MICRO X-RAY DIFFRACTION CHARACTERISTICS OF EXPERIMENTALLY SHOCKED ANDESINE ANORTHOSITE: IMPLICATIONS FOR QUANTIFYING SHOCK EFFECTS IN METEORITES. F. Cao[1], S. J. Jaret[2], R.L. Flemming[1], M. R. M. Izawa[1,3], J. R. Johnson[4], [1]Department of Earth Sciences/ Institute for Earth and Space Exploration, University of Western Ontario, London, ON, Canada (fcao23@uwo.ca), [2]Department of Earth and Planetary Sciences, American Museum of Natural History, NY, NY, [3]Institute for Planetary Materials, Okayama University, Misasa, Tottori, Japan, [4]Johns Hopkins University Applied Physics Laboratory, Laurel, MD, USA.

Introduction: Plagioclase feldspars are common rock-forming minerals that can be used to evaluate the shock pressures in impact craters, or shock stages in meteorites, by petrographic and spectroscopic methods (e.g., Raman) [1–4]. Impact processes occurring on terrestrial planets and asteroids in our solar system produce a suite of distinctive and permanent shock metamorphic features in minerals, including mechanical twinning, intracrystalline structure (plastic) deformation (i.e., mosaic spread of subgrain orientations or bending), transformation to polymorphs, cataclasis, and melting under different impact pressures [5–9]. The deformation features of shocked plagioclase include undulatory extinction, mosaicism, and PDFs at low to moderate pressure levels and transformation to diaplectic glass at moderate to high levels, which are barometers to generally recognize different stages of shock metamorphism [5, 8, 9].

In situ micro X-ray diffraction (μXRD) techniques have been used to document systematic changes in streakiness of 2D diffraction peaks with different shock pressures through measuring the full width at half maximum (FWHMχ) along the Debye rings (chi dimension) [9–13]. It provides a quantitative approach to assessing metamorphism of shocked minerals in experimentally and naturally shocked samples, e.g., clinopyroxene and plagioclase [9, 13]. Here we present the first systematic μXRD investigation of experimentally shocked intermediate composition plagioclase of different shock pressures (0–56 GPa); it is useful to calibrate μXRD data for shocked plagioclase minerals in meteorites.

Samples and Methods: *Andesine anorthosite samples* were acquired from St. Urbain, Canada. They are monomineralic rocks that contain ~ 95% andesine ($An_{36–46}$), with minor amounts of quartz and potassium feldspar, with grains < 5–10 mm [14, 15]. These rocks were experimentally shocked to pressures between 15–56 GPa, from which thin sections were made [1].

Micro X-ray diffraction (μXRD) was performed using a Bruker D8 Discover microdiffractometer [10] with a 300 μm nominal beam diameter, using CoKα radiation (λ = 1.7889 Å), operating at 35 kV and 45 mA and a two-dimensional (2D) General Area Detector Diffraction System (GADDS). Using EVA software, 2D images were integrated to produce either intensity vs. 2θ plots over the 2θ range from 15° to 105°, or intensity vs. χ plots. Seven of the available 18 samples were analyzed thus far [15]. FWHMχ was determined by peak fitting with WIRE 4.2 software for all the samples except the unshocked target (details in Table 1).

Results: Experimentally-shocked andesine minerals display a continuous dispersion of diffracted X-ray intensity or "streaking" along the Debye ring or chi (χ) dimension when loaded pressure is between 15–35 GPa (Fig.1). The average streak length tends to increase with increasing pressure from 0 to 35 GPa (Fig. 3). Andesine shows decreasing diffraction intensities with increasing pressure, which can be seen from the increased noise and background from XRD patterns (Fig. 2). The transition from crystalline to amorphous is gradual. Andesine starts to be partially amorphous at ~29 GPa (sample 3511) and becomes almost completely amorphous (diaplectic glass) at ~ 47 GPa (sample 3518).

