AMOEBOID OLIVINE AGGREGATES FROM THE ALHA 77307 CO3.0 CHONDRITE: MICROSTRUCTURAL CONSTRAINTS ON THE ORIGIN OF REFRACTORY COMPONENTS. Jangmi Han[1] and Adrian J. Brearley[1], [1]Department of Earth and Planetary Sciences, MSC03-2040, 1University of New Mexico, Albuquerque, NM 87131, USA. (E-mail: jmhan@unm.edu).

Introduction: Amoeboid olivine aggregates (AOAs) are the most common type of refractory inclusion in carbonaceous chondrites and have preserved evidence for condensation, evaporation, melting, and annealing within the solar nebula. AOAs are widely thought to represent aggregates of nebular gas-solid condensates such as forsterite, Fe,Ni-metal, and a refractory component, which experienced high-temperature annealing but largely escaped extensive melting [1,2]. Despite extensive study, there are still several outstanding questions relating to the origins of these inclusions that remain unresolved.

The CO3 chondrite, ALHA 77307 (CO3.0), is one of the most pristine carbonaceous chondrites, currently known [3]. This chondrite has highly unequilibrated mineral compositions and abundant presolar silicates [4,5] making it a valuable resource for studying early solar system processes.

In order to understand the relationship between the refractory component and olivine in AOAs and interpret their origins, we have studied AOAs in ALHA 77307 (CO3.0) using SEM/EDS and FIB/TEM techniques.

Methods: Elemental X-ray maps of two thin sections of ALHA 77307 were made by FEGSEM/EDS mapping to identify AOAs. Individual AOAs were studied using SEM/BSE imaging. Two regions from one AOA were sectioned using FIB techniques and then examined by TEM to determine their fine-scaled mineralogy and microstructures.

Results: From about 80 mm^2 of two thin sections of ALHA 77307, a total of about 250 AOAs have been identified. In ALHA 77307, AOAs are typically irregularly-shaped and very fine-grained, as described by [6,7]. The size of AOAs ranges from 20 µm up to 1mm, but most AOAs are less than 300 µm. Most AOAs in ALHA 77307 consist mainly of forsterite and lesser amounts of refractory, Ca-Al-rich phases such as Al,Ti-bearing diopside, ± anorthite, ± spinel, and rarely melilite. Texturally, AOAs in ALHA 77307 are similar to those in CV and CR chondrites [1,8].

One AOA (~350 µm in size, Fig. 1) found in our survey is an irregularly-shaped object containing ~40 vol.% of a refractory component surrounded by relatively compact olivine grains. The refractory CAI-like component occurs as four, rounded spinel-rich nodules which range in size from 50 µm to 100 µm. Each nodule consists of a zoned sequence with a spinel-rich core, a layer of intergrown spinel and diopside, and a diopside rim. Two melilite grains occur within the largest nodule, surrounded by diopside and spinel.

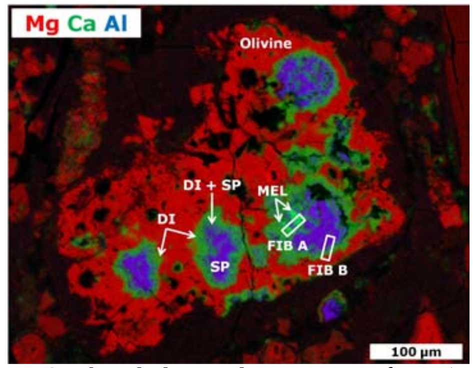

Figure 1. Combined elemental X-ray map of Mg (red), Ca (green), Al Kα (blue) of the AOA in the ALHA 77307 we studied. The AOA consists of olivine (red) and refractory components (greenish/bluish) such as diopside (DI), spinel (SP), and melilite (MEL). White boxes indicate the locations of FIB sections.

Two FIB sections were prepared from the largest CAI-like nodule in the AOA (Fig. 1). One FIB section (A) was prepared across a region of the nodule where two melilite grains occur and a second FIB section (B) was cut across the zonal sequence from the spinel core to the surrounding olivine of the AOA.

The FIB A section is dominated by gehlenitic melilite with Al,Ti-rich diopside and minor spinel. The region of the section containing melilite is highly compact and shows no evidence of pores. The melilite grains are highly irregular in shape and are defect free except locally where high densities of dislocation are present. The absence of subgrain boundaries and the complex grain boundary microstructures indicate that the melilite has not been annealed. Diopside and spinel also have relatively low dislocation densities.

The FIB B section consists of olivine, spinel, diopside, and minor anorthite. The central part of the section is a fine-grained (< 1 µm) intergrowth of diopside, minor spinel, olivine and anorthite. Small spinel grains have a subrounded morphology and are generally surrounded by grains of diopside and occasionally anorthite with a highly unequilibrated grain boundary microstructures. At the boundary between the intergrowth zone and the forsteritic olivine of the AOA, a region of finer-grained olivine and diopside is present with equilibrium 120˚ triple junctions indicative of high-temperature annealing.

