Analysis of a Calcium-Aluminum-Rich Inclusion From The Allende Meteorite Using Electron-Backscatter Diffraction

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Introduction: Calcium-aluminum-rich inclusions (CAIs), so named because of the Ca- and Al-rich phases they contain, occur in primitive meteorites and are widely accepted as being the first solids to have formed within our solar system [1]. Many CAIs can be described as having a core-shell microstructure in which the core consists of melilite [(Ca,Na)$_2$Al$_2$Si$_2$O$_7$] grains surrounded by a multilayered shell known as the Wark-Lovering Rim (WLR) [2]. WLRs were hypothesized to have formed by several processes including condensation, flash heating, and metosomatic alteration [3-5]. We have been studying the microstructures of CAIs and WLRs using a combination of focused-ion-beam scanning-electron microscopy (FIB-SEM) and transmission electron microscopy (TEM) to gain new insights into their genesis [6-7]. Here we expand on those results by reporting complementary analysis using electron-backscatter diffraction.

Samples and Methods: In the present study we focused on a fluffy type-A CAI identified in a petrographic thin section (TS25, U. Chicago) from the Allende CV3 chondrite, a member of the oxidized CV3 sub-group [8]. The thin section was prepared by polishing with 0.5 μm colloidal silica on an automatic vibromat for approximately two hours. The sample was analyzed on a Hitachi S-5000 SEM operating at an acceleration voltage of 20 kV. The stage is positioned at a 70° tilt from the horizontal. Electron-backscatter diffraction (EBSD) and energy dispersive x-ray spectroscopy (EDS) were used to characterize its structure and composition. Automated EBSD analysis was performed with the HKL Channel 5 software package. Maps were constructed with 0.5 μm step size and a dwell time of 0.5 seconds.

Results and Discussion:
We selected a region of interest measuring 11,000 μm$^2$, comprising both the WLR and melilite core of the CAI. EDS mapping shows that the WLRs contain pyroxene [(Mg,Fe,Ca)$_3$Si$_2$O$_6$], anorthite [CaAl$_2$Si$_2$O$_8$], and spinel [MgAl$_2$O$_4$], consistent with previous measurements [9]. EBSD shows that the WLRs are polycrystalline, with grain sizes ranging from 0.56 to 8.87 μm in diameter.

The orientation of the pyroxene crystals within the WLR varies (Fig. 1). Their mean orientation, as defined by the three Euler angles, is $\phi_1=87.8^\circ$, $\Phi=84.5^\circ$, $\phi_2=177.4^\circ$. Individual pyroxene grains can vary by more than 50° from their neighbors. However, on a more localized scale, clusters of pyroxene crystals have similar Euler orientations. We hypothesize that locally similar orientations is suggestive of in situ nucleation rather than ex situ condensation followed by oriented attachment to the melilite inclusion.
Crystallization of the pyroxene layer may have begun at several different nucleation sites on the inclusion that later merged together creating the observed microstructure.

The anorthite layer also exhibits clustering of similarly oriented grains. Based solely on Euler angle orientations, the anorthite layer is less homogenous than pyroxene. A more detailed look into the textural properties of the WLRs, including the spinel layer, will be presented at the conference.

References

Fig. 1. EBSD data. (a) An Euler orientation map where the same color indicates the same orientation; px: pyroxene, an: anorthite, sp: spinel, ml: melilite. (b) A band contrast map with pyroxene grain boundaries that are assigned a color based on misorientation between the grains (blue >2°, red >5°, green >10°, fuchsia >20°, yellow >50°).