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GEOLOGICAL SURVEY OF CANADA
OPEN FILE 8719

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Canada

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

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The Readme file provides the complete list of files and sub-directories containing the datasets:

FOREWORD

The Geo-mapping for Energy and Minerals (GEM) program laid down the foundation for sustainable economic development in the North. The Program provided modern public geoscience that will set the stage for long-term decision making related to investment in responsible resource development. Geoscience knowledge produced by GEM supports evidence-based exploration for new energy and mineral resources and enables northern communities to make informed decisions about their land, economy and society. Building upon the success of its first five-years, GEM was renewed until 2020 to continue the production of new, publicly available, regional-scale geoscience knowledge on Canada's North.

The Cretaceous volcanic terrain exposed in the east-central Sverdrup Basin, known as the Canadian portion of the High Arctic Large Igneous Province (HALIP), was the focus of an activity approved for the second phase of NRCan's Geo-Mapping for Energy and Minerals Program (Western Arctic Region Project). The main objective of the HALIP Activity was to test the hypothesis that areas on Axel Heiberg Island and northern Ellesmere Island have high potential for Ni-Cu-PGE deposits (**Figure 1**). Specific activities included (1) detailed mapping of sills and dykes not included in current 1:250 000 scale geological maps; (2) the collection of samples for mineralogical and geochemical studies; (3) the development of geological models and a regional stratigraphic and structural framework to identify volcanic-intrusive complexes that could host nickel sulphide deposits; and (4) the transfer of data, maps and knowledge to decision-makers and stakeholders in northern communities, government, and industry.

Mineral Prospectivity of the HALIP

The HALIP consists of volcanic rocks and associated intrusive rocks of Cretaceous age occurring in the Canadian Arctic Archipelago, Franz Josef Land (Russia), Svalbard (Norway) and the Barents Sea (Ernst, 2014). Portions of the HALIP occurring in Canada's Arctic Archipelago (**Figure 2**) are prospective for magmatic Ni-Cu-PGE (platinum group element) mineralization, based on geochemical evidence (Jowitt et al., 2014) and similarities to world class mining camps such as Norils'k-Talnakh, Russia (Williamson and MacRae, 2015).

This report contains databases of geochemical and mineralogical data acquired during regional stream sediment surveys carried out on central Axel Heiberg Island. The datasets provide additional constraints to existing studies on the regional-scale mineral prospectivity of the HALIP on Axel Heiberg Island and northern Ellesmere Island (Saumur et al., 2016; McNeil et al., 2017, 2018; Williamson et al., 2016, 2017; Wilton et al., 2017, 2019).

