Molybdenum and Osmium isotopic compositions of Ryugu sample

Nao Nakanishi[1,2], Akira Ishikawa[2], Tetsuya Yokoyama[2], and Richard J. Walker[1],
The Hayabusa2-initial-analysis chemistry team, The Hayabusa2-initial-analysis core.
[1]*Dept. of Geology, University of Maryland,USA*
[2]*Dept. of Earth & Planetary Sciences, Tokyo Institute of Technology, Japan*

The Hayabusa2 mission conducted two sampling sequences on the Cb-type asteroid Ryugu and brought 5.4 g of the asteroidal materials back to Earth. The initial analyses found that Ryugu samples are dominated by minerals that experienced extensive aqueous alteration in the parent body and are related to CI (Ivuna-like) carbonaceous chondrites [1]. To further investigate the origin of the materials that accreted to form Ryugu and chemical processes that affected these materials after accretion we examined the isotopic compositions of the siderophile elements Os and Mo. Eleven $^{187}Os/^{188}Os$ ratios were obtained from bulk Ryugu samples (A0106-A0107, and C0108 from both sampling locations) using N-TIMS (*Triton Plus*) at Tokyo Tech. A composite sample of four bulk Ryugu samples that were combined (A0106-A0107, A0106, C0108, and C0107 from both sampling locations) was dedicated for the determination of the Mo isotopic composition of the composite using MC-ICP-MS (*Neptune Plus*) at UMd.

The bulk Ryugu samples have uniform $^{187}Os/^{188}Os$ ratios, averaging 0.1264 ± 0.0005 (2SD, n = 11) (Fig. 1), which is consistent with the $^{187}Os/^{188}Os$ ratio of bulk CI chondrites (0.1265 ± 0.0001, 2SD; [2]). This observation supports the main conclusion of previous studies that Ryugu is mainly composed of materials related to CI chondrites [3]. The uniform $^{187}Os/^{188}Os$ ratio implies homogeneous distribution of elemental Re/Os ratios of the Ryugu materials. This is likely to reflect the redistribution of Re and Os by aqueous alteration that occurred on the Ryugu parent body. Given the sample size for one analysis (0.4–1.1 mg), the Re/Os homogenization would be achieved even on a small scale.

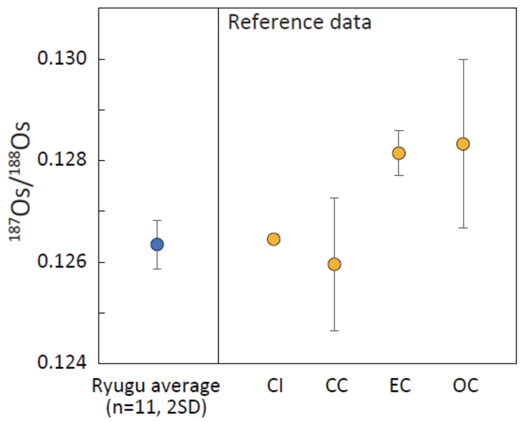

Figure 1. Os isotopic composition of Ryugu materials and chondrites. Reference data are from [2]. The error bars reflect the range of isotopic compositions measured for each category (Ryugu: 2SD; Chondrites: 1SD).

The composite bulk Ryugu sample analyzed for Mo is characterized by positive $\varepsilon^{i}Mo$ values ($\varepsilon^{i}Mo = [(^{i}Mo/^{96}Mo)_{sample}/(^{i}Mo/^{96}Mo)_{standard} - 1] \times 10^4$) for ^{92}Mo, ^{94}Mo, ^{95}Mo, and ^{97}Mo, consistent with a deficit of *s*-process Mo isotopes (Fig. 2). Previous studies have shown that Mo isotopic data for carbonaceous (CC) and non-carbonaceous (NC) meteorites define two separate linear trends on the $\varepsilon^{95}Mo$–$\varepsilon^{94}Mo$ diagram (e.g., [4]). The Ryugu sample plots on the CC line (Fig. 3), which is consistent with the observation that Ryugu samples are also characterized by CC-type $\varepsilon^{50}Ti$–$\varepsilon^{54}Cr$ isotopic systematics [3]. The $\varepsilon^{94}Mo$ and $\varepsilon^{95}Mo$ values for the composite Ryugu sample are larger than those of any known bulk carbonaceous chondrites including CIs (Fig. 3).

There are at least three possible explanations for the large *s*-process deficits in the Ryugu sample. First, the measured Mo isotopic composition might accurately reflect the composition of the bulk asteroid. In this case, it would suggest that Ryugu formed from a nebular region with a Mo isotopic composition that differed from that of the limited number of CI chondrites analyzed for Mo to date. This would be in conflict with the evidence from the lithophile Ti and Cr isotopic compositions. Second, Mo isotopes might have been heterogeneously distributed on the asteroid Ryugu. In this case, the Mo isotopic composition obtained from the ~70 mg of Ryugu material analyzed may not represent the bulk composition of the asteroid, and may instead reflect the redistribution and concentration of strongly *s*-process depleted Mo by aqueous processes. Third is incomplete dissolution of presolar SiC grains during the acid digestion steps, given that SiC grains are resistant to dissolution by the acid digestion techniques applied for this measurement. SiC is characterized by *s*-process-enriched compositions [e.g., 5]. A leachate study on Orgueil found that incomplete digestion creates anomalies in Mo isotopic composition [6]. Thus, the *s*-process deficit may reflect an absence of the SiC component contribution to the bulk composition.

