A SEARCH FOR INTERNAL ^{26}AL ISOCHRONS IN CM HIBONITE

Ming-Chang Liu[1], Larry R. Nittler[1], Conel M. O'D Alexander[1] and Typhoon Lee[2]. [1]Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington DC, 20015 (mliu@dtm.ciw.edu), and [2]Institute of Earth Sciences, Academia Sinica, Taipei, Taiwan.

Introduction: Hibonite ($CaAl_{12}O_{19}$) has long been recognized as one of the first solids in the solar system from a thermodynamic perspective [1] and it generally occurs in CM chondritic meteorites as individual, 30–80μm inclusions [2]. Morphological studies by Ireland (1988) classified these inclusions into three groups: Spinel-HIBonite spherules (SHIBs), PLAty hibonite Crystals (PLACs) and Blue AGgregates (BAGs) [3]. SHIBs primarily consist of intergrown spinel and hibonite crystals of various sizes ($\lesssim 15\mu$m), whereas PLACs and BAGs are typically monomineralic, with exceptions of rare occurrences of corundum inclusions.

Numerous ion microprobe measurements have demonstrated that Mg isotopic compositions categorize CM hibonite grains into two distinct populations that are correlated with hibonite morphology [3, 4, 5, 6, 7]. SHIBs are broadly characterized by ^{26}Al/^{27}Al = (4.5–5)$\times 10^{-5}$, consistent with the so-called "canonical" ratio found in a majority of Ca-Al-rich Inclusions (CAIs) [8]. However, it should be pointed out that the relatively large analytical errors would allow for an apparent scatter of ^{26}Al/^{27}Al up to 7×10^{-5} [9]. On the contrary, PLACs and BAGs generally lack resolvable excesses of radiogenic ^{26}Mg. This ^{26}Al distribution, along with other isotopically anomalous signatures that are exclusive to PLACs/BAGs, leads to a qualitative chronological scenario that SHIBs formed concurrently with CAIs, and PLAC/BAG formation should have taken place prior to SHIBs/CAIs [6, 10].

The above interpretation is based on the assumption that ^{26}Al/^{27}Al = $(4.5 - 5) \times 10^{-5}$ characterizes the solar system initial value and that ^{26}Al/^{27}Al in SHIBs is truly "canonical". However, it should be pointed out that none of the ^{26}Al/^{27}Al ratios is actually deduced from an internal isochron in individual SHIBs, but instead from a "two-point" regression, i.e. connecting a SHIB point to the origin where ^{26}Mg/^{24}Mg = 0.13932 and ^{27}Al/^{24}Mg = 0 [e.g. 3, 4]. This is because a typical primary beam size ($\sim$10–15μm) for Mg isotopic analyses in SHIBs is insufficient to spatially resolve the complicated intergrown phases and one can only conduct one measurement in each grain in most cases (a typical SHIB is $\sim$30–40μm across) [e.g. 3, 4, 7]. Therefore, not only are the measured Mg isotopic compositions mixtures of hibonite and spinel, but the ^{26}Al/^{27}Al ratio inferred from a two-point isochron may not fully represent the true ratio at SHIB formation if the grain was subject to isotopic reset-

ting and only part of the grain was sampled. To ensure that both SHIBs and CAIs are characterized by the same ^{26}Al/^{27}Al, an internal isochron approach for SHIBs is necessary. Here we report the first high spatial-resolution investigation of the internal Mg isotopic distribution in a CM spinel-hibonite spherule.

Experimental: An attempt to seek an internal ^{26}Al isochron in a SHIB that had been previously studied by [7] was performed on the Carnegie CAMECA NanoSIMS 50L under two different modes. For isotope analyses (spot mode), a $\sim$0.2–0.5 pA ^{16}O primary beam (depending on Mg content) was slightly defocused onto the sample surface for a 5μm $\times$ 5μm raster, generating a ^{24}Mg signal $\sim (1-2)\times 10^5$ counts per second. For isotope imaging (image mode), a 30μm $\times$ 30μm raster was made with a $\sim$0.3 pA focused primary beam. In each case, secondary ions were collected simultaneously by multiple detectors, with ^{24}Mg$^+$, ^{25}Mg$^+$ and ^{26}Mg$^+$ on electron multipliers (EMs) and ^{27}Al$^+$ (spot mode) or ^{27}Al^{2+} (image mode) on a Faraday cup or an EM, respectively. The mass resolution was set at $\sim 10,000$ (the slope between 10% and 90% of a peak) to separate hydrides, ^{48}Ca^{2+} and ^{50}Ti^{2+} from the peaks of interest. A synthetic pyroxene glass (courtesy of Kevin McKeegan) was used as a standard to calculate the intrinsic mass fractionation (δ^{25}Mg and δ^{26}Mg) and the excesses of radiogenic ^{26}Mg ($\equiv \Delta^{26}$Mg*) by sample-standard bracketing and to determine the Al/Mg and the ^{27}Al$^+$/^{27}Al^{2+} relative sensitivity factors (RSF). An exponential mass fractionation law with exponent = 0.514 was assumed [11]. Isotope image processing was carried out with the L'Image software developed under the PV-Wave environment.

Result and Discussion: The internal magnesium isotopic distribution in the SHIB is summarized in Fig. 1. Each data point is the weighted average of 5 duplicated analyses of hibonite. Spinel was excluded in this trial due to insufficient precision to conclusively resolve ^{26}Mg excesses. This preliminary result shows that one spot exhibits well-resolved Δ^{26}Mg* that yields an inferred ^{26}Al/^{27}Al $\sim 6 \times 10^{-5}$, corroborating the result in [7]; whereas the other two points, $\sim 10 - 30\mu$m away from the first point, are essentially "normal". An internal isochron obtained from isotope imaging of the area where the three spot analyses were conducted is

2

shown in Fig. 2. The best fit yields an ^{26}Al/^{27}Al of $(5.31 \pm 3.18) \times 10^{-5}$ with an intercept $(\Delta^{26}Mg^*)_0 = (-0.85 \pm 4.56)$‰ ($\chi^2 = 2.1$). Unfortunately, large analytical uncertainties does not allow a precise determination of the initial ^{26}Al/^{27}Al ratio in this grain

The SHIB appears to be isotopically heterogeneous among three 5μm spots (Fig. 1), which is most likely attributed to fine-scaled redistribution of Mg isotopes in this sample. This may imply that hibonites in SHIBs might not be as resistant to Mg isotopic resetting as was generally believed. From this view, all previous SHIB measurements carried out with a $\gtrsim$10–15μm primary ion beam might have been more or less compromised by partial disturbance, and the observed scatter of inferred initial ^{26}Al/^{27}Al ratios [e.g. 3, 4, 5, 6, 7] would be a natural outcome.

However, at this point we are not fully convinced that the observed Mg heterogeneity in this sample is real. This is because the sample surface might not be evenly flat, even though it had been repolished after being severely sputtered for various isotope measurements. For ultra fine-scaled analyses, the uneven flatness might cause different degrees of charging from one spot to another, which makes the control of instrumental mass fractionation difficult. This apparent heterogeneity might have simply been an artifact and would need to be confirmed after further repolishing the sample, if possible. Another caveat is that the RSF determined from the pyroxene glass might not be applicable to hibonite due to the difference in matrices. A wrong RSF, which leads to a wrong ^{27}Al/^{24}Mg ratio, would impact the resulting ^{26}Al/^{27}Al, although in this case we do not expect a significant change when an RSF obtained from an oxide standard is applied.

This survey is still ongoing. Several improvements will be made for the future work. First, we will start with fresh samples to avoid charging effects. Second, proper oxide standards, such as Madagascar hibonite or terrestrial spinel, will be placed nearby the samples for better characterizations of the RSFs and to ensure that samples and standards are analyzed under a similar condition. Third, sample-standard bracketing needs to be performed more often to minimize the fractionation effects caused by drifting of the machine. Stay tuned.

References

[1] Grossman, L. (1972). *GCA*, 36, 597–619. [2] Brearley, A. and Jones, R. H. (1998). *Planetary Materials*, 36, 3:01 − 3:370. [3] Ireland, T. R. (1988). *GCA*, 52,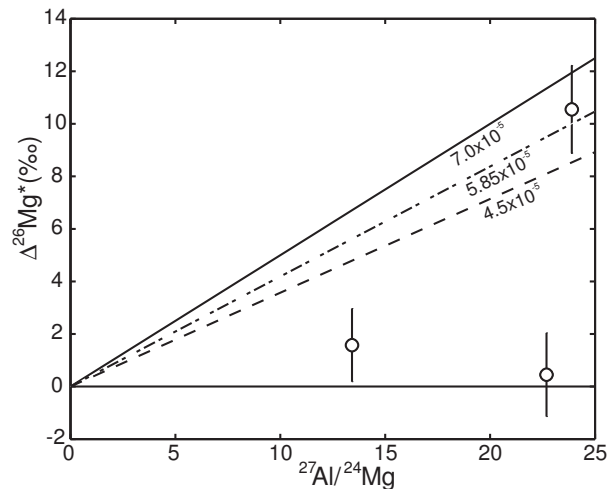 2827–2839. [4] Fahey, A. J. et al. (1987). *GCA*, 51, 329–350. [5] Ireland, T. R. (1990). *GCA*, 54, 3219–3237. [6] Sahijpal, S. et al. (2000). *GCA*, 64, 1989–2005. [7] Liu, M.-C. et al. (2009). *GCA*, (*in press*). [8] MacPherson, G. J. et al. (1995). *Meteoritics*, 30, 365–386. [9] Liu, M.-C. and McKeegan, K. D. (2005). *MAPS*, 40, Abstract #5304. [10] Sahijpal, S. and Goswami, J. N. (1998). *ApJL*, 509, 137–140. [11] Davis, A. M. et al. (2005). *LPS*, 36, Abstract #2334.

Figure 1: Magnesium isotope distributions in the SHIB. Three reference lines represent three different initial ^{26}Al/^{27}Al ratios. Errors in ^{27}Al/^{24}Mg are smaller than the symbol size. All errors are 2σ.

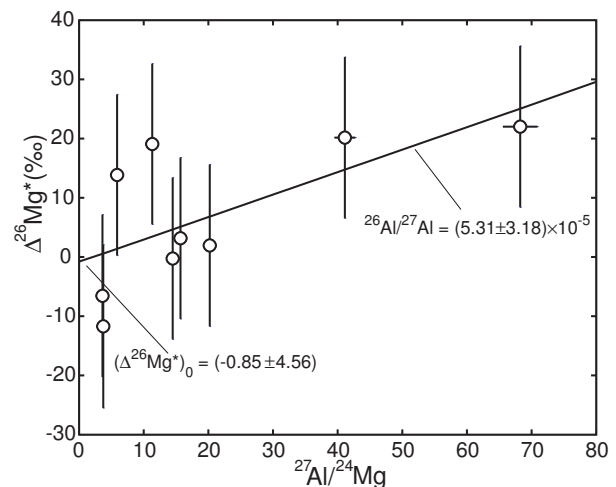Figure 2: An internal isochron diagram obtained from isotope imaging. All errors are 2σ.