth in 2023 (e.g., Lauretta et al. 2024). The Bennu samples have been curated in the newly built cleanroom in NASA JSC (Righter et al. 2023) and the OSIRIS-REx sample analysis team began its characterization and analysis of Bennu particles. Comparative studies of Ryugu and Bennu samples linked with the data from the asteroid operation phases of the respected missions bring new insights into the origin and evolution of the early formed planetary bodies in the

*Correspondence:
Tatsuaki Okada
okada.tatsuaki@jaxa.jp
[1] Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, Sagamihara 252-5210, Japan
[2] Graduate School of Science, The University of Tokyo, 7-3-1 Hongo, Bunkyo, Tokyo 113-0033, Japan
[3] Department of Earth and Environmental Sciences, University of Rochester, Rochester, NY 14627, USA
[4] Institut d'Astrophysique Spatiale, Université Paris-Saclay, CNRS, 91400 Orsay, France
[5] Department of Geology, Rowan University, Glassboro, NJ 08028, USA
[6] Department of Earth and Planetary Science, American Museum of Natural History, New York, NY 10016, USA

Solar System. Analysis of samples from both missions provides continued data on the potential origins of volatiles on Earth as well as the delivery of prebiotic compounds needed for life. Furthermore, new sample return missions are planned such as Martian Moons Exploration (MMX) mission by JAXA, which is going to explore the Martian moons Phobos and Deimos as well as Mars itself by remote sensing, with a surface mobile lander on Phobos, and return a sample from Phobos to Earth, to constrain the origin of the moons and the dynamical evolution process of the solar system (Usui et al. 2020). Next generation small body sample return (NGSR) mission is also under study by JAXA to visit and explore a primitive body like a comet (the current candidate target is 289P/Blanpain) and return the sample to Earth, to investigate the formation of materials in our Solar System and also in the pre-Solar System in the Galaxy, as well as to investigate the formation of celestial bodies in the early Solar System (Saiki et al. 2024; Shimaki et al. 2024).

A combination of remote sensing, surface in situ measurements, and analyses of returned samples is essential to make available the multiscale studies of Solar System planetary materials. A series of HAYABUSA symposia organized by the Astromaterials Science Research Group in ISAS, JAXA, has provided the annual meeting venue for the scientists and engineers worldwide to discuss a variety of topics focused on the results from the study of all three asteroids. In addition, at these meeting such topics as comparative studies of extraterrestrial materials like meteorites and interplanetary dust particles, laboratory experiments and numerical simulations to interpret the observed results, any theoretical, experimental, and observational studies of Solar System primitive bodies, new technique and methodology contributing to the analytical and curatorial works, and future primitive body missions have been discussed.

In the past, two *EPS* special issues originated from the topics of the HAYABUSA symposia have been published (Okada et al. 2015, 2017). This is the third *EPS* special issue, which focuses more on the Hayabusa2 mission and the related studies, consisting of 20 individual manuscripts. Eight manuscripts are on the topic of instrumentation, methodology, and catalogue of sample curation and sample description. Four manuscripts show the new results of Ryugu sample analysis in comparison with the typical characteristics of carbonaceous meteorites. Three manuscripts are on the topic of Hayabusa2 artificial impact experiments. Two manuscripts summarize the findings of the Hayabusa2 MASCOT lander experiments in comparison with remote sensing and the analysis of returned samples, and the first measurement of reflectance of Ryugu by LIDAR. Another manuscript shows the in-flight calibration of the optical navigation camera (ONC) and its usability during the extended mission. Two more manuscripts are focused on the Hayabusa mission and the related numerical study on the evolution of asteroid Itokawa. Further details are shown in the text below.

The topic of instrumentation, methodology, and catalogue of sample curation and sample description are most specialized and a focus of this special issue. Yada et al. (2023) summarizes the design concept and the performances of the Hayabusa2 curation facility including the clean room, the clean chambers, the devices and tools used there, considering the contamination control. Compared with the Hayabusa curation facility for the sample from S-type asteroid Itokawa, the Hayabusa2 curation facility for the sample from C-type asteroid Ryugu, where organic matters must be taken care of, implements an IR microscope (MicrOmega) and a Fourier-Transform Infrared Spectroscopy (FT-IR) for composition analysis, instead of a SEM/EDX to avoid damage from electron irradiation. The facility stores part of the samples in vacuum for long-term storage without contamination and degradation. A flat window type chamber useful for setting an optical microscope about the window is implemented. This facility is a suitable candidate for a state-of-the-art facility for the future sample return mission.

Miura et al. (2022) describes the design concept, instrumentation, procedures of operation, pre-calibration and tests, and performances of the portable GAEA (GAs Extraction and Analysis system) which was used for the quick extraction and measurement of gas sample from the Hayabusa2 reentry capsule within two days after its recovery. The results and lessons learned from this experience are useful for the future sample return missions. Okazaki et al. (2022c) summarizes the methods and tools for the gas analysis of Hayabusa2 returned sample, extracted in the JAXA Hayabusa2 Curation Facility. Its design concept, the instrumentation, the operation procedure, and the results of analysis of volatile components are described in detail, to be useful in the future sample return missions.

Hatakeda et al. (2023) introduces the Fourier-Transform Infrared Spectroscopy (FTIR) for Hayabusa2 Curation Facility and its performances for regolith of Ryugu returned samples. Most samples collected during the first and second samplings show a similar spectral profile including the absorption bands of hydroxyls and organic matters, but there are rare types of inclusions that show high reflectance, carbonates, or intense and wide OH bonds. Rubino et al. (2023) established the pipeline for handling and analysis of

returned samples for performing infrared synchrotron micro-spectroscopy as well as FTIR, Raman, and the shape and interior structures (SEM and XCT) under nondestructive and noncontaminated conditions.

Nakato et al. (2023) observed 205 individual Ryugu samples by microscopy and classified the Hayabusa2 Ryugu samples into four categories: Dark, Glossy, Bright, and White. Representative samples of each category were investigated by SEM and XRD, to conclude that the category White is related to carbonates and the other categories indicate different degrees of space weathering. Miyazaki et al. (2023) updated the results of averaged density of Ryugu returned samples as 1.79 ± 0.31 g/cc, almost the same as that of Tagish Lake or CI chondrite meteorites, more precisely than that of the previous study (Yada et al. 2022) by comparing 16 individual particles whose sizes were more accurately measured through XCT during the initial analysis (Nakamura et al. 2022b). Nishimura et al. (2023) developed the Ryugu Sample Database System to catalogue all the archived individual samples (>1 mm) and regolith samples (<1 mm) with the size, weight, microscopic images, and near-infrared spectra by FTIR and MicrOmega, and descriptions such as the category type by Nakato et al. (2023). This catalogue is useful for researchers to apply these samples for new research.

New results of Ryugu sample analysis are also published in this special issue. Aponte et al. (2023) compared the Ryugu samples with Orgueil CI chondrite meteorites using the GCxGC–HRMS method and showed similar patterns of organic molecules, especially PAHs (Polycyclic Aromatic Hydrocarbons), hydrocarbons and dimethylsulfides indicating interstellar parent bodies. Relationship of Ryugu samples to cometary materials (Wild2) remains uncertain due to terrestrial contamination. Hashiguchi et al. (2023) compared the Ryugu samples with Orgueil (CI) and Murchison (CM2) meteorites through DESI–HRMS, and found they are more like CI enriched in CHO more than CHN and CHNO, and more like CM2 not depleted in CHN and CHNO, but unlike CI and CM2 depleted in Mg-bearing organic matters, probably due to different evolution processes of organic matters in parent bodies or even on Earth. Tack et al. (2022) investigated rare-earth elements of Ryugu returned rock samples using synchrotron XRF and found apatite grains enriched in REE more than the average of CI chondrites, dolomite grains slightly enriched in LREE, and the matrix almost the same as CI chondrites. Bazi et al. (2022) investigated trace elements of micro areas of Ryugu samples through synchrotron confocal XRF and found the matrix similar to CI chondrites, and identified each fine mineral such as magnetite, dolomite, apatite, pyrrhotite, and breunnerite grains.

