

EXPERIMENTAL TEST OF USING SI AND MG ISOTOPES TO FIND THE PRECURSOR OF CAI-LIKE EVAPORATION RESIDUES. F.M. Richter¹, R.A. Mendybaev¹, P. E. Janney², K. Ziegler³, and E. Young³. ¹The University of Chicago, Chicago, IL 60637, USA. ²Arizona State University, Tempe, AZ 85287, USA. ³University of California Los Angeles, Los Angeles, CA 90095, USA. (richter@geosci.uchicago.edu)

Introduction: Calculations of the composition of materials that condense as a function of temperature and pressure from a solar composition gas [1] provide an important baseline to compare with actual compositions of primitive refractory inclusions in chondritic meteorites. Obvious candidates for such a comparison are the Type B CAIs, which are the oldest known materials to have formed in the solar system. However, it is almost always the case that the reported bulk composition of Type B CAIs are significantly depleted in MgO compared to that of materials that would have condensed from a solar composition gas (see Fig. 1 for a comparison with calculated condensates from a solar gas with $P=10^{-3}$ bars). A clue as to why this might be comes from the fact that many Type B CAIs are enriched in the heavy isotopes of silicon and magnesium in much the same way as has been found in laboratory evaporation residues of Type B CAI-like liquids [2,3]. The main functions of laboratory evaporation experiments are: (1) To determine the kinetic isotope fractionation factor α (=isotopic composition of the evaporation flux/isotopic composition of the condensed phase) that establishes the relationship between the amount of a volatile component removed by evaporation (e.g., MgO or SiO₂) and the associated isotopic fractionation of the residue. (2) To determine the evaporation flux J_i (moles i per cm² per second) as a function of temperature, pressure, and the fO_2 of the surrounding gas. The results are used to constrain the thermal history of CAIs by requiring that they be molten for a sufficient time to become isotopically fractionated to the degree observed. The general result is that typical Type B CAIs were molten for a few tens of hours or a few days [4]. A much more demanding use of the laboratory derived evaporation parameters involves using the isotopic fractionation of CAIs to calculate the amount of MgO and SiO₂ volatilized and then add this to their measured bulk composition to find the precursor composition. An example of this is given in Fig. 1. In principle this method should allow one to determine whether the precursors of the Type B CAIs are plausibly condensates from a solar composition gas. However when this has been done with actual CAIs (see [5] and Fig.1) the estimated precursor composition often do not fall along a condensation trajectory but instead show a great deal of scatter that could be due to the precursors having condensed under dif-

ferent conditions, or that they were not condensates from a well-mixed solar composition gas, or due to some limitation of the assumptions used for the calculations. The work reported here involves a laboratory test of how well one can recover the precursor composition using the magnesium and silicon isotopic composition of the evaporation residues.

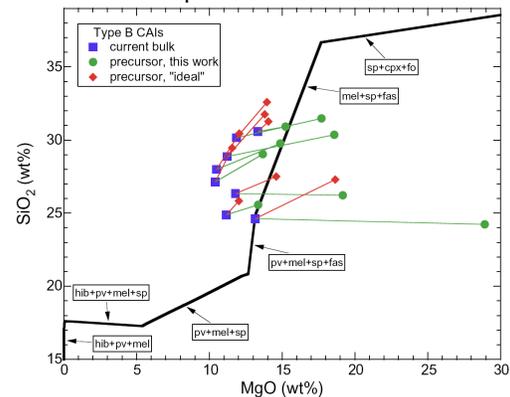


Figure 1. Example taken from [3] of the results of estimating the precursor of Type B CAIs using the magnesium and silicon isotopic composition to calculate the amount of MgO and SiO₂ that had evaporated. The red symbols are precursors estimated assuming the kinetic fractionation factors α are the inverse square root of the mass of the isotopes. The green symbols use the experimentally determined kinetic isotope fractionation factors. The solid line is the condensation trajectory for a total pressure of 10^{-3} bars.

Experimental Samples: For present purposes we will use both evaporation residues from our previous studies (see [6] for a summary) and a new set of evaporation residues made specifically for testing the proposition that we can find the precursor (i.e., the starting composition) by measuring the bulk composition and the magnesium and silicon isotopic of the residues. All the samples were evaporated while molten in the high vacuum ($P < 10^{-6}$ Torr) furnace at the University of Chicago. The earlier experiments (B133, FUN1, FUN2) were quenched as rapidly as the furnace would allow in order that the residue be glass or have a relatively homogeneous distribution of quench crystals. This makes determining the bulk composition of the evaporation residue relatively straight forward. Each of the five new experiments (the EY series) had different starting compositions and more complicated thermal

histories. They were first evaporated at 1700°C. The temperature was then rapidly dropped so that further evaporation was negligible and finally slowly cooled from about 1400°C to produce a more realistic texture.

