**The formation and shock-history of phosphate minerals in Chelyabinsk (LL5)**

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**Introduction:** Chelyabinsk (LL5) is an Ordinary Chondrite (OC) containing the phosphate minerals merrillite ($Ca_9NaMg(PO_4)_7$) and apatite ($Ca_5(PO_4)_3(F,Cl,OH)$), as well as notable shock-melt veins (SMVs) that imply it endured a high energy impact. Recent models propose OC phosphate formation as a result of early thermal metamorphism on the parent bodies, based on ancient radioisotope ages (~ 4.53 Ga; [1]), their general absence in low petrologic type OCs and textures indicative of formation by silicate-replacement [2]. However, reported abundant phosphate phase-associations with olivine (~ 98%) and maskelynite-normative glass (i.e. maskelynite) (~ 75%) [3] and anomalously young U-Pb ages for phosphates from highly shocked OCs (e.g. ~ 4.45 Ga – Chelyabinsk, Sahara 98222 and Novato) [4, 5, 6] demand investigation and raise some interesting questions: A) Do phosphates record textural evidence of shock metamorphism? B) If so, what do these textures tell us about their shock-history and modes of origin? C) How should we interpret geochronological information derived from shocked phosphates? In order to answer such questions, we investigated the textural response to shock of phosphate grains in Chelyabinsk using SEM-based panchromatic Cathodoluminescence (CL) imaging and Electron Backscatter Diffraction (EBSD) imaging techniques.

**Methods:** SEM-CL imaging of two Chelyabinsk sections ('light' and 'dark' lithology; [7]) was carried out in order to further characterize previously imaged phosphate grains [3]. Based on these results, grains were selected for EBSD analysis. EBSD images provide more detailed information on phase crystallinity and crystal structure distortion. CL-imaging and EBSD-mapping were carried out at the Open University (OU). Phosphates were targeted from a range of mineralogical and textural settings.

**Results:** Combined CL and EBSD images indicate that phosphate crystallinity is generally degraded in both lithologies; this is coupled to distortion of their crystal structure, which shows up to 16 degrees of crystal-plastic deformation in some grains. Grains in contact with maskelynite are most degraded, whilst those in contact solely with olivine are less degraded. Those phosphates proximal to SMVs display clear recrystallization textures; grains of this type do not display evidence of internal deformation, contrasting with phosphates in other settings.

**Discussion:** *Modes of origin* – Phosphates within maskelynite-chromite symplectites have been proposed to grow from shock-melt pools [4]. However, degraded phosphate crystallinity in these settings in Chelyabinsk contrasts with the recrystallised textures observed for SMV-proximal grains – instead appearing similar to phosphates found in contact with maskelynite elsewhere in the sample. The fact that the recrystallised textures of SMV-proximal phosphates are well preserved proves metamorphism associated with the shock-melting event in Chelyabinsk was not overprinted. Therefore, the phosphates must have existed *prior to* the shock-melting impact – favouring an origin during thermal equilibration. *Shock-processing* – We propose that anomalously high phosphate phase associations with maskelynite and olivine derives from impact-propagation of maskelynite along grain boundaries (as observed in SEM images), during which olivine was least easily separated from phosphates. This bolsters the idea that phosphates grow via olivine-replacement [2,3], for the resulting Phosphate-Olivine-Assemblages (POAs) should be more resistant to mechanical separation than more weakly lithified assemblages in the chondrite (e.g. phosphate-pyroxene). High shock impedance phases (e.g. olivine) also appear to have protected phosphates, where surrounded, from shock degradation. *Impact geochronology* – Estimates for the shock-melting event vary from ~ 4.53 Ga to 28.6 Ma [8, 9]. Degraded phosphate crystallinity and recrystallization textures observed in EBSD images demonstrate the operation of deformation processes which have been previously shown to cause U-Pb resetting in zircon [10]. We therefore agree that the Chelyabinsk apatite U-Pb upper intercept age of ~ 4.45 Ga [4], which should reflect full resetting, best reflects the highest-energy impact endured. U-Pb analyses of the recrystallised phosphates could be carried out to test this conclusion. Overall, we propose the following timeline of events: 1) Phosphate development during thermal metamorphism at ~ 4.53 Ga 2) Textural and isotopic disruption at ~ 4.45 Ga by a shock-melting impact. 3) Subsequent impacts of moderate-to-low energy, producing no textural record.

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