COMPOSITIONAL, BIOLOGICAL AND SPECTRAL INVESTIGATIONS OF REACTIVE GOSSANS IN THE CANADIAN ARCTIC AS ANALOGUES FOR MARS.

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Introduction: Gossans are one of the few iron-rich aqueous environments known to provide a habitable setting on Earth and potentially on Mars [1]. They form when a sulfide mineral (e.g., pyrite) deposit interacts with permafrost, aerated groundwater, or hydrothermal fluids. This allows for the generation of sulfuric acid and/or ferric sulphate that act as local oxidizing agents, dissolving iron which then reprecipitate as iron oxides (e.g., hematite, goethite). Gossans develop a profile that range from highly oxidized low-pH material at the surface towards more reduced high-pH material at depth [2]. They generally have a "rusty" look from the presence of red-brown-orange iron oxides at the surface. The presence of dissolved iron in gossans can power microbial metabolisms [1]. Texturally preserved biosignatures, such as mineralized microbial filaments, have been identified in gossans thousands to several millions of years old in Spain [3] and in California [4,5], supporting their astrobiological relevance. Although gossans have not yet been identified on Mars, oxidative weathering of sulfides may have played an important role in the planets past and could arguably still be occurring in the subsurface today [6]. Hundreds of gossans have been identified in the Canadian Arctic [7]. Some of these gossans display reactive zones which suggest that reworking still takes place seasonally at a slow pace. Reactive gossans make for excellent natural laboratories for the study of potential gossans as well as sulfates and iron oxides formation on Mars due to their similar environmental settings [8-10].

The main goal of the T-MARS (Terrestrial Mineral Analysis by Remote Sensing, http://tmars.igeomedia.com/en/) project is to better understand the composition, organic content, and spectral properties of reactive gossans as potential analogues for Mars, which will in turn better inform the search for such potential biosignature-preserving formations on Mars. The T-MARS project involves (1) the analysis of orbital remote sensing imagery to refine current geologic map of the area and identify gossans from orbit, (2) the sampling of gossans in the field and the validation of the geologic map, and (3) the spectral, compositional, and biological analysis of the returned samples in the laboratory. The team conducted fieldwork in July 2022 and July 2023 to study reactive gossans in the Expedition Fiord area of Axel Heiberg Island, Nunavut, Canada, in the vicinity of the McGill Arctic Research Station (79°24'55" N 90°44'53" W) (Fig. 1). The T-MARS team comprises members of academia, government, and industry, and allowed to train 10 students as part of the Canadian Space Agency Flights and Fieldwork for the Advancement of Science and Technology funding initiative.

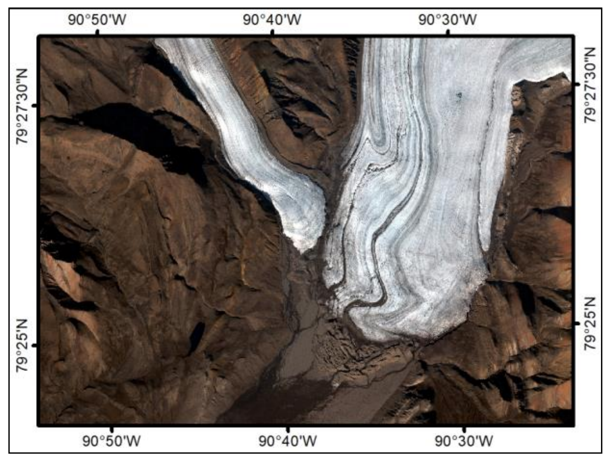

Figure 1. Location of the field area, Expedition Fiord, Axel Heiberg Island (WorldView-2 image). Fieldwork was conducted in the vicinity of the McGill Arctic Research Station (white star). The image is ~12 km wide.

