

USNM 3515: AN ALLENDE CAI WITH LI ISOTOPIC VARIATIONS. J. M. Paque^{1,2}, D. S. Burnett¹ and M. Chaussidon³, ¹Div. of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA, 91125, ²jheather@gps.caltech.edu, ³CRPG-CNRS BP 20 54501 Vandoeuvre-les-Nancy, France.

Introduction: Ion probe analyses of the Allende Type B1 CAI USNM 3515 by Chaussidon et al. [1,2] (CRM) revealed Li isotopic variations over $\pm 10\%$ from terrestrial. There is an overall tendency of Li and Be abundances (Figure 1) to correlate, but with considerable scatter. CRM showed that subsets (“groups”) of the Li-Be trend exhibited good correlations of Li and Be and also showed a correlation of $^7\text{Li}/^6\text{Li}$ with $^9\text{Be}/^6\text{Li}$, the expected isochron signature of live ^7Be (53 day half-life) when 3515 formed. Live ^7Be indicates very early formation of planetary materials at a time when the protosun was highly active, producing intense fluxes of particles with sufficient energy to produce ^7Be by spallation reactions [3]. Total inclusion data do not show a $^7\text{Li}/^6\text{Li} - ^9\text{Be}/^6\text{Li}$ correlation. The case for ^7Be rests entirely on the significance of the groups.

Given the implications of ^7Be , we have carried out a detailed petrographic study of the USNM 3515 section used by CRM. The goals were: (a) search for additional criteria for the (Li, Be) groups by studying the local petrology of the ion probe points; (b) test the ^7Be origin of Li isotopic variations; (c) search for alternative interpretations of Li isotopic variations, both empirical and hypothesis-driven; and (d) characterize 3515 and compare with other Type B1 CAIs.

Results: Type B1 CAIs are well defined, but individual inclusions have distinct features. Comparison to 3515, a 1-2 mm fragment of a large CAI, is conveniently done by reference to well-documented events in B1 CAI evolution (Table 1). The remaining Wark-Lovering (WL) rim has conspicuous indentations and protrusions, possibly relating to processes c or i.

The classic rim melilite+core structure is present, but the rim is thin ($\sim 200 \mu\text{m}$) with relatively high Ak (25-30). The canonical increase in Ak inward from the rim is present, but subtle. 3515 may have higher Mg and Si concentrations and/or may have been remelted more extensively and/or more often than other B1 CAIs. Figure 2 shows the correlation between Na_2O (high precision) and Ak in a core melilite grain. As discussed in [4] or [5], the large increase in Na_2O at about Ak=40 marks the boundary between primary (or earlier melting episodes) and remelted zones. Melilite Li and Be distributions produced by fractional crystallization should correlate with Ak, but both show a scatter of nearly two orders of magnitude both for Ak<0.4 (80% of spots) and for Ak>0.4 (20% of spots), measured at the same spot as the ion probe analysis. Adequate data for modeling are unavailable, but given high Li diffusivity, it would be expected that the temperatures associated with processes b-f would have resulted in an equilibrated Li distribution for both elements and isotopes and that the heterogeneous Li distributions (see also Fig. 1) happened later. 3515 is extensively altered and fractured with shearing indicated by displacement of the WL rim. Alteration is characterized by phases low in Na and Fe, and in some areas is sufficiently coarse-grained for good electron, perhaps ion probe, analysis of individual phases. Uniquely, some small forsterite grains are present. These could be alteration, relict phases, or a mesostasis phase. *In summary 3515 is a fairly typical B1 CAI, but heavily altered and fractured and perhaps showing a higher degree of remelting than typical.*

Discussion: Independent of the (Li, Be) elemental trends discovered by CRM, we have yet to find any strong petrographic commonalities of the points in the ^7Be isochron groups. Individual ion probe analyses of a given group are in different phases and in different regions. Independent suggestions of ^7Be isochrons exist when only points are considered from one (“SW”) region of rim melilite, from only anorthite, or from only clinopyroxene. However, there are also a significant number of discordant points in each case. The extensively studied SW region contains rim melilite grain A (6 ion probe analyses). Grain A points do not define a good ^7Be isochron, nor is

Table 1. Documented Processes for Type B1 CAIs:

