A first look at the interior and exterior of Ryugu preserved in samples collected by Hayabusa2

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Sample return missions represent great opportunities to study materials from known locations. The Hayabusa mission returned material to Earth from the asteroid Itokawa in 2010 and revealed through geochemistry and micro-petrograpy that it is genetically related to ordinary chondrite meteorites and the surface of the modern-day asteroid is being actively bombarded by hyper-velocity small particles (e.g., Kawaguchi *et al.*, 2003; Nakamura *et al.*, 2012). The Hayabusa2 mission returned material to Earth from Ryugu on 6th of December, 2020 (Tsuda *et al.*, 2020). Based on the very low geometric albedo indicated by remote observations (Sugita *et al.*, 2019; Kitazato *et al.*, 2019), abundant organic matter on Ryugu, compared to those in carbonaceous chondrites, might be expected (Potiszil *et al.*, 2020). The initial uncontaminated and non-destructive observations for the entire set of returned samples in the Phase-1 Curation at JAXA/ISAS (Yada *et al.*, 2021) demonstrated that Hayabusa2 retrieved the representative and unprocessed (albeit slightly fragmented) Ryugu sample. The data further expanded on the indications from the remote sensing observations that Ryugu is dominated by hydrous carbonaceous chondrite-like materials, similar to CI chondrites, but with an optically darker, more porous, and more fragile nature.

In order to analyze both organic and inorganic matter, the pieces of Ryugu were subject to in-depth investigations in the Pheasant Memorial Laboratory (PML), Okayama University at Misasa. The 16 particles of Ryugu sample (A0022, A0033, A0035, A0048, A0073, A0078, and A0085 from the natural surface of the equatorial region of Ryugu, and C0008, C0019, C0027, C0039, C0047, C0053, C0079, C0081, and C0082 from the surrounding site of the artificial impact crater on Ryugu; total ~55 mg) were selected during the Phase-1 Curation. The selected samples were then transferred to the ultimate clean room in the PML for Phase-2 Curation, to catalog the samples via a comprehensive analytical strategy.

The particles were first characterized under digital optical microscope and then their volume and mass were measured to determine their densities. The average density was 1530 ± 250 kg m^{-3}, which was systematically larger than the value reported in Yada et al (2021). To elucidate the systematic differences among the 16 pieces, both plainer surfaces and powder were created from each piece using an ultra-microtome equipped with a diamond knife. The surface was observed using optical microscope and SEM, the major element distribution and mineral phases were determined by EDS installed in SEM, micro-Raman spectroscopy, micro-XRD and TEM, all without coating. Subsequently, major and trace element compositions were determined from a given powder by ICP-MS. Element and isotope compositions of H, C, N and O were determined by gas-source mass-spectrometry, and those of Ne were determined by laser-heating noble-gas-mass-spectrometry using small broken pieces. Solvent soluble organic matter was extracted from sample powders using various solvents, including water, acetonitrile, ethyl acetate and formic acid. Meanwhile, insoluble organic matter was isolated after solvent extraction and demineralization by HCl, HF and boric acid. After the first-round characterization, the microtomed surfaces were surveyed using micro-Raman spectroscopy, SIMS and desorption electrospray ionization-orbitrap-mass spectrometry (DESI-OT-MS).

The 16 pieces were found to consist of magnetite, carbonate, phosphates, sulfides and minor silicate fragments interfiled by matrix (modal abundance of 86-96%) that was dominated by sub-micron-sized phyllosilicates. Average modal abundances of the aforementioned phases (excluding matrix) were 3.7, 2.4, 0.8, 2.5 and 0.4 %, respectively. The phyllosilicates were mainly composed of the serpentine and smectite groups. As noted by the Phase-1 Curation, the existence of high-temperature nebular products, such as refractory inclusions and chondrules were not found. The magnetite was present as micron-sized euhedral to subhedral grains and sub-micron-sized grains with a framboidal and plaquette texture. Non-carbonate carbon-rich phases of several micrometers in size, were discovered embedded in the matrix (modal abundance is ~0.2%). The presence of soluble and insoluble organic matter was confirmed by DESI-OT-MS and FTIR and micro-Raman spectroscopy, respectively. Further characterization of the solvent soluble fraction via HPLC-OT-MS and GC-MS is currently underway. The organic matter is ubiquitous in the matrix according to observations by SIMS and micro-Raman spectroscopy.

The major and trace element compositions and O isotope composition are homogenous, with the major and trace element compositions representing the proto-solar abundance of Lodders (2020). However, a significant variation of H, C, N and Ne isotopic compositions at the sub-mm scale among the particles was found, which suggests that Ryugu has experienced a complex evolutionary history.

In this talk, preliminary results from the Misasa Phase2 Curation team will be presented.

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