HYDROGEOLOGICAL CONSTRAINTS ON GULLY FORMATION AND THE EFFECTS ON MICROBIAL COLONIZATION.

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Introduction: Gully systems on Earth often evolve through multiple mechanisms, such as rainfall and snowmelt [e.g., 1]. However, the dominant process by which a gully is formed—combined with the properties of the substrate through which the gully incises and the level of gully activity—may leave behind telltale morphological signatures [e.g., 2–4]. Gully systems, particularly those in polar environments, provide a relative "oasis" for microbial life, serving as a concentration mechanism for water in limited systems. Microbial organisms tend to be aerially distributed across the globe [5,6]. Thus, many Arctic (or Antarctic) surface and subsurface communities may represent subsets of successful microbes sourced from a metacommunity (e.g., organisms adapted to specific extreme conditions). This can result in marked similarities between environmentally analogous yet distal locales [7]. We propose to explore the idea of globally sourced, but specialized microbial communities, within gully habitats. Specifically, we wish to determine if gullies with similar morphological and soil moisture profiles have similar microbial community compositions, and to explore the metabolic profiles of such communities. This study will also inform where in a gully system sampling should take place, in the event that sampling of gullies becomes a reality for the Mars exploration program. The high likelihood of water being involved in the formation of martian gullies [e.g., 8–9] and recurring slope lineae (RSL) [10]— potentially comprising a continuum of water-related features on martian hillslopes—make these locations some of the best targets for possible life detection.

Methodology: *Gully Activity and Substrate Effects* We propose to explore gully formation (and related biology) at three Mars analogue sites over the course of the next 2–3 summer field seasons: Devon Island and Axel Heiberg Island in Nunavut, Canada and the Westfjords, Iceland. At each of these sites, we propose to collect the following data:

1. Cross sections and long profiles of individual gullies, giving information on substrate properties, activity level and the ability to distinguish between fluvial, debris flow, and dry systems [e.g., 4, 11].
2. Measurements of substrate properties such as grain size and chemical composition to directly relate them to gully morphology.
3. Monitoring of gully activity over the course of multiple seasons using a combination of aerial and ground-based automated imaging and weather stations to correlate activity and its triggers with morphological changes.

Gully morphology can be linked to factors such as active erosion [2–3], differences in erosion processes, and variations in substrate properties such as texture and chemistry [e.g., 4]. Therefore, studying gully morphologies in martian analogue environments on Earth can help us to understand gully formation and substrate material properties on Mars.

Gully Microbiology. Our second focus is to explore the related microbiological differences across different portions of individual gully systems (i.e., alcove, channel, apron) at each of the three field sites, which may elucidate the controls that different gully systems have on microbial community composition. Influences such as substrate type and dissolution, friability, porosity, water retention, and slope angle should all play important roles in ecosystem development.

Samples will be sterilely collected in triplicate from the alcove, channel, and apron. A linear cross-section consisting of three data points will be conducted for sample collection at each of the indicated gully sites; thus, a total of 27 samples at 10 g per sample will be collected per gully. DNA extraction will be conducted *in situ* using extraction methods being integrated into the Search for Extraterrestrial Genomes (SETG) life detection instrument [12–15] (currently under development for future use on Mars missions), as well as using conventional methods. Environmental samples will then be surveyed for microbial diversity using Illumina Mi Seq (v3.) for 16S DNA, which will provide bacterial and archaeal abundances and taxonomy.

Field Locations: *Haughton Impact Structure, Devon Island, Nunavut.* The Haughton Impact Structure is located at 75°22' N, 89°41' W [Fig. 1A]. Its high latitude and elevation (1920 m) results in a polar desert environment, with a mean annual temperature of -16°C and total annual precipitation of ~150 mm, two-thirds of which falls as snow [16]. An approximately 600 m-thick permafrost layer is present [17]. These conditions make Devon an excellent Mars analogue environment. Within the Haughton structure, gullies incise into slopes of the Impact Breccia Unit and the Bay Fjord Formation (Lower Middle Ordovician gypsum-rich limestone) [Fig. 1B]. These gullies are <10,000 years old, post-dating the last major episode of glacial erosion on Devon Island [17]. Present-day gully activity is dominated by melting of surface snow and ice deposits, with minor contributions from melting of 8–10 ka subsurface ice deposits from the last glacial maximum [17]. The morphology of the gullies is very distinct between the Impact Breccia Unit and the Bay Fjord Formation [Fig. 1B]. Observations from the 2013 field season suggest that gullies are generally larger and better-developed within the impact melt breccia, including where the impact breccias overlie uplifted and relatively intact megablocks of the various target lithologies; conversely, smaller less-developed gullies are observed exclusively within uplifted and relatively intact megablocks of the various sedimentary target lithologies.

Axel Heiberg Island, Nunavut. Axel Heiberg (79°26’ N, 90°46’ W) lies within the Sverdrup Basin, consisting of folded/faulted Triassic-Tertiary sedimentary rocks locally intruded by Upper Paleozoic evaporites in the form of salt diapirs [18]. The island hosts a cold polar desert environment, with a mean annual air temperature of -19.7°C and a permafrost thickness of 400–600 m [18]. While Axel Heiberg is perhaps most well-known for its perennial saline springs, some of which have gullies associated with them [e.g., 18], the island hosts many other gullied slopes beyond the immediate vicinities of spring activity [e.g., Fig 2D]. Our study will focus the gullies not associated with the perennial springs. The prevalence of salts within the units of Axel Heiberg act to depress the freezing point of water. This allows the diapir-related springs to flow year-round, even in winter when air temperatures drop as low as -40°C [e.g., 18]. Understanding how the presence of salts might affect gully activity on Axel Heiberg, and in turn how they affect the microbiology, could potentially help to improve models of martian RSL formation, as perchlorate salts appear to be involved in some manner [10].

