EBSD ANALYSES OF SEVEN ORDINARY CHONDRITES: DEFORMATION METRICS AND IMPLICATIONS FOR PARENT BODY THERMAL HISTORIES.

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Introduction: We utilized electron backscatter diffraction (EBSD) methods with a focus on the mineral olivine to study the shock histories of seven type 6 ordinary chondrites previously examined [1] with optical microscopy (OM) and transmission electron microscopy (TEM). These meteorites were interpreted as having experienced varied pre-shock temperatures and post-shock annealing, with four shock-stage [2] S1 meteorites (Kernouvé, Portales Valley, Miller Range (MIL) 99301, Park) showing evidence for static heating caused by syn-metamorphic shock or post-shock burial in warm materials, or both, and three shock stage S4-S5 meteorites (Leedey, Bruderheim, Morrow County) showing evidence of having been heavily shocked from a cold initial condition followed by rapid cooling [1]. A goal was to see whether these histories can be reconciled with EBSD data, and if so, whether EBSD metrics can be identified that record these histories.

Methods: In previous work, OM was used to assign a weighted shock stage to each specimen according to the method of Jamsja and Ruzicka [3], and representative areas were prepared via Ar milling for TEM analysis of dislocation character and density [1]. For this study, thin sections were mapped using EBSD to determine deformation intensity via misorientation maps, crystallographic texture via pole figures, and mesoscale slip plane analysis via crystal rotation figures. In MIL 99301, data were evaluated separately for a large, fine-grained (apparently shock-melt-emplaced) clast and the host.

Results: *Deformation intensity.* EBSD deformation intensity metrics correspond well with shock stage based on OM, and with dislocation density based on TEM. Different metrics were examined, including GOS (Grain Orientation Spread, a measure of average angular misorientation in a grain), MOS (Maximum Orientation Spread in a grain), and KAM (Kernel Average Misorientation, average misorientation in adjacent 9-pixels). Mean values of these parameters are well correlated with one another, but within meteorites GOS varies less from area to area and so may be a more robust statistic for overall deformation. For grains >50 µm across in the 7 meteorites, the same as used for OM shock stage, weighted shock stage is well correlated with average GOS and MOS (r^2 values of 0.941 and 0.970, respectively). Average dislocation density is correlated with average KAM and GOS (r^2 values 0.978 and 0.987, respectively), except for Kernouvé, MIL 99301 and Portales Valley, which fall off the trend to lower densities and which were previously identified as having undergone microstructural recovery that reduced dislocation density [1].

Pre-shock temperature. Misorientation rotation axes for 2-10° misorientations suggest a dominance of **c**-type slip directions in olivine from Leedey, Bruderheim, and Morrow County, which indicate low-temperature deformation. Kernouvé, Portales Valley, MIL 99301 host and clast, and Park have higher proportions of **a**-type or multiple slip directions which are a signature of higher-temperature deformation. Relating non-**c**-type slip proportion to higher temperature, apparent deformation temperature increases in the sequence Portales Valley < Kernouvé < MIL clast ~ MIL host < Park. For all but possibly the MIL 99301 melt clast, these correspond to high ambient temperature prior to shock, as strongly shocked (S4 and S5) meteorites record predominant low-temperature slip.

Post-shock annealing. Microstructural recovery during post-shock annealing causes dislocations to climb into "picket-fence" subgrain boundaries as seen by TEM in olivine from Kernouvé, Portales Valley, and MIL 99301 host, and creates misorientation boundaries in otherwise weakly-deformed olivine as seen by OM in the same meteorites and to a lesser extent in Park. With EBSD, recovery is indicated by the presence of (mostly larger) grains with elevated GOS and subgrain boundaries amidst low-GOS grains that lack subgrain boundaries; an inferred annealing parameter is (mean GOS)/(median GOS) values in larger (>50 µm) grains. On this basis, annealing increased in the sequence Park < MIL 99301 host < Kernouvé < Portales Valley.

Discussion: EBSD mesoscale slip plane analysis confirm earlier TEM findings with regard to dislocation character (**c-** vs **a**-type slip and evidence for cross-slip) and can be used to identify meteorites that were at elevated temperature prior to shock deformation, including Kernouvé, Portales Valley, MIL 99301 host, and Park. Similarly, EBSD data can be used to identify post-shock annealing, and imply that Park was annealed in addition to Kernouvé, Portales Valley, and MIL 99301 host. EBSD data thus indicate that the same meteorites which show evidence for elevated pre-shock temperature also show evidence for post-shock annealing, suggesting impacts into warm parent bodies. These meteorites also have old Ar degassing ages, whereas the other meteorites have younger Ar ages. This implies warm parent bodies only in the earliest epochs, with impacts occurring during the period of thermal metamorphism.

References: [1] Ruzicka A. et al. (2015) *Geochimica et Cosmochimica Acta* 163, 219-233. [2] Stöffler D. et al. (1991) *Geochimica et Cosmochimica Acta* 55, 3845-3867. [3] Jamsja N. and Ruzicka A. (2010) *Meteoritics & Planetary Science* 45, 828-849.