

EFFECTIVE FASSAITE/LIQUID TRACE ELEMENT DISTRIBUTION COEFFICIENTS FOR TYPE B CAI'S; A. M. Davis¹, S. B. Simon² and L. Grossman^{1,2}, ¹Enrico Fermi Institute, ²Department of the Geophysical Sciences, University of Chicago, Chicago, IL 60637

Fassaite pyroxene is the major carrier of Sc, Ti, Y, Zr, Nb, Hf, Th, U and REE in Type B Ca-Al-rich inclusions (CAI's). Fassaite in these inclusions is typically strongly zoned, with cores rich in Sc and Ti and rims rich in Y, Nb, Th, U and REE. It has not been possible to model zoning profiles in fassaite in Type B CAI's because equilibrium solid/liquid distribution coefficients have not been measured for pyroxene of appropriate composition. Type B CAI's are known to have cooled rapidly, so that partitioning may have been affected by formation of boundary layers enriched in incompatible elements.

We have analyzed 26 spots on several large texturally subliquidus fassaite crystals in the Allende Type B1 CAI TS34F1, to determine the range of trace element abundances in subliquidus fassaite. We found a wide range of trace element compositions, including large enrichments in Y, Nb, Th, U and REE in the low Ti, late-crystallizing rims of crystals, and concluded that the range of subliquidus fassaites overlapped that of texturally "relict" fassaites. The relationship between texturally "relict" and subliquidus fassaite is discussed in detail in a companion abstract [1].

When plotted vs. Sc on log-log plots, data for many trace elements in fassaite fall along linear arrays. Some examples are shown in Fig. 1. These linear arrays allow calculation of relative fassaite/liquid trace element distribution coefficients. The order of crystallization of Type B inclusions is spinel, melilite, pyroxene and anorthite [2]. For most Type B inclusions, pyroxene begins to crystallize after 50-70% of the inclusion has crystallized. Scandium is a compatible element in fassaite and incompatible in melilite, spinel and anorthite in TS34F1. For our calculations, we assume that the ratio of crystallizing spinel+melilite+anorthite to crystallizing pyroxene remains the same once pyroxene has begun to crystallize and that the trace elements of interest do not partition into spinel, melilite or anorthite to a significant extent. Trace element zoning patterns in fassaite can be modelled with the Rayleigh fractionation law, $C_{liq}/C_{liq0} = f^{(D-1)}$, where C_{liq0} is the concentration in the liquid when fassaite crystallization begins, f is the fraction of liquid remaining and $D = C_{fas}/C_{liq}$. For two elements A and B, this equation can be written $\ln C_{liq}^A = \ln C_{liq0}^A + (D^A-1) \ln f$ and $\ln C_{liq}^B = \ln C_{liq0}^B + (D^B-1) \ln f$. These equations can be combined to give $\ln C_{liq}^A = K_1 + (D^A-1)/(D^B-1) \ln C_{liq}^B$, where K_1 is a constant. This equation can be written in terms of C_{fas} , using the relation $C_{fas} = D C_{liq}$: $\ln C_{fas}^A = K_2 + (D^A-1)/(D^B-1) \ln C_{fas}^B$, where K_2 is a constant. If the D's are constant over the range of fassaite compositions observed, a log-log plot of the concentrations of elements A and B in fassaite should be linear with a slope of $(D^A-1)/(D^B-1)$. If D is known for one element, the D's for other elements can be calculated from such plots. The elements showing linear arrays of points with significant slopes on log-log plots vs. Sc are Ti, V, Cr, Y, Zr, Nb, REE, Hf, Th and U. On these plots, the points lie along a tight linear array except for analysis spots containing less than $10 \times C_1$ (times C_1 chondritic) Sc. This scatter of low-Sc points is caused by localized effects in the liquid, not poor Sc analyses. The five low-Sc points shown in Fig. 1 were excluded from the calculation of slopes and their uncertainties that are given in Table 1.

