Variable Garnet Compositions in the Allende CV3 Chondrite: Further Evidence for Complex Alteration on the CV3 Parent Body.

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Introduction: Members of the Allende-like subgroup of the oxidized CV3 chondrites ($CV3_{OxA}$) exhibit evidence of secondary alteration that has resulted in the formation of a wide range of phases that are mainly anhydrous. Calcium-bearing phases, e.g., garnet, likely formed via fluid-rock interactions with Calcium-Aluminum-Rich Inclusions (CAIs), chondrules, and matrix [1-2]. Despite the widespread evidence of fluid-rock interactions, many aspects of the alteration of these chondrites are not well constrained. In particular, andradite and grossular garnet, which have been shown to provide valuable insights into fluid-rock interactions in terrestrial skarn formation have not been extensively studied in CV chondrites [3]. In this study, we have carried out a detailed study of different occurrences of garnets in the Allende meteorite to gain an improved understanding of alteration reactions that result in the formation of garnet.

Methods: Six polished thin sections of Allende were studied using an FEI Quanta 3D Field Emission Gun SEM. High resolution BSE images and X-ray elemental maps were taken of andradite, grossular, and associated minerals within the matrix, around CAIs, and within CAIs. Electron microprobe analyses of garnet grains and associated mineral phases were obtained using a JEOL 8200 Superprobe using WDS spectrometry. Concentrations of Fe^{3+} and Fe^{2+} in garnet formulae were calculated using the procedures described by [4]. Garnet endmembers for each analysis were calculated using the method developed by [5], based on recalculated weight percentages of Fe_2O_3 and FeO.

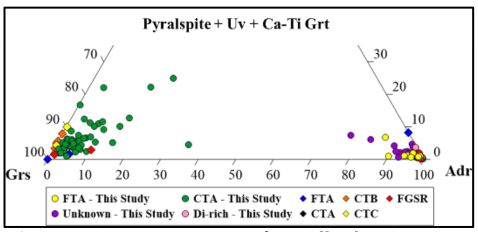

Figure 1: Garnet compositions from Allende CAIs; this study and compiled data. FTA: Fluffy Type A, CTA: Compact Type A, CTC: Compact Type C, CTB: Compact Type B, FGSR: Fine-grained spinel-rich inclusion. Data sources: [6 & references therein, 7, 8].

Results: The compositions of garnet in seventeen matrix nodules are andraditic, $Adr_{95.2-99.7}$. Grains deviating from almost pure andradite contain minor amounts of either grossular ($Grs_{3.7}$) or almandine ($Alm_{2.7}$) components. BSE imaging shows that andraditic garnet is present in the fine-grained rims around CAIs. Among the six Allende samples, the most prominent rims are around two Compact Type A (CTA) CAIs. Andraditic garnet compositions range from $Adr_{97.5}$-$Adr_{99.9}$. Some grains contain minor amounts of either a Grs ($Grs_{2.09}$) or Prp ($Prp_{0.64}$) component. Among the Allende samples, we observed garnets in four types of CAIs: CTA, Fluffy Type A (FTA), heavily altered CAIs that are too modified to classify, which we denote as Alt. CAIs., and a Di-rich inclusion. Figure 1 illustrates the diversity in garnet compositions found in the CAIs compared to literature data. Andradite is the dominant garnet type observed in the FTAs ($Adr_{86.3}$-$Adr_{98.6}$), Alt. CAIs, ($Adr_{76.8}$-$Adr_{99.4}$), and the Di-rich inclusion ($Adr_{95.9}$-$Adr_{99.19}$). Grs-rich garnet is the dominant garnet present in the CTAs; Adr-rich garnet is found as an accessory phase. Many of the grossular-rich grains exist as clusters, exhibit rim zonation with Mg, and have euhedral to subhedral morphologies. The amount of zoning observed was variable among grains but was present in the majority of grains. A few examples of grossular-rich garnet were observed in contact with melilite, but the majority was found as clusters within the interior and along the inner edge of the CTAs and not directly adjacent or in contact with melilite. While the CTA garnets are primarily Grs-rich ($Grs_{54.1}$-$Grs_{95.99}$), many grains contain either a Prp component ($Prp_{0.9}$-$Prp_{24.1}$), an Adr ($Adr_{0.3}$-$Adr_{35.2}$) component, or a mixture.

Discussion: The textural and spatial relationships of the garnets in the matrix nodules, the rims around CAIs, and within CAIs observed in this study are similar to those reported in previous work e.g. [2]. However, our much more extensive EPMA dataset for garnet compositions show compositional variability that has not been described in previous studies. This variability is particularly apparent in the compositions of grossular-rich garnets in CTA CAIs, which can show quite extensive pyrope solid solution. The zoning observed in the grossular grains could reflect a change in the fluid as observed in zoned skarn garnets [3]. It is also possible this zoning feature reflects Mg influx from the breakdown of Mg-rich melilite, but more data is needed to reach a definitive conclusion. Our observations and the compositions of the andradite-rich garnets in the matrix garnets corroborate the release of Ca into the matrix from alteration of CAIs and chondrule mesostasis via a fluid. The homogenous compositions of garnets in the matrix, suggests that fluid played a role in the formation of the garnet, but variations in garnet chemistry in the CTAs indicate that local compositional controls have also affected the garnet chemistry. The relative roles of these two processes will be explored using the trace element chemistry of the garnets in future work.

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