TEXTURAL EVIDENCE FOR SHOCK-RELATED METASOMATIC REPLACEMENT OF OLIVINE BY PHOSPHATES IN THE CHELYABINSK CHONDRITE. C. R. Walton[1] and M. Anand[2,3], [1]School of Earth & Environmental Science, University of St Andrews, Scotland, KY16 9AJ, UK (cw90@st-andrews.ac.uk), [2]School of Physical Sciences, The Open University, Milton Keynes, MK7 6AA, UK. [3]Department of Earth Sciences, The Natural History Museum, London SW7 5BD, UK (mahesh.anand@open.ac.uk).

Introduction: Phosphate minerals are thought to occur in chondritic parent bodies mainly as a result of secondary alteration processes [1]. Jones et al., [2] investigated the textural occurrences of phosphates in a range of Ordinary Chondrites (OCs) (petrologic types 3.9–6) and found support for a model involving progressive solid-state recrystallisation and equilibration in a closed parent body system. However, the nature of the phosphate source materials and their mode of incorporation into mineral form is not fully understood.

Here we investigate the textural relationships in the recent 'Chelyabinsk' meteorite (LL5, S5) fall and provide supporting evidence for the phosphate minerals being secondary, specifically following olivine replacement.

Background: Typically, OC's contain two prominent phosphate minerals: merrilite ($Ca_9NaMg(PO_4)_7$) and apatite ($Ca_5(PO_4)_3(OH,F,Cl)$). Prevailing models of phosphate growth involve the initial generation of merrilite during mild heating on the asteroidal parent body and the subsequent formation of apatite by reaction of merrillite with halogen-rich aqueous fluids.

Chelyabinsk is a brecciated and highly shocked chondrite which contains both merrilite and apatite. Isotopic and petrological studies are yet to fully provide a definitive model of formation [3-5]. We have undertaken a comprehensive textural study to assess these models.

Methods: Phosphates in the sample were characterised utilising petrographic and scanning electron microscopy (SEM). The SEM is equipped with an Energy Dispersive Spectrometer (EDS) and was used to construct major elemental maps of the sample. We targeted individual phosphate grains for detailed imaging and textural examination. Point-and-Identification analysis was used to distinguish the phosphate phases and define their relationships to coexisting mineral phases.

Results: Relative frequencies for key textural associations of phosphates in Chelyabinsk are shown in Figure 1. Associations with olivine, fractures and chromite/plagioclase (maskelynite) are dominant; these are, predominantly, grain boundary contacts (regular, irregular and embayed) as well as, more rarely, inclusions of given phases within phosphates and the hosting of phosphate grains entirely within a given phase. Figure 2 is an example showing key observed phosphate textural associations.

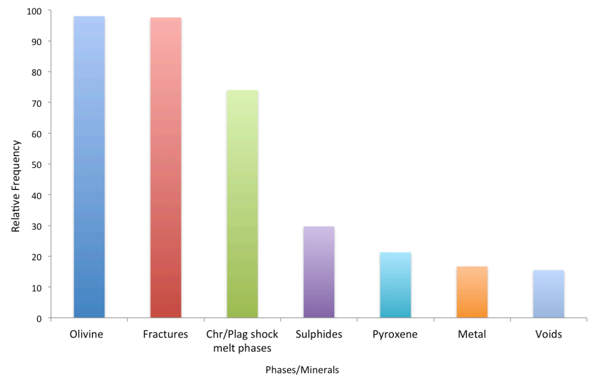

Figure 1: Textural associations of phosphates with other minerals in Chelyabinsk. The relative frequencies in each class are similar between apatite and merrillite; figures given are averages across all grains observed.

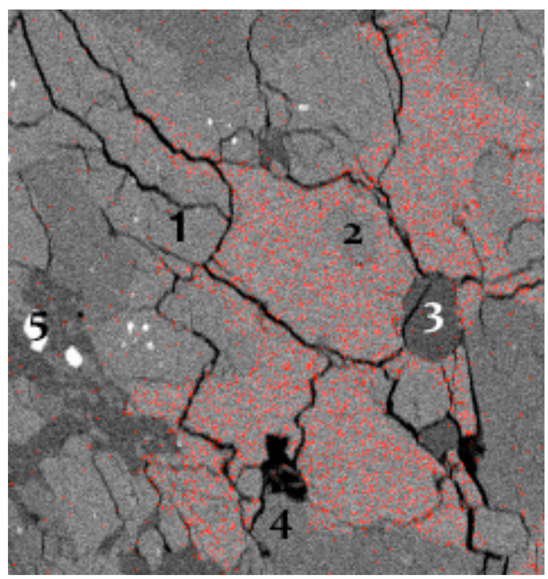

Figure 2: Complex merrillite grain (in red) (200µm across) showing often embayed contacts with olivine (1), olivine inclusions (2), plagioclase (3) and pyroxene (4). '5' indicates a sulphide grain. Red spots indicate increased phosphorous intensities as detected by EDS mapping. Grain morphology generally corresponds to fractures, yet is not fully bound by them.

