HAYABUSA2 SAMPLING OPERATIONS AND EXPECTED SAMPLES FROM C-TYPE NEAR-EARTH ASTEROID (162173) RYUGU. S. Tachibana[1,2], H. Sawada[2], R. Okazaki[3], Y. Takano[4], Y. N. Miura[5], C. Okamoto[6], H. Yano[2], K. Sakamoto[1], and K. Yogata[2], [1]UTokyo Organization for Planetary and Space Science (UTOPS), Univ. Tokyo, 7-3-1 Hongo, Tokyo 113-0033, Japan (tachi@eps.s.u-tokyo.ac.jp), [2]ISAS/JAXA, 3-1-1 Yoshinodai, Sagamihara, Kanagawa 252-5210, Japan. [3]Dept. Earth Planet. Sci., Kyushu Univ., 744 Motooka, Nishu-ku, Fukuoka 819-0395, Japan. [4]Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Yokosuka, Kanagawa 237-0061, Japan. [5]Earthquake Res. Inst., Univ. Tokyo, 1-1-1 Yayoi, Tokyo 113-0032, Japan. [6]Dept. Planetology, Kobe Univ., 1-1 Rokkodai-cho, Kobe 657-8501, Japan.

Introduction: Hayabusa2 explored C-type near Earth asteroid (162173) Ryugu for seventeen months (June 2018–November 2019) including two landing operations for sample collection. Ryugu (mean radius of 448 ± 2 m) has a top shape with an equatorial ridge and has a retrograde rotation with a period of 7.6326 hours and an obliquity of 172° [1]. Its bulk density of 1.19 ± 0.03 g cm^{-3} suggests that Ryugu is a rubble-pile body with a large macro-porosity of ~50–60 % considering a typical density of carbonaceous chondrites [1]. Many decameter-sized boulders, which are too large to be impact ejecta from craters found on Ryugu, are present at the surface with a number density twice as large as that of Itokawa, and no smooth terrain like Muses Sea on Itokawa is found [2]. The low bulk density and the abundant large boulders on the surface suggests that Ryugu is a rubble-pile body [1, 2].

The surface has a very low geometric albedo (~0.02) [2], darker than most of meteorite samples in the terrestrial collection, and shows a weak but ubiquitous 2.72-μm absorption feature of O-H vibration in hydrous minerals [3]. The absorption feature at 2.72-μm is weaker than those of hydrated carbonaceous chondrites [3] and that of B-type asteroid Bennu observed by NASA's sample-return spacecraft OSIRIS-REx [4, 5].

The in-situ observation of the Ryugu surface by the MASCOT lander showed that the surface is not covered with fine regolith particles [6] and that a ~3-cm pebble has a thermal inertia of ~280 J m^{-2} K^{-1} $s^{-1/2}$, which is much lower than chondritic meteorites [7]. The low thermal inertia implies that the pebble has a porosity larger than 28 % and that the tensile strength of the pebble is likely to be only a few hundred kPa [7].

Hayabusa2 left Ryugu in November 13, 2019 after all the planned proximity operations and is now on the way to the Earth.

Sampling Operations at Ryugu: Hayabusa2 made its first landing operation on the equatorial ridge on February 22, 2019 to collect surface samples and the second landing operation nearby the artificial crater made by the small carry-on impactor [8] on July 11, 2019 to collect both surface samples and impact ejecta (sub-surface samples). A 5-gram tantalum projectile was shot through a 1-m long sampler horn at an impact velocity 300 m s^{-1} at the timing of each touchdown, triggered by bending and/or shrinkage of the sampler horn [9]. The firing of projectiles was confirmed for two landing operations through the temperature rise near the projector due to firing. The ejecta is supposed to be put into a sample catcher through an extendable sampler horn and a conical horn under a microgravity condition. On-ground laboratory experiments using the full-scale sampling device with 1 mm-sized glass spherules at one gravity showed that 150–250 mg of samples can be collected with a projectile shooting, which is expected to be increased under the microgravity condition because low-velocity ejecta can be effectively collected [9].

The basic concept and design of the Hayabusa2 projectile-shooting sampling device are the same as those of the Hayabusa sampling device [10], which did not fire projectiles on Itokawa. Two landing operations of Hayabusa2 proved for the first time that the projectile-shooting sampling device works at the asteroid surface.

