Diversity of Insoluble Organic Matter at the Nanoscale in Asteroid Ryugu

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Acid-insoluble, macromolecular organic matter represents up to 4 wt% of the matrix of carbonaceous chondrites (CC). Many properties of the insoluble organic matter (IOM), including microstructure, functional group chemistry, and mineralogical associations strongly correlate with asteroid parent body grouping and alteration history [1]. However, the IOM of many chondrites shows significant variation in structure, chemistry, and isotopic composition at the nanoscale [2,3]. The microstructure of CC IOM ranges from discrete sub-micron blebs called nanoglobules; to micrometer and larger sized veins; diffuse intergranular material; OM intercalated into phyllosilicates, and poorly-graphitized carbonaceous grain coatings. In addition, the IOM can serve as host to inorganic carbonaceous phases, such as presolar nanodiamond [4] and phase-Q [5]. This variation results from a combination of inherited molecular cloud chemistry, nebular processing, parent body and terrestrial alteration. Studies of the nanoscale variation in the IOM in the returned samples of Ryugu provide the first chance to examine the IOM of a CC parent body largely free of terrestrial alteration signatures, in order to better constrain the alteration history of a specific asteroid, and provide unprecedented constraint on the evolution of carbon in the early solar system.

Our primary method for the Initial Analysis of the nanoscale diversity of Ryugu IOM microstructure and functional chemistry is scanning transmission electron microscopy (STEM), in coordination with scanning transmission x-ray absorption spectroscopy (STXM), and isotopic characterization with NanoSIMS. The STEM measurements are carried out with the Nion UltraSTEM 200-X at the Naval Research Lab, operated at 60 kV to minimize electron beam damage. STEM measurements include annular dark field (ADF) imaging, electron energy loss spectroscopy (EELS), and energy dispersive x-ray spectroscopy (EDS). The EELS and EDS data are collected as simultaneous spectrum images to allow direct correlation of the elemental composition with the C functional chemistry, and microstructure [6]. As of this abstract submission, we have examined slices of three grains from Chamber A (A0108), one prepared as a focused ion beam (FIB) lift-out section, and two prepared as sulfur-embedded ultramicrotome slices. The FIB section was analyzed with STXM at Photon Factory Bl-19 prior to the STEM analysis. Adjacent microtome slices of were prepared for coordinated STXM and NanoSIMS measurements at the Advanced Light Source and Carnegie Institution of Washington, respectively. Measurements of additional FIB and microtome slices of Chamber A and Chamber C particles are planned.

Overall, our STEM measurements indicate IOM microstructures and functional chemistry consistent with low temperature aqueous alteration, broadly consistent with CI and CM chondrites. Small nanoglobules (< 400 nm) are abundant, but larger nanoglobules > 1000 nm are less common. Diffuse carbon intercalated into phyllosilicates is also common. Carbonate and nanoscale Fe, Ni sulfides are also found in association with IOM Coordination of the STEM results with the ongoing STXM and NanoSIMS measurements of slices from the same grains will ultimately help constrain the nature of Ryugu and its relationship to known carbonaceous chondrites, and the history of the organic matter it contains.

References

[1] Alexander C. M. O'D. et al. 2017. Chemie der Erde - Geochemistry 77:227. [2] De Gregorio B. T. et al. 2013. Meteoritics & Planetary Science 48:904. [3] C. Le Guillou et al. 2014. Geochemica et Cosmochemica Acta 131: 368. [4] Garvie, L.A.J. (2010), Lunar and Planetary Science Conference, #1388. [5] Amari, S., et al. 2013. Astrophysical Journal 778:37. [6] Stroud R. M. et al. Microscopy and Microanalysis 27(S1):2546.