Mobility of Ca during Formation of Grossular-rich Veins in Ca-Al-rich Inclusions from the CV3 Chondrite Allende.

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Introduction:

Ca-Al-rich inclusions (CAIs) are among the earliest rocks that formed in our solar system and are used to interpret physical conditions (temperatures, pressures, oxygen fugacities, heating & cooling rates,…) of hot regions of the solar nebula [1,2]. These interpretations depend on determining the whole-rock elemental compositions of CAIs. In addition, the possibility of changes in composition due to processes that post-dated the nebular stages of CAIs should also be addressed.

In this study, we examine two type B CAIs from the CV3 Allende and ask whether these CAIs were open to fluxes of Ca during formation of grossular-rich veins. Grossular-rich veins are typical secondary features of Allende CAIs, and most (perhaps all) of these veins formed during metamorphism on the Allende parent body [3,4]. CAIs are abundant in Allende and have been used in many studies to infer high-temperature conditions and processes in the solar nebula [5]. Thus it is important to establish whether Allende CAIs have a compositional bias due to their metamorphic histories.

Methods:

Textures, mineral compositions and modes were determined for CAI 3655A (type B1) and CAI 4022, (type B2) from Allende (Fig. 1). These data were determined from two polished thin sections on loan from the Smithsonian Institution. Back-scattered electron (BSE) and elemental images, and quantitative analyses of minerals were collected using a JEOL JXA-8900 electron microprobe (EPMA) at Waseda University.

The main primary minerals in CAIs 3655A and 4022 consist of melilite, fassaite, spinel and anorthite. Secondary minerals are much finer-grained and occur in (1) grossular-rich veins that extend throughout CAI interiors and (2) semi-continuous alkali-FeO-rich domains near CAI margins (Figs. 2,3; also see [3]). Modes of primary minerals were determined from a grid overlain on a BSE image of each CAI. Modes of minerals in the alkali-FeO domains were determined from energy dispersive (EDS) spectra at grid nodes. Main minerals in the alkali-FeO domains are nepheline, sodalite, Fe-bearing spinel, and a yet-to-be-determined mineral with a composition similar to anorthite (possibly margarite; see [7]), and are sufficiently distinct in composition to be identified by EDS. EDS was conducted using a JEOL JSM-5900 secondary electron microscope at the Japan National Institute of Polar Research (NIPR; see [6]).

The main secondary minerals in and adjacent to the grossular-rich veins are grossular, monticellite and wollastonite and primary melilite. Compositional similarities of these minerals and the high porosity of the veins (Figs. 2,3) make it difficult to identify minerals from a CAI-scale image, even if EDS is used. So detailed BSE images were collected at several locations along the grossular-rich veins (e.g., Fig. 3), grids were overlain, and minerals and pores were identified manually at the grid nodes.

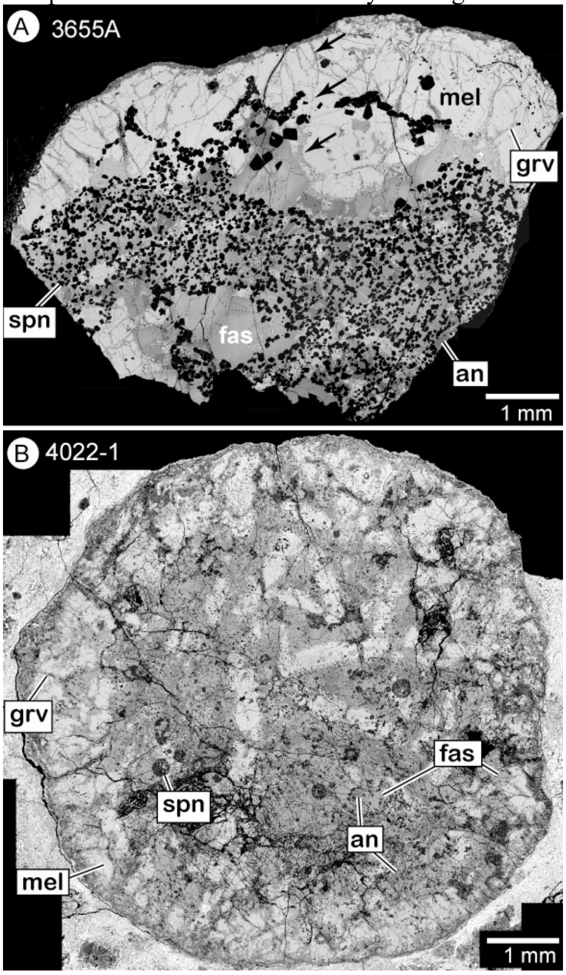

Fig. 1. Back-scattered electron (BSE) images of CAIs 3655A (A) and 4022 (B). Arrows in (A) point to grossular-rich vein shown in Fig. 2. See * for mineral abbreviations.

Results:

Secondary minerals comprise 17.4 mode % of CAI 3655A and 28.8 % of 4022. Thus, on the order of 1/5 to 1/4 of the original primary minerals in these CAIs were metamorphosed after their high-temperature stage of petrogenesis in the solar nebula. Based on textures, most of the secondary minerals formed by replacement of melilite +/- minor anorthite (Figs. 2,3).

