PETROGRAPHY, MINERALOGY AND MG ISOTOPE COMPOSITION OF VICTA: A VIGARANO CaAl$_4$O$_7$-BEARING TYPE A INCLUSION.

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Thermodynamic calculations [1] predict that Ca-dialuminate (CaAl$_4$O$_7$) condenses from a cooling gas of solar composition after hibonite and before melilite. Although Ca-dialuminate has now been recorded from Ca Al-rich inclusions (CAIs) in at least 9 meteorites [2,3,4,5,6,7,8], compared to hibonite it is a relatively rare phase. As pointed out by Michel-Levy *et al.* [2] the absence of Ca-dialuminate from most hibonite-bearing inclusions poses a serious problem for the condensation model of CAI formation. Here we describe an inclusion which contains abundant Ca-dialuminate partially altered to a hercynite-rich (FeAl$_2$O$_4$) assemblage. The evidence from VICTA indicates that compared to all other phases in type A inclusions, Ca-dialuminate is the most susceptible to secondary alteration; a feature which may explain its restricted occurrence. Unaltered Ca-dialuminate and melilite in VICTA display excess ^{26}Mg$^{\cdot}$ indicative of *in situ* decay of ^{26}Al.

Petrography and Mineralogy Measuring 7mm x 6mm, VICTA has a convoluted structure and consists of a series of distinct but interconnected regions each with a melilite-rich core enclosed by a thick rim sequence. Large matrix-filled cavities are present throughout the inclusion. Coarse-grained gehlenitic melilite (Ak0-14) forming the core regions contains local concentrations of rounded inclusions of both perovskite (up to 30μm diameter)and Fe-free spinel (5-15μm diameter). Hibonite is also present as laths up to 40μm long, forming small irregularly-shaped clumps. Ca-dialuminate occurs as densely-packed elongate grains up to 100μm long within a 300μm x 600μm zone at the centre of the largest melilite-bearing area (figure 1). The melilite-rich cores are enclosed by a 70-300μm-wide layer consisting of fine-grained hibonite laths with subordinate interstitial spinel. This layer has a high porosity with numerous 5-10μm diameter voids lined by melilite. The junction with the core region is sharp, but irregular in detail with hibonite and spinel in the outer zone apparently having formed by replacement of coarse-grained melilite. External to the hibonite-rich zone a 50-60μm-thick Wark-Lovering rim sequence is developed comprising the following layers: (from innermost out) i) spinel (FeO 1.5wt%) with minor hibonite (40μm thick), ii) melilite (Ak9.4-17.3) (5μm thick), iii) clinopyroxene zoned outwards from fassaite (Al$_2$O$_3$ 16.1wt%, TiO$_2$ 3.7wt%) to diopside (10μm thick) and iv) olivine (Fo$_{99}$)(2-5μm thick).

Alteration The only phase in VICTA showing evidence of secondary alteration is Ca-dialuminate which has been partially altered to a fibrous material with a composition close to pure hercynite (FeAl$_2$O$_4$); ZnO values of up to 3 wt% were measured in some areas (figure 2). Hercynite presumably formed from Ca-dialuminate by the reaction CaAl$_4$O$_7$ + 2FeO → 2FeAl$_2$O$_4$ + CaO with the FeO being supplied by the meteorite matrix. The external surfaces of VICTA are decorated by a discontinuous 10-15μm thick layer of kirschteinite CaFeSiO$_4$, which from its morphology appears to have formed *in situ*. The CaO required to produce kirschteinite may have been supplied via breakdown of Ca-dialuminate with FeO and SiO$_2$ being supplied from an external source.

Mg isotopes Mg isotopes and ^{27}Al/^{24}Mg measurements were carried out using the P7-Concept ion microprobe designed in Cambridge [9]. Analyses were made with a 15kV, ^{16}O^{-} duoplasmatron primary beam of 0.5-1.0 nA and 5-10μm spot size. A mass resolution of >4000 was used to separate ^{24}MgH$^+$ from ^{25}Mg$^+$.

