Small-scale Cr-Ti isotopic heterogeneity in Ryugu samples induced by aqueous alteration

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The Hayabusa2 spacecraft collected ~5.4 g of material from the Cb-type asteroid Ryugu [1]. Subsequent sample analyses showed that Ryugu materials have mineralogical, chemical, and isotopic similarities to CI chondrites, including nucleosynthetic isotope anomalies of Cr and Ti [2]. However, Ryugu samples with masses <25 mg showed a variation in ε^{54}Cr (from +1.22±0.06 to +2.22±0.13) exceeding the documented range of literature values for CIs (+1.53±0.22), while the calculated ε^{54}Cr value of the Ryugu composite sample (~90 mg) is consistent with the CI value [3]. On the other hand, the ε^{50}Ti values were relatively uniform (from +1.63±0.11 to +1.94±0.14). These observations suggest the presence of mm-scale ε54Cr variability in the Ryugu samples, which was primarily caused by fluid-driven decoupling via parent body aqueous alteration between Cr in chemically labile phases with a slightly low ε54Cr value and 54Cr-rich presolar Cr oxide nanoparticles [3].

To further investigate the isotopic heterogeneity of Ryugu samples, we analyzed the Cr and Ti isotopic compositions in eight Ryugu particles (A0066, A0238, A0247, A 0256, A0259, A0268, A0301, A0313) allocated by JAXA's second Anouncement of Opportunity (AO2). The eight particles, of which masses ranged from 1.6 to 4.3 mg, were each weighed into a Teflon vial and acid digested at 220 °C using HF, HNO_3, and HCl. After digestion, a portion (~10%) of the solution was separated, and the abundance of 54 elements was measured using a triple quadrupole ICP-MS (iCAP TQ) [4]. Subsequently, Cr and Ti were chemically separated from the remaining sample solution (~90%), and isotopic analyses of Cr and Ti were performed using TIMS (TRITON plus) at Tokyo Tech and MC-ICP-MS (Neptune plus) at the University of Tokyo, respectively.

The obtained ε^{54}Cr values of the eight Ryugu particles ranged from +0.89 ± 0.11 to +2.24 ± 0.13 (Fig. 1), and the variation was larger than that in the reference [3]. Contrary to our previous observation [3], no meaningful correlation was confirmed between the ε^{53}Cr and ε^{54}Cr values of the Ryugu particles (Fig. 1). These results suggest that Ryugu samples contain microscale ε^{54}Cr heterogeneity, i.e., local enrichment of ^{54}Cr-rich presolar particles (such as Cr oxide nanoparticles). This heterogeneous distribution of presolar particles is thought to be due to the selective destruction of chemically labile phases with low ε^{54}Cr values by aqueous alteration in the parent body, followed by removal of low ε^{54}Cr components by fluids. In contrast to previous studies, the ε^{50}Ti values of Ryugu particles varied widely, from +0.75 ± 0.20 to 2.18 ± 0.16, which is negatively correlated with the Cr/Ti ratio (Fig. 2). As with Cr, this suggests that there is a local concentration of presolar particles (such as SiC) rich in ^{50}Ti, and the cause is thought to be the selective destruction of chemically labile phases with low ^{50}Ti values due to aqueous alteration, and the migration of low ^{50}Ti components by fluids. In many previous studies, Ti has been considered to be insoluble in fluids and difficult to move due to aqueous alteration, but the results of this study show that Ti is greatly affected by Ryugu's water cycle, causing microscale ε^{50}Ti fluctuations in Ryugu samples.

References

[1] Yada T. et al. 2022. Nat. Astron. 6:214. [2] Yokoyama T. et al. 2023. Science 379:eabn7850. [3] Yokoyama T. et al. 2023. Sci. Adv. 9:eadi7048. [4] López García et al. 2024. JpGU2024.

