Hibonite-bearing inclusions from Murchison (CM2) meteorite: A Mg isotopic study using a NanoSIMS. Shogo Sasaki[1], H. Hiyagon[1], W. Fujiya[1], N. Takahata[2] and Y. Sano[2], [1]Department of Earth and Planetary Science, Graduate School of Science, The University of Tokyo, [2]Atmosphere and Ocean Research Institute, The University of Tokyo.

Introduction

Hibonite ($CaMg_xTi_xAl_{12-2x}O_{19}$) is one of the most refractory minerals [e.g., 1] and may record high temperature process(es) in the early solar system. Hibonite-bearing inclusions in CM chondrites are morphologically divided into several types, such as SHIBs (Spinel-HIBonite inclusions), PLACs (PLAty Crystals) and BAGs (Blue AGgregates) [2]. It is known that these morphological types are strongly correlated with their isotopic characteristics [2, 3]. For example, SHIBs tend to show resolvable excesses in ^{26}Mg with the inferred initial ^{26}Al/^{27}Al ratios of ~4.5 x 10^{-5} (~canonical value [4]), while PLACs and BAGs generally lack resolvable excess ^{26}Mg or even show small apparent deficits in ^{26}Mg by 3-4 ‰ [5]. Also SHIBs tend to show no anomalies in Ca and Ti isotopes, while PLACs and BAGs tend to show isotopic anomalies (positive or negative) in ^{48}Ca and ^{50}Ti. Lack of excess ^{26}Mg in PLACs and BAGs suggests either they formed *after* ^{26}Al decayed completely or they formed *before* ^{26}Al was injected into the solar system from (a) nearby stellar source(s). The presence of Ca and Ti anomalies in PLACs and BAGs seems to support the latter interpretation [5]. If this is the case, various types of hibonite inclusions may represent different stages of early solar system evolution. Our goal is to understand the process(es) of isotopic homogenization in the early solar system.

Samples and analytical conditions

First, about 10 grams of Murchison meteorite was disaggregated using the freeze-thaw method, then a size separation, a magnetic separation and a density separation (using methylene iodide: ~3.3 g/cm^3) were applied. Candidates of hibonite-bearing inclusions (usually having light blue to blue colors) were hand-picked under an optical microscope from non-magnetic, dense fractions of the separated grains. After preliminary examinations of these grains with SEM-EDS, they were fixed on a glass slide with epoxy and were examined using an optical microscope. Finally the glass slide was polished so that surfaces of most of the grains were exposed together. About 30 hibonite-bearing inclusions were recovered in this study. So far, we analyzed two PLACs (MC026 and MC028), two SHIBs (MC042 and MC043), one "blue spinel" (MC003, spinel with some hibonite grains embedded in it [6]) and two grains with Fe-rich silicates (MC037 and MC040, composed of hibonite, spinel and Fe-silicates). Backscattered electron images of the selected grains are shown in Fig. 1.

The Al-Mg isotopic analyses were performed using NanoSIMS in Atmosphere and Ocean Research Institute, The University of Tokyo. A primary beam of $^{16}O^-$ with a diameter of 3-5μm and an intensity of 30-200pA was used for the analyses. Positive ions of Mg isotopes, $^{24}Mg^+$, $^{25}Mg^+$ and $^{26}Mg^+$, were detected using an electron multiplier (EM) (Tr4) by a peak jumping mode, and $^{27}Al^{++}$ was detected simultaneously with $^{24}Mg^+$ using another EM (Tr2). In order to detect Al ions using an EM for high Al/Mg samples, $^{27}Al^{++}$ instead of $^{27}Al^+$ was used in this study. Madagascar hibonite, placed and polished together with the Murchison hibonite grains on the same slide glass, was used as a terrestrial standard for Mg isotopes and Al/Mg ratios. Terrestrial hibonite standard was analyzed repeatedly during the analysis period and all the hibonite inclusion data were normalized to the terrestrial standard data to correct for instrumental mass fractionation of Mg isotopes and relative sensitivity factor of Al^{++}/Mg^+ for hibonite.

In order to precisely estimate excess ^{26}Mg, a correction for mass-dependent fractionation is essential, especially for extremely mass-fractionated samples. For this purpose, we adopted the formula recommended by Davis et al. [7], that is,

$$\delta^{25}\mathrm{Mg} = 1000 \times \ln\left\{\frac{(^{25}\mathrm{Mg}/^{24}\mathrm{Mg})_{\mathrm{sample}}}{(^{25}\mathrm{Mg}/^{24}\mathrm{Mg})_{\mathrm{std}}}\right\}\ (‰),$$

and similarly for δ^{26}Mg,

and

$$\Delta^{26}\mathrm{Mg} = \delta^{26}\mathrm{Mg} - \delta^{25}\mathrm{Mg}/0.514\ \ (‰).$$

Their evaporation experiments on CAI-like melt show that Mg isotope data line along a straight line with a slope of 0.514 on a δ^{25}Mg *vs* δ^{26}Mg plot. This fractionation law may also be applied to our hibonite samples.

