

THE ROLE OF INCLUSIONS IN MANTLE MELILITE: REFRACTORY LITHOPHILE TRACE ELEMENT COMPOSITIONS IN A TYPE B1 CAI. J. M. Paque¹, D. S. Burnett, J. R. Beckett and Y. Guan, California Institute of Technology, Pasadena, CA 91125, ¹jheather@gps.caltech.edu.

Introduction: Concentrations of refractory lithophile trace elements in Allende Type B1 CAI mantle melilite do not agree with expectations from the fractional crystallization processes believed to have formed these objects [1-4]. SIMS analyses on melilite in the Type B1 CAI Leoville 3537-2 provide an opportunity to examine the detailed trace element distributions on a sample absent the pervasive secondary alteration present in all Allende CAIs.

Analyses: The Zinner-Crozaz energy offset technique was adapted to the Caltech Cameca 7f Geo ion microprobe. Two standards were used: an Åk₄₀ melilite glass (for Sc and Zr) and a CAI Type B bulk composition glass doped with Sr, Y, Ba, La, Ce, and Eu at levels analyzable by electron probe (nominal 1000 ppm). Each analyzed spot contained between 20 and 50 individual analyses, or slices approximately 40 µm in diameter by 0.1 µm deep, cut perpendicular to the plane of the thin section. The data were examined both in terms of trends as a function of depth within a spot, and spot to spot variations.

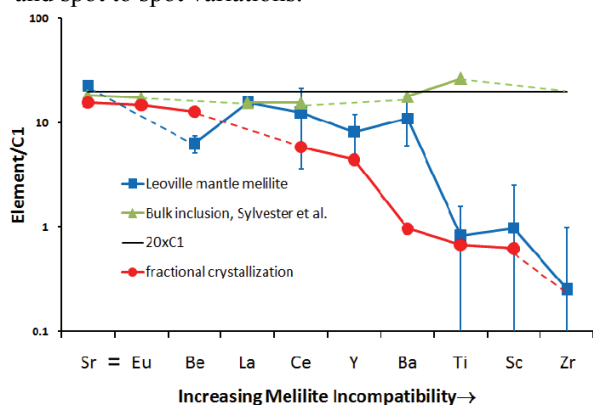


Figure 1. Mantle melilite in Leoville 3537-2 lithophile element concentrations vs. compatibility of the element in melilite.

Results: Data for most elements are dominated by variability on all scales. Fig. 1 shows the grand averages of ~1000 slices from mantle melilite along with the bulk measurement from 3537-2 (approximately 20 times CI [5]). The “error bars” reflect a large amount of interspot variability (1σ) of the analyses, which would not be expected for fractional crystallization from a homogeneous liquid. There is an overall decreasing trend with melilite incompatibility, but, in detail, there are major deviations from the predicted pattern (red).

Fig. 2 shows variations of spot average data for Ti, Sc, Ba, and Sr, with respect to the åkermanite (Åk)

content of the melilite and a model fractional crystallization trend (assuming that melilite crystallized from a homogeneous molten inclusion using bulk concentrations for the inclusion from [5]). For Sr and, especially Ba, measured concentrations are higher than the model (solid curves). For Ti and Sc, the highly variable data show no clear Åk trend, although many analyses are

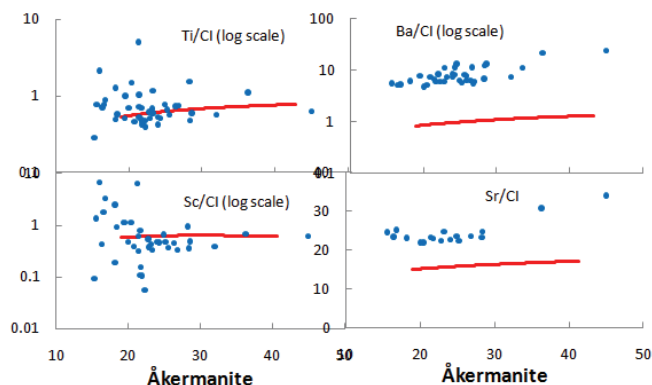


Figure 2. CI normalized trace elements concentrations in melilite as a function of åkermanite content. Solid lines are model fractional crystallization curves.

near the fractional crystallization predictions. Discrepancies are similar for the other elements analyzed and for data in Allende CAIs [1-4].

In many, but not all, profiles there is an excellent correlation between Sc and Ti suggesting that the hot spots may be due to clinopyroxene or UNK. The contribution of inclusions to the trace element profile can be easily observed by examining a depth profile of ⁴⁷Ti and ⁴⁵Sc (e.g., Fig. 3), which shows a prominent

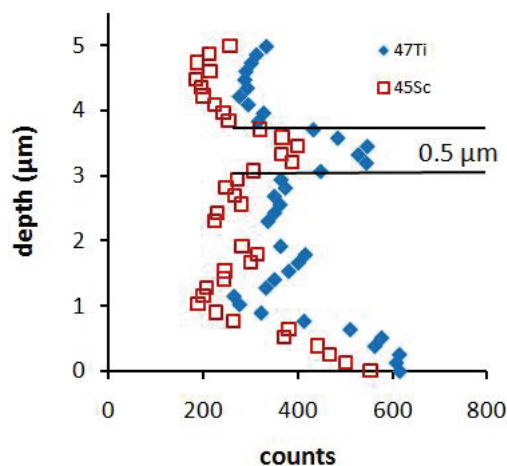


Figure 3. Variation in raw counts of Ti and Sc with depth for spot 1-7.