Hayabusa2 conducted an artificial impact experiment using the Small Carry-on Impactor (SCI) under the micro gravity condition. Kadono et al. (2022a) performed impact experiments to the granular targets with various size of grains, to realize the pattern of ejecta curtain observed in the Hayabusa2 impact experiment. For the cases of (1) large and small grains, (2) gradual distribution of large to small grains, and (3) uniform sized grains, the case (1) shows most similar pattern to the SCI experiment, indicating the presence of large and small boulders on Ryugu. Kadono et al. (2022b) investigated various shape of projectiles to the basalt (solid) and gypsum (porous) targets by performing laboratory experiments and numerical simulations using iSALE code to compare with, and found the crater scaling law (π scaling law) is applicable in the strength regime (under microgravity conditions). Ogawa et al. (2022) investigated the size population of boulders inside and outside the SCI crater and found the typical power law index is $\alpha = -2.5$, but $\alpha = -1.6$ for the boulders outside the crater and smaller than 0.5 m in diameter. This occurs because the smaller boulders were buried with the ejecta sediments.

The Hayabusa2 surface experiment with the small lander contributed to filling the gap of the sub-mm to cm scale of features between remote sensing and the analysis of returned samples. Otto et al. (2023) displayed the observation results of the camera (MasCAM), the thermal radiometer (MARA) and the magnetometer (MasMAG) onboard the small lander MASCOT. Bright spots observed in the surface boulders by MasCAM indicated the carbonate grains and partly space weathered inclusions. The thermal inertia of boulders is much lower than that of the typical CI chondrites due to numerous cracks and pores. Thermal infrared band ratios of MARA indicated the composition of Ryugu boulders similar to hydrated carbonaceous chondrites.

The first laser albedo map from 40S to 20N of asteroid Ryugu was obtained using the LIDAR onboard Hayabusa2. Yamada et al. (2022) mapped the intensities of zero-angle reflected laser pulses of 1.064 μm wavelength. The surface albedo of Ryugu shows mostly homogeneous and low values of 0.040–0.045 with the average of 0.0405. Hayabusa2 started its extended mission after its sample recovery in December 2020, and it is important to recognize the degree of degradation and update the calibration pipeline with new observation data. Yamada et al. (2023) performed the in-flight calibration of the telescopic and wide-band optical navigation cameras (ONC-T and ONC-W1) and shows the degree of degradation is limited and does

not strongly influence the results during the extended mission, including the observations of the zodiacal lights and the transit of exoplanets during the cruise of the spacecraft.

Two papers are published within this special issue on the study of asteroid Itokawa. Chaves and Thompson (2022) investigated the fine structure of Itokawa samples by TEM analysis and discovered the different pattern of space weathering processes in sulfides and silicates (FeNiS, FeS, olivine and pentlandite). It is applicable for understanding the history of space weathering process of C-type and S-type asteroids. Hallstron and Bose (2023) performed a numerical study of the formation process of Itokawa parent body as an example to investigate which physical properties could most constrain the formation processes of LL4 to LL6 parent bodies in its diameter and the timing of formation since CAI formation. They found that the size and timing could be most influenced by the physical parameters such as heat capacity and the amount of ^{26}Al, with the results of 1.6–2.5 Ma for the diameter of the parent body > 19 km, and 1.4–3.5 Ma for the diameter > 17 km.

All manuscripts in this special issue provide fruitful and constructive information for the ongoing discussion of the origin and evolution of the early Solar System, and for progress in the past, current and future, multiscale primitive body missions such as Hayabusa Hayabusa2, OSIRIS-REx, MMX, and NGSR missions. Furthermore, these activities also provide motivation for new missions to yet unvisited types of primitive bodies, such as NASA Psyche mission to visit M-type asteroid 16 Psyche (Elkins-Tanton et al. 2020), NASA Lucy mission for multiple flybys of Trojan asteroids (Levison et al. 2021), UAE MBR explorer to flyby six main belt asteroids and rendezvous with 269 Justitia (El-Maarry et al. 2023), and JAXA DESTINY + mission to flyby Phaethon and some other asteroids (Toyota et al. 2023). Planetary Defense missions are more focused on investigating physical properties of asteroids which should be done in parallel with the analysis of chemical, mineralogical and organics properties by the other types of missions like sample return, or spectroscopy from orbit or on surface. Planetary Defense missions also contribute to understanding the Solar System origin and evolution such as NASA DART (Rivkin and Cheng 2023), and ESA Hera missions to Asteroid Binary Didymos and Dimorphos (Michel et al. 2022), as well as the RAMSES mission to 99,942 Apophis (Küppers et al. 2024).

Author contributions
All authors of this article served as guest editors for this special issue. To drafted the manuscript. All authors read,corrected, and approved the final manuscript.

Data availability
Not applicable.

Declarations

Competing interests
The authors declare that they have no competing interests.

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Publisher's Note

FRONTIER LETTER Open Access

Variations of the surface characteristics of Ryugu returned samples

Aiko Nakato*, Toru Yada, Masahiro Nishimura, Kasumi Yogata, Akiko Miyazaki, Kana Nagashima, Kentaro Hatakeda, Kazuya Kumagai, Yuya Hitomi, Hiromichi Soejima, Jean-Pierre Bibring, Cedric Pilorget, Vincent Hamm, Rosario Brunetto, Lucie Riu, Lionel Lourit, Damien Loizeau, Tania Le Pivert-Jolivet, Guillaume Lequertier, Aurelie Moussi-Soffys, Masanao Abe, Tatsuaki Okada, Tomohiro Usui, Satoru Nakazawa, Takanao Saiki, Satoshi Tanaka, Fuyuto Terui, Makoto Yoshikawa, Sei-ichiro Watanabe and Yuichi Tsuda

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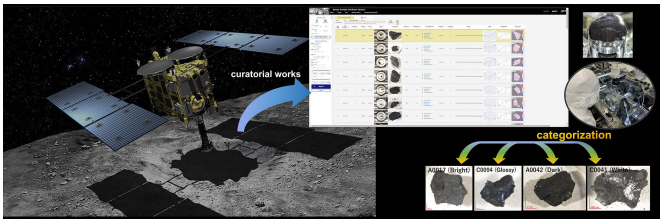
Abstract

Hayabusa2 spacecraft successfully collected rock samples from the surface of C-type near-Earth asteroid 162173 Ryugu through two touchdowns and brought them back to Earth in 2020. At the Extraterrestrial Sample Curation Center in JAXA, we performed initial description of all samples to obtain fundamental information and prepare the database for sample allocation. We propose morphological classifications for the returned samples based on the initial description of 205 grains described in the first 6 months. The returned samples can be distinguished by four morphological characteristics: dark, glossy, bright, and white. According to coordinated study to provide an initial description and detailed investigation by scanning electron microscopy and X-ray diffraction analysis in this study, these features reflect the differences in the degree of space weathering and mineral assemblages. The degree of space weathering of the four studied grain types is heterogeneous: weak for A0042 (dark group) and C0041 (white group); moderate for C0094 (glossy); and severe for A0017 (bright). The white phase, which is the mineral characteristic of the white group grains, is identified as large carbonate minerals. This is the first effort to classify Ryugu returned samples into distinct categories. Based on these results, researchers can estimate sample characteristics only from the information on the JAXA curation public database. It will be an important reference for sample selection for further investigation.



Graphical abstract

Keywords: Hayabusa2, Ryugu, Curation, Returned samples, Classification

*Corresponding author: Aiko Nakato, nkt.aiko@gmail.com

FULL PAPER Open Access

Space weathering signatures in sulfide and silicate minerals from asteroid Itokawa

Laura C. Chaves* and Michelle S. Thompson

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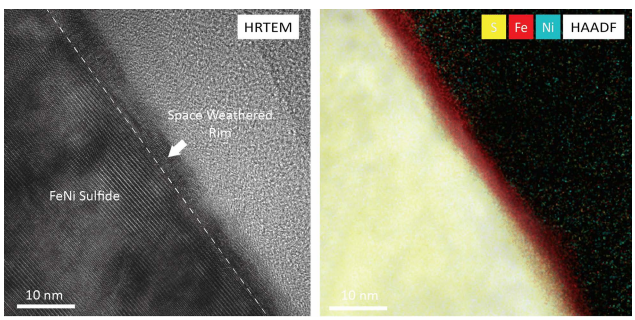
Abstract

Transmission electron microscopy analyses of the polymineralic regolith particle RC-MD01-0025 show microstructural and microchemical characteristics indicative of space weathering on the surface of asteroid Itokawa. The depletion of sulfur and nickel was identified in space weathered rims on troilite and pentlandite minerals. This corresponds to the first report of nickel depletion in samples returned from asteroid Itokawa by the Hayabusa mission. Microstructurally, the sulfide minerals present crystalline rims and the olivine presents both crystalline and amorphous zones in the rim. These results suggest that sulfides might be more resistant to amorphization caused by solar wind irradiation. The space weathering features identified in the regolith particle analyzed here are likely formed via solar wind irradiation. Additionally, the differences in the space weathering features in olivine, pentlandite, and troilite suggest that silicates and sulfides respond differently to the same space weathering conditions in interplanetary space.



