Natural Resources Canada / Ressources naturelles Canada

GEOLOGICAL SURVEY OF CANADA
OPEN FILE 9235

A preliminary inventory of gossans identified in the Canadian Arctic

É. Brassard, M. Lemelin, and M.-C. Williamson

2025

Canada

GEOLOGICAL SURVEY OF CANADA
OPEN FILE 9235

A preliminary inventory of gossans identified in the Canadian Arctic

É. Brassard[1], M. Lemelin[1], and M.-C. Williamson[2]

[1] Université de Sherbrooke, 2500 Boulevard de l'Université, Sherbrooke, Québec, J1K 2R1
[2] Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario, K1A 0E8

2025

Recommended citation
Brassard, É., Lemelin, M., and Williamson, M.-C., 2025. A preliminary inventory of gossans identified in the Canadian Arctic; Geological Survey of Canada, Open File 9235, 1 .zip file. https://doi.org/10.4095/ptdd7ztk2y

Publications in this series have not been edited; they are released as submitted by the author.

ISSN 2816-7155
ISBN 978-0-660-76727-7
Catalogue No. M183-2/9235E-PDF
https://doi.org/10.4095/ptdd7ztk2y

INTRODUCTION

Gossans are intensely oxidized and weathered rocks that occur within the upper and exposed part of an ore deposit or mineral vein (Figure 1). The mineralogy of gossans (e.g., silica, jarosite and goethite) results from the oxidation of sulphides by oxidizing fluids, creating an acidic environment. The alteration of iron-bearing minerals, such as pyrite, leads to the reddish-brown colour of gossans, which makes the deposits easy to map on satellite images (Percival and Williamson, 2016). Gossans are of interest to the mineral exploration industry because of their association with nearby metalliferous deposits (Harris et al., 2015; Percival and Williamson, 2016). They are also of environmental interest because they serve as natural laboratories that mimic some of the processes leading to the formation of acid mine tailings (Peterson et al., 2014; Williamson, 2015). Finally, gossans are considered analogues of potentially similar deposits on Mars (e.g., West et al., 2009; Peterson et al., 2014).

In this report, we present the first inventory of gossans identified in northern Canada, based on 68 sources of information. The goals of the inventory are to (1) provide a list of geographic coordinates for gossans in areas where their occurrence was reported, (2) emphasize the importance of including gossans on geological maps and in field reports, and (3) provide the fundamental information needed to develop new research and mineral exploration projects.

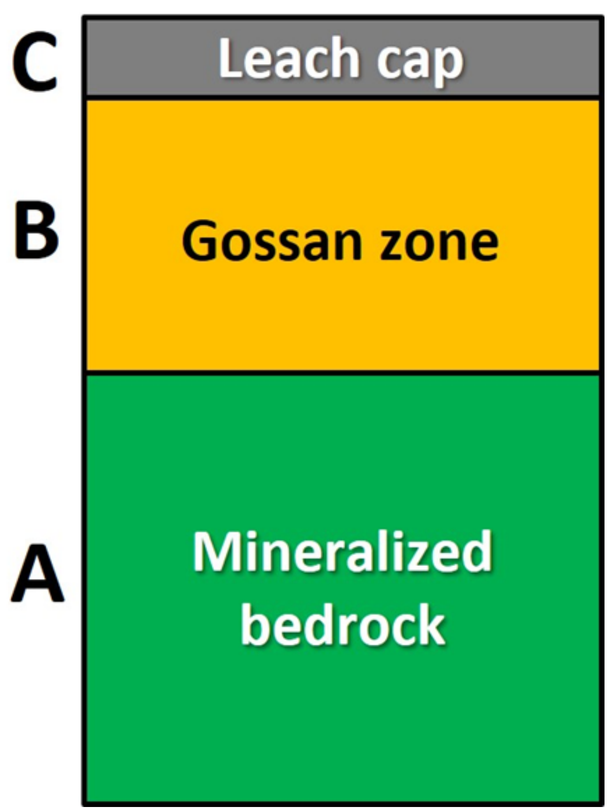

Figure 1. Simplified classic gossan profile. Zone A consists of bedrock or a vein with primary sulphides. Zone B is enriched with Fe-oxides and oxyhydroxides. Zone C is sulphide-depleted and silica-enriched.

PREVIOUS WORK

Gossans are found in many parts of the world, and they are routinely included on geological maps. The deposits are typically linear, lensoid, or circular in outcrop, and their size varies from a few metres to 1-2 kilometres (Percival and Williamson, 2016). Research on gossans mapped in the Canadian Arctic under the Geological Survey of Canada's Environmental Geoscience, GEM-1, GEM-2 and GEM-GeoNorth programs has led to new insights into the geological context, morphology, stratigraphy, mineralogy, and geochemistry of gossans. Study protocols included (1) identifying gossans using satellite imagery (Behnia et al., 2012; Peterson and Williamson, 2012; Williamson et al., 2012; Harris et al., 2014, 2015; Brassard et al., 2022); (2) field mapping, sampling and conducting *in situ* spectral analyses of gossanous soils (Williamson et al., 2011; Froome et al., 2012; Williamson et al., 2013; Williamson, 2015); (3) mineralogical and geochemical studies of reactive gossans in permafrost (Peterson et al., 2014; Percival and Williamson, 2016; Wilton et al., 2017a); and (4) comparative studies of bedrock and stream sediments located near gossans (Williamson et al., 2015; McNeil et al., 2018).

