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Open system reactions during alteration of Allende CAIs

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Primary minerals in Ca-Al-rich inclusions (CAIs) from the CV3 chondrite Allende have been partially replaced by secondary minerals. Some secondary minerals concentrated near CAI rims are enriched in alkalies or Fe, indicating open-system behavior during alteration. This is supported by the presence of a Ca-rich aureole around one CAI studied by Ford and Brearley (2008), who suggested that Ca was lost from the CAI during alteration, transported into the surrounding matrix and incorporated into Ca-rich minerals in the aureole. On the other hand, secondary minerals in veins in CAI interiors (e.g., grossular, monticellite) are composed of the same elements that are abundant in primary minerals. It has been proposed that these minerals may have formed by closed-system metamorphic reactions (Hutcheon and Newton, 1981). This study focuses on closed-system vs. open-system behavior during formation of secondary minerals in Allende CAIs. We address this issue by (1) determining whether Ca-rich aureoles are characteristic of Allende CAIs; and (2) a detailed study of mass balances required to form grossular-rich veins in one CAI.
We mapped the abundance of chondrules, matrix and CAIs in one slab of Allende. Six polished thin sections were prepared and nine relatively large CAIs (3 coarse-grained and 6 fine-grained) were identified. Elemental maps (Na, Al, Mg, Si, S, Cl, K, Ca, Ti, Cr, Mn, Fe; all K-alpha) of the CAIs and surrounding matrix areas were collected using a JEOL JXA-8900 electron microprobe at Waseda University.
All three of the coarse-grained CAIs have Ca-rich aureoles; of the six fine-grained CAIs, three are surrounded by aureoles, one has a partial aureole, and two do not have Ca-rich aureoles in the plain of the thin section. One of the CAIs with no aureole is within 5 mm of a CAI that does have a Ca-rich aureole. Thus Ca-rich aureoles are typical, but not universal, in Allende CAIs, and factors determining whether a CAI has an aureole must vary on a scale on the order of millimeters. The main factor may be the abundance of Ca-rich primary minerals such as anorthite and melilite. CAIs that are poor in melilite and anorthite are likely to be poor sources of Ca and, thus, may not be surrounded by Ca-rich aureoles.
As pointed out by Hutcheon and Newton (1981), it is possible, based on mass-balance considerations, that grossular-rich veins form by a closed system reaction. Many reactions are possible, but the most likely, taking into account textures of primary minerals, is: 4 Ca2AlAlSiO7 + 3 MgSiAl(-1)Al(-1) + CaAl2Si2O8 = 2 Ca3Al2Si3O12 + 3 CaMgSiO4. This reaction predicts that the grossular-rich veins should consist of 2/3 grossular and 1/3 monticellite by volume. Detailed examination of grossular-rich veins in one of the coarse-grained CAIs showed grossular, but no monticellite. Furthermore, monticellite was not identified in any part of this CAI. Thus this reaction cannot account for formation of the grossular-rich veins in this case. A closed-system reaction that forms grossular but no spinel is possible: 8 Ca2AlAlSiO7 + 3 MgSiAl(-1)Al(-1) + 5 CaAl2Si2O8 = 7 Ca3Al2Si3O12 + 3 MgAl2O4. However, this reaction predicts that significant primary anorthite breaks down and spinel forms during formation of the veins. This prediction is not consistent with observed textures. Grossular crystals in some of the veins near the CAI-rim occur with nepheline and secondary anorthite. Even though the grossular-rich veins are texturally distinct from alkali-rich alteration near CAI rims, we suggest that both the veins and rims formed by open-system reactions, and may have formed during a single alteration event.

Keywords: Allende, Ca-Al-rich inclusions, alteration