BORON ISOTOPIC COMPOSITIONS IN CM HIBONITES: A NANOSIMS APPROACH
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**Introduction:** An outstanding question in cosmochemistry concerns the origins of short-lived radionuclides in the early Solar System. Two short-lived isotopes, $^{10}$Be ($t_{1/2} = 1.5$ My) and $^7$Be ($t_{1/2} = 53$ days), can only be produced via energetic particle spallation [1]. Thus, a quantitative understanding of the initial abundances and distributions of these two radionuclides in meteorites could help constrain the irradiation environment in the solar nebula.

It is now well established that $^{10}$Be was present in various types of refractory inclusions with different inferred $^{26}$Al/$^{27}$Al ratios. The inferred $^{10}$Be/$^9$Be ratios range from $(3–4) \times 10^{-4}$ up to $18 \times 10^{-4}$, albeit with significant analytical errors in most cases [2, 3, 4, 5, 6]. Amongst $^{26}$Al-bearing CV CAIs, the best constrained initial $^{10}$Be/$^9$Be = $(8.8 \pm 0.6) \times 10^{-4}$ (2$\sigma$) [7]. For $^{26}$Al-free inclusions, the most precise $^{10}$Be/$^9$Be ratio of $(5.1 \pm 1.4) \times 10^{-4}$ (2$\sigma$) was obtained in a suite of CM PLAty hibonite Crystals (PLACs) [6]. Within errors, $^{10}$Be/$^9$Be ratios in other $^{26}$Al-free objects corroborate this value [4, 5, 8].

Live $^{10}$Be in the early solar system most likely formed as a consequence of protosolar irradiation with variable abundances in meteorites arising from varied irradiation histories [2, 3, 4, 5, 6]. This view was challenged by a proposition that $^{10}$Be was derived from trapped Galactic Cosmic Ray (GCR) nuclei by the magnetic fields of the progenitor molecular cloud core [10]. However, a comparison between $^{26}$Al-bearing CAIs and $^{26}$Al-free PLACs suggested that the difference in $^{10}$Be/$^9$Be has no chronological meaning [6]. This contradicts a major prediction of the trapping model, making it less likely to be the primary $^{10}$Be contributor.

The above argument that $^{10}$Be was of solar irradiation origin is based on a chronological viewpoint. If one aims to quantitatively understand the spatial distribution of $^{10}$Be in a certain time period, examinations of different objects that formed closely in time would be needed. CM Spinel-HIBonite spherules (SHIBs) would be a good target for this purpose, as their $^{26}$Al/$^{27}$Al indicates that they formed $\sim 1 \times 10^5$ years after CAIs [6]. However, resolvable $^{10}$Be excesses have not yet been found in SHIBs, primarily because of pervasive B contamination from surface cracks and the lack of large surface area for a typical ion probe spot ($\sim 30 – 50 \mu$m, [e.g., 6]). This problem could hopefully be overcome with the high spatial resolution of the NanoSIMS. Here we report the preliminary results of Be-B isotopic measurements in CM hibonites obtained with the CIW NanoSIMS 50L.

**Experimental:** Hibonite grains were hand-picked from an acid residue of the Murchison meteorite prepared at the University of Chicago (courtesy of Andy Davis). Of 3 dozen hibonite samples found, only 6 grains (2 SHIBs and 4 PLACs) that had large enough areas of hibonite ($\sim 20 – 40 \mu$m across) were selected for measurements.

For the Be-B measurements, a 16 KeV $^{16}$O$^-$ primary beam with an intensity of $\sim 5–10$ nA ($\phi \sim 7 – 10 \mu$m) was used to generate a $\sim 15 \times 15 \mu$m$^2$ raster over polished, epoxy-mounted samples. Beam blanking was applied in every analysis, so that only signals from the central $6 \times 6 \mu$m$^2$ area were collected. This helped to eliminate contributions from scattered ions from the surroundings. Before each measurement, the sample was pre-sputtered for 5–10 mins until the B signal became steady. The mass resolution was sufficient to resolve interferences (e.g., hydrides, $^{27}$Al$^{3+}$, $^{28}$Si$^{4+}$) from peaks of interest. Secondary ions ($^{6}$Li$^+$, $^{7}$Li$^+$, $^{9}$Be$^+$, $^{10}$B$^+$, $^{11}$B$^+$, $^{27}$Al$^{10+}$) were counted simultaneously with six electron multipliers. The counting time of each cycle was optimized based on the count rate of $^{10}$B ($\sim 0.003$ counts/sec $\sim 10$ counts/sec) to reach sufficient counting statistics. Each analysis was comprised of 300 cycles, so that the total analytical duration ranged from 1.5 hours to 3 hours. Sample charging was monitored and corrected for every 30 cycles. The backgrounds of the EMs ($\sim 0.003$ counts/sec) were measured overnight when measurements were not being performed. The deadline effect of the counting system was negligible because of the low intensities of secondary ions ($\lesssim$ a few thousand counts/sec). Under such low count rates, the analytical uncertainty was primarily determined by counting statistics.

The instrumental mass fractionation (IMF) and relative sensitivity factor (RSF) of Be to B were characterized on a NBS612 glass ($^{10}$/B$^{11}$B = 0.2469; $^{9}$/Be$^{11}$B = 1.79 [11]). Contributions from spallogenic $^9$Be, $^{10}$B, and $^{11}$B in hibonite samples by GCRs were also estimated. However, they were insignificant compared to the analytical errors.

**Result and Discussion:** The B isotopic compositions of the measured grains are shown in Fig 1.
\(\delta^{10}\text{B}\) ranges from \(-13\%\) to 330\%. The best fit through all the points yields a slope corresponding to \(^{10}\text{Be}/^{9}\text{Be} = (5.7\pm 1.6) \times 10^{-4}\), with an intercept \(^{10}\text{B}/^{9}\text{B} = 0.250 \pm 0.004 \) (2\(\sigma\)). Two points with the highest \(\text{Be}/\text{B}\) ratios are from the same PLAC grain. Although this correlation line is primarily defined by the two high points, the reduced \(\chi^2 = 1.3\) indicates that all the hibonite grains could have sampled a common \(^{10}\text{Be}\) reservoir. This result corroborates the previous estimates by [4] and [6]. If we combine the NanoSIMS results with those in [6] obtained with CAMECA IMS1270 (Fig. 2), the slope of the best fit yields a \(^{10}\text{Be}/^{9}\text{Be} = (5.3\pm 1.0) \times 10^{-4}\) and intercept of 0.252 \pm 0.002 (\(\chi^2_{\text{red}} = 1.3\)).

The \(^{10}\text{Be}/^{9}\text{Be}\) value of \((5.3\pm 1.0) \times 10^{-4}\) in \(^{26}\text{Al}\)-free CM PLACs further argues against the GCR-trapping model of [10]. Assuming chronological significance for \(^{10}\text{Be}\), the minimum difference in formation time between \((5.3\pm 1.0) \times 10^{-4}\) (PLACs) and \((8.8\pm 0.6) \times 10^{-4}\) (CAIs, [7]) is \sim 0.6\ My, inconsistent with what is inferred from \(^{26}\text{Al}/^{27}\text{Al}\) ratios (\(> 3\) My, e.g., [12]). A heterogeneous distribution of \(^{10}\text{Be}\) seems a more likely explanation. Another line of evidence for a heterogeneous distribution of \(^{10}\text{Be}\) comes from the initial \(^{10}\text{B}/^{11}\text{B}\). The initial ratios for PLACs (0.252 \pm 0.002) and for Allende CV CAIs (0.253 \pm 0.001, [2, 7]) are essentially identical, indicating that these solids formed in the same B reservoir whose average \(^{10}\text{B}/^{11}\text{B}\) was not affected by the widespread decay of \(^{10}\text{Be}\). Thus, we conclude that all these observations can be best explained by \textit{in-situ} production of \(^{10}\text{Be}\) by protosolar irradiation.

Unfortunately, this study fails to obtain resolvable \(^{10}\text{B}\) excesses in SHIBs because they appear to have much more B than do PLACs. Even though we were able to analyze pure hibonite, low \(^{9}\text{Be}/^{11}\text{B}\) ratios (<1) would have obscured any \(^{10}\text{B}\) excesses, if present. The high B concentrations in SHIBs might have been due to introduction of “common boron” into hibonite during either remelting (SHIBs crystallized from a melt e.g., [13]), or alteration through cracks. Therefore, meaningful comparisons of \(^{10}\text{Be}/^{9}\text{Be}\) between \(^{26}\text{Al}\)-bearing SHIBs and CAIs still remain difficult, if not impossible.

References