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## INTRODUCTION

The poster presents an overview of the objectives and preliminary results of the Geological Survey of Canada's Arctic Gossans activity over a 2-year period from April 2011 to December 2013. The poster was presented at a GSC manager's retreat held in September 2013 as a means to communicate preliminary results and collect feedback prior to project closure in March 2014.

This report describes the scientific contributions of participants and collaborators in each part of the study: remote predictive mapping, mineralogy, geochemistry and stream sediment sampling for heavy mineral separations and geochemical analyses. The captions for the photographs arranged along the borders of the poster are also included.

## BACKGROUND INFORMATION

Gossans consist of highly weathered Fe-rich soils overlying sulphide-rich materials that can be used as exploration targets for base metal deposits. The Arctic Gossans activity was approved in 2011 as a *proof of concept* to investigate the fate of toxic metals in a permafrost environment. The 3-year activity was funded by the Environmental Impact Assessment project (Northern Environment) of the Environmental Geoscience Program[1], Earth Sciences Sector, Natural Resources Canada.

A long-term objective is to document the fate of toxic trace elements such as As, Cd, Co, Cu, Ni and Pb in the soils and permafrost surrounding gossans. By integrating remote predictive mapping, field work and laboratory protocols, the proposed activity could provide innovative methods to study the dispersal of metals at mine disposal sites in Arctic regions of Canada. Results of the activity contribute in reducing the knowledge gap between the Exploration and Environmental Assessment cycles in the North by involving participants in the Geo-Mapping for Energy and Minerals (GEM) and Environmental Geoscience programs (Fig. 1).

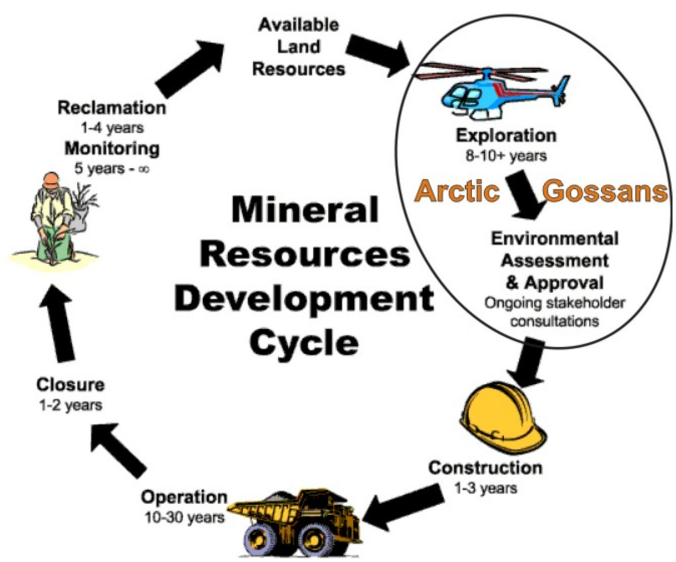


**Figure 1.** Schematic diagram illustrating the mineral exploration cycle, clockwise from top. Reproduced with permission from Sheila Stenzel, Mineral Resources Education Program of BC

[1] https://www.nrcan.gc.ca/earth-sciences/resources/federal-programs/environmental-geoscience/10902

(Pers. Comm., 2013).

Natural sulphide-rich gossans located in the Canadian Arctic constitute first order economic targets, and are often detected using Earth Observation data. A case in point is the High Lake Cu-Zn sulphide deposit in Nunavut, originally discovered in the 1950s by recognition of kilometer-scale gossans. At High Lake, sulphide-rich mounds are located in intensely fractured bedrock or glacial deposits and form local topographic highs (Petch, 2005). The naturally-occurring alteration zones and acidic lakes are clearly visible on Google Earth© (67.37972, -110.84361). The mineralogy and geochemistry of these gossans are indicative of a complex acid rock generation process in which freeze–thaw cycles and chemical weathering ensure a continuous degradation of sulfide-rich rocks, and expose reactive gossanous soil (Elberling and Langdahl, 1998; West et al., 2009). Based on these observations and the results of previous field campaigns in Nunavut (e.g. Williamson et al., 2011), the following scientific hypothesis was formulated:

*Arctic gossans constitute analogues of how mine waste will behave in a permafrost environment. They are natural laboratories that record the processes leading to potentially acid generating mine tailings and mine waste rock in a permafrost environment, such as oxidation, metal recycling, deposition, sorting and burial.*

The following research objectives were proposed as a preamble to test this hypothesis:

1. Locate oxide-sulphide gossans using remote predictive mapping (RPM) techniques.
2. Measure the spectral signatures of surficial materials at key locations to improve the accuracy of remote predictive maps.
3. Map and sample surface materials of alteration zones and host rocks.
4. Determine the stratigraphy, mineralogy, and geochemistry of deposits to document facies and origin.
5. Integrate the results from 1-4 with stream sediment geochemical data.

