Mineral alteration of type B1, B2, and fluffy type A Ca-Al-rich inclusions from the Allende CV3 chondrite

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Calcium-aluminum-rich inclusions (CAIs) from chondritic meteorites preserve a geologic record of early solar system processes and conditions. Primary minerals from many CAIs have been partially replaced by secondary minerals; however, the physical conditions of alteration and implications for nebular and parent-body history are poorly known. This is partly due to the fine-grain size and complex textures of secondary minerals and partly due to greater research emphasis on the primary minerals.

This study focuses on secondary alteration of CAIs from the CV3 chondrite Allende. Secondary minerals have been identified previously in Allende CAIs, but their modes and distribution are poorly known, due in part to fine-grain size. In this study, modes of primary and secondary minerals were determined for one type B1 (3655A), one type B2 (4022-1) and one fluffy type A (FTA, 3529-47-1) CAI in Allende. The FTA CAI consists of several melilite-cored, diopside-rimmed nodules connected by FeO-rich silicate matrix, whereas the type B CAIs are single objects that apparently had sub-spherical form. Our thin section of 3655A consists of a wedge-shaped fragment of the original CAI.

Modes were determined using back-scattered electron (BSE) images and energy dispersive spectroscopy (EDS). BSE images of the three CAIs were collected and assembled into digital mosaics. Grids were overlain on the BSE images, and minerals on the grid cross points were identified based on BSE-brightness. Melilite, fassaite, primary anorthite, Mg-spinel, diopside, perovskite and secondary grossular were identified at this stage. Several secondary minerals, including secondary anorthite, Fe-bearing spinel, nepheline and sodalite, are fine-grained, occur together, and have similar dark appearance in BSE. These minerals were grouped together and defined as *BSE-dark minerals*. Grid points in the BSE-dark material were analyzed by SEM-EDS using the JEOL JSM-5900 secondary electron microscope at the National Institute of Polar Research (NIPR) and identified based on EDS spectra.

The modes indicate that all three CAIs were altered extensively. Approximately 25% of the original CAI minerals in the 3655A, 30% in the 4022-1 and 60% of the 3529-47-1 have been altered to form secondary minerals.

The two type B CAIs show similar patterns of alteration. Grossular is the most abundant secondary mineral in both CAIs (˜20 mode% in 3655A and ˜25% in 4022-1). Grossular occurs with relatively minor secondary anorthite and monticellite in veins that appear to replace melilite in both CAIs. Akermanite-rich melilite in the core of 3655A is partially pseudomorphed by grossular+monticellite+/-wollastonite. BSE-dark minerals in both type B CAIs are concentrated near the CAI margins, although some BSE-dark patches occur in the interior of 4022-1. The modes of BSE-dark minerals are minor (˜2.4% in 3655A, 7% in 4022-1) relative to grossular.

CAI 3529-47-1 differs from the type B CAIs in pattern of alteration. A much higher proportion of 3529-47-1 consists of secondary minerals (˜61 mode%). Furthermore, in contrast to the type B CAIs, BSE-dark minerals are more abundant (˜49%) than grossular (˜12%). The most abundant secondary minerals in 3529-47-1 are secondary anorthite (˜21%) and Fe-bearing spinel (˜18%), but nepheline (˜6%) and sodalite (˜1.5%) are also present.

The higher extent of alteration and greater abundance of BSE-dark minerals of the FTA CAI are due to the higher surface area of this CAI. An influx of Na, Cl and Fe occurred during BSE-dark alteration. The grossular-rich alteration veins and patches did not require this influx.