COMPOSITIONAL ANALAYSIS OF ARCTIC GOSSANS AS MARTIAN ANALOGS USING A SUITE OF SPECTROSCOPIC INSTRUMENTS. G. Belleau-Magnat[1], M. Lemelin[1], E. Cloutis[2] and R. Léveillé[3], [1]Department of applied geomatics, Université de Sherbrooke, Québec, Canada, J1K 2R1 (Gaelle.Belleau-Magnat@usherbrooke.ca, Myriam.Lemelin@usherbrooke.ca), [2]Department of Geography, University of Winnipeg, Manitoba, Canada, R3B 2E9, [3]Department of Earth and Planetary Sciences, McGill University, Montréal, Québec, Canada, H3A 0E8

Introduction: Recently, one of the main goals of space exploration has been to search for signs of life on Mars. The Mars 2020 mission was designed to gather samples that could hold biosignatures and cache them on the Martian surface. The subsequent Mars Sample Return mission will aim to collect these samples and bring them back to Earth for further analysis. While the suite of spectroscopic instruments installed on the Perseverance rover has been used to select the samples, their return in the coming years will be key to confirm the presence of past life forms. However, given the limited quantity of material that can be brought back to Earth, it is essential to prioritize the samples to be collected. In the future, exploration missions will also prioritize acquiring subsurface data because the likelihood of preserving biosignatures is higher beneath the surface. This environment offers protection against solar and cosmic radiation, as well as more stable climatic conditions, particularly in terms of temperature fluctuations. This objective aligns with the ExoMars rover's mission, as it is equipped with a drill specifically designed to probe for biosignatures beneath the Martian surface.

Rovers currently active on Mars are equipped with an array of spectroscopic instruments like PIXL, ChemCam, CheMin, SHERLOC, and SuperCam, able identify a wide range of minerals and organic molecules. Studies have emphasized the effectiveness of rover-like tools for identifying biosignatures, on Earth, in Martian analog environments. The use of such methods makes it possible to simulate the approaches used by rover vehicles to identify potential biosignatures and thus, guide the selection of Martian sampling sites as part of in situ missions. The T-MARS project aims to study Canadian Arctic gossans, iron-rich aqueous environments that could offer a habitable setting for primitive forms of life on Earth and potentially on Mars [1], using a suite of spectroscopic instruments [2].

Gossans are the superficial and oxidized portion of a massive sulfide deposit. They form through the alteration of sulfide-rich bedrock by acidic fluids, and thus contain abundant alteration minerals formed in the presence of liquid water. Different strata can generally be identified using the color of the sediments which is associated to the oxidation level, ranging from grey to dark orange [3]. If present on Mars, these geological formations would be key places to search for biosignatures. Indeed, the presence of biosignatures, such as hydrous ferric oxide filaments, in terrestrial gossans has already been identified [4]. While gossans have not yet been identified on Mars, their presence has been hypothesized [5], due to the similarities of environmental settings and mineralogy (e.g., jarosite, hematite, goethite) between Martian terrain and terrestrial gossans.

When dealing with iron-rich settings like gossans, the methods used to identify minerals and biosignatures generally involve laboratory manipulations that can't be conducted on site. This leads us to consider the possibility of experimenting with a combination of high-resolution and rover-mountable spectroscopic tools to detect biosignatures in Mars-like gossans. The development of such a methodology on Earth would make it possible to apply it to similar terrains on Mars.

The project aims (1) to assess the potential of spectroscopic techniques (VIS-IR reflectance, X-ray diffraction, X-ray fluorescence, Raman spectroscopy) to identify biosignatures within gossans, (2) to characterize the composition of gossan samples using spectral features and (3) to evaluate the vertical compositional variation within a gossan.

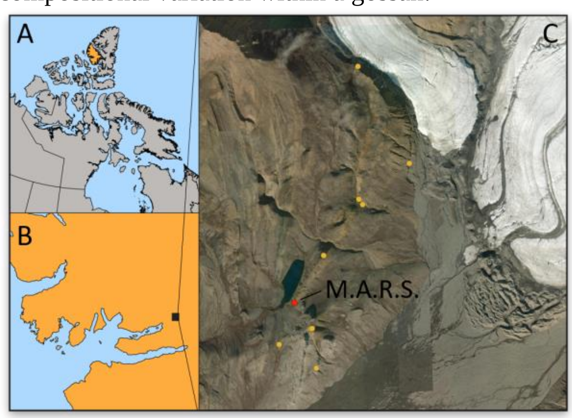

Figure 1: Map showing (A) Axel Heiberg Island, Nunavut (orange), (B) the location of the study area and (C) sampling sites.

