# Initial analysis of "stone" size Ryugu samples: current status

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As a part of the initial analysis of the Ryugu samples, we perform a variety of analyses of millimeter-sized "stones". Our goals are to elucidate the entire formation process of Cb-type asteroid Ryugu from the viewpoint of petrology and mineralogy and obtain necessary information by sample analysis, and then simulate the formation of Ryugu based on the evidence obtained from sample analysis. Eighteen stones (8 from the chamber A and 10 from the chamber C) were received from the ISAS curation facility on June 1, 2021, and placed into a fully nitrogen-displaced glove box at Tohoku University. At the same time, we also received the powder samples from the chamber A and the chamber C. All the allocated samples were put in the sample transport containers prepared by ISAS in the nitrogen atmosphere inside the clean chamber system dedicated to Ryugu samples. The containers were then transferred to the nitrogen glovebox at ISAS, where all the containers were completely sealed in plastic bags with moisture and oxygen absorbers. No moisture or oxygen was detected when the bags were opened in the glove box at Tohoku University, so it was confirmed that there was no exposure to the atmosphere during transport.

To date, a number of analyses have been carried out successfully and within schedule margins. The analysis started with the measurement of reflectance spectra, which are sensitive to atmospheric oxidation, hydroxylation, and adsorbed water. The ultraviolet, visible, near-infrared, and mid-infrared reflectance spectra were measured while the samples were kept airtight. The spectra of powder samples and stone samples (as aggregates and as a single stone) were successfully obtained. Concurrent with the analyses described below were ultra-violet spectral observations on stone samples, also transported and performed in an inert environment, conducted at the University of Illinois Urbana-Champaign (USA).

A major feature of the stone team's analysis is the use of synchrotron radiation facilities around the world. Since this analysis is non-destructive, stone samples whose reflectance spectra were measured were sent to KEK, SPring-8, ESRF (France), SOLEIL (France), DESY (Germany), and APS (USA). Using these synchrotron radiation facilities, high spatial resolution and sensitivity XRD, STXM, XANES, CT [1], IR-CT, FT-IR [2, 3], XRF, and Mössbauer [4] analyses were performed. Most of the analyses were carried out under airtight conditions on the stone samples and the particulates separated from the stone samples. These analyses allowed us to determine the three-dimensional distribution of solid phases and elements, redox state, density, and porosity of the stone samples.

Furthermore, as a characteristic analysis of the stone team, light elemental analysis using negative Muon was performed at the MLF facility of J-PARC with an exceptionally long allocation of machine time. This is the non-destructive method to measure the concentration of light elements in the whole (not the surface) of stone samples. Because the characteristic X-rays produced by muon irradiation are much higher in energy than the fluorescent X-rays produced by X-ray irradiation, there is little effect of self-absorption by the sample, and therefore, the concentration of light elements such as carbon, oxygen, and sodium in the entire "stone" sample can be determined.

Some stone samples are currently being measured for thermal conductivity and strengths in order to understand the physical properties of asteroid Ryugu. The data obtained from these measurements are useful for interpreting the remote-sensing data data taken from the surface layer of the asteroid Ryugu [5-8]. It is also important for understanding the behavior of the Ryugu material during impact events.

The surfaces of many stone samples were observed by electron microscopy and other techniques, especially on natural “flat” surfaces formed on 5 stones. As a result, characteristric mineral aggregates formed by the reactions with water and characteristic impact features were observed on some samples. Based on the observations of surfaces and the synchrotron measurements of the whole stones, important objects such as characteristic structures and specific crystal aggregates for understanding the formation history of the asteroid were identified, and these parts were separated from the stone samples using a Xe beam (pFIB) and analyzed by various methods including transmission electron microscopy and synchrotron radiation analysis. Many stone samples, from which important objects have been separated, are embedded in epoxy resin and cut to produce many polished sections. Electron microscopy and spectroscopic measurements of the polished surfaces are being carried out to reveal the detailed mineralogical properties and elemental distribution inside the stone samples. In this fall, the allocate beam time for synchrotron radiation will begin, and we plan to analyze single crystals and characteristic objects separated from the stone samples. Photometric measurements in the ultra-violet and visible to near-infrared will also be made this fall on the powders produced in the structural experiments to facilitate comparisons with the ONC-T and NIRS3 remote sensing observations.

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