TRANSMISSION ELECTRON MICROSCOPY STUDY OF A PRESOLAR SILICATE GRAIN FROM THE UNIQUELY ALTERED MILLER RANGE 07687 CHONDRITE

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Introduction: Presolar grains are formed in the circumstellar envelopes of ancient stars and in the ejecta of stellar explosions such as supernovae. Analysis of their structure and chemistry can provide insight into stellar nucleosynthesis, the thermodynamic conditions under which they formed, and subsequent alteration histories. Presolar silicates in particular are more susceptible to destruction and secondary processing than other presolar grain types, and can therefore be used as tracers of nebular and secondary processing [1]. Here we report the coordinated analysis of a presolar silicate grain from the Miller Range (MIL) 07687 CO3 carbonaceous chondrite.

Sample and Methods: Isotopically anomalous presolar grains were identified via raster-ion-imaging in a petrographic thin section of MIL 07687 [1]. We selected one grain, MIL '7a1-1 ol' from an unaltered region of MIL 07687 [1] for detailed structural and chemical analysis using transmission electron microscopy (TEM). Using focused ion-beam scanning-electron microscopy (FIB-SEM) techniques [2], an electron transparent cross section was prepared with the FEI Helios G3 FIB-SEM located at the Lunar and Planetary Laboratory (LPL). The FIB section was then analyzed using the 200 keV aberration-corrected Hitachi HF5000 scanning TEM (S/TEM) at LPL. The HF5000 is equipped with STEM-based secondary electron (SE), bright-field (BF), and dark-field (DF) imaging detectors, as well as an Oxford Instruments X-Max^N 100 TLE energy dispersive x-ray spectroscopy (EDS) system with dual 100 mm^2 windowless silicon-drift detectors (solid angle of 2 sr).

Results: NanoSIMS analysis reveals that MIL 7a1-1 ol contains enrichments in ^{17}O relative to solar system values, with $^{17}O/^{16}O$ ($\times10^{-4}$) = 8.40 ± 0.12 and $^{18}O/^{16}O$ ($\times10^{-3}$) = 1.72 ± 0.02 [1]. These isotopic compositions place MIL 7a1-1 ol in the Group-1 field of presolar grains as defined by [3]. S/TEM imaging shows that MIL 7a1-1 ol is a fine-grained domain that occurs below the Pt fiducial marker, and EDS reveals spatial correlations among O, Si, and Mg. The edge of MIL 7a1-1 ol contains an Fe-rich composition. In comparison, the FIB section contains a porous, fine-grained matrix. EDS shows spatially correlations among O, Si, Mg, Fe, minor Ca, and local regions of Fe, Ni and S. We also observe elongated fibrous grains, with measurements ranging from 600 nm to 1.8 µm in length, that contain Fe and O.

Selected-area electron-diffraction (SAED) patterns acquired across MIL 7a1-1 o1 show that it is polycrystalline, with d-spacings consistent with a Mg-rich pyroxene. A crystalline SAED pattern was also obtained from the Fe-oxide fibers in the matrix and measurement reveals d-spacings consistent with ferrihydrite.

Discussion: MIL 07687 is currently classified as a CO3 chondrite, however recent work suggests an ungrouped chondrite classification with affinities to CO chondrites [1,4-5]. MIL 07687 is unique because it contains mixed regions of altered (Fe-rich) and unaltered (Fe-poor) material [1]. Although the FIB section containing MIL 7a1-1 o1 was extracted from an unaltered region, we do observe evidence suggesting secondary processing occurred, including the presence of ferrihydrite fibers and minor Fe diffusion from the surrounding matrix into MIL 7a1-1 ol. Isolated fibers of ferrihydrite were previously reported in the Fe-poor matrix of MIL 07687 [1], which suggested minor aqueous alteration of fine-grained matrix material under highly oxidizing conditions or terrestrial weathering. Comparison of FIB sections from altered regions will provide further insight as to the degree of alteration of presolar grains between altered and unaltered regions within MIL 07687.

Comparison of the O-isotopic data of MIL 7a1-1 ol with nucleosynthetic models of stellar evolution [7-8] is consistent with a close-to-solar metallicity AGB/RGB star of approximately 1.5 $M_\odot$. Additionally, comparison of the composition and structure of MIL 7a1-1 ol with thermodynamic models can provide first-order constraints on the origins of presolar grains [6]. Mg-rich pyroxenes such as enstatite are predicted to condense via equilibrium processes from a gas of solar composition at 1316 K assuming a total pressure of 10^{-4} bars [9]. The enstatite composition and polycrystalline structure of MIL 7a1-1 ol are consistent with such predictions, suggesting it could have formed through equilibrium processes in its host circumstellar envelope but was subsequently altered on its parent asteroid.

References: [1] Haenecour P. et al. (2020) *Meteoritics & Planetary Science* 55: 1228-1256. [2] Zega T. J. et al. (2007) *Meteoritics & Planetary Science* 42: 1373-1386. [3] Nittler L. et al. (1997) *The Astrophysical Journal* 483: 475-495. [4] Brearley A. J. (2012) *LPS XLIII*, Abstract #1233. [5] Brearley A. J. (2013) *Meteoritics & Planetary Science 47,* Abstract #5206. [6] Davidson J. et al. (2014b) *LPS L*, Abstract #1376. [7] Boothroyd A. I. et al. (1994) *The Astrophysical Journal* 430: L77-L80. [8] Boothroyd A. I and Sackmann I. J. (1999) *The Astrophysical Journal* 510: 232-250. [9] Lodders K. (2003) *The Astrophysical Journal* 591: 1220-1247.