MULTI-ISOTOPIC ANALYSES OF BULK RYUGU SAMPLES RETURNED BY THE HAYABUSA2 MISSION. T. Yokoyama[1], The Hayabusa2-initial-analysis chemistry team, The Hayabusa2-initial-analysis core. [1]Tokyo Institute of Technology (tetsuya.yoko@eps.sci.titech.ac.jp)

Introduction: The Hayabusa2 mission conducted two sampling sequences on the C-type asteroid Ryugu, and brought 5.4 g of the asteroidal materials back to Earth in Dec. 2020. Analyses of the returned samples in the primary curation phase and subsequent initial analyses revealed that Ryugu samples lack CAIs and chondrules but contain hydrated silicates, carbonates, and organics representing a similarity to CI chondrites [1, 2]. To obtain data that chemically characterize the asteroidal materials, the initial-analysis-chemistry-team conducted destructive, multi-isotopic analyses for two bulk Ryugu samples (< 25 mg each) from the two touchdown sites. The fundamental knowledge that will be obtained by the multi-isotopic analyses includes 1) the origin of Ryugu (using nucleosynthetic isotope anomalies: e.g., ^{50}Ti, ^{54}Cr), 2) the age of Ryugu (using radiogenic isotope systems: e.g., Mn-Cr, Rb-Sr, U-Pb), and 3) the evolutionary history that Ryugu experienced (using mass-dependent isotope fractionations: e.g., K, Fe, Zn). Here, we report preliminary results on the isotopic compositions of Ti, Cr, and Pb obtained from the Ryugu samples and some carbonaceous chondrites. The data elucidate the timing and location for the formation of Ryugu materials and their linkage to related meteorites.

Experiments: Two Ryugu samples (A0106-A0107 from the first touchdown and C0108 from the second touchdown) and three carbonaceous chondrites [Tagish Lake (C2-ung), Murchison (CM2), and Allende (CV3)] were examined in this study.

The Ti isotopic compositions of the samples were measured by MC-ICP-MS (Neptune-Plus; Thermo Fisher Sci.) at U. of Tokyo. The Ti isotopic ratios are reported in ε units representing the 10^4 times relative deviation from the ratio of an Alfa Aesar Ti standard. The Cr isotopic compositions of the samples were measured using TIMS (Triton-Plus; Thermo Fisher Sci.) at Tokyo Tech. The Cr isotope ratios in the samples are reported in ε units relative to the NIST 979 standard. The Pb isotopic compositions in the samples were also measured with TIMS (Triton plus) at Tokyo Tech. The accuracy and precision of the Pb isotopic measurement was evaluated by analyses of the NIST 981 standard. Analytical methods are described in detail elsewhere [3].

Results and Discussion: The ε^{50}Ti and ε^{54}Cr data for Ryugu and the carbonaceous chondrites obtained in this study are reported in the Figure 1. Also shown are literature data for chondrites and achondrites [4]. Previous studies have revealed a dichotomy in the distribution of Ti and Cr isotopes between non-carbonaceous (NC) and carbonaceous (CC) meteorites [4]. The bulk Ti and Cr isotopic compositions of the Ryugu samples plot closest to the CI chondrite value in the CC meteorites region, but also overlap with the compositions of CB chondrites and Tagish Lake. A possible linkage between Ryugu and CM chondrites as expected by spectral observations [5] is not supported from this diagram. Additionally, the metal-rich nature of CBs rejects their possible kinship with Ryugu. These observations suggest that 1) the source materials of Ryugu are related to those of the CIs and/or Tagish Lake, and 2) such materials were supplied to asteroids orbiting outer part of the current asteroid belt.

Figure 2 shows the ε^{53}Cr and ^{55}Mn/^{52}Cr data for the bulk samples of Ryugu and three carbonaceous chondrites measured in this study, as well as literature data [6]. The two Ryugu samples, especially A0106-A0107, possess higher ^{55}Mn/^{52}Cr ratios and ε^{53}Cr values than any other carbonaceous chondrites including CIs. Fractionation of Mn/Cr can occur via thermal processing because of the difference in 50% condensation temperature ($T_{50\%}$) between Mn (1158 K) and Cr (1296 K) [7]. In general, elemental abundances in the Ryugu samples do not show systematic depletions/enrichments, relative to CI chondrites, as a function of $T_{50\%}$ [3]. However, Ryugu A0106-A0107 has relatively higher Ca content than Ryugu C0108 and CIs, suggesting that the suprachondritic Mn/Cr ratio and ε^{53}Cr value could be caused by the enrichment of the sample in aqueously formed carbonates with high Mn/Cr ratios [8]. The ^{53}Mn-^{53}Cr isochron for dolomite in Ryugu obtained by SIMS showed that the aqueous alteration of Ryugu occurred at 5.2 (+0.7/–0.8) million years after the birth of the Solar System [3]. Because of the relatively small sample size (< 25 mg) used for the isotopic analysis, it is not clear whether the entire Ryugu body has a Mn/Cr ratio higher than CIs on an average.

