Discovery of New hibonite-bearing FUN inclusions from the Murchison(CM2)meteorite.

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Introduction:

Refractory inclusions [Calcium-aluminum-rich inclusions, (CAIs)] are the oldest known solar system solids and would retain information about the early solar system evolution [1]. There is a minor group of CAIs, so called FUN (*F*ractionation and *U*nidentified *N*uclear effects [2]) CAIs, which exhibit distinct isotopic characteristics: (i) large mass-dependent fractionation in O, Mg and Si preferring heavy isotopes (F-signature), (ii) presence of unknown nuclear effects, esp., positive or negative anomalies in ^{48}Ca and ^{50}Ti (UN-signature), and (iii) little or no excess ^{26}Mg (and excess ^{41}K) from the decay of ^{26}Al (and ^{41}Ca). Absence of excess ^{26}Mg suggests either their late formation *after* the complete decay of ^{26}Al, or their early formation *before* injection of ^{26}Al into the solar system from (a) stellar source(s). The presence of Ca and Ti isotopic anomalies may suggest their earlier formation. The origin of FUN CAIs is still not well understood, but they may have important information about evolution and isotopic homogenization process(es) in the early solar system.

We found three FUN-like hibonite-bearing inclusions (MC037, MC040, MC003) from the Murchison (CM2) meteorite, which exibit extremely large mass-dependent fractionation in Mg isotopes (up to ~55‰/amu) but almost no excess in ^{26}Mg. Assuming a Rayleigh distillation process, more than 95% of Mg must have been lost (evaporated) from the molten precursors of these inclusions [3]. In order to better understand their origin and evolution, we conducted electron backscattered diffraction (EBSD) analyses and ion microprobe analyses of Mg, Ca and Ti isotopes on these inclusions.

Samples:

Two inclusions, MC037 (~150μm x ~200μm) and MC040 (~200μm x ~200μm), consist of abundant hibonite grains (5-30μm) with some spinel grains (5-10μm for MC037 and 10-30μm for MC040) embedded in Fe-rich silicates. Numerous μm-sized perovskite grains are almost uniformly distributed in Fe-rich silicate portion of MC040. They are probably the exsolution product from rapidly cooling melt. MC037 also contains perovskite in the Fe-rich silicate portion. Seven μm-sized ultra-refractory metal grains (enriched in Pt, Ru, Ir, etc.) are found in both inclusions. They also may be produced by severe evaporation of more volatile Fe-Ni-rich metal grains [4].

MC003 (~100μm x ~100μm) are composed mostly of spinel with rounded hibonite grains (3-20μm). This inclusion is similar to Blue Spinel by Ireland et al. [5].

Analytical conditions:

EBSD analyses: Silicates and perovskites of MC037 and MC040 were analyzed by a SEM-EBSD (Hitachi S-4500) at The University of Tokyo. The EBSD was used to identify mineral phases by Kikuchi lines. The obtained Kikuchi patterns were analyzed using a software developed by Kogure [6].

Mg isotopes: Magnesium isotopes were measured using a NanoSIMS at AORI, The University of Tokyo. Analytical details were previously described in [7]. In order to precisely estimate excess ^{26}Mg, a correction for mass-dependent fractionation, presumably caused by an evaporation process, is essential and we adopted the formula recommended by Davis et al. [8], where $\varphi(^{25,26}\text{Mg})$ is defined by $1000 \times \ln\{(^{25,26}\text{Mg}/^{24}\text{Mg})_{\text{sample}}/(^{25,26}\text{Mg}/^{24}\text{Mg})_{\text{std}}$ and $\Delta^{26}\text{Mg} = \varphi(^{26}\text{Mg}) - \varphi(^{26}\text{Mg})/0.514$. The fractionation factor (0.514) was experimentally determined using a CAI-like melt composition [8], which may also be applied to the FUN-like inclusions in this study.

Ca and Ti isotopes: Calcium and titanium isotopes were measured using a CAMECA ims-1270 ion microprobe at AIST, Tsukuba, Japan. Analytical details were previously described in [7,9,14]. An exponential law was applied for Ca and Ti isotopes, with ^{40}Ca and ^{44}Ca for reference isotopes of Ca, and ^{46}Ti and ^{48}Ti for reference isotopes of Ti [9]. Measured ratios for Madagascar hibonite standard were consistent with the literature values within uncertainties [10,11].

Results and discussion:

EBSD analyses obtained no Kikuchi pattern from Fe-rich silicates of MC037 and MC040, indicating that it is indeed amorphous. The result is considered that two inclusions were quenched from molten precursors.