Participants in the 2011 and 2013 field campaigns are listed below:

1. Victoria Island, Northwest Territories – 2011: M.-C. Williamson (party chief), R.C. Peterson (co-investigator), L. Fenwick (student), J. Froome (student).

2. Axel Heiberg Island, Nunavut – 2013: M.-C. Williamson (party chief), R.J. McNeil (co-investigator), S.J. Day (co-investigator), C.G. Kingsbury (PhD student, Carleton University).

## POSTER CONTENTS

### Remote Predictive Mapping

Field work was carried out in July 2011 to investigate gossans discovered by R. Rainbird and J. Bédard during bedrock mapping on central Victoria Island. The field campaign included four components:

1. Remote predictive mapping of gossans in advance of field work using Landsat-7 images;
2. Applied reflectance spectroscopy of surficial deposits and reference rock samples on site;
3. Soil, mineral and water sampling;
4. *In situ* mineral identification using a portable X-ray diffractometer.

Remote Predictive Mapping (RPM) involves the compilation and interpretation of all available geoscience data sources to produce predictive maps. These datasets guide geologists and serve as first order geological information in advance of mapping, particularly in Canada's North (Harris, 2008; Harris et al., 2012). The small size of most gossans (15 m to less than 1 km in length) requires careful search and analysis through RPM prior to field work. The geology of the Minto Inlier is dominated by the presence of the early Neoproterozoic Shaler Supergroup (Rainbird, 1993) and mafic extrusive and intrusive rocks (Bédard et al., 2012). The poster illustrates the result of using a Principal Component Transform and a 3/1 band ratio to highlight the presence of ferric iron on Landsat7 images. The work was done by P. Behnia as part of a broader study of RPM techniques applied to the Franklin Large Igneous Province exposed in central Victoria Island (Behnia et al., 2012). The technique proved to be of limited use to detect gossans prior to the 2011 field campaign because of 3 factors: (1) low spatial resolution of Landsat images; (2) interference caused by outcrops of red shale and (3) local weathering and alteration of dykes or sills in contact with the host rock. WorldView-2 (WV-2) images acquired by the GEM program in April 2012 proved to be far more effective in detecting gossans because of higher spatial resolution (Froome et al., 2012). The alteration zones at the Gossan Hill locality, for example, are mappable using classification methods applied to WV-2 images. The results are currently under further investigation by the RPM team led by J. Harris.

**Mineralogy**

Gossans enclosed in permafrost are exposed at 2 localities on central Victoria Island. The 2011 field team mapped and sampled gossans from Gossan Hill and Sill Gossan (Peterson and Williamson, 2012; Williamson et al., 2012; Table 1). This section of the poster shows the results of mineralogical and spectral reflectance studies carried out on samples of the Sill Gossan by J.B. Percival (Percival et al., 2012). The stratigraphy of the Sill Gossan is the reverse of what is expected in gossans, i.e. the most sulphide-rich layer is located at the top of the trench whereas the most oxidized layer is located above the contact with permafrost. The infrared spectral analyses measured by a portable spectroradiometer (FieldSpec Pro® ASD, Inc.) are compared with XRD results. Spectral analyses show gypsum and jarosite, and XRD indicates variable amounts of goethite, hematite, pyrite, chlorite, calcite and feldspar.

**Geochemistry**

This section of the poster was prepared by M.-C. Williamson in collaboration with J. Bédard. The Sill Gossan provided spectacular exposure of the gossan underlying a mafic sill and rheomorphic breccia, and the opportunity to inspect the trace element composition of both units. The schematic profile of the field relationships at the Sill Gossan locality show where massive sulphides occur (1) at the basal contact (NT-5) and (2) within the rhemorphic breccia (NT-4). A comparison between the concentrations of transition metals in the gossan and overlying sill and breccia suggests a complex evolution and economic potential warranting further study (Percival and Williamson, 2013; Williamson et al., 2013).

**Stream Sediments**

The Arctic Gossans participants discussed the rationale for field work on Axel Heiberg Island, Nunavut, during two science definition meetings held in March and April 2013. The rationale for additional field work to be conducted in Nunavut included:

1. The greater number of occurrences of gossans identified on Axel Heiberg Island by

previous workers (Williamson et al., 2011; Harrison and Jackson, in press).

2. The value of carrying out an orientations survey that would integrate investigations on gossans with stream sediment, heavy mineral, and stream water geochemical databases (E. Grunsky, Pers. Comm., 2013; McCurdy et al., 2013);
3. The new knowledge to be gained on the prospectivity of both volcanic provinces for Ni-Cu-PGE targets through an integrated approach.
4. The opportunity to test Ganfeld protocols specifically tailored to the sampling of gossans (Shimamura et al., 2008).

