REFLECTANCE SPECTRAL COMPARISON BETWEEN A LARGE RYUGU RETURNED SAMPLE AND CARBONACEOUS CHONDRITES. K. Amano[1], M. Matsuoka[2], T. Nakamura[1], E. Kagawa[1], T. Hiroi[3], E. Tatsumi[4,5], R. Milliken[3], R. Brunetto[6], P. Beck[7], S. Potin[2], T. Morita[1], M. Kikuiri[1], H. Yurimoto[8], T. Noguchi[9], R. Okazaki[10], H. Yabuta[11], H. Naraoka[10], K. Sakamoto[12], S. Tachibana[5], S. Watanabe[13], and Y. Tsuda[12]. [1]Division of Earth and Planetary Materials Science, Graduate School of Science, Tohoku University, Aoba, Sendai, Miyagi 980-8578, Japan (email: amakana@dc.tohoku.ac.jp), [2]Laboratoire d'Etudes Spatiales et d'Instrumentation en Astrophysique, Observatoire de Paris, 92195 Meudon, France, [3]Brown University, Providence, RI 02912, USA, [4]Instituto de Astrofísica de Canarias, University of La Laguna, Tenerife 38205, Spain, [5]The University of Tokyo, Tokyo 113-0033, Japan, [6]Institut d'Astrophysique Spatiale, Université Paris-Saclay, Orsay 91405, France, [7]Université Grenoble Alpes, CNRS, IPAG, 38000 Grenoble, France, [8]Hokkaido University, Sapporo 060-0810, Japan, [9]Kyoto University, Kyoto 606-8502, Japan, [10]Kyushu University, Fukuoka 819-0395, Japan, [11]Hiroshima University, Higashi-Hiroshima 739-8526, Japan, [12]ISAS/JAXA, Sagamihara 252-5210, Japan, [13]Nagoya University, Nagoya 464-8601, Japan.

Introduction: Reflectance spectroscopy of Ryugu samples, which were brought back to the Earth from Cb-type asteroid Ryugu by the Hayabusa2 spacecraft in 2020, provides us mineralogical and chemical information on the sample themselves and insights to understand compositional distribution on the surface of asteroid Ryugu. Spectral comparison between Ryugu samples and carbonaceous chondrites (CCs) enables us to investigate how unique or common Ryugu materials are in the context of meteoritics. We measured reflectance spectra of Ryugu samples as the primary analysis in the Hayabusa2 initial analysis "Stone" team [1] and compared the results with reflectance spectra of CCs.

Sample preparation and analytical procedures: Large Ryugu sample C0002 with a major axis of ~8 mm was collected from the second touchdown site. C0002 was placed on a dark substrate set on a stainless-steel sample dish (Fig. 1) in a N_2-purged glove box at Tohoku University. The sample on the dish was packed together with standard materials such as Spectralon and Infragold into an air-tight cell. The cell was sealed by a CaF_2 window and a ZnSe window for the measurements at 0.4-~8 µm and ~8-18 µm in wavelength, respectively. The cell was put into a Bruker FT-IR VERTEX 70v at Tohoku University. The sample had never been exposed to the air through curation at JAXA, transportation from JAXA, the sample preparation, and measurements to avoid effects of terrestrial alteration such as adsorption and oxidation by the atmosphere.

The spectral measurements were done with an incidence angle of 30 ° and an emission angle of 0 ° in vacuum conditions. Spectral resolution at IR wavelengths is 4 cm^{-1}. The detailed configuration of the FTIR system is reported in [1].

The spectra were obtained from an area with ~3 mm in diameter on a rough surface of C0002. C0002 was measured at three different azimuth conditions (0 °, 120 °, and 240 ° in rotation angles) to average specular reflection and other anomalous effects of the surface. Here we report the averaged spectrum (Fig. 2). Chip and powdered (<155 µm in grain size) samples of Orgueil CI, Tagish Lake, and Murchison CM were measured using the same FTIR system. At Visible-Near infrared (Vis-NIR) wavelengths, Ryugu is compared with CC chip samples because the grain size of samples especially affects Vis-NIR reflectance spectra. Powdered samples of those CCs were measured after preheating at ~150 °C for several hours to remove adsorbed water.

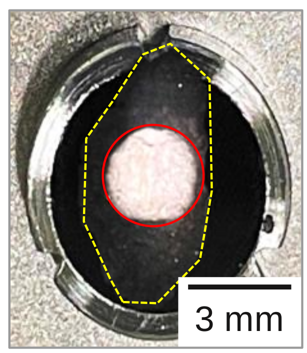

Fig. 1. An image of Ryugu C0002 sample. The dotted yellow line indicates the outline of C0002 sample. Reflectance spectra were obtained from the area indicated by the red circle.

Vis-NIR reflectance spectra: Ryugu C0002 has ~3% of reflectance at v-band (0.55 µm in wavelength) and slightly red-sloped featureless spectrum at Vis-NIR wavelengths (Fig. 2A). Vis-NIR spectrum of C0002 is similar to that of Tagish Lake rather than those of Orgueil and Murchison chips which have a bluer spectral slope and a steep drop-off towards UV regions (Fig. 2A). The absence of the 0.7-µm absorption band due to Fe^{2+}+Fe^{3+}-bearing phyllosilicates [e.g., 2] and very low reflectance of Ryugu C0002 spectrum deny the compositional similarity between Ryugu and CM chondrites.