The overarching conclusion from these studies is that the morphology and stratigraphy of gossans are complex (Percival and Williamson, 2017; Williamson, 2020; Bethell et al., 2022). For example, the observed stratigraphy does not always match the classic gossan profile of sulphide-depleted and silica-enriched cap underlain by Fe-oxides and other secondary minerals, as shown in Figure 1 (Percival et al., 2015). Moreover, identifying and mapping gossans using multispectral and hyperspectral optical remotely sensed imagery is an essential prerequisite for fieldwork on gossans in Canada's North (Williamson, 2020). Studies based on geomatics, remote sensing, and applied spectroscopy have confirmed the importance of remote predictive mapping (RPM) techniques (Harris et al., 2015) and deep learning approaches (Clabaut et al., 2020) in mapping gossans and characterizing their composition, with implications for mineral exploration (Williamson et al., 2017, 2021; Wilton et al., 2017b, 2019; Bethell et al., 2023). Studies have also examined reactive gossans in permafrost as terrestrial analogues for Mars (Williamson et al., 2008; Peterson and Williamson, 2012; Peterson et al., 2014; Lemelin et al., 2020a, 2020b, 2024; Aoid et al., 2023; Williamson et al., 2023; Belleau-Magnat et al., 2024; Brassard et al., 2024).

METHODOLOGY

Gossan localities were collected from sources of information grouped in two categories: geological maps published by the Geological Survey of Canada (GSC) and scientific publications (both shown in grey in Figure 2). For both categories, the inventory is limited to the geographical area covered by continuous permafrost in the Canadian Arctic, as mapped by Natural Resources Canada (1995). A total of 574 geological maps were examined in this project, including surficial geology maps, bedrock geology maps, and general geology maps. These geological maps were examined for point, line, or polygon locations showing gossans. A literature review of scientific publications was also conducted to inventory gossans that had been previously studied or identified. These two categories of information led to five methods of integrating point coordinates into the gossan inventory, represented by number 1 to 5 on Figure 2 (shown in colour). Appendix A contains the list of references for the 68 sources of information on gossans used in this inventory.

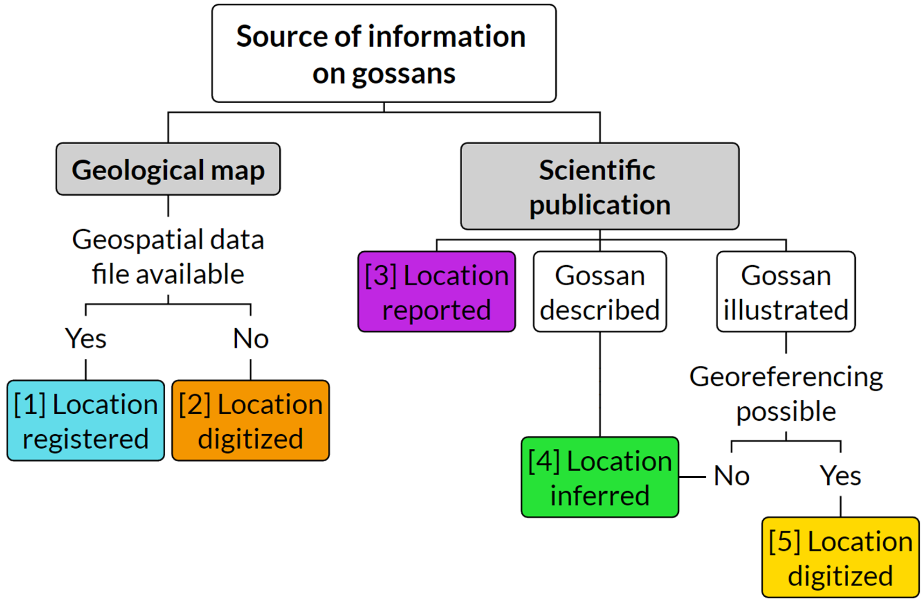

Figure 2. Flow diagram illustrating the methodology used to generate the gossan inventory. The two categories of sources of information are shown in grey and the five methods of integrating data into the inventory are shown in colour keyed to Figure 3.

