SECTOR-ZONING IN FASSAITE IN TYPE B2 REFRACTORY INCLUSIONS.

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Introduction:

Type B (pyroxene-rich) refractory inclusions are one of the major types of inclusions found in carbonaceous chondrites. They are subdivided into two types based on the presence (B1s) or absence (B2s) of a countinuous, nearly monomineralic melilite mantle enclosing the inclusion. Much of what we know about Type B inclusions comes from studies of Type B1 inclusions; little detailed data exist for Type B2s. To remedy this situation, we are studying a suite of B2s from Allende. In addition to documenting features of B2s, we are looking for contrasts with B1s to improve our understanding of the formation of both types. One such difference is the relatively common occurrence of sector-zoning in Ti-, Al-rich clinopyroxene, termed fassaite [1], in Type B2s and the rarity of such zoning in fassaite in B1s, which may provide constraints on crystal growth rates. We studied a suite of sector-zoned crystals optically and with the scanning electron microscope, and analyzed them by electron microprobe (EMP) and laser-ablation ICP mass spectrometry (LA-ICP-MS).

Observations:

Fassaite in Type B CAIs is commonly concentrically zoned with gradually decreasing Ti oxide and increasing MgO and SiO_2 contents from core to rim [2]. Sector-zoned pyroxenes, however, have sharp discontinuities in the distributions of these oxides and Al_2O_3 that commonly are not concentric with respect to the cores of crystals. The structure of a euhedral, sector-zoned proxene can be thought of as a set of adjacent pyramids whose apices meet at the center of the crystal and whose bases are the crystal faces [3]. As noted in [4], in fassaite the sectors are either MgO-, SiO_2-rich or are relatively Al_2O_3-rich. The sector-zoning is thus mainly defined by variations of the Di ($CaMgSi_2O_6$) and CaTs ($CaAl_2SiO_6$) components of the pyroxene. The Ti-bearing components, T_3P ($CaTi^{3+}AlSiO_6$) and T_4P ($CaTi^{4+}Al_2O_6$) are slightly enriched in the CaTs-rich sectors relative to the Di-rich sectors, making the zoning discernable by backscattered electron imaging. One of the goals of the present study is to identify other elements, if any, whose distributions within fassaite crystals are affected by sector zoning.

Contacts between sectors tend to be straight and sharp. The apparent shapes of the sectors are strongly dependent upon sectioning. Four triangular sectors may be exposed in a near-central plane through a crystal, but more commonly, in the plane of the section grains may have just one Di-rich and one CaTs-rich sector adjacent to each other or one enclosed by the other.

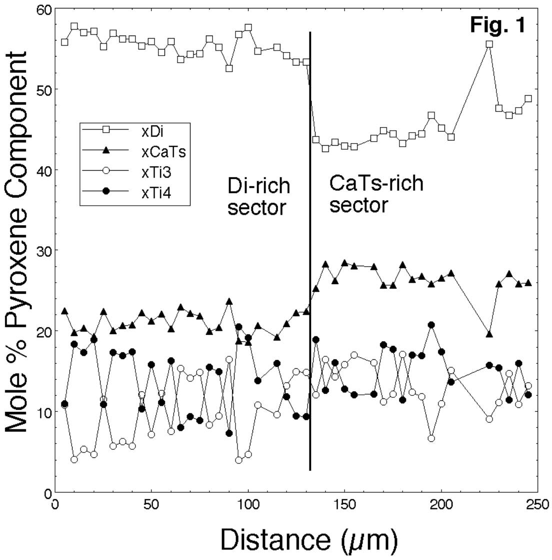
Fig. 1

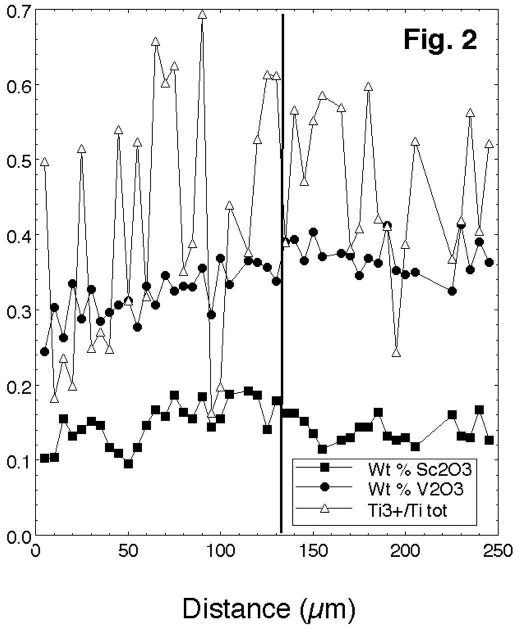
Fig. 2

The results of an electron probe traverse across a contact between two sectors of a crystal in Allende Type B2 inclusion TS65 are summarized in Figs. 1 and 2. Note the sharp contrast in the Di and CaTs contents of the two sectors and the relative uniformity of Ti-component contents in the sectors. We looked for, but did not find, sector-related differences in the Ti^{3+}/Ti^{tot} and in the distributions of the minor elements V and Sc (Fig. 2). The analytical uncertainties by EMP are ± 6% for V and ± 15% for Sc, less than the ~20% change in the Di component. The absence of sharp changes in Ti^{tot} and V contents distinguishes sectors from fractionated, late overgrowths and from the Ti-, V-enrichment zones, or “spikes” found in fassaite in some Type B1s [5].