The slopes on the log-log plots allow limits to be placed on D's. The plot with the largest negative slope is that for Sc vs. Th, where the slope is -0.708. Since D^{Th} cannot be less than 0, the upper limit for D^{Sc} is 2.41, the value calculated for $D^{Th} = 0$. This value is somewhat lower than the value (4.3) inferred for the first-crystallizing fassaite by a different method in the Type B2 CAI TS22F1 [3]. The effective D's calculated in the present work average over almost the entire course of fassaite crystallization, during which equilibrium D's such as that inferred in [3] may have been modified by boundary layer formation and other effects (see below). We have adopted the D^{Th} measured for diopside in the Ab-An-2Di system, 0.029 [4]; this gives a value of 2.37 for D^{Sc} . This value was used to calculate D's for other elements that concentrate into fassaite (Table 1).

The regression lines have been plotted in Fig. 1. In general, the measured trace element concentrations cluster tightly about the regression line until the Sc content drops below $10 \times C_1$, or 60 ppm. If the Sc concentration in fassaite is controlled by Rayleigh fractionation, with $D^{Sc} = 2.4$, $10 \times C_1$ Sc corresponds to 97% crystallization of fassaite, or ~99% crystallization of the inclusion. The wider scatter of trace element concentrations in the last 3% of crystallization is not unexpected, given that the melt is probably not interconnected at this point and any boundary layers that formed in the liquid would make up a major volume fraction of the liquid.

This treatment of trace elements in fassaite contains many oversimplifications, given possible equilibrium and kinetic effects that can modify fassaite/liquid distribution coefficients. These include changes of D's due to temperature, changes in liquid composition, changes in fassaite composition, formation of boundary layers enriched in incompatible elements and depleted in compatible elements and different D's on different faces of a growing sector-

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zoned pyroxene. Nonetheless, the excellent correlations in Fig. 1 suggest that the effective D's inferred in this work are applicable over ~97% of the crystallization of fassaite.

References: [1] Simon S. B., Davis A. M. and Grossman L. (1990) *LPS XXI*, this volume. [2] Beckett J. R. (1986) Ph. D. Thesis, Univ. of Chicago. [3] Simon S. B. and Grossman L. (1990) *LPS XXI*, this volume. [4] Benjamin T., Heuser W. J., Burnett D. S. and Seitz M. G. (1980) *GCA* 44, 1251-1264.

Table 1. Slopes and calculated fassaite/liquid partition coefficients from log trace element vs. log Sc plots.

	Slope	D
Sc	1	≈ 2.37
Ti	$0.324 \pm .032$	$1.44 \pm .04$
V	$0.789 \pm .163$	$2.08 \pm .22$
Cr	$-0.177 \pm .067$	$0.76 \pm .09$
Y	$-0.279 \pm .023$	$0.62 \pm .03$
Zr	$0.102 \pm .023$	$1.14 \pm .03$
Nb	$-0.325 \pm .079$	$0.55 \pm .11$
La	$-0.407 \pm .047$	$0.44 \pm .06$
Ce	$-0.366 \pm .041$	$0.50 \pm .06$
Pr	$-0.323 \pm .035$	$0.56 \pm .05$
Nd	$-0.309 \pm .033$	$0.58 \pm .04$
Sm	$-0.283 \pm .026$	$0.61 \pm .04$
Gd	$-0.310 \pm .028$	$0.58 \pm .04$
Tb	$-0.297 \pm .026$	$0.59 \pm .04$
Dy	$-0.324 \pm .024$	$0.56 \pm .03$
Ho	$-0.340 \pm .025$	$0.53 \pm .03$
Er	$-0.334 \pm .024$	$0.54 \pm .03$
Tm	$-0.323 \pm .029$	$0.56 \pm .04$
Yb	$-0.321 \pm .028$	$0.56 \pm .04$
Lu	$-0.295 \pm .031$	$0.59 \pm .04$
Hf	$0.372 \pm .025$	$1.51 \pm .03$
Th	$-0.708 \pm .134$	$0.03 \pm .18$
U	$-0.422 \pm .157$	$0.42 \pm .22$

Figure 1. Log trace element vs. log Sc diagrams for subliquidus fassaite in TS34F1. Regression lines are calculated from all points with Sc > 10 × C1 chondrites.