RESULTS

The inventory takes the form of an Excel database (Appendix B) containing 1,301 entries, where each row represents a gossan exposed in an outcrop in the Canadian Arctic. The columns provide various metadata about these gossans, including their name, location, coordinates, and source of information. This database can be transformed into a geospatial data file (e.g., shapefile) in GIS software (e.g., QGIS). Figure 3 illustrates the results on a map of the study area, where the gossan points in the database are assigned a colour code keyed to the data integration methods numbered from 1 to 5 on Figure 2.

Figure 4 shows the index of the GSC map examined in this study, where the maps are classified according to whether or not they contain gossans. Out of the 574 maps examined to extract gossan locations, 44 contain gossans. These 44 maps include 20 surficial geology maps, 18 bedrock geology maps, 4 general geology maps, and 2 others (mineral deposits compilation and geoscience data compilation). Figure 4 illustrates that at least one map has been examined for the majority of the Canadian Arctic covered by continuous permafrost, with gaps mainly on mainland Nunavut. In several locations, two or more maps were examined, represented by darker colours. In some areas represented in green in Figure 4, a map without gossans (blue) is superimposed with a map containing gossans (orange). Some gossans in the database do not overlap with a map containing gossans, indicating that their locations were extracted from scientific publications ("Journal articles" or "GSC Open File reports" in Appendix A) rather than geological maps.

It is important to note that in some cases, several gossan points in the database may correspond to the same large-scale geological unit, so the total number of database entries may not represent the actual number of independent gossans.

The inventory created in this study aims to be as comprehensive as possible. Geological maps and scientific publications up to April 2020 were meticulously examined to extract gossan locations. However, some geological maps or publications are missing from the inventory. For example, the Northwest Territories and Nunavut mineral occurrence databases (e.g., Nunavut Mineral Project Inventory), as well as prospecting and exploration industry reports, are not included.

Before publication of this Open File, the gossan inventory was used by Clabaut et al. (2020), and portions of the inventory were used in two projects recently completed by M.-C. Williamson and É. Brassard under the GEM-GeoNorth program.

