SHOCK CONDITIONS EXPERIENCED BY HAUGHTON CRYSTALLINE BASEMENT ROCKS: A COMBINED RAMAN SPECTROSCOPY AND ELECTRON BACKSCATTER DIFFRACTION STUDY OF A SAMPLE FROM ANOMALY HILL. E. L. Walton[1], N. E. Timms[2], H. A. M. Jurak[1] and G. R. Osinski[3], [1]Department of Physical Sciences, MacEwan University, 10700 104 Ave, Edmonton, AB, T5J 4S2 (waltone5@macewan.ca). [2]School of Earth and Planetary Sciences, The Institute for Geoscience Research (TIGeR), Curtin University, GPO Box U1987, Perth, WA, Australia, [3]Department of Earth Sciences / Centre for Planetary Science and Exploration, University of Western Ontario, London, ON, N6A 5B7, Canada.

Introduction: Haughton is a 23-million year old impact structure with an apparent crater diameter of 23-km, formed in mixed target rocks of the Canadian High Arctic on Devon Island [1]. At the time of impact, the target stratigraphy comprised 1880 meters of Lower Paleozoic sedimentary rocks unconformably overlying granulite-facies tonalitic and granitic gneisses of the Precambrian Canadian Shield. A location near the center of the structure, characterized by strong negative gravimetric and positive magnetic anomalies, has been coined "Anomaly Hill" [3]. Highly shocked lithic clasts resembling pumice are particularly abundant at this locale, including carbonate-rich and gneiss clasts [4, 5]. In this study, a hand specimen from Anomaly Hill was investigated using an array of advanced analytical techniques. The goal is to constrain shock conditions experienced by Haughton crystalline basement rocks and their post-shock evolution.

Samples and Methods: A crystalline rock fragment, was collected in 1999 from Anomaly Hill by GRO. From this hand specimen, three polished thin sections were produced. The distribution of 24 elements over one entire thin section was mapped using a Bruker M4 Tornado micro-XRF instrument at the University of Western Brittany. The resultant XRF maps show the location and distribution of feldspars, quartz, calcite, sulfides and zircon. The optical properties of zircon grains were then observed using a petrographic microscope, with detailed microtextures characterized using a ZEISS Sigma 300 field emission scanning electron microscope (FESEM) in back-scattered electron (BSE) imaging mode at the University of Alberta. BSE images were acquired using an accelerating voltage of 20 kV. A Bruker X-ray energy dispersive spectrometer (EDS), aided in mineral identification. Those Zr-bearing grains potentially composed of several phases, were further characterized using micro-Raman spectroscopy at MacEwan University using a Bruker SENTERRA instrument. A 532 nm Ar+ laser was directed through the 100X objective lens of an optical microscope to achieve a spot size of ~1 μm. Peak positions and intensities in the Raman spectrum were compared to natural mineral standards, and spectra made available through the online RRUFF Raman database.

Phase and orientation maps of the 18 zircon grains were acquired via EBSD mapping with a Tescan MIRA3 FESEM fitted with Oxford Instruments AZtec combined EDS-EBSD system at Curtin University. EBSD/EDS data were collected using a Symmetry EBSD detector and XMax 20 mm SDD EDS detector with a specimen tilt of 70°, acceleration voltage of 20 kV and a working distance of 18.5 mm. EBSD camera parameters were optimized for an acquisition speed of 198 Hz. EBSD data were processed using Oxford Instruments Channel 5.12 by removing isolated erroneous data points via a 'wildspike' filter, followed by extrapolative infill of unindexed points using a minimum of seven nearest neighbours. Maps of EBSD pattern quality, phase, crystallographic orientation, and pole figures were produced in Channel 5.12.

Results and Discussion: The hand specimen is weakly foliated and highly vesiculated, composed of K-feldspar and quartz, with minor biotite and Fe-Ti-oxides, and accessory zircon, apatite, Fe-sulfide and thorite. The layered texture and mineralogy of the sample indicate that the protolith was a granitic gneiss from the crystalline basement.

Shock metamorphism in major and minor minerals: Quartz and feldspar are isotropic or show very low birefringence and appear colorless to brownish. Feldspar is highly vesiculated – it is the location and distribution of this mineral that largely determines the overall porosity of the rock (30–40 vol%). Feldspar occurs as pure end member $(K,Na)AlSi_3O_8$ and non-stoichiometric glasses. Opaque grains of biotite are in various stages of thermal decomposition. SiO_2, interpreted as former quartz, displays a range of textures and physical / optical properties: (1) vesiculated SiO_2 glass (i.e., lechatelierite), (2) diaplectic glass and (3) diaplectic glass containing planar deformation features (PDFs) and (4) coesite, the high-pressure, high-temperature SiO_2 polymorph. Coesite was identified by well-defined peaks in the Raman spectrum at 270, 427, 466 and 521 cm^{-1}. Silica glass exhibits a broad hump centered over ~465 cm^{-1} in the Raman spectrum. Coesite occurs as aggregates associated with lechatelierite, typically aligned to form stringers of micrometer-size crystals.

