NON-DESTRUCTIVE MEASUREMENT OF CRYSTALLOGRAPHICALLY ORIENTED FE-MG ZONING PROFILES IN CHONDRULE OLIVINE VIA X-RAY COMPUTED TOMOGRAPHY COMBINED WITH DIFFRACTION CONTRAST TOMOGRAPHY (XCT/DCT)

R. H. Jones[1], M. J. Pankhurst[2], J. Oddershede[3], O. Barbee[2], D. Morgan[4] D. M. Thorley[1], DLS i13 beamline team[5], [1]Department of Earth and Environmental Sciences, The University of Manchester, Manchester M13 9PL, UK, Rhian.jones-2@manchester.ac.uk, [2]Instituto Volcanológico de Canarias (INVOLCAN), 38320 San Cristóbal de La Laguna, Tenerife, Spain, [3]Xnovo Technology ApS, 4600 Køge, Denmark, [4]School of Earth and Environment, University of Leeds, UK, [5]i13 Imagine and Coherence beamline, Diamond Light Source Ltd, Didcot, OX11 0DE, UK

Introduction: Non-destructive analysis of rare meteorites and samples returned from extra-terrestrial bodies provides a means to optimize the science return, while preserving valuable material. We are developing an X-ray micro-computed tomography (μCT) method for obtaining quantitative, non-destructive analyses of olivine grains in chondritic meteorites and sample return materials. Our test sample is the CM-anomalous (heated CM) chondrite, Northwest Africa 11346 (NWA 11346). The method, which is similar to that described by [1,2], is based on a synchrotron μCT density calibration of a set of well characterised olivine grains with a range of compositions across the solid solution series. We have also conducted complementary laboratory-based μCT / diffraction contrast tomography (DCT) scans on the same sample. The combined datasets enable us to extract quantitative compositional zoning profiles from olivine within the chondrite sample volume, with the choice of crystallographic orientations and crystal faces. Here we demonstrate the success of the technique by extracting zoning profiles from olivine grains in a Type II porphyritic olivine chondrule in NWA 11346. Interpretation of the profiles in terms of grain growth and diffusion models allows us to interpret formation conditions of chondrules (e.g. [3-5]).

Methods: The sample of NWA 11346 measures 0.8 x 2 x 5 mm. Synchrotron X-ray attenutation tomography was performed on the i13 beamline at the Diamond synchrotron. Since the i13 beam is close to monochromatic, the linear relationship between X-ray attenuation and (electron) density of the olivine solid solution allows for the brightness values in reconstructed 3D images to record a close-to-linear relationship with forsterite content. Olivine standards were measured in a single continuous helical scan. A separate helical scan was made of the NWA 11346 sample, under identical beam conditions, along with one compositionally zoned terrestrial olivine grain as an internal standard. Voxel size (xyz) was 1.125 μm. Calibration of the olivine standards, and measurement of unknowns, were carried out using *Fiji* [6]. We found a linear relationship ($R^2 = 1.00$) between olivine composition and brightness values over five olivine standards, with compositions from Fo0 (fayalite) to Fo81. Uncertainties are of the order of ±1 mole% Fo.

XCT/DCT scans were performed on a ZEISS Xradia 520 Versa X-ray Microscope equipped with a polychromatic, divergent X-ray source and a LabDCT Pro module. An XCT scan was made to locate a 0.8 x 0.5 x 0.8 mm region of interest (ROI) (the Type II chondrule), and then DCT was used to determine the crystallographic orientations of the olivine grains in the ROI. Within the ROI, crystallographic orientations of 89 olivine grains larger than 20 μm were reconstructed from the DCT data using the GrainMapper3DTM software [7]. For each grain, the combined XCT volume and DCT grain map was rotated into the crystallographic reference frame of the grain such that x=a, y=b, z=c. The monochromatic synchrotron XCT data was then rotated into the crystallographic reference frame of the selected grains, enabling the extraction of zoning profiles for any given crystallographic orientation and face.

Results: We selected eight olivine grains in the Type II chondrule for detailed analysis. Zoning profiles were obtained through the centres of grains along defined crystallographic axes. A typical profile is around 50 μm in length, with olivine composition extracted in steps of 1.6 μm. Several grains have a relict forsterite core, with compositions varying from Fo100 in the centre to around Fo70 at the edge. Zoning profiles show growth from a resorbed relict forsterite core, and a diffusion-controlled interface between the relict grain and FeO-rich overgrowth.

Discussion: The extracted zoning profiles provide a non-destructive method that can be used to infer formation conditions of individual olivine grains. The method enables us to obtain diffusion-and-growth profiles through ideal sectioning planes at the centres of grains and at specific crystallographic orientations. This is a significant advantage compared with conventional analyses of polished sections in which the profile is limited to the random crystallographic orientation presented on the polished surface, along with the uncertainty of not knowing whether the section transects the centre of the grain or other out-of-plane features.

References: [1] Uesugi M. et al. (2013) *Geochimica et Cosmochimica Acta* 116: 17-32. [2] Pankhurst M. J. et al. (2018) *American Mineralogist* 103: 1800-1811 [3] Miyamoto M. T. et al. (2009) *Meteoritics and Planetary Science* 44:521-530. [4] Hewins R. H. et al. (2009) *LPSC XL*, Abstract #1513 [5] Stockdale S. C. et al. (2018) *81st MetSoc LPI Contribution 2067*, Abstract #6272. [6] https://imagej.net/Fiji [7] Bachmann F. et al. (2019) *Journal of Applied Crystallography* 52: 643–651.