Results

Preliminary data for Mg isotopes so far obtained are shown in a Δ^{26}Mg vs ^{27}Al/^{24}Mg plot (Fig. 2) and a δ^{25}Mg *vs* δ^{26}Mg plot (Fig. 3). Figure 2 clearly shows that there are two distinct groups in the hibonite-bearing inclusions. One group is SHIBs (MC042 and MC043), which show resolvable excess ^{26}Mg and the inferred ^{26}Al/^{27}Al ratio is consistent with the canonical ratio (~4.5 x 10^{-5}). The other group includes PLACs (MC026 and MC028), blue spinel (MC003) and two inclusions containing Fe-rich silicates (MC037 and MC040), which show Δ^{26}Mg values of almost zero or even negative (up to -3 to -4 ‰). These results are very consistent with the previous studies (see e.g., [5]), but in our case, blue spinel and other two inclusions (MC003, MC037 and

MC040) also belong to the latter group. It should be noted that the two inclusions containing Fe-rich silicates (MC037 and MC040) show extremely large mass fractionation in Mg isotopes even exceeding ~50 ‰/amu (Fig. 3). Blue spinel (MC003) also shows significant mass fractionation (~18 ‰/amu). Such large mass fractionation of Mg isotopes may be produced by significant evaporation of precursor melts and suggests some relations to so-called FUN inclusions [4].

An interesting observation is that PLACs may have negative Δ^{26}Mg of -3 to -4 ‰. This is consistent with the results of [5]. This can be interpreted by the presence of deficit in ^{26}Mg and/or excess in ^{25}Mg in PLACs. However, because of the limited number of analyses so far conducted and because of relatively large uncertainties including large corrections for mass-fractionation, the results are not conclusive at present. Further studies are required to confirm these results. It is also essential to study other isotope systems, such as O, Ca, Ti, Be, etc., and trace element studies as well, for better understanding the formation processes of hibonite-bearing inclusions, and hopefully, isotopic homogenization processes in the early solar system.

References

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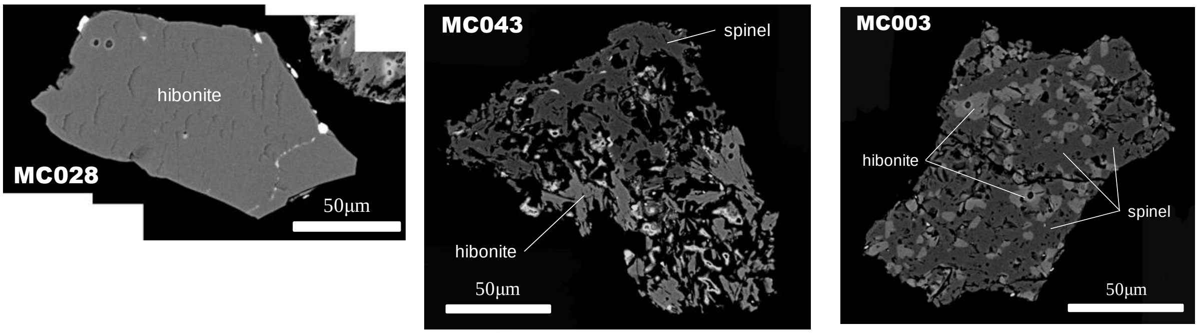

Fig. 1. Backscattered electron images of selected hibonite-bearing inclusions from Murchison: MC043 (SHIB), MC028 (PLAC) and MC003 (blue spinel).

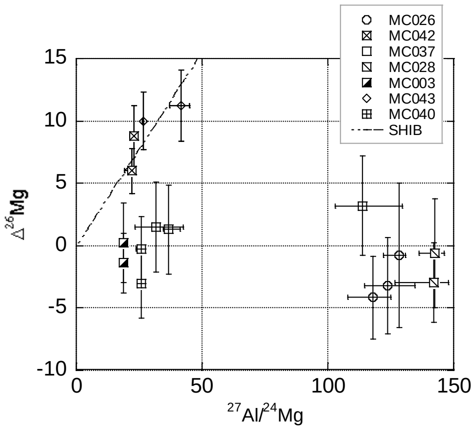

Fig. 2. Excess ^{26}Mg (Δ^{26}Mg) *vs* ^{27}Al/^{24}Mg diagram for hibonite-bearing inclusions. SHIBs show resolvable excesses in ^{26}Mg, while PLACs, blue spinel and two inclusions with Fe-rich silicates show almost no, or even slightly negative, Δ^{26}Mg.

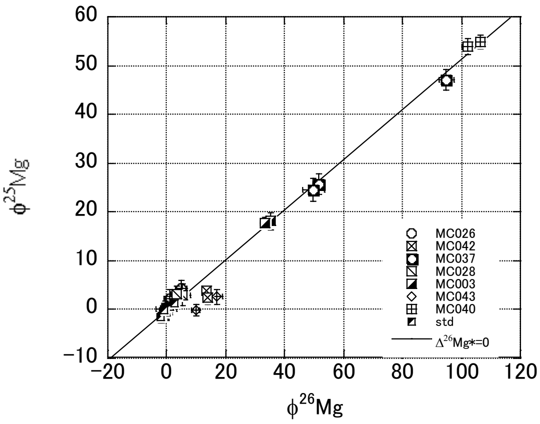

Fig. 3. A ϕ^{25}Mg *vs* ϕ^{26}Mg plot. PLACs show extremely large mass fractionation of up to ~50 ‰/amu, and blue spinel also shows relatively large mass fractionation (~18 ‰/amu).