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RYUGU CHEMICAL CHARACTERISATION FROM SYNCHROTRON SPECTROSCOPY IN THE MID TO FAR INFRARED OF HAYABUSA 2 SAMPLES.

Emmanuel Dartois¹, Yoko Kebukawa², Cécile Engrand³, Jean Duprat⁴, Laure Bejach³, Jérémie Mathurin⁵, Alexandre Dazzi⁵, Ariane Deniset-Besseau⁵, Lydie Bonal⁶, Eric Quirico⁶, C. Sandt⁷, F. Borondics⁷, Hikaru Yabuta⁸, Hisayoshi Yurimoto⁹, Tomoki Nakamura¹⁰, Takaaki Noguchi¹¹, Ryuji Okazaki¹², Hiroshi Naraoka¹³, Kanako Sakamoto¹⁴, Shogo Tachibana^{13,14}, Sei-ichiro Watanabe¹⁵ and Yuichi Tsuda¹³, Tomoyo Morita¹⁰, Mizuha Kikuri¹⁰, Kana Amano¹⁰, Eiichi Kagawa¹⁰ and the Hayabusa2-initial-analysis IOM and Stone teams. ¹Institut des Sciences Moléculaires d'Orsay, CNRS, Univ. Paris-Saclay, 91405 Orsay, France (emmanuel.dartois@universite-paris-saclay.fr), ²Yokohama National Univ., Yokohama 240-8501, Japan, ³IJCLab Univ. Paris-Saclay/CNRS, 91405 Orsay, France, ⁴IMPMC/MNHN, SU, Paris, France, ⁵Institut Chimie Physique, Univ. Paris-Saclay/CNRS, 91405 Orsay, France, ⁶Institut de Planétologie et d'Astrophysique, Univ. Grenoble Alpes; 38000 Grenoble, France, ⁷Synchrotron SOLEIL, CNRS, CEA, Paris-Saclay, France. ⁸Hiroshima University, Higashi-Hiroshima 739-8526, Japan, ⁹Hokkaido University, Sapporo 060-0810, Japan, ¹⁰Tohoku University, Sendai 980-8578, Japan, ¹¹Kyoto University, Kyoto 606-8502, Japan, ¹²Kyushu University, Fukuoka 812-8581, Japan, ¹³ISAS/JAXA, Sagami-hara 252-5210, Japan, ¹⁴The University of Tokyo, Tokyo 113-0033, ¹⁵Nagoya University, Nagoya 464-8601, Japan.

Introduction: The 6th December 2020, the Hayabusa 2 mission from the Japanese space agency (JAXA) returned samples collected on the Cb-type dark asteroid *Ryugu* to Earth [1]. For the first time, *Hayabusa 2* brought back samples from the surface of a known carbonaceous asteroid. These Solar System objects preserved ancient material that escaped planetary accretion and differentiation, providing genuine mineral and organic phases formed within the first million years after the proto-Sun gravitational collapse. The amount of material collected by Hayabusa 2 (5.4g) is larger than one hundred mg planned. The InfraRed (IR) analyses of these samples provide unprecedented information on the formation and early evolution of Solar System and allow to make the link between primitive interplanetary material and astronomical observations. A key goal of this study between the IOM [2] and Stone [3] Initial Analysis Teams is to elucidate the distributions and chemical characteristics of macromolecular organic materials and minerals in a C-type asteroid. In this work, we provide hyperspectral analyses showing the characteristics content and distribution of both the organics and the minerals of Hayabusa 2 particles that will enable the comparison with other types of asteroid and cometary samples available in the laboratory.

Samples and methods: Ryugu samples provided by the IOM and the Stone initial analysis teams were originating from chamber A (surface sample collected at the first touchdown site) and chamber C (potentially containing sub-surface material ejected from the Hayabusa2-made artificial crater). Three fragments from chamber A and six from chamber C were prepared for Fourier Transform IR microspectroscopy (μ -FTIR), in particular for pre-characterisation before

IR nanospectroscopy (AFM-IR, [4]) Each fragment was micro-manipulated and transferred into a diamond compression cell.

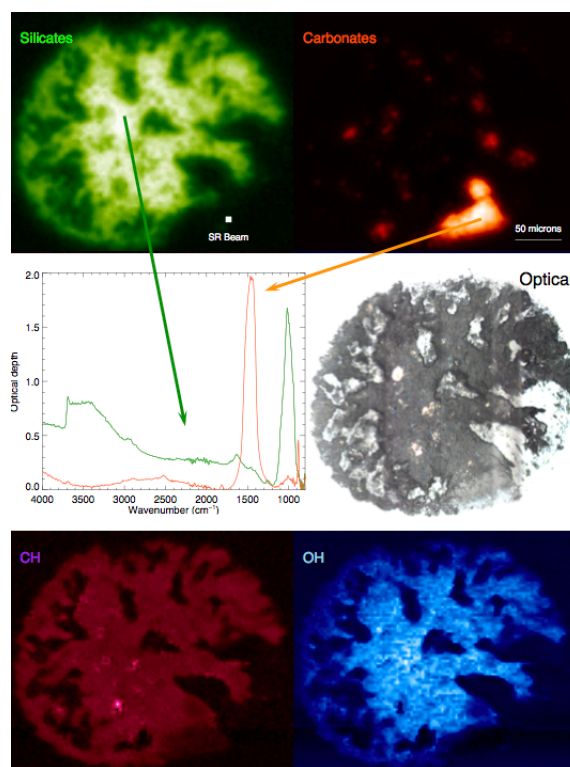


Figure 1: Chamber A sample A0108-19-03 from the Ryugu asteroid: optical image of the crushed fragment and false colour images of synchrotron SOLEIL μ -FTIR hyperspectral maps. The maps were recorded close to the diffraction limit at the SMIS beam line (6x6 μ m). The distributions of the integrated optical depth of identified main components are shown: phyllosilicates SiO stretch (1010 cm^{-1} , green), CO_3 carbonates asymmetric mode ($\sim 1415 \text{ cm}^{-1}$, orange), aliphatic

