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Gossan Hill, Victoria Island, Northwest Territories: An analogue for mine waste reactions within permafrost and implication for the subsurface mineralogy of Mars

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ABSTRACT

Gossan Hill is located within the Minto Inlier in central Victoria Island, Northwest Territories (N 71.36697°, W 114.95155°). A study of the mineralogical associations and geological setting of this deposit indicates that it is an arrested hydrothermal system frozen in permafrost. From above, the hill stands out because of the topographic relief of 75 m and the orange-brown color of the surficial material. The surface of the hill is marked by areas of concentric color zonation up to 3 m across, with light gray centers surrounded by a yellow–orange ring that is surrounded by an orange–brown color that covers the rest of the surface of the hill. Trenches dug into these areas reveal that the central zone contains quartz and pyrite +/− native sulfur in a loose aggregate of sand-sized grains. This central area is surrounded by a zone dominated by gypsum and quartz with some jarosite. Beyond this, the surrounding surface consists of quartz, hematite, and amorphous iron oxides. The radial arrangement of the mineral assemblage indicates an increase in oxidation of sulfur from the center outward. Analysis of isotopic composition of the sulfur indicates the source of sulfur could be the underlying strata. The hill is underlain by inter-bedded carbonate and sulfate-evaporite sedimentary rocks of the Kilian formation in the upper part of the Neoproterozoic Shaler Super group. The sedimentary rocks were intruded by diabase sills of the 720 Ma Franklin igneous event, which crop out 2 km to the south of Gossan Hill. The soft friable nature of the deposit and the topographic relief of the hill indicate a post-glacial (Pleistocene) age of formation. Permafrost has maintained the disequilibrium mineral assemblage since the cessation of fluid flow. Extraction of the permafrost ice from the central zone yields a liquid with a pH of 2.3. The observed long-term persistence of pyrite encased within the acidic permafrost indicates that oxidation and dissolution reactions common in mine waste are slowed, if not stopped, in such an environment. The predicted rise of Arctic temperatures will cause the active layer to move deeper and result in the release of the acidic solutions frozen in the permafrost. Water ice or frozen CO_2 just below the Martian surface would also preserve such mineral disequilibrium for very long periods of time. No region exists on Earth where ice has existed continuously for millions of years, but the Gossan Hill deposit is an excellent terrestrial analogue. On Mars, the subsurface ice may be very old. Ancient reactive Martian mineral assemblages and the fluids associated with them will reflect conditions that existed in the past.

1. Introduction

Mineral deposits are becoming more accessible in Canada's north as the extent of summer sea ice decreases and the possibility of maritime shipping increases. The development of mineral resources creates environmental impacts and the details of the reactions that are involved in these processes need to be fully understood. The reaction of sulfide minerals exposed by mining operations has been the subject of much research at a variety of locations (Nordstrom, 2011) but very little study has been made about mineral reactions in permafrost regions (Elberling and Langdahl, 1998). An issue of concern in environmental assessments of future mine sites in the North is the conditions under which trace metals released from the oxidation of sulfides are concentrated, contained, remobilized, and dissolved in permafrost (Hornbrook and Jonasson, 1971; Dawson and Morin, 1996). The mineralogy

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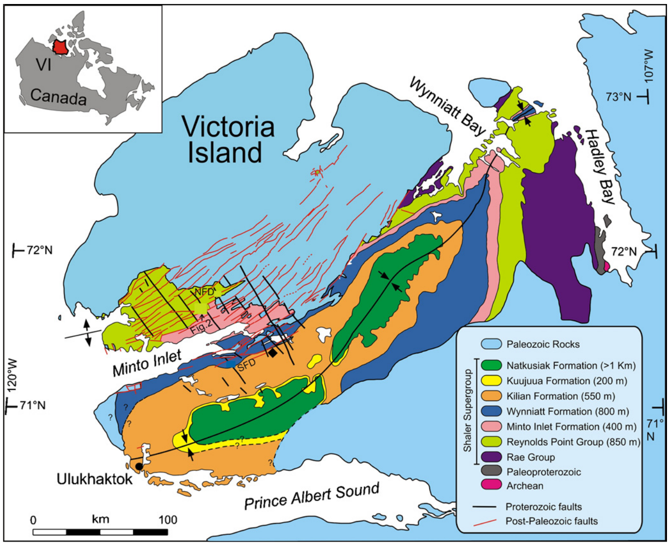

Fig. 1. A geological map of the Minto Inlier, central Victoria Island, Northwest Territories. The location of Gossan Hill is indicated by the diamond symbol.