Both Ca-dialuminate and melilite in VICTA display ^{26}Mg$^{\cdot}$ excesses which correlate positively with ^{27}Al/^{24}Mg ratios and are therefore ascribed to *in situ* decay of ^{26}Al. Ca-dialuminate with ^{27}Al/^{24}Mg of 300-700 shows ^{26}Mg$^{\cdot}$ excesses of 114-207‰, melilite with ^{27}Al/^{24}Mg of 25-86 shows excesses of ^{26}Mg$^{\cdot}$ in the range 15-52‰.

Discussion The rarity of Ca-dialuminate relative to hibonite in CAIs has been used as an argument against a condensation origin for these inclusions [2]. However, our evidence suggests that Ca-dialuminate is highly susceptible to secondary alteration and therefore may originally have been more widespread in CAIs. The presence of up to 2.2 wt% FeO in some Leoville Ca-dialumunates was cited as evidence in favour of an igneous origin for the host CAI [2]. However, in VICTA high FeO contents in Ca-dialuminate correlate with degree of alteration and suggest that this is not a valid criterion on which to base petrogenetic models.

As pointed out by Bischoff et al. [7] Ca-dialuminate-bearing inclusions appear to form two distinct groups, with isolated grains such as those in Colony [6] or Acfer 182 [7] showing no detectable ^{26}Mg*, whereas those like VICTA which are associated with melilite display large ^{26}Mg* excesses. Melilite-free Ca-dialuminate-rich inclusions from Adelaide [8] with large ^{26}Mg* excesses appear to be anomalous in this respect. However, we note that so far Mg isotope measurements have been made on only a small number of Ca-dialuminate-bearing inclusions.

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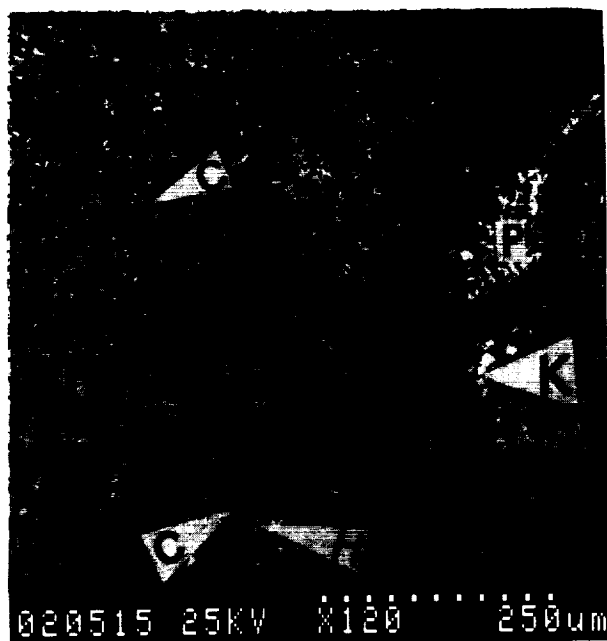
Figure 1   Figure 2

Figure 1. Melilite-rich Ca-dialuminate-bearing core of VICTA enclosed by a thick rim sequence. Coarse-grained melilite (M) contains abundant inclusions of Ca-dialuminate (C) partially replaced by a fibrous hercynite-rich alteration assemblage (H). The melilite-rich core is rimmed by a thick hibonite-rich layer (light grey) in which abundant perovskite (P) inclusions are present locally. The hibonite-rich layer is separated from the enclosing meteorite matrix (MM) by a 50μm wide wark-lovering rim sequence (see text for details). Grains of Kirschteinite (K) CaFeSiO$_4$ occur locally along the margin of the inclusion (back-scattered electron image).

Figure 2. Ca-dialuminate (C) inclusion in melilite (M) partially replaced by a fibrous hercynite-rich alteration product (H) (back-scattered electron image).