IR reflectance spectra: Ryugu C0002 shows an absorption band at 2.71 µm due to Mg-rich phyllosilicates [3], which is similar to those of Orgueil and Tagish Lake (Fig. 2B). Considering that typical CM2 chondrites such as Murchison have an absorption feature at ~2.8 µm due to Fe-rich phyllosilicates [e.g., 3] (Fig. 2B), the phyllosilicate composition of Ryugu C0002 is richer in Mg than CM2 chondrites.

Ryugu C0002 also presents absorption bands due to aliphatic compounds at ~3.4 µm, and carbonates at ~3.4 and ~3.8-3.95 µm (Fig. 2B). The intensity of absorption bands due to carbonates of Ryugu and Tagish Lake suggests C0002 contains less abundant carbonates than Tagish Lake.

Mid-IR (MIR) reflectance spectra: The MIR spectrum of C0002 is dominated by the Reststrahlen band (RB) with a maximum peak at 9.8 µm (Fig. 2C), suggesting that phyllosilicate is dominant in C0002 [e.g., 4,5]. The RB peak position of phyllosilicates is similar to those of Orgueil and Tagish Lake. The Christiansen feature (CF) of C0002 is located at 9.1 µm, which is also similar to those of Orgueil and Tagish Lake although the CF of Orgueil is affected by doublet peaks at 8.65 and 8.9 µm due to sulfates [6]. White sulfates in Orgueil are suggested to be formed by terrestrial alteration and many open spaces in Orgueil are filled with such sulfates [7]. MIR spectrum of C0002 is unlike that of Murchison CM (Fig. 2C), whose IR signature is dominated by serpentine [e.g., 5].

Ryugu C0002 spectrum shows a small peak at 11.20 µm possibly due to out-of-plane bending (ν_2) of carbonates, especially indicating the presence of dolomite [8], while a large peak at ~11.25 µm in Tagish Lake spectrum indicates the abundant presence of siderite, ankerite, or calcite instead of dolomite [8].

Discussion: Ryugu C0002 spectrum indicates that Ryugu contains Mg-rich phyllosilicates, carbonates, and aliphatic compounds. Anhydrous silicates such as olivine and pyroxene are not identified in the spectrum, suggesting their low abundance.

Ryugu has the best IR spectral match with Orgueil (Fig. 2B, C) and it suggests that Ryugu materials are CI-like, which is consistent with mineralogical and compositional signatures reported in [1]. However, Vis-NIR spectrum (0.4-2.5 µm) of C0002 is similar to that of Tagish Lake rather than Orgueil. Possible causes for this difference between Ryugu and Orgueil can be suggested as terrestrial alteration of Orgueil such as oxidation including the formation of bright sulfates and increase in Fe^{3+}/Fe^{2+} ratio in phyllosilicates, and compositional difference in organics. However, we have not yet achieved a clear explanation for the causes of the difference, which should be investigated to elucidate the spectral diversity of C-complex asteroids and their origin because Vis-NIR spectral shapes are essential to interpret reflectance spectra of C-complex asteroids obtained by ground-based observations [e.g., 9].

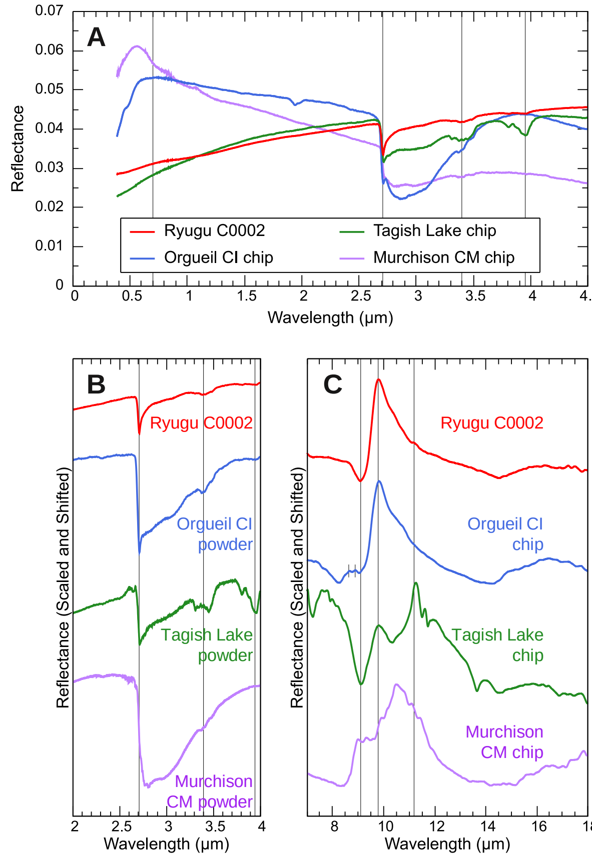

Fig. 2. A: Vis-IR reflectance spectra of Ryugu C0002(red), Orgueil (blue), Tagish Lake (green), and Murchison (purple). Gray lines indicate 0.70, 2.71, 3.40, and 3.95 µm in wavelength. **B:** Scaled and shifted IR reflectance spectra of Ryugu C0002 and powdered CCs. Gray lines indicate 2.71, 3.40, and 3.95 µm. **C:** Scaled and shifted MIR reflectance spectra of the same samples as A. Gray lines indicate 8.65, 8.90, 9.10, 9.80, and 11.20 µm.

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