SHOCK EFFECTS IN CARBONATES FROM THE HAUGHTON IMPACT STRUCTURE USING X-RAY DIFFRACTION. J. D. Newman[1], R. L. Flemming[1], and G. R. Osinski[1]. [1]Department of Earth Sciences / Institute for Earth and Space Exploration, University of Western Ontario, London, ON, Canada. (jnewma49@uwo.ca)

Introduction: Shock metamorphism is the primary evidence of the high shock pressures generated by hypervelocity impact events [1]. Shatter cones are the only macroscopic evidence of shock and may be found in sedimentary and crystalline target rocks; fine-grained carbonates often display exceptional shatter cones [2]. Microscopic indicators of shock metamorphism most commonly manifest in silicate minerals such as quartz and feldspar, and include planar fractures, planar deformation features (PDFs), and diaplectic glass [1]. Unfortunately, none of these microscopic shock indicators develop in carbonates, so shock effects were examined at the crystal structural level here.

This work is a continuation and expansion of the preliminary data presented by Flemming et al. [3] that investigated shocked carbonates using powder X-ray diffraction and Rietveld refinement. Here, the focus is lattice strain and how the resulting values relate to distance from the centre of the Haughton impact structure and variations observed between dolomite and calcite.

Samples and methods: Twenty-two carbonate samples were studied from across the Haughton impact structure, (Figure 1). Limestone and dolostone samples were spread across two suites that include locations within and beyond the rim of the impact structure. When possible, samples exhibiting shatter cones were selected to indicate that the rocks had experienced shock pressures of at least ~2 GPa [2]. Carbonate samples from the central uplift were difficult to acquire as the area is filled by crater-fill deposits which limits target rock exposure.

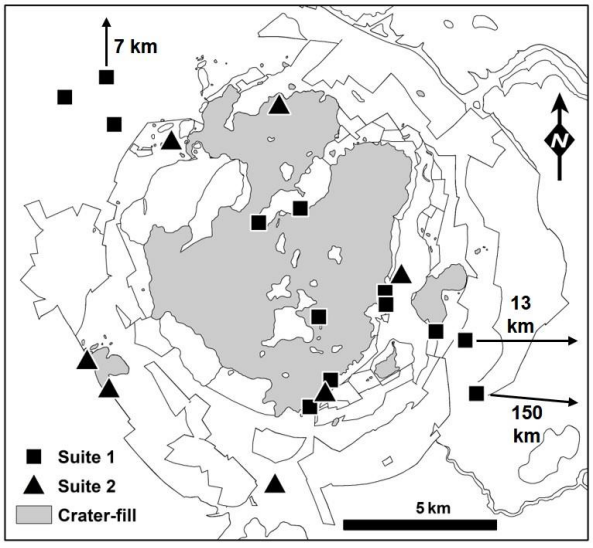

Figure 1. Location of samples from the Haughton impact structure. Suite 1 consists of in situ bedrock samples and suite 2 consists of shatter cone samples from crater-fill and ballistic ejecta deposits. Three samples were collected beyond the extent of the map are indicated by arrows and distance.

Sample suite 1. Samples from suite 1 were collected from exposed bedrock outcrops and spaced ~1 km apart. These outcrops represent varying levels of shock from within the impact structure to unshocked samples beyond the rim. Six samples were collected within the shatter cone distribution or ~4.5 km from the centre.

Sample suite 2. Samples in suite 2 are shatter cone clasts from crater-fill and ballistic ejecta deposits. The provenance of these shatter cones is unknown as they have been transported relative to their pre-impact location. This means their distance relative to the centre of the impact structure has no bearing on the level of shock the shatter cones experienced. Nine samples examined by [3] are included in suite 2 and four samples in suite 1.

X-ray diffraction. Samples not previously analyzed by [3] were powdered with an agate mortar and pestle under ethanol for 30 minutes and then reverse mounted into an aluminum sample holder using 220 grit sandpaper. The sandpaper was used to minimize preferred orientation. Powders were analyzed using a Rigaku DMAX powder diffractometer with Bragg-Brentano geometry, graphite monochrometer and scintillation counter. Collection parameters were Co $K\alpha_1$ radiation (λ = 1.78897 Å), step size of 0.02°/step, 5 s per step count time, 40 kV, 35 mA, and 2θ range from 5–120°.

Rietveld refinement was conducted on all samples using TOPAS 5.0 (Bruker AXS). Refined parameters were kept consistent among samples in both suites, so samples previously refined from suite 2 [3] were re-analyzed to match the parameters of suite 1. Refined parameters include background, sample displacement, unit cell parameters, atomic positions, thermal parameters, preferred orientation, occupancy, grain size, and crystal strain. Following the analytical method of [3], Gaussian size and strain algorithms were used and whole patterns were fit using a PV_TCHZ profile. Starting crystal structures were obtained from the American Mineralogist Crystallographic Database.

