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JAMSTEC
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Japan Synchrotron Radiation Research Institute
National Institute of Polar Research
National Institutes of Natural Sciences, Institute for Molecular Science
Tokyo Metropolitan Public University Corporation
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The Open University

Returned Asteroid samples imaged at ultra-high-resolution by the Phase 2 Curation "Team Kochi" at SPring-8: One of the world's most powerful Synchrotron Radiation Facilities.

Between June 20th and 23rd, 2021 "Team Kochi" [note 1], led by senior researcher Dr Motoo Ito [note 2], undertook cutting edge imaging analysis of samples returned to Earth from Asteroid Ryugu [note 3] by the JAXA Hayabusa2 spacecraft [note 4]. This marked the start of an intensive analytical campaign involving researchers from a wide range of institutions, both in Japan and internationally [note 5], including the Open University in the UK and UCLA in the US.

The samples being analyzed by "Team Kochi" were collected by the Japan Aerospace Exploration Agency (JAXA) Hayabusa2 spacecraft from the surface of the "primitive" asteroid: Ryugu. Hayabusa2 was launched in December 2014, arrived at asteroid Ryugu in 2018 and then commenced one of the most successful asteroid exploration missions of all time. This involved a detailed survey of the asteroid using onboard instruments. Samples from the surface of asteroid Ryugu (approximate mass 5.4 g) were collected by the Hayabusa2 spacecraft and then successfully delivered to Earth on December 6th 2020.

The analysis performed by "Team Kochi" on June 20–23, 2021 involved the use of the SPring-8 synchrotron facility [note 6] to undertake computed tomography (CT) analysis [note 7]. This allowed the team to obtain extremely detailed three-dimensional images of the Ryugu samples. The exact technique that was used has been specifically developed for Ryugu samples, as they contain hydrous mineral phases and organic matter with a complex microstructure. An ultra-high-resolution 3D visualization technique (integrated CT technique (XRD-CT, CT, nano-CT, and Phase-contrast CT)) [note 7][note 8] will be performed later this year at SPring-8 to obtain the distribution of organic matter in the Ryugu samples.

The images and data obtained at SPring-8 will be of assistance to the other members of "Team Kochi" in their studies of these exceptionally important extraterrestrial samples. "Team Kochi" will be applying a wide range of compositional and isotopic measurement techniques to learn as much as possible about the formation and evolution of the Ryugu grains. [note 9]

The oxygen isotope work to be performed at the Open University in the UK will provide critical information about the origin and early history of this material and will tell us how it relates to other extraterrestrial samples, such as meteorites. Material from asteroids similar to Ryugu may have brought water and organic matter to early Earth, thus making it a more habitable planet.

High-spatial resolution and high-precision isotope microanalysis work will be performed at the UCLA SIMS lab in the US. Stable isotope analysis, in combination with a chronological study of particular minerals, will provide constraints on the exchange processes between water and minerals and the timing of aqueous alteration within a carbonaceous asteroid. This information is critical in deciphering the earliest history of water-mineral phase reactions inside a planetesimal.

Scientific analysis undertaken by research institutes in Japan, UK and US as part of "Team Kochi" will not only help to constrain the history of organic matter and water on Ryugu, but may also help us to understand the early evolution of Earth.

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NOTES

[1] Phase 2 Curation "Team Kochi". Phase 2 Curation Kochi(Ph2K) will be acting under the scientific direction and strong ethic of the Astromaterial Science Research Group (ASRG) of JAXA and was authorized by the steering committee of the ASRG in 2017. The Phase 2 curation activities include sample characterizations, secure storage, allocation management, sample distribution to world-wide community, and research and development for future and current returned samples. Kochi institute for Core sample research of JAMSTEC is currently leading these curation-related activities regarding the Hayabusa2 returned samples in collaboration with JASRI, UVSOR Synchrotron Facility/National Institutes of Natural Sciences, Institute for Molecular Science, National Institute of Polar Research (NIPR), Tokyo Metropolitan University, Nagoya University, Osaka University, Open University and UCLA.

