OLIVINE COMPOSITIONAL VARIATION OF ASTEROID RYUGU SAMPLES: POSSIBLE PRECURSORS OF RYUGU'S PARENT ASTEROID.

T. Mikouchi[1], T. Nakamura[2], M. E. Zolensky[3], H. Yoshida[1], D. Nakashima[2], K. Hagiya[4], T. Morita[2], M. Kikuiri[2], K. Amano[2], E. Kagawa[2], H. Yurimoto[5], T. Noguchi[6], R. Okazaki[7], H. Yabuta[8], H. Naraoka[7], K. Sakamoto[9], S. Tachibana[1,9], S. Watanabe[10], Y. Tsuda[9], [1]Univ. of Tokyo, Tokyo 113-0033, Japan, [2]Tohoku Univ., Sendai 980-8578, Japan, [3]NASA-JSC, Houston, TX 77058, USA, [4]Univ. of Hyogo, Kamigori 678-1297, Japan, [5]Hokkaido Univ., Sapporo 060-0810, Japan, [6]Kyoto Univ., Kyoto 606-8502, Japan, [7]Kyushu Univ., Fukuoka 812-8581, Japan, [8]Hiroshima Univ., Higashi-Hiroshima 739-8526, Japan, [9]ISAS/JAXA, Sagamihara 252-5210, Japan, [10]Nagoya Univ., Nagoya 464-8601, Japan, E-mail: mikouchi@um.u-tokyo.ac.jp

Introduction: JAXA's Hayabusa2 spacecraft successfully recovered samples from Cb-type asteroid Ryugu and returned samples are now under detailed scrutiny by the international community. The ongoing initial analysis has so far revealed that the Ryugu samples are pristine primitive asteroidal materials mostly composed of secondary minerals such as phyllosilicates, carbonates, Fe sulfides and magnetite associated with organic matter [e.g., 1]. However, some samples contain small amounts of anhydrous silicates and oxides such as olivine that are thought to be the precursors of the Ryugu parent asteroid. Their sizes are mostly <5 μm, and detailed mineralogical analysis is possible using an electron microprobe with field emission gun (FE-EPMA). Here we report results of our extensive FE-EPMA analysis of anhydrous minerals focusing on olivine to compare with literature chondritic data. We also performed synchrotron XRD of olivine crystals to evaluate the shock degree of Ryugu samples. These analyses allow us to discuss the formation of Ryugu in light of the solar system early evolution.

Samples and Methods: Polished sections of A0055, A0106, C0002, C0023, C0025, C0033, C0040, C0046, C0055, C0076, and C0103 were analyzed. JEOL JXA-8530F FE-EPMA at Univ. of Tokyo was employed for both WDS mapping and quantitative analyses using well-characterized natural and synthetic standards. The quantitative analysis was carried out at 12 kV accelerating voltage with 30 nA beam current. Counting times at peaks were 30 sec. This condition allowed us to acquire accurate chemical compositions of ~1 μm olivine crystals including minor elements. Some olivine crystals in the C0025 section (C0025-03) were also analyzed at BL37XU, SPring-8 to obtain single crystal XRD data using an energy scanning method (30-20 keV with 50 eV interval) [2]. The X-ray beam size was ~1 μm.

Results: FE-EPMA X-ray mapping analysis clearly shows the brecciated texture of Ryugu samples on mm-to-μm scale and reveals the rare occurrence of olivine-bearing fragments [1] (Fig. 1). C0002, C0023, C0025, C0033, C0040, C0046 and C0076 are found to contain olivine crystals although the abundance widely varies, related to the degree of aqueous alteration. The most olivine rich fragment is present in C0002 and contains ~14% olivine with ~12% pyroxene in modal abundances, which appears the least altered lithology in the Ryugu samples analyzed [1].