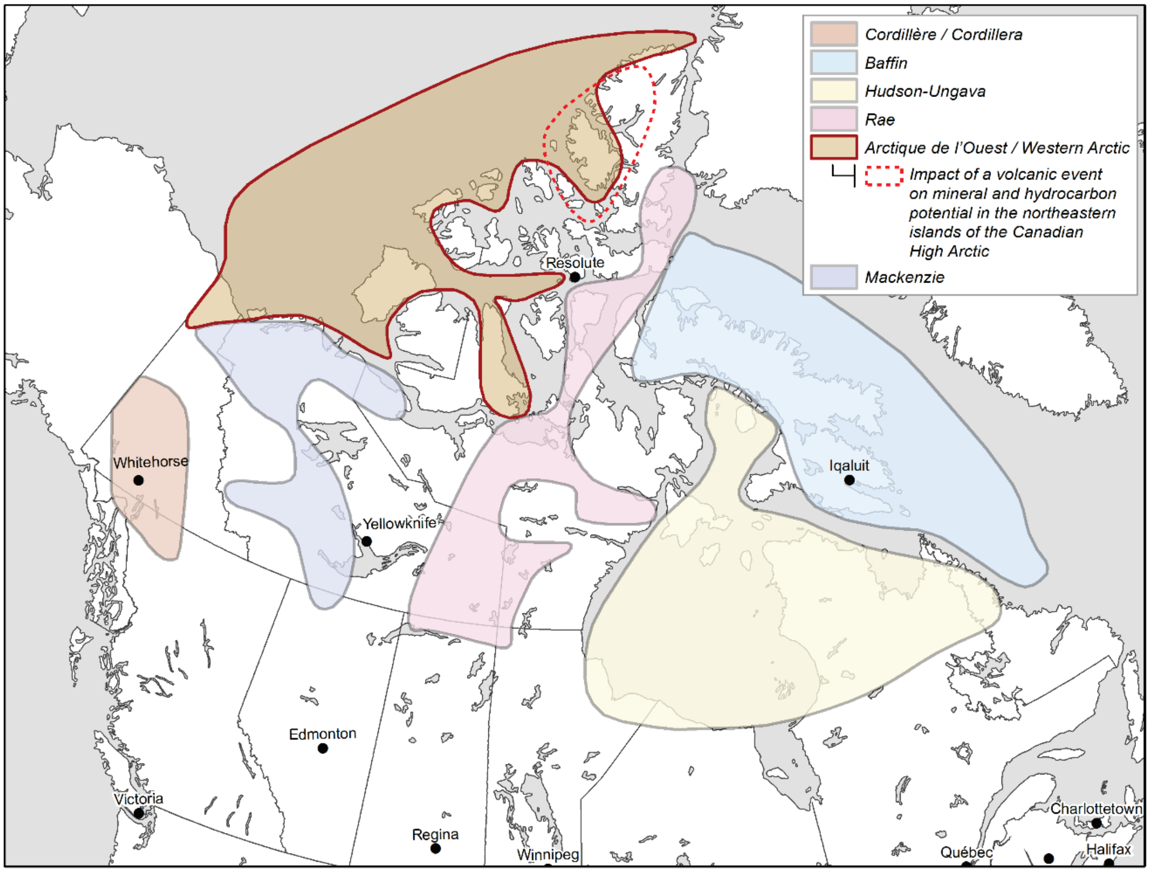


Figure 1. Regional map of the GEM 2 activities (2014-2017) showing the area covered by the Western Arctic Region Project. The area covered by the HALIP activity (red dotted line) includes Axel Heiberg Island and northern Ellesmere Islands, Nunavut.