The Ryugu samples and carbonaceous chondrites measured in this study are positively correlated in Fig. 2. The regression line for the five data points yields a slope of $(^{53}\text{Mn}/^{55}\text{Mn})_0 = (4.1\pm0.9)\times10^{-6}$, corresponding to the age of 4564.6±1.2 Ma when the D'Orbigny angrite is used as an anchor [9]. However, as discussed in [6], this age may be averaging the effects of multiple fractionation events because carbonaceous chondrites consist of mechanical mixtures of CAIs, chondrules, metals, and matrix that may have formed at different

times in the early Solar System and experienced aqueous activity at different times.

Whole rock Pb-isotopic data for Ryugu samples and carbonaceous chondrites measured in this study, as well as the literature data for carbonaceous chondrites [10] and Allende matrix samples devoid of terrestrial contamination [11], form a straight array that closely passes through the point of primordial Pb defined by either Nantan troilite [12] or Canyon Diablo troilite [13]. The Ryugu Pb isotopic compositions are less radiogenic than in most analyzed carbonaceous chondrites and the Allende matrix, indicating lower content of chondrule- or CAI-like refractory material depleted in moderately volatile elements. The y-intercept of the regression yields an age of 4575.6 ± 7.3 Ma when the $^{238}U/^{235}U$ ratio is assumed to be 137.780 ± 0.027, which is slightly older than the age of the Solar System initial (4567.3 ± 0.16 Ma; [14]). As discussed in [11], this old age could be related to the presence of various components in chondrites with different ages and $^{238}U/^{235}U$ ratios.

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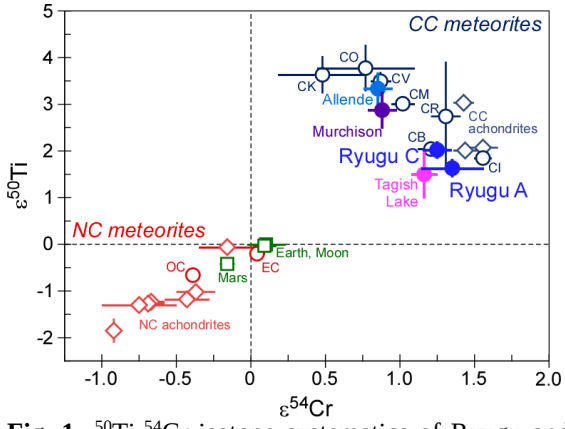

Fig. 1 ^{50}Ti-^{54}Cr isotope systematics of Ryugu and meteorites. Open symbols are literature data [4].

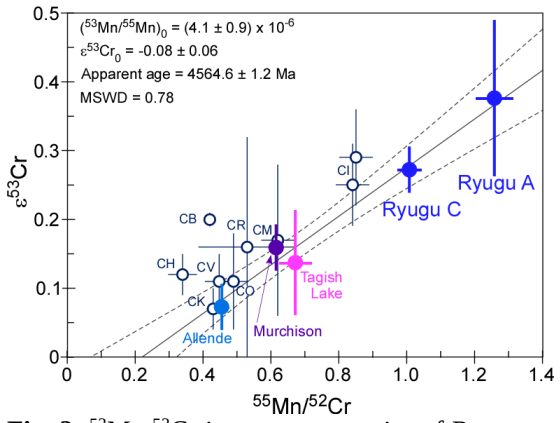

Fig. 2 ^{53}Mn-^{53}Cr isotope systematics of Ryugu and meteorites. Open symbols are literature data [6]. Regression line was determined by *IsoplotR* [15].

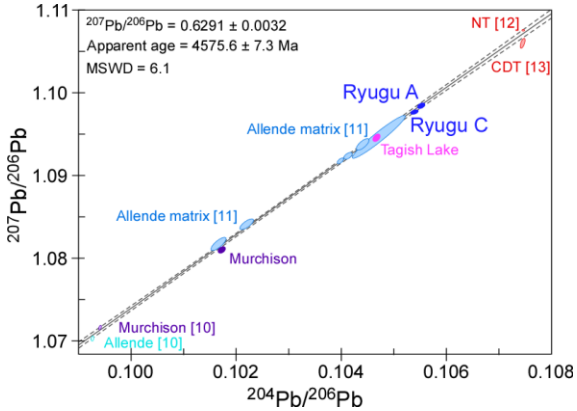

Fig. 3 ^{207}Pb-^{206}Pb isochron for Ryugu, carbonaceous chondrites [this study, 10], and Allende matrix [11]. Primordial Pb composition, assumed to be either Nantan troilite (NT; [12]) or Canyon Diablo troilite (CDT; [13]), was not included in the determination of isochron using *IsoplotR* [15].