In 2017, we successfully developed our universal sample holders for FIB, TEM, NanoSIMS, STXM, and a sample transport container that can be pumped to vacuum or filled with an inert gas so that sample transportation between labs can be carried out without compromising the samples' intactness (see Ito et al., 2020). These R&D activities are to contribute to JAXA curation for future and current returned samples. Phase 2 Curation Team Kochi aims to gain scientific results from the asteroid Ryugu grains by detailed and systematic investigations of the Hayabusa2 returned samples with the *state-of-the-art* instruments/techniques and nationwide/international collaborative research activities.

Since 2015, the Ph2K team has been working closely with the JAXA Curation. The Ph2K team, in addition to making research plans for analysis of Ryugu samples, has developed a universal sample holder for multi-instruments, and a secure sample transport container for nationwide/international transportation. The Ph2K research activities started in 2017, and we have been pushing forward with state-of-the-art analytical instrumentation, expanding their capabilities, and developing new techniques through multi-institutional collaboration.

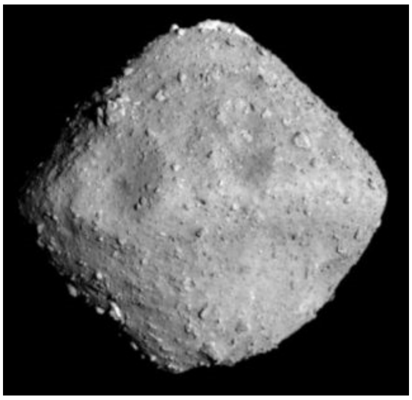
On June 20–23, 2021, the Ph2K team will conduct analysis of Ryugu samples using a synchrotron-based integrated computed tomography (CT) analysis at SPring-8 BL20XU to obtain a three-dimensional μm-scale structural characteristics, and spatial distributions of minerals in the Ryugu samples. The integrated CT technique used here consists of X-ray diffraction CT[note 7] (XRD-CT) and phase-contrast CT[note 8]. This new technique was specifically developed for Ryugu samples, since they are expected to contain hydrous mineral phases and organic matter with a complex microstructure. We also plan to apply an ultra-high-resolution 3D visualization technique (nano-CT) at SPring-8 BL47XU the fall of 2021 to obtain the distribution of the organic matter in the Ryugu samples.

The data acquired from member institutions working as part of Ph2K will be integrated to resolve various long-term questions in cosmochemistry, including the chemical and isotopic evolutions of organic matter coexisting with minerals and water on a primitive asteroid. Furthermore, these findings are expected to shed light on the relationship between the asteroid Ryugu and the available planetary materials (e.g., carbonaceous chondrites and interplanetary dust particles) in our collection, and on the origin of water and life on Earth.

[2] Dr. Motoo Ito is a senior researcher of the Kochi Institute for Core Sample Research, Institute for Extra-cutting-edge Science and Technology Avant-garde Research (X-star), Japan Agency for Marine-Earth Science and Technology (JAMSTEC). He is currently serving as the leader of the Phase 2 Curation Team Kochi (Ph2K). The team will be carrying out a systematic investigations of the asteroid Ryugu grains collected by the Hayabusa2 planetary exploration mission. The first attempt by the Ph2K team to analyze the Ryugu grains will be undertaken at the large synchrotron radiation facility SPring-8[note 6] on the 20th of June 2021 (Sunday).

The SR-CT (synchrotron radiation based computed-tomography) analysis forms part of the SPring-8 long-term project "Initial Analysis of Hayabusa2 Samples Using X-Ray CT: Technical developments, Evaluation of analytical methods, and Analysis: Principal Investigator, Professor Akira Tsuchiyama (Ritsumeikan University)."

[3] Asteroid 62173 Ryugu, is a near-Earth object, approximately 1 kilometre (0.62 mi) in diameter. It is a dark, primitive object of a rare spectral class, showing characteristics of both B and C types.



