Be-B ISOTOPE SYSTEMATICS IN CV AND CM HIBONITES: IMPLICATIONS FOR SOLAR ENERGETIC PARTICLE PRODUCTION OF SHORT-LIVED NUCLIDES IN EARLY SOLAR SYSTEM.

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Fossil records of the now-extinct short-lived nuclide ^{10}Be have been found in early solar system objects that either host other short-lived nuclides, such as, ^{26}Al and ^{41}Ca, or are devoid of them [1-6]. The presence of ^{10}Be in several Murchison hibonites devoid of detectable radiogenic ^{26}Mg (initial ^{26}Al/^{27}Al $<2\times10^{-6}$) and ^{41}K (initial ^{41}Ca/^{40}Ca $<3\times10^{-9}$) was considered as an indicator for separate sources for these nuclides [1]. A stellar source is proposed for ^{26}Al and ^{41}Ca, while interactions of solar energetic particles (SEP) with nebular material appears to be the most plausible source of ^{10}Be, which is not a product of stellar nucleosynthesis. A limit on the SEP irradiation of the solar nebula was placed based on these observations [1]. We present here new results on Be-B isotope systematics in a couple of CV and CM hibonite and evaluate the contribution from SEP production towards the inventory of the short-lived nuclides in the early solar system.

The two samples analyzed in this study are a fragment of the hibonite-rich Allende FUN inclusion HAL and a Murchison hibonite (CH-C4) having platelet morphology. HAL displays correlated nuclear effects and extreme isotopic mass fractionation in several elements [7, 8]. However Mg in HAL hibonite is not fractionated and it has well-resolved ^{26}Mg excess from ^{26}Al decay with an extremely low initial ^{26}Al/^{27}Al ratio of $(5.2 \pm 1.7)\times10^{-8}$ [9]. HAL hibonite is devoid of detectable ^{41}K excess with an upper limit of 4×10^{-9} for initial ^{41}Ca/^{40}Ca [10]. The high isotopic mass fractionation and REE abundances suggest HAL to be of a distillation origin [7, 11].

We have measured REE abundances and Mg isotopic composition in the Murchison hibonite CH-C4 and Be-B isotope systematics in a fragment of HAL hibonite and in CH-C4 with a Cameca ims-4f ion microprobe using procedures reported elsewhere [1, 10]. Relative ion yield and instrumental mass fractionation were determined using Madagascar hibonite, GB-4, NBS-616 and NBS-614 standards. We could not detect resolvable ^{26}Mg excess in CH-C4 and infer an upper limit of 8×10^{-6} for initial ^{26}Al/^{27}Al in this hibonite. It is characterized by a Group III REE pattern, typical of platelet hibonites and could be a nebular condensate. Both HAL and CH-C4 have well resolved ^{10}B excess and the measured ^{10}B/^{11}B ratios correlate with ^{9}Be/^{11}B ratio (Figs. 1a and 1b) indicating that the excess ^{10}B is due to in situ decay of now-extinct ^{10}Be. We infer initial ^{10}Be/^{9}Be ratios of $(4.4\pm1.5)\times 10^{-4}$ and $(8.0\pm3.3)\times10^{-4}$ for HAL hibonite and CH-C4, respectively, at the time of closure of the Be-B isotope system in these objects.

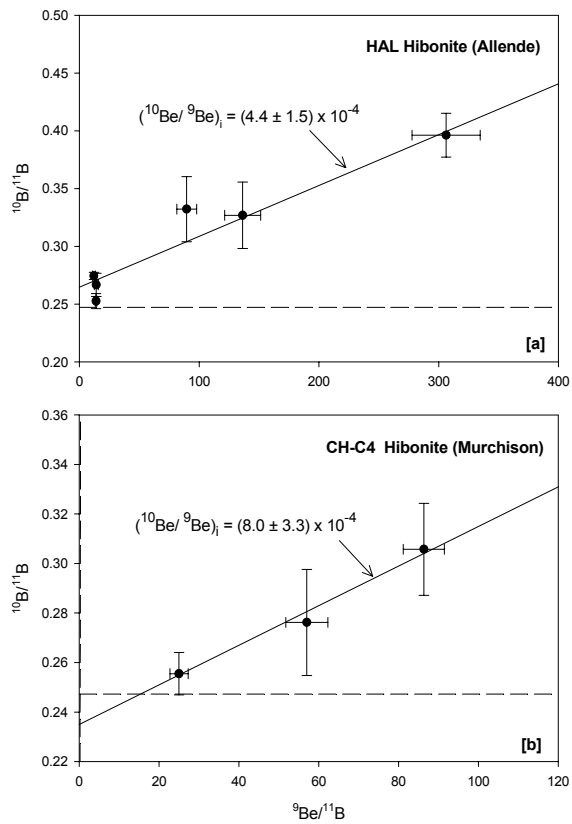

Fig. 1. Be-B isotopic systematics in HAL hibonite (fig. a) and in Murchison hibonite CH-C4 (fig. b). The dashed line represents reference ^{10}B/^{11}B ratio. Error bars are 1σ.

The present results, particularly those for HAL hibonite, strengthen our earlier inference based on data for CM hibonites that the source responsible for production of ^{10}Be did not contribute significantly to the inventory of the short-lived nuclide ^{26}Al present in the early solar system. The lack of a correlation between Al-Mg and Be-B isotope systematics was also reported previously for another FUN inclusion AXCAI2771 from the CV meteorite Axtell [6]. This inclusion has a resolved excess in ^{10}B with an initial

$^{10}Be/^{9}Be$ ratio of ~6×10^{-4}, but is devoid of resolved ^{26}Mg excess (initial $^{26}Al/^{27}Al$ <1.1×10^{-5}). Discordance between Al-Mg and Be-B isotope systematics has also been found in normal CAIs from two other CV meteorites, Allende and Efremovka [4].

^{10}Be present in the early solar system is of spallogenic origin and various sources of energetic particles (SEP, low energy particles in star forming regions, galactic cosmic rays, r-process jets) and sites for spallation reactions (solar nebula, protosolar cloud, expanding supernova envelope) have been proposed. We have suggested that interaction of SEPs characterized by a flatter energy spectrum ($dN \propto E^{-\gamma}dE$ with $\gamma \leq 2$) with nebular material is the most plausible source of ^{10}Be present in the early solar system [1]. In Fig. 2, we show the result of our calculation for a value of 2 for the spectral index γ. A CI composition was assumed for the target (nebula) material. The ^{10}Be production was constrained to match the HAL data [$(^{10}Be/^{9}Be)_i$ ~5×10^{-4}] for the entire range of irradiation duration (10 to 10^7 years). Also plotted in this figure are the inferred abundances of initial ^{26}Al and ^{41}Ca in HAL and CM hibonites based on results obtained in the present and previous studies [1, 9, 10]. The expected abundances of SEP produced ^{26}Al and ^{41}Ca are close to the measured value in HAL (^{26}Al) and consistent with the upper limit estimates for ^{26}Al in CM hibonites and for ^{41}Ca in HAL and CM hibonites. If we attribute the initial abundance of ^{26}Al in HAL entirely to SEP production, it is obvious that contribution from SEP production towards the inventory of ^{26}Al in early solar system, characterized by an initial $^{26}Al/^{27}Al$ ratio of ~5×10^{-5}, is insignificant. A small contribution from SEP production towards the inventory of ^{41}Ca, however, cannot be ruled out.

A notable feature of the Be-B systematics in early solar system objects is the spread in the inferred initial $^{10}Be/^{9}Be$ ratios (~4×10^{-4} to 1.5×10^{-3}) in samples with initial $^{26}Al/^{27}Al$ ratios both close to the canonical value of 5×10^{-5} (in CV CAIs) as well as in samples with extremely low initial $^{26}Al/^{27}Al$ or devoid of detectable ^{26}Al (FUN CAIs and CM platelet hibonites). In a SEP production scenario for ^{10}Be, the observed spread may be attributed to variation in the SEP irradiation dose or irradiation geometry of the CAI precursor nebular material. It is interesting to note that the fossil records of the now-extinct short-lived nuclide ^{53}Mn in several Allende CAIs also suggest a spread in the inferred initial $^{53}Mn/^{55}Mn$ values over a much wider range (10^{-5} to 1.25×10^{-4}) at the time of closure of Mn-Cr system in these objects [12, 13]. We have evaluated the possible production of ^{53}Mn along with ^{10}Be using the same SEP parameters noted above and the results are also shown in Fig. 2 along with the range of initial ^{53}Mn abundances measured in Allende CAIs. Although late stage alterations in the Mn-Cr isotopic systematics could have led to the observed spread in the initial $^{53}Mn/^{55}Mn$ ratios, it appears that SEP production is insufficient to match even the lowest value of ~10^{-5} for solar system initial $^{53}Mn/^{55}Mn$ ratio inferred from CAI data and also from studies of chondrules and eucrites [14, 15].

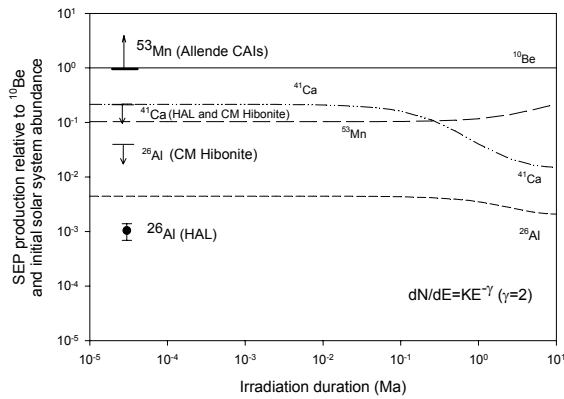

Fig. 2. SEP production of short-lived nuclide relative to initial solar system values and ^{10}Be. Normalization is based on $(^{10}Be/^{9}Be)_i = 5\times10^{-4}$; $(^{26}Al/^{27}Al)_i = 5\times10^{-5}$; $(^{41}Ca/^{40}Ca)_i = 1.4\times10^{-8}$ and $(^{53}Mn/^{55}Mn)_i = 10^{-5}$].

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