QUANTITATIVE *IN SITU* XRD MEASUREMENT OF SHOCK METAMORPHISM IN MARTIAN METEORITES: OLIVINE LATTICE STRAIN AND STRAIN-RELATED MOSAICITY. L. E. Jenkins*[1,2], R. L. Flemming[1,2] and P. J. A. McCausland[1,2], 1. Department of Earth Sciences and 2. Centre for Planetary Science and Exploration (CPSX), Western Univeristy, London, Ontario, Canada, N6A 5B7. *(*ljenkin9@uwo.ca*)

Introduction: Impact cratering is an important planetary process that alters the surface of all celestial bodies in the solar system through shock metamorphism. Hypervelocity impact events can eject rocks off planet surfaces, creating planetary achondrites, such as the martian meteorites [1]. Martian meteorites have all undergone some level of shock metamorphism.

This study presents two independent methods to quantitively evaluating shock metamorphism using olivine to determine the shock stages and peak shock pressures for five martian meteorites (DaG 476, NWA 6234, NWA 1068/1110, SaU 005/8 and Nakhla).

Background: Shock metamorphism can cause strain-related mosaicisty (SRM) and lattice strain [2,3].

Strain-related mosaicity can be seen as streaking along the Debye-Scherrer rings in 2D X-Ray Diffraction (XRD) data [2,4]. This streaking can be measured in the chi dimension (χ) with the line shape parameter Full-Width-Half-Maximum ($FWHM_\chi$) as shown in Fig. 1 [2]. McCausland et al. [5] measured the $FWHM_\chi$ of the streaks in XRD data from olivine from several ordinary chondrites and plotted the $FWHM_\chi$ values against their known shock stages. One can use $FWHM_\chi$ of streaks in olivine to determine the shock stage of a meteorite [5].

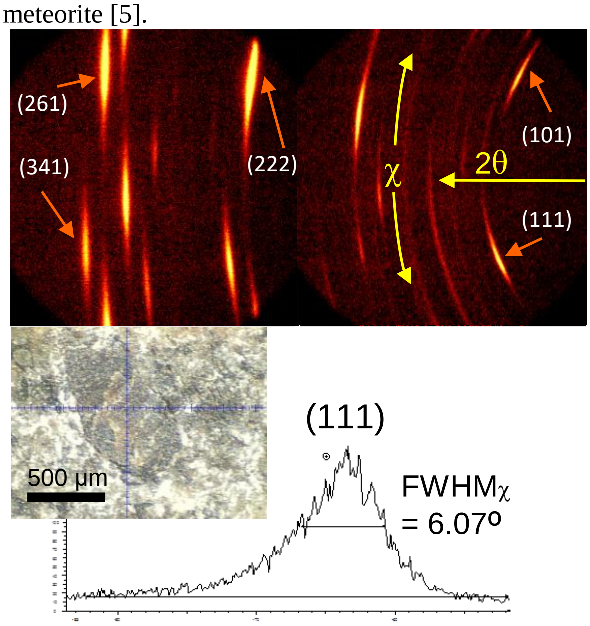

Fig. 1. FWHMχ measurement of diffraction peaks unique to olivine for grain 3 of SaU 005/8 (inset image). Data are shown as 2D General Area Detector Diffracion System (GADDS) images (top) with Miller indices of streaked olivine diffraction spots shown. The olivine (111) streak was integrated over 2θ to produce an intensity vs χ plot (bottom) from which a FWHMχ of 6.07° was measured.

Lattice strain can be determined with the use of Williamson-Hall (WH) plots [6]. To create a WH plot, the tangent of the diffraction angle (tanθ) of diffraction peaks in an XRD diffraction pattern are plotted against the line shape parameter integral breadth (β) as measured in the 2θ dimension, as shown in Fig. 2 [6]. The lattice strain can be calculated from the trend line produced from the plot, whose equation should be $\beta = 4\varepsilon\tan\theta + \beta_o$, where ε is strain and β_o is a constant [6,3]. Uchizono et al. [3] developed a method to determine the precise peak shock pressure a meteorite has experienced using artificially shocked olivine grains. They created WH plots for each of the olivine grains, calculated the lattice strain from each plot, and plotted the lattice strain values against the known peak shock pressures of the olivine grains, creating a calibration curve [3]. The equation of this calibration curve is $P = (\varepsilon - 0.0337) \div 0.0034$, where P is the shock pressure [3]. From this equation, the precise peak shock pressure experienced by olivine can be calculated from its lattice strain value [3].

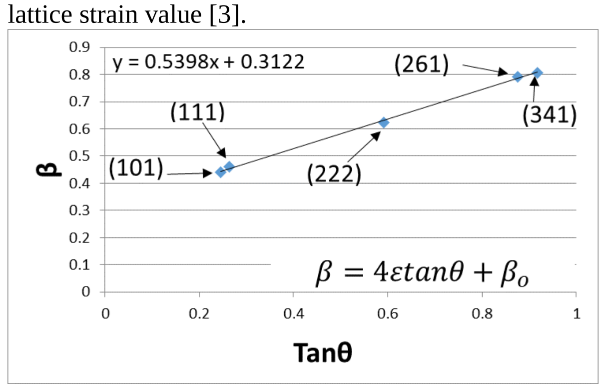

Fig. 2. WH plot for grain 3 on SaU 005/8. Points are labelled with their Miller indices. The formula of the trend line is also given. From this WH plot it can be determined that this olivine grain experienced a shock pressure of 29.8 GPa.

