IN SITU MICROSPECTROSCOPY OF A TYPE B CAI IN ALLENDE: MINERAL IDENTIFICATION IN PETROGRAPHIC CONTEXT.

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Introduction: Visible/near infrared and thermal infrared spectroscopy has been used as a means of characterizing chondritic meteorites, primarily for comparison to astronomical spectra of asteroids [e.g., 1-6]. Most prior spectral analyses of chondrites are of powdered bulk samples, or more rarely, of powdered matrix and/or CAI separates. Such analyses require destructive preparation, they cannot always isolate phases, and do not retain information about the spatial relationships (petrographic context) between phases.

Objectives: (1) Demonstrate the utility of microspectroscopy for non-destructive, *in situ* characterization of chondritic phases at scales down to 10s of microns (where 10-25 μm is the diffraction limit in the TIR). (2) Reference the spectral characterization to backscatter and x-ray elemental mapping of a CAI and to electron microprobe analyses of the phases. (3) Use the data we obtain to constrain the pre- and post-accretion history of a Type B CAI in the Allende meteorite. We will accomplish these objectives by measuring spatially resolved reflectance spectra of a portion of Allende (CV3.2), identifying the phases represented, and evaluating the distribution of each phase.

Sample and Methods: We analyzed a portion of a thin section of Allende (USNM 3509) that includes a Type B, Ca-, Al-rich inclusion (CAI) designated HC-17. Because the majority of phases in our sample do not exhibit VNIR features, our initial analysis focused on measuring reflectance spectra from ~6000 - 400 cm^{-1} (~1.67 - 25 μm) with 4 cm^{-1} spectral sampling using a Thermo Scientific iN10 FTIR microscope at SwRI-Boulder. We show data for the fundamental vibrational features, 1350 - 400 cm^{-1} (7 - 25 μm). We collected 256 spectra over an 800-μm^2 area with pixel/spot sizes of 50 μm (Figure 1). This area includes portions of the CAI, matrix, and an isolated olivine grain. Upon identification of each mineral, we produced spectral indices (e.g., band depth values) to map their distributions. These spectra are referenced to backscatter electron and elemental x-ray mapping of the sample with the Cameca SX-50 electron microprobe (EMP) at the Lunar and Planetary Laboratory of the University of Arizona. We also obtained initial electron microprobe analyses on the same instrument of areas over which we collected spectra.

Results: To date, we have identified eight distinct minerals in spectra of the Allende thin section: feldspar, garnet, melilite, pyroxene, olivine (two types), oxide (likely spinel), and sodalite (Figure 2). We discuss our results starting with phases identified within the CAI and at its edge, followed by the matrix, and concluding with an isolated olivine grain.

CAI Interior. Phases identified in the interior of the CAI include feldspar, melilite, pyroxene, garnet, a probable oxide (spinel) phase, and sodalite.

Feldspar band positions are consistent with anorthite (Ca, Al feldspar). As compared to the spectrum of terrestrial, granular anorthite, Allende anorthite has narrower features with additional minima superposed on the broader bands; this may be attributable to greater purity (~An_{99}) than our comparison laboratory samples (An_{88-90}) [7]. Optic axis orientation can explain this characteristic only if all grains may be expected to have the same orientation, which seems unlikely.

We do not have reflectance or emission spectra of melilite series phases for direct comparison, so we have utilized transmission data [8] to infer that the solid solution composition in Allende is likely <Ak_{30}, closer to the Ca, Al end member composition. Whether this spectrum represents a single composition or the integrated signature of zoned grains is not yet known.

Pyroxene is not prevalent within this portion of the CAI, but we observe several spectra with features that are broadly similar to fassaite [9], a Ti-rich pyroxene.

Garnet spectra have band positions of grossular, a Ca, Al garnet. The similarity of Allende garnet spectra to those of particulates, and the fact that several spectra appear to be mixtures of other phases with garnet, suggest that the garnets may be present as randomly oriented, sub-pixel-sized grains or clusters of grains.

Several pixels in our map exhibit strong absorptions at low wavenumbers, suggesting a dominance of metal-oxygen (oxide) bonds. We found no exact match to this spectrum, but chromite has a similar shape with features offset to lower wavenumbers; this suggests that the Allende phase is a spinel, but with more tightly bonded cations, possibly hercynite. Some of the spectra also include features that may be due to chromite, pointing to a possible solid solution/alteration relation.

We have identified approximately a dozen spectra containing features matching a reference sodalite spectrum. Sodalite is known to occur in Allende as an alteration product of melilite and/or anorthite [e.g., 10]. Spectra with the strongest sodalite features occur along the inner edge of the CAI. Detection of sodalite exemplifies the advantages of *in situ* analysis as such minor phases rarely can be identified from bulk spectra.