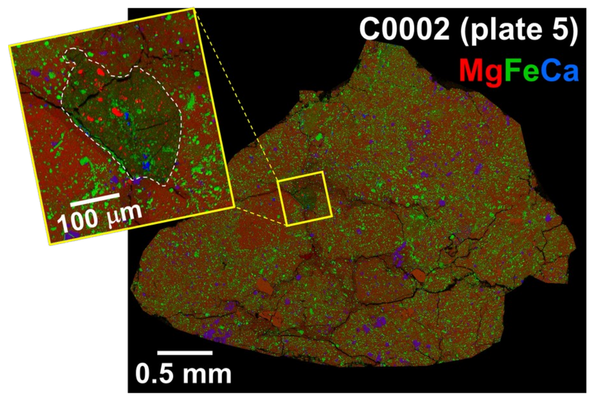


Fig. 1. Composite X-ray map of C0002 plate 5. Red: Mg, green: Fe and blue: Ca. An enlarged map of an olivine-bearing fragment is shown. Olivine is in bright red color.

The largest olivine grain reaches ~30 μm in size. The grain shapes are variable: rounded, irregular, angular or wormy, independent of sizes. Some olivine grains are present in chondrule-like objects [1] (Fig. 2).

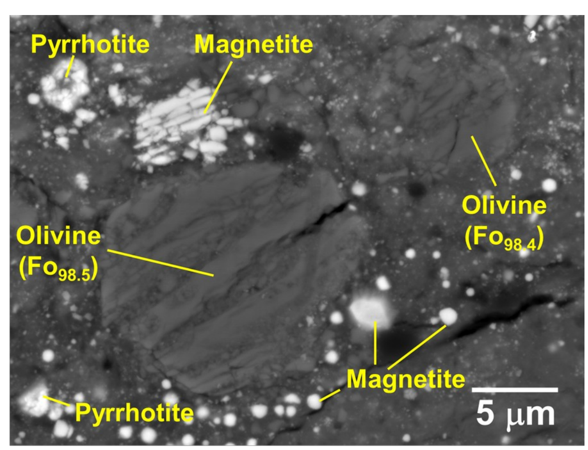


Fig. 2. Back-scattered electron image of chondrule-like objects in C0046 (C0046-01).

We selected more than 700 individual crystals of olivine and could successfully obtain ~600 good analytical FE-EPMA analyses. The obtained olivine compositions are clustered at Fo_{99} (Figs. 3-4). In some samples, all olivine grains have thin Fe-rich rims (0.1~0.2 μm) adjacent to the matrix regardless of crystal shapes (but not analyzable even by FE-EPMA). There are rare Fe-rich olivine crystals whose composition reach up to Fo_{44}. Olivine grains with >0.5 wt% MnO are not unusual, but LIME olivine (MnO/FeO>1 in wt%) is rare. A few grains contain up to 4.3 wt% MnO. Most olivine grains are Ca-poor (CaO: <0.1 wt%), but Ca shows a slight increase with increased Fe. The Cr_2O_3 content is usually 0.1-0.4 wt %. As Ca shows, we see a similar positive correlation between Cr and Fe when Fa content is higher than Fa_1. The Al_2O_3 content is lower than 0.05 wt% in most grains.

Other anhydrous minerals include pyroxene, chromite, Mn-rich ilmenite (up to 9.5 wt% MnO) and Mg-Al spinel. Some chromite is also Mn-rich (MnO: ~14 wt%). Pyroxene is sometimes associated with olivine, but pyroxene is much rarer than olivine. Low-Ca pyroxene compositions range $En_{98.8}Wo_{0.03}$-$En_{93.3}Wo_{5.5}$. There is one grain of augite ($En_{45.0}Wo_{42.0}$). CAI-like objects composed of hibonite and Mg-Al spinel are also found [1].

Synchrotron XRD data of olivine show sharp diffraction spots, suggesting minimal shock metamorphism of the sample.

Discussion and Conclusion: FE-EPMA analysis revealed that Ryugu samples contained rare olivine grains. We could not find olivine in samples from the 1st touchdown site (Chamber A samples). We consider that this is due to a sample bias because we analyzed only two Chamber A samples. There are no significant differences in olivine size, texture and composition among samples analyzed. In accordance with the general mineralogy and petrology of Ryugu samples resembling CI chondrites [1], olivine compositions are within the range of reported values of CI olivines including minor elements [3-5]. Since forsteritic olivine in C2 and C3 chondrites has slightly more Mg-rich compositions, typically $Fo_{>99}$, Ryugu olivine is different [e.g., 5]. The low Ca content (<0.1 wt% CaO) of most Ryugu olivine grains is also distinct from C2-C3 chondrites [e.g., 5].