Graphical abstract

Keywords: Hayabusa, Itokawa, Space weathering, Sulfides, Transmission electron microscopy, Energy-dispersive X-ray spectroscopy

*Corresponding author: Laura C. Chaves, lchavesm@purdue.edu

FULL PAPER Open Access

Pattern in ejecta curtain generated by the impact into granular targets of various sized particles and application to the ejecta curtain observed in the Hayabusa2 impact experiment

Toshihiko Kadono*, Ayako I. Suzuki, Ryo Suetsugu, Yuri Shimaki and Sunao Hasegawa

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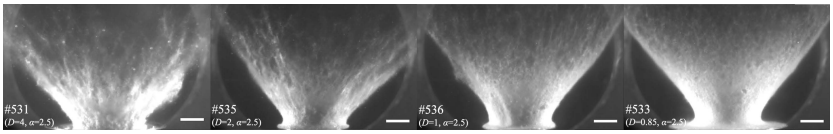
Abstract

We conducted impact experiments using targets composed of particles with size distributions and projectiles with a size larger than or comparable with the maximum size of particles in targets. The pattern and particle concentration in the ejecta curtain were investigated. The results show three types of ejecta curtain features: (i) filament pattern extending throughout the entire curtain and high concentration, (ii) filament pattern and low concentration, and (iii) mesh-like pattern with a structure on smaller scales than the entire curtain and low concentration. When the target consists of particles using a bimodal size distribution with size differences of more than one order of magnitude, the filament pattern appears, exhibiting case (i). If the target consists of particles with various sizes with size differences of more than one order of magnitude, the filament pattern appears, but the concentration decreases, appearing the features of case (ii). Case (iii) occurs when the target consists of particles with a single size or when the mass of particles with a certain size is dominant. Thus, the size distribution of the particles in the targets determines the pattern and particle concentration in the ejecta curtain. Based on these results, we confirm that the pattern in the ejecta curtain caused by the impact of the Small Carry-on Impactor (SCI) in the Hayabusa2 mission showing case (i) is consistent with the evaluated sizes and masses of grains and boulders in the ejecta curtain.

Keywords: Impact cratering, Ejecta curtain, Pattern formation, Size distribution, Asteroid Ryugu, SCI crater



Graphical abstract

*Corresponding author: Toshihiko Kadono, kadono@med.uoeh-u.ac.jp

FULL PAPER Open Access

Effect of projectile shape and interior structure on crater size in strength regime

T. Kadono*, M. Arakawa, S. Tsujido, M. Yasui, S. Hasegawa, K. Kurosawa, K. Shirai, C. Okamoto, K. Ogawa, Y. Iijima, Y. Shimaki and K. Wada

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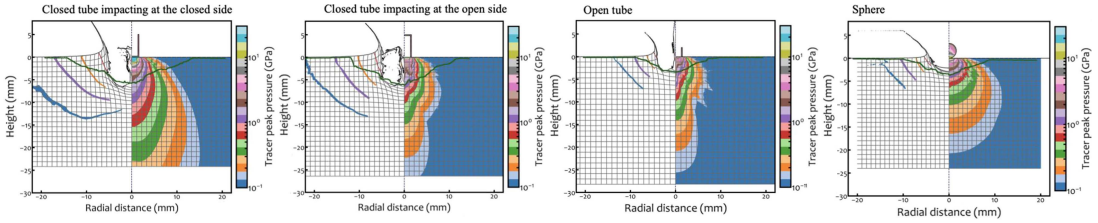
Abstract

Experiments on crater formation in the strength regime were conducted using projectiles of various shapes with an aspect ratio of ~ 1, including both solid and hollow interiors. The surface diameter, inner (pit) diameter, and depth of the craters on basalt and porous gypsum targets were measured. Using the bulk density of the projectile, the surface diameter and depth for basalt and the pit diameter and depth for porous gypsum were scaled using the pi-scaling law for crater formation in the strength regime. The numerical code iSALE was used to simulate the impact of projectiles of various shapes and interior structure with similar bulk densities. Results show that the distributions of the maximum (peak) pressure experienced and particle velocity in the targets were similar regardless of projectile shape and interior structure, implying that the dimensions of the final craters were almost identical. This is consistent with the experimental results. Thus, we conclude that the size of the craters formed by the impact of projectiles with different shape and interior structure can be scaled using a conventional scaling law in the strength regime, using bulk density as projectile density.

Keywords: Hypervelocity impact, Crater formation, Strength regime, Hollow projectile, Scaling law



Graphical abstract

*Corresponding author: T. Kadono, kadono@med.uoeh-u.ac.jp

FULL PAPER Open Access

Rare earth element identification and quantification in millimetre-sized Ryugu rock fragments from the Hayabusa2 space mission

Pieter Tack*, Ella De Pauw, Beverley Tkalcec, Miles Lindner, Benjamin Bazi, Bart Vekemans, Frank Brenker, Marco Di Michiel, Masayuki Uesugi, Hisayoshi Yurimoto, Tomoki Nakamura, Kana Amano, Megumi Matsumoto, Yuri Fujioka, Yuma Enokido, Daisuke Nakashima, Takaaki Noguchi, Ryuji Okazaki, Hikaru Yabuta, Hiroshi Naraoka, Kanako Sakamoto, Shogo Tachibana, Toru Yada, Masahiro Nishimura, Aiko Nakato, Akiko Miyazaki, Kasumi Yogata, Masanao Abe, Tatsuaki Okada, Tomohiro Usui, Makoto Yoshikawa, Takanao Saiki, Satoshi Tanaka, Fuyuto Terui, Satoru Nakazawa, Sei-Ichiro Watanabe, Yuichi Tsuda and Laszlo Vincze

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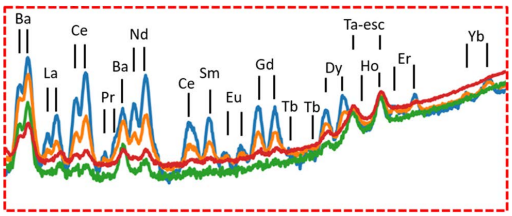
Abstract

Millimetre-sized primordial rock fragments originating from asteroid Ryugu were investigated using high energy X-ray fluorescence spectroscopy, providing 2D and 3D elemental distribution and quantitative composition information on the microscopic level. Samples were collected in two phases from two sites on asteroid Ryugu and safely returned to Earth by JAXA's asteroid explorer Hayabusa2, during which time the collected material was stored and maintained free from terrestrial influences, including exposure to Earth's atmosphere. Several grains of interest were identified and further characterised to obtain quantitative information on the rare earth element (REE) content within said grains, following a reference-based and computed-tomography-assisted fundamental parameters quantification approach. Several orders of magnitude REE enrichments compared to the mean CI chondrite composition were found within grains that could be identified as apatite phase. Small enrichment of LREE was found for dolomite grains and slight enrichment or depletion for the general matrices within the Ryugu rock fragments A0055 and C0076, respectively.