The sample catcher of the Hayabusa2, located at the top end of the conical horn, has three chambers to store samples, acquired at different surface locations, separately [9]. A rotatable inlet, connected to the conical horn, to the sample catcher was successfully rotated after the first landing operation to change the chamber for sample storage.

On August 26, 2019, the sample catcher, of which chambers were all closed, was transported into the sample container inside the Earth re-entry capsule and sealed successfully. The container sealing method adopted for Hayabusa2 is an aluminum metal seal, where the sample catcher is sealed in the sample container by deformation of the curved surface lid with the edge of the sample container [11]. This sealing method allows only a leak of 1 Pa air for 100 hours at atmospheric pressure [11].

Capsule Recovery and Quick Look Operation: Hayabusa2 will return to the Earth with the Ryugu samples at the end of this year (2020). Hayabusa2 will make an escape maneuver after separation of the

Earth-return capsule (not like Hayabusa), and the capsule alone will land on the Woomera Prohibited Area in South Australia.

The sample container will be taken out from the returned capsule at the quick-look facility (QLF) that is planned to be established near the capsule landing point. The sample container will be checked and cleaned, and the bottom part of the sampler horn is then planned to be attached to a vacuum line of the gas sampling system at the QLF. The container bottom, a part of which is thinned, will be pierced with a tungsten carbide needle in the gas sampling system to extract volatiles for collection and in-situ analysis [11]. The extracted gases will be first collected passively through diffusion in gas bottles at room temperature and then actively in gas bottles cooled with liquid nitrogen in the gas sampling system. The extracted gases in the gas line will be analyzed by mass spectroscopy and infrared spectroscopy.

After the gas extraction, the sample container will be put into the nitrogen-purged transportation box and transported from the QLF to the JAXA curation facility for the container opening and sample curation [12].

Expected Samples from Ryugu: The remote sensing observation by scientific instruments on board the spacecraft [1–3] and in-situ surface observation by the MASCOT lander [6, 7] found that samples from C-type asteroid Ryugu would be 'atypical' compared to typical hydrated carbonaceous chondrites in the terrestrial collection.

Dehydrated carbonaceous chondrite-like materials. The low albedo and the weak 2.72-μm absorption feature of Ryugu could be attributed to thermal and/or shock-induced dehydration of hydrated carbonaceous chondrite-like materials on the asteroid because mildly dehydrated carbonaceous chondrites have an albedo as low as Ryugu [2]. If Ryugu samples are dehydrated carbonaceous chondrites, the sample analysis will reveal alteration and metamorphic processes on the Ryugu's parent planetesimal or on the current Ryugu. If sub-surface materials are identified from the samples collected nearby the artificial crater by sample analysis (e.g., analysis of galactic cosmic ray-produced nuclides), the petrology, mineralogy, and volatile chemistry of sub-surface samples would put constraints on the surface dehydration process that would be induced by solar heating.

Even if the Ryugu samples experienced dehydration, they are expected to contain hydrated minerals that cause the 2.72-μm absorption feature, suggesting that the samples were not heated like Itokawa samples [e.g., 13]. The Ryugu samples should thus provide us with the information of material evolution prior to planetesimal accretion in the Sun's protoplanetary disk as well [14].

Weakly altered pristine materials. The MASCOT observation implies that the surface pebble is more fragile than typical carbonaceous chondrites and would be too fragile to survive when it enters into the Earth's atmosphere as a meteor [7]. The Ryugu sample may thus represent pristine Solar-System materials that experienced only weak aqueous alteration on the Ryugu's parent body like weakly altered Antarctic micrometeorites [15, 16].

If this is the case, the Ryugu samples could contain abundant pristine components that formed in the Sun's protoplanetary disk, in the Sun's parent molecular cloud, and even in outflows from evolved stars prior to the Solar System formation [14]. The low albedo of Ryugu could be due to the presence of abundant macromolecular organic components. Pristine volatile materials such as H_2O, CO_2, CH_4, NH_3 and organic molecules could also be released from the fragile samples that might be broken inside the sample catcher. Extracted gases, which would be the first volatile component returned from space, and their isotope compositions would be an important analysis target to understand the evolution of volatiles in the early Solar System and the delivery of volatiles to the inner Solar System.

At present it is not clear whether Ryugu with the weak -OH vibration feature is dehydrated or weakly altered, detailed analysis of Ryugu samples will reveal the history of Ryugu and the Solar System from the beginning to the present [14].

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