

HIGH-PRECISION MG ISOTOPIC COMPOSITION OF TYPE B1 AND B2 CAI MELILITE. F. M. Richter^{1,2}, N. T. Kita⁴, R. A. Mendybaev^{1,2}, A. M. Davis^{1,2,3}, and J.W. Valley⁴. ¹Dept. of the Geophysical Sciences, ²Chicago Ctr. for Cosmochemistry, ³Enrico Fermi Inst., The University of Chicago, Chicago, IL 60637, ⁴Dept. of Geology and Geophysics, University of Wisconsin-Madison, Madison, WI 53706. (richter@geosci.uchicago.edu)

Introduction: Both subtypes of Type B CAIs, the B1s with a continuous melilite mantle at or near the surface and the B2s without such a mantle, are known to have isotopically heavy Si and Mg. This is generally regarded as indicating that they lost some of their original Si and Mg by evaporation. Most of the isotopic data that exists for these CAIs is for bulk inclusions. Here we report on our efforts to determine the Mg isotopic mass fractionation of melilite crystals from Type B1 and B2 CAIs as a function of the local åkermanite composition of the melilite. There are a number of reasons for focusing on melilite rather than on the bulk inclusion. (1) Melilite is a solid solution between åkermanite ($\text{Ca}_2\text{MgSi}_2\text{O}_7$) and gehlenite ($\text{Ca}_2\text{Al}_2\text{SiO}_7$), and the åkermanite zoning provides a record that can be interpreted in terms of initial crystallization conditions and crystallization progress [1]. (2) The Mg isotopic fractionation of melilite as a function of the åkermanite content can be used to determine how much additional volatilization of Mg took place in the temperature interval between the initial and final crystallization of melilite. (3) The Mg isotopic fractionation as a function of the åkermanite content in Type B1 and B2 CAIs can be used to test the recent suggestion [2] that the melilite mantle of the Type B1 CAIs will have effectively isolated the inclusion from further evaporation and thus the subsequent crystallization of melilite will have taken place in an effectively closed system (i.e., no isotopic zoning of the melilite once the mantle had formed). In the case of Type B2 CAIs, the lack of such a mantle might have allowed melt to be exposed at the surface and evaporated while melilite was crystallizing, which would result in the melilites being isotopically zoned.

Sample Characterization: Polished sections of Type B inclusions from the CV3 chondrites Leoville (USNM 3535-1, a Type B1 inclusion) and Allende (USNM 3529-26, a Type B2) were mapped, first for the entire inclusion using backscattered electron imaging, and then by detailed x-ray composition maps of selected melilite-rich areas (e.g., Fig. 1) to determine the åkermanite zoning and guide where the ion probe isotopic measurements should be made. After the ion probe measurements were done, the composition immediately adjacent to the ion probe spots was measured by electron microprobe to obtain more precise Al/Mg and åkermanite compositions of the exact spots where ion probe data were taken.

Experimental Techniques: The CAMECA IMS-1280 at the University of Wisconsin was used for the

Mg isotope analyses. A $10\mu\text{m O}^-$ primary beam with 8nA intensity was used and secondary ^{24}Mg , ^{25}Mg , ^{26}Mg and ^{27}Al ions were simultaneously collected using multicollector Faraday Cups. The reproducibility of Mg isotope ratios ($\delta^{25}\text{Mg}$, $\delta^{26}\text{Mg}$) for an Ak₁₀₀ standard was better than 0.1‰. Synthetic zoned melilite crystals with Ak₂₀₋₇₀ were also used to calibrate the instrumental mass fractionation (IMF) of Mg isotope ratios and the $^{27}\text{Al}/^{24}\text{Mg}$ relative sensitivity factor (RSF). The IMF changes from -3.2‰ to -2.2‰ and RSF from 1.05 to 0.85 from Ak₂₀ to Ak₁₀₀. The excess ^{26}Mg was calculated using an exponential law with a slope of 0.514 derived from evaporated CAI-like materials [3]. A total of 30 and 13 analyses were done on melilite from the B1 and B2 inclusions, respectively. The $\delta^{25}\text{Mg}$ of core melilite was found to be fairly homogeneous with ~5‰ for the B1 and ~2.5‰ for the B2, while those of melilite close to the surface were significantly lower (Fig. 2). The Al-Mg isochron diagram is shown in Fig. 3. A well-defined isochron was obtained for the B1 inclusion with an initial $^{26}\text{Al}/^{27}\text{Al}$ ratio of $(5.68 \pm 0.34) \times 10^{-5}$. Data from the Allende B2 inclusion were significantly scattered around this isochron and a precise initial $^{26}\text{Al}/^{27}\text{Al}$ ratio could not be obtained.

