THE CANADIAN ARCTIC ARCHIPELAGO: A MARS GLACIAL ANALOGUE SITE. A. Grau Galofre[1], G. R. Osinski[2], A. M. Jellinek[3], S. M. Chartrand[4] [1]School of Earth and Space Exploration, Arizona State University, Tempe, US (agraugal@asu.edu), [2]Department of Earth Sciences/Institute for Earth and Space Exploration, University of Western Ontario, London, Canada, [3]Department of Earth, Ocean, and Atmospheric Science, University of British Columbia, Vancouver, Canada, [4]School of Environmental Science, Simon Fraser University, Vancouver, Canada.

Introduction: Large-scale continental glaciation carved some of the most arresting erosional landscapes on Earth. Ice masses such as Antarctica, Greenland, as well as smaller ice caps on the Canadian high Arctic accumulate meltwater at their bases, which triggers the sliding motion of ice at rates of ~1 to 1000 m/yr. The motion of large glacial ice masses sliding on their bed results in the scouring and quarrying of the landscape, exposing upon ice retreat landforms such as striae, moraines, drumlins, lineations, etc. (Fig. 1).

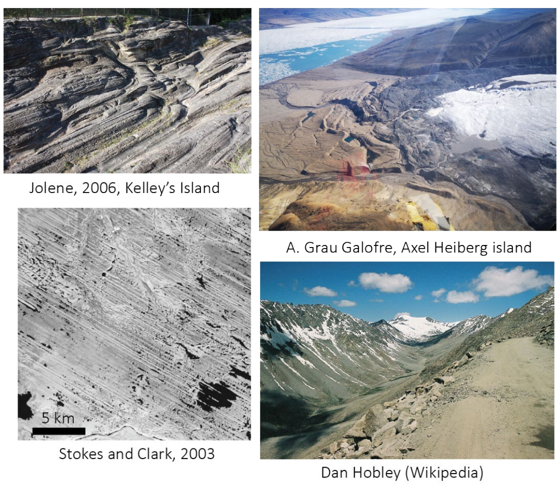

Figure 1: Landscapes eroded by sliding glaciers and ice sheets. Upper left: glacial grooves. Upper right: push moraine. Lower left: mega-scale lineations. Lower right: U-shaped valley.

The near absence of these characteristically large features on Mars has largely dissuaded researchers from considering that widespread, wet-based glaciation occurred on Mars in the past. However, remains of the subglacial drainage system, such as sediment-filled conduits (eskers) found in the Dorsa Argentea Formation [1], the Argyre basin [2], and in localized areas of the northern lowlands [3,4], as well as possible subglacial channels among the Martian valley networks [5], provide evidence that water did exist under Martian ice masses.

The unique landscapes of the Canadian High Arctic provide an excellent terrestrial analogue to help understand the form and role of glacial erosion on Mars, including the effects of glacial drainage. We present observations from high Arctic field campaigns, with a focus on Devon and Axel Heiberg islands, to build understanding of the role of subglacial drainage and the influence of 'low gravity' (using low shear stress as a proxy) on the fingerprints of wet-based glacial erosion.

The Arctic Archipelago as an analogue: A large fraction of the Arctic Archipelago was under Innuitian glaciation until ~8 kyr ago [6, 7]. Although ice was likely cold-based (frozen to the ground) during most of the glaciation [6, 7], Innuitian retreat was wet-based to polythermal (basal ice is at the pressure melting point). Our focus lies on Devon and Axel Heiberg Islands. Both islands currently contain relict ice caps with basal conditions ranging from cold to wet-based: the Devon ice cap [8] and the Stacie and Müller ice caps (Axel Heiberg). These are excellent analogues for Early Mars ice sheets, mostly cold-based with episodes of punctuated melting. Owing to the cold temperatures and low precipitation rates typical of a polar desert climate [9], Arctic Archipelago landscapes have received minimal fluvial modification since ice retreat [6, 10].

Figure 2: Context map showing the location of the Canadian Arctic Archipelago, highlighting our field sites. Southern: Devon Island by the Haughton Impact Structure. Northern: Axel Heiberg Island, southeastern coast.

One of the most important characteristics that make both islands excellent Mars glacial analogues is the relatively small ice sheet thicknesses (~ 700 m). While it is irrelevant to consider the effects of the Earth-Mars difference in gravity when considering liquid water, the dynamics and motion of ice are largely affected by its weight and basal pressure. We argue that scaling ice thickness by a factor three when comparing Earth and Mars glacial analogue sites is an intuitive way to include the effect of gravity. A 2,100 m thick ice sheet on Mars would therefore behave similarly to the ~700 m thick Devon ice cap, owing to their similar downslope shear stresses.

