

POST-IMPACT HYDROTHERMAL ACTIVITY AT THE HAUGHTON IMPACT STRUCTURE, DEVON ISLAND, NUNAVUT, CANADA. G. R. Osinski¹, J. G. Spray¹, T. E. Bunch², R. A. F. Grieve³, J. W. Schutt, and P. Lee⁴, ¹Impact Geology Group, Geology Dept., University of New Brunswick, NB, E3B 5A3, Canada (f532b@unb.ca), ²NASA Ames Desert Research Field Station, Prescott, AZ 86301, USA, ³Geological Survey of Canada, Ottawa, Canada, ⁴NASA Ames Research Center, Moffet Field, CA 94035-1000, USA.

Introduction: The relatively uneroded 23.4 Ma old [1] Haughton impact structure, situated near the western end of Devon Island in the Canadian Arctic Archipelago, is the highest latitude terrestrial impact crater known on land (75° 22' N, 89° 41' W). Estimates of the original rim diameter range from ~20 km [2] to ~24 km [3]. The target sequence comprises a ~1750 m thick series of predominantly carbonate rocks of Lower Paleozoic age, underlain by Precambrian metamorphic basement. Several horizons of gypsum and anhydrite are also present. Geological mapping performed as part of this study indicates that the oldest rocks are exposed in the centre, and are surrounded by concentrically arranged fault-bounded blocks (faulted annulus) of progressively younger Paleozoic formations, confirming earlier studies [2,4 and 5]. Polymict impact breccias form a more or less continuous deposit covering ~56 km² within the central area of the structure and extend out into a ring of hills. Discontinuous deposits of breccia occur up to a radial distance of ~7.5 km in the east of the structure. The light grey-weathering breccias comprise a finely comminuted, friable matrix containing variably shocked lithic and mineral clasts, interpreted as representing a major section of the pre-impact stratigraphy to a depth of 2000 m or more [6].

Post-impact hydrothermal activity: To further the geological characterization of Haughton as a terrestrial impact structure and because of the potential astrobiological significance of impact-induced hydrothermal activity on Mars and other planets [e.g., 7], the search for, and characterization of, any post-impact hydrothermal signature at Haughton has been a high-priority item for the NASA-led Haughton-Mars Project (HMP), an ongoing Mars analog field research program on Devon Island [8]. Field work carried out during the 1999 field season of the HMP has revealed the presence of two distinct settings of post-impact hydrothermal alteration within the Haughton impact structure: (1) pipe structures spatially associated with the faulted annulus; (2) cavity and fracture fillings within the polymict impact breccias.

Pipe structures. These hydrothermal deposits are only found within the faulted annulus, and are not present in the polymict impact breccia. The structures range from ~1 m to ~7 m in diameter and may be seen exposed over lengths of up to ~20 m. Commonly, there are extensive volumes of mineralized monomict breccia in the pipes. The breccia clasts are supported

by a carbonate matrix and do not appear to have been formed by grinding via impact or faulting, but instead by hydraulic fracturing. Powder X-ray diffraction (XRD) analysis indicates that marcasite (FeS₂) and pyrite (FeS₂) are the dominant minerals, with subordinate chalcopyrite (CuFeS₂). The pipe structures are characterized by intense Fe-oxide alteration of the dolomite and limestone country rocks (Figure 1). XRD analysis of altered dolomite reveals that goethite (FeO(OH)) is the dominant alteration product, with accessory hematite (Fe₂O₃).



Figure 1. An exposed pipe structure in a faulted annulus valley at Haughton (Photo NASA HMP).

Cavity and fracture fillings. Cavity and fracture fillings are restricted to the polymict impact breccia. Evidence for two distinct episodes of hydrothermal activity has been found: (1) sulfide ore mineral deposition; (2) sulfate mineral deposition.

