HAYABUSA2 RETURNED SAMPLES: UNIQUE AND PRISTINE RECORD OF SOLAR SYSTEM MATERIALS FROM ASTEROID RYUGU.

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Introduction: The Hayabusa2 spacecraft successfully returned surface materials from the C-type asteroid 162173 Ryugu to Earth on December 6th, 2020. The sample capsule contained a large number of small grains (a few to several mm in size), collected from touchdown (TD) sites 1 and 2 on Ryugu, with a total mass of ~5.4 g [1]. After initial characterization of the grains by JAXA curation (e.g., size, weight, FTIR and MicrOMEGA spectroscopic survey) [1,2], eight Ryugu particles (approximately 60 mg in total), four from Chamber A (1st TD site) and four from Chamber C (2nd TD site), were allocated to the Phase2 curation Kochi team (Ph2K, Table 1). The principal goals of the research are to elucidate the nature, origin and evolutionary history of asteroid Ryugu, and to document the similarities to and/or differences from other known extraterrestrial samples, such as chondritic meteorites, interplanetary dust particles (IDPs) and returned cometary samples collected by the NASA Stardust mission.

Experiment: On June 19th, 2021, we started initial characterization studies of the allocated particles using a synchrotron radiation-based CT and XRD at the SPring-8. An air-tight sealed carbon nano-tube sample holder was used for CT analysis. In order to avoid degradation and contamination due to interaction with the terrestrial atmosphere (water vapor and oxygen gas) [3], all of the sample preparation (chipping by a chisel, cutting by a counter balanced diamond wire saw, and epoxy mount preparation) was conducted in a glove box in an atmosphere of pure, dry nitrogen (Dew point: -80 to -60˚C, O_2 ~50 to 100 ppm). Once we had acquired high-resolution, detailed three-dimensional structural and crystallographic information (0.85 µm/pixel for CT) for each of our samples, we were able to define a priority list for the next phase of the analytical campaign, which involved coordinated micro- and bulk analysis.

A summary of the Ph2K's coordinated micro- and bulk chemical analysis activities for each particle is given in Fig. 1 and Table 1. Coordinated micro-analysis work involved the use of a wide range of multi-beam instruments to acquire detailed micro-textural and chemical information about the samples at a sub-micrometer scale using a combination of FIB, STXM-NEXAFS, NanoSIMS and TEM [4]. In parallel, we conducted bulk systematic analysis of the samples using SEM-EDS, EPMA, XRD, large geometry type SIMS, high precision O isotopic analysis by laser fluorination and INAA. We have used air-tight containers (FFTC [4]) for sample transportation to both national and international institutes by hand carry.

Results and Discussions: All petrological [5], mineralogical [6], oxygen isotopic [7] and elemental characteristics indicate that the allocated Ryugu particles are very similar to CI chondrites [8-10]. These

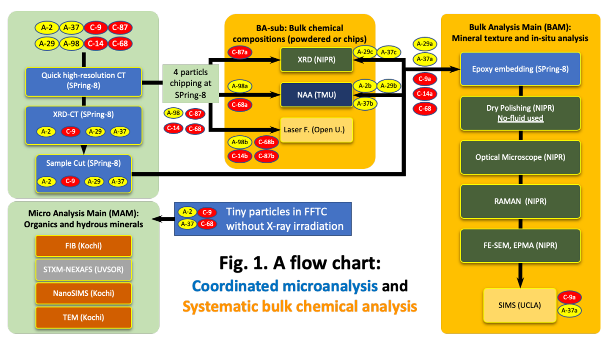


Fig. 1. A flow chart: Coordinated microanalysis and Systematic bulk chemical analysis

