CHEMICAL AND ISOTOPIC CHARACTERIZATION OF ASTEROID RYUGU. H. Yurimoto[1], The Hayabusa2-initial-analysis chemistry team, The Hayabusa2-initial-analysis core, [1]Hokkaido University.

Introduction: The Hayabusa2 spacecraft made two successful landings onto asteroid Ryugu to collect asteroidal materials in 2019 and delivered the collected samples to the Earth on December 6th, 2020. The colors, shapes and macro-structures of the returned samples are consistent with those acquired by remote sensing observations, indicating that the returned samples are representative of the asteroid Ryugu [1-9]. Laboratory examination of the samples paints a much sharper picture of the constituents and history of Ryugu.

The goals of the Hayabusa2-initial-analysis-chemistry team analyses are to provide fundamental answers to questions related to the provenance of Ryugu samples for enabling a framework for in-depth research by the international scientific community. This paper addresses the questions: (i) what are the elemental abundances of Ryugu?; (ii) what are the isotopic compositions of Ryugu?; (iii) does Ryugu consist of primary materials formed in the protosolar disk or of secondary materials formed in the asteroid or in its parent asteroid?; (iv) when were Ryugu's constituent materials formed?; and (v) what, if any, relationship does Ryugu have with known meteoritic samples?

Experimental Methods: Ryugu samples from the first touchdown site (small grain aggregates: A0106, A0107; individual grains: A0040, A0058, A0094) and second touchdown site (small grain aggregates: C0107, C0108; individual grain: C0002) were used in this study. Polished sections from A0058 and C0002 were investigated by scanning electron microscopy to determine their petrology and mineralogy.

We applied X-ray fluorescence (XRF) analysis, inductively coupled plasma mass spectrometry (ICP-MS), thermogravimetric analysis coupled with mass spectrometry (TG-MS), and combination analyses of pyrolysis and combustion (EMIA-Step) to determine elemental abundances for bulk samples. Multi-collector (MC)-ICP-MS and thermal ionization mass spectrometry (TIMS) were applied for isotope analyses of bulk samples.

Laser-fluorination isotope-ratio mass-spectrometry (LF-IRMS) and secondary ion mass spectrometry (SIMS) were applied for O isotope analyses of bulk samples and in-situ analyses in the polished sections, respectively. SIMS was also applied for C isotopes and ^{53}Mn-^{53}Cr systematics for carbonate minerals in the sections.

Results and Discussion: We have quantified the abundance of 66 elements in Ryugu samples: H, Li, Be, C, O, Na, Mg, Al, Si, P, S, Cl, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, Ge, As, Se, Rb, Sr, Y, Zr, Nb, Mo, Ru, Rh, Pd, Ag, Cd, In, Sn, Te, Cs, Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Hf, Ta, W, Tl, Pb, Bi, Th, and U. There appears to be a slight variation of chemical compositions between samples from the first and the second touchdown sites, but given the small sample mass analyzed, the variations could be due to heterogeneity at the small scale analyzed. The Cr-Ti stable isotope systematics and the lack of depletion in volatile elements suggest that Ryugu is mainly composed of materials of the CI chondrite group. The chemical heterogeneities [10] and Cr-Ti-Pb-Mn-Cr isotope systematics [11] for Ryugu bulk samples are discussed in detail in separate abstracts of this conference.

The mineral assemblages and mineral compositions of Ryugu samples resemble the CI chondrite group materials: they consist of magnetite, breunnerite, dolomite, and pyrrhotite grains embedded in the matrix composed of serpentine and saponite; anhydrous silicates are virtually absent, indicating extensive aqueous alteration in the parent body from which Ryugu was derived (Fig. 1).

The bulk oxygen isotopic compositions of the Ryugu samples are comparable to the CI chondrite group materials. The aqueous alteration temperature determined by oxygen-isotope thermometry of coprecipitated dolomite and magnetite from an aqueous solution is 37 ±10 °C. The ^{53}Mn-^{53}Cr systematics reveal that the aqueous alteration of Ryugu occurred at 5.2 (+0.7/–0.8) million years after the birth of the Solar System. The O isotope systematics [12] and Mn-Cr systematics [13] are compared with those of CI chondrites in separate abstracts of this conference.

Phyllosilicate minerals are the main reservoir of water in Ryugu samples. The amount of the structural water in Ryugu is comparable to CI chondrites, but the interlayer water in Ryugu is essentially absent, suggesting that this asteroid had lost its interlayer water to space. This observation demonstrates that the Ryugu samples remained at moderately low temperature (below ~90 °C) following aqueous alteration until the present. The dehydration mechanism is likely to have been a combination of impact heating, solar heating, solar wind irradiation, and long-term exposure to ultra-high vacuum of space.

Loss of interlayer water from phyllosilicates could be responsible for the comet-like activity of some carbonaceous asteroids [14] and the ejection of solids from the surface of asteroid Bennu [15].

Conclusions: Our data suggest that Ryugu samples are more primitive than any CI chondrite group samples and therefore represent the most pristine Solar System material available for study. Materials observed in the CI chondrites may have been significantly changed or modified on Earth from their primary states in space. Such modification likely resulted in the alteration of the structures of organics and phyllosilicates, the adsorption of terrestrial water, and the formation of sulfates and ferrihydrites for the CI chondrites fallen on the Earth.

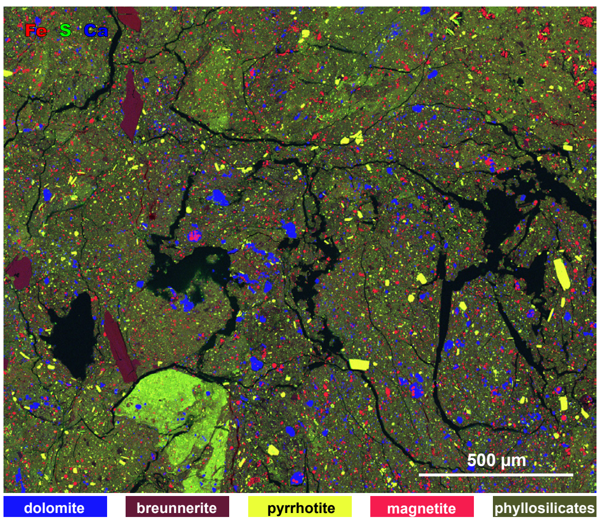

Fig. 1. Representative petrography of Ryugu samples. Combined characteristic X-ray elemental map in Fe Kα (red), S Kα (green), Ca Kα (blue) of C0002-C1001. All visible minerals in this figure are formed by aqueous alteration in the Ryugu parent body.

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