These olivine grains appear to be precursors of the parent Ryugu asteroid that escaped severe aqueous alteration because they were located at sub-surface layers of the parent asteroid [1]. The current Ryugu asteroid is thus a mixture of both highly altered and less altered materials from different depths of the original parent body assembled as a rubble-pile body [1]. The general mineralogical similarity between Ryugu and CI olivines suggest a common origin and some Ryugu olivines (e.g., wormy texture) may be condensation products from the solar gas because of textural similarity to AOAs [1].

Acknowledgments: We thank ISAS/JAXA for allocating the Ryugu samples to initial analysis teams.

References: [1] Nakamura T. et al. (2022) *Science*, submitted. [2] Mikouchi T. et al. (2014) *EPS, 66,* #82. [3] Kerridge J. F. and Macdougall J. D. (1976) *Earth Planet. Sci. Lett*., *29*, 341-348. [4] Steele I. M. et al. (1990) *Meteoritics*, *35*, 302-307. [5] Frank D. R. et al. (2014) *Geochim. Cosmochim. Acta*, 142, 240-259.

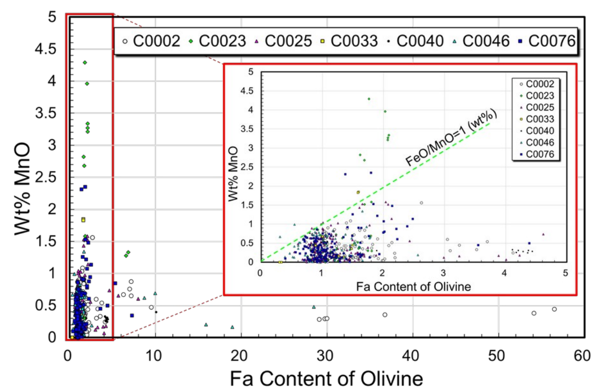
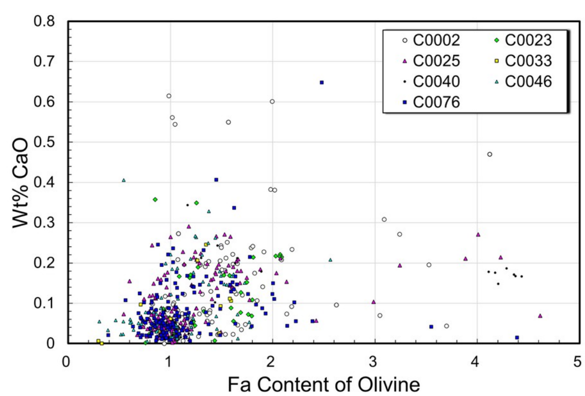


Fig. 3 Variation of MnO *vs*. Fa content of olivine in Ryugu samples. Enlarged diagram shows olivine composition whose Fa content is lower than Fa_5.



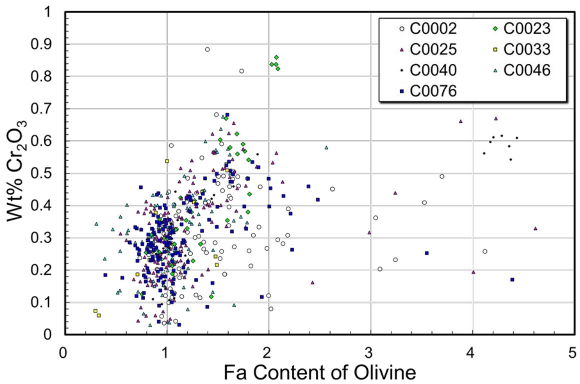


Fig. 4 Variation of CaO and Cr_2O_3 *vs*. Fa content of forsteritic olivine in Ryugu samples.