HYDROCARBONS IN THE HAUGHTON IMPACT STRUCTURE, DEVON ISLAND, NUNAVUT, CANADA.

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Hydrocarbons in Impact Craters: The occurrence of organic matter in terrestrial impact craters is important to astrobiology, as it may offer insight into possible relationships between impact events and the genesis, distribution and preservation of biologically-relevant materials on planets. In particular, the processing and mobilization of preexisting organic material in planetary targets is of interest for studies of pathways to chemical complexity. Observations in old (Palaeozoic, Precambrian) craters indicate that organic carbon can survive large impacts [1,2,3]. However, limited exposure and superimposed geological events can make the detailed history of organic matter in old craters difficult to decipher [1,2]. We present here the first identification of hydrocarbons in the young (23 Ma, Miocene) Haughton impact structure.

Geological Setting: The structure was formed about 23 Ma in a ~1750m series of Lower Palaeozoic sedimentary rocks dominated by carbonate facies overlying a Precambrian crystalline basement [4]. The crater is filled with carbonate-rich impact melt rocks [5], which contain clasts of basement, indicating an excavation depth of 2km+. Limited Tertiary lacustrine sediments lie upon the melt rocks. The rocks within the central part of the crater include hydrothermal mineral veins of quartz and calcite [6]. Exposure is generally excellent at Haughton. The site has not experienced geological events which would complicate interpretation or impair detailed analysis of its hydrocarbon system. Country rocks around the crater are predominantly brown dolomites with a sucrosic, porous texture, and are generally unveined.

Hydrocarbons in Haughton Impact Structure: Hydrocarbons were first evident in the Haughton impact structure through a fluid inclusion study of the hydrothermal mineral veins. A calcite vein from the northeastern part of the crater (Fig. 1) contains inclusions of liquid hydrocarbon (Fig. 2). The inclusions are both primary and secondary (in cross-cutting trails), in the size range up to 25 microns, and fluoresce yellow-green to blue-white under ultra-violet light. They are monophase, or two-phase with a high degree of liquid fill. Aqueous inclusions yield homogenization temperatures (Th) up to 140 ºC. These observations indicate that liquid hydrocarbons were entrained in hydrothermal fluids at this locality.

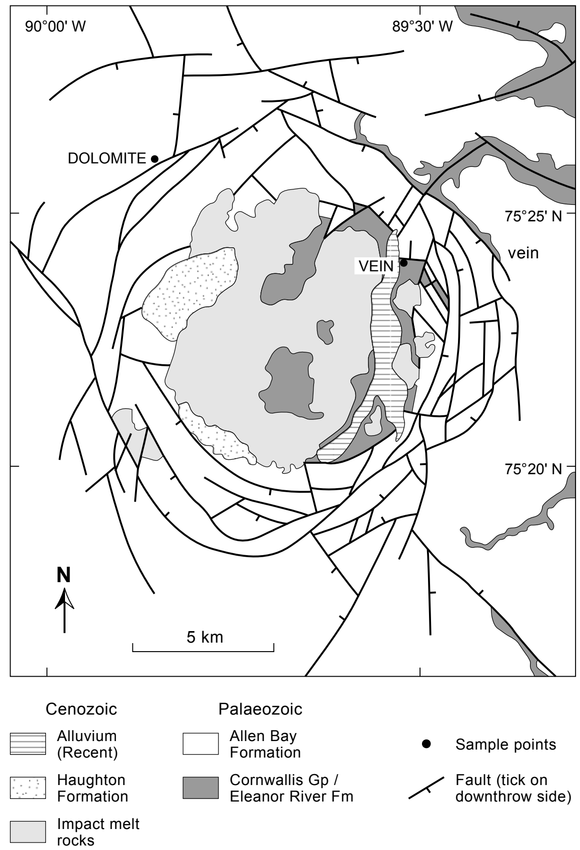

Fig. 1. Map of Haughton impact structure, showing location of calcite vein and dolomite country rock samples.

Gas chromatography-mass spectrometry (GC-MS) of a dolomite sample from the NASA Haughton-Mars Project base camp (Fig. 1) shows that the dolomite does indeed contain migrated hydrocarbons. The saturates fraction of an extract in dichloromethane (Fig. 3) is dominated by n-alkanes, and triterpanes (hopanes). This is a normal liquid hydrocarbon chemistry.

A m/z 191 fragmentogram for hopanes (not shown) yields a $C_{32}\alpha\beta$ S/S+R ratio of about 0.63, typical of generation within the oil window. The dolomite therefore contains a source of liquid hydrocarbons that could be incorporated into hydrothermal solutions.

