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The Haughton-Mars Project: Overview of science investigations at the Haughton impact structure and surrounding terrains, and relevance to planetary studies

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The Haughton impact structure (23 km in diameter) on Devon Island, High Arctic, has been the subject of a number of scientific investigations since its identification as an impact structure in the early 1970s (see Grieve 1988 for a summary). Due to its near polar location (75.2°N, 89.5°W), Haughton has experienced a predominantly cold and relatively dry climate throughout most of its history, and is for this reason exceptionally well preserved considering its age (~39 Ma). While by no means subject to environmental conditions as extreme as those encountered on Mars at present, the structure's general climatic setting in a terrestrial polar desert (annual average temperature is –16 °C; annual precipitation is <13 mm)—including the implied continuous permafrost underlying its terrains—and the presence of a number of other geologic features at or near the crater that bear possible relevance to Mars, make the site attractive as a potential analog for Mars (Lee 1997). Haughton is the only terrestrial impact structure known to be set in a polar desert.

In 1997, a pilot study was initiated to visit Haughton with an eye towards comparative planetary studies (with focus on Mars) and a small field party of four deployed to Devon Island with support from the US National Aeronautics and Space Administration (NASA), the US National Research Council (NRC), and Natural Resources Canada (NRCan) (Lee et al. 1998). Haughton and its surrounding terrains proved to offer a wide range of investigative possibilities for analog studies (e.g., Lee and Rice 1999; Lee et al. 1999; Lee 2000; Lee et al. 2001, 2002, 2003, 2004, 2005; Glass et al. 2002, 2005), with the prospect of many seasons of field work needed ahead to complete even initial surveys, and so the Haughton-Mars Project was established as a longer term effort. Now in its tenth year of operation, the Haughton-Mars Project (HMP) is an international multidisciplinary planetary analog field research project centered on the scientific study of the Haughton impact structure and surrounding terrains, with both a science program (seeking to advance our scientific understanding of the site in the broad context of planetary science and astrobiology) and an exploration program (seeking to use the site and the fact that actual scientific field investigations are taking place there [not simulations thereof] as an opportunity to drive and mature technologies and strategies for future planetary exploration with both robotic systems and humans). Being set in a polar desert, i.e., an environment which, by terrestrial standards, is extremely cold, dry, rocky, dusty, UV-irradiated, and largely unvegetated, the site presents real operational challenges to field exploration that are analogous in fundamental ways (although much more forgiving, of course) to those expected in planetary surface exploration.

At present, each summer the HMP hosts tens of researchers (scientists and engineers), graduate and undergraduate students, and support staff at its base camp—the Haughton-Mars Project Research Station (HMP RS) established in the northwestern rim area of the Haughton crater—with the bulk of its research activities supported by NASA and the Canadian Space Agency (CSA). The project and station are managed jointly by the Mars Institute and the SETI Institute, and involve partnerships with several government agencies from both the US and Canada, and also a number of other organizations from the private sector, including academic institutions, industrial partners, and non-profit groups. Current research emphasis of the HMP's science program is in the fields of impact geology, geomorphology, glacial and periglacial geology, geophysics and geochemistry, hydrology and limnology, astrobiology, and microbiology.

The following papers in this special issue represent the latest contributions of the HMP's science program to our understanding of the geology and biology of the Haughton impact structure. Emphasis is placed on results relating to the Haughton impact structure per se, as opposed to other features of possible planetary analog relevance elsewhere on Devon Island. The findings reported here build upon earlier work at Haughton by the HMP (e.g., Lee 1997; Lee et al. 1998; Osinski and Spray 2001, 2003; Osinski et al. 2001; Cockell et al. 2002, 2003; Lim and Douglas 2003; Parnell et al. 2004, 2005a), and previous workers, in particular, the Haughton Impact Structure Studies (HISS) project (see Grieve 1988 for a summary). When taken together, these investigations make the Haughton impact structure one of the most intensely studied impact craters on Earth.

Importantly, craters of Haughton's size are large enough to display all of the characteristic features of complex impact structures (e.g., central uplifts, collapsed/terraced rims, etc.), yet they are small enough that detailed geological characterization is possible in a few field seasons. There are also enough impact structures in this size range and in a variety of target rocks that valuable comparisons can be made. Indeed, the systematic study of mid-size impact structures is deemed to be a high-priority area of research for the impact community (see results of the recent workshop, Impact Cratering: Bridging the Gap between Modeling and Observations, http://www.lpi.usra.edu/meetings/impact2003 and related special issue of *Meteoritics & Planetary Science* of February 2004). Haughton is one of only a handful of craters in this size range that are well preserved and with sufficient exposure to allow detailed field investigations to be carried out. Thus, it is hoped that knowledge gained from studying Haughton will provide valuable information on the impact cratering process that will encourage and direct further systematic studies of other terrestrial impact sites, and provide the necessary constraints for numerical models. Ultimately, such studies will help advance our understanding of impact cratering as a universal planetary process.