Magnesium isotope data are plotted in the $\varphi(^{25}\text{Mg})$ *vs* $\varphi(^{26}\text{Mg})$ diagram (Fig. 1). All the data for MC037, MC040 and MC003 lie on the mass fractionation line within uncertainties. Data for MC040 and MC003 show rather homogeneous composition with φ(^{26}Mg) from ~97‰ to ~107‰ and ~29‰ to ~35‰, respectively. However, MC037 data show highly heterogeneous composition with φ(^{26}Mg) from ~27‰ up to ~95‰. Hibonite and spinel in MC037 probably crystallized at various stages of the evaporation event, while those in MC040 and MC003 only at the last stage of the evaporation event, suggesting slightly different heating conditions for these inclusions. Figure 2 shows a Δ^{26}Mg *vs* ^{27}Al/^{24}Mg diagram. All the data for these inclusions show no excess ^{26}Mg (Δ^{26}Mg ~0) within uncertainties. Again MC037 data show large variations in the ^{27}Al/^{24}Mg ratio.

The obtained Ca and Ti isotopic compositions are shown in Figs. 3 and 4, respectively. These inclusions have small (< ± 10‰) but resolvable anomalies in ^{48}Ca and ^{50}Ti.

Highly fractionated Mg isotopes, lack of resolvable excess in ^{26}Mg and existence of ^{48}Ca and ^{50}Ti anomalies suggest that they are newly found FUN CAIs. The present results and previous works show that there are variations in F, UN, and ^{26}Mg excess signatures among different types of FUN (F) CAIs [11,12,13].

Outlook:

We are planning to measure oxygen isotopic compositions of these inclusions using SIMS, and the results may be presented at this meeting if possible.

References:

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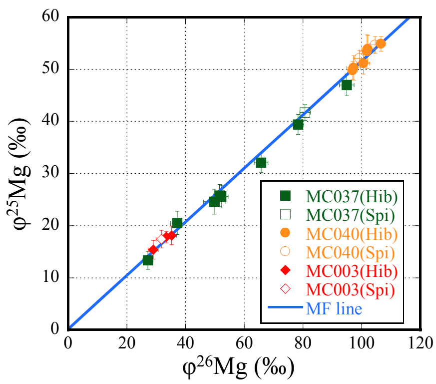

Fig. 1. The φ^{26}Mg-φ^{25}Mg plot for MC037, MC040 and MC003. Hibonite and Spinel in these inclusions show extremely large mass fractionation of up to ~55‰/amu.

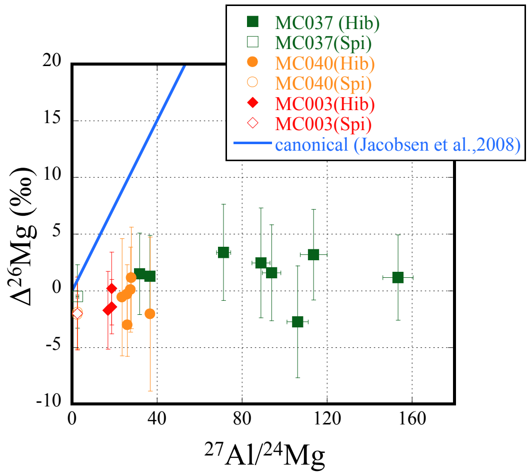

Fig. 2. Excess ^{26}Mg (Δ^{26}Mg) *vs* ^{27}Al/^{24}Mg diagram for MC037, MC040 and MC003. The Blue line represents the canonical ^{26}Al/^{27}Al = (5.23 ± 0.13) × 10^{-5} by Jacobsen et al. [14]. All the data for these inclusions show almost no excess ^{26}Mg.

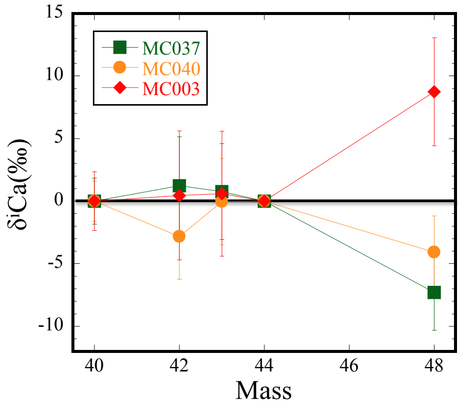

Fig. 3. Normalized Ca-isotopic compositions of the MC037, MC040 and MC003. MC037 and MC040 have negative anomaly in ^{50}Ti, but MC003 has positive one relative to the terrestrial value [10].

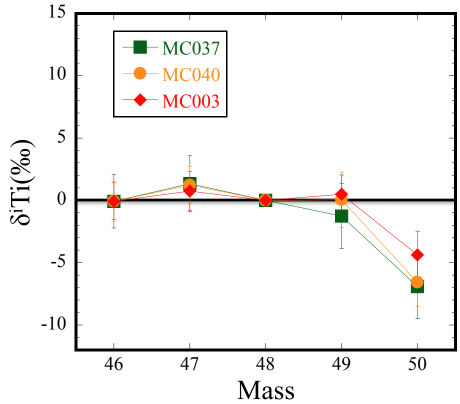

Fig. 4. Normalized Ti-isotopic compositions of the MC037, MC040 and MC003. All the data for these inclusions show negative anomaly in ^{50}Ti relative to the terrestrial value [11].