Shock effects in zircon: BSE imaging, EBSD, and Raman analysis of zircon grains across the thin section show that zircon heterogeneously records a range of different microstructures, including: crystalline zircon with no definitive evidence of shock, but some fracturing and limited crystal-plasticity (n = 10); poor crystallinity zircon, commonly with irregular fractures and vesicles (n = 3); zircon bearing lamellar reidite (n = 2), patchy and/or granular textured reidite (n = 3); and granular textured zircon (n = 2). No evidence of planar deformation bands, shock twins, or thermal decomposition of zircon was observed. Lamellar reidite form thin (<1 μm wide), closely-spaced sets of roughly parallel lamellae that cross cut zircon primary growth zoning. They are identified as reidite by a broad, low-intensity peak at 608 cm^{-1} in Raman spectra, along with a doublet at 816 and 862 cm^{-1}. Peaks are accompanied by a triplet at 192, 200, and 212 cm^{-1}, and sharp, well-defined peaks at 344, 426, 962, and 994 cm^{-1}, all of which are consistent with zircon. Reidite lamellae yield poor EBSD patterns that could not be indexed. Sub-micrometer granular reidite occurs in poor crystallinity zircon and is spatially associated with fractures and grain margins of highly-crystalline zircon, and indexed well by EBSD mapping. Reidite typically has a distinctive epitaxial crystallographic orientation relationship with the host zircon, with one $\{110\}_{reidite}$ aligned with $(001)_{zircon}$, and the other $\{110\}_{reidite}$ aligned with $\{110\}_{zircon}$. These relationships have been described elsewhere [8, 9] and are readily explained by transformation from a single zircon orientation via multiple symmetrically equivalent pathways resulting in broadly two orthogonal reidite orientations. Discrete, sub-micrometer granular-textured zircon domains are spatially associated with reidite in these grains, and predominantly define up to three mutually orthogonal crystallographic orientation clusters. This microstructure is best explained as neoblasts formed by back-transformation to zircon from reidite via multiple, symmetrically equivalent pathways [8]. This texture has been termed FRIGN (former reidite in granular neoblasts) by [10]. Raman spectra acquired from these grains show mixed spectral signatures with peaks assigned to reidite and zircon.

Available experimental data shows that shock transformation of zircon to reidite begins at ~30 GPa and is complete by ~53 GPa [11]. Thus, it is reasoned that zircon grains that preserve reidite or evidence of its former presence (i.e., FRIGN zircon) experienced a minimum shock-pressure of ~30 GPa. Reidite is also sensitive to post-shock temperature and has been documented to revert to zircon at temperatures >1200 °C [12]. Therefore the presence of FRIGN zircon could indicate that these grains reached >1200 °C. However, the lack of any dissociation textures in zircon grains (e.g., coronas of baddeleyite + silica glass), imply that zircon did not reach temperatures >1673 °C [9, 13]. The remaining zircons exhibit igneous textures, some of which possess growth zones and margins that can be described as highly porous. These porous grains yield Raman spectra that exhibit low intensity, broad peaks at 344, 426, 962, and 994 cm^{-1}. Broadened peaks in the Raman spectrum indicates these materials are poorly crystalline, consistent with localized radiation damage of U-rich growth zones. Vesicles are interpreted as a consequence of degassing from pre-existing impurity-rich metamict domains during impact-related heating.

Conclusions: Based upon shock effects described in feldspar (vesicular glass) and quartz (coesite, diaplectic glass and lechatelierite), this clast can be assigned to shock stage III [14]. Reidite has been identified in a subset of zircon grains by Raman spectroscopy and EBSD mapping. However, the heterogeneous distribution of shock features in zircon suggests that shock pressure and temperature conditions varied locally at the grain scale. Nevertheless, shock stage III is associated with shock pressures ~45 GPa, with an upper limit of 60 GPa; this shock pressure range is consistent with the experimentally-determined stability of reidite [e.g., 13]. Likewise, the formation and preservation conditions of coesite is sensitive to the pressure-temperature-time path experienced by shocked rocks. TEM observation of coesite in suevite from the Ries crater, have shown they form during the shock unloading path by crystallization from silica melt [15]. The lower pressure stability range of coesite (~2–11 GPa at elevated temperature, [16]) compared with reidite, is consistent with coesite formation by crystallization from shock-produced melt during decompression. The presence of FRIGN zircon, but lack of zircon dissociation textures, indicates that temperatures locally reached >1200 °C but did not exceed ~1673 °C.

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