~0.5 μm spike in both Ti and Sc. Sc is the only analyzed element to consistently correlate with Ti, although some of the most enriched spots are also high in Zr. The absence of Ti-Y or Ti-La correlations argues against perovskite inclusions.

Sr and Ba profiles do not show pronounced structure. Fig. 4 shows that spot average Ba and Sr are uncorrelated but consistently much higher than expected for fractional crystallization (Fig. 2). A cluster of 25/44 analyses have Sr/CI ~23 and Ba/CI ~7. The remaining 19/44 spots have higher Ba, including some exceeding the total rock concentration, very surprising for a highly incompatible element.

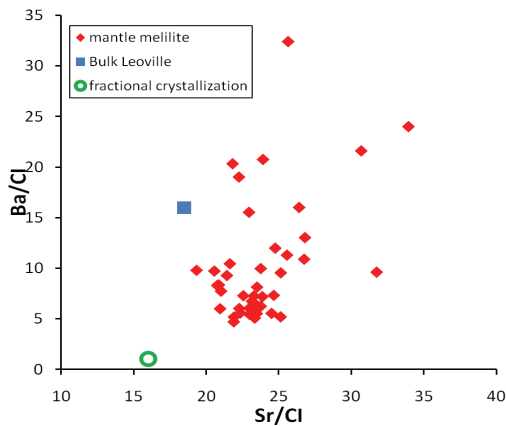


Figure 4. Ba/CI vs. Sr/CI for all mantle melilite spots.

Discussion: There is heterogeneity of refractory lithophile elements on all scales in this Leoville CAI: From grain to grain, within a single grain (e.g., the variation with \AA k), and within a single analysis spot (due to small inclusions). The similarity of results for a nominally unaltered Leoville CAI and altered Allende Type B1s [1-4] implies that the Allende alteration process did not produce major disturbances in melilite refractory lithophile trace element concentrations.

Observations suggesting exsolution: For approximately 80% of spots, the 40 individual slices show a clear Sc-Ti correlation (e.g., Fig. 3). The Zr data have larger errors, and are incompletely processed; nevertheless, there are also some examples of unambiguous Zr/Ti correlations. Overall, these patterns are suggestive of clinopyroxene inclusions, which have been previously observed [6] and interpreted as formed by exsolution. Melilite Ti/Sc ratios vary widely, and it is not obvious that this would be expected for exsolved clinopyroxene which concentrated local Ti, Sc, and Zr partitioned into melilite during the primary crystallization. The Zr is especially hard to explain in terms of crystallization for a homogeneous liquid as the melilite-liquid partition coefficient, although not well constrained, is very small. The Ti/Sc variability compli-

cates comparison with Ti/Sc from mantle clinopyroxene in this inclusion and with literature Ti/Sc data. Independently, rod-shaped perovskite grains observed by SEM in this inclusion are suggestive of an exsolved phase, however the expected enrichment of Ti, without associated Sc, is not found.

The case for relict phases. Refractory lithophile trace element carrier phases (e.g., perovskite, allendeite, davisite, barioperovskite) were likely among the precursor crystals present in outer regions of the inclusion during melting. These either (a) dissolve to produce local heterogeneities leading to anomalously high trace element concentrations in later crystallizing mantle melilite, or (b) are trapped as undissolved grains in mantle melilite, or (c) react with the liquid to produce other phases that were then incorporated into the crystallizing melilite. These alternatives are not mutually exclusive. SIMS analyses are sensitive to submicron size inclusions because of the small depth sampled. A relict phase model is perhaps most compatible with the observed variability. In an extreme version of this model, crystal-liquid partitioning is irrelevant; melilite is simply a host for relict grains, and melilite abundance patterns then reflect the local bulk concentrations of these crystals as defined by the distribution of precursor phases. In Fig. 1, note that Sr, Ba, La, Ce, and Eu have *average* concentrations close to those of the bulk CAI, consistent with expectations for relict phases. In contrast, depletion of Ti, Sc and Zr reflect partitioning after dissolution of the relevant carriers. Perovskite as a relict phase in outer portions of a B1 was suggested by [4], although other phases may have been present.

Summary: We have resolved a major discrepancy between observed concentrations of refractory lithophile elements in CAI melilite and expectations from fractional crystallization [1-4]. Although an imprint of fractional crystallization is present (e.g., Fig. 1), inclusions play a major role, as previously anticipated by [4]. Relict phases, potentially even primary nebular condensates, would be of considerable importance and warrant additional study, but the possibility that exsolution may account for some of these grains also needs to be considered. Exsolved phases could provide useful constraints on the subsolidus thermal history. The role of evaporative processes to locally manipulate melt concentrations of elements also needs to be considered.

References: [1] Davis A. M. et al. (1992) *LPS XXIII*, 281-281. [2] Simon S. B. et al. (1996) *LPS XXVII*, 1201-1202. [3] Davis A. M. et al. (1996) *LPS XXVII*, 291-292. [4] Kennedy A. K. et al. (1997) *GCA 61*, 1541-1561. [5] Sylvester P. J. et al. (1992) *GCA 56*, 1343-1363. [6] MacPherson G. J. et al. *J. Geology* 92, 289-305.