NANOSTRUCTURES OF MATRIX OLIVINE IN THE ALLENDE CV3 CHONDRITE: AN INVESTIGATION BY ABERRATION CORRECTED SCANNING TRANSMISSION ELECTRON MICRSCOPY.

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Introduction: Iron-rich olivine is a predominant constituent in the matrices of CV3 carbonaceous chondites. The matrix olivine occurs as extremely fine grains (<5 μm in size). Thus, transmission electron microscopy has been widely used to study it [e.g., 1]. However, there still remains much to be known about the formation process of matrix olivine. We present here results of a mineralogical study of Fe-rich olivine in the matrix of the Allende CV3 chondrite using an aberration corrected scanning transmission electron microscope (STEM). This microscope allows us to conduct imaging and chemical analysis in combination with an energy dispersive X-ray spectrometer (EDS) at atomic resolution. Our purpose was to provide new insight into the formation process of matrix olivine by observing its internal structure at a significantly higher resolution than before.

Methods: Ultrathin sections for STEM observations were extracted from the specific portions in a thin section of the Allende meteorite using a focused ion beam instrument (JEOL JIB-4501). The processed samples were studied using an aberration corrected 300 kV STEM (JEOL JEM-ARM300F) equipped with a cold field emission electron gun. This microscope is equipped with a newly developed ultrahigh sensitive X-ray detection system, which is composed of a wide gap objective lens pole-piece and two windowless silicon drift detectors whose sensor areas are 158 mm^2 [2]. The system allows total X-ray collection solid angle to be approximately 2.21 steradians [2].

Results: Our STEM observations reveal that some olivine grains in the Allende matrix contain numerous voids. Their diameters are ranging from 100 down to <10 nm. Relatively large voids (50-100 nm) show irregular to round shapes, and small voids (<50 nm) tend to be flattened in a direction perpendicular to [100] of the host olivine. The olivine grains also contain extremely thin (<1 nm thick) planar precipitates parallel to (100). They made their electron diffration patterns displaying diffuse streaks along [100]. In high angle annular dark field (HAADF) STEM images, the precipitates appear brighter than the host olivine, suggesting that they contain heavier elements than the host olivine, because HAADF-STEM image has Z contrast. Our analysis of atomic resolution HAADF-STEM images led to that the precipitates are most likely to have a spinel structure. The boundaries between the spinel and host olivine tend to have a specific crystallographic orientation relationship: [111] and [11-2] of the spinel are parallel to [100] and [010] of the host olivine, respectively. Our EDS analyses show that the spinel precipitates are enriched in Fe and depleted in Mg compared with the host olivine and show a wide range of Cr/Al ratios. These results suggest that the spinel precipitates are chromite and/or hercynite.

Discussion: Planar precipitates parallel to (100) of olivine have been reported from Fe-rich olivine in the matrices of the Mokoia CV3 chondrite [1]. Those precipitates were inferred to be Fe-rich oxide or hydroxide that formed during oxidation of olivine [1]. Our present study reveals that the precipitates in Allende are Fe-rich spinel (chromite and/or hercynite). The crystallographic orientation relationship between the spinel precipitates and the host Fe-rich olivine is similar to one between chromite precipitates and Fe-rich olivine reported from an FeO-rich vein inside Mg-rich olivine phenocrysts of Allende chondrules [3]. With the results of previous and present studies, we can suggest that both chondrules and matrix of Allende have experienced similar alteration process, which resulted in oxidation of olivines and produced spinel precipitates inside the olivines.

References: [1] Tomeoka K. and Buseck P. R. (1990) *Geochim. Cosmochim. Acta* 54:1745–1754. [2] Ohnishi I. et al. (2016) *Microscopy & Microanalysis* 22:218–319. [3] Weinbruch S. et al. (1990) *Meteoritics* 25:115–125.