Primordial abundance of chondrule in CI chondrite

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CI chondrite is the most significant extraterrestrial sample to estimate the primordial materials in the Solar System. However, CIs lost the primordial features due to heavy aqueous alteration in their parent bodies. Nevertheless, small amounts of anhydrous minerals, such as olivine and pyroxene, have been reported from CIs and CI-related Ryugu samples (e.g., [1]). They are thought to be relicts of chondrule and refractory inclusion. Thus, it is highly probable that CIs had primarily comprised chondrule, refractory inclusion, opaque minerals, and matrix, before aqueous alteration, like other carbonaceous (C) chondrites. Here we estimate the primordial abundance of chondrule in CIs from the calculations based on the bulk chemical compositions of CIs. The parameters for calculations are as follows 1) The chemical compositions of primordial chondrule, refractory inclusion, and opaque minerals were similar to those in C chondrites that were not suffered from the aqueous alteration. 2) The primary matrix composition of CIs was close to the average bulk composition of CIs ([2]) as suggested by [3]. We use the average major elemental compositions of chondrule and refractory inclusion in Y-81020, CO3.05 (Kimura unpublished data), and their variable modal abundances arbitrarily selected for the calculations. Our results are within the range of previously reported CI bulk chemical compositions in case chondrule abundances are < 10 wt. %. If chondrule is more abundantly contained, the bulk composition becomes enriched in volatile elements, such as Na and S, like CM chondrites. The low abundance of chondrule obtained here is consistent with the rare occurrence of anhydrous minerals in CIs and Ryugu. We also calculate the bulk chemical compositions of Tagish Lake, ungrouped C2, which experienced aqueous alteration heavily, and chondrules rarely survived in it (e.g., [4])). Our results show that Tagish Lake primarily had <20 wt. % chondrules before the alteration. The estimated chondrule abundances of CIs and Tagish Lake are much lower than those in the other C chondrites.

The primary low abundance of chondrule in CIs should be closely related to the formation conditions and locations of chondrule. McCain et al. (Nature Astronomy, submitted) suggested that the alteration age of the Ryugu materials was ~1.4 Ma after CAI formation from Mn-Cr dating for carbonate. In this case, the CI chondrite parent body should have formed before chondrule formation, ~1.9 to 4 Ma after CAI formation (e.g., [5]). Almost fine-grained dust (precursor of the matrix) with abundant ice should have accreted to the CI parent body. On the other hand, Mn-Cr ages of carbonates in CI, CM, and Tagish Lake are also estimated to be 4–6 Ma after CAI formation (e.g., [6]). Carbonates in Ryugu formed 3-7 Ma after CAI (e.g.,[7]). In this case, chondrule formed before the accretion and alteration of the CI parent body. Therefore, the CI formation reservoir must have hardly contained chondrules to explain the low primary abundance of chondrules. Desch et al. [8] showed that CIs formed in the outer region of the solar system, >15AU, without chondrule and refractory inclusion, whereas CM and CO formed at 3–4 AU mainly based on the model calculation. Ito et al. [9] showed that Ryugu is partly related to comets. Bryson et al. [10] suggested that Tagish Lake formed at >8–13 AU based on paleomagnetic data. From them, we suggest that almost dust with abundant ice accreted to the CIs and Tagish Lake parent bodies in the outer Solar System. Chondrule had been hardly included in the precursor materials of CIs, whereas it slightly included those of Tagish Lake. On the other hand, chondrule had been primarily abundant for other C chondrite reservoirs in the inner Solar System, and dust and ice were poorer in abundance than those of CIs and Tagish Lake. The primordial chondrule abundance is one of the keys to clarify the physical and chemical conditions and evolution of the early Solar System.

References

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