Discussion: The phosphates in the Chelyabinsk meteorite show complex grain morphologies and textural associations. The main finding of this work is that olivine associations in particular are prevalent, and deemed pivotal. Chelyabinsk phosphates are almost exclusively in contact with olivine. Olivine contacts are often embayed and olivine inclusions are observed. Phosphates are also commonly hosted entirely within larger olivine grains (see Fig. 2, which appears to show a relict olivine grain partially replaced by a phosphate phase). This is not the case in relation to any other mineral phase in this sample, which suggests that phosphate growth is not randomly distributed. We argue that the control on these reactions is dynamic and chiefly relates to the availability of source materials (chemistry) and their mode of incorporation into mineral form. Together, this can be taken as evidence for the involvement of olivine in phosphate formation via a fluid-mediated replacement reaction.

Olivine alone contains few of the necessary components to form phosphate minerals and so source materials must be brought in from elsewhere, either via mineral diffusion or exchange with an aqueous phase. The latter is favoured in particular for apatite, which structurally requires OH/Cl/F and can obtain these constituents via interaction with a fluid or vapour phase [6]. This assertion may also extend to merrilite, however, as phosphates regularly occur within olivine grains where diffusional exchange with other phases would likely be especially limited at peak metamorphic temperatures < 680 °C (below the closure temperature of diffusion in olivine) [7, 8]. To circumvent this issue, fluids transported by fractures may have played a key role in phosphate formation.

Chelyabinsk is known to have experienced multiple impact events during its history; in particular, apatite U-Pb ages reported by Lapen et al., [4] at 4.45 Ga, are much younger than can be accounted for in a typical radiogenic thermal history and thus require impact reheating of the system.

The presence of chromite/plagioclase symplectites is discussed by Rubin [9] as a product of shock melting and their occurrence with phosphates may indicate the crystallisation of igneous phosphate during impact events [2]. Figure 3 is an example of such an occurrence in Chelyabinsk, thus the involvement of shock in phosphate growth can be supported. A consequence of such shock processing would be the creation of fractures and the mobilisation of aqueous fluids, thus providing the basis for a mechanism of phosphate generation in Chelyabinsk, as follows: **i)** Impact generation of fractures **ii)** Mobilisation of fluids **iii)** Interaction of fluids with olivine and replacement reaction to form phosphates.

Phosphate grain morphologies in Chelyabinsk generally show coordination with fractures (see Fig. 2). Given that Chelyabinsk has not undergone thermal annealing [10], this could be a telling sign that impact fractures acted as conduits/surfaces of chemical exchange during an ancient episode of metasomatic olivine replacement by phosphates.

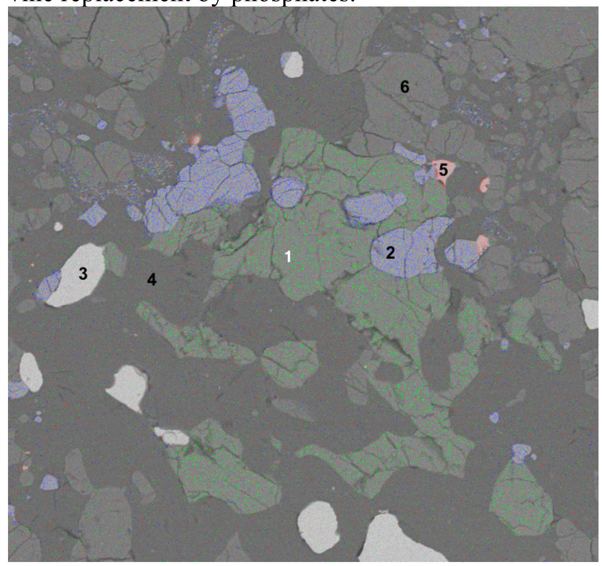

Figure 3: Elemental map [Cr(B)S(R)Cl(G)] showing a chromite/plagioclase symplectite with possible igneous chlorapatite (250μm across), of potential shock-melt origin. Cl-apatite (1); chromite (2); metal (3); plagioclase (4); sulphide (5); olivine (6).

Conclusions: Textural evidence from Chelyabinsk phosphates appears to suggest formation via shock-fracture mediated olivine replacement. Further work must be carried out to ascertain both the chemical and kinetic feasibility of this process, as olivine is not an obvious precursor to phosphate and the heat from impact events may dissipate quickly relative to the commonly slow reaction rates of silicate phases. If confirmed, the process described in this work may be important for phosphate growth in shocked chondrite bodies generally, with Chelyabinsk providing an ideal target for use in full characterisation of the reaction(s) involved.

References: [1] McCubbin, F. M. and Jones, R. H. (2015) *Elements, 11,* 183–188. [2] Jones, R. H. et al (2014) *GCA*, *132,* 120–140. [3] Taylor, L. A. et al (2014) *45th LPSC.* [4] Lapen, T. J. et al (2014) *45th LPSC.* [5] Righter, K. et al (2015) *Meteoritics & Planet. Sci., 50,* 1790–1819. [6] Treiman, A. H. et al (2014) *Am. Min., 99,* 1860–1870. [7] Bezaeva, N. S. et al (2014) *Meteoritics & Planet. Sci., 49,* 958-977. [8] Donohue, P. H. et al (2016) *47th LPSC.* [9] Rubin, A. E. (2002) *GCA, 67,* 2695–2709. [10] Righter, K. et al (2016) *47th LPSC.*

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