Keywords: Fundamental parameter quantification, Hayabusa2, REE, Ryugu, X-ray fluorescence spectroscopy



Graphical abstract

*Corresponding author: Pieter Tack, pieter.tack@ugent.be

FULL PAPER Open Access

Particle size distributions inside and around the artificial crater produced by the Hayabusa2 impact experiment on Ryugu

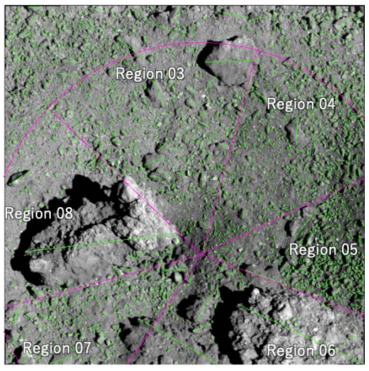
K. Ogawa, N. Sakatani, T. Kadono*, M. Arakawa, R. Honda, K. Wada, K. Shirai, Y. Shimaki, K. Ishibashi, Y. Yokota, T. Saiki, H. Imamura, Y. Tsuda, S. Nakazawa, Y. Takagi, M. Hayakawa, H. Yano, C. Okamoto, Y. Iijima, T. Morota, S. Kameda, E. Tatsumi, Y. Cho, K. Yoshioka, H. Sawada, M. Matsuoka, M. Yamada, T. Kouyama, H. Suzuki, C. Honda and S. Sugita

Earth, Planets and Space 2022, **74**:153 DOI: 10.1186/s40623-022-01713-3
Received: 15 March 2022, Accepted: 29 September 2022, Published: 17 October 2022

Abstract

Japanese Hayabusa2 spacecraft has successfully carried out an impact experiment using a small carry-on impactor (SCI) on an asteroid (162173) Ryugu. We examine the size distribution of particles inside and outside an artificial impact crater (the SCI crater) based on the images taken by the optical navigation camera onboard the Hayabusa2 spacecraft. The circumferential variation in particle size distribution inside the SCI crater is recognized and we interpret that major circumferential variation is caused by the large boulders inside the SCI crater that existed prior to the impact. The size distribution inside the SCI crater also shows that the subsurface layer beneath the SCI impact site had a large number of particles with a characteristic size of ~ 9 cm, which is consistent with the previous evaluations. On the other hand, the size distribution outside the SCI crater exhibits the radial variation, implying that the deposition of ejecta from the SCI crater is involved. The slope of the size distribution outside the crater at small sizes differs from the slope of the size distribution on the surface of Ryugu by approximately 1 or slightly less. This is consistent with the claim that some particles are buried in fine particles of the subsurface origin included in ejecta from the SCI crater. Thus, the particle size distributions inside and outside the SCI crater reveal that the subsurface layer beneath the SCI impact site is rich in fine particles with ~ 9 cm in size while the particles on the surface have a size distribution of a power-law form with shallower slopes at small sizes due to the deposition of fine ejecta from the subsurface layer. Finally, we discuss a process responsible for this difference in particle size distribution between the surface and the subsurface layers. The occurrence of segregation in the gravitational flow of particles on the surface of Ryugu is plausible.

Keywords: Asteroid Ryugu, SCI crater, Particle size distribution, Ejecta deposition



Graphical abstract

*Corresponding author: T. Kadono, kadono@med.uoeh-u.ac.jp

FULL PAPER Open Access

Trace-element analysis of mineral grains in Ryugu rock fragment sections by synchrotron-based confocal X-ray fluorescence

Benjamin Bazi*, Pieter Tack, Miles Lindner, Bart Vekemans, Ella De Pauw, Beverley Tkalcec, Frank E. Brenker, Jan Garrevoet, Gerald Falkenberg, Hikaru Yabuta, Hisayoshi Yurimoto, Tomoki Nakamura, Kana Amano, Megumi Matsumoto, Yuri Fujioka, Yuma Enokido, Daisuke Nakashima, Masayuki Uesugi, Hiroshi Naraoka, Takaaki Noguchi, Ryuji Okazaki, Kanako Sakamoto, Toru Yada, Masahiro Nishimura, Aiko Nakato, Akiko Miyazaki, Kasumi Yogata, Masanao Abe, Tatsuaki Okada, Tomohiro Usui, Makoto Yoshikawa, Takanao Saiki, Satoshi Tanaka, Fuyuto Terui, Satoru Nakazawa, Shogo Tachibana, Sei-ichiro Watanabe, Yuichi Tsuda and Laszlo Vincze

Earth, Planets and Space 2022, **74**:161 DOI: 10.1186/s40623-022-01726-y
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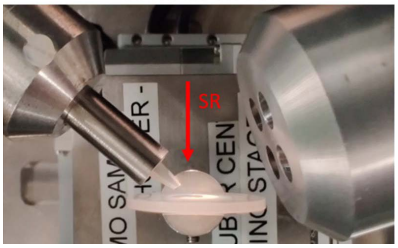
Abstract

A fundamental parameter-based quantification scheme for confocal XRF was applied to sub-micron synchrotron radiation X-ray fluorescence (SR-XRF) data obtained at the beamline P06 of the Deutsches Elektronen-Synchrotron (DESY, Hamburg, Germany) from two sections C0033-01 and C0033-04 that were wet cut from rock fragment C0033 collected from Cb-type asteroid (162173) Ryugu by JAXA's Hayabusa2 mission. Trace-element quantifications show that C0033 bulk matrix is CI-like, whereas individual mineral grains (i.e., magnetite, pyrrhotite, dolomite, apatite and breunnerite) show, depending on the respective phase, minor to strong deviations. The non-destructive nature of SR-XRF coupled with a new PyMca (a Python toolkit for XRF data analysis)-based quantification approach, performed in parallel with the synchrotron experiments, proves to be an attractive tool for the initial analysis of samples from return missions, such as Hayabusa2 and OSIRIS-REx, the latter returning material from a B-type asteroid (101955) Bennu in 2023.

Keywords: X-ray fluorescence, Confocal, Quantification, Fundamental parameter method, Ryugu, Hayabusa2



Graphical abstract

*Corresponding author: Benjamin Bazi, benjamin.bazi@ugent.be

FULL PAPER Open Access

Derivation of 1.064 μm normal albedos on the C-type asteroid Ryugu from laser pulse intensity measurement of the Hayabusa2 LIDAR

Ryuhei Yamada*, Keiko Yamamoto, Shoko Oshigami, Hiroshi Araki, Hiroki Senshu, Hirotomo Noda, Noriyuki Namiki, Koji Matsumoto, Fumi Yoshida, Shinsuke Abe, Naru Hirata, Sho Sasaki and Takahide Mizuno

Earth, Planets and Space 2022, **74**:166 DOI: 10.1186/s40623-022-01717-z
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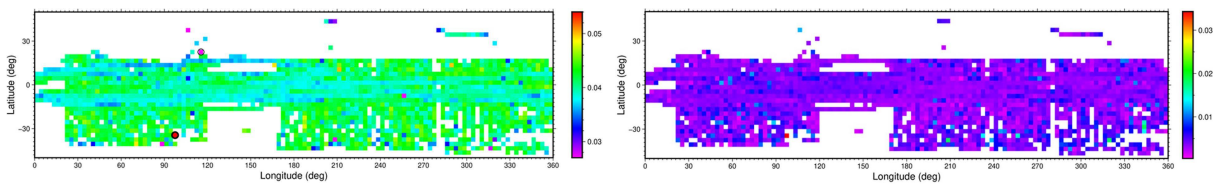
Abstract

Japanese asteroid explorer Hayabusa2 arrived at C-type asteroid 162,173 Ryugu in June 2018. The laser altimeter (LIDAR) onboard Hayabusa2 measured its own transmitted laser and returned pulse intensities from a Ryugu surface until November 2019. Because the Ryugu surface is extremely rough, topography dominates over the material properties in the conventional derivation of normal albedo. Thus, we developed a method to retrieve the normal albedo from the rough surface of a C-type asteroid at a LIDAR laser wavelength of 1.064 μm. The albedo map covering an equatorial band between − 40° and + 20° in latitude was created with 3°-by-3° resolution using the intensity data obtained before the conjunction of the spacecraft with the Sun. The average of the normal albedo is 0.0405 ± 0.0027, whereas approximately half of the 3°-by-3° grids are between 0.04 and 0.045. The low and uniform normal albedo feature is common to other remote-sensing observations of Ryugu by visible and near-infrared cameras onboard Hayabusa2.