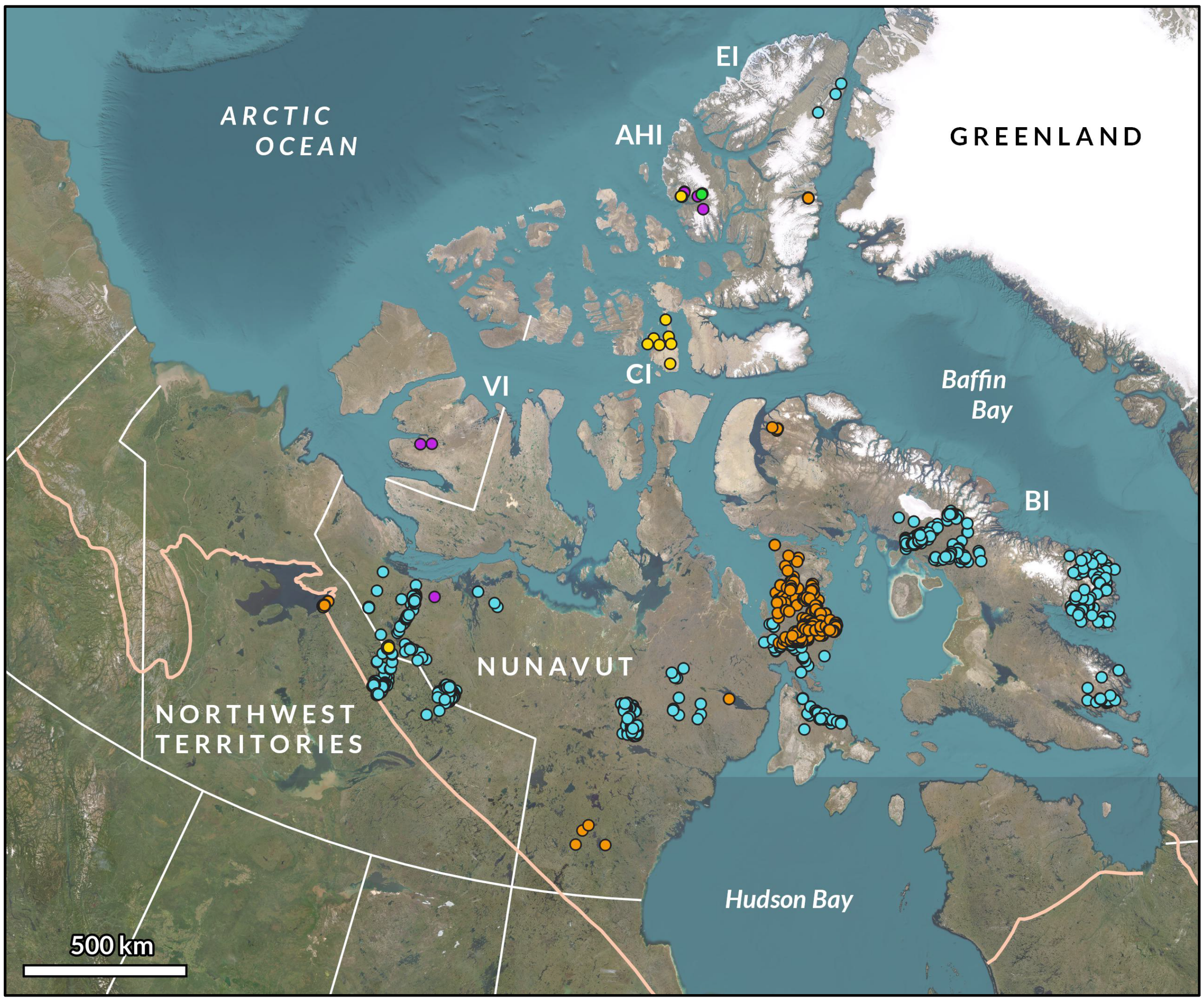

Figure 3. Map of the Canadian Arctic illustrating the gossan database (coloured circles) plotted on the World Imagery basemap (Esri et al., 2024). The limit of continuous permafrost from Natural Resources Canada (1995) is shown in beige. Provincial and territorial boundaries (white lines) are simplified from Statistics Canada (2018). The colour of filled circles is keyed to the data integration methods indicated on Figure 2: Blue is [1] Location registered (n = 943); Orange is [2] Location digitized (n = 328); Purple is [3] Location reported (n = 11); Green is [4] Location inferred (n = 5); Yellow is [5] Location digitized (n = 14). VI, Victoria Island; AHI, Axel Heiberg Island; EI, Ellesmere Island; CI, Cornwallis Island; BI, Baffin Island.