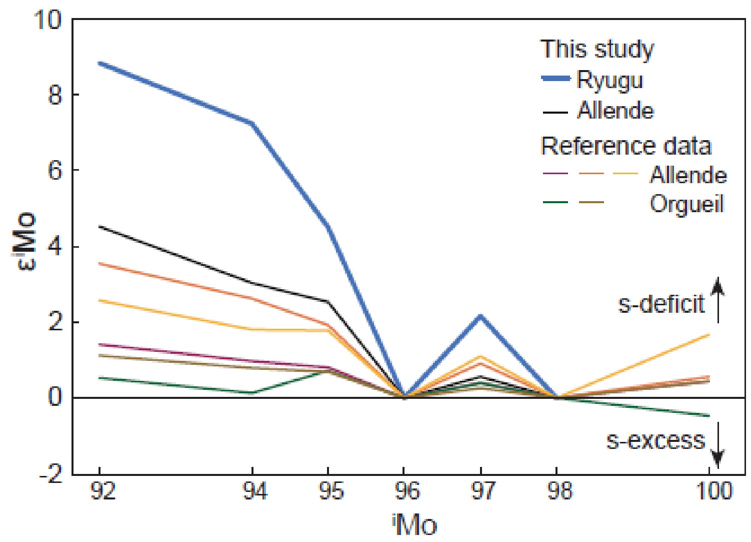

Figure 2. Mo isotopic composition of Ryugu and Allende analyzed in this study. The reference bulk meteorite data are from [6-8]

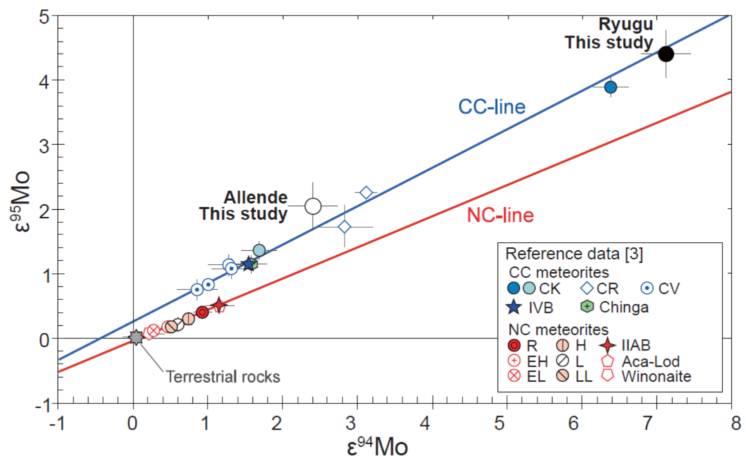

Figure 3. ε^{95}Mo-ε^{94}Mo diagram of Ryugu material and bulk Allende. The reference bulk meteorite data are from [8].

References

[1] Yada T. et al. 2022. Nature Astronomy 6:214. [2] Walker R. J. et al. 2002. GCA 66:4187. [3] Yokoyama T. et al. 2022 Science abn7850. [4] Kleine, T. et al. 2020. Space Sci. Rev. 216:1. [5] Stephan T. et al. 2019. ApJ 877:101. [6] Dauphas N. et al. 2002 ApJ 569:139. [7] Burkhardt C. et al. 2011. EPSL 312:390. [8] Yokoyama, T. et al. 2019. ApJ 883:62.

The Hayabusa2-initial-analysis chemistry team: T. Yokoyama, K. Nagashima, I. Nakai, E.D. Young, Y. Abe, J. Aléon, C.M.O'D. Alexander, S. Amari, Y. Amelin, K. Bajo, M. Bizzarro, A. Bouvier, R. W. Carlson, M. Chaussidon, B.-G. Choi, N. Dauphas, A. M. Davis, T. Di Rocco, W. Fujiya, R. Fukai, I. Gautam, M. K. Haba, Y. Hibiya, H. Hidaka, H. Homma, P. Hoppe, G.R. Huss, K. Ichida, T. Iizuka, T.R. Ireland, A. Ishikawa, M. Ito, S. Itoh, N. Kawasaki, N. T. Kita, K. Kitajima, T. Kleine, S. Komatani, A. N. Krot, M.-C. Liu, Yuki Masuda, K.D. McKeegan, M. Morita, K. Motomura, F. Moynier, A. Nguyen, L. Nittler, M. Onose, A. Pack, C. Park, L. Piani, L. Qin, S.S. Russell, N. Sakamoto, M. Schönbächler, L. Tafla, H. Tang, K. Terada, Y. Terada, T. Usui, S. Wada, M. Wadhwa, R.J. Walker, K. Yamashita, Q.-Z. Yin, S. Yoneda, H. Yui, A.-C. Zhang, H. Yurimoto.

The Hayabusa2-initial-analysis core: S. Tachibana, T. Nakamura, H. Naraoka, T. Noguchi, R. Okazaki, K. Sakamoto, H. Yabuta, H. Yurimoto, Y. Tsuda, S. Watanabe.