USING TARGET DETECTION ALGORITHMS TO MAP ARCTIC GOSSANS AS ANALOGUES FOR MARS.
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Introduction: Gossans are yellow to orange to red surface deposits formed by the oxidation of sulfide minerals to produce iron oxides and secondary sulfates, creating an acidic environment (Fig. 1) [1]. In the Canadian Arctic, gossans generally range from a few meters to 1-2 km, and are therefore visible on high-resolution satellite imagery [1, 2]. The study of analogue environments on Earth is a critical element of space exploration missions. Although the Canadian Arctic is a different environment than the volcanic terrains on Mars, it provides access to similar geological conditions [3]. Gossans are key geological formations for the study of the Martian surface because of their unique formation processes and mineralogy [2, 4], and their potential to preserve ancient traces of life [5].

While one of the priorities of the scientific community is to document the geological history and processes that have shaped the surface of planetary bodies [6], this study represents a multi-scale analysis of Mars-like environment from outcrop to laboratory to orbital sensors. The objective of this study is to contribute new knowledge on the geology and remote sensing of gossans in the Canadian Arctic as Martian analogues to assess their potential for detection by satellite images using a field-based spectral library of gossans. This study is part of the T-MARS (Terrestrial Mineral Analysis by Remote Sensing) project based at U. de Sherbrooke (http://tmars.igeomedia.com/en/) [7].

Figure 1. Yellow to orange gossan sampled in 2022. The three parts of the outcrop together measure around 15 m at the base. Photo by Sean Clark.

Study areas & Data: This study focuses on central Axel Heiberg Island, Nunavut, Canada. Fieldwork was conducted in the first study area at Expedition Fiord in July 2022. The second study area at East Fiord (located ~60 km to the west) was not visited and is used to validate the remote sensing results. For each study site, a WorldView-2 or 3 satellite image (2 metres per pixel, multispectral) and a PRISMA satellite image (30 metres per pixel, hyperspectral) were used to test target detection algorithms.

Methods: Fieldwork led to 42 surface samples being collected on 17 gossan outcrops in the vicinity of the McGill Arctic Research Station. At the Université de Sherbrooke, all samples were hand-crushed and sieved (< 2 mm) in the laboratory. The VNIR-SWIR reflectance of each sample was measured with an *ASD FieldSpec 4 Hi-Res NG* spectroradiometer, and pH was measured in aqueous solution with a *Mettler Toledo FE20* pH meter. The 42 samples were sorted by colour as a proxy of their oxidation state, from grey (unoxidized) to yellow to orange to dark brown (highly oxidized) [1]. A subset of 12 representative samples based on their colour and spectral characteristics was selected for mineralogical and geochemical analysis using X-Ray diffraction and fluorescence techniques (XRD with a *Panalytical X'Pert Pro MPD* diffractometer and XRF with a *Panalytical Axios Advanced* spectrometer). A spectral library compatible with ENVI software was created from the reflectance measurements of these 12 samples. Using this library, seven target detection algorithms (OSP, ACE, MTMF, TCIMF, MTTCIMF, SAM, SFF) [8] were tested on WorldView-2 and 3 and PRISMA satellite images. The target detection method was then refined with the SFF algorithm, which produced the best results.

Results:

Mineralogy. A qualitative interpretation of the XRD results shows that all 12 representative samples contain quartz (SiO_2), 9 contain gypsum ($CaSO_4 \cdot 2\,H_2O$), and less than half contain goethite ($\alpha FeO(OH)$), jarosite ($KFe_3(SO_4)_2(OH)_6$) or barite ($BaSO_4$). Goethite, andradite and massive sulfur are present only in dark samples (more oxidized), while jarosite, kaolinite, hydroniumjarosite, anorthite, pyrite, anatase and microcline are present only in light samples (less oxidized). Albite, barite, muscovite and calcite are found in both light and dark samples.

Geochemistry. XRF shows that silica (Si), calcium (Ca) and barium (Ba) are the dominant elements in the 12 samples, with significant quantities (> 5 %m) of iron (Fe) and sulfur (S).

pH. The laboratory pH of all the samples ranged from 1.85 to 7.51. Grouping the subset of 12 samples by dominant mineralogy (A-jarosite, B-goethite or C-no iron oxide or hydroxide) shows that pH appears to be related to dominant mineralogy, with group A having more acidic pHs and group C near-neutral pHs.

