SAMARIUM AND NEODYMIUM ISOTOPIC COMPOSITIONS OF C-TYPE ASTEROID (162173) RYUGU.
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Introduction: The Hayabusa2 spacecraft returned 5.4 g of material from the Cb-type near-Earth asteroid (162173) Ryugu [1]. Petrologic analyses demonstrated that Ryugu samples are mixtures of fine- and coarse-grained fragments with few Ca-Al-rich inclusions or chondrules present [2]. Analyses of bulk elemental abundances revealed no systematic depletions relative to CI (Ivuna-like) chondrites as a function of volatility, unlike other carbonaceous chondrite (C-chondrite) groups, suggesting that Ryugu samples may be related to CI chondrites [1]. The relationship between Ryugu samples and C-chondrites, and more specifically CI chondrites, is further supported by bulk Ti [1], Cr [1], Fe [3], Cu [4], Zn [4], Ca [5] and O [1, 6] isotopic compositions and ^{53}Mn–^{53}Cr dating [1].

C-chondrites exhibit a ~30 ppm deficit in ^{142}Nd/^{144}Nd compared to terrestrial rocks. As this deficit is accompanied by elevated ^{145}Nd/^{144}Nd, ^{148}Nd/^{144}Nd, and ^{150}Nd/^{144}Nd ratios, the isotopic variations are best interpreted as nucleosynthetic in origin, reflecting a deficit in s-process Nd isotopes in C-chondrites compared to terrestrial Nd [7–11] along with some amount of additional contribution to ^{142}Nd from the radioactive decay of short-lived ^{146}Sm in an Earth reservoir with a superchondritic Sm/Nd ratio [12–14].

At the whole rock scale, nucleosynthetic anomalies in Sm in C-chondrites are expressed as a ~100 ppm deficit in ^{144}Sm/^{152}Sm [7, 13, 15]. The corresponding nucleosynthetic anomalies seen in ^{142}Nd/^{144}Nd in ordinary and enstatite chondrites compared to terrestrial Nd are smaller, ~15 ppm and ~10 ppm, respectively [13], but only C-chondrites have a resolved anomaly in ^{144}Sm. Apart from the ^{144}Sm anomaly, the main isotopic variability in Sm in extraterrestrial objects is caused by thermal neutron capture on ^{149}Sm to create ^{150}Sm caused by exposure to galactic cosmic rays [16]. Sm and Nd isotopic measurements can therefore enable further evaluation of potential genetic relationships between Ryugu samples and known chondrite groups and track the cosmic ray exposure history of Ryugu.

Samples: In this study, we measured the Sm and Nd isotopic compositions of six C-chondrites, including Murchison (CM2), Orgueil (CI1), Alais (CI1), Tarda (C2-ung), Tagish Lake (C2-ung), and two aliquots of Allende (CV3), and four Ryugu samples, including A0106 and A0106-A0107 from Chamber A (first touchdown) and C0107 and C0108 from Chamber C (second touchdown).

Methods: Initial sample processing and elemental separation chemistry was conducted at Tokyo Institute of Technology, and final Sm and Nd separation chemistry was conducted at the Carnegie Earth and Planets Laboratory (EPL) following the methods of [17]. A total of 2–6 ng of Sm and 7–18 ng of Nd per sample were processed for isotopic analyses. The Sm and Nd isotopic compositions were measured statically using 9 faraday cups equipped with 10^{13} ohm amplifiers on the EPL Triton XT thermal ionization mass spectrometer (TIMS). All ratios are expressed as parts per million (μ) deviations from terrestrial standards measured using the same techniques. The total procedural blank was always <1% of the sample amount for both Sm and Nd. Analyses of 4 samples each of BCR-2 and BHVO-2 using these techniques yielded average μ^{142}Nd = –3 ± 21 and –3 ± 11, respectively.

Results and Discussion: The μ^{142}Nd compositions of the C-chondrites measured in this study range to more negative values but overlap with previous measurements of C-chondrites within the larger analytical uncertainties associated with measuring low amounts of Nd in this study. Three of the Ryugu samples exhibit μ^{142}Nd deficits that are resolved from zero while one value is negative but overlaps with zero within the analytical uncertainty. The four values overlap within the analytical uncertainties with C-chondrite compositions (Fig. 1). The ^{145}Nd/^{144}Nd and ^{148}Nd/^{144}Nd measured for all samples are not resolved from the terrestrial standard, but the four Ryugu samples average to a μ^{150}Nd = 77 ± 38, compared to an average μ^{150}Nd of 40 ± 71 for the C-chondrites measured here. These compare with higher precision C-chondrite data measured on larger amounts of Nd that range from 0 to 60, with an average of 26 ± 7 reported by [10].