Sulfide mineralization has been discovered at two closely spaced localities in a well-exposed cliff section along the Haughton River valley, in the southeastern sector of the Haughton impact structure. The irregularly-shaped cavities are both ~5 to 10 m³ in volume. Mineralization is concentrated on the interior surface of the cavity walls. XRD analysis and scanning electron microscopy (SEM) indicates that marcasite is the dominant phase, with trace amounts of Fe,Cu,Ni,Zn-sulphides. Marcasite occurs in several different forms and settings: (1) as thin crusts (<0.5 mm thick) of very fine grained crystals on hydrothermal carbonates; (2) crusts of radiating crystals ~2 to 7 mm thick (Figure 2); (3) as irregular tongues of botryoidal form, up to ~15 cm long,

extending into the now empty cavity; (4) as chimney structures up to several centimetres in diameter, with the marcasite rim infilled with hydrothermal calcite; (5) as discrete bands within well-laminated hydrothermal calcite and/or natron ($\text{Na}_2\text{CO}_3 \cdot \text{H}_2\text{O}$).

Transparent secondary selenite ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) is common throughout the polymict impact breccia. It occurs both as large tabular plates from 0.1 to 1 m^2 and as single, well-formed prismatic crystals growing on clasts within the breccia. At one location, a mass of intergrown selenite crystals combines to form a deposit $\sim 1.5 \text{ m}^3$ in volume. It is widely known that gypsum is mobile at very low temperatures and it thus appears that the deposition of selenite is a late-stage hydrothermal event. It is suggested that two possible explanations may account for the origin of the selenite: (1) precipitation from gypsum-rich fluids, derived from underlying Bay Fiord Formation gypsum beds; (2) reaction of sulfurous vapours on Ca-bearing minerals within the breccia [9].

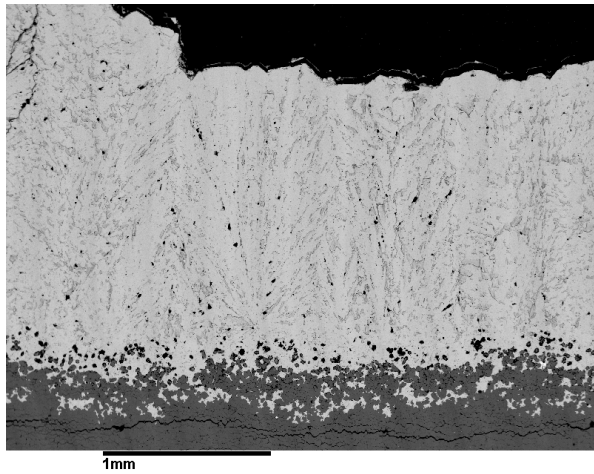


Figure 1. Backscattered electron image of marcasite from a cavity within the polymict breccia. Note the radiating texture of the marcasite (light grey) and the gradation from hydrothermal calcite (dark grey at bottom of image).

Hydrothermal conditions. It is well-documented that most pyrite and marcasite in hydrothermal deposits form from solution. The predominance of marcasite over pyrite provides important information about the conditions that prevailed at the time of deposition. Experiments have shown that marcasite is the predominant precipitate below pH 4.5 and pyrite the dominant precipitate above pH 4.5 [10,11]. The temperature of formation is more difficult to constrain. In black smokers from the East Pacific Rise, it has been suggested that marcasite formed at temperatures in excess of 300°C [12], while in some Mississippi Valley Type (MVT) lead-zinc deposits, temperatures as low as

80°C have been inferred [13]. However, the phase relations between pyrite, marcasite and pyrrhotite (FeS_{1-x}) below 300°C reveal that marcasite is only stable on a geological time scale at <160°C [14].

The pristine, unaltered nature of marcasite found within the polymict impact breccias would seem to favour relatively low temperatures for the hydrothermal system. We suggest that a conservative estimate for the temperature of the post-impact hydrothermal system within the Haughton polymict impact breccia is ~ 100 to 200 °C. The deposition of selenite would have occurred following a decrease in temperature, and would depend also on the saturation state of the fluid.

The presence of pyrite and chalcopyrite in addition to marcasite within the pipe structures, and the observed monomict brecciation, suggest that temperatures were higher in the hydrothermal system developed through the faulted annulus, than that developed within the polymict impact breccia. Field mapping and seismic reflection studies [3] indicate that the majority of faults within the faulted annulus are listric extensional faults, dipping in towards the centre of the structure. We suggest that these faults may have channelled fluids from greater depths than the source of fluids in the polymict impact breccias, resulting in higher temperature mineralization.

Plans are underway to further the characterization of post-impact hydrothermal activity at Haughton.

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