Possible reactions to produce the grossular-rich veins were investigated using a reaction space approach [8,9,10]. The identified modes (%) of grossular, monticellite and wollastonite are:

	grossular	monticellite	wollastonite
3655A	11.2	4.1	0.8
4022	17.8	3.1	0.5

These modes can be produced from the breakdown of primary melilite + anorthite by linear combinations of: (a) 3 akr + geh + 4 an = 5 gr + 3 mc; (b) 3 akr + 2 mc + geh = 5 mon + an; (c) 5 akr = 5 mon + 5 wo (see * for abbreviations; also see [11]).

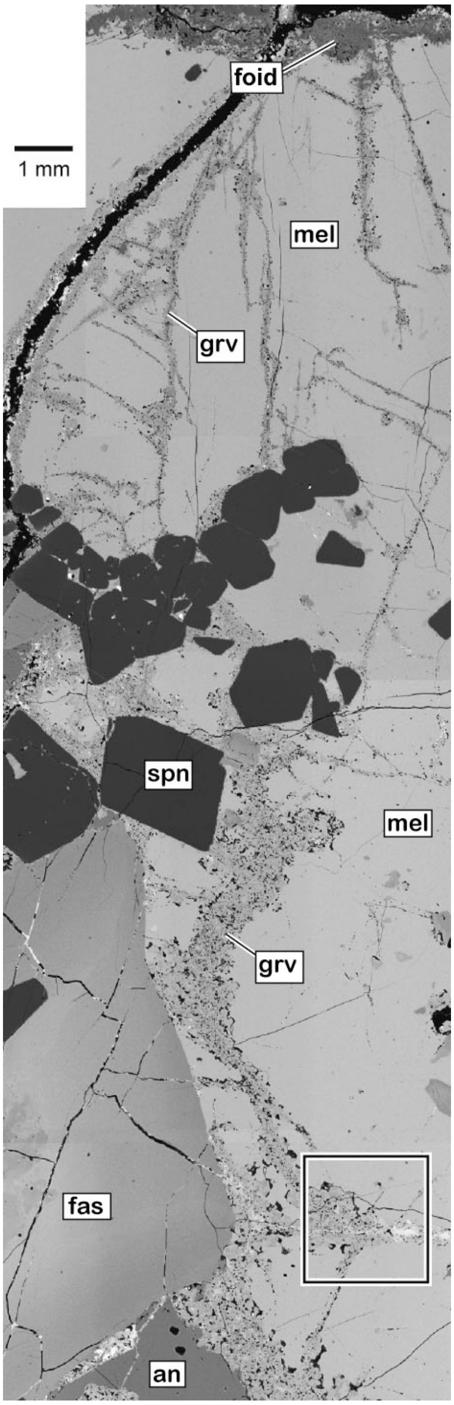

Fig. 2. BSE image of grossular-rich vein from CAI 3655A. Box highlights area shown in detail in Fig. 3.

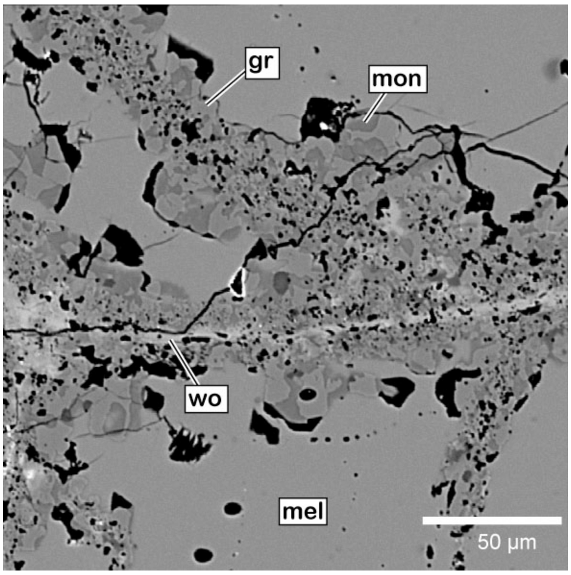

Fig. 3. Detailed BSE image of portion of grossular-rich vein.

These reactions (a,b,c) produce the observed modes of grossular, monticellite and wollastonite in a model closed system. However, they predict high akermanite-contents of melilite consumed ($\sim Ak_{80}$) and high volumes of anorthite/(anorthite+melilite) consumed (~30%). Based on natural mineral compositions and textures, melilite consumed should have compositions $<Ak_{70}$ and an/(an+mel) should be <20%. Better fits to these two constraints are met if Ca is lost from the reacting system during metamorphism. This accounts in part for the Ca-rich aureoles observed around many Allende CAIs [12] and predicts that type B CAIs from Allende should have lower Ca/Al than type B CAIs from less metamorphosed CV3 chondrites.

***Mineral Abbreviations:** akr = akermanite; an = anorthite; fas = fassaite; foid = feldspathoid-rich domain; geh = gehlenite; gr = grossular; grv = grossular-rich vein; mc = $MgCa_{-1}$ exchange in grossular-rich garnet solid solution; mel = melilite; mon = monticellite; spn = spinel; wo = wollastonite.

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