Chondrule Olivine: Relationship Between Structure and Composition Using Synchrotron X-Ray Laue Microdiffraction. A.L. Butterworth1, G.K. Benedix2,3, N. Tamura4, O.N. Menzies4, and P.A. Bland2,3. 1Space Sciences Laboratory, 7 Gauss Way, University of California, Berkeley, California 94720-7450, 2Dept. of Mineralogy, The Natural History Museum, Cromwell Road, London, SW7 5BD UK, 3IARC, Dept. of Earth Science and Engineering, Imperial College London, Prince Consort Road, London SW7 2AZ, UK. 4Advanced Light Source, Lawrence Berkeley National Laboratory, 1 Cyclotron Road, Berkeley CA 94720.

Introduction: Chondrules are sub-mm-sized spherules commonly found in primitive (i.e. chondritic) meteorites. They are thought to have formed by melting of pre-existing dust in the primitive solar nebula prior to incorporation into larger bodies. Textures and chemistry indicate that heating and cooling of the chondrules during formation was relatively rapid. Ferromagnesian silicates dominate the mineralogy of most chondrules. They have been studied in depth from chemical, isotopic, textural, and mineralogical points of view [1].

In this study, the use of focused, white beam synchrotron XRD (μ-XRD) on a single crystal of olivine found in a Type II chondrule in a CM chondrite determines the structural characteristics. The variety of data that can be determined using the single crystal method includes grain orientation [2], and elastic and plastic strain maps.

Samples and Analytical Methods: Figure 2a shows the chondrule studied in EET 83389. EET 83389 was recovered from the Elephant Moraine icefield during the ’83-’84 season. The single crystal analyzed in this study was located during the course of other studies on this rock [3]. Mineral compositions were gathered using electron microprobe techniques using well-known standards, typical operating conditions, and analyses were corrected using company supplied ZAF programs.

XRD Data Collection. High lateral resolution XRD and XRF maps of the olivine grain were acquired using Scanning X-ray Microdiffraction (Beamline 7.3.3) at the Advanced Light Source, LBNL. A synchrotron bend magnet 5 to 14 keV achromatic X-ray source was focused to <2 μm spot using a pair of elliptically bent Kirkpatrick-Baez mirrors, with resulting 1 x 10⁹ photons/s/μm²/3x10⁴ BW flux at the sample. The sample was positioned 45° from the horizontal incident beam and 45° from a 133 mm diameter MAR CCD detector (held vertically). Laue diffraction patterns were collected from reflected X-rays on the CCD detector during 5-second exposures. The sample was scanned relative to the X-ray source at 2μm X and 5μm Y steps, using a 0.5 μm-precision Huber X,Y,Z stage. The total sampling rate was 5 images per minute.

An ORTEC High Purity Ge solid state detector simultaneously collected X-ray fluorescence data for five selected elements: Fe, Ca, Cr, V and Zn, which all have k-edges in the 5-14 keV energy range (Fluorescence signal of light elements such as Mg cannot be detected at this beamline because of air and beryllium window absorption). XRF maps were also collected to aid sample navigation and comparison with electron probe data.

Data Processing. The Laue diffraction patterns were processed with the XMAS custom software (ALS, LBNL) to locate and analyze olivine. Automatically, each pattern was fitted to orthorhombic forsterite based on the following parameters: space group Pbnm, Unit cell a = 4.752 Å, b = 10.1936 Å, c = 5.977 Å. Outside of set tolerances, areas were deemed to contain no olivine and no further information was retained (unless raw image files were re-analyzed for a different crystal fit). The algorithm tolerances included all Fo0 to F00β and these Laue patterns were used to produce maps of strain indicators, and high angular resolution grain orientation (±0.01°).

Olivine composition. The fact that olivine cell parameters vary linearly with Mg:Fe composition is routinely employed in monochromatic powder or single crystal XRD. Calibrating the Laue μXRD in a similar way would provide micron-resolution composition maps in addition to the grain structure and orientation information. We are unaware of this approach having been applied to white-beam μXRD. Therefore, Laue patterns were collected from several particles of six powdered synthetic olivines (Natural History Museum, London) and their measured a/b ratios were plotted against their known Mg mol% composition. The resulting calibration was used to make co-located composition maps for the EET 83389 zoned olivine.

Results and Discussion: The calibration for composition change with lattice parameters is shown in Figure 1. The overall fit is good compared with expected values, however the spread in a/b values was well above errors, and likely to be a real measure of different grain sizes and strain from the olivine syntheses and sample grinding. The spread was significantly lower for mapping the single crystal zoned olivine in the EET 83389 chondrule (Fig 2b).
Fig. 1. Linear fit (black solid) of olivine composition against measured lattice $a/b$ gives Mg% = -7579.5 + 16468 $a/b$ (R = 0.97642) compared with Mg% = -7577.5 + 16468 $a/b$ derived from literature values (green dashed).

In EET 83389, the texture is dominated by a large (~400µm), zoned ($F_{a1.30}$) euhedral olivine grain that is surrounded by a void-filled, fine-grained matrix with brecciated clasts of fayalitic olivine distributed randomly throughout it (Fig. 2a). Two electron-probe traverses along the short width of the grain show zoning from a rim ($F_a30$) that is relatively FeO-rich relative to its core ($F_a15$). Zoning is also found in the vicinity of the inclusions (Figs. 2a and 2b).

**Conclusions:** The olivine grain in EET 83389 is a single grain, as illustrated by the grain map (Fig. 2c) and the coarse angle orientation map (Fig. 2d). The second orientation map (Fig. 2e) shows that the majority of the grain has the same orientation to within 0.5 degrees. Variations in crystal orientation occur at the edges of the grain and around the inclusions, but do not follow exactly the zoning shown in Figure 2b. Figure 2f illustrates the average peak width (FWHM). For a single crystal, peak broadening is related to only to strain (and not grain size) [4], and in this case the measured strain gradient (~10^{-3}/µm) varies with the measured composition gradient. This would indicate that the zoned olivine exhibits little or no measured strain beyond variation in chemical composition and likely cooled in a slow formation process. Further studies of olivine in different chondrule settings are planned, taking advantage of the high lateral and angular resolution of the µXRD demonstrated here.

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**References:**