Target detection. The absorption-feature-based Spectral Feature Fitting algorithm (SFF) worked best in the study areas of Expedition Fiord and East Fiord, to detect gossans that were investigated during fieldwork, as well as others that were not ground truthed during this study. WorldView high-spatial-resolution satellite images are useful to precisely delineate gossans, but they also detect false targets (e.g., red sandstones). PRISMA satellite images with high spectral resolution eliminate most false targets, thanks to their better correspondence with the hyperspectral library used in this project (Fig. 2). A combination of the two types of images is therefore optimal for 1) detecting targets with WorldView and PRISMA imagery, 2) eliminating false targets with PRISMA imagery, and then 3) fine-tuning target contours with WorldView imagery.

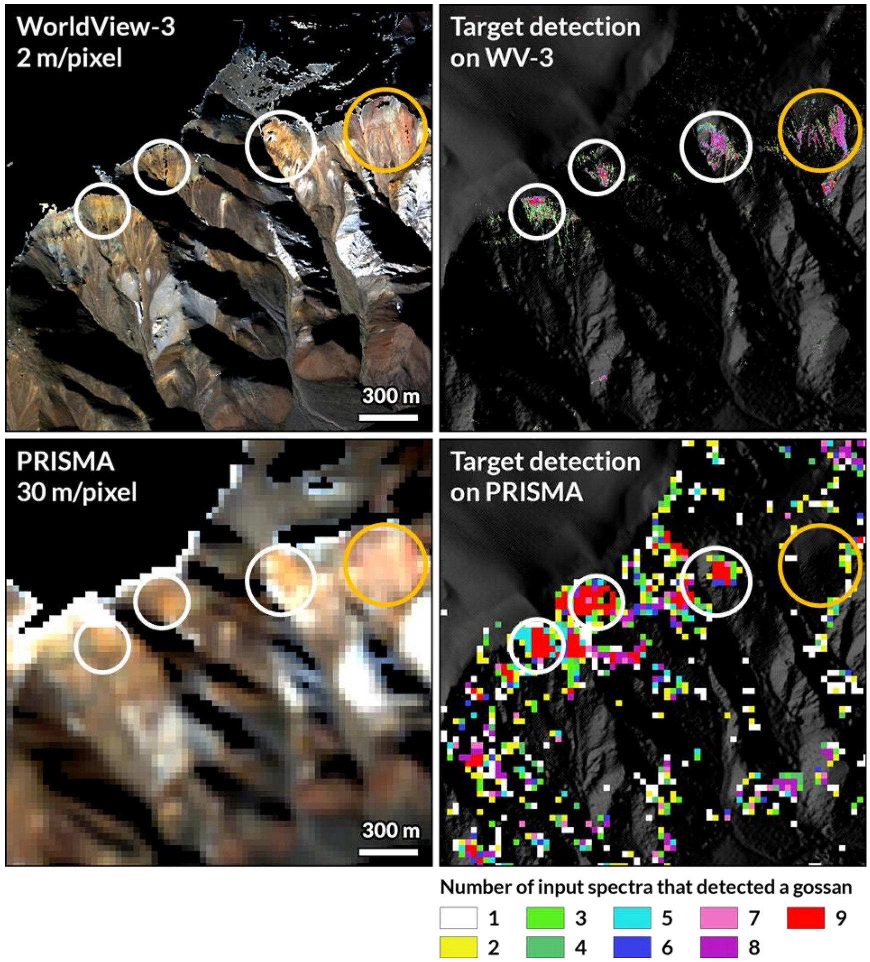

Figure 2. *Left:* True-colour satellite images. *Right:* Target detection images. The pixel colour represents the number of spectra from the spectral library input that have identified this pixel as a gossan. High values are therefore more likely to be gossans. White circles indicate true target detection, while yellow circles indicate false target detection on the WorldView image (note the absence of false detection in the yellow circle on the PRISMA image).

Future work: Before being applied to satellite images of Mars (e.g., CRISM), the gossan remote sensing method developed in this project will need to be applied to other gossan-rich regions in the Canadian Arctic to validate the results and reduce uncertainties. Testing the method on satellite images of Mars in combination with other data sources (e.g., topography and geology) could potentially lead to the localization of areas with properties similar to terrestrial gossans, and therefore prime targets in the search for ancient traces of life.

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