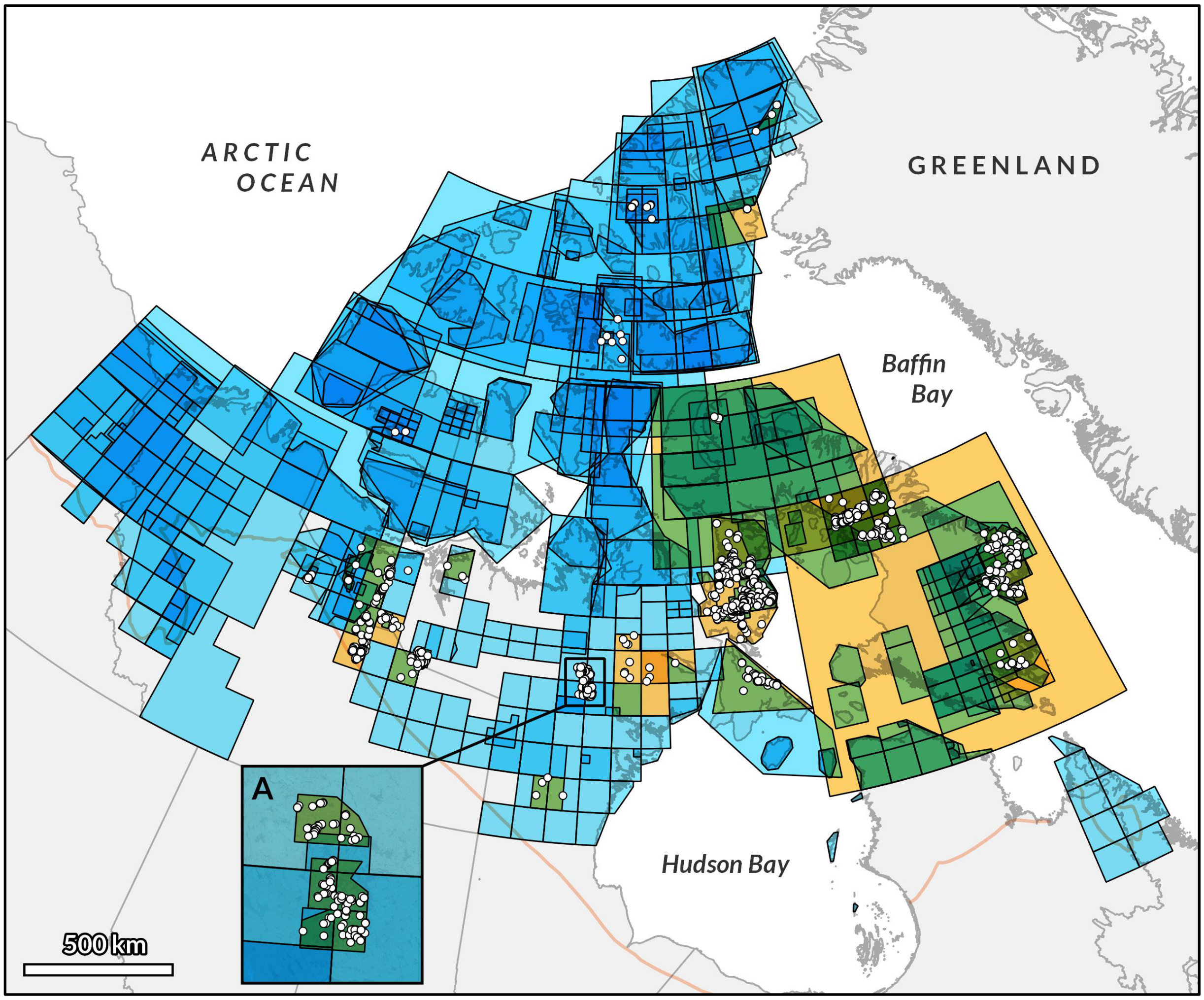

Figure 4. Index of the GSC maps examined in this study showing the maps that contain gossans (orange, n = 44) versus those that do not contain gossans (blue, n = 530). Green areas represent locations where a map without gossans is superimposed with a map containing gossans. The gossan database is shown in white circles. Inset "A" illustrates a region where small maps contain many gossans, while large maps do not. Among the 530 maps that do not contain gossans, only 512 are rendered on the figure based on map size for visibility purposes. The limit of continuous permafrost is the same as Figure 3. The index map shown in this figure was created using the "Surficial geology index map" and the "Bedrock geology index map" layers from Natural Resources Canada (2017, 2024), with modifications and additions.

FUTURE WORK

Figure 5 provides a visual snapshot of the inventoried gossans that have been studied so far, either by fieldwork or remote sensing. We recommend that current and planned geoscientific research projects include mapping geographic locations of gossans, as well as their attitude, host rocks, and other observations collected during fieldwork and geo-mapping. These additional steps will enhance our understanding of Arctic gossans, which has already been significantly advanced by the many studies completed by the Geological Survey of Canada (GSC) and Canadian universities.

To date, many areas in the Canadian Arctic remain unexplored for gossans, and expanding field and remote sensing studies to these regions would help fill existing knowledge gaps. The inventory compiled in this Open File can serve as a foundation for further investigation and more comprehensive mapping of gossan deposits across the Arctic. Continued collaboration between the GSC, academic institutions, and the mineral exploration industry will be essential to advancing research on gossans and their potential for indicating metalliferous deposits, as well as for understanding their environmental significance.