A fluid inclusion study of the dolomite shows that inclusions of liquid hydrocarbon occur within the dolomite crystals. These inclusions fluoresce yellow, and appear to be primary, i.e. they were trapped during crystal growth. Primary aqueous inclusions in the dolomite crystals yield Th in the range 70 to 110 ºC.

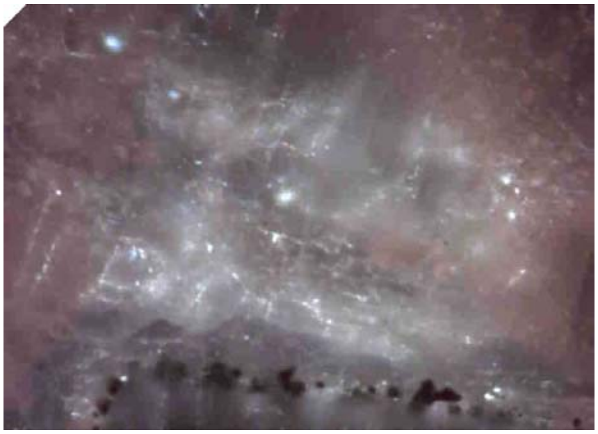

Fig. 2. Hydrocarbon inclusions fluorescing under U-V light in vein calcite. Each inclusion 5-10 microns size.

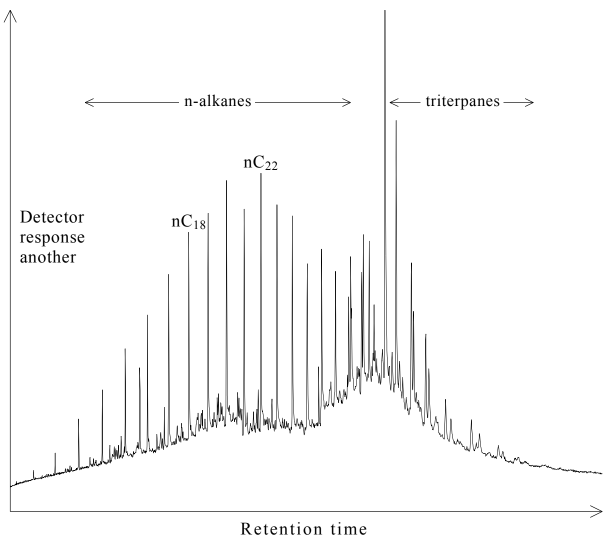

Fig. 3. Total Ion Chromatogram for dolomite sample, dominated by n-alkanes and triterpanes.

Model for Hydrocarbon Emplacement: Hydrocarbons in a hydrothermal system could be derived directly from a hydrocarbon source rock, or from a pre-existing accumulation of hydrocarbons. A deep water mudrock facies in the Lower Palaeozoic host sequence occurs to the west and north of Devon Island [7], at least 100km from the Haughton structure. It is unlikely that this facies could have been tapped directly by the hydrothermal activity in the structure. A more realistic scenario is regional hydrocarbon generation from the mudrock facies, migration laterally/updip into the porous dolomite facies, and entrainment by later hydrothermal activity.

Regional estimates of source rock maturity in the Lower Palaeozoic indicate that they are within the window of liquid hydrocarbon generation, based on mean graptolite reflectance values mostly below 1.0 Ro max [7]. This is consistent with the level of maturity for the dolomite-hosted hydrocarbons, deduced from GC-MS data. It is therefore reasonable to assume that the hydrocarbons in the dolomite were derived from the Lower Palaeozoic source rocks. Other source rocks in the Canadian Arctic, of Precambrian [8] and Triassic [9] ages, have no plausible role at Haughton.

The temperature data from the dolomite indicates crystallization at depths of 3-4km, i.e. the present dolomite texture, and its enclosed hydrocarbons, are a product of deep burial diagenesis. It is difficult to assess when this occurred, as a lack of post-Palaeozoic rocks prevents us from modelling the complete burial history. However as the succession of Siluro-Devonian rocks above the dolomite was probably once several km thick [7], the burial depth may have been adequate for hydrocarbon generation during the Palaeozoic.

Our initial model involves hydrocarbon emplacement in the country rocks pre-impact, then entrainment of these hydrocarbons in the post-impact hydrothermal system. In the centre of the crater, the heat of impact was sufficient to partially volatilize and/or melt large volumes of rock [5], but near the rim the degree of heating was probably much less and some organic matter could have survived. The hydrothermal system was on a km-scale [6], therefore hydrocarbons could also have been incorporated from the crater margin where heating was less marked. A continued programme of organic geochemistry on samples from different parts of the crater should help to further understand the hydrocarbon system in the Haughton impact structure. The hydrocarbon occurrences at Haughton are of no economic significance.

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