Asteroid Ryugu – (image: JAXA)

[4] A decade ago, the Japan Aerospace Exploration Agency (JAXA) spacecraft Hayabusa returned to the Earth a small amount of surface materials from the S-type asteroid Itokawa. JAXA followed this success with the development of the Hayabusa2 spacecraft, designed to explore the primitive C-type asteroid Ryugu. The main goal of the Hayabusa2 mission, in addition to performing a series of studies by different types of spectrometers (thermal emission, infrared, and visible spectrometers), is to return surface and subsurface materials from the Ryugu asteroid for various analyses in laboratories. The Hayabusa2 spacecraft has successfully obtained the Ryugu samples from the surface and subsurface in February and April 2019. On 6th December 2020 the sample capsule from the Hayabusa2 spacecraft was successfully landed on Earth in the Woomera desert of Australia. Approximately 5.4 g of black, mm-sized particles have been retrieved from the sample capsule. The initial descriptions of these particles utilizing a series of none-destructive observations (optical images, individual weight, size, and colors) were performed at JAXA's Extraterrestrial Sample Curation Center (ESCuC).

[5] On the 17th of June, the samples will be allocated by JAXA curation to two Phase 2 Curation teams and six initial analysis teams from the JAXA curation. The Ph2K team is going to analyze the asteroid Ryugu grains in collaboration with the ESCuC of JAXA.

[6] SPring-8 is a large synchrotron radiation facility which delivers the most powerful synchrotron radiation currently available. Consisting of narrow, powerful beams of electromagnetic radiation, synchrotron radiation is produced when electron beams, accelerated to nearly the speed of light, are forced to travel in a curved path by a magnetic field. The research conducted at SPring-8, located in Harima Science Park City, Hyogo Prefecture, Japan, includes nanotechnology, biotechnology, and industrial applications. The name "SPring-8" is derived from "Super Photon ring-8 GeV" (8 GeV, or 8 giga electron volts, being the energy of electron beam circulating in the storage ring).

SPring-8 is managed by RIKEN, with the Japan Synchrotron Radiation Research Institute (JASRI) in charge of the operation, maintenance, and promotion of use.

[7] X-ray diffraction computed tomography (XRD-CT). CT is a method through which 3D information is numerically reconstructed from multi-directional projection images of an object. Through conventional CT, it is difficult to identify multiple different minerals contained in a sample. Thus, a limited mineral identification method called the dual-energy tomography (DET) was used to analyze the Hayabusa samples. This method takes advantage of the fact that different elements absorb energy differently. Hayabusa2 sample analysis will be performed by a combination of X-ray diffraction (XRD) analysis and CT—the synchrotron radiation XRD-CT method. This method allows the identification of many mineral types and their spatial positions with high resolution although the constituent minerals in the sample are unknown. For example, this method facilitates precise distinction between the spatial positions of minerals in the samples that contain water and those that do not.

[8] Phase-contrast CT. When substances, such as organic matter, water, and gases, that absorb X-rays more weakly than rock minerals are contained in rock materials, their distinction is difficult because of the weak contrast. Phase-contrast CT is a method that can increase the contrast in the CT images of substances that weakly absorb X-rays by up to approximately 1,000 times. Using this method, it is possible to detect water, organic matter, and air in rock materials and to investigate their locations in the samples.

[9] The environment in the early Solar System is of great interest in the field of planetary science, as a better understanding of it helps scientists place stronger constraints on the formation of the planetary system. The astrophysical and chemical information about the early Solar System cannot be obtained via terrestrial materials as geological and weathering processes throughout the Earth's history have largely, if not completely, modified and destroyed the starting composition/components the Earth formed with. On the other hand, the asteroid Ryugu, which was recently reached by the Hayabusa2 spacecraft, is believed to have experienced significantly less heating since its formation, and therefore, may have preserved the original components involved in the formation and evolution of planetesimals, including organic matter and hydrous minerals. By understanding the natures and origins of these materials, we, as scientists, aim to decipher the history of the Solar System. Moreover, some of these findings may have important implications for the origin of water and evolution of organic matter that led to life on Earth.

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