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MINERALOGICAL COMPARISON BETWEEN ASTEROID RYUGU SAMPLES RETURNED BY THE HAYABUSA2 SPATIAL MISSION AND ANTARCTIC MICROMETEORITES (AMMs). L. Bejach¹, C. Engrand¹, J. Duprat¹, E. Dartois², J. Mathurin³, A. Dazzi³, A. Deniset-Besseau³, N. Rividi⁴, C. Sandt⁵, F. Borondics⁵, T. Nakamura⁶, T. Morita⁶, M. Kikui⁶, K. Amano⁶, E. Kagawa⁶, H. Yabuta⁷, T. Noguchi⁸, H. Yurimoto⁹, R. Okazaki¹⁰, H. Naraoka¹⁰, K. Sakamoto¹¹, S. Tachibana^{11,12}, S. Watanabe¹³, Y. Tsuda¹¹ and the Hayabusa2-initial-analysis Stone team, ¹Univ. Paris-Saclay, CNRS, IJCLab, France (laure.bejach@ijclab.in2p3.fr), ²Univ. Paris-Saclay, CNRS, ISMO, France, ³Univ. Paris-Saclay, CNRS, ICP, France, ⁴CAMPARIS, Univ. Paris Sorbonne, Jussieu, France, ⁵Synchrotron SOLEIL, France, ⁶Tohoku University, Sendai 980-8578, Japan, ⁷Hiroshima University; Higashi-Hiroshima, Hiroshima, 739-8526, Japan, ⁸Kyoto University, Kyoto 606-8502, Japan, ⁹Hokkaido University, Sapporo 060-0810, Japan, ¹⁰Kyushu University, Fukuoka 819-0395, Japan, ¹¹Institute of Space and Astronautical Science (ISAS), Japan Aerospace Exploration Agency (JAXA), Sagami-hara 252-5210, Japan, ¹²The University of Tokyo; Bunkyo-ku, Tokyo, 113-0033, Japan, ¹³Nagoya University; Chikusa-ku, Nagoya, 464-8601, Japan.

Introduction: Micrometeorites are pristine material that shed light on the primitive conditions of the Solar System. Mineralogical arrangement and composition of micrometeorites allow to retrace their primitive formation conditions and degree of thermal or aqueous alteration. *Ryugu* is a Cb-type asteroid sampled by the Japanese mission Hayabusa2 in 2019. Both surface (Chamber A) and potential sub-surface (Chamber C) of *Ryugu* were sampled and returned to Earth in December 2020 [1]. The comparison between those two sets of samples allows to investigate possible differences between these sampling sites. *Ryugu* is composed of primitive material including organic matter. The dominant extraterrestrial infalling on Earth is constituted by micrometeorites that are efficiently collected in Antarctica (Antarctic micrometeorites – AMMs [2], [3]). In order to investigate a potential relationship between *Ryugu* and AMMs, their textures and mineralogical compositions have been compared.

Materials and methods: Twenty-five particles were prepared from the samples allocated by the “Stone” initial-analysis-team of *Ryugu* samples. They were analyzed by analytical scanning electron microscopy (SEM-EDX), electron microprobe (EMPA), Fourier transform IR microscopy (μ -FTIR) and far-infrared microscopy (FIR). Among these 25 particles, only 2 originate from chamber A (A0064-FO013-16 and A0064-FO013-17) and 23 were extracted from chamber C samples (8 particles from C0002-FC016, 3 particles from C0002-FC017, 4 particles from C0040-FC025, 8 particles C0046-FC004-010). Thus, the representativity of chamber A samples in this study should be considered with caution. Particles were moved with a quartz needle from their quartz holder to carbon tape and were carbon-coated on 2 different stubs (ST02 for smaller particles and ST03 for larger ones) for SEM analysis. Another stub, ST05, was made in the same way with the remaining samples (from C0002-FC016 and C0046-FC004-010). The three stubs (ST02, ST03 and ST05) were embedded in epoxy and polished with diamond pads down to 0.25 μ m. Antarctic micrometeorites (AMMs) collected in Antarctica from

1990's to present days have been filtered from melted ice and snow water (Cap Prudhomme and Concordia collections). All samples found on the filters were hand-picked and analyzed by SEM-EDX to identify and classify the extraterrestrial particles. AMMs with magnetite framboids and platelets were selected to be compared with *Ryugu* samples. Polished sections of the three *Ryugu* stubs and of AMMs were analyzed by EMPA at 15 kV and 10 nA at CAMPARIS University Paris Sorbonne (Jussieu). In addition, four *Ryugu* samples (C0046-FO004-010, C0002-FC016, A0064-FO013-17 and C0040-FC025) were flattened in custom-made diamond cells and were analyzed by infrared transmission microspectroscopy (μ -FTIR) and by far infrared (FIR) on the SMIS line at synchrotron SOLEIL (France) in July and October 2021. The synchrotron beam was coupled to a Nicolet continuum IR microscope. Hyperspectral maps with a spatial resolution of 6x6 μ m, and 3 μ m step have been produced, and IR nanospectroscopy was also performed on some samples (see also [4], [5]). Each cell contained two samples of the same particle, which stucked to the top and bottom diamond windows.