Discussion: Before interpreting the data shown in Fig. 3 one needs to decide whether the Mg isotopic composition near the rim of the inclusions should be regarded as relating to the original crystallization of the melilite or whether it is due to some separate process such as later exchange with a surrounding gas. Note however that the Mg isotopic values in the rim plot on or close to an isochrons in Fig. 3, implying that very little time elapsed between the process or processes that determined the properties of the melilite crystals and those of the rims. Based on the backscattered electron images and the x-ray compositional maps, we are inclined to the view that the rims on the Allende sample are not part of the original crystallization of the melilite, but that in the case of the Leoville inclusion the low values near the rim might very well be reflecting the Mg isotopic composition of the earliest crystallized melilite.

Some of the main implications of the Mg isotopic composition as a function of the åkermanite content of melilites from a Type B1 and a Type B2 CAI (Fig. 2) can be seen with reference to Fig. 4 taken from [1] (see also [2] for an example of how this figure has been used to infer the thermal and compositional history of Type B CAIs). The figure shows the crystallization temperature of melilite as a function of the ratio, V/R, of the volatile

oxides $\text{MgO}+\text{SiO}_2$ to the refractory $\text{CaO}+\text{Al}_2\text{O}_3$. Also shown is the correlation of the åkermanite content of the melilite with the ratio of the volatile oxides to the refractories. The melilite in the Type B1 Leoville inclusion starts at about Åk_{20} , which using Fig. 4 suggests that crystallization began at about 1400°C from a melt with $\text{V/R}\sim 0.9$, which is well within the typical range of Type B1 inclusion compositions reported by Simon and Grossman [3]. Ignoring the rim, the B2 inclusion from Allende has melilite starting at about Åk_{35} , which Fig. 4 suggests requires a lower crystallization temperature of about 1350°C and a more volatile-rich composition with $\text{V/R}\sim 1.0$. The Mg isotopic data shown in Fig. 2 is consistent with the Allende B2 inclusion having a lower crystallization temperature and a greater amount of volatiles compared to the Leoville B1 inclusion. The B2 inclusion by having lost significantly less volatiles (i.e., Mg) by evaporation should be, as we found, less fractionated in its Mg isotopic composition.

We have to admit that the details of the Mg isotopic fractionation as a function of åkermanite content (Fig. 3) are not entirely what we had expected. We expected that the Mg isotopic composition of melilites in a Type B1 inclusion would be relatively constant regardless of the Åk value, once a sufficiently thick mantle had formed and protected the still partially molten inclusion from further evaporation. This we found, but what we don't understand is the reason for the very much isotopically lighter Mg near the surface. Our expectation for a B2 inclusion such as our Allende sample was that because there is no melilite mantle to protect the melt from further evaporation while melilite is crystallizing, the melilites would become progressively heavier in their Mg isotopic composition as crystallization progressed. At least for the Type B2 inclusion we have so far analyzed, this is not what we found. There is no significant change in the Mg isotopic composition of the melilite as a function of åkermanite content. It is possible that the Allende Type B2 inclusion cooled sufficiently rapidly that not much Mg had time to evaporate. To limit the Mg isotopic fractionations to less than a few tenths of a permil would require cooling rates of the order of tens of $^\circ\text{C h}^{-1}$ (see Fig. 15 in [4]).