For better precision for Sc (±5–10%) at low concentrations and to see if trace element contents of Di-rich and CaTs-rich sectors differ systematically, we analyzed for Sc, Y, Zr, La and Er by LA-ICP-MS in four sector-zoned crystals. Sc is strongly compatible in fassaite [2] as is Ti, and although the differences in Ti contents between the sectors are small, we can expect Sc to be correlated with Ti and anticorrelated with the incompatible trace elements. We found a range of Sc contents from ≤ 150 to 1120 ± 100 ppm. The results differ from those expected from fractional crystallization in that Ti-, CaTs-rich sectors of the grains do not tend to be enriched in Sc relative to coexisting Di-rich sectors. Also, in two of the grains, the CaTs-rich sectors have Y, Zr, La and Er contents greater than or equal to those of the Di-rich sectors, as in the example shown in Fig. 3, possibly reflecting sector-zoning of these elements. In the other two grains, however, the Di-rich sectors are enriched in Y, La and Er relative to the CaTs-rich sectors. Sector-dependent partitioning of elements may have been obscured in some cases by the effects of fractional crystallization. Detailed traverses by LA-ICP-MS across contacts between sectors, rather than analysis of several points within sectors, should help us resolve the trace element preferences of the Di-rich and CaTs-rich sectors.

Discussion:

Studies have shown that within a single crystal, different faces can have different effective partition coefficients because they expose different sets of crystallographic sites to the melt [6], leading to the development of sector zoning. The zoning is preserved if crystal growth is faster than diffusion. Watson and Liang [7] used this constraint to define conditions under which sector-zoning would and would not be expected. According to their model, a crystal should be sector-zoned if its growth rate is greater than its internal diffusion rate (D) divided by the width of a growth layer (taken to be 10 Å). For CaTs-Di (AlAl $\Leftrightarrow$ MgSi) interdiffusion at 1523 K, $D= 1.65 \times 10^{-13}$ cm^2 s^{-1} [8]. This yields a critical growth rate of 1.65×10^{-2} µm s^{-1}, or ~ 1 µm min^{-1}. This is at the high end of the range found by [9] for occurrence of pyroxene as polyhedral (*vs.* hopper or dendritic) grains, and based on their experiments would be consistent with formation at ~25°C supercooling. Sector-zoning was also produced, however, in crystals grown at one-tenth this rate, as slow as 1.2×10^{-3} µm s^{-1} (at 13°C supercooling, or 1310°C) [9], conditions under which the model of [7] would not allow sector zoning if the rate for CaTs-Di diffusion is used. Noting this, it was suggested in [7] that interdiffusion rates involved in the coupled substituion $Ti^{4+} + 2Al^{3+} \Leftrightarrow Mg^{2+} + 2Si^{4+}$ may be significantly lower than those in the Ti-free, CaTs-Di system considered by [8]. This is reasonable, as the T_4P-Di exchange involves substitutions among six cations, and CaTs-Di exchange involves just four. A lower D would decrease the critical growth rate required for sector-zoning.

Fassaite in Type B1s could not have had sector-zoning that was erased by reheating because any event long and hot enough to do so would have completely homogenized the grains, and the observed core-rim variations would have been lost. Assuming that the minimum growth rate for the formation of sector-zoned fassaites in Type B2 inclusions is ~0.1–1 µm min^{-1}, we conclude that fassaite in Type B2 inclusions grew at least this fast, and that in Type B1s grew more slowly. High degrees of supercooling need not be invoked for the development of sector zoning, consistent with experimental petrologic studies of CAIs [e.g. 10] which do not support crystallization of CAIs from supercooled melts. The results here are qualitatively consistent with faster cooling rates for B2s than for B1s, but there are many factors affecting crystal growth rates, such as the maximum temperature reached (T_{max}), time spent at T_{max}, and kinetics, which prevent direct inference of cooling rates from crystal growth rates.

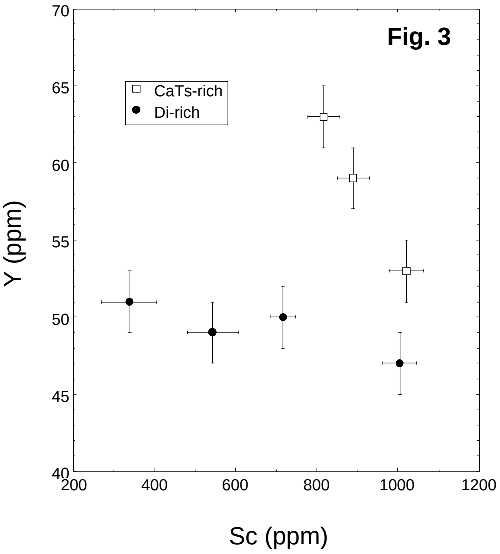

Fig. 3

References:

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