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Comparison of alteration of type B CAIs from CV3 chondrites Allende and Efremovka

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This study compares alteration histories of type B Ca-Al-rich Inclusions (CAIs) in two CV3 chondrites: Allende and Efremovka. Two CAIs from Allende (3655A and 4022) and one CAI from Efremovka (CGI-10) were studied. The main primary minerals of these CAIs are: melilite (Mel); fassaite (Fas); anorthite (Ano); Mg-spinel (Mg-spn). These minerals have similar interlocking, igneous-appearing (compact) textures in all three CAIs; however, secondary minerals and textures differ. Both the Allende and Efremovka CAIs have sodalite-rich alteration domains near CAI margins, but in the Allende CAIs, sodalite occurs with an assemblage of secondary minerals including nepheline, Fe-bearing spinel, grossular, an elongate Ca-Al-rich silicate (anorthite and/or margarite or possibly combinations of fine-grained minerals). We have not identified a similar assemblage in our initial work on CGI-10.

Furthermore, in the Allende CAIs, grossular-rich veins (GRV; mostly grossular (Grs) + monticellite (Mon) + wollastonite (Woll)) occur along grain boundaries of primary melilite. In contrast, melilite grain boundaries in CGI-10 appear fresh and free of replacement. The GRV and alkali-FeO-rich alteration domains indicate that the Allende CAIs have undergone a greater degree of secondary mineralization. This is consistent with the inference that Allende has been metamorphosed at higher temperatures than Efremovka (Bonal et al., 2006, GCA v. 70, 1849-1863).

It is obvious that a change in composition is necessary to produce the alkali-FeO-rich secondary minerals from the CAI primary minerals?namely an influx of Na, K, Cl and Fe and an outward flux of at least one element (possibly Ca). However, it is not obvious whether the GRV formed in an open system (elements being exchanged between CAI and surrounding environment) or closed system (little transport of elements between the CAI interior and surrounding environment during metamorphism).

To address this question, we used two approaches: (1) examine the GRV to identify exotic minerals; (2) make a model mass balance (reaction space) system to ask whether closed or open system models make better fits to the observed mineral abundances and textures. In approach (1) we were able to identify troilite (FeS) and wadalite (Ca6Al5Si2O16Cl3) in GRV in the interior of CAI 3655A, indicating that some S and Cl (and possibly Fe) were introduced into the CAI interior during metamorphism.

In approach (2) we construct a model reacting system including Ano, Mel, Grs, Mon, Woll, with Tschermak exchange (Al-1Al-1MgSi) to describe gehlenite-akermanite, and MgCa-1 for garnet solid solution (textures and low Ti-contents of secondary minerals indicate that Mg-spinel and fassaite are not consumed in significant quantities during formation of the GRV). These minerals and solid solutions can be described by the components CaO, MgO, Al2O3, SiO2 (CMAS). We invert the composition matrix and determine the following reactions for this system: (r1) 3tkr + 4Mel + 4 Ano = 5Grs + 3mc, (r2) 3tkr + 4Mel + 2mc = 5Mon + Ano, (r3) 5tkr + 5Mel = 5 Woll + 5 Mon. We determined modes for CAIs 3655A and 4022 to calculate the forward progress on reactions r1, r2, r3. Solutions can be calculated for both CAIs, but the solutions predict that the volume ratio of Ano/(Ano+Mel) consumed exceeds 0.3 and that the composition of melilite consumed exceeds Ak70. This Ak-content exceeds exceeds the Ak-contents of melilite present in the CAIs. The Ano/(Ano+Mel) consumed ratio is estimated as <0.1 for 3655A and <0.2 for 4022. Better fits to these parameters are reached if CaO is lost during formation of the GRV. These results suggest that, even though the main GRV minerals are CMAS phases, the CAIs were open metamorphic systems and that CaO was lost from Allende CAIs during formation of the GRV.

Keywords: CV chondrites, CAIs, alteration, metamorphism