

MG ISOTOPE FRACTIONATION IN MELILITE WITHIN AN ALLENDE TYPE B2 CAI

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Introduction: Type B CAI are large, rounded inclusions found within CV3 chondrites. They are divided into three different types: B1, B2 and B3/FoB inclusions [1]. Type B1 and B2 CAI are similar in mineralogy, consisting primarily of coarse grained melilite, pyroxene and anorthite and abundant fine-grained spinel. B1 inclusions have a thick (up to 3mm), continuous melilite mantle surrounding a coarse-grained core of melilite + pyroxene + anorthite + spinel. B2 inclusions lack this thick rim, and have a thin and/or discontinuous rim of melilite, and a uniform distribution of minerals in their interior. The coarse-grained texture of these inclusions suggests that they were reheated after they initially formed, and recrystallized from a melt [2].

The aim of this work is to measure the magnesium isotopic fractionation of melilite as a function of melilite composition (i.e. mole % åkermanite) in a Type B2 CAI, to test ideas about the effect the lack of a mantle has had on the evolution of Type B2 CAIs. It has been suggested that once the melilite mantle in a B1 CAI forms, then evaporation of magnesium (and silicon) is suppressed, with the effect that the melilite grows in an effectively closed system, and magnesium (and silicon) isotopic composition of the melilite should be uniform [3]. The Type B2 CAIs, lacking a mantle, could continue to evaporate while melilite crystallizes, with the effect that melilite would become increasingly isotopically heavy as crystallization progresses.

A previously identified feature of the elemental and isotopic zoning of melilite near the rim of Type B CAI is a region of a few 100 µm with very low % åkermanite (5-10 wt%) and distinctly steep gradients in silicon and magnesium isotopic composition compared to the interior (eg. Leoville 3535-1) [4, 5, 6]. In this study, we are concentrating on analyses of melilite that does not occur in this region.

Method: A thin section of Allende TS33 (Fig. 1) was studied petrographically using reflected and transmitted light optical microscopy, followed by SEM imaging and quantitative element mapping of Mg, Al, Si, Ca and Ti using the JEOL JSM-5800LV SEM with a 15 kV accelerating voltage under high vacuum conditions at the University of Chicago. The element maps were used to create melilite zoning maps, which in turn were used to guide the choosing of locations for ion probe analysis. Mg isotope analyses were obtained using the Cameca IMS-1280 at the University of Wisconsin (WiscSIMS). The O⁻ primary beam was focused to ~10 µm, and four static Faraday cups enabled simultaneous

measurement of ²⁴Mg, ²⁵Mg, ²⁶Mg and ²⁷Al. Calibrating for instrumental mass fractionation required the use of synthetic melilite glass standards. After SIMS analysis, the location of each ion probe pit was confirmed using the SEM, to ensure that analyses were of a single phase and did not overlap with cracks that may have affected the result. Of a total of 74 melilite analyses, eleven were discarded because the ion probe beam overlapped a large crack.

Constraints on the cooling rate for TS33 were determined using experimental data and equations from [7, 8]. A series of crystallization experiments carried out by [2] has shown that CAI with a Type B composition must have cooled at rates slower than 50°C/hour, in order for large, elongated melilite crystals (as found in both Type B1 and B2 CAI) to form.

Results: Åkermanite zoning maps of melilite crystals within TS33 show that many grains crystallized inwards from the rim of the inclusion. In one case, a melilite crystal can be seen crystallizing from the core of the inclusion out towards the rim (Fig. 2), suggesting that melt was still present at this location. Melilite in both the core and the rim of TS33 ranges from Åk₁₅₋₆₅, except in one area in the rim which approaches Åk₅, presumably as a result of some later processing event.

Mg isotopes throughout the inclusion are consistently heavy, with δ²⁵Mg ~3.6‰ to 5.0‰. There is no apparent correlation with the Åk content of melilite grains (Fig. 2). Grains that grew inwards from the rim of the inclusion show Åk zoning from ~Åk₁₅₋₆₅, but show no systematic variation in Mg isotopic composition, with δ²⁵Mg ranging from 4.0‰ to 4.5‰. A traverse measured along the grain that crystallized towards the edge of the inclusion shows that melilite ranges from ~Åk₁₅₋₃₀ but again shows no systematic trend in δ²⁵Mg, with values from 4.1‰ to 4.9‰. At the very edge of the grain, closest to the rim of the inclusion the grain appears to be slightly lighter, with δ²⁵Mg of 3.7‰.

Discussion and Conclusion: The range of both Åk values and δ²⁵Mg in TS33 are consistent with values seen in other Type B inclusions. The fact that melilite occurs in the core and the rim of TS33 suggests that melilite in both these locations crystallized simultaneously; there are no large differences in Åk between rim and core grains, as seen in Type B1 inclusions.

There is no apparent correlation between Mg isotopes and Åk zoning within melilite crystals (Fig. 3). The maximum cooling rate for CAI with a Type B composition is 50°C/hour, in order for large, elongated

melilite crystals (as found in both Type B1 and B2 CAI) to form [2]. Experimental work shows that Type B2 inclusions must have evaporated at $P_{H_2} < 10^{-5}$ bar in order that the rate of evaporation is not significantly faster than the rate of diffusion [3]. If the rate of diffusion is much slower than the rate of evaporation, then the surface of the inclusion becomes relatively depleted in magnesium and silicon, resulting in melilite crystal growth and the formation of the characteristic B1 rim. For a cooling rate for TS33 of $10^\circ\text{C}/\text{hour}$, and $P_{H_2} < 10^{-5}$ bar, we should expect to see fractionation of ^{25}Mg of $\sim 1\%$ as a result of evaporation (Fig. 4). At $50^\circ\text{C}/\text{hour}$ and $P_{H_2} < 10^{-5}$ bar, evaporation should produce $\delta^{25}\text{Mg}$ of $\sim 0.2\%$. Both of these are significantly below the degree of $\delta^{25}\text{Mg}$ fractionation seen in TS33, suggesting either TS33 is the product of multiple reheating and evaporative events, or that the Mg isotopic signature is partially inherited from the precursor materials. ^{26}Al - ^{26}Mg systematics suggest the latter conclusion for a number of other CAIs in CV chondrites [9].