References. [1] Mendybaev R. A., Richter F. M., and Davis A. M. (2006) *GCA*, 70, 2622. [2] Richter F. M., Mendybaev R. A., and Davis A. M. (2006) *Meteoritics*, 41, 83. [3] Davis A. M., Richter F. M., Mendybaev R. A., Janney P. E., Wadhwa M., and McKeegan K. D. (2005) *LPS XXXVI*, #2334. [4] Simon S.B. and Grossman L. (2006) *GCA*, 70, 780. [5] Richter F. M., Davis A. M., Ebel D. S., and Hashimoto A. (2002) *GCA*, 66, 521.

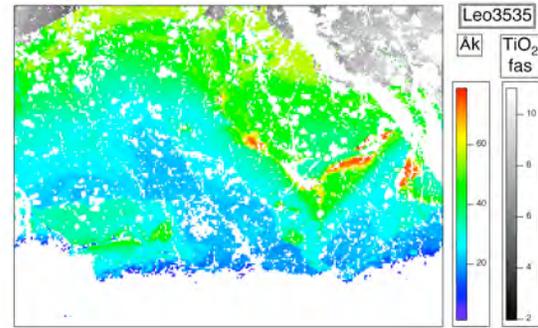


Fig. 1. Åk map of Leoville 3535-1 melilite 2.

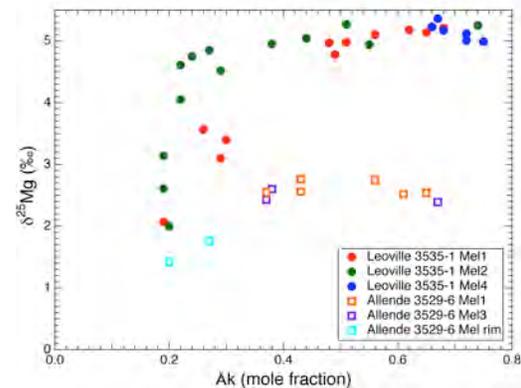


Fig. 2. $\delta^{25}\text{Mg}$ vs. Åk in melilite.

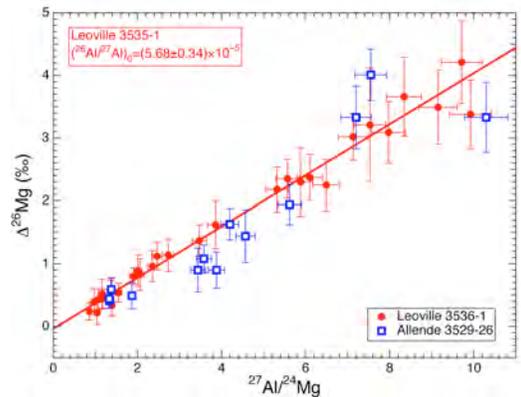


Fig. 3. Isochron diagram.

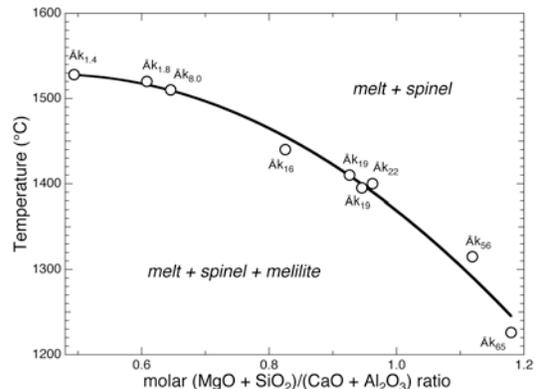


Fig. 4. Melilite crystallization temperature vs. refractory/volatile ratio from [2].