TRACE ELEMENT CONSTRAINTS ON THE FORMATION OF THE RIM ON A COMPACT TYPE A INCLUSION;

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Introduction: Compact Type A (CTA) calcium-aluminium-rich inclusions (CAI) crystallised from melts and are composed of >75% low akermanite content (Ak 3 - Ak 35) melilite (Mel) that poikilitically encloses spinel (Sp) and perovskite (Pv). Sp and fassaite (Fass), and sometimes hibonite (Hib) and plagioclase (Plag) occur as interstitial material in the cores of some inclusions. CTA often have complex evolutionary histories, having undergone metamorphism, alteration and deformation [1]. Some examples of this complexity are: (1) Mg isotopes show late formation of plagioclase, after substantial decay of ^{26}Al, in comparison with hibonite in the same CTA [2]; (2) Radial change of Mg isotope mass fractionation and isotopic disequilibrium between Mel, Sp and Pv have been identified in E-2 and E-50, CTA from Efremovka [3, 4]; (3) There is no relationship between Mel Ak and trace elements (TE) concentrations in some CTA and this feature has been explained by kinetic effects and dissolution of relict Pv [5]. Wark-Lovering rims are thin, multi-layered sequences surrounding CAI that rarely exceed 50 um in width [6]. Individual layers are fine-grained aggregates of 1 to 3 phases that exhibit relatively constant thickness [6]. An idealised rim sequence [6] from innermost to outermost layer is (1) Sp+Pv±Hib±Fass; (2) Mel± its alteration products; (3) Fass grading to diopside (Diop); and (4) hedenbergite±Diop±andradite or olivine. Models for rim formation include evaporative loss from the surface, a second period of nebular condensation, cyclic vaporisation and recondensation, metasomatic reaction with nebular gas, and crystallisation from a melt. There is no preferred alternative due to conflicting evidence and the overall complexity of rims [7].

We have examined a large elongate (1.8 cm x 0.9 cm) Allende CTA, hereafter referred to as 134-1, that contains minor amounts of Sp and Pv and that has a very thick (>1 mm) multi-layered (up to 6 layers) rim sequence surrounding the interior Mel. We have measured major element compositions of the different phases by SEM, and have used the high resolution and sensitivity of the Western Australian SHRIMP II ion microprobe to measure P, K, Sc, Ti, V, Cr, Mn, Sr, Y, Zr, Nb, Ba, Hf, Ta, REE, Pb, Th and U in Mel, Pv and clinopyroxene (Cpx). The thick multi-layered rim of this CTA allows comparison of TE and REE within the rim and interior phases, and this allows us to study the development of the rim. In addition, the distribution of the trace elements in interior Mel and Pv provides a history of the formation and evolution of this CTA.

Petrography: 134-1 has a convoluted shape and the interior is composed of an aggregate of randomly oriented Mel crystals, with a few crystals reaching 1 mm in length. Some Mel have igneous textures and radiate inward from the rim of the inclusion, but this a localised occurrence. Most Mel exhibits undulose extinction in polarised light and alteration along grain boundaries and cleavage planes. Sp occurs as small (< 50 um) rounded grains poikilitically enclosed in Mel and as larger 50-100 um euhedral interstitial grains. Pv occurs as small (<50 um) rounded grains scattered throughout, but is more abundant towards the core. It occurs as both interstitial grains and as inclusions in Mel. No Fass, Plag or Hib occurs in the interior of 134-1. The rim layers in order from inner to outer are: (1) a Sp-rich layer with Sp occurring as large patches (up to 100 um wide) surrounded and intimately intergrown with Mel ± Cpx; (2) a ~150 um wide intergrowth of approx. equal amounts of small (<20 um) Sp and Cpx; (3) a 20 um to 100 um wide graphic intergrowth of Pv+Sp+Cpx; (4) a fine-grained intergrowth of Mel, Sp, Cpx and nepheline; (5) a Sp-rich layer with large patches of Sp and Cpx surrounded by small zones of nepheline; (6) a 10 um wide zone that contains Cpx and Fe-Ni metal.