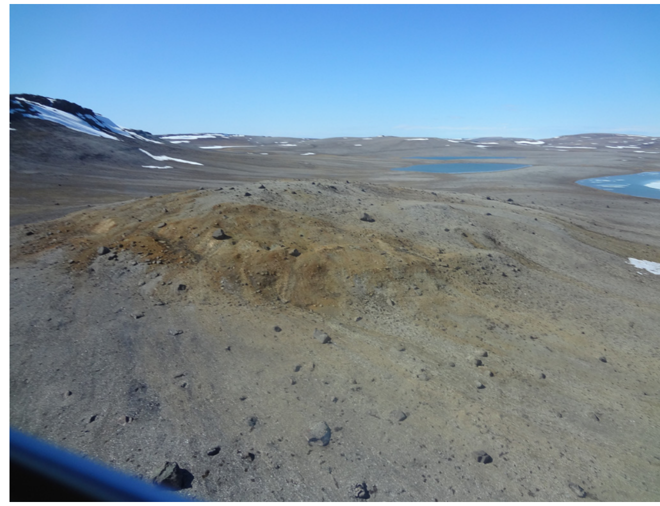

Fig. 2. Gossan Hill as seen from the air looking west. The hill consists of loosely consolidated material and large blocks of assorted rock types. The hill rises approximately 75 m above the surrounding tundra and has a diameter of 1200 m. The surface of the upper part of the hill has areas of concentric changes in color from white to yellow to brown coloration caused by concentrations of gypsum, jarosite, and ferric hydroxides, respectively. Large blocks of rock are present on the surface of the hill that cannot be explained solely by a hot spring origin of the hill. Field of view is approximately 400 m. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Fig. 3. Color zoning of the surface of Gossan Hill. The white center is composed of gypsum and quartz. This is surrounded by a yellow area consisting of gypsum, quartz, and jarosite. This yellow area is then surrounded by a brown area consisting of quartz and poorly crystalline ferric hydroxide material including goethite. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

and geochemistry of natural gossans provide a unique long-term view into the complex acid rock generation process during freeze–thaw cycles that is not possible to duplicate with short-term laboratory experiments. In this paper, we report the detailed mapping and sampling of a natural gossan deposit to determine the stratigraphy, mineralogy, and geochemistry. Material was sampled at and below the surface where the dissolution of sulfides within the active layer of permafrost can be observed. This forms the first part of a larger collaborative project that also includes the identification of gossan zones on Victoria Island using available LANDSAT satellite imagery as well as making "ground truth" observations during fieldwork by collecting and analyzing surface materials that control spectral signatures. The intended long-term outcome of the entire project is to contribute to the evaluation of the risks of environmental impact related to mineral development in Canada's North.

2. Location and geological setting of Gossan Hill

The Gossan Hill deposit is located within the Minto Inlier at (N 71.36697°, W 114.9515°) on central Victoria Island, Northwest Territories, Canada. The deposit was discovered by R. Rainbird in 1987 during his PhD studies of the area (Fig. 1). The Minto Inlier comprises sedimentary rocks of the early Neoproterozoic Shaler Supergroup (Thorsteinsson and Tozer, 1962; Young, 1981; Rainbird, 1993; Rainbird et al., 1996) and mafic extrusive and intrusive rocks of the ca. 720 Ma Franklin igneous event (Heaman et al., 1992; Hulbert et al., 2005). The Shaler Supergroup is dominated by shallow-water carbonate rocks, with subordinate mudrocks, sandstones and evaporites, representing a shallow-water intracontinental basin (Amundsen Basin) developed within the supercontinent Rodinia (Young, 1981; Rainbird et al., 1996). The Shaler Supergroup is capped by the Natkusiak Formation which is a thick flood basalt (up to 1 km preserved thickness) (Thorsteinsson and Tozer, 1962; Baragar, 1976; Jefferson et al., 1985; Dupuy et al., 1995).

The hill rises approximately 75 m above the plane of the surrounding tundra and is distinctive because of the orange and brown color of the surface (Fig. 2). The host rocks are in the Kilian Formation, a $\sim$500 m-thick succession of shallow marine carbonate rocks, sulfate evaporite rocks and subordinate siltstone, and quartz arenite. The diameter of the hill, as defined by the break in slope from the surrounding tundra, is 1200 m. The hill is covered with unsorted rubble consisting of large blocks of diverse rock types which include fragments of the fine-grained siltstones of the Kilian Formation. No outcrop of bedrock was observed on the hill. The deposit forms a small isolated hill of limited height compared to the cliffs formed by the Franklin gabbro sills that crop out 2 km to the south. Although outcrop is scarce in the immediate area of Gossan Hill, new 1:50,000 geological mapping of NTS 87H/05 places it in the lower evaporite-carbonate member of the Kilian Formation, just above limestones of the upper carbonate member of the Wynniatt Formation (Rainbird et al., 2013).

3. Field observations

Several portable instruments were used to investigate the mineralogy of the surface of the deposit as well as samples obtained