Gleiðarhjalli, Iceland. Gleiðarhjalli is located in the Westfjords of Iceland, immediately to the northwest of the town of Ísafjörður (66°04’N, 23°07’W) [Fig. 1E]. Gleiðarhjalli is comprised of a 1500 m long, 400–500 m wide bench rising ~450–500 m above the town. The slopes of the bench are covered with a thick layer of talus, with an angle of 25–35°. Up to 20–35 m of sediments cover the bench surface. Regional bedrock consists of Miocene-age jointed basaltic lava flows inter-bedded with lithified sedimentary horizons [19]. The slopes of Gleiðarhjalli host active gullies [Fig. 1F], with at least 110 individual debris flows triggered (typically by snowmelt) over the past 104 years [19]. In winter, snow collects on the flat top of Gleiðarhjalli. In spring, this snow melts and percolates downward through the thick sediment mantle until reaching the underlying impermeable basalt. Meltwater then travels along the basalt layer until it exits the side of Gleiðarhjalli, flowing downhill and triggering debris flows. This is an excellent terrestrial analogue for the melting ground ice formation model for martian gullies [20].

References: [1] Decaulne, A. and Sæmundsson, P. (2007) *Earth Surf. Proc. Land., 32*, 1971–1983. [2] Heede, H. (1974) *U.S. Dept. of Agriculture Forest Service Res. Paper* RM-68, 1–15. [3] Schumm, S. A. et al. (1984) *Water Resources Publications.* [4] Rowntree, K. (1991) *GeoJournal, 23,* 19–27. [5] Prospero et al. (2005) *Aerobiologia*, *21,* 1–19. [6] Smith et al. (2012) *Microb. Ecol., 64,* 973–985. [7] Walker, J. J. and Pace, N. R. (2007) *Ann. Rev. Microbiol*., *61*, 331-347. [8] Malin, M. C. and Edgett, K. S. (2000) *Science, 288,* 2330–2335. [9] Harrison, T. N. et al. (2015) *Icarus, 252,* 236–254. [10] Ojha, L. et al. (2015) *Nat. Geosci., 8,* 829–832. [11] Conway, S. J. et al. (2014) *LPSC 45,* 2438. [12] Lui, C. et al. (2011) *IEEE, 1–12*. [13] Carr, C. E. et al. (2013) *Astrobiology, 13,* 68–78. [14] Carr, C. E. et al. (2013) *Astrobiology, 13,* 560–569. [15] Carr, C. E. et al. (submitted), *IEEE*. [16] Environment Canada (2004), Canada Atmospheric Environment Service. [17] Lee, P. and McKay, C. (2003) *LPSC XXXIV,* 2127. [18] Pollard, W. et al. (1999) *Can. J. Earth Sci.,* 36, 105–120. [19] Decaulne, A. et al. (2005) *Geografiska Annaler, 87A,* 487–500. [20] Costard, F. et al. (2002) *Science, 295,* 110–113.

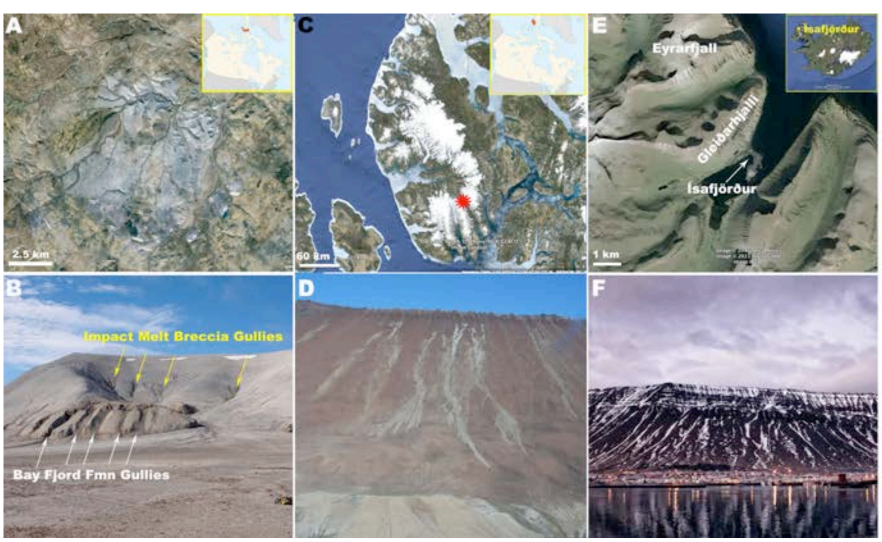

Figure 1. A) Context map of Devon Island (inset) and the Haughton impact structure. Image credit: DigitalGlobe/-Connormah*. **B)** Gullies in the Bay Fjord Formation (sedimentary target material) and the impact melt breccia in the Haughton impact structure. Image credit: L.L. Tornabene. **C)** Context map of Axel Heiberg Island with the location of gullies in D denoted by the red dot. Image credit: DigitalGlobe/Connormah*. **D)** Gullies marked in C. Image credit: G.R. Osinski. **E)** Context map of Iceland and Ísafjörður. Image credit: Digital Globe/USGS. **F)** Snow-filled gullies on the slope of Gleiðarhjalli. The town of Ísafjörður is visible at the base of the slope. Image credit: Isa Bjarki Sigursveinsson*.