Arctic analogue missions: The Expedition fiord area (~80°N, ~90°W) is located in the Sverdrup basin, a major early Carboniferous to Paleogene depocenter in the Canadian Arctic Islands. The Sverdrup basin developed as a rift basin ~350 Ma and accumulated sediments that were subsequently intruded by mafic sills sourced from the Alpha-Mendeleev mantle plume during the formation of the High Arctic Large Igneous Province (HALIP) ~120-80 Ma. Regional anticlines formed during Paleogene Eurekan orogeny (65-35 Ma) probably detached on autochthonous Carboniferous evaporites, that enabled the formation of 46 evaporitic diapirs now exposed at the surface [11]. Carbonate- and quartz-bearing vein arrays of hydrothermal origin have been identified in the area, suggesting the presence of a paleo-hydrothermal system (avg. ~200 ± 45°C) prior to the current perennial spring activity [12]. Gossans identified in the area are associated with igneous, sedimentary, and evaporitic rocks within the HALIP volcanic terrain [10]. The HALIP lava flows, sills and dykes mixed with evaporite clearly provide the metal cargo required to generate gossans in the area. The Expedition fiord area lives under polar desert conditions characterized by cold, dry winters and cool summers, with a ~500 m thick permafrost (and a ~50 cm thick active layer) [13].

Methodology: *Mapping*. WorldView multispectral, PRISMA hyperspectral, Radarsat-2 and ArcticDEM images were used to refine the existing geologic map of the area [14]. We used a Random Forest classification algorithm [15] and trained it with the existing geologic map as well as the localization of gossans from the 2022 field campaign.

Fieldwork. In 2022, 43 surface samples were collected at 16 different gossan outcrops [16], and 3 gossans were sampled following strict sterile procedures for biological analyses [17]. In 2023 (Fig. 2), 10 vertical cross-sections were dug in gossans to gather information on stratigraphy. A total of 67 additional sterile samples were collected and kept frozen for biological analyses [18].

Figure 2. The T-MARS team walking on "color ridge".

Laboratory analyses. Most samples collected have been analyzed using X-Ray diffraction and X-Ray fluorescence techniques at the Université de Sherbrooke. The spectral signature of samples has also been acquired using an ASD FieldSpec 4 Hi-Res NG instrument (Université de Sherbrooke). Two methods were used for biological analyses. The sterile samples from 2022 were analyzed for lipids. We extracted and quantified n-alkane biomarkers with gas chromatography–mass spectrometry (GC-MS) at McGill University. The sterile samples from 2023 were analyzed using a B&W Tek i-Raman (532 nm) at the University of Winnipeg.

Results: Random Forest classification of the satellite imagery allowed to create a refined geologic map of the area. The same geological units as found in [14] were identified at a refined spatial resolution of 2 meters per pixel (compared to ~30 mpp previously), with the addition of two new classes: gossans and vegetation cover. A similar method could be applied on Mars to detect gossans using CRISM, HiRISE and MOLA images. Laboratory analyses indicate that all samples contain silica, calcium, iron, and sulfur, while some samples contain barium and aluminum. Most samples contain quartz, gypsum, albite, goethite and or barite, while some samples contain jarosite, kaolinite, pyrite, muscovite, and calcite among others [18-19]. The pH of samples ranges between ~3-7. n-alkane analysis of the 2022 samples revealed preserved even-over-odd distribution patterns in short chain n-alkanes that can most likely be attributed to a microbial source. Evidence for n-alkanes from plant sources were also found [17]. A diversity in biosignature patterns was found across samples within each gossan, which suggests that n-alkane presence and/or preservation may vary on a small scale in these environments [17]. Raman analysis of the 2023 samples revealed the presence of graphene, however its biological origin has not been confirmed [18].

Conclusion: The field expeditions and laboratory analyses allowed us to better understand reactive gossans in our field area as potential analogues for Mars. Analyses confirm that reactive gossans provide a habitable setting on Earth and could likely (have) provide(d) one on Mars as well. The presence of n-alkane chemical biosignature in highly acidic and sulfur rich gossans provides evidence that similar formations on Mars can be promising targets for preserved organic biosignatures. Raman spectroscopy can be used to identify carbon-bearing material, although the biologic origin of the carbon cannot be confirmed from Raman alone. Spectral analyses in the ultraviolet and infrared are underway and could potentially provide additional clues. LIBS measurements could also provide valuable information.

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