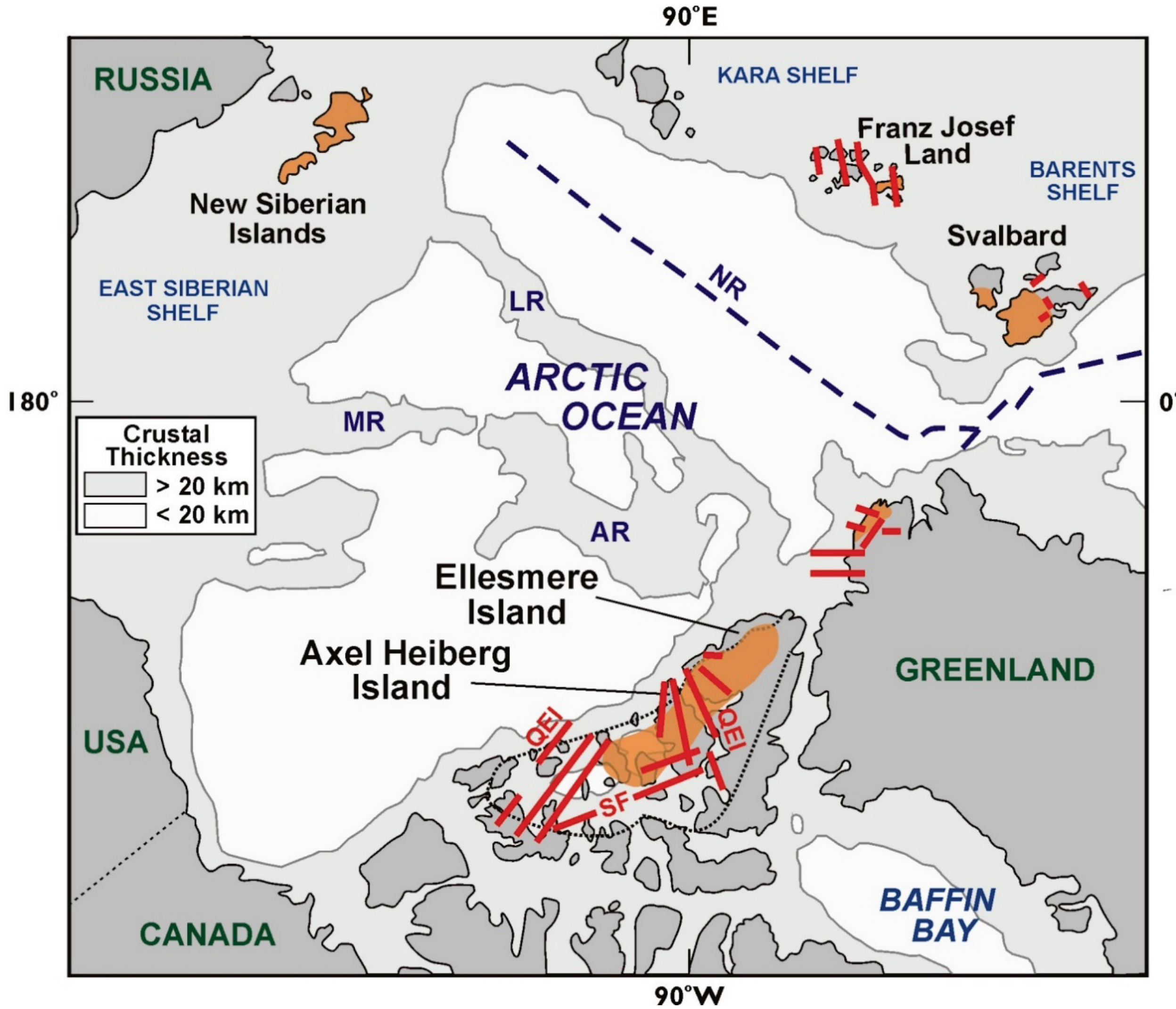


Figure 2. Map of the circum-Arctic region (from Williamson, 2015). Areas in orange show the general distribution of exposures of the HALIP (after Jowitt et al., 2014). The extent of the intrusive rocks in the Canadian HALIP matches the outline of the Sverdrup Basin shown by a black dotted line. The simplified pattern of the Queen Elizabeth Island dyke swarm (QEI) and the Surprise Fiord dyke swarm (SF) are illustrated by thick red lines (after Buchan and Ernst, 2006). The crustal thickness of the submarine portion of the High Arctic is after Alvey et al. (2008). The crustal structure highlights the geometry of submarine features of the Arctic Ocean: AR – Alpha Ridge; MR – Mendeleev Ridge; LR – Lomonosov Ridge; NR – Nansen Ridge.

ABSTRACT

We report the results of a stream sediment and water study that was carried out as part of the GEM2 Western Arctic Region Project's HALIP activity in Canada's Arctic Islands. The survey was complementary to bedrock mapping in three areas of central Axel Heiberg Island, Nunavut. The objective of the study was to use regional drainage sediment and water to evaluate the mineral potential in these areas. This activity was part of a larger project, undertaken to evaluate mineral potential of the High Arctic Large Igneous Province (HALIP). It also expanded the drainage coverage from the original study conducted in 2013 in the East Fiord area of western Axel Heiberg Island that provided promising results.

Stream silt and water samples were collected from 72 sites. At 32 of these sites, bulk sediment samples were collected for the heavy mineral concentrate (HMC) component in the <2 mm fraction. Silt and water samples were analysed by ICP-MS and ICP-ES as well as for carbon content. Water samples were also submitted for alkalinity, anions by ion-chromatography and *in situ* physico-chemical measurements. Bulk sediment samples were processed and the resulting HMC samples were picked for indicator minerals of various deposit types. Sampling and analytical techniques followed established NGR methodologies, ensuring data compatibility with the NGR database. Although limited in scope, the study yielded a second drainage dataset for the northernmost part of Nunavut.

Stream sediment surveys carried out in the Lightfoot River and Geodetic Hills areas of Axel Heiberg Island do not show any clear evidence of mineralization. The most promising geochemical and mineral data resulted from a survey in the Expedition Fiord area. We highlight some of the results in a pilot mineralogical study of the Heavy Mineral Concentrates (HMC) using the MLA-SEM technique. A comparison of data for the East Fiord (2013) and Expedition Fiord (2015) areas highlights the presence of sulphides in the HMCs as well as other similarities in the geological setting. Notable differences in water, silt and HMC composition between the two areas are not well understood, and require further research on (1) the age, composition and volume of mafic intrusions in the two areas; (2) the extent of mechanical mixing between igneous and evaporite rocks in proximity to diapirs; (3) compositional variations in streams with distance from glaciers; and (4) the role of conduits for fluid flow in the wall-and-basin evaporite structures in the Strand Fiord-Expedition Fiord area.