Results: Peak broadening is evident in diffraction patterns of dolomite and calcite with more broadening present in samples within the central uplift and from suite 2. Lattice strain values determined by Rietveld refinement for carbonates in both sample suites are provided in Table 1 and Table 2 below.

Table 1. Lattice strain values for Suite 1 carbonates

Sample suite 1	Distance from centre (km)	Calcite strain % (error)	Dolomite strain % (error)
07-020	2.26	0.421(19)	--
06-093	4.10	0.37(4)	--
99-063B	1.59	0.35(10)	--
02-139	1.46	0.34(6)	--
16-1018	3.41	0.32(4)	--
16-1014	5.05	0.282(9)	--
16-1046	4.34	0.21(9)	--
16-1017*	18.80	0.12(4)	--
16-1064	5.46	--	0.251(14)
05-007	8.50	--	0.19(4)
05-005	7.15	--	0.16(3)
06-108*	14.04	--	0.11(9)
05-010*	160.00	--	0.20(3)

* unshocked bedrock sample.

Table 2. Lattice strain values for Suite 2 carbonates

Sample suite 2	Distance from centre (km)	Calcite strain % (error)	Dolomite strain % (error)
00-124	7.52	0.41(3)	--
00-158[+]	7.25	0.31(3)	0.43(3)
02-061	5.08	0.20(5)	--
00-019[+]	4.89	0.18(8)	0.73(10)
05-023[§]	7.29	0.17(7)	0.40(4)
02-127[+]	4.63	0.16(8)	0.42(3)
02-128	4.63	--	0.60(6)
99-006	4.19	--	0.55(4)
02-126	4.63	--	0.46(8)

[+] dolomite sample contained >10% calcite.

[§] calcite sample contained >10% dolomite.

Discussion: With peak broadening evident in samples from the Haughton impact structure, comparing the broadening observed in their diffraction patterns is quantitative, but not calibrated. While there is potential for calibration, the broadening simply shows which samples may have been shocked [4,5] and provides enough information to continue analyzing for strain.

The main trend among samples from sample suite 1 (Table 1) is that the highest strain values for calcite are nearer to the centre of the structure and strain decreases toward the rim. This can be said for dolomite as well but to a lesser extent as there were no dolomite bedrock samples from the central uplift available for this study.

For calcite samples in suite 2, lattice strain values fall within the calcite range for suite 1 as these samples span from the centre to beyond the rim of the impact structure. It should be noted that sample 00-124 is the only ballistic ejecta sample analyzed and has one of the highest calcite lattice strain values in either suite. Dolomite samples in suite 2 have higher lattice strain values than any suite 1 sample. This is consistent with shatter cone formation occurring within the central uplift and closer to the centre than the closest suite 1 sample at ~5.5 km.

Assessing samples from both sample suites, dolomite has higher overall strain values compared to calcite. Even in samples that contain both dolomite and calcite (Table 2), dolomite has the higher lattice strain value. This is similar to the results obtained by Martinez et al. [6] experimentally, and Huson et al. [5] who compared calcite and dolomite from the Sierra Madera impact structure to tectonically deformed carbonates. While their study [5] only compared peak full width half maximum (FWHM) values obtained from Rietveld refinement, not lattice strain, shocked dolomite was found to be more distinguishable than calcite from tectonically deformed carbonate samples.

Exceptions to the main trend among bedrock samples (Table 1) could have been caused by deviation in modal carbonate abundance (07-020), elevation difference (06-093), or by mild tectonic strain unrelated to the cratering process (05-010). Acquisition of samples with similar composition and collection locations are needed to further explore these minor deviations from the main lattice strain trend.

Conclusions: Determining lattice strain values in carbonates using powder X-ray diffraction shows promising results based on samples analyzed from the Haughton impact structure. To fully assess the application of X-ray diffraction to identify shock effects and their variation in carbonates, samples from additional carbonate-rich impact structures are required.

Acknowledgments: Collection of X-ray diffraction data and preliminary Rietveld refinements for Haughton sample suite 2 [3] was a collaborative effort by J. Newman, R. Flemming, M. McCraig and A. Rupert with graduate students R. Botor, F. Cao, C. Caudill, M. Galarneau, J. Geiger, V. Houde, L. Jenkins, Y. Li, J. Maris, M. Metcalf, and G. Tolometti from the 2017 Geology 9516B Advanced Mineralogy and Crystallography course at the University of Western Ontario. We also thank M. Raudsepp and J. Kabel for guidance with sample mounting for Rietveld refinement.

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