Synchrotron radiation-based X-ray computed nanotomography of unheated and experimentally heated Murchison CM chondrite

*Megumi Matsumoto[1], Akira Tsuchiyama[2,3], Masahiro Yasutake[4], Akira Miyake[5], Kentaro Uesugi[4], Akihisa Takeuchi[4], Tsukasa Nakano[6], Tomoki Nakamura[1]

1. Graduate School of Science, Tohoku University, 2. Research Organization of Science and Technology, Ritsumeikan University, 3. Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, 4. Japan Synchrotron Radiation Research Institute, 5. Graduate School of Science, Kyoto University, 6. Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology

Hayabusa2 mission succeeded to touchdown on the surface of C-type asteroid 162173 Ryugu and will bring Ryugu surface material to the earth. Spectroscopic observation shows that Ryugu surface is dark and exhibits a small 2.7 μm absorption band suggesting a presence of phyllosilicates [1-3]. The spectroscopic feature is similar to partially dehydrated carbonaceous chondrites. This means that heated hydrous carbonaceous chondrites are the closest analogues to Ryugu surface material. In this study, we obtained three-dimensional (3D) microstructures of unheated, 400℃-, and 600℃-experimentally heated Murchison CM chondrite matrix [4] using a synchrotron radiation-based X-ray computed nanotomography (SR-XCT) at SPring-8 BL47XU.

Two ~50 μm particles for each of the unheated, 400℃-, and 600℃-heated Murchison chondrite matrix were mounted on C-fibers or Ti-needles and analyzed by the SR-XCT using two methods: dual energy tomography (DET) and scanning imaging X-ray microtomography (SIXM) [5, 6]. In the DET, we obtained 3D images with X-ray linear attenuation coefficients (LACs) at 7 and 7.35 keV; one above and one below the K-absorption edge energy of iron. The images at 7 keV correspond closely to compositional (Z) contrast, and those at 7.35 keV strongly depend on Fe content and emphasize Fe-rich materials. In the SIXM, we obtained 3D images with X-ray phase contrast reflecting refractive index decrements (RIDs). RID is simply the difference between the refractive index and unity and is almost proportional to material density. We performed image matching at common voxel size (60.4 nm) and sample direction on the three kinds of CT images. The well-matched CT image sets give us both LAC and RID values for specific voxels. This enables us to obtain 3D distribution of specific phases in micro-samples. We also made 2D histogram plots of LAC and RID values for each sample to obtain bulk mineralogies. Besides the XCT, we performed X-ray diffraction (XRD) analysis on the particles mounted on C-fibers at KEK-PF BL3A.

The 3D imaging revealed that the unheated Murchison samples mainly consist of a few micron-sized forsterite, enstatite, and nano-sized Fe-Ni sulfides embedded in matrix. The matrix is divided into Fe-rich and Fe-poor regions. Considering the XRD results, the former and the latter consist mainly of tochilinite-cronstedtite intergrowth and Mg-rich serpentine, respectively. The volume proportion of the two components varies in samples. In 2D histogram plots of LAC and RID values, the two components form one broad sum peak around the serpentine-cronstedtite line. The peak top located in Mg-rich side (close to serpentine point). The 400℃ samples are texturally similar to the unheated ones. In 2D histogram plots, Fe-poor matrix forms a broad peak similar to that of the unheated samples while Fe-rich matrix forms another peak close to cronstedtite point. The difference should reflect mineralogical changes due to heating that were confirmed by XRD: decomposition of serpentine and tochilinite and formation of unknown phase(s). The 600℃ samples are texturally homogeneous compared to the unheated and the 400℃ samples and contain small amounts of nano-sized secondary Fe-rich metal grains. In 2D histogram plots, the homogenized matrix forms a broad peak at the intermediate point of the two peaks found for

the 400℃ samples. It is noted that the XRD results suggest the presence of secondary olivine that should be contained in the homogenized matrix.

These suggest that the SR-XCT technique is useful to estimate heating degrees of hydrous carbonaceous chondrites and Ryugu sample. We will perform further microscopic analysis to uncover microtextural changes due to heating.

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