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Overview of analogue science activities at the McGill Arctic Research Station, Axel Heiberg Island, Canadian High Arctic

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ABSTRACT

The Canadian High Arctic contains several of the highest fidelity Mars analogue sites in the world. Situated at nearly 80° north, Expedition Fjord on Axel Heiberg Island is located within a polar desert climate, with the surrounding landscape and conditions providing an invaluable opportunity to examine terrestrial processes in a cold, dry environment. Through the Canadian Space Agency's Analogue Research Network program, scientific activities based out of the McGill Arctic Research Station (M.A.R.S.) are extremely broad in scope, representing physical, biological, and technological investigations. Some of the most unique hydrogeologic features under investigation near M.A.R.S. are a series of cold saline springs that maintain liquid-state flow year round regardless of air temperature. Previous studies have examined their geomorphic relation to discharge-related formations, water chemistry, temperature monitoring, discharge rates, and combined flow/thermal modeling. Recent investigations have identified microbial communities and characterized biological activity within the springs and within permafrost sections, having direct relevance to astrobiological analogue research goals. Another main thrust of research activities based at M.A.R.S. pertains to the detection, mapping, and quantification of subsurface ice deposits. A long-term study is presently underway examining polygonal terrain, comparing surficial patterns found in the region with those identified on Mars, and using surface morphology to estimate ice wedge volumes through a combination of aerial photography interpretation and ground-based geophysical techniques. Other technological developments include the use of *in situ* microscopy for the detection of biomarkers and improved permafrost drilling techniques. This paper presents an overview of previous studies undertaken at M.A.R.S. over the past decades and will describe in detail both present and upcoming work.

1. Introduction

Conceptually there are two approaches we can use to improve our understanding about other planets: (i) efficient analysis of existing and future data sets, and; (ii) the development of innovative techniques that could potentially be incorporated as payload or methodological constituents on future missions. With regards to Mars, one of the most effective ways to accomplish these goals is to exploit the environments on Earth that are the most similar to the conditions we expect to exist there – namely very cold and very dry – like those found in terrestrial polar deserts.

Such is the basis of the "analogue approach" to geoscientific research. Eicken (2002) notes that terrestrial analogue studies are integral to interplanetary research because they allow us to develop and test conceptual models about the properties inferred or observed on other planets and also provide constraints to theories about planetary development and composition. In essence, given the excessive costs and risks associated with full Mars missions the most viable alternative is to use to the Earth to simulate Martian environments as closely as possible.

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Table 1
Characteristics of the Canadian High Arctic making it suitable for terrestrial analogue studies.

What are desirable analogue characteristics?	Why the Canadian High Arctic?
Fidelity: Reproduce, to the maximum possible extent, the characteristics of Mars.	*Fidelity*: An isolated and harsh region of the Earth possessing a variety of Mars analogue environments.
Accessibility: Allow the analogue environment to be reached/ reproduced by CSA and potential partners (e.g. NASA).	*Accessibility*: Regular access to a limited set of facilities are provided by PCSP during the summer. Intermittent access is possible in winter.
Repeatability: Access to the analogue should be available over an extended period and under a full range of conditions.	*Repeatability*: Canadian Polar Continental Shelf Program (PCSP) has been in operation since 1958 providing high quality logistics support to Canadian scientists working in Arctic regions.
Affordability: Provide maximum leverage of available funds and partnership contributions.	*Affordability*: Relatively low-cost, because leverage of PCSP logistics costs and infrastructure is available. PCSP is interested in investing in CSA-derived technology for Arctic operations. Only area in Canada combining fidelity characteristics with available infrastructure.
Utility: If possible, provide benefits to other Government agencies, industry, isolated Communities, and scientific community by use of the analogue.	*Utility*: Provides direct benefit to PCSP work in Canadian High Arctic, and provides a terrestrial test bed to prove out systems of use to industry and to isolated communities within Canada. Will enhance use of Canadian High Arctic by scientific community.