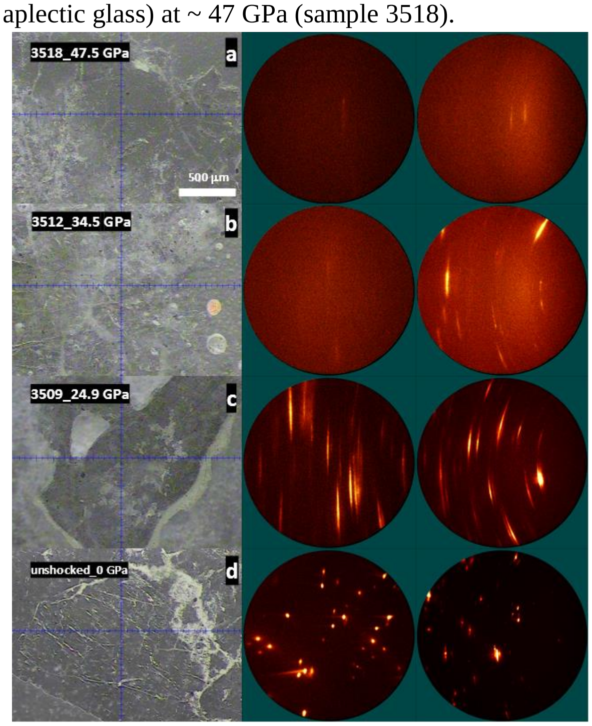

Figure 1. Photographs of mineral grains from different shock pressures and corresponding 2D XRD images showing single diffraction spots in unshocked andesine (Fig. 1d), strain-related mosaicity (i.e., streaking) in sample 3509 (24.9 GPa; Fig. 1c), partial to complete amorphization in 3512 (34.5 GPa) and 3518 (47.5 GPa; Fig. 1a, b). The measured FWHMχ is 0.65° (1d), 5.28° (1c), and 6.40° (1b) (Table 1). Increased streak length corresponds with a higher shock level [9–13].

Table 1. Experiment Samples and Average FWHMχ

Sample ID	GPa	Targets	FWHMχ (°)
unshocked	0	1	0.67
3510	15.8	3	2.93
3509	24.9	3	5.28
3511	29.6	3	7.36
3514	30.6	3	6.41
3512	34.5	3	6.40
3518	47.5	3	None

Note: For sample 3512, only two spots were used for measuring FWHMχ because the third spot had no diffraction lines (i.e., completely amorphous). Almost complete amorphization occurred on all three spots of sample 3518.

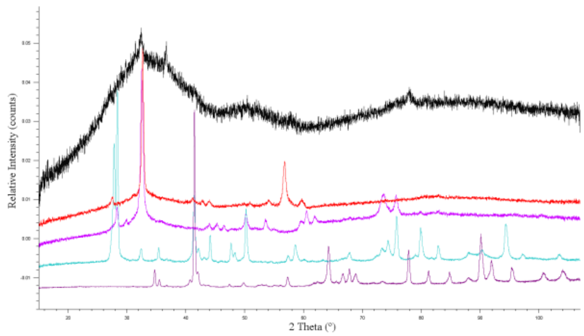

Figure 2. Representative X-ray diffraction patterns for five experimentally-shocked andesine samples under different pressures (P) (GPa): 0, 24.9, 29.6, 34.5, 47.5 (from bottom to top). Andesine feldspars exhibit characteristic degradation of diffraction features with increasing pressure, e.g., increasing noise and amorphous 'hump' formation. Samples became almost completely amorphous (e.g., maskelynite) > 34.5 GPa.

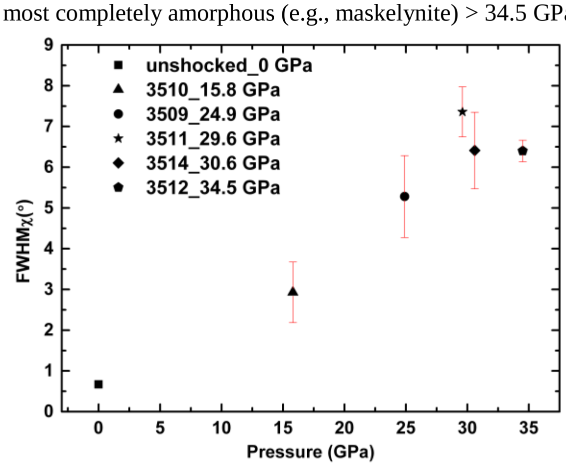

Figure 3. Relationship between FWHMχ of 2D X-ray diffraction peaks for andesine samples shock and pressure. Data correspond to average FWHMχ from several lattice planes. Error bars are one standard deviation (1σ), which implies the streak homogeneities for different samples.

Conclusions: Andesine feldspar displays mechanical disaggregation of the crystal structures from plastic deformation of crystallites (e.g., streaks) to progressive breakdown of the lattice planes (e.g., generation of diaplectic glass) with increasing shock stress determined by μXRD methods. This is consistent with previous Raman studies on naturally and experimentally shocked plagioclase minerals [1, 2, 16]. The transition occurs at approximately 29 GPa for andesine-rich samples and virtually complete amorphization at 47.5 GPa in the samples studied thus far.

The μXRD changes among these intermediate composition plagioclase samples are sensitively related to shock pressures, thereby providing the means to extract specific shock histories from extraterrestrial specimens, including meteorites and future returned samples, subjected to natural impact processes on terrestrial planets and asteroids. One specific implication for Mars' exploration is that μXRD data for plagioclase at different shock levels will be helpful in quantifying naturally shocked plagioclase samples on Mars.

Future work: Additional μXRD data for shocked andesine samples will be collected to check the homogeneity of the observed shock effects. μXRD will be used to study experimentally-shocked (0–56 GPa) albite-rich and bytownite-rich rocks as a function of pressure and composition.

Calibration Curve fitting will be done to pursue the quantitative relationship between the strain-related mosaicity in the χ dimension and the corresponding shock pressure. It will be used for calibration of naturally shocked plagioclase in meteorites. There will also be detailed shape analysis of the X-ray scans.

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