Analytical Measurements: The elemental analyses of the starting materials and evaporation residues were done using JEOL JSM-5800LV SEM equipped with an Oxford Link ISIS-300 energy dispersive analytical system. The bulk composition of the evaporation residues was estimated by averaging compositions measured by scanning ~50x40 μm areas along a number of profiles in different directions across a polished surface of each sample. The magnesium and silicon isotopic composition of the starting composition and evaporation residues of the B133, FUN1, and FUN2 series samples was measured by laser ablation inductively coupled plasma mass spectrometry (LA-ICPMS) at Arizona State University with a Photon Machines Analyte 193 laser ablation system connected to a ThermoFinnigan Neptune multicollector ICPMS [5]. The isotopic composition of the EY series starting compositions and evaporation residues was measured at UCLA by LA-ICPMS with a Photon Machines Analyte 193 laser ablation system connected to a ThermoFinnigan Neptune multicollector ICPMS.

Results: Figure 2 shows the results of finding the starting composition (i.e., the precursor) of the B133, FUN1 and FUN2 residues using their magnesium and silicon isotopic composition to calculate the amount of MgO and SiO₂ evaporated and adding this to the measured bulk composition of the residue.

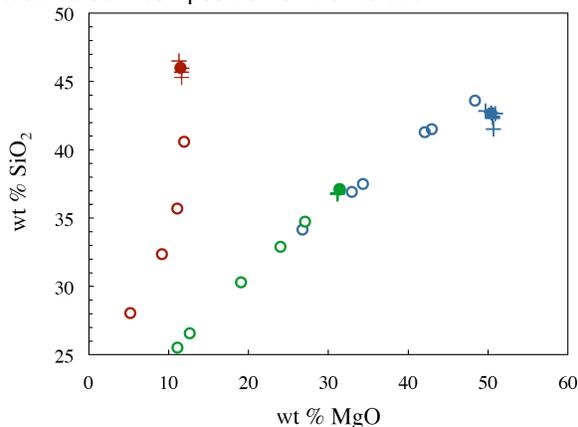


Figure 2. The composition of the starting compositions (filled circles) and evaporation residues (open circles) in MgO-SiO₂ space with B133 samples in red, FUN1 in blue, and FUN2 in green. The crosses are the calculated composition of the starting composition determined using experimentally determined kinetic isotope fractionation factors α [2,3] to translate the magnesium and silicon isotopic composition of each of

the residues into the amount of MgO and SiO₂ evaporated. The data used in this figure are from [6].

Figure 3 shows the degree to which we were able to reconstruct the starting composition of the EY series of evaporation samples.

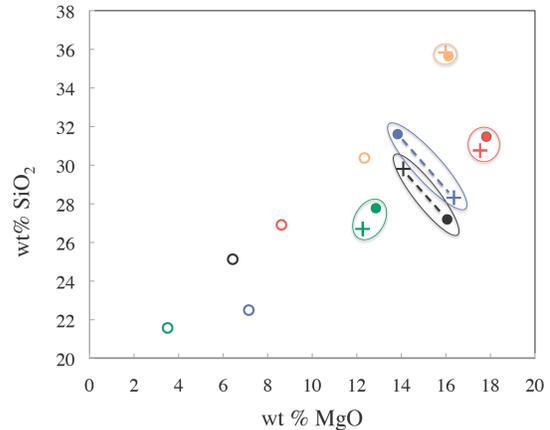


Figure 3. Same as Fig 2 now for the five EY series starting compositions (filled circles) and residues (open circles).

Conclusions: Reconstructing precursors using the magnesium and silicon isotopic composition of residues works very well when the bulk composition of the residues is accurately known as in the case of the B133 and the FUN experiments (Fig. 2). In the more realistic case of the EY series of experiments (Fig. 3), only three out of the five starting compositions are reasonably well recovered. In the other two cases the estimated starting composition is off by about 3 wt% in both MgO and SiO₂. The most likely explanation for the two cases where the starting composition is not recovered is that the bulk composition of the residues is not accurate because of the difficulty of determining a true bulk composition of a residue with a heterogeneous distribution of relatively large mineral grains. The scatter of the reconstructed precursors shown in Fig. 1 might very well also be due to the reported bulk compositions of the Type B CAIs not being representative of the true bulk composition. Resolving the issue of the relationship of the precursors of the Type B CAIs to condensation trajectories of a solar composition gas will, at the very least, require better validated determinations of their present bulk composition.

References: [1] Grossman L. (1972) *GCA* 36, 597-619. [2] Richter F.M. (2007) *GCA* 71, 5544-5564. [3] Knight et al. (2009) *GCA* 73, 6390-6401. [4] Richter F.M. et al. (2006) *Meteor. Planet. Sci.* 41, 83-93. [5] Grossman L. et al., (2008) *GCA* 72, 3001-3021. [6] Janney P. et al., (2010) *Chem. Geol.* in press.