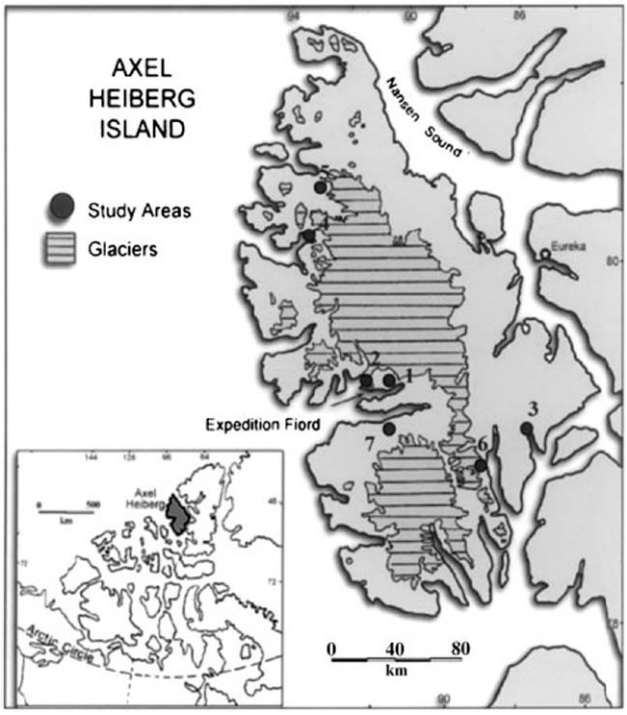

Fig. 1. Map of Axel Heiberg Island, Canadian High Arctic. Numbered study sites represent locations of perennial spring occurrences, including: (1) Gypsum Hill, (2) Colour Peak, (3) Whitsunday Bay, (4) Middle Fjord, (5) Bunde Fjord, (6) Skaere Fjord, and (7) Junction Diapir ("Lost Hammer") (See Section 3.2).

As summarized in Table 1, the Earth's polar regions provide a unique opportunity to examine the physical and biological processes related to cold, dry environments, and to develop and test technological advances that could potentially be used for future Mars missions (Andersen et al., 1990, 1992, Vali et al., 1999). Through the Canadian Analogue Research Network (CARN) program (Hipkin et al., 2007; Osinski et al., 2007), the Canadian Space Agency (CSA) has identified two sites in the High Arctic as centers for analogue-based research: (i) the Haughton Mars Project, Haughton Impact Structure, Devon Island, and; (ii) the McGill Arctic Research Station (M.A.R.S.), Expedition Fjord, Axel Heiberg Island. The latter represents the focus of this paper.

Originally established by McGill University in 1960, M.A.R.S. (79°26′N, 90°46′W; Fig. 1) has been providing support to teams of scientists involved in research focusing on glaciology, geocryology, meteorology, biology, microbial ecology, geology and isolation psychology. While the original camp has been in operation for nearly 50 years, financial support provided through the CARN agreement with CSA has facilitated the development of a new camp approximately 10 km further west along Expedition Fjord. Additionally, M.A.R.S. field activities sometimes extend beyond the immediate local station to other parts of Axel Heiberg Island and regions of west-central Ellesmere Island such as the Fosheim Peninsula where the resources of Environment Canada's Eureka weather station are often used. Eureka is located at 79°59′N, 85°56′W, approximately 100 km east of the M.A.R.S. camp.

The primary goals of the new camp are to provide enhanced logistical support for researchers involved in CARN-funded studies, to build upon McGill's legacy of collaborations in space-related research over the past decades, and to set the foundation for future national and international collaboration in analogue research. The objective of this paper is thus to present a review of the numerous past and ongoing analogue science activities conducted at M.A.R.S. and to identify areas where future collaborations will be possible.

2. Physical setting

2.1. Climate

Polar desert conditions characterized by cold, dry winters and cool summers are predominant in the region. The nearest long-term meteorological records are from Eureka, which reveal a mean annual air temperature (MAAT) of −19.7 °C, mean monthly temperatures of −36.1 °C and +5.4 °C for January and July, respectively, and minimum air temperatures frequently reaching −55 °C. Periodic meteorological records are available for Expedition Fjord over the past 47 years, with a more complete record for Colour Lake available since 1992 displaying a MAAT of −15.5 °C (Andersen et al., 2008). Recent data from a broader network of automatic weather stations for the Expedition Fjord area indicate MAAT's as much 2–3 °C cooler than the Colour Lake site depending on setting.

Annual precipitation at Eureka consists of approximately 64 mm total, of which 60% falls as snow (Pollard and Bell, 1998). Though long-term precipitation values are not available for Expedition Fjord, it is assumed that the totals are somewhat greater than those measured at Eureka likely due to a rain shadow effect caused by the mountain range on the eastern Axel Heiberg Island that blocks precipitation systems from reaching Ellesmere Island (Edlund and Alt, 1989). Earlier research near Expedition Fjord suggests a mean annual accumulation of 371 mm of water equivalent on the nearby Mueller ice cap (Muller 1963).

2.2. Geology

Axel Heiberg Island is situated within the Sverdrup Basin (Hoën, 1964; Thorsteinsson and Tozier, 1970), a northeasterly striking sedimentary trough covering an area of approximately 3,13,000 km^2 (Pollard et al., 1999). Near the head of Expedition