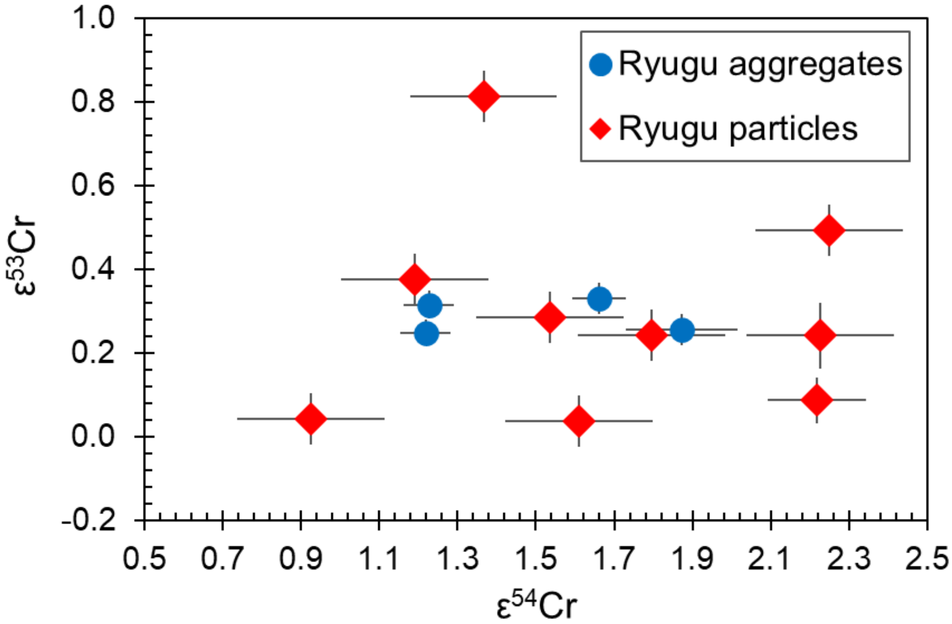

Figure 1. ε^{53}Cr and ε^{54}Cr values of Ryugu particle (this study) and aggregatess [3].

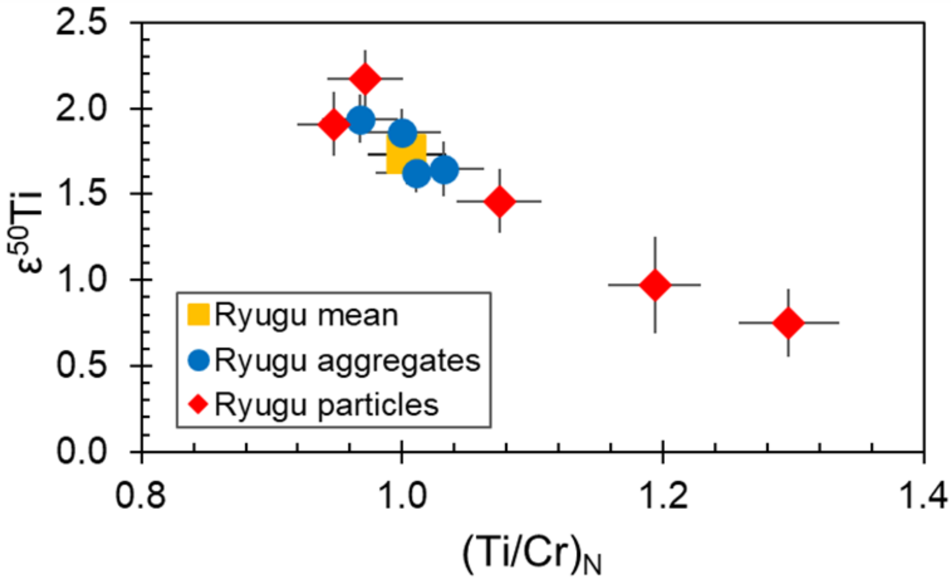

Figure 2. ε^{50}Ti and Ti/Cr ratios of Ryugu particles (this study), Ryugu mean [3], and aggregates [3].