

BORON ISOTOPIC COMPOSITIONS IN CM HIBONITES: A NANOSIMS APPROACH

Ming-Chang Liu^{1,2}, Larry R. Nittler¹, Conel M. O'D Alexander¹ and Typhoon Lee². ¹Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington DC, 20015 (mliu@dtm.ciw.edu), and ²Institute of Astronomy and Astrophysics, Academia Sinica, Taipei, Taiwan.

Introduction: An outstanding question in cosmochemistry concerns the origins of short-lived radionuclides in the early Solar System. Two short-lived isotopes, ¹⁰Be ($t_{1/2} = 1.5$ My) and ⁷Be ($t_{1/2} = 53$ 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 ¹⁰Be was present in various types of refractory inclusions with different inferred ²⁶Al/²⁷Al ratios. The inferred ¹⁰Be/⁹Be ratios range from $(3-4) \times 10^{-4}$ up to 18×10^{-4} , albeit with significant analytical errors in most cases [2, 3, 4, 5, 6]. Amongst ²⁶Al-bearing CV CAIs, the best constrained initial ¹⁰Be/⁹Be = $(8.8 \pm 0.6) \times 10^{-4}$ (2σ) [7]. For ²⁶Al-free inclusions, the most precise ¹⁰Be/⁹Be ratio of $(5.1 \pm 1.4) \times 10^{-4}$ (2σ) was obtained in a suite of CM PLATy hibonite Crystals (PLACs) [6]. Within errors, ¹⁰Be/⁹Be ratios in other ²⁶Al-free objects corroborate this value [4, 5, 8].

Live ¹⁰Be 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, 9]. This view was challenged by a proposition that ¹⁰Be was derived from trapped Galactic Cosmic Ray (GCR) nuclei by the magnetic fields of the progenitor molecular cloud core [10]. However, a comparison between ²⁶Al-bearing CAIs and ²⁶Al-free PLACs suggested that the difference in ¹⁰Be/⁹Be has no chronological meaning [6]. This contradicts a major prediction of the trapping model, making it less likely to be the primary ¹⁰Be contributor.

The above argument that ¹⁰Be was of solar irradiation origin is based on a chronological viewpoint. If one aims to quantitatively understand the spatial distribution of ¹⁰Be 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 ²⁶Al/²⁷Al indicates that they formed $\sim 1 \times 10^5$ years after CAIs [6]. However, resolvable ¹⁰B 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 ($\sim 30 - 50 \mu\text{m}$, [e.g., 6]). This problem could hopefully be overcome with the high spatial resolution of the NanoSIMS. Here we report the pre-

liminary 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 ($\sim 20 - 40 \mu\text{m}$ across) were selected for measurements.

For the Be-B measurements, a 16 KeV ¹⁶O⁻ primary beam with an intensity of $\sim 5-10$ nA ($\phi \sim 7 - 10 \mu\text{m}$) was used to generate a $\sim 15 \times 15 \mu\text{m}^2$ raster square on polished, epoxy-mounted samples. Beam blanking was applied in every analysis, so that only signals from the central $6 \times 6 \mu\text{m}^2$ 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, ²⁷Al³⁺, ²⁸Si⁴⁺) from peaks of interest. Secondary ions (⁶Li⁺, ⁷Li⁺, ⁹Be⁺, ¹⁰B⁺, ¹¹B⁺, ²⁷Al⁺⁺) were counted simultaneously with six electron multipliers. The counting time of each cycle was optimized based on the count rate of ¹⁰B ($\ll 1$ count/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 (~ 0.003 counts/sec) were measured overnight when measurements were not being performed. The deadtime 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 (¹⁰B/¹¹B = 0.2469; ⁹Be/¹¹B = 1.79 [11]). Contributions from spallogenic ⁹Be, ¹⁰B, and ¹¹B 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 $^{10}\text{B}/^{11}\text{B} = 0.250 \pm 0.004$ (2σ). Two points with the highest Be/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}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 ± 0.002 ($\chi^2_{red} = 1.3$).

The $^{10}\text{Be}/^9\text{Be}$ value of $(5.3 \pm 1.0) \times 10^{-4}$ in ^{26}Al -free CM PLACs further argues against the GCR-trapping model of [10]. Assuming chronological significance for ^{10}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 ~ 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}Be seems a more likely explanation. Another line of evidence for a heterogeneous distribution of ^{10}Be comes from the initial $^{10}\text{B}/^{11}\text{B}$. The initial ratios for PLACs (0.252 ± 0.002) and for Allende CV CAIs (0.253 ± 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}Be . Thus, we conclude that all these observations can be best explained by *in-situ* production of ^{10}Be by protosolar irradiation.

Unfortunately, this study fails to obtain resolvable ^{10}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}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}Al -bearing SHIBs and CAIs still remain difficult, if not impossible.

References

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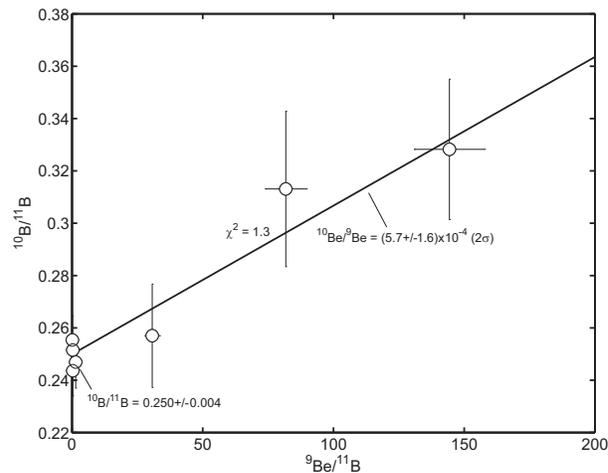


Figure 1: NanoSIMS results of B isotopic compositions of CM hibonites. All errors are 2σ .

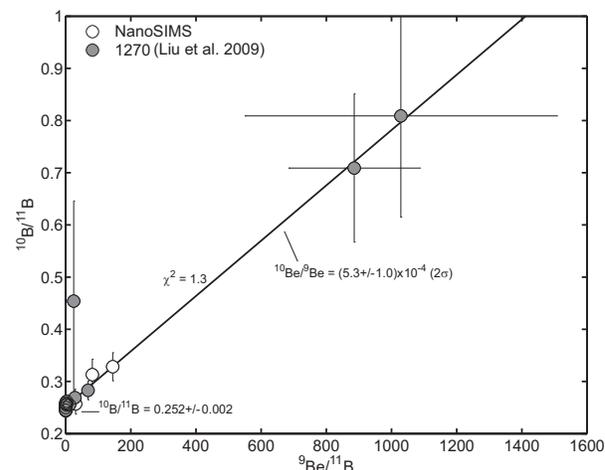


Figure 2: ^{10}Be - ^{10}B diagram of CM hibonites. Data plotted here include the present NanoSIMS results and values reported in [6]. All errors are 2σ .

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