References: [1] Brerley A. J. & Jones R. H. (1998) *Reviews in Mineralogy*, v36. [2] Stolper E. and Paque J. M. (1986) *GCA* 50 1785-1806. [3] Mendybaev R. A. et al. (2006) *GCA* 70 2622-2642. [4] Knight K. B. et al. (2009) *GCA* 73, 6390-6401. [5] Richter, F. M. et al. (2007) *LPSC XXXVIII Abs #2303* [6] Simon J. I. et al. (2005) *EPSL* 238, 272-283. [7] Richter, F. M. et al. (2002) *GCA* 66, 521-540. [8] Richter F. M. et al. (2006) *MaPS* 41, 83-93. [9] Davis A. M. et al. (2010) *LPS XLI*, this volume.

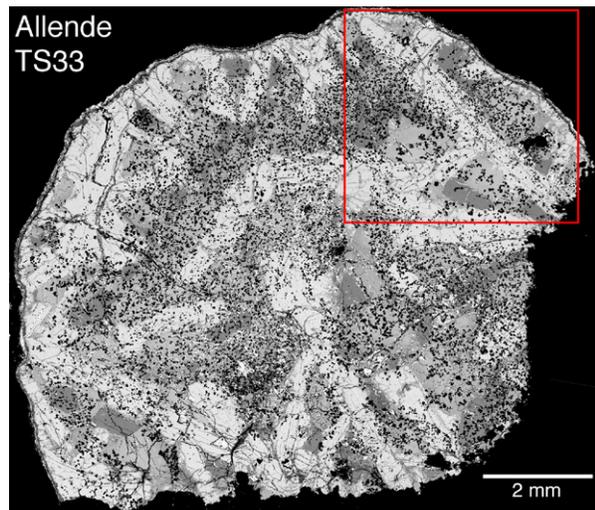


Figure 1. Back-scatter electron image of Allende TS33. Light grey = melilite, mid-grey = pyroxene, dark grey = anorthite, fine-grained black material within inclusion is spinel. Area of interest (shown in figure 2) is the long melilite lath running NW-SE within the red box.

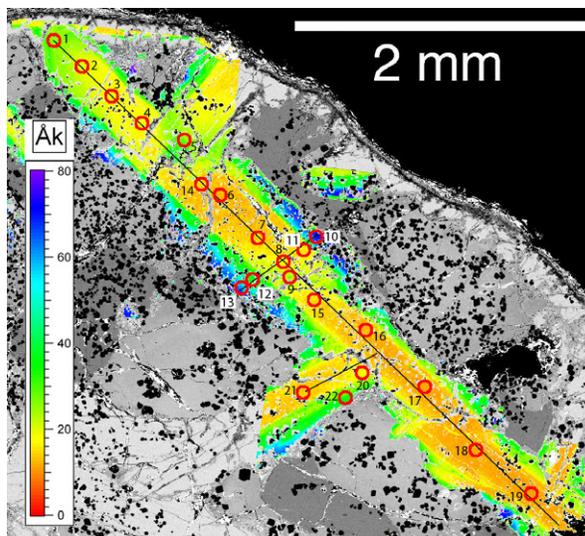


Figure 2. Åkermanite map of a melilite grain growing outwards towards the rim of the inclusion (area shown is outlined in red in Fig. 1). SIMS analysis locations are shown by red circles.

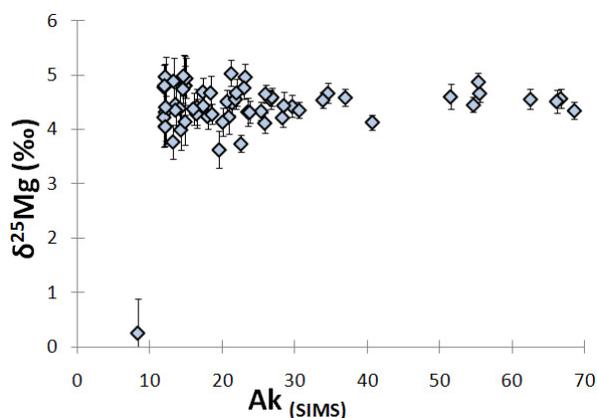


Figure 3. $\delta^{25}\text{Mg}$ versus Åkermanite content of melilite grains in TS33. Most analyses show $\delta^{25}\text{Mg}$ of 4 to 5‰, with the exception of a gehlenitic grain at the very rim of the inclusion (Åk_8 ; $\delta^{25}\text{Mg} \sim 0.25\%$).

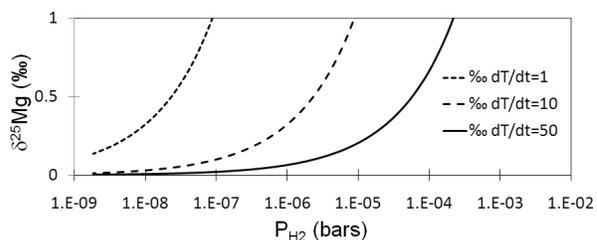


Figure 4. Degree of fractionation of $\delta^{25}\text{Mg}$ versus P_{H_2} at cooling rates of $1^\circ\text{C}/\text{hour}$, $10^\circ\text{C}/\text{hour}$ and $50^\circ\text{C}/\text{hour}$ in TS33.