Study area: The study area is located on Axel Heiberg Island in Nunavut, Canada (Fig. 1). This island in the Canadian Arctic Archipelago is part of the High Arctic Large Igneous Province (HALIP). The area of interest for this project is Expedition Fiord due to the high number of gossans found in the region [6]. The gossans found in the area occur in sedimentary and evaporitic rocks in association with HALIP igneous rock [7]. A field campaign took place in the summer of 2023 to collect samples. The team base camp was located near M.A.R.S. (the McGill Arctic Research Station, 79°24'55" N 90°44'53" W). Sampling sites were selected within a few kilometers' radius of the research station, accessible by foot.

Methodology:

Field work. Ten vertical cross sections were dug in various gossans to gather information of the near subsurface (Fig. 2), aiming to acquire insights into the stratigraphic variation of minerals and distribution of potential biosignatures. Samples were collected from each identified stratum for laboratory measurements. A total of 67 samples were collected in a sterile manner and kept frozen for laboratory analyses.

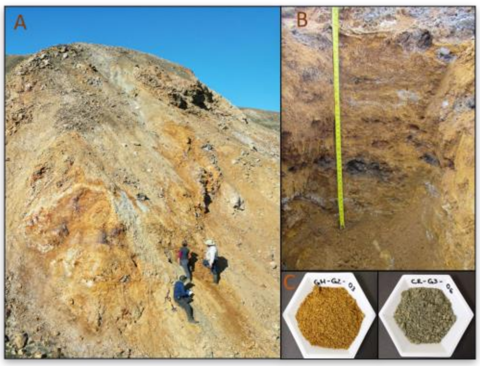

Figure 2: (A) Example of a gossan sampled, (B) cross-section dug in a gossan and (C) example of samples collected in the field.

Laboratory work. The samples were dried and crushed to <45 microns. Subsequently, samples underwent analysis utilizing a suite of spectroscopic instruments. X-ray fluorescence measurements were done using a Panalytical Axios Advanced X-ray spectrometer (Université de Sherbrooke). This enabled the acquisition of elemental composition. Mineral characterization was done by X-ray diffraction using a Bruker D8 advance diffractometer (University of Winnipeg). Additionally, VIS-IR reflectance measurements were acquired using an ASD FieldSpec 4 Hi-Res NG instrument (Université de Sherbrooke) and Raman scattering data were obtained using a B&W Tek i-Raman with a laser of 532 nm (University of Winnipeg) to inform on the mineralogy and detect the presence of potential biosignature.

Data analysis. The spectra were processed and analyzed using a combination of Python libraries and the *Spectragryph* software. In the next month, a literature review and spectral library searches will be used to interpret the spectra. Further spectral characterization will be pursued through data fusion techniques and statistical methodologies, such as principal component analysis (PCA) and linear discriminant analysis (LDA). These approaches yield significant improvements in distinguishing between phases [8] and could serve as an asset in characterizing unfamiliar samples.

Preliminary results: So far, our findings indicate that the samples' elemental composition is dominated by silicium, iron, sulfur, and calcium. This aligns with our expectations since the sampled gossans are found in proximity of evaporite rocks and a mafic sill from the HALIP. Most samples contain gypsum, quartz, albite, and/or calcite. Some samples also contain pyrite, jarosite, goethite, amongst other minerals. Although differences exist among sampling sites, yet minimal variations in mineralogy have been observed between layers, identified based on their distinct colors, within a specific gossan.

Raman spectra obtained from diverse samples exhibit both the G-band (~1600 cm^{-1}) and D-band (~1350 cm^{-1}), associated respectively to the primary mode of graphene and the disordered structure of graphene. These organic carbon features are known to exist in compounds of both biological and abiogenic origins [9]. Differentiating between these origins based solely on the Raman spectra is challenging. Nonetheless, these spectral characteristics remain promising as potential biosignatures. The identification of organic carbon within a sample could advocate for its inclusion in a sample caching effort for a future return mission. However, confirming the biogenic origin would necessitate further analysis upon the sample's return to Earth.

So far, spectroscopic measurements allowed the identification of organic carbon as potential biosignatures within gossans and the characterization of the general mineral composition of the samples. Additional analysis will enhance the description of the samples based on spectral features and allow to evaluate the vertical compositional variation within a gossan.

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