The relationship between Ryugu samples and CY and CI chondrites: Another twist in the tale.

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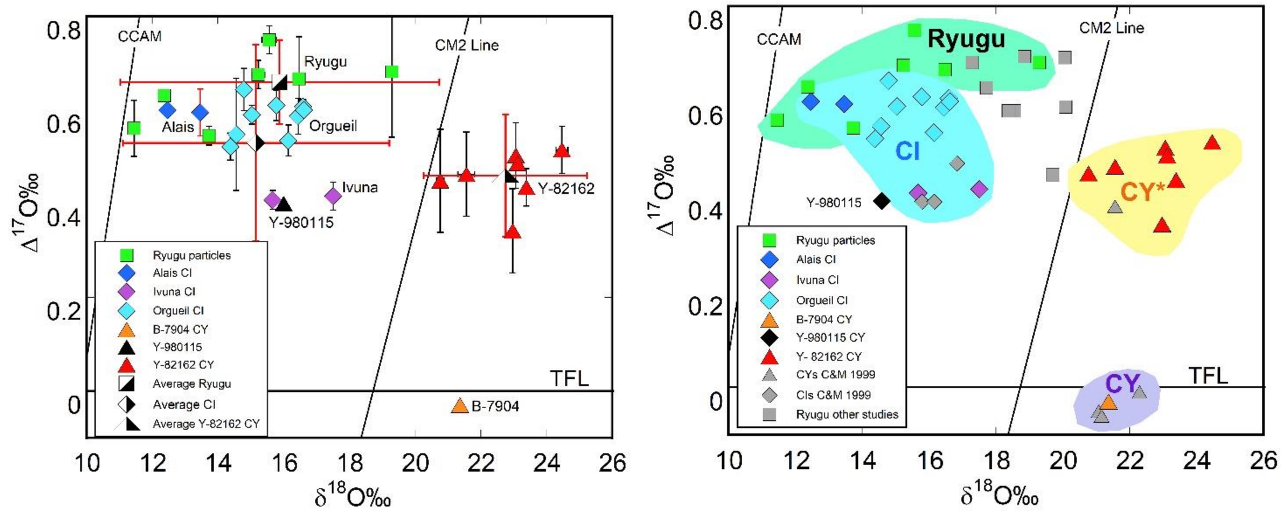
Between June 2018 and November 2019, the JAXA Hayabusa2 spacecraft made detailed observations and measurements of the C-type asteroid 162173 Ryugu. Two samples were collected and returned to Earth on 6th December 2020: a surface sample stored in Chamber A of the return capsule and a sub-surface sample in Chamber C. Near-IR orbital spectroscopic data indicated that Ryugu comprised material “similar to thermally and/or shock-metamorphosed carbonaceous chondrite meteorites” [1], with a possible match to the CY (Yamato-type) chondrites [2]. In contrast, initial studies at the JAXA ISAS facility suggested that the samples were “most similar to CI chondrites” [3]. As part of Phase2 Kochi curation studies [4], we have undertaken high precision oxygen isotope analysis of 4 Ryugu particles [5], with the aim of investigating their possible relationship to carbonaceous chondrites, in particular the CI and CY groups.

Seven sub-samples from four of the particles allocated to Kochi curation were analysed by laser fluorination [6]. Three particles were from Chamber C (C0014,21; C0068,21; C0087,2) and one from Chamber A (A0098, 2). CI chondrites Alais (n=2), Ivuna (n=2) and Orgueil (CI) (n=9), and CY chondrites B-7904 (n=1), Y-82162 (n=7) and Y-980115 (n=1) were analysed for comparison purposes. Sample transport, loading and analysis techniques employed ensured that the Ryugu particles were never exposed to atmospheric contamination [5]. All the samples in this study, with the exception of Y-82162, were run in “single shot” mode [7]. In most cases, due to the very small quantity of material involved, the amount of O_2 gas liberated during fluorination of the Ryugu particles was less than 140 µg, the approximate limit for bellows analysis on the MAT 253 mass spectrometer. In these cases analysis was undertaken using the MAT 253 cryogenic micro-volume. $\Delta^{17}O$ values were calculated as $\Delta^{17}O = \delta^{17}O - 0.52\delta^{18}O$ [5].