A major focus at Haughton of the past few field seasons of the HMP has been the systematic, detailed 1:10,000 to 1:25,000 scale mapping of the impact structure. This has resulted in the production of a 1:25,000 scale geological map that is included as part of this special issue and which shows the geology of Haughton in unprecedented detail (see map insert). It is notable that this represents the most detailed, complete geological map of an impact structure of this size. The new mapping effort and allied investigations constrain the apparent diameter of Haughton to 23 km, with a best estimate for the rim (final crater) diameter of ~16 km. Such a distinction as to size has not been made for many terrestrial craters. However, this is critical in impact cratering studies as the apparent diameter is the value typically quoted by field geologists and is the only possible estimate of crater size in eroded structures; whereas, the rim diameter is the metric used in numerical models and computer simulations.

The paper by Osinski et al. (2005a) provides a geological overview of Haughton, including a summary of previous work carried out by the HMP and other efforts, a detailed discussion of the target stratigraphy, and a conceptual model for the formation of the Haughton crater.

Another important new contribution in this special issue concerns the age of the Haughton impact structure. The age of Haughton is revisited by Sherlock et al. (2005) using high-precision ^{40}Ar–^{39}Ar laser probe dating of potassic glasses contained in impactites. Their study yields a new age of ~39 Ma for Haughton, making it substantially older than previously thought (23.4 ± 1.0 Ma; Jessberger 1988). This has implications for quantifying post-impact modification processes, which is explored in several other papers in this special issue.

A paper by Osinski et al. (2005b) builds upon previous works by Osinski and Spray (2001, 2003) and improves our knowledge of the response of sedimentary rocks, in particular carbonates, to a hypervelocity impact. In particular, it is now clear that carbonates, evaporites, sandstones, and shales, underwent melting during the Haughton impact event, a fact that was not recognized prior to HMP studies. The extent and depth of the melt zone and depth of excavation are constrained, which, together with the new mapping results, allows a reconstruction of the transient cavity to be made.

Osinski and Spray (2005) present a detailed investigation of the tectonics of the Haughton impact event. The authors then combine the results from Haughton with data from other terrestrial impact structures, allowing a better understanding of the kinematics and mechanics of complex impact crater formation in general to be made.

A synthesis of new geological and remote sensing data is provided by Tornabene et al. (2005). Their study serves as a terrestrial proof of concept that visible-near infrared (VNIR), shortwave infrared (SWIR), and thermal infrared (TIR) spectroscopic and remote sensing methods can be used to map lithologies uplifted in the center of complex impact structures on Earth and Mars, thus allowing initially buried lithologies to be identified.

In addition to the excellent exposure and preservation of Haughton, the site has not experienced substantial subsequent geological alteration other than glaciation (e.g., burial, tectonism, metamorphism), which would complicate interpretation of its hydrocarbon system. Parnell et al. (2005) show how different types of geochemical signatures remain recorded at a relatively large impact site by tracing organics from pre-impact country target rocks to debris resulting from the erosion and weathering of impact-processed materials. These results have important implications for the potential recoverability of ancient biosignatures on Mars, which might be preserved even in impact-processed terrains.

Post-impact processes have been an important focus of the HMP, both in terms of understanding the modification of the Haughton crater through time and because of possible implications for understanding the Martian impact cratering record, Mars's climate evolution, and the search for life (e.g., Lee et al. 2005). Osinski et al. (2005c) present new data on the impact-induced hydrothermal system at Haughton, including temperature constraints and the first map showing the complete distribution of different hydrothermal deposits around a mid-size complex impact structure.

The intra-crater sedimentary record at Haughton is the focus of a paper by Osinski and Lee (2005). In addition to the recognition of a series of new sedimentary units, this work shows that the Haughton Formation, a post-impact crater lake sequence, was deposited up to several million years after the formation of the Haughton crater and not in the immediate aftermath of the impact event. Their study also identifies a glacial record at Haughton.

Finally, post-impact biological succession and recovery following the Haughton impact event is addressed by Cockell et al. (2005). These authors also combine data gathered at Haughton with data from other craters to develop a better understanding of the effects of impact on habitats for microbial lithophytic organisms. An important astrobiological insight gained through microbiology studies at HMP is the possibility that impact events, rather than being strictly life-destroying events, may have also represented habitat generating opportunities for at least microbial life.

The results presented here and ongoing HMP research on Devon Island are helping reshape our thinking about several aspects of impact cratering, planetary evolution, and astrobiology. It is our hope that many generations of scientists and students will continue to work at Haughton in the future to further the areas of research we have only begun to touch and the many others still left unexplored.

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