UNTANGLING THE HISTORY OF A CHONDRULE IN NORTHWEST AFRICA 5205 (LL3.2) WITH ELECTRON BACKSCATTER DIFFRACTION AND TRANSMISSION ELECTRON MICROSCOPY

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Introduction: Northwest Africa (NWA) 5205 (LL3.2) is a type 3 ordinary chondrite with a distinct cluster texture. The dominant lithology (A) has large chondrules (0.5 – 3mm) with deformation commonly concentrated at chondrule impingement points. Previous studies have suggested that while individual chondrules experienced variable thermo-mechanical histories prior to accretion [1], accretion occurred while chondrules were warm [2,3]. However, recent Electron Backscatter Diffraction (EBSD) analysis [4] shows chondrules were deformed at variable temperatures and experienced variable levels of secondary heating. To investigate the full range of chondrule histories, we use EBSD and Transmission Electron Microscopy (TEM) to characterize deformation, fracture, and annealing in individual chondrules. Here we examine chondrule 10-5-ch4, an “average” chondrule in NWA 5205 with low overall deformation intensity, a warm EBSD deformation signature and a low EBSD annealing signature [4].

Deformation and annealing microstructures: With EBSD and TEM we observe distinct olivine deformation signatures that are related to slip systems activated at different temperatures [5, 6]. At the lowest temperatures, strong Peierls forces constrain dislocations to straight c-type screw segments with short edge segments. As higher temperatures overcome the Peierls barrier, highly curved c-types become prevalent. At high temperature we find mixtures and tangles of curved c- and a-types. These signatures are characterized via EBSD misorientation axis figures [5,7] and TEM weak-beam dark field images. Macroscopic deformation is also accommodated by brittle fractures which may be filled with vein deposits. We characterize these deposits via SEM and TEM Energy Dispersive X-ray spectroscopy.

Post-deformation annealing allows for dislocation recovery, which creates low-angle grain boundaries that surround low-strain sub-grains within a deformed parent grain. At the EBSD scale these features are visualized with Grain Reference Orientation Deviation (GROD) maps. In TEM images, recovery features include regular “picket-fence” dislocation arrays that surround relatively dislocation-free regions [5].

Chondrule 10-5-ch4 microstructure and interpretation: EBSD analysis generally confirms a warm deformation temperature that activated a mix of c-type and a-type slip systems. GROD maps reveal clear recovery signatures in many but not all grains. TEM analysis extends these results, revealing admixtures of end-member temperature signatures. In Figure 1, a moderate density of straight c-type screw dislocations (blue arrow) is intermixed with a low density of highly curved dislocations (yellow arrows) and a dense tangle of c- and a-type dislocations (red arrow). We also find a picket-fence dislocation array (green arrow - individual dislocations not visible in this image) that does not bound regions of reduced dislocation density. In other regions, micro- and nano-scale fractures are pervasive and are sometimes found to be filled with nanocrystalline Fe deposits containing small amounts of Ni, Cr, Al, S, and/or P.

The intermingling of disparate deformation and annealing signatures suggests a complex history in which low intensity events did not entirely overprint prior microstructures. Our tentative interpretation is that the chondrule was moderately deformed while warm to create curved dislocations and tangles, cooled slowly enough to form picket-fence dislocation arrays, and later impacted at ambient temperature just strongly enough to mobilize metals and generate a new suite of straight c-type screw dislocations. Any or all of these events may have been associated with chondrite agglomeration.

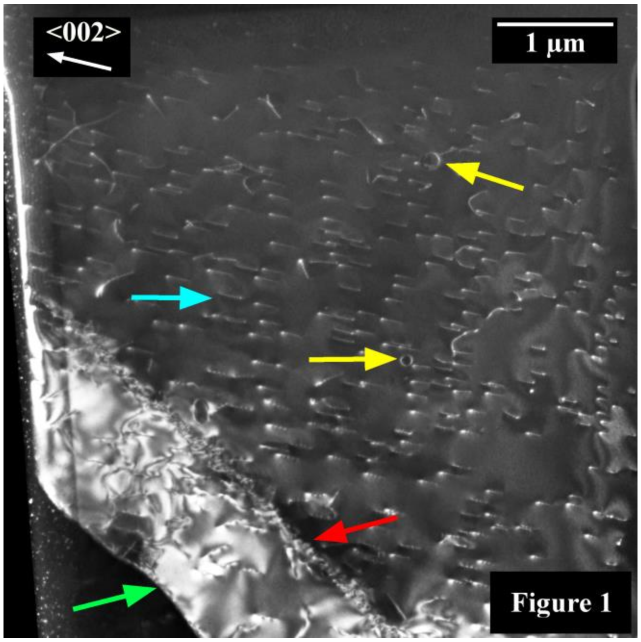

Figure 1

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