ELEMENTAL COMPOSITION AND MICROSTRUCTURE OF A SUPERNOVA POLYCRYSTALLINE OLIVINE AGGREGATE IN THE CO CHONDRITE DOMINION RANGE 08006. L. B. Seifert, P. Haenecour, T. J. Zega, Lunar and Planetary Laboratory, University of Arizona, 1629 E University Blvd. Tucson, AZ, 85721-0092, lseifert@lpl.arizona.edu. 2Materials Science and Engineering, University of Arizona.

Introduction: Supernovae (SNe) occur when a massive star falls out of hydrostatic equilibrium and its stellar core contracts, rebounds, and sends a shock wave propagating through the circumstellar envelope. The propagation of the shock wave triggers rapid nucleosynthesis and results in a radial explosion away from the star. Solids condense in this ejected material, and some of these circumstellar grains are transported through the interstellar medium (ISM). A fraction of such grains are preserved in primitive materials such as meteorites.

Information on the structure and chemistry of grains derived from SNe is still severely limited. To date, while >100 grains were identified based on their isotopic composition, only 10 of those were analyzed for detailed structure [1-6]. Nonetheless, these studies reveal diverse structures and morphologies, including single crystals, aggregates and amorphous phases, highlighting the varied chemical and physical conditions in the ejecta of SNe. Messenger et al. [1] identified an aggregate of crystalline forsterite grains, with compositions consistent with the mixing of multiple supernova (SN) layers. Zega et al. [3] identified a single crystal of hibonite with a crack extending through the grain, which could be an indication of a collision event. Other studies identified six amorphous grains: one with a composition consistent with stoichiometric enstatite, and five with non-stoichiometric silicate compositions including forsterite, diopside, Fe-rich silicates resembling glass with embedded metal and sulfide (GEMS) and a Ca-rich pyroxene [4-5]. Here we report on a SN silicate grain identified in the Dominion Range (DOM) 08006 CO3.0 chondrite.

Methods: Local isotopic enrichments (‘hotspots’) were identified via NanoSIMS raster-ion-imaging of C and O isotopes in a thin section of DOM 08006 and elemental compositions were provided by Auger spectroscopy [7]. We chose one anomalous hotspot, DOM-35, thought to originate in SN ejecta for detailed chemical and structural analysis using transmission electron microscopy (TEM).

A cross-section of DOM-35 was prepared using established focused-ion beam scanning-electron microscopy (FIB-SEM) techniques [8] with the FEI Helios G3 FIB located at the Lunar and Planetary Laboratory (LPL). The section was then analyzed with LPL’s 200 keV aberration-corrected Hitachi HF5000 S/TEM. The HF5000 is equipped with secondary electron (SE) detectors, scanning TEM (STEM)-based bright-field (BF) and dark-field (DF) imaging detectors, as well as an Oxford Instruments X-Max® 100 TLE EDS system with dual 100 mm² windowless silicon-drift detectors.

Results: NanoSIMS analysis of a local area of DOM 08006 reveals enrichment in both 18O and 17O relative to solar system values, with 18O/16O = 4.0E-4 ± 2.0E-5 and 18O/16O = 3.34E-3 ± 7.0E-6 [8], placing it in the group-4 field of presolar grains as defined by [9]. The O-anomaly has an oblate shape (Fig. 1), measuring roughly 235 × 235 nm, as confirmed by TEM data.

Figure 1: (A) SE image of hotspot (red circle) within DOM 08006 matrix. (B) NanoSIMS δ18O image with arrow indicating the oblate hotspot and enrichment in 18O.

TEM-EDS mapping of the overall FIB section reveals a matrix containing Si, O, Mg, Ca, Fe and large grains containing Fe and S. DOM-35 contains O, Mg, and Si, with localized enrichment in Fe and Ca (Fig. 2). Fe is enriched in the lower half and left and right sides of the anomaly.

Selected-area electron-diffraction (SAED) patterns were acquired across the hotspot. The anomalous region DOM-35 is an olivine aggregate. The left part of this region is a single crystal of stoichiometric forsterite (Fo55). The right part of the anomaly is a polycrystalline assemblage as revealed by SAED patterns. Measurement of the patterns, together with EDS spectroscopy indicates an Fe-rich olivine (Fo65).

Discussion: Confining the thermodynamic conditions under which SNe grains condense is challenging because SNe are highly energetic environments and the pressure and temperature conditions within them are poorly constrained. However, a few studies are available in the literature. For example, Fedkin et al. [10] used model compositions of thin layers of ejecta within the main burning zones of type-II SNe, computed by [11], to construct the chemical compositions of minerals condensed by equilibrium processes in 15-.
21- and 25-M$_{\odot}$ SNe. The resulting minerals, compositions, sequences of condensation and temperatures of condensation are similar for all three masses [10]. Olivine is a predicted condensate in the H, He/N, O/C, O/Ne and O/Si SN layers [10]. The compositions of the H and He/N layers are reducing because they are close to solar composition, therefore, forsterite is the favorable condensate, and $X_{Fe}$ cannot exceed 0.002 above 1000 K. In the deeper, more O-rich zones forsterite is favorable between 1500 and 1600 K, and the fayalite content is between 0<$X_{Fe}$<0.03 due to the low atomic Fe/Mg ratio. Below these zones, temperatures are too low for the formation of silicates, despite abundant Fe$^{0}$ metal due to a low oxygen fugacity. In order to produce a more fayalitic composition, mixing between SN layers is required. Alternatively, Nozawa et al. [12] demonstrated that forsterite is a predicted condensate in both unmixed and mixed SN ejecta through non-steady-state nucleation and grain growth.

We can place constraints on the progenitor SNe of DOM-35 via comparison of the grain data to these models. In comparison to [10], the $^{16}$O/$^{18}$O ratio of DOM-35 is most consistent with a 15 M$_{\odot}$ SN, and the stoichiometric (Fo$_{50}$) single-crystal forsterite is consistent with equilibrium condensation in a 15 to 25M$_{\odot}$ SN between 1063-1575 K. We note that Nozawa et al. [12] developed a model in which forsterite could condense in unmixed SN ejecta through non-steady-state nucleation and grain growth. However, mixing between SN layers is required to produce the Fe-rich composition of the polycrystalline region of DOM-35 (Fo$_{50}$). Moreover, astronomical observations of SNe remnants show that the ejecta are heterogeneous, clumpy, and large scale mixing is occurring, e.g. [13]. Thus, while we cannot completely rule out forsterite condensation in an unmixed zone of the progenitor star to DOM-35, it seems unlikely that both a single-crystal forsterite grain and Fe-rich polycrystalline olivine aggregate could otherwise accrete together without significant transport occurring within or between zones and hence mixing.

We note that only two other stoichiometric SN silicates, B10A [1] and 2_4 [5], were previously identified in meteoritic samples. The data from both of these grains are consistent with equilibrium condensation, the former at 1560 K in a solar-metallicity star with a mass 15 M$_{\odot}$, but mixing was required to produce its Fo$_{50}$ composition [1]. The single-crystal forsterite in DOM-35 is similar in crystal structure and chemical composition to SN grain B10A [1], but its isotopic composition is significantly different. Thus, while it is conceivable that the single-crystal forsterite in DOM-35 formed under similar thermodynamic conditions as B10A, the data imply different nucleosynthetic origins.

**References:**


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**Figure 2:** EDS maps of DOM-35 with HAADF image showing anomalous region with red circle for comparison.