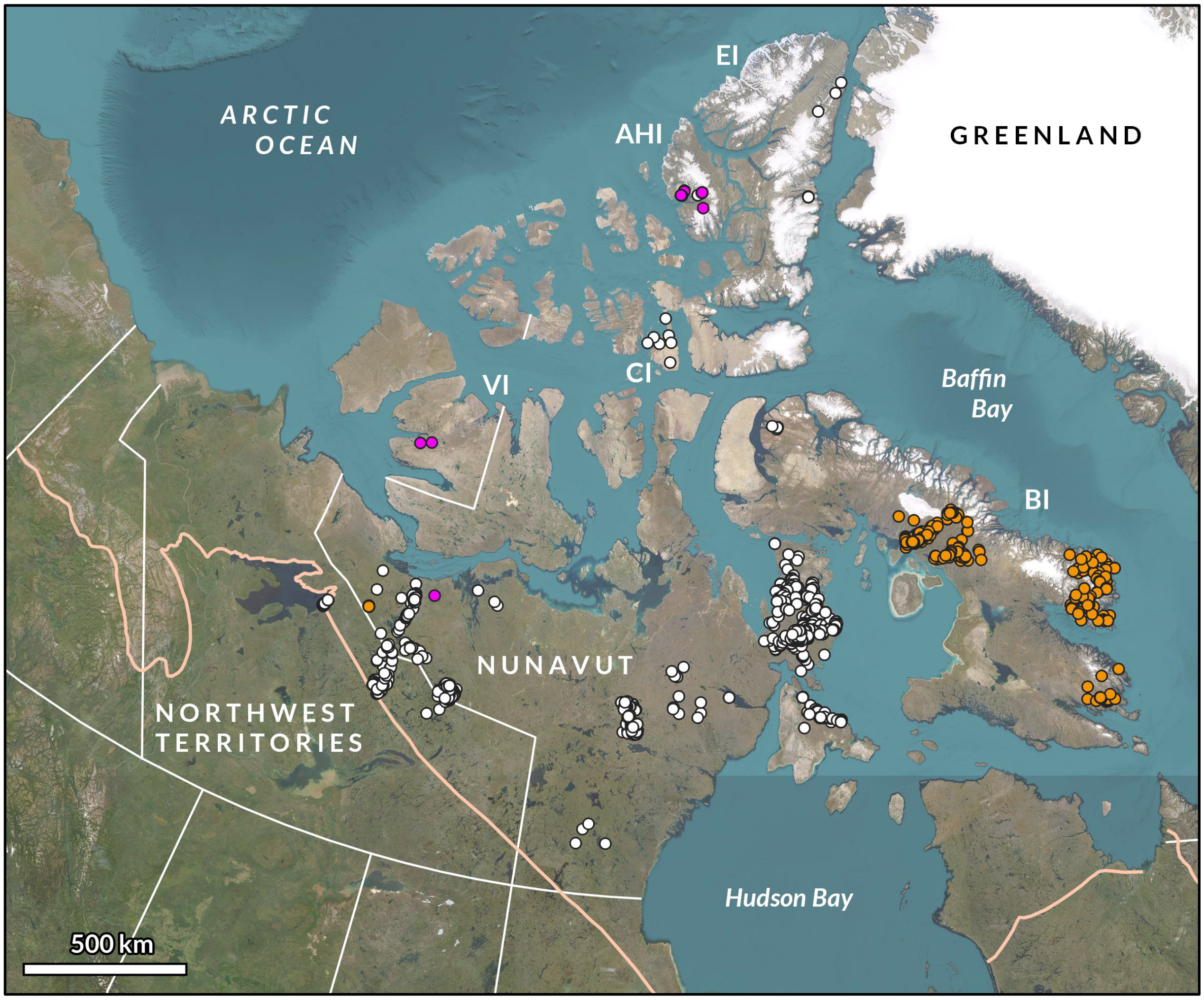

Figure 5. Map of the Canadian Arctic showing the gossans that have been studied so far by fieldwork (pink, n = 16) or remote sensing (orange, n = 382) versus those that have been identified but not studied (white, n = 900). The limit of continuous permafrost, basemap, provincial and territorial boundaries, and island abbreviations are the same as Figure 3.

ACKNOWLEDGEMENTS

This work was part of an undergraduate research internship project completed in 2020 by the first author under the supervision of M. Lemelin with NSERC funding (USRA, Undergraduate Student Research Awards). M.-C. Williamson and É. Brassard completed two projects funded by the GEM-

GeoNorth program using the results of this study. The authors wish to thank Roger Paulen for comments that improved an earlier version of the manuscript.

REFERENCES

Aoid, H., Léveillé, R., Douglas, P., Lemelin, M., Williamson, M-C., 2023. N-Alkane Biosignatures in a High Arctic Mars Analogue Gossan Deposit. ARPHA Conference Abstracts 6: e108199. https://doi.org/10.3897/aca.6.e108199.

Behnia, P., Harris, J.R., Rainbird, R.H., Williamson, M.-C., Sheshpari, M., 2012. Remote predictive mapping of bedrock geology using image classification of LANDSAT and SPOT data, western Minto Inlier, Victoria Island, Northwest Territories, Canada. International Journal of Remote Sensing 33, 6876-6903. https://doi.org/10.1080/01431161.2012.693219

Belleau-Magnat, G., Lemelin, M., Cloutis, E., Léveillé, R.J., 2024. Compositional analysis of Arctic gossans as Martian analogs using a suite of spectroscopic instruments. 55th Lunar and Planetary Science Conference, Abstract no. 1572. https://www.hou.usra.edu/meetings/lpsc2024/pdf/1572.pdf

Bethell, E.M., Brassard, É., Williamson, M.-C., Lemelin, M., 2022. Remote predictive mapping of gossans on Baffin Island, Nunavut – Geomorphic attributes, in: M.-C. Williamson, B.M. Saumur, A. M. Savoie and N. Bingham-Koslowski (eds.), 9th International Conference on Arctic Margins Abstracts Volume, 68. https://doi.org/10.4095/331345

Bethell, E.M., Williamson, M.-C., Brassard, É., 2023. Remote predictive mapping of gossans in the Muskox feeder dyke, Nunavut. GAC-MAC-SGA 2023 Sudbury Meeting Abstracts 46, Geoscience Canada 50, 117.

Brassard, É., Bethell, E.M., Williamson, M.-C., Lemelin, M., 2022. Remote predictive mapping of gossans on Baffin Island, Nunavut – Spectral signatures, in: M.-C. Williamson, B.M. Saumur, A. M. Savoie and N. Bingham-Koslowski (eds.), 9th International Conference on Arctic Margins Abstracts Volume, 66. https://doi.org/10.4095/331345

Brassard, É., Lemelin, M., Williamson, M.-C., 2024. Using target detection algorithms to map Arctic gossans as analogues for Mars. 55th Lunar and Planetary Science Conference, Abstract no. 1635. https://www.hou.usra.edu/meetings/lpsc2024/pdf/1635.pdf

Clabaut, É., Lemelin, M., Germain, M., Williamson, M.-C., Brassard, É., 2020. A deep learning approach to the detection of gossans in the Canadian Arctic. Remote Sensing 12, 3123. https://doi.org/10.3390/rs12193123

Esri, Maxar, Earthstar Geographics, and the GIS User Community, 2024. World Imagery [basemap]. Environmental Systems Research Institute (ESRI). https://www.arcgis.com/home/item.html?id=10df2279f9684e4a9f6a7f08febac2a9

Froome, J., Williamson, M.-C., Peterson, R.C., 2012. Applied Reflectance Spectroscopy and Mineralogical Studies of Gossan Hill, Victoria Island, Northwest Territories, Canada. Geological Association of Canada-Mineralogical Association of Canada Abstracts 35, 46.