CH ($\sim 2920\text{ cm}^{-1}$, carmin red), and OH stretching mode ($\sim 3300\text{ cm}^{-1}$, blue). Two spectra are shown, that correspond to regions dominated by hydrated matrix (in green) and by a carbonate (in orange - dolomite).

The fragments were then flattened to provide an optimal thickness for IR spectroscopic transmission measurements. The IR measurements were performed on the SMIS beam line at the synchrotron SOLEIL during two runs in July and October 2021. The synchrotron beam was coupled to a Nicolet continuum IR microscope. For the measurements presented in this analysis, the infrared spot size was optimized close to the diffraction limit, with a $6 \times 6\text{ }\mu\text{m}$ sampling window, and maps were recorded using orientations adapted to the geometry of each Ryugu fragment. The map sampling step was $3\text{ }\mu\text{m}$ (Nyquist sampling). Synchrotron IR spectra are decomposed into individual contributions corresponding to specific vibrational modes, to produce false-colour images of the different components. The synchrotron beam IR μ -spectrometry is mandatory to sample the distribution of small components (e.g. carbonates) and to evaluate their spatial distribution and individual sizes, as well as to build such analytical chemical maps. In addition, far IR spectra were recorded on a Nicolet Nic-Plan IR microscope using a bolometer, with larger spot sizes covering the entire size of the considered particles.

Results: The hyperspectral μ -FTIR maps (Fig. 1) are dominated by a phyllosilicate matrix component. The aliphatic CH_x component of the organics present in Ryugu are intimately linked to this matrix at the scale probed by the synchrotron. We measured the distribution of carbonates, which are dominated by dolomite. We noticed the occurrence of large individual carbonates, measuring several tens of

microns after crushing. In transmission, we also measured the spatial distribution of “opaque minerals” leading to a wavelength-dependent decrease of the infrared signal in the spectra. Although the infrared measurement cannot directly give access to their nature, these “opaque minerals” trace the distribution of Fe-sulphides and magnetite.

The far infrared spectra of Ryugu samples provide important clues on the nature of the dominant carbonate and phyllosilicate present in the samples. Specific bands, as shown by vertical dashed blue lines in Fig. 2 show that the large carbonates in most of the samples are close to the dolomite composition. Several band characteristics of saponite are also identified.

By combining these different synchrotron IR measurements, estimates of the modal distribution of the individual components constitutive of Ryugu samples from chambers A and C can be provided. Further work will include comparison with known classes of meteorite and micrometeorite (see also [7-10]).

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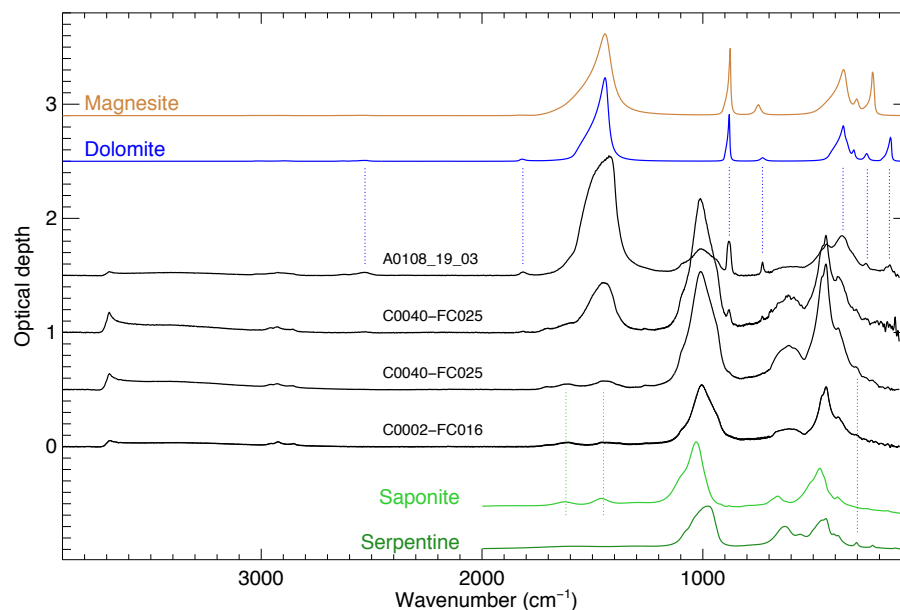


Figure 2: Combined mid-infrared and far infrared spectra covering the $3900\text{--}100\text{ cm}^{-1}$ spectral range for selected samples from chamber A and chamber C, showing the evolution from phyllosilicate-dominated spectra and increasing carbonate contribution from the bottom to the top spectrum (in black). The two top spectra (in orange and blue) show calculated absorption for dolomite and magnesite using optical constants from [5]. Bottom spectra shown the saponite and serpentine phyllosilicate calculated absorption using optical constants from [6].