The weighted average of the Ryugu analyses (Fig. 1), both in terms of $\Delta^{17}O$ and $\delta^{18}O$, is close to CI average, but plots away from average value for the CY chondrite Y-82162 and our analysis of CY chondrite B-7904. Our new analysis of Y-980115 plots close to the CI chondrite Ivuna. However, while Y-980115 has been included in the CY group [2] it retains phyllosilicates and appears to have undergone variable heating [8]. Based on our new analysis, Y-980115 appears to have closer affinities to the CIs than the CYs. The data presented in Fig. 1 and 2 support the proposed relationship between Ryugu and the CI chondrites [3,4]. A possible match between Ryugu samples and CIs has also been suggested on the basis of bulk oxygen isotope data in two other recent studies [9.10].

Individual Ryugu analyses show a large range in $\delta^{18}O$ values, from 11.46‰ to 19.30‰ (Fig.1). This large range reflects intrinsic isotopic heterogeneity at the sampling scale involved [5], with detailed mineralogical studies [4,9,10] indicating a significant level of heterogeneity within individual Ryugu particles. In addition, SIMS analysis reveals that Ryugu mineral phases are isotopically heterogeneous, with magnetite and carbonates differing by more than 30‰ [11]. Calculations, using Ryugu modal data [4], yield bulk $\delta^{18}O$ values close to the range determined in this study [5]. There is a small resolvable difference between the average $\Delta^{17}O$ composition of the Ryugu particles and Orgueil, (0.66 ± 0.09‰ and 0.0.58 ± 0.09‰ respectively (2SD weighted)). Calculations indicate that this difference reflects the terrestrial contamination of Orgueil [5]. Orgueil is known to have undergone significant mineralogical alteration due to terrestrial contamination since its fall in 1864 [12]. Weathering in the terrestrial environment would pull the bulk analysis closer to the terrestrial fractionation line (TFL). This conclusion is consistent with evidence that interlayer water in Orgueil is of terrestrial origin [13], and that Orgueil contains ferrihydrite and sulphate [14], whereas Ryugu particles do not [4]. While Ryugu particles are the most uncontaminated CI-related material we have [5], they are not pristine and have been modified by a variety of processes in the regolith [15]. The evidence from Ryugu suggests that care needs to be taken when using CI meteorite data as Solar System proxy values e.g. [16].

Our new data has implications for the CY chondrites [2]. Instead of a single CY group our oxygen isotope data suggests that these meteorites may be derived from a minimum of two groups. Our data for Y-82162 is in agreement with that of [17] and shows a significant difference in $\Delta^{17}O$ compared to B-7904 (Fig.2). Y-86720 and Y-86789 are close in oxygen isotope composition to B-7904 [17] and can be considered to represent a sub-group. The $\Delta^{17}O$ difference between B-7904 sub-group and Y-82162 would appear to preclude the possibility that both are derived from a single parent body. The fact that Y-980115, previously proposed to be a CY [2], plots away from both of the other CY clusters reinforces the likelihood that dehydrated and partially dehydrated carbonaceous chondrites are derived from multiple parent bodies. We are currently undertaking further oxygen isotope analysis to try and better define the relationship between unheated, hydrated carbonaceous chondrites and those groups that experienced varying levels of dehydration subsequent to aqueous alteration [2]. But it is already clear that the relationships between these various groups is complex and likely involves multiple parent bodies.



Figs. 1,2 Oxygen isotopic composition of Ryugu particles compared to CI and CY chondrites. Additional CY and CI data [17], additional Ryugu analysis [9,10].

References

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