Harris, J.R., Williamson, M.C., Percival, J.B., Behnia, P., 2014. Detecting and Mapping Gossans Using Remotely Sensed Data: A Review. Geological Association of Canada-Mineralogical Association of Canada, Abstracts 37, 114.

Harris, J.R, Williamson, M.-C., Percival, J.B., Behnia, P., Macleod, R., 2015. Detecting and mapping gossans using remotely sensed data, in: Environmental and economic significance of gossans; Williamson, M.-C. (ed.); Geological Survey of Canada, Open File 7718, 3-13. https://doi.org/10.4095/296574

Lemelin, M., Williamson, M.-C., Léveillé, R.J., 2020a. Reactive gossans in permafrost as indicators of ancient hydrothermal activity on Mars. AGU 2020 (online), Abstract no. 728264.

Lemelin, M., Williamson, M.-C., Léveillé, R.J., Doucet, F.R., 2020b. Comparative Geologic Mapping of Gossans on Earth and on Mars. 51st Lunar and Planetary Science Conference, Abstract no. 2656. https://www.hou.usra.edu/meetings/lpsc2020/pdf/2656.pdf

Lemelin, M., Williamson, M.-C., Léveillé, R., Aoid, H., Belleau-Magnat, G., Brassard, É., Lachance, S., Marion, C.L., Clark, S., Castillo-Guimond, L., 2024. Composition, biological and spectral investigations of reactive gossans in the Canadian Arctic as analogues for Mars. 55th Lunar and Planetary Science Conference, Abstract no. 1561. https://www.hou.usra.edu/meetings/lpsc2024/pdf/1561.pdf

McNeil, R.J., Day, S.J.A., Williamson, M.-C., 2018. Geochemical, mineralogical and indicator-mineral data for stream silt sediment, water and heavy-mineral concentrates, East Fiord area, western Axel Heiberg Island, Nunavut (part of NTS 59-G); Geological Survey of Canada, Open File 7779, 30 p. https://doi.org/10.4095/306606

Natural Resources Canada, 1995. Permafrost, Atlas of Canada, 5th Edition [cartographic document]. Government of Canada, Ontario. https://open.canada.ca/data/en/dataset/d1e2048b-ccff-5852-aaa5-b861bd55c367

Natural Resources Canada, 2017. Surficial geology index map [feature layer]. Government of Canada, Ontario. https://open.canada.ca/data/en/dataset/cebc283f-bae1-4eae-a91f-a26480cd4e4a

Natural Resources Canada, 2024. Bedrock geology index map [feature layer]. Government of Canada, Ontario. https://open.canada.ca/data/en/dataset/5887347a-f64d-c5e6-b983-8cace169313b

Percival, J.B., and Williamson, M.-C., 2016. Mineralogy and spectral signature of reactive gossans, Victoria Island, NT, Canada. Applied Clay Science 119P2, 431-440. http://dx.doi.org/10.1016/j.clay.2015.05.026

Percival, J.B., and Williamson, M.-C., 2017. Morphology, mineralogy and geochemistry of gossans, Axel Heiberg Island, Nunavut, in: GEM 2 High Arctic Large Igneous Province (HALIP) activity workshop report; Williamson, M.-C. (ed.); Geological Survey of Canada, Open File 8151, 22-26. https://doi.org/10.4095/300706

Percival, J.B., Williamson, M.-C., McNeil, R.J., Day, S.J.A., Harris, J.R., 2015. Morphology of gossans in the Canadian Arctic Islands, in: Environmental and economic significance of gossans; Williamson, M.-C. (ed.); Geological Survey of Canada, Open File 7718, 58-73. https://doi.org/10.4095/296581

Peterson, R.C., and Williamson, M.-C., 2012. Gossan Hill, Victoria Island, Northwest Territories: An analogue for mine waste reactions within permafrost and mineral persistence in the sub-surface of Mars. Geological Association of Canada-Mineralogical Association of Canada Abstracts 35, 105.