CAI Rim. The edge of the CAI is characterized by the presence of spectra having signatures of oxide/spinel mixed variably with other phases. The consistent presence of oxide/spinel at the edge of the inclusion may be evidence of a chemical reaction.

Matrix. Olivine is the dominant matrix phase observed in our spectra, and band positions are consistent with a composition of ~Fo_{50} [11]. The band shapes and depths of matrix olivine differ somewhat from those of granular laboratory olivines, suggesting that they may display preferential orientation, which may be expected based on their platy or lath-like habit.

Isolated Olivine Grain. This grain occurs in proximity to the inclusion and although its spectra are similar to granular laboratory olivine having a composition of ~Fo_{90} [11] the bands are shifted slightly to higher wavenumbers, indicating that the Allende composition is even more magnesian. The similarity of band shapes to those of granular materials suggests that the isolated "grain" actually is comprised of several smaller crystals lacking a common optic axis orientation.

The margins of this isolated olivine grain exhibit spectral differences in the shape and/or position of the olivine bands, suggesting that the composition is closer to Fo_{90}, representing alteration of the grain.

Questions & Ongoing Work: Work is in progress to address questions such as: How much of the spectral differences between Allende phases and their terrestrial counterparts are due to preferred orientation in the thin section vs. differences in composition? Are the observed melilite spectra representative of a single composition or zoned compositions? What is the full extent of alteration mineralogy in this Allende CAI and what can we infer about the alteration history from these phases and their spatial relations? What are the proportions of phases in mixed spectra?

To address these questions, we are using a linear least squares model to determine the mineral proportions represented in mixture spectra. We also are in the process of acquiring spectra in the same area at higher spatial resolution (e.g., 25 µm spot sizes at 25-µm spacing) and collecting corresponding microprobe data. We will reference each spectra obtained with quantitative EMP analyses and thus accurately reference the spectra to mineral chemistry.

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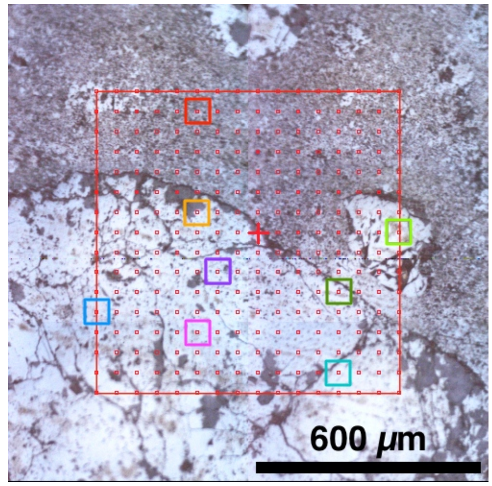

Fig. 1. Reflected light image of Allende thin section HC-17. Large box denotes mapped area & red squares denote each 50-µm spot. CAI at bottom, matrix at top, isolated olivine grain at right of center. Colored boxes denote example locations of spectral types in Fig. 2.

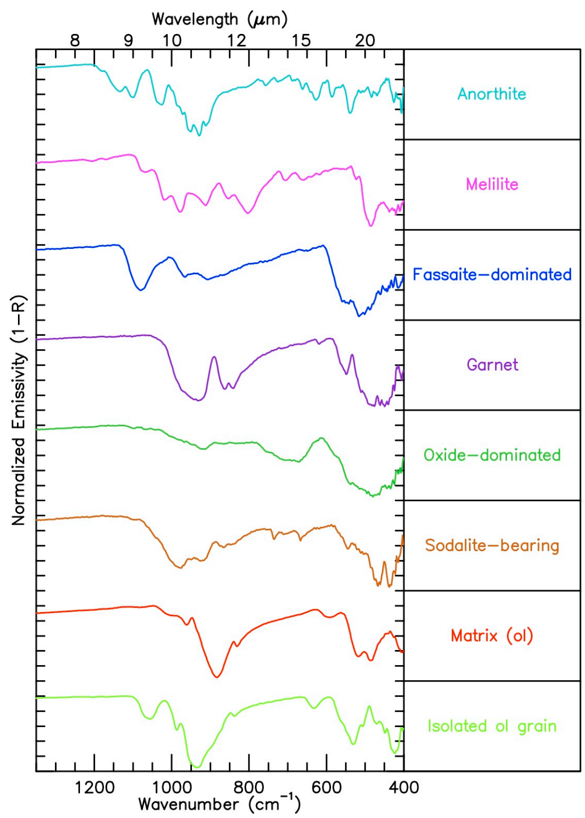

Fig. 2. Example normalized emissivity (inverted reflectance) spectra of Allende phases acquired in situ.