The CI chondrites measured in this study show larger μ^{149}Sm deficits than the CV, CM, and ungrouped chondrites, with the largest μ^{149}Sm deficit exhibited by Orgueil, which overlaps with the value from [7]. Three of the Ryugu samples (A0106, A0106-A0107, and C0107) exhibit negative μ^{149}Sm values that are resolvable from zero and within the range of C-chondrites, while the fourth (C0108) has a smaller μ^{149}Sm deficit that overlaps with both zero and two of the other Ryugu samples within the analytical uncertainties. The ^{150}Sm/^{152}Sm and ^{149}Sm/^{152}Sm ratios for the C-chondrites and Ryugu samples measured in this study fall along a calculated theoretical correlation line resulting from changing one atom of ^{149}Sm to ^{150}Sm, indicating that these isotopic compositions are the result of thermal neutron capture on ^{149}Sm (Fig. 2). The relatively small anomalies in ^{149}Sm and ^{150}Sm in the Ryugu samples are consistent with the short ~4–5 Myr cosmic ray exposure history previously reported for Ryugu samples [18, 19] and are smaller than the anomalies measured in Sm in two other CI chondrites, Alais and Orgueil, though in the case of the meteorites the exposure history includes the transit time required to reach Earth.

On the ^{147}Sm–^{143}Nd isochron diagram, ordinary chondrites, enstatite chondrites, and C-chondrites scatter along a 4.567 Ga isochron. Using the Sm/Nd ratios measured by ICP-MS [1] the Ryugu samples also scatter along this line within the analytical uncertainties in the range defined by chondrites.

Conclusions: The Sm and Nd isotopic compositions of Ryugu are consistent with a genetic relationship between Ryugu and C-chondrites, although the Ryugu samples display larger, though overlapping, deficits in ^{142}Nd/^{144}Nd, and shorter cosmic ray exposure histories than measured here for the CI chondrites Orgueil and Alais. These results also demonstrate the analytical capability to resolve Sm and Nd isotopic anomalies in C-chondrites and Ryugu samples in small, <10 ng sample sizes via TIMS using 10^{13} ohm amplifiers.

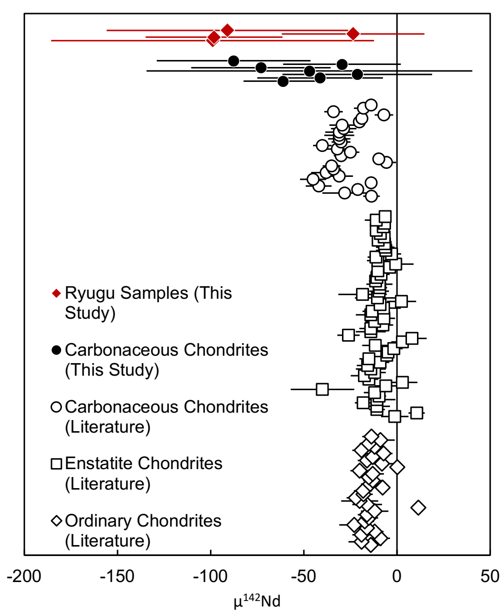

Fig. 1. The μ^{142}Nd compositions of Ryugu samples (red diamonds) and C-chondrites (black circles) from this study and ordinary chondrites (white diamonds), enstatite chondrites (white squares), and C-chondrites (white circles) from previous studies [7–14, 20]. Data are corrected for ^{146}Sm decay to an average chondritic ^{147}Sm/^{144}Nd = 0.1960 [21].

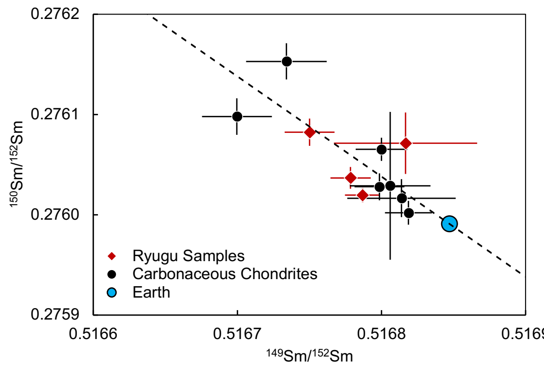

Fig. 2. ^{150}Sm/^{152}Sm vs. ^{149}Sm/^{152}Sm for the Ryugu samples (red diamonds) and C-chondrites (black circles) measured in this study. The black dashed line represents a calculated theoretical correlation resulting from changing one atom of ^{149}Sm to ^{150}Sm.

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