Olivine in the AOA is very close to pure forsterite with very uniform composition. Plagioclase is near pure anorthite and spinel is near end-member $MgAl_2O_4$. In contrast, pyroxene is highly variable in composition, with distinct compositional ranges in the two FIB sections (Fig. 2). All pyroxene grains from the FIB B section have uniform, low TiO_2 contents (≤ 2.5 wt.%) but vary in Al_2O_3 contents from 0.3 wt.% to 18 wt.%. This change in Al_2O_3 content occurs progressively with increasing distance from the interface with olivine (0.3 wt.%) to the interface with spinel (18 wt.%). Thus, the FIB B section consists of the zonal sequence of spinel, Al-rich diopside, Al-poor diopside, and forsterite. In contrast, pyroxene grains in the FIB A section have relatively constant Al_2O_3 (17-26 wt.%), but a wide range of TiO_2 contents (1.1-13 wt.%).

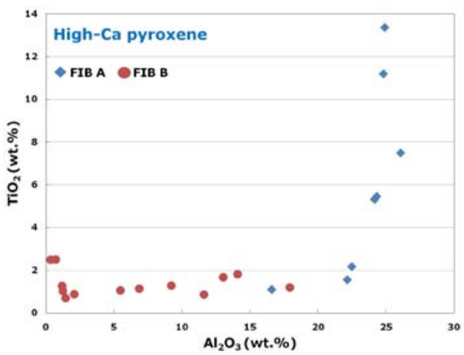

Figure 2. TiO_2 versus Al_2O_3 (wt.%) in pyroxene from two FIB sections.

Discussion: The mineralogy and textures observed in the two FIB sections indicate a high degree of compositional and textural disequilibrium. In particular, the heterogeneity of Al and Ti contents in pyroxene is quite remarkable. These features, specifically the intergrowth of fine-grained phases in the FIB B section, appear to be indicative of reaction relationships between spinel and diopside and in the case of the FIB A section, between melilite and spinel.

Based on the mineralogical studies of refractory component in AOAs, several different reactions have been proposed by [1] to explain the observed phase assemblages. Two of these reactions involve spinel as a reactant with either diopside or melilite:

(1) $3Ca_2Al_2SiO_{7(s)} + MgAl_2O_{4(s)} + 5SiO_{2(g)} + Mg_{(g)} + 6H_2O_{(g)}$
$= [4CaAl_2SiO_6 + 2CaMgSi_2O_6]_{(px\ ss)} + 6H_{2(g)}$

(2) $2MgAl_2O_{4(s)} + 2CaMgSi_2O_{6(s)} + SiO_{(g)} + H_2O_{(g)}$
$= CaAl_2Si_2O_{8(s)} + 2Mg_2SiO_{4(s)} + CaAl_2SiO_{6(s)} + H_{2(g)}$

Our observations for the FIB B section are quite consistent with these two reactions, assuming that melilite was originally present associated with spinel. [1] noted that in the earliest stages of reaction (1), the diopside is Al-poor, but becomes Al-rich as the reaction proceeds, because twice as much Ca-Tschermak's (CATS) pyroxene as diopside is produced. This appears to be exactly the effect we observe, with the progressive increase in Al contents in diopside as the interface with spinel is approached. According to thermodynamic calculations [1], reaction (2), forming anorthite, becomes possible once diopside with a CATS component > 20 mol.% is reached. We attribute the small amount of anorthite in the intergrowth to such a reaction. However, Al-rich diopside in the intergrowth significantly exceeds 20 mol.% CATS, suggesting that reaction (2) may have been kinetically inhibited. Nevertheless, in the area of the object sampled by the FIB B section, melilite, if originally present, has been completely consumed and the resulting mineral assemblage was unable to attain chemical equilibrium by diffusional processes.

For the melilite-bearing assemblage in the FIB A section, reaction (1) also appears to have occurred, but did not go to completion. However, the significant difference in TiO_2 contents between pyroxene in the FIB A vs. the FIB B sections suggests that a Ti-rich phase such as perovskite must also have been involved in the reaction. We have no evidence of perovskite in our FIB sections or indeed anywhere within the AOA, so we must infer that perovskite was present, but was consumed entirely during the reaction. We suggest that perhaps once Al,Ti-rich pyroxene formed by a reaction between melilite, spinel, and perovskite, the activity of $CaMgSi_2O_6$ in the pyroxene solid solution was too low to allow reaction (2), forming anorthite to proceed.

In summary, this single CAI-like object records differences in the sequence of condensation reactions on an extremely localized scale. In both cases, the reaction phase assemblages show a high degree of compositional and textural disequilibrium. These observations provide further evidence of rapid cooling of the nebular region where these refractory objects formed [1], in order to prevent complete reaction of melilite prior to condensation of olivine. Further microstructural studies are in progress to understand the complex history of this and other AOAs in ALHA 77307.

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