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Intrinsic isotopic heterogeneities in Ryugu unravel the origin of carbonaceous asteroid and its aqueous evolution

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High-precision isotope measurements of extraterrestrial materials have revealed large-scale isotopic heterogeneity in the protoplanetary disk, most notably expressed as the isotopic dichotomy between carbonaceous (CC) and non-carbonaceous (NC) meteorites [1]. While planetary-scale isotopic heterogeneity is now well established, far less is known about how such heterogeneity is preserved or modified within individual bodies. Chondrites retain records of the materials accreted to their parent asteroids, however, parent-body processes can overprint or redistribute the inherited fingerprints. Consequently, isotopic heterogeneity observed in chondrites reflects an interplay between primordial nebular signatures and secondary processing. Bridging this internal heterogeneity with planetary-scale isotopic variations is essential for understanding how Solar System materials evolved from presolar sources to planetary building blocks.

Here we address this gap by focusing on samples returned from asteroid Ryugu by JAXA's Hayabusa2 mission. We performed coordinated analyses of nucleosynthetic Cr-Ti isotope anomalies, ^{53}Mn-^{53}Cr chronology, and multi-element chemical compositions for eight individual millimeter-sized Ryugu particles. These samples exhibit significant variation in ε^{54}Cr and ε^{50}Ti values exceeding the range observed in Ryugu aggregate samples [2], suggesting that the ^{54}Cr-rich and ^{50}Ti-rich phases are locally distributed within Ryugu materials, with each phase presumably retained in specific minerals. This notion is substantiated by a discernible correlation between the isotopic compositions and the chemical grouping of Ryugu particles. According to [3], Ryugu particles can be classified into three types: Type 1 shows enrichments in REEs with elevated P-Ca-Mn-Sr abundances, Type 2 exhibits most element abundances within ±20% of the average Ryugu composition, and Type 3 is depleted in REEs and P-Ca-Mn-Sr. We found that Type 1 particles exhibit comparatively low ε^{54}Cr and ε^{50}Ti values relative to Type 2 and 3 particles, reflecting evolutionary history of aqueous alteration in the Ryugu parent body. Despite the prevailing hypothesis that Ti is less susceptible to aqueous alteration than Cr, the Ti isotopic composition of Ryugu samples exhibited notable influence from water circulation, as evidenced by the mm-scale variability in ε^{50}Ti.

[1] Kleine et al. (2020), Space Sci Rev, 216, 55. [2] Yokoyama et al. (2023), Sci. Adv., 9, eadi7048. [3] Lopez Garcia