Method: Olivine grains in each martian meteorite where targeted *in situ* in rock slabs or thin sections using a Bruker D8 Discover micro X-Ray Diffractometer at Western University. For more details on instrument, see [7]. From the 2D XRD data, conventional diffraction patterns were produced and peaks unique to olivine were isolated. From these diffraction peaks, their $FWHM_{\chi}$ values were measured in χ. The average $FWHM_{\chi}$ for each meteorite was then compared to McCausland et al.'s [5] plot to determine shock stage. The diffraction peaks unique to olivine were then used to create a WH plot for each grain, from which each grain's lattice strain was calculated. The lattice strain of each grain was then input into Uchizono et al.'s [3] equation to determine shock pressure. The average of the top 25% of the shock pressures calculated from the lattice strain values were taken to determine the peak shock pressure of each meteorite.

Results: Representitative olivine grains and GADDS images for each meteorite can be seen in Fig. 3. The results of this study are shown in Table 1.

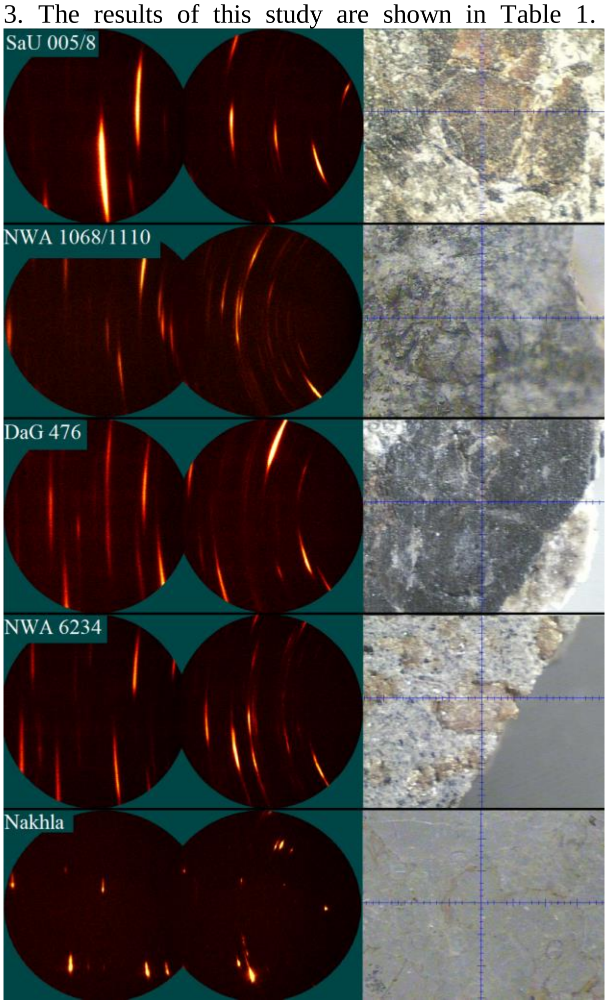

Fig. 3. Representative GADDS images for each meteorite accompanied by images of the corresponding olivine grains. From top to bottom, SaU 005/8 (Grain 5), NWA 1068/1110 (Grain 15), DaG 476 (Grain 3), NWA 6234 (Grain 5), and Nakhla (Grain 5). Note how the relatively unshocked meteorite Nakhla has less streaking along Debye-Scherrer rings than the other more shocked meteorites.

Table 1. Final Shock Assessment of Martian Meteorites

Meteorite	Shock Stage[a]	Peak Shock Pressure (GPa)[b]	Literature Shock Pressure Range (GPa)
DaG 476	S5	45.0 ± 0.2	40-45 [1]
NWA 1068/1110	S5	53.9 ± 3.0	N/A
NWA 6234	S3-S4	44.6 ± 4.3	N/A
Nakhla	S2-S3	18.6 ± 0.35	5-20 [8]
SaU 005/8	S5	40.1 ± 0.35	42.9 ± 3.7 [9]

[a]As determined using the SRM method [5]

[b]As calculated using the lattice strain method [3]

Most shock stages determined with the SRM method [5] matched peak shock pressure ranges presented in the literature, with the exception of SaU 005/8. All peak shock pressure values determined by the lattice strain method [3] matched literature values and most matched the shock stages determined by the SRM method [5] with the exception of SaU 005/8. This discrepancy with the SRM method [5] in regards to SaU 005/8 is believed to be a result of human error as The SRM method [5] lacks calibration and shocks stages often overlap in regards to SRM values.

Conclusion: Both XRD methods were shown to correlate well as calculated shock stages and peak shock pressure values were often congruent with each other and literature values (Table 1). These methods are both quantitative and non-destructive, making them advantageous for the evaluation of shock metamorphism in meteorites. Limitations of these methods do exist however. The SRM method [5] lacks calibration beyond visual shock stage binning which may cause difficulty in interpretation of data and the lattice strain method [3] can only be applied to the mineral olivine.

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