INTRODUCTION

Stream sediment and water sampling programs such as the Geological Survey of Canada's (GSC) National Geochemical Reconnaissance (NGR) program (Friske, 1991) were established to acquire systematic mineralogical and geochemical data as indicators of regional mineral prospectivity. The principal assumption in orientation surveys of this type is that the sediment chemistry and mineralogy reflect the bedrock and surficial geology of the catchment area upstream from the sample site. In the absence of mineralization, the sediment geochemistry reflects background element concentrations typical of the source bedrock. The presence of mineralized bedrock will be revealed by locally elevated metal and/or indicator mineral contents in sediment. Heavy mineral concentrates are typically composed of key indicator minerals that indicate the presence of a specific type of mineralization, alteration or lithology (McClenaghan, 2005).

Axel Heiberg Island is located within the High Arctic Large Igneous Province (HALIP), which is comprised of widespread mafic Cretaceous intrusive and extrusive igneous rocks emplaced in the Sverdrup Basin, a rift basin that contains a thick succession of marine and non-marine clastic rocks (Embry and Beauchamp, 2019; **Figure 3**). On Axel Heiberg Island, all the lava flows analysed to date are tholeiitic. However, the composition of sills and dykes in subvolcanic complexes varies from mafic to intermediate (e.g. Williamson et al., 2016).

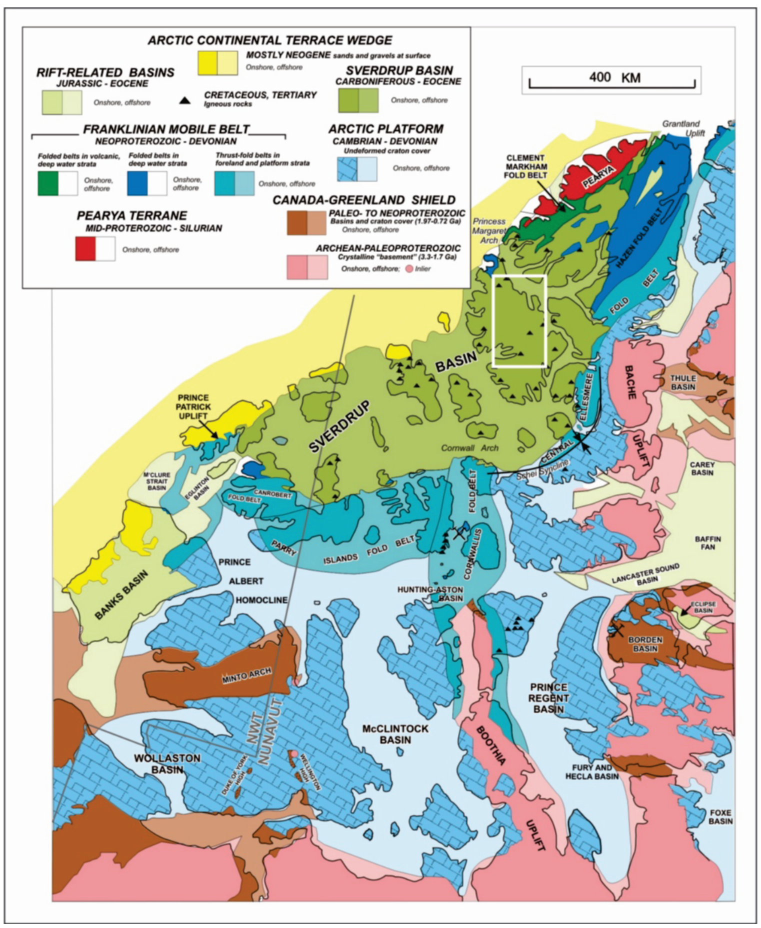


Figure 3. Simplified geological map of the Canadian Arctic Islands showing the location of the study area on Axel Heiberg Island (contributed by J.C. Harrison).

In this report, we present the results of a regional-scale drainage survey carried out in areas with distinct geological settings: **Area 1**, Lightfoot River; **Area 2**, Geodetic Hills; and **Area 3**, Expedition Fiord (**Figure 4**). We also include preliminary results of a quantitative mineralogical study of the Heavy Mineral Concentrates (HMC) from the survey in Area 3. The MLA-SEM technique provides a quantitative measurement of mineral phases present in each type of sample. The overall objective was to expand the initial 2013 study by acquiring several regional datasets that could then be integrated with the results of new bedrock mapping and geochemical analysis of HALIP igneous rocks from other parts of Axel Heiberg Island and western Ellesmere Island.