Table 1. The Ryugu samples for the Phase2 curation Kochi

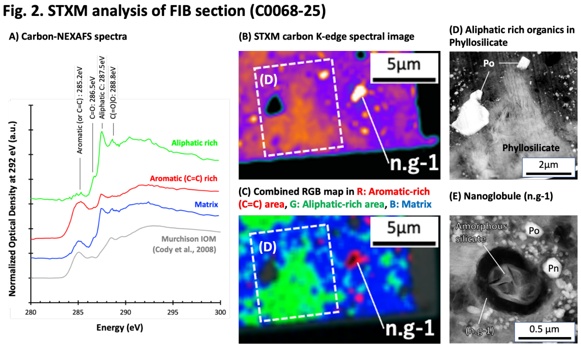
Sample No.	mg	µm	SPring-8	Microanalysis (STXM, NanoSIMS, TEM)	Bulk Analysis (SEM-EDS, EPMA, Raman)	High Precision O isotopes	SIMS	INAA	XRD
A0002	19.3	4,092	HR-CT, XRD, XRD-CT	Y				Y	
A0029	9.1	3,069	HR-CT, XRD, XRD-CT	Y	Y			Y	Y
A0037	7.8	3,129	HR-CT, XRD, Phase-contrast CT	Y	Y		Y	Y	Y
A0098	1.9	1,868	HR-CT			Y		Y	
C0009	11.1	3,520	HR-CT, XRD, XRD-CT	Y	Y		Y		
C0014	6.8	3,527	HR-CT		Y	Y			
C0068	1.68	1,980	HR-CT	Y	Y	Y		Y	
C0087	2	3.242	HR-CT			Y			Y

findings are consistent with the results from the initial non-destructive examination of the Ryugu particles undertaken in a contamination-free and pure N_2 filled chamber at the JAXA curation facility [1, 2].

Using a combination of STXM-NEXAFS – NanoSIMS – TEM techniques, we have been able to establish the spatial distribution of organics with an aliphatic-rich carbon structure that are associated with phyllosilicates at sub-micrometer scale in the C0068-25 FIB section (Fig. 2).

C-NEXAFS spectra in the C0068-25 section show a variety of functional groups of aromatic (or C=C), C=O, aliphatic and C(=O)O, without 1σ-r* exciton of graphene structures (Fig. 2A). Figure 2B shows the spatial distribution of carbon in the section. In Fig. 2C three representative areas of aromatic (or C=C)-rich organics can be seen in red, aliphatic-rich carbon is shown in green and matrix in blue. Areas with an intense aliphatic-rich carbon structure (green area in Fig. 2C) are present locally in coarse-grained phyllosilicates in the section (Fig. 2D), as well as areas with a poorly aromatic (C=C) carbon structure. The distribution of organics with an aliphatic carbon structure may vary significantly depending on the existence of coarse-grained phyllosilicates. The carbon-NEXAFS revealed that the organics in the Ryugu particles are chemically distinct from the previously studied IOM of the Murchison CM chondrite [11] and show greater similarity to IDPs [12] and cometary particles obtained by the Stardust mission [13].

Fig. 2. STXM analysis of FIB section (C0068-25)



We found a nanoglobule (n.g-1) in the section (Fig. 2E) that contains large aromatic (or C=C), weak C=O, and aliphatic carbon structures (Fig. 2). Due to the fact that the aliphatic carbon is concentrated in the vicinity of (or around) the nanoglobule, the aliphatic feature in n.g-1 could come from the surrounding matrix. However, it cannot be ruled out that the nanoglobule contains aliphatic carbon structures due to limited spatial resolution of analysis (STXM: 150 nm).

NanoSIMS isotope imaging analysis of the C0068-25 reveals that δD (841‰) and $\delta^{15}N$ (169‰) of aliphatic-rich organics in coarse-grained phyllosilicates are slightly higher than the those of the average C regions (δD =528 ‰, $\delta^{15}N$=67 ‰). This observation indicates that aliphatic-rich organics in coarse-grained phyllosilicates could be more primitive than the surrounding organics, and they might have been formed from precursor molecules in the protoplanetary disc or interstellar medium before Solar System formation [14], and then slightly modified during aqueous alteration in the Ryugu (grand)parent body.

A question that arises is whether the unique nature of the aliphatic carbon-rich organics associated with coarse-grained phyllosilicates observed in this study is a unique feature, only found in the Ryugu asteroid. This question requires additional work. In particular, further study is needed to fully define the nature of the organics and their relationship with the surrounding hydrous mineral phases.

Summary: Systematic investigations as part of the first six months of Ph2K activity include studies of detailed bulk petrology, high-resolution mineralogy, high-precision O isotopic compositions of selected particles, and *in-situ* SIMS oxygen isotopic analysis of anhydrous and carbonate minerals. This work has provided powerful constraints on the origin and evolution of the materials collected from Asteroid Ryugu by the Hayabusa2 spacecraft. Further detailed aspects of this work are presented in companion abstracts at this meeting [5-7, 15, 16].

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