AN UPDATED OVERVIEW OF MACROMOLECULAR ORGANIC MATTER IN THE C-TYPE ASTEROID RYUGU SAMPLES.

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Introduction: Macromolecular organic matter in primitive small body materials is one of the reliable indicators to determine the chemical evolution in the early Solar System. JAXA's Hayabusa2 mission explored the carbonaceous asteroid Ryugu and collected its surface materials [1]. On December 6, 2020, the asteroid sample was returned to the Earth. Through the curatorial work at JAXA, it was reported that the Ryugu samples contain high abundances of hydrous minerals and organic matter [2, 3]. Afterward, the initial sample analysis has started from June 2021 to classify and characterize the Ryugu samples in the context of the Solar System formation. In order to uncover the significance of organic matter on C-type asteroid, the Initial Analysis Organic Macromolecule team unveiled the chemical, isotopic, and morphological compositions of macromolecular organic matter from the Ryugu samples.

Samples and Methods: Chamber A aggregates (A0108) and Chamber C aggregates (C0109) collected at the first and second touchdown sites, respectively, have been analyzed. The individual intact grains from A0108 and C0109 range from 200 to 900 μm in size. Additional aggregates from Chamber A (A0106) and Chamber C (C0107) were transferred from the Soluble Organic Molecules team after their water and solvent extractions, and were treated with 6M HCl and 1M HCl/9M HF to yield insoluble organic matter (IOM) at Hiroshima University [4]. The main stream of the analytical procedures included a combination of μ-FTIR, μ-Raman spectroscopy, synchrotron-based STXM-XANES, STEM-EELS-EDS, AFM-IR, NanoSIMS [4]. Additional protocols by Xe-PFIB, TXM, XRF, Solid-state ^{1}H and ^{13}C NMR, ToF-SIMS, Visible spectroscopy, and AFM have been included for the latter half of the initial analysis. EA-IRMS and noble gas isotope analysis of Ryugu IOM were also performed in collaboration with Soluble organic molecule (SOM) team [5] and Volatile team [6], respectively.

Results and discussion: Macromolecular organic matter were abundant and has complex structures consisting of aromatic carbons, aliphatic carbons, ketones and carboxyls [7, 8]. The functional group compositions are typically seen in IOM from CI and CM chondrites. The functional group variations correlated with the morphologies of nano-sized organic matter; organic nanoglobules and nanoparticles are aromatic-rich, while organic matter mixed with Mg-rich phyllosilicate matrix and carbonates are IOM-like or diffuse carbon [8, 9]. The observed functional group diversity is likely influenced by aqueous evolution on the asteroid parent body without significant heating event. The δD distributions of Ryugu IOM from the Ryugu samples were within the δD range of CM, CI, and Tagish Lake chondrites [10]. The δ^{15}N of bulk C and insoluble organics from the Ryugu samples showed similar values to those from CI chondrites [10]. Extreme D and/or ^{15}N enrichments or depletions in some carbonaceous grains could possibly have been derived from the solar nebula or protosolar molecular cloud. A very small fraction of carbonaceous particles show anomalous carbon isotopes including presolar SiC grains [11]. Ryugu organic matter likely resulted from heterogeneous aqueous processing that occurred on carbonaceous asteroids from the common primordial materials formed at an earlier stage of the solar nebula. These results proved the direct link between macromolecular organic matter in the carbonaceous asteroid and that in primitive carbonaceous chondrites.

References: [1] Tachibana S. et al. (2022) Science 375: 1011-1016. [2] Yada T. et al. (2022) Nature Astronomy 6: 214–220. [3] Pilorget C. et al. (2022) Nature Astronomy 6: 221–225. [4] Yabuta H. et al. LPS LIII, Abstract #2241. [5] Naraoka H. et al. this meeting. [6] Krietsch D. et al. this meeting. [7] Kebukawa Y. et al. this meeting. [8] De Gregorio B. T. et al. this meeting. [9] Stroud R. et al. this meeting. [10] Remusat L. et al. this meeting. [11] Barosch J. et al. this meeting.