

X-ray nanotomography of CM and CI chondrites and their heated samples: as a rehearsal of Hayabusa2 sample analysis.

*Mingqi Sun¹, Akira Tsuchiyama^{1,2}, Megumi Matsumoto³, Yuri Fujioka³, Tomoki Nakamura³, Junya Matsuno², Akira Miyake⁴, Shota Okumura⁴, Naotaka Tomioka⁵, Motoo Ito⁵, Yu Kodama⁶, Stefano Rubino⁷, Naoto Nakano⁴, Kentaro Uesugi⁸, Akihisa Takeuchi⁸, Masahiro Yasutake⁸

1. CAS Key laboratory of Mineralogy and Metallogeny, Guangzhou Institute of Geochemistry, Chinese Academy of Science, Guangzhou 510640, China, 2. Research Organization of Science and Technology, Ritsumeikan University, Japan, 3. Graduate School of Science, Tohoku University, Japan, 4. Graduate School of Science, Kyoto University, Japan, 5. Kochi Institute for Core Sample Research, Japan, 6. Marine Works Japan Ltd., Japan, 7. Institut d'Astrophysique Spatiale, Université Paris-Saclay, France, 8. JASRI/SPRING-8, Japan

The Hayabusa2 spacecraft has successfully returned to Earth on 6th of Dec. 2020, carrying samples of the C-type near-Earth asteroid 162173 Ryugu. It is highly expected that the samples are similar to carbonaceous chondrites, which play a significant role in water and organic material delivery to the earth [1]. SR-based X-ray nanotomography (nanoXCT) is a powerful technique to characterize nondestructively the detailed 3D structures including external shapes and constituent phases of a small particle (<100 nm). We have analyzed extraterrestrial samples by combining two types of nanoXCT (e.g., [2]): dual-energy tomography (DET) [3] and scanning-imaging X-ray microscopy (SIXM) [4] with the resolution of ~100 nm at SPRING-8, SR facility in Japan (DET-SIXM). We consider that the DET-SIXM method could be beneficial to recognize the mineralogical features and estimate the heated condition of the asteroid Ryugu samples.

As a rehearsal of the initial analysis for the Hayabusa2 samples, we performed the DET-SIXM analysis of small particles (20~80 nm in size) from different groups of carbonaceous chondrites; Murchison, Murray and Mighei CM chondrites and Orgueil CI chondrites. Murchison samples heated at different temperatures from 400 to 990°C for 50 hrs., Murray samples heated at 600°C for different durations from 10 to 1000 hrs. and Orgueil samples at 500°C for 50 hrs. were also analyzed to examine the effect of heating, which is expected to occur on the Ryugu samples. We obtained 3D distribution of the linear attenuation coefficients (LAC) and X-ray refractive index decrement (RID) of the samples by DET and SIXM, respectively, for phase discrimination. In this paper, we focused on the mineralogy based on the LAC and RID values of the CM and CI samples to understand the variations in the same meteorites and among different groups (CM and CI) and the effect of heating. The textural variations will be also reported by Matsuno et al. and TEM observation of specific phases in one of the nanoXCT sample by Matsumoto et al. in this meeting.

We obtained the peak(s) of the 3D histogram of the LAC and RID values as the representative(s) of the constituent material(s) in each sample grain by image analysis. The first peaks generally come from the matrix of the meteorites and correspond to Fe-bearing hydrous silicates, which should be serpentine in CM and saponite and/or serpentine in CI (note that we cannot discriminate between serpentine and saponite in DET-SIXM). We usually obtained the second and sometimes third peaks in CM, corresponding to tochilinite-cronstedtite intergrowth (TCI) or TCI-like objects, forsterite and/or enstatite and calcite. The Mg# of the hydrous silicates has some variations among different grains of the same meteorite and we cannot distinguish between the three different CM meteorites by their Mg#. In contrast, the Mg# of CI is slightly smaller than that of CM.

In Murchison (CM), the serpentine peak positions heated at 400°C for 50 hrs. are almost similar to the unheated samples while that at 600°C for 50 hrs. becomes poor in the Mg# and partially dehydrated. The peak position at 990°C for 50 hrs. suggests that this contains heavy elements like Ca as well as Fe probably due to partial melting. In Orgueil (CI), the hydrous silicate peak positions heated at 500°C for 50 hrs. shows slight decrease in the Mg# and the degree of dehydration. In Murray (CM), the matrix became poor in the Mg# and partially dehydrated at 600°C for 10 hrs. but the Mg# and the degree of dehydration were almost the same even by increasing the heating duration. Based on the above results, it is concluded that by the DET-SIXM method (1) we may recognize the carbonaceous chondrite groups, CM and CI, (2) we can recognize samples heated at temperatures larger than ~500°C, and (3) estimation of heating duration may not be sensitive.

[1] K. Kitazato et al. (2019) *Science*, **364**, 272-275. [2] M. Matsumoto et al. (2019) *Science Advances*, **5**, eaax5078. [3] A. Tsuchiyama et al. (2013) *Geochim. Cosmochim. Acta*, **116**, 5-16. [4] A. Takeuchi, (2013) *J. Synchrotron Rad.* **20**, 793-800.

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