Devon Island: Our field site on Devon Island is located east of the Haughton impact structure, in central-north Devon Island [9, 10] (Fig. 2). The plateaus under study contain no evidence of any of the characteristic morphologies of sliding ice in Fig. 1 [6, 10]. Instead, the landscape contains networks of channels displaying finger-like patterns, oriented towards the direction of Innuitian paleoflow (S-SE to N-NW, Fig. 3). Channels are organized into networks with 7-15 tributaries that are regularly spaced (~ 60-90 m), with cross-sections measuring on the range of 30-50 m [10]. Network interfluves are undissected by subsequent fluvial erosion and their morphology is currently dominated by periglacial processes, as shown in Fig. 3.

The presence of longitudinal profile undulations, absence of inner channels, anastomosing patterns, near-constant cross-sectional width downstream, direction aligned with paleo-ice flow, as well as other characteristics, lead to the interpretation that these channels (Fig. 3) formed subglacially [10].

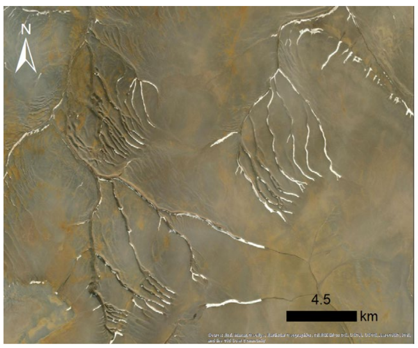

Figure 3: Subglacial channel networks (channel cross-section ~ 50 m) incised on dolomitic bedrock on Devon Island. Image is centered at 75°16'50.63"N, 89° 7'23.71"W. Credit: Maxar/Esri.

The striking morphological similarity of these subglacial channels to a fraction of valley networks on Mars, including planform similarity, presence of longitudinal profile undulations, cross-sectional shape and evolution, lack of inner channels, etc. is suggestive that a fraction of Martian valley networks could have formed by water flowing under ice sheets [5,11].

Axel Heiberg Island: Our field site is located on the south-eastern side of the island, SE from the Stacie ice cap margin. The terrain here consists on flat plateaus dissected by U-shaped glacial valleys, with groups of channel networks similar to the Devon subglacial channels [10] incising the upper flat areas (Fig. 4).

Whereas on Devon Island there was no evidence for glacial sliding, Axel Heiberg shows abundant glacial sliding signs (including moraines as shown in Fig. 1 and 4) largely concentrated along the rugged, mountainous western coast, as well as funneled in steep valleys (Fig. 4, left). The flat inter-glacier plateaus are incised with clusters of channels that flow against the topographic gradient, with little to no signs of sliding or interfluve dissection in between (Fig. 4, right).

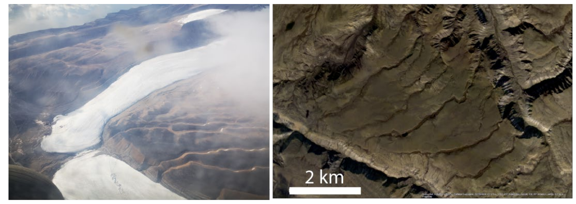

Figure 4: Subglacial channels on sandstone bedrock (left), next to a piedmont style glacier on southern Axel Heiberg Island. (right) Planet imagery of our field site showing regularly spaced subglacial channels (center 87°46'W, 79°17'N).

We find that differences exist between the subglacial channels incised on carbonate bedrock on Devon Island (Fig. 3) and the channels carved into sandstone bedrock of Axel Heiberg (Fig. 4). Sandstone channels have smaller cross-sections (20-30 m) and similar lengths (~ 1 km), and networks show smaller Strahler orders (2-3 in Axel Heiberg, 3-4 in Devon Island). Anastomosing patterns such as those visible in the tributaries in Fig. 3 are also rarer, and instead single channels with higher sinuosity appear with more frequency.

Concluding remarks: The landscapes of the Canadian Arctic Archipelago, in particular those of Devon Island and eastern Axel Heiberg Island, record wet-based glaciations where the glacial drainage system is incised into bedrock, as opposed to the more common signs of glacial sliding erosion in Fig. 1. These landscapes provide valuable insight about Early Mars wet-based glaciation, suggesting that Martian glaciers may have shaped the landscapes beneath them in a fundamentally different manner to what most terrestrial ice sheets did during the last glacial maximum.

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References: [1] Head J. W. and Pratt S. (2001) J*GR: Planets*, *106*(E6). [2] Banks M. E. et al. (2009) *JGR: Planets*, *114*(E9). [3] Butcher, F.E.G. et al. (2017) *JGR: planets 122*(12), 2445-2468. [4] Gallagher C. and Balme M. (2015) *Earth and Planetary Science Letters 431*, 96-109. [5] Grau Galofre et al., (2020). *Nature Geoscience,* [6] Dyke, A. (1999). *Quaternary Science Reviews*, *18*(3), 393-420. [7] Dyke A. et al. (2002) *Quaternary Science Reviews*, *21*(1-3), pp.9-31. [8] Boon S. et al. (2010) *Arctic*, pp.13- 29. [9] Osinski G. et al. (2006) *Geoscience Canada*, *33*(4). [10] Grau Galofre, A. et al. (2018), *The Cryosphere, 12*(4), 1461 [11] Grau Galofre A., et al. *(submitted).*