Results: The SEM data show that the Mel in 134-1 has a small Ak range, Ak 4 - Ak 14, with the higher Ak compositions occurring in larger crystals. There is no apparent trend to higher Ak going from the rim to the core of the inclusion. Sp from the outermost layer of the Wark-Lovering rim has higher FeO (up to 6%) than Sp from the interior of the inclusion (<1.5%) and from the Pv+Sp+Cpx layer of the rim (~1%). Cr also increases in Sp towards the exterior of the inclusion ranging from below the SEM detection limit in interior Sp to 0.4% in the outermost Sp-rich layer. Similar variations occur in Cpx. Fe, Cr and Na are only present, and Sc and Mn reach their highest levels, in Cpx from the outer layers of the rim, and these Cpx have Al_2O_3~ 11% and TiO_2~1%. A variety of REE patterns occur in the phases of 134-1 (Fig. 1 & 2). Mel and Pv from the interior have approx. flat ($Ce/Er_{c.n.}$~1) REE patterns. Mel shows a slight depletion of both LREE and HREE relative to the MREE, and small +ve Eu anomalies. Pv from the interior of the inclusion have similar shaped REE patterns, but with -ve Eu anomalies and much higher REE concentrations (LREE 50 x ch, MREE 200 x ch, HREE 20 xch). Pv from the Pv+Sp+Cpx rim layer has two types of REE pattern (Fig. 2). Both patterns have HREE/LREE>1 and a -ve Yb anomaly, and they are unlike those of interior Pv. Different levels of REE enrichment and the size of the Eu and Yb anomalies distinguish the different types of rim Pv. Rim Pv has higher Sc, Th, Zr and Nb, and lower V than Pv from the interior of the inclusion. Differences in REE levels between individual rim Pv are paralleled by differences in other TE, i.e. Y, Sc, Zr, Nb. REE patterns for Cpx in the Wark-Lovering rim are relatively flat, with -ve Eu and Yb anomalies, have moderate REE levels and a slight enrichment of La (Fig. 1).

Discussion: In general TE concentrations decrease with increasing Mel Ak in 134-1. This relationship and the distribution of TE between Mel and Pv is similar to that expected from TE partitioning experiments [8, 9] and consistent with crystallisation of 134-1 from a melt with a group I REE pattern. Any model for rim formation on 134-1 must explain the different REE patterns for rim and interior phases, the two different REE patterns of rim Pv and differences in Sc, V, Nb, Zr and Y abundances. A model that relies entirely upon secondary condensation of the rim Pv+Sp+Cpx layer from a nebular environment requires different refractory and REE characteristics in the nebular environment to explain the observed differences. However, this model must invoke multiple episodes with different levels of REE, Sc, Y, Zr, Nb etc. relative to Ti and Ca in the gas from which the low REE Pv was deposited, or different partitioning behaviour. A model that is based on evaporative loss of material from the exterior of 134-1 would require conditions producing minor enrichment of HREE over LREE, the generation of a -ve Yb anomaly and slight enrichment of refractory elements, such as Sc, Y, Zr and Th, in the residue that formed the Pv+Sp+Cpx layer. This model requires variable degrees of enrichment of REE and TE due to evaporative loss for intimately associated (20 um apart) Pv grains. At present we favour the secondary condensation model, but it is obvious that additional data is required before any model can be adequately tested. However, our data shows that Wark-Lovering rims can have different REE patterns to the inclusions they surround.

References: [1] Teshima and Wasserburg 1985 LPS XVI, p855; [2] Hutcheon et al. 1983 Meteoritics 19, p244;[3] Fahey et al. 1987 GCA 51, p3215; [4] Goswami et al. 1991 Meteoritics 26, p339; [5] Kennedy et al. 1991 Abstr. LPS XXII, p621[6] McPherson et al. 1988 in Meteorites and the Early Solar System, p746[7] Murrell and Burnett 1987 GCA 51, p985;[8] Beckett et al. 1990 GCA 54, p1755; [9] Kennedy et al. 1994 Chem.Geol. 117, p379.