	<i>Process</i>	<i>3515?</i>	<i>Evidence</i>
a.	Initial melting	Spherical shape	no?
		Layered B1 structure	yes
b.	Partial remelting	Melilite Na-Ak trend [4]	yes
c.	Rim formation (flash heating?)	Wark-Lovering rim	yes
d.	O exchange	^{16}O -poor melilite, an	yes, CRM
e.	??	Chaotic refractory trace elements [5]	yes (Be)
f.	Subsolidus heating	Composition of spinel inclusions in cpx [6]	TBD
g.	Alteration	Alteration phases	extensive
h.	Dust interaction	Accretionary rims.	??
i.	Parent body incorporation	Fracturing/shearing/faulting	extensive

there any correlation of ${}^7\text{Li}/{}^6\text{Li}$ with Ak. Independent of ${}^7\text{Be}$, one plausible model for the Li isotopic variations is that 3515 formed from isotopically anomalous Li, but experienced significant addition of “chondritic” Li (${}^7\text{Li}/{}^6\text{Li} = 12.2$) during low temperature alteration. The SW melilite data in Figure 3 are consistent with this model in that the region with isotopically anomalous Li has low ${}^7\text{Li}/{}^6\text{Li}$, plausibly of spallogenic origin. Considering all data, the points with highest Li concentration tend to have ${}^7\text{Li}/{}^6\text{Li}$ approaching 12 with the approach from lower ${}^7\text{Li}/{}^6\text{Li}$. However, this model fails to explain analyses with ${}^7\text{Li}/{}^6\text{Li}$ significantly greater than chondritic. One alternative is to assume that chondritic Li was added and/or redistributed in a shock event which produced the observed extensive fracturing and shearing, or by pulse reheating events as suggested by CRM. Significantly different diffusion rates are experimentally observed for ${}^7\text{Li}$ and ${}^6\text{Li}$ (F. Richter, private communication) so it is possible that the high ${}^7\text{Li}/{}^6\text{Li}$ points represent material with extensive diffusion loss of Li. Statistically there are many more points with low ${}^7\text{Li}/{}^6\text{Li}$ than high (17 vs 5), although melilite, clinopyroxene, and anorthite all show high and low ${}^7\text{Li}/{}^6\text{Li}$.

Anorthite. Both high and low ${}^7\text{Li}/{}^6\text{Li}$ grains contain only about 1 ppb Li, lower by at least a factor of 3 from 5 other points with ${}^7\text{Li}/{}^6\text{Li}=11.6-12.0$. A consistent model is that initially 3515 anorthite had $\text{Li}\approx 1$ ppb and ${}^7\text{Li}/{}^6\text{Li}$ around 11. Alteration with chondritic Li caused Li to increase to ppm levels and ${}^7\text{Li}/{}^6\text{Li}$ to approach 12.2. A pulse heating or shock event could produce intense but highly localized heating causing factors of >1000 loss in Li and accompanying increases in ${}^7\text{Li}/{}^6\text{Li}$. The anorthite grain with the high ${}^7\text{Li}/{}^6\text{Li}$ is consistent with this model in that it has highly serrated boundaries and is enclosed in a region of relatively coarse-grained alteration. However, overall, we have not yet found anything petrographically unique about the points with high ${}^7\text{Li}/{}^6\text{Li}$.

Clinopyroxene. Since one must appeal to the complexities of shock or pulse heating, it is obvious that a variation of the same model could explain why some ${}^7\text{Be}$ isochrons are intact, whereas most are reset. The data for two compositionally indistinguishable clinopyroxene grains in contact, one with high and the other with low ${}^7\text{Li}/{}^6\text{Li}$, are a critical test for all models. There are not enough clinopyroxene analyses to define systematics between Li isotopes and concentrations, but like anorthite, the point with the lowest ${}^7\text{Li}/{}^6\text{Li}$ has the lowest (1.6 ppb) Li concentration. The clinopyroxene data are perhaps best explained by the ${}^7\text{Be}$ hypothesis with 3/5 analyses consistent with ${}^7\text{Be}/{}^9\text{Be} = 0.13$, within the range inferred by CRM.

Summary: *We are unable to find clear confirming petrographic interpretations of the (Li-Be) concentration groups of CRM. This does not necessarily mean that the inferred interpretation of live ${}^7\text{Be}$ is incorrect but may mean that the effects of alteration, shock and/or pulse heating have produced highly disturbed Li-Be systematics overall and that the unaffected points are so far only recognized by tight Li-Be elemental correlations, possibly reflecting the fractional crystallization trend in various remelting episodes.*

References: [1] Chaussidon M. et al. (2002) *LPSC XXXIII*, Abstract #1563. [2] Chaussidon M. et al. (2002) *MAPS*, 37, A31. [3] Leya I. et al. (2002) *MAPS*, 37, A86. [4] Beckett J. et al. (2000) *Geochim. Cosmochim. Acta* 64, 2519. [5] Simon S. et al. (1996) *LPSC XXVII*, 1201. [6] Connolly H. et al., (2003) *Geochim. Cosmochim. Acta*, in press.