Peterson, R.C., Williamson, M.-C., Rainbird, R.H., 2014. Gossan Hill, Victoria Island, Northwest Territories: An analogue for mine waste reactions within permafrost and implication for the sub-surface of Mars. Earth and Planetary Science Letters 44, 88- 93. https://doi.org/10.1016/j.epsl.2014.05.010

Statistics Canada, 2018. Province and territory 2016 [feature layer]. Government of Canada, Ontario. https://open.canada.ca/data/en/dataset/9ab4c77c-409e-4f78-984a-f540a1900511

West, L., McGown, D.J., Onstott, T.C., Morris, R.V., Suchecki, P., Pratt, L.M., 2009. High Lake gossan deposit: An Arctic analogue for ancient Martian surficial processes? Planetary and Space Science 57, 1302–1311. https://doi.org/10.1016/j.pss.2009.05.011

Williamson, M.-C., Germain, M., Lavoie, D., Gulick, V.C., 2008. Comparative geoscientific and geomatic analysis of hydrothermal zones in volcanic terrain on Earth and Mars. 39th Lunar and Planetary Science Conference, Abstract no. 2188. https://www.lpi.usra.edu/meetings/lpsc2008/pdf/2188.pdf

Williamson, M.-C., Smyth, H.R., Peterson, R.C., Lavoie, D., 2011. Comparative geological studies of volcanic terrain on Mars: Examples from the Isachsen Formation, Axel Heiberg Island, Canadian High Arctic, in: Garry, W.B. and Bleacher, J.E. (eds.), Analogs for Planetary Exploration: Geological Society of America Special Paper 483, pp. 249–261. https://doi.org/10.1130/2011.2483(16)

Williamson, M.-C., Harris, J., Percival, J.B., Bédard, J., Froome, J., Peterson, R.C., Rainbird, R., 2012. Occurrence and environmental impact of oxide-sulphide gossans and their reactive zones in permafrost, in: Watson, D.M. (compiler), 40th Annual Yellowknife Geoscience Forum Abstracts, Abstracts Volume 2012, 51-52.

Williamson, M.-C., Harris, J., Percival, J.B., McNeil, R.J., Day, S.J., Kingsbury, C.G., Grunsky, E., McCurdy, M., Shepherd, J., Buller, G., 2013. Regional geochemical mapping of oxide-sulphide gossans and their reactive zones in permafrost, Canadian Arctic Archipelago. Geological Society of America Annual Meeting & Exposition, Abstract no. 391-12.

Williamson, M.-C., (ed.), 2015. Environmental and Economic Significance of Gossans; Geological Survey of Canada, Open File 7718, 100 p. https://doi.org/10.4095/296571

Williamson, M.-C., McNeil, R.J., Day, S.J.A, McCurdy, M.W., Rainbird, R.H., Grunsky, E.C., 2015. Environmental impact of gossans revealed by orientation surveys for base metals in the Canadian Arctic Islands, in: Environmental and Economic Significance of Gossans; Williamson, M.-C. (ed.); Geological Survey of Canada, Open File 7718, 74-84. https://doi.org/10.4095/296571

Williamson, M.-C., Harrison, J.C., McNeil, R.J. 2017. Origin of base metal showings associated with evaporite diapirs and HALIP intrusive rocks, in: GEM 2 High Arctic Large Igneous Province (HALIP) activity workshop report; Williamson, M.-C. (ed.); Geological Survey of Canada, Open File 8151, 51-55. https://doi.org/10.4095/300713

Williamson, M.-C., 2020. Reactive Gossans in permafrost: Case studies from the Canadian Arctic Islands. Geological Society of America Abstracts with Programs 52, Abstract no. 32-6. http://doi.org/10.1130/abs/2020AM-357919

Williamson, M.-C., Abraham, A.C., McNeil, R.J., Day, S.A., Saumur, B.M., Percival, J.B., Wilton, D.H.C., Lemelin, M., 2021. Beyond the red dot: Mapping gossans as vectors to hydrothermal deposits in the High Arctic Large Igneous Province. Geological Association of Canada-Mineralogical Association of Canada, Abstracts 44, 242.

Williamson, M.-C., Lemelin, M., Marion, C., Saumur, B.M., 2023. Breccias and gossans associated with shallow igneous intrusions on Earth and Mars: Case studies at two analogue sites in the Canadian Arctic Islands. 54th Lunar and Planetary Science Conference, Abstract no. 2525. https://www.hou.usra.edu/meetings/lpsc2023/pdf/2525.pdf

Wilton, D.H.C., Williamson, M.-C., McNeil, R.J., 2017a. Quantitative MLA-SEM modal mineralogy of gossans and stream sediments in the HALIP: implications for economic potential, in: GEM 2 High Arctic Large Igneous Province (HALIP) activity workshop report; Williamson, M.-C. (ed.); Geological Survey of Canada, Open File 8151, 45-50. https://doi.org/10.4095/300712

Wilton, D.H.C., Williamson, M.-C., McNeil, R.J., 2017b. Quantitative mineralogy of gossans and stream sediments in the High Arctic Large Igneous Province (HALIP) via SEM-MLA: Implications for economic potential. Geological Association of Canada-Mineralogical Association of Canada Abstracts 40, 421.

Wilton, D.H.C., Saumur, B.M., George, A., Williamson, M.-C., 2019. Enigmatic massive sulphide mineralization in the High Arctic Large Igneous Province, Nunavut, Canada. Canadian Journal of Earth Sciences 56, 790–801. https://dx.doi.org/10.1139/cjes-2018-0156