A previously unrecognized example of the shock-induced breakdown of biotite to garnet from the Steen River impact structure, Canada.

E. L. Walton[1,2], T. G. Sharp[3], J. Hu[3] and O. Tschauner[4], [1]MacEwan University, Department of Physical Sciences, Edmonton, AB, T5J 4S2 (waltone5@macewan.ca / ewalton@ualberta.ca). [2]University of Alberta, Department of Earth & Atmospheric Sciences, Edmonton, AB, T6G 2E3. [3]Arizona State University, Tempe, AZ, 85287-1404. [4]University of Nevada, Department of Geoscience, Las Vegas, NV 89154-4002.

Introduction: Shock metamorphic effects from quartz and feldspar have been studied in detail, and to a lesser extent olivine and pyroxene. Less is known about how shock is manifest in other minerals such as double chain inosilicates, phyllosilicates, carbonates and sulfates. In this study, we investigate shock in crystalline basement rocks from the Steen River impact structure (SRIS), a 25-km diameter complex crater in NW Alberta, Canada [1]. An array of advanced analytical techniques was used to characterize progressive stages of shock metamorphism as a function of distance from localized regions of shear-induced shock melting. Here, we focus on the reponse of biotite to shock and report a novel breakdown of this mineral to form almandine garnet + fluid accompanied by Fe-oxidation.

Samples and Methods: Three continuous drill holes sampled the crater fill impactites of the SRIS. One hole (ST003) penetrated 16 m of crystalline basement rock (feldspar-quartz-pargasite-annite gneiss) before bottoming out at ~381 m. Three polished thin sections of the crystalline basement rock were prepared for study. Backscattered electron images, wavelength dispersive spectrometry (WDS) analyses, WDS X-ray elemental maps, micro-Raman spectra, transmission electron microscopy (TEM) selected area electron diffraction patterns, TEM energy dispersive spectrometry analyses, TEM bright field and dark field images, and synchrotron micro-X-ray diffraction patterns were acquired on minerals within and surrounding 5—510 µm wide shock veins. These reveal the presence of novel phase transformations, which can be used to constrain shock conditions, crystallization pressure of the vein, shock duration and yield information on the spatial distribution of high temperature, high pressure minerals within shocked rocks. This study focuses on shock in biotite whereas our previous results focused on amphibole transformation [2].

Results & Discussion: In non-veined regions of the host rock, quartz and feldspar exhibit moderate to strong mosaicism and development of planar deformation features. According to the progressive stages of shock metamorphism, these deformation features correspond to stage 1a (~20 GPa; [3]). Biotite is pleochroic in shades of brown and yellow, with kink bands documented from several grains. EMP results give a representative formula of $(K_{0.98}Na_{0.02})(Fe^{2+}{}_{2.18}Mg_{0.80}Ti_{0.23}Mn_{0.02})(Al_{1.32}Si_{2.78})O_{22}(OH)_2$ with totals of 96.51—96.87 wt% oxides. These compositions correspond with Mg# <50 ([100Mg/(Mg+Fe)] computed on a molar basis) and are therefore annite, the Fe-rich end member in the biotite series. In transmitted light, former annite grains in contact with the now-quenched shock vein are opaque deep reddish brown. Reflected light and BSE images reveal a fine-grained granular texture of ~1—15 µm size equant, euhedral crystals poikilitically enclosing smaller bright grains. The Raman spectrum from these grains contain sharp peaks near 664 cm^{-1} and 910 cm^{-1} that are consistent with a mixture of garnet + magnetite. EMP spot analyses of the equant crystals + bright grains yield consistently good totals (99.84—100.49 wt% oxides) that correspond to an almandine (42—53%)-pyrope (28—54%)-skiagite (1—10%) garnet solid solution. FIB-TEM extractions across these poikilic garnets show that they are coarse-grained and deformed but not polycrystalline. The inclusions are rounded, 50—200 nm size and occur as both Fe-rich and Fe-poor varieties based on TEM-EDX spot analyses. The former correspond to titanomagnetite. TEM-EDX spectra acquired on garnets give representative formula of $K_{0.06}Ca_{0.06}Fe_{1.92}Mg_{1.02}Al_{1.91}Ti_{0.12}Si_{2.93}O_{12}$, which is less Fe-rich compared with EMP results from garnet ± inclusions. Based on these results we interpret the poikilitic almandine garnet crystals observed along vein margins to result from the breakdown of annite to almandine accompanied by Fe-oxidation and H_2 release by the simplified reaction: $KFe^{2+}{}_3AlSi_3O_{10}(OH)_2\ (s) \rightarrow (2Fe^{2+}K)(AlFe^{3+})Si_3O_{12}\ (s) + H_2\ (aq)$. This is consistent with the results of [2], on the non-isochemical breakdown of ferro-pargasite in the same rock to form an almandine-andradite-majorite garnet accompanied by oxidation ($Fe^{3+}/\sum Fe = 0.19$—0.24) and loss of volatile species including Na, K and Cl. Shock conditions calculated based on garnet chemistry are 18.0 ± 2.1 GPa and 19.4 ± 1.6 GPa, which are not appreciably different from the shock pressure recorded in the host rock, based on deformation in quartz and feldspar [2]. The phenomenon whereby high pressure minerals form almost exclusively in and around shock melts has been well-documented from meteorites and support our observations from the SRIS. We interpret the breakdown of annite to garnet and pargasite to garnet to be the results of elevated tempreatures along shock vein margins by conduction of heat to the wall rock during vein formation. The excess heat lowered the kinetic barrier for phase transformation and facilitated garnet formation. This is analogous to the phase transformation seen along shock veins in meteorites.

References: [1] Carrigy M. A. and Short N. M. 1968. In Shock Metamorphism of Natural Materials, pp. 367-378. [2] Walton E. L. et al. 2016. *Geochimica et Cosmochima Acta* 180:256—270. [3] Stöffler D. and Grieve R. A. F. 2007. In Metamorphic Rocks: A classification and glossary of terms.