This section of the poster was prepared by R. McNeil and S. Day to illustrate the concept of a regional and detailed survey carried out in the study area on Axel Heiberg Island. Additional details can be found in the 2013 field report (Kingsbury et al., 2013, 2014).

## POSTER BORDER PHOTOGRAPHS

The border photographs showcase 7 types of gossans in the two study areas. The year of field work is shown at top right on the first of a series of photographs that record field observations at the same locality.

**Table 1**. Location of gossans on Victoria Island, Northwest Territories (NT) and Axel Heiberg Island (NU).

| Name | Location | Photo # |
|---|---|---|
| Gossan Hill | N 71.36697, W 114.95155 | NT-1, NT-2 |
| Sill Gossan | N 71.24214, W 115.85755 | NT-3 to NT-6 |
| East Fiord 1 | N 79.5006, W 93.21722 | NU-1 |
| East Fiord 2 | N 79.47762, W 93.22075 | NU-2 |
| Dome Gossan | N 79.36596, W 93.53236 | NU-3, NU-4 |
| Ridge Gossan | N 79.37710, W 93.68956 | NU-5, NU-6 |
| Stream Gossan | N 79.37861, W 93.63884 | NU-7, NU-8 |

### NT – Victoria Island, Northwest Territories

**NT-1** View of the Gossan Hill locality looking North. The rust-coloured cap on Gossan Hill preserves high concentrations of loosely-consolidated pyrite ore. Several discrete oxidation halos were mappable along the circumference of the hill. Gossan Hill is a prominent topographic feature that is 400 m long at the base (Peterson et al., in press).

**NT-2** Picks and shovels were used by the field team to dig through the surface of the oxidized cap at Gossan Hill in order to reach permafrost. Blocks of frozen soil were sampled. The extracted pore waters are extremely acidic, with a pH of 2, confirming our working hypothesis that this type of oxide-sulphide gossan can provided an analogue of how mine waste will behave in a permafrost environment. Shown here from left to right are: Prof. Ron Peterson, Lindsay Fenwick, and Jackson Froome.

**NT-3** View of the Sill Gossan locality. The rust-coloured scree slope preserves high concentrations of loosely-consolidated pyrite ore.

**NT-4** The Sill Gossan is a poorly-consolidated gossan associated with a mafic sill in proximity to a fault. The photograph shows sulphide pods in a rheomorphic breccia located at the base of the sill.

**NT-5** GEM-Victoria project leader Jean Bédard discovered the Sill Gossan locality during field mapping. J.B. is shown here at the contact between the mafic sill and underlying rheomorphic breccia.

**NT-6** Type section for the Sill Gossan locality showing an inverted gossan profile where the most oxidized layer occurs at depth. Lisel Currie (GSC Calgary) assisted with field sampling.

**NU – Axel Heiberg Island, Nunavut**

**NU-1** Remnant of a sulphide chimney deposit that outcrops in the North Agate Diapir, East Fiord, Axel Heiberg Island. At this locality, the brecciated 'pipe' material contains up to ~ 25% chalcopyrite by volume. Petrographic analysis indicates that chalcopyrite grains are locally replaced by goethite and cut by quartz veins (Williamson et al., 2011).

**NU-2** Gossan discovered in poorly consolidated quartzose sands of the Isachsen Formation, East Fiord. Prof. Ron Peterson is sampling a gossan that shows reaction in permafrost (Williamson et al., 2011).

**NU-3** Partially preserved sulphide mounds in evaporite diapir. There are several components that include: breccia, silica-rich unit, and acidic soils. Hammer for scale.

**NU-4** Close up of the locality shown on NU-3. Rick McNeil is taking *in situ* measurements of soil acidity.

**NU-5** Gossan exposed on a ridge, overlain by the Walker Island Member, Isachsen Formation. Shovel for scale.

**NU-6** Note the layering in the gossan. Rick McNeil is sampling each layer for geochemical analysis.

**NU-7** Stream exposure of a gossan located near camp. Cole Kingsbury at centre in red coat for scale. Sill at top, black shale at left, rust-coloured gossan at base.

**NU-8** Close up shows the irregular layering at this locality that contrasts the stratigraphy at the location shown on photograph NU-6.

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**Data Sources**:

**Poster** Fig. 8 A. Landsat-7 mosaic: University of Maryland Global Land Cover Facility, Earth Science Data Interface http://www.landcover.org; U.S. Geological Survey (1999-07-22) Landsat ETM+ Scene, WRS-2, Path 053, Row 003, Sioux Falls, SD.