Characterization of Mg-Fe carbonates in the Ryugu returned samples with MicrOmega

Loizeau, D.[1]; Mahlke, M.[1]; Pilorget, C.[1]; Brunetto, R.[1]; Baklouti, D.[1]; Ito, M.[2]; Bibring, J.-P.[1]; Le Pivert-Jolivet, T.[1]; Aléon-Toppani, A.[1]; Riu, L.[3]; Jiang, T.[1,4]; Hatakeda, K.[5]; Yogata, K.[5]; Nakato, A.[5,6], Carter, J.[1]; Yada, T.[5]; Okada, T.[5]; Tahara, R.[5]; Usui, T.[5]; Langevin, Y.[1]; Lantz, C.[1]; Tomioka, N.[2]; Yamaguchi, A.[6]; Uesugi, M.[7]; Miyazaki, A.[5]; Nishimura, M.[5]; Nagashima, K.[5]; Kumagai, K.[5]; Hitomi, Y.[5]; Sugiyama, Y.[5]; Nakata, A.[5]

[1]*Institut d'Astrophysique Spatiale, Université Paris-Saclay, CNRS, France,* [2]*Kochi Institute for Core Sample Research, JAMSTEC, Japan,* [3]*ESAC, ESA, Madrid, Spain,* [4]*School of Earth Sciences, China University of Geosciences, Wuhan, China,* [5]*Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, Japan,* [6]*National Institute of Polar Research, Japan,* [7]*JASRI/SPring-8, Japan*

The Ryugu samples brought back by the Hayabusa2 spacecraft in December 2020 have been delivered to the JAXA Extraterrestrial Curation Center [1]. Bulk samples and then sub-bulks and individual grains have been picked up and stored into sapphire dishes, weighed, and analyzed with an optical microscope, FTIR spectroscopy, and MicrOmega hyperspectral imaging [2] for initial description within the curation facility [1]. The MicrOmega instrument used in the JAXA Extraterrestrial Curation Center is a NIR hyperspectral microscope. This configuration allows a mineralogical characterization of pristine Ryugu samples, as they have never been exposed to terrestrial environment.

MicrOmega has a total field of view of 5 mm × 5 mm, with a resolution of ~22.5 µm/pixel in the focal plane. It covers the spectral domain from 0.99 µm to ~3.6 µm. Its capabilities enable the identification of organic matter and different minerals in the returned samples [3]. In particular, carbonates can be detected and characterized in the MicrOmega spectral domain primarily through a strong absorption band at 3.3-3.5 µm, together with shallower specific bands at 2.5 and 2.3 µm, and for some carbonates a large absorption band around 1 µm.

A recently published study [4] based on the analysis of MicrOmega data of ~180 extracted individual grains (a few mm in size) and 14 aggregate samples (all observed with MicrOmega within the Curation Center in 2021) has shown that carbonates are distributed in two main populations. Those populations are different in composition and size/morphology: most detections are made on small grains and inclusions (<100 µm large) with a spectrum similar to dolomite $CaMg(CO_3)_2$, while for the largest detections, although less numerous, spectra similar to breunnerite $(Mg,Fe)CO_3$ dominate.

Dolomite is present in many grains as inclusions, and in many aggregate samples, and many occurrences have been reported in recently published studies analyzing some grains in detail [e.g., 5-11]. Breunnerite occurrences have been listed only in studies accessing a larger volume of samples [e.g., 10-13]. However, the large size of breunnerite occurrences [4] makes them a significant component of the returned Ryugu material, showing that it is important to understand when and how they formed compared to the dolomite, and what was the source of Fe and C for this population of carbonates.

The largest breunnerite inclusion was found on grain C0041, covering ~0.25 mm², or ~10% of the visible surface of the grain. This grain is one of the grains with "White regions" described in [5]. This carbonate inclusion shows a complex morphology with three branches, 100s µm long, around a main area, that could point to a formation in a fracture or between grains. In addition, several detached grains of breunnerite, 100s µm long, have been detected in several aggregate samples, indicating possibly many other large inclusions from which those grains were separated.

MicrOmega did not detect any obvious spatial transition from dolomite to breunnerite within a carbonate detection at the surface of grains, which would have indicated a possible gradient during a single formation event, although one observation of dolomite in contact with breunnerite has been made through SEM observations [10]. To better understand formation processes, we are investigating spatial heterogeneity of carbonate composition with a more systematic technique at small scale (few 10s µm) in the MicrOmega data to check for gradients in Mg or Fe content for example: to achieve this, we check for shifts in NIR absorption band positions and shapes at the MicrOmega pixel level. We have also succeeded in extracting one loose grain of breunnerite (in collaboration with the Phase 2 curation Kochi team) and studying it with different techniques (imaging IR spectroscopy, Raman spectroscopy, EDS) that will enable us to check for heterogeneities in carbonate composition of the grain or the presence of other minerals or molecules within the grain at a smaller scale (<10 µm).

The two main populations of carbonates question the formation process or processes that occurred on Ryugu's parent body/bodies, and their respective age of formation. To our knowledge, only one attempt of Ryugu's breunnerite dating has been published so far [6] that does not conclude on a noticeable difference in age of formation between breunnerite and dolomite. More studies of breunnerite occurrences are required to better constrain their age, formation, and carbon sources.

References

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