Keywords: C-type asteroid, Albedo, LIDAR, Hayabusa2



Graphical abstract

*Corresponding author: Ryuhei Yamada, ryamada@u-aizu.ac.jp

FULL PAPER Open Access

PAHs, hydrocarbons, and dimethylsulfides in Asteroid Ryugu samples A0106 and C0107 and the Orgueil (CI1) meteorite

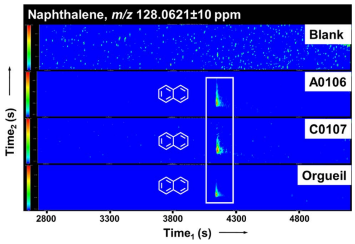
José C. Aponte*, Jason P. Dworkin, Daniel P. Glavin, Jamie E. Elsila, Eric T. Parker, Hannah L. McLain, Hiroshi Naraoka, Ryuji Okazaki, Yoshinori Takano, Shogo Tachibana, Guannan Dong, Sarah S. Zeichner, John M. Eiler, Hisayoshi Yurimoto, Tomoki Nakamura, Hikaru Yabuta, Fuyuto Terui, Takaaki Noguchi, Kanako Sakamoto, Toru Yada, Masahiro Nishimura, Aiko Nakato, Akiko Miyazaki, Kasumi Yogata, Masanao Abe, Tatsuaki Okada, Tomohiro Usui, Makoto Yoshikawa, Takanao Saiki, Satoshi Tanaka, Satoru Nakazawa, Yuichi Tsuda, Sei-ichiro Watanabe, The Hayabusa2-initial-analysis SOM team and The Hayabusa2-initial-analysis core team

Earth, Planets and Space 2023, **75**:28 DOI: 10.1186/s40623-022-01758-4
Received: 1 July 2022, Accepted: 20 December 2022, Published: 27 February 2023

Abstract

Evaluating the molecular distribution of organic compounds in pristine extraterrestrial materials is cornerstone to understanding the abiotic synthesis of organics and allows us to better understand the molecular diversity available during the formation of our solar system and before the origins of life on Earth. In this work, we identify multiple organic compounds in solvent extracts of asteroid Ryugu samples A0106 and C0107 and the Orgueil meteorite using two-dimensional gas chromatography and time-of-flight high resolution mass spectrometry (GC×GC–HRMS). Our analyses found similarities between the molecular distribution of organic compounds in Ryugu and the CI carbonaceous chondrite Orgueil. Specifically, several PAHs and organosulfides were found in Ryugu and Orgueil suggesting an interstellar and parent body origin for these compounds. We also evaluated the common relationship between Ryugu, Orgueil, and comets, such as Wild-2; however, until comprehensive compound-specific isotopic analyses for these organic species are undertaken, and until the effects of parent body processes and Earth's weathering processes on meteoritic organics are better understood, their parent–daughter relationships will remain unanswered. Finally, the study of organic compounds in Ryugu samples and the curation practices for the future preservation of these unvaluable materials are also of special interest for future sample return missions, including NASA's OSIRIS-REx asteroid sample return mission.

Keywords: Hayabusa2, Ryugu, PAHs, Aqueous alteration, Soluble organics, GC×GC, Chromatography, Aliphatic organics



Graphical abstract

*Corresponding author: José C. Aponte, jose.c.aponte@nasa.gov

FULL PAPER Open Access

Inflight calibration of the optical navigation camera for the extended mission phase of Hayabusa2

Manabu Yamada*, Toru Kouyama, Koki Yumoto, Eri Tatsumi, Naofumi Takaki, Yasuhiro Yokota, Tomokatsu Morota, Naoya Sakatani, Masahiko Hayakawa, Moe Matsuoka, Rie Honda, Chikatoshi Honda, Shingo Kameda, Hidehiko Suzuki, Yuichiro Cho, Kazuo Yoshioka, Kazunori Ogawa, Kei Shirai, Hirotaka Sawada and Seiji Sugita

Earth, Planets and Space 2023, **75**:36 DOI: 10.1186/s40623-023-01789-5
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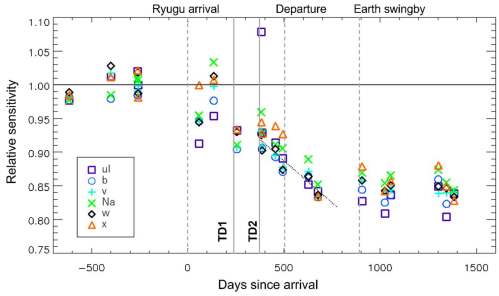
Abstract

After delivering its sample capsule to Earth, the Hayabusa2 spacecraft started its extended mission to perform a flyby of asteroid 2001 CC_{21} in 2026 and rendezvous with asteroid 1998 KY_{26} in 2031. During the extended mission, the optical navigation camera (ONC) of Hayabusa2 will play an important role in navigation and science observations, but it has suffered from optical deterioration after the spacecraft's surface contact with and sampling of asteroid Ryugu. Furthermore, the sensitivity of the telescopic camera (ONC-T) has continued to decrease for more than a year, posing a serious problem for the extended mission. These are problems that could potentially be encountered by other sample-return missions involving surface contact. In this study, we evaluated the long-term variation of ONC performance over the 6.5 years following the launch in 2014 to predict how it will perform during observations of the two target asteroids in its extended mission (6 and 11 years from the Earth return, respectively). Our results showed several important long-term trends in ONC performance, such as transmission, dark noise level, and hot pixels. During the long cruising period of the extended mission, we plan to observe both zodiacal light and exoplanet transits as additional science targets. The accuracy of these observations is sensitive to background noise level and stray-light contamination, so we conducted new test observations to search for the lowest stray light, which has been found to depend on spacecraft attitude. The results of these analyses and new test observations suggest that the Hayabusa2 ONC will be able to conduct cruising, flyby, and rendezvous observations of asteroids with sufficient accuracy.

Keywords: Hayabusa2, Optical navigation camera, Extended mission, Calibration



Graphical abstract

*Corresponding author: Manabu Yamada, manabu@perc.it-chiba.ac.jp

FULL PAPER Open Access

Homogeneity and heterogeneity in near-infrared FTIR spectra of Ryugu returned samples

Kentaro Hatakeda*, Toru Yada, Masanao Abe, Tatsuaki Okada, Aiko Nakato, Kasumi Yogata, Akiko Miyazaki, Kazuya Kumagai, Masahiro Nishimura, Yuya Hitomi, Hiromichi Soejima, Kana Nagashima, Miwa Yoshitake, Ayako Iwamae, Shizuho Furuya, Tomohiro Usui and Kohei Kitazato

Earth, Planets and Space 2023, **75**:46 DOI: 10.1186/s40623-023-01784-w
Received: 20 August 2022, Accepted: 10 February 2023, Published: 28 March 2023

Abstract

Surface and subsurface materials of C-type near-Earth asteroid 162173 Ryugu were collected and successfully returned to the Earth in the Hayabusa2 mission. Fourier Transform Infrared Spectroscopy (FTIR) has been conducted to characterize these returned samples as one of the initial descriptions in a non-destructive manner under a purified nitrogen condition without terrestrial contamination. We selected the individual grains and aggregate samples that were not severely influenced by the reflection of incident beam at the sapphire dish and analyzed their reflectance spectra using the primary component analysis (PCA). The result indicates that Ryugu returned samples are highly homogeneous with only a little heterogeneity. The average spectrum of the main PCA group is represented by four absorption bands at 2.7, 3.05, 3.4, and 3.95 μm. The spectral feature is consistent with that obtained from bulk FTIR measurements, indicating potential presence of hydroxyl, organics, and carbonates. Rarely observed types of grains with unique spectra are categorized into three groups: significantly high reflectance, carbonates, and hydroxyl compounds with broad OH absorption.

Keywords: Hayabusa2, Ryugu returned samples, FTIR, Initial description, Curation

Graphical abstract

*Corresponding author: Kentaro Hatakeda, hatakedak@mwj.co.jp

FULL PAPER Open Access

MASCOT's in situ analysis of asteroid Ryugu in the context of regolith samples and remote sensing data returned by Hayabusa2

Katharina Otto*, Tra-Mi Ho, Stephan Ulamec, Jean-Pierre Bibring, Jens Biele, Matthias Grott, Maximilian Hamm, David Hercik, Ralf Jaumann, Masahiko Sato, Stefan E. Schröder, Satoshi Tanaka, Ulrich Auster, Kohei Kitazato, Jörg Knollenberg, Aurelie Moussi, Tomoki Nakamura, Tatsuaki Okada, Cedric Pilorget, Nicole Schmitz, Seiji Sugita, Koji Wada and Hikaru Yabuta

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Abstract

The Hayabusa2 mission provided a unique data set of asteroid Ryugu that covers a wide range of spatial scale from the orbiter remote sensing instruments to the returned samples. The MASCOT lander that was delivered onto the surface of Ryugu aimed to provide context for these data sets by producing in situ data collected by a camera (MasCam), a radiometer (MARA), a magnetometer (MasMag) and a spectrometer (MicrOmega). In this work, we evaluate the success of MASCOT as an integrated lander to bridge the gap between orbiter and returned sample analysis. We find that MASCOT's measurements and derivatives thereof, including the rock morphology, colour in the visible wavelengths, possible meteorite analogue, density, and porosity of the rock at the landing site are in good agreement with those of the orbiter and the returned samples. However, it also provides information on the spatial scale (sub-millimetres to centimetres) at which some physical properties such as the thermal inertia and reflectance undergo scale-dependent changes. Some of the in situ observations such as the presence of clast/inclusions in rocks and the absence of fine particles at the landing site was uniquely identified by MASCOT. Thus, we conclude that the delivery of an in situ instrument like MASCOT provides a valuable data set that complements and provides context for remote sensing and returned sample analyses.

Keywords: Asteroid Ryugu, In situ analyses, Asteroid sample return, Multi-scale analysis, Asteroid regolith properties, Asteroid regolith, MASCOT, Hayabusa2

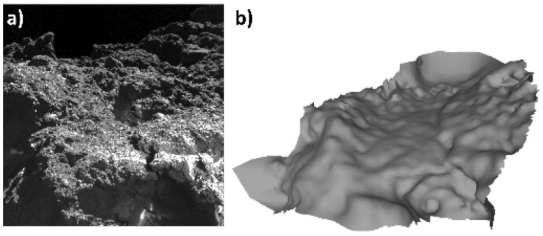

Fig. 2

*Corresponding author: Katharina Otto, katharina.otto@dlr.de

FULL PAPER Open Access

The spatial distribution of soluble organic matter and their relationship to minerals in the asteroid (162173) Ryugu

Minako Hashiguchi*, Dan Aoki, Kazuhiko Fukushima, Hiroshi Naraoka, Yoshinori Takano, Jason P. Dworkin, Karin E. Dworkin, José C. Aponte, Jamie E. Elsila, John M. Eiler, Yoshihiro Furukawa, Aogu Furusho, Daniel P. Glavin, Heather V. Graham, Kenji Hamase, Norbert Hertkorn, Junko Isa, Toshiki Koga, Hannah L. McLain, Hajime Mita, Yasuhiro Oba, Nanako O. Ogawa, Naohiko Ohkouchi, Francois-Regis Orthous-Daunay, Eric T. Parker, Alexander Ruf, Saburo Sakai, Philippe Schmitt-Kopplin, Haruna Sugahara, Roland Thissen, Véronique Vuitton, Cédric Wolters, Toshihiro Yoshimura, Hisayoshi Yurimoto, Tomoki Nakamura, Takaaki Noguchi, Ryuji Okazaki, Hikaru Yabuta, Kanako Sakamoto, Shogo Tachibana, Toru Yada, Masahiro Nishimura, Aiko Nakato, Akiko Miyazaki, Kasumi Yogata, Masanao Abe, Tomohiro Usui, Makoto Yoshikawa, Takanao Saiki, Satoshi Tanaka, Fuyuto Terui, Satoru Nakazawa, Sei-ichiro Watanabe and Yuichi Tsuda

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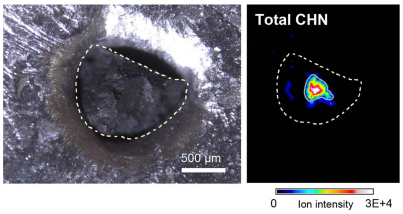
Abstract

We performed *in-situ* analysis on a ~ 1 mm-sized grain A0080 returned by the Hayabusa2 spacecraft from near-Earth asteroid (162173) Ryugu to investigate the relationship of soluble organic matter (SOM) to minerals. Desorption electrospray ionization-high resolution mass spectrometry (DESI-HRMS) imaging mapped more than 200 CHN, CHO, CHO–Na (sodium adducted), and CHNO soluble organic compounds. A heterogeneous spatial distribution was observed for different compound classes of SOM as well as among alkylated homologues on the sample surface. The A0080 sample showed mineralogy more like an Ivuna-type (CI) carbonaceous chondrite than other meteorites. It contained two different lithologies, which are either rich (lithology 1) or poor (lithology 2) in magnetite, pyrrhotite, and dolomite. CHN compounds were more concentrated in lithology 1 than in lithology 2; on the other hand, CHO, CHO–Na, and CHNO compounds were distributed in both lithologies. Such different spatial distribution of SOM is likely the result of interaction of the SOM with minerals, during precipitation of the SOM via fluid activity, or could be due to difference in transportation efficiencies of SOMs in aqueous fluid. Organic-related ions measured by time-of-flight secondary ion mass spectrometry (ToF–SIMS) did not coincide with the spatial distribution revealed by DESI-HRMS imaging. This result may be because the different ionization mechanism between DESI and SIMS, or indicate that the ToF–SIMS data would be mainly derived from methanol-insoluble organic matter in A0080. In the Orgueil meteorite, such relationship between altered minerals and SOM distributions was not observed by DESI-HRMS analysis and field-emission scanning electron microscopy, which would result from differences of SOM formation processes and sequent alteration process on the parent bodies or even on the Earth. Alkylated homologues of CHN compounds were identified in A0080 by DESI-HRMS imaging as observed in the Murchison meteorite, but not from the Orgueil meteorite. These compounds with a large C number were enriched in Murchison fragments with abundant carbonate grains. In contrast, such relationship was not observed in A0080, implying different formation or growth mechanisms for the alkylated CHN compounds by interaction with fluid and minerals on the Murchison parent body and asteroid Ryugu.

Keywords: Ryugu, Hayabusa2, Spatial distribution of soluble organic compounds, DESI-HRMS imaging, ToF–SIMS analysis



Graphical abstract

*Corresponding author: Minako Hashiguchi, hashiguchi@eps.nagoya-u.ac.jp

FULL PAPER Open Access

A newly revised estimation of bulk densities and examination of the shape of individual Ryugu grains

Akiko Miyazaki*, Toru Yada, Kasumi Yogata, Kentaro Hatakeda, Aiko Nakato, Masahiro Nishimura, Kana Nagashima, Kazuya Kumagai, Yuya Hitomi, Hiromichi Soejima, Rui Tahara, Rei Kanemaru, Arisa Nakano, Miwa Yoshitake, Ayako Iwamae, Shizuho Furuya, Akira Tsuchiyama, Shogo Tachibana, Tatsuhiro Michikami, Tatsuaki Okada, Masanao Abe and Tomohiro Usui

Earth, Planets and Space 2023, **75**:171 DOI: 10.1186/s40623-023-01904-6
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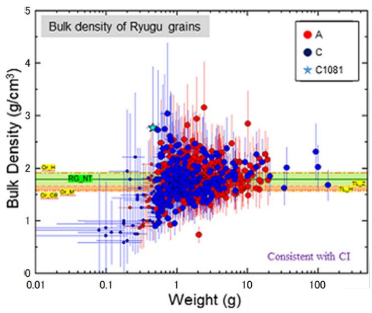
Abstract

The bulk density of grains from a celestial body is a fundamental property related to its composition and structure, contributing to the understanding of its evolutionary history. In this study, we provide the bulk density of 637 grains returned from the C-type near-Earth asteroid 162173 Ryugu. This is the largest number of grains to date for the curation activity, corresponding to 38 wt.% of the total returned samples (approximately 5.4 g). Although several densities of the Ryugu grains were reported, the volume estimation of some samples showed uncertainties. Therefore, we applied a new volume estimation model calibrated by X-ray micro-computed tomography (XCT) to the Ryugu grains to more accurately estimate their bulk density. The obtained average bulk density of 637 Ryugu grains was 1.79 ± 0.31 g/cm^3 (1σ variation) for weights of 0.5–100 mg (sub-mm –to 10 mm) irrespective of their 3D shapes characterized by three axial length ratios, considered to be a representative of the returned samples. The bulk density distributions of the grains in Chambers A and C were statistically distinguishable, with mean values of 1.81 ± 0.30 and 1.76 ± 0.33 g/cm^3 (1σ variations), respectively. Despite the small difference, bulk density may have differed by sampling site. The obtained average bulk density value of A + C samples was almost the same as that of 16 Ryugu grains estimated based on CT scanned data, and was consistent with the densities of CI chondrites (1.57–1.91 g/cm^3). The axial ratios of the grains in Chambers A and C were similar and those of the 724 returned samples and the flying particles ejected during the sampling operations were also similar, suggesting that relatively small Ryugu materials (mm–cm in size) are similar in shape. The minor difference between the Rygu grains and flying particles could be attributed to events such as scraping during sampling operations and transportation.

Keywords: Hayabusa2, Curation, Ryugu grains, Bulk density, 3D shapes



Graphical abstract

*Corresponding author: Akiko Miyazaki, miyazaki.akiko@jaxa.jp

EXPRESS LETTER Open Access

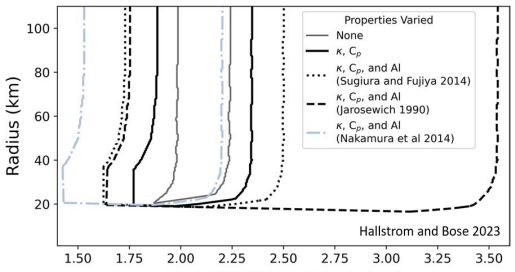
Uncertainties in physical properties of Itokawa-like asteroids widen constraints on their formation time

Jonas Hallstrom* and Maitrayee Bose

Earth, Planets and Space 2023, **75**:11 DOI: 10.1186/s40623-022-01751-x
Received: 31 July 2022, Accepted: 13 December 2022, Published: 20 January 2023

Abstract

One of the outstanding questions in planetary science is to determine how the fundamental mechanical and physical properties of materials determine the thermal evolution of asteroids, and which properties have the greatest influence. We investigate the effects of uncertainty in the material properties of asteroid parent bodies on the ability of thermal evolution models to constrain the sizes and formation times of ordinary chondrite parent asteroids. A simple model is formulated for the thermal evolution of the parent body of asteroid 25143 Itokawa. The effects of the uncertainties in the values specified for specific heat capacity, thermal diffusivity, and aluminum abundance are determined. The uncertainties in specific heat capacity and aluminum abundance, or heat production more generally, are found to both have significant and approximately equal effects on these results, substantially widening the range of possible formation times of Itokawa's parent body. We show that Itokawa's parent body could have formed between 1.6 and 2.5 million years after the origin of calcium–aluminum inclusions with a radius larger than 19 km, and it could have formed as early as 1.4 millions years, as late as 3.5 million years, or with a radius as small at 17 km if more lenient definitions of uncertainty in aluminum abundance are considered. These results stress the importance of precise data required of the material properties of a suite of LL type 4-6 ordinary chondrite meteorites to place better constraints on the thermal history of Itokawa's parent body.



Graphical abstract

Keywords: Thermal evolution models, Itokawa, Chondrites, Asteroids

*Corresponding author: Jonas Hallstrom, jlhallst@asu.edu

TECHNICAL REPORT Open Access

The GAs Extraction and Analyses system (GAEA) for immediate extraction and measurements of volatiles in the Hayabusa2 sample container

Yayoi N. Miura*, Ryuji Okazaki, Yoshinori Takano, Kanako Sakamoto, Shogo Tachibana, Keita Yamada, Saburo Sakai and Hirotaka Sawada

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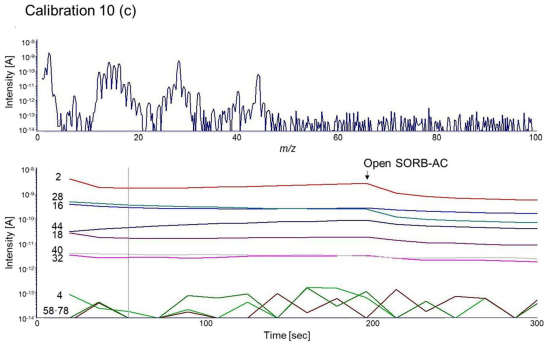
Abstract

Hayabusa2 returned surface samples from the C-type near-Earth asteroid (162173) Ryugu to Woomera, South Australia, in December 2020. The samples returned from Ryugu are expected to contain not only volatile components reflecting its primitive nature, but also solar wind components due to exposure to space. Such volatiles may partly be released inside the sealed sample container enclosing Ryugu samples due to particle destruction or container heating in a contingency case. In order to collect and analyze volatiles released in the container prior to the container-opening, we set up a gas extraction and analyses system (GAEA: GAs Extraction and Analyses system). The system requires ultra-high vacuum conditions, small vacuum line volume to minimize dead volume and simple configuration as well as having an interface to connect the container. The system includes gas bottles for passive collection of volatiles at room temperature and bottles for active collection at liquid nitrogen temperature. A quadrupole mass spectrometer is installed to analyze gases in the vacuum line, and a non-evaporative getter pump is also used when noble gases are analyzed. The rehearsal operation of the GAEA was made at ISAS/JAXA as well as transportation tests in Japan. In November 2020, it was transported safely to the Quick Look Facility (QLF) in Woomera. It was set up at the QLF and worked as planned for collection and analysis of gas components from the returned sample container. Here we report the concept, design and calibration results for the GAEA and an outline of analytical protocols applied in Woomera.



Graphical abstract

Keywords: Hayabusa2, Sample return, C-type asteroid, Volatiles, Gas analysis

*Corresponding author: Yayoi N. Miura, yayoi@eri.u-tokyo.ac.jp

TECHNICAL REPORT Open Access

Methods and tools for handling, transportation, weighing, and pelletization applied to the initial analysis of volatile components in the Hayabusa2 samples

Ryuji Okazaki*, Shinji Yamanouchi, Kazuhiko Shimada, Atsushi Baba, Fumio Kitajima and Toru Yada

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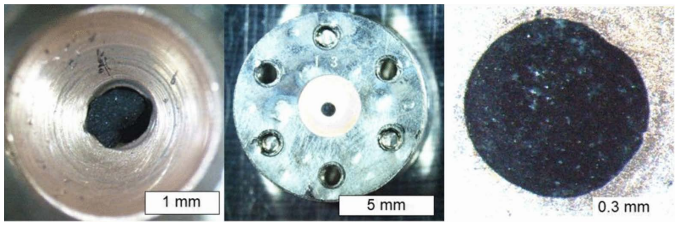
Abstract

The Hayabusa2 spacecraft succeeded in sampling and returning materials from the C-type, near-Earth asteroid (162173) Ryugu. As part of the Hayabusa2 Initial Analyses, chemical and isotopic compositions of volatile species were measured. The samples analyzed were grains of about 1 mm in diameter and were individually treated without exposure to Earth's atmosphere throughout the entire analytical/experimental processes to minimize alteration and contamination effects by adsorption of Earth's atmosphere or chemical reactions with reactive species such as oxygen and water in Earth's atmosphere. In order to perform spectroscopic and electron-microscopic observations in advance of a series of the isotopic measurements, the sample surface needed to be smoothed. We employed a pelletization method to obtain the required flatness for the returned samples because pelletization is a less sample-consuming method compared to mechanical polishing, microtomy, or ion milling. In order to perform the subsequent analyses, the samples must undergo minimal contamination during the pelletization procedure and be easy to remove from the pelletization tools. Therefore, embedding with resins or low-melting-point metals was not employed. Under these constraints, tools and methods for sample pelletization, handling, and transportation were developed. The tools developed for pelletization and housing also contributed to easier handling of small (less than about 1 mm in diameter) samples. Here we describe the methods and the tools that enable treatment of pristine asteroidal samples under non-atmospheric exposure conditions throughout transportation, weighing, pelletization, and installation into the instruments for chemical and isotopic measurements. The methods and tools we developed can be applied to other small samples including meteorites, cosmic dust, and future returned samples.

Keywords: Hayabusa2, Pelletization, Weighing, Handling, Transportation, Volatile isotopes, Airtight



Graphical abstract

*Corresponding author: Ryuji Okazaki, okazaki.ryuji.703@m.kyushu-u.ac.jp

TECHNICAL REPORT Open Access

Small grains from Ryugu: handling and analysis pipeline for infrared synchrotron microspectroscopy

Stefano Rubino*, Zélia Dionnet, Alice Aléon-Toppani, Rosario Brunetto, Tomoki Nakamura, Donia Baklouti, Zahia Djouadi, Cateline Lantz, Obadias Mivumbi, Ferenc Borondics, Stephane Lefrançois, Christophe Sandt, Francesco Capitani, Eva Héripré, David Troadec, Megumi Matsumoto, Kana Amano, Tomoyo Morita, Hisayoshi Yurimoto, Takaaki Noguchi, Ryuji Okazaki, Hikaru Yabuta, Hiroshi Naraoka, Kanako Sakamoto, Shogo Tachibana, Seiichiro Watanabe, Yuichi Tsuda and the Hayabusa2-initial-analysis team

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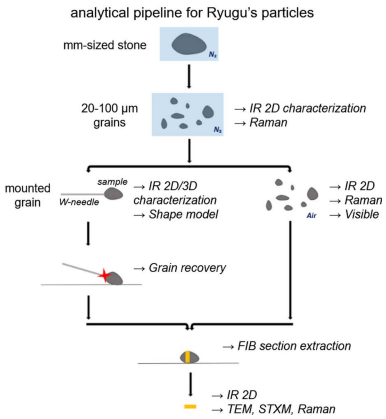
Abstract

Sample-return missions allow the study of materials collected directly from celestial bodies, unbiased by atmospheric entry effects and/or terrestrial alteration and contamination phenomena, using state-of-the-art techniques which are available only in a laboratory environment—but only if the collected material stays pristine. The scarcity of outer-space unaltered material recovered until now makes this material extremely precious for the potential scientific insight it can bring. To maximize the scientific output of current and future sample-return missions, the scientific community needs to plan for ways of storing, handling, and measuring this precious material while preserving their pristine state for as long as the 'invasiveness' of measurements allows. In July 2021, as part of the Hayabusa2 (JAXA) "Stone" preliminary examination team, we received several microscopic particles from the asteroid Ryugu, with the goal of performing IR hyper-spectral imaging and IR micro-tomography studies. Here, we describe the sample transfer, handling methods and analytical pipeline we implemented to study this very precious material while minimizing and surveilling their alteration history on Earth.

Keywords: Sample-return mission, Hayabusa2, IR spectroscopy, Precious samples, Non-destructive analysis, Analytical pipeline



Graphical abstract

*Corresponding author: Stefano Rubino, stefano.rubino@universite-paris-saclay.fr

TECHNICAL REPORT Open Access

Ryugu Sample Database System (RS-DBS) on the Data Archives and Transmission System (DARTS) by the JAXA curation

Masahiro Nishimura*, Aiko Nakato, Masanao Abe, Kana Nagashima, Hiromichi Soejima, Toru Yada, Kasumi Yogata, Akiko Miyazaki, Kentaro Hatakeda, Miwa Yoshitake, Ayako Iwamae, Cedric Pilorget, Rosario Brunetto, Damien Loizeau, Jean-Pierre Bibring, Lucie Riu, Koki Yumoto, Yuichiro Cho, Yuna Yabe, Seiji Sugita, Motoo Ito, Tatsuaki Okada, Shogo Tachibana and Tomohiro Usui

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Abstract

The JAXA Astromaterials Science Research Group developed a web-based database system for the Hayabusa2-returned samples from C-type asteroid Ryugu. The Ryugu Sample Database System database (RS-DBS) is designed as an online catalog for users of wide scientific communities to choose their preferred samples and propose the sample loan through the JAXA Ryugu Sample Announcement of Opportunity. Ryugu samples can be sorted and given identification numbers as individual particles larger than 1 mm and aggregate samples consisting of less than 1 mm particle through the Phase1 curation (i.e., the initial description). The RS-DBS lists all samples with analytical data such as a microscopy image, size, mass, spectroscopic data, and shape model obtained by the initial description at the JAXA curation facility. The list also includes research results conducted by previous projects (i.e., the Hayabusa2 initial analysis team and Phase2 curation teams). The RS-DBS, built with open-source technologies, archives the data securely and long-term on the Data Archives and Transmission System (DARTS) at ISAS/JAXA.

Keywords: Hayabusa2, Ryugu returned samples, Initial description, Curation, Database, Data archive

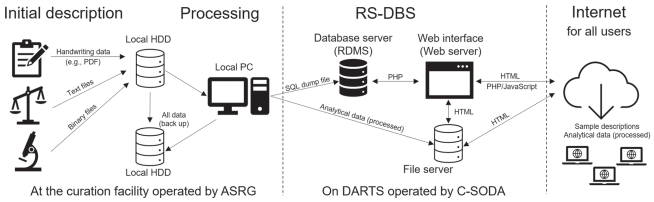

Fig. 2

*Corresponding author: Masahiro Nishimura, nishimura.masahiro2@jaxa.jp

TECHNICAL REPORT Open Access

A curation for uncontaminated Hayabusa2-returned samples in the extraterrestrial curation center of JAXA: from the beginning to present day

Toru Yada*, Masanao Abe, Masahiro Nishimura, Hirotaka Sawada, Ryuji Okazaki, Yoshinori Takano, Kanako Sakamoto, Tatsuaki Okada, Aiko Nakato, Miwa Yoshitake, Yuki Nakano, Kasumi Yogata, Akiko Miyazaki, Shizuho Furuya, Ayako S. Iwamae, Shunichi Nakatsubo, Kentaro Hatakeda, Yuya Hitomi, Kazuya Kumagai, Shino Suzuki, Yayoi N. Miura, Motoo Ito, Naotaka Tomioka, Masayuki Uesugi, Yuzuru Karouji, Kentaro Uesugi, Naoki Shirai, Akira Yamaguchi, Naoya Imae, Hiroshi Naraoka, Yuhji Yamamoto, Shogo Tachibana, Hisayoshi Yurimoto and Tomohiro Usui

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Abstract

Developing a cleanroom and clean chambers (CCs) for Hayabusa2 returned samples has been discussed with the committee for Hayabusa2 sample curation facility since 2015. One major difference from the specifications of the CCs used for Itokawa samples is that a part of samples was decided to be handled and preserved in vacuum to avoid terrestrial nitrogen contamination with organics or unknown materials that might easily react with the samples. Thus, the CCs for Hayabusa2 samples were divided into two CCs for vacuum processes and three CCs for purified nitrogen conditions. The cleanroom was built in summer 2017, while the CCs were installed in the summer of 2018. After the installation of the CCs, instruments for initial descriptions, sample containers, handling tools for powder and particle samples, and jigs to assist handling samples were developed in parallel with functional checks and repeated rehearsals between the fall of 2018 and the fall of 2020. The curatorial works on Hayabusa2-retuned samples were conducted as previously planned. Simultaneously, contaminations and influences of inorganics, organics, microbial, and magnetic constructs have been assessed to evaluate their potential effects on the analysis of the returned samples. Additionally, the tools used to touch samples directly have been demagnetized to avoid sample magnetization during their handling and the tool magnetization was measured before and after their usages. The series of developments and experiences from the curatorial works of Hayabusa2-returned samples represent valuable implications for future sample return missions.

Keywords: Hayabusa2, Ryugu, C-type asteroid, Curation, Cleanroom, Clean chamber

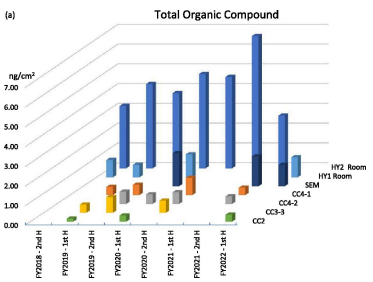

Fig. 6

*Corresponding author: Toru Yada, yada@planeta.sci.isas.jaxa.jp

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