BERYLLIUM-10 IN CM HIBONITES: IMPLICATIONS FOR AN IRRADIATION ORIGIN. Ming-Chang Liu¹, Kevin D. McKeegan¹, Andrew M. Davis² and Trevor R. Ireland³ ¹Department of Earth and Space Sciences, UCLA, Los Angeles, CA 90095 (mcliu@ess.ucla.edu), ²Department of the Geophysical Sciences, Enrico Fermi Institute, and Chicago Center for Cosmochemistry, University of Chicago, Chicago, IL 60637, ³Research School of Earth Sciences, ANU, Canberra, ACT, Australia.

Introduction: The origin(s) of short-lived radionuclides have been a long standing problem in cosmochemistry. Among all the most short-lived radionuclides \( (t_{1/2} \leq 1.5 \text{ My}) \), \(^{10}\text{Be}\) and \(^{60}\text{Fe}\) require specific nucleosynthetic mechanisms. \(^{60}\text{Fe}\), due to its neutron-rich nature, has to be produced by stellar nucleosynthesis. On the other hand, \(^{10}\text{Be}\) requires an origin that involves nuclear reactions with energetic particles since it is destroyed in stars. However, there has not been a consensus as to the true origin of solar system \(^{10}\text{Be}\).

The existence of \(^{10}\text{Be}\) in the solar system was first proven by [1] in a CV3 CAI with an initial \(^{10}\text{Be}/^{9}\text{Be}\) of \(~9.5 \times 10^{-4}\). A re-examination of the same CAI by [2] yielded a more precise number of \((8.8 \pm 0.6) \times 10^{-4}\). In addition to these studies, there have been other measurements in different refractory inclusions from various meteorites. Among all the measurements, the most interesting results are from [3-4], who revealed the abundance of \(^{10}\text{Be}\) on the order of \(5 \times 10^{-5} \times ^{9}\text{Be}\) in a suite of \(^{26}\text{Al}\)-free but isotopically anomalous platy hibonite crystals, including the famous FUN inclusion HAL. MacPherson et al. (2003) [5] examined another FUN CAI, which lacks \(^{26}\text{Al}\), from Axtell and found that it also exhibits a lower \(^{10}\text{Be}/^{9}\text{Be}\) ratio of \(~3 \times 10^{-4}\).

McKeegan et al. (2000) [1], Gounelle et al. (2001, 2006) [6,7], Marhas et al. (2002) [2] and MacPherson et al. (2003) [3] assessed the irradiation contributions from both solar energetic particles and galactic cosmic rays (GCR) and concluded that an \textit{in-situ} irradiation by the proto-Sun is the most likely origin for \(^{10}\text{Be}\) as the steady state GCR contributions fall short by around an order of magnitude compared to the CAI initial. A potential implication of this origin is the heterogeneity of \(^{10}\text{Be}\) in the solar nebula and \(^{10}\text{Be}\) can not be used as a chronometer [5]. However, Desch et al. (2004) [8] challenged this view, on the basis of the “ubiquitous presence of \(^{10}\text{Be}\)” at the level of \((0.45-1.8) \times 10^{-3} \times ^{9}\text{Be}\) in refractory samples from meteorites, by considering the trapping of GCR-produced \(^{10}\text{Be}\) nuclei in the progenitor molecular cloud core. From this view, \(^{10}\text{Be}\) recorded in meteoritic materials does not require a local irradiation production and its spatial distribution in the solar nebula would have must been homogeneous. A consequence would be that \(^{10}\text{Be}\) might be a good chronometer for the early solar system [8].

We are engaged in a study to evaluate \(^{10}\text{Be}\) abundances in CM hibonite grains with higher precision with a goal of better understanding the origin and distribution of \(^{10}\text{Be}\) and its chronological meaning, if there is any, in the early solar system. Some results are reported here.

Experimental: The isotope compositions of Li, Be, and B were analyzed and absolute concentrations estimated by following the procedures described in [1] and [3]. Samples were sputtered by a 22.5 keV \(^{16}\text{O}\) primary beam of between 20 to 50 nA (depending on B concentration) to obtain sufficient count rates on Li, Be and B. Mass resolution (M/AM) was set at 2500 to separate Li-Be-B main peaks from all possible molecular interferences (hydrides and Al\(^{+}\), Si\(^{+}\)). All secondary ions were collected by magnetic field peak switching onto an electron multiplier (EM) detector through the mass sequence \(5.9^{\text{B}}, \, 7^{\text{Li}}, \, 7^{\text{Li}}^{+}, \, 9^{\text{Be}}^{+}, \, 10^{\text{B}}^{+}, \, 11^{\text{B}}^{+}\). Counting time on each mass was optimized based upon Li-Be-B abundances and total analytical duration ranged from 45 minutes to two hours for each spot. Instrumental mass fractionation and relative sensitivity factors (RSF) were determined by analyses of NBS 612 glass \((^{10}\text{B}/^{11}\text{B} = 0.2469114, \, ^{7}\text{Li}/^{6}\text{Li} = 1.49; \, ^{9}\text{Li}/^{6}\text{Li} = 12.3917952; \, ^{8}\text{Be}/^{6}\text{Li} = 12.22)\). Matrix effects on B isotope compositions are not strongly dependent on sample chemistry [9] thus no additional correction is made mass fractionation of B (or Li). The contributions of spallogenic Li, Be and B from galactic cosmic ray exposures were also evaluated and corrected in the data reduction.

Results and Discussion: The results are shown in the Fig. 1. Resolvable \(^{10}\text{Be}\) excesses are detected in a suite of PLACs, in correlation with \(^{9}\text{Be}/^{11}\text{B}\) of the grains. The slope yields \(^{10}\text{Be}/^{9}\text{Be}\) ratio of \((5.1 \pm 1.4) \times 10^{-4}\) (2\(\sigma\)) with the intercept of \(^{10}\text{Be}/^{11}\text{B} = 0.253 \pm 0.002\). This initial \(^{10}\text{Be}/^{11}\text{B}\) is in very good agreement with the result found by [3-4] and the precision of the slope is improved by a factor of 2, confirming that the hibonite value is significantly lower than the best constrained ratio for a CV CAI of \(^{10}\text{Be}/^{9}\text{Be}\) of \(8.8 \times 10^{-4}\). The intercepts obtained from these two kinds of refractory inclusions are identical. Thus if these correlations are interpreted as isochrons, the implied time difference is ~1.2 Myr.

However, it is unlikely that platy hibonite crystals postdated CAIs by 1.2 Myr because they still record much larger magnitudes of stable isotope anomalies (in \(^{50}\text{Ti}\) and \(\Delta^{17}\text{O}\)) than CAIs [10]. Moreover, 1.2 Myr is...
not consistent with the total lack of $^{26}$Al in PLACs, assuming CAIs obtained $^{26}$Al from an external stellar source. The implication is that $^{10}$Be was not homogeneously distributed in the solar nebula. If PLACs formed prior to CAIs, as proposed by [10], and $^{10}$Be was indeed homogeneously distributed, as what [8] suggested, we should have seen at least as high $^{10}$Be/$^9$Be initial values in PLACs as it is in CAIs. Thus the origin of $^{10}$Be is most likely due to the local irradiations of the proto-Sun rather than the trapping of $^{10}$Be from GCR.


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Fig. 1. CM hibonites on the $^{10}$Be-$^{10}$B diagram. The best fit through all the data points gives rise to the slope of $^{10}$Be/$^9$Be = (5.1±1.4)×10⁻⁴ with the intercept of $^{10}$B/$^{11}$B = 0.253±0.002. Errors are 2 sigma.