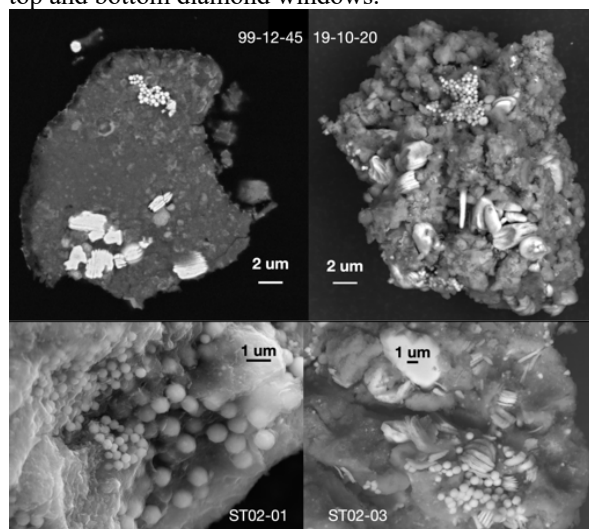


Figure 1. SEM images of magnetite framboids and platelets embedded in two different AMMs (top left – polished section and right – external surface) and in Ryugu samples (bottom left and right – external surface).

Results and discussion: SEM examination revealed that Ryugu samples are composed of a fine-grained hydrated matrix containing characteristic aggregates of magnetite framboids ranging in size from 200 nm to 1 μm , along with magnetite platelets and magnetite “sprays” (Fig. 1). EMPA analysis of chamber A and chamber C samples revealed a dominant phyllosilicate matrix, mostly saponite and Mg-serpentine, with magnetite, carbonates (mostly dolomite), Fe-Ni sulfides such as pyrrhotite, troilite or pentlandite, and rare phases such as apatite and a potential Mg-phosphate (as identified by EDX on the external surface of sample C0046-FO004-010). μ -FTIR analyses revealed widespread organics intimately linked to phyllosilicate matrix and the presence of carbonates and IR-opaque minerals in the matrix [4].

According to EMPA and μ -FTIR analysis of Ryugu samples, carbonates (dolomite for the most part), are observed more frequently and of bigger sizes in chamber A than in chamber C samples (Fig. 2).

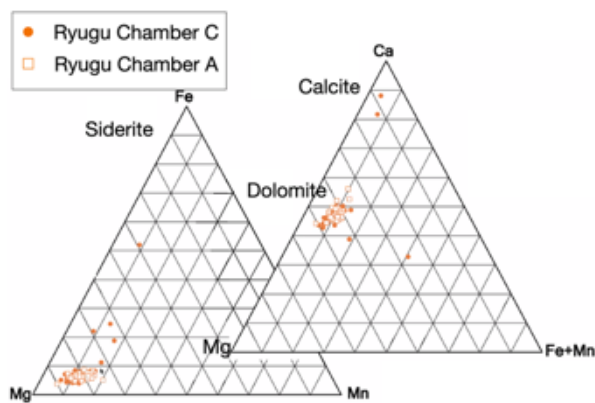


Figure 2. Composition of carbonates displayed in ternary diagrams in Ryugu samples from chamber A and chamber C. Dolomite $\text{CaMg}(\text{CO}_3)_2$ is only for the right diagram.

The occurrence of magnetite framboids and platelets is typical of C1 meteorites (especially CI1 and CR1). Magnetite framboids probably formed directly by precipitation from a fluid supersaturated in Fe, in acidic conditions [6]. This type of magnetite texture is also found in AMMs, even if there is only ~5% of AMMs displaying these features.

The major elemental composition of Ryugu, as measured by averaging the EMPA measurements, shows an enrichment in Ca and Mn compared to C1-like AMMs, which are enriched in Al and K compared to

Ryugu samples. In comparison with Ryugu samples, only few carbonates and Fe sulfides have been found within C1-like AMMs so far.

Conclusion and further investigations: Ryugu samples studied in this work are composed mostly of phyllosilicates with structural OH and interlayer water (saponite and Mg-serpentine), magnetite with different textures (framboids, platelets, sprays), Fe sulfides such as pyrrhotite, troilite and pentlandite, carbonates (mostly dolomite), and rare minerals such as apatite and potential Mg phosphate. These mineralogical components show similarities with C1 meteorites, except for the presence of Fe sulfates and the lack of Fe sulfides in C1 meteorites, probably due to the terrestrial alteration of sulfides in C1 meteorites [7]. In the Cap Prudhomme and Concordia AMM collections, around 5% of the particle show magnetite framboids or platelets. We call these particles “C1-like AMMs” Structural OH have been found in Ryugu samples and rare structural OH are known to be present in AMMs in general [8, 9]. C1-like AMMs analyses are ongoing. Moreover, very few carbonates and Fe sulfides have been found in AMMs so far but are significantly present in Ryugu samples. This diversity can be furthermore explored at a nanoscale using combination of IR microscopy and nanospectroscopy (AFM-IR) [4] and NanoSIMS [10,11], hence giving complementary information on the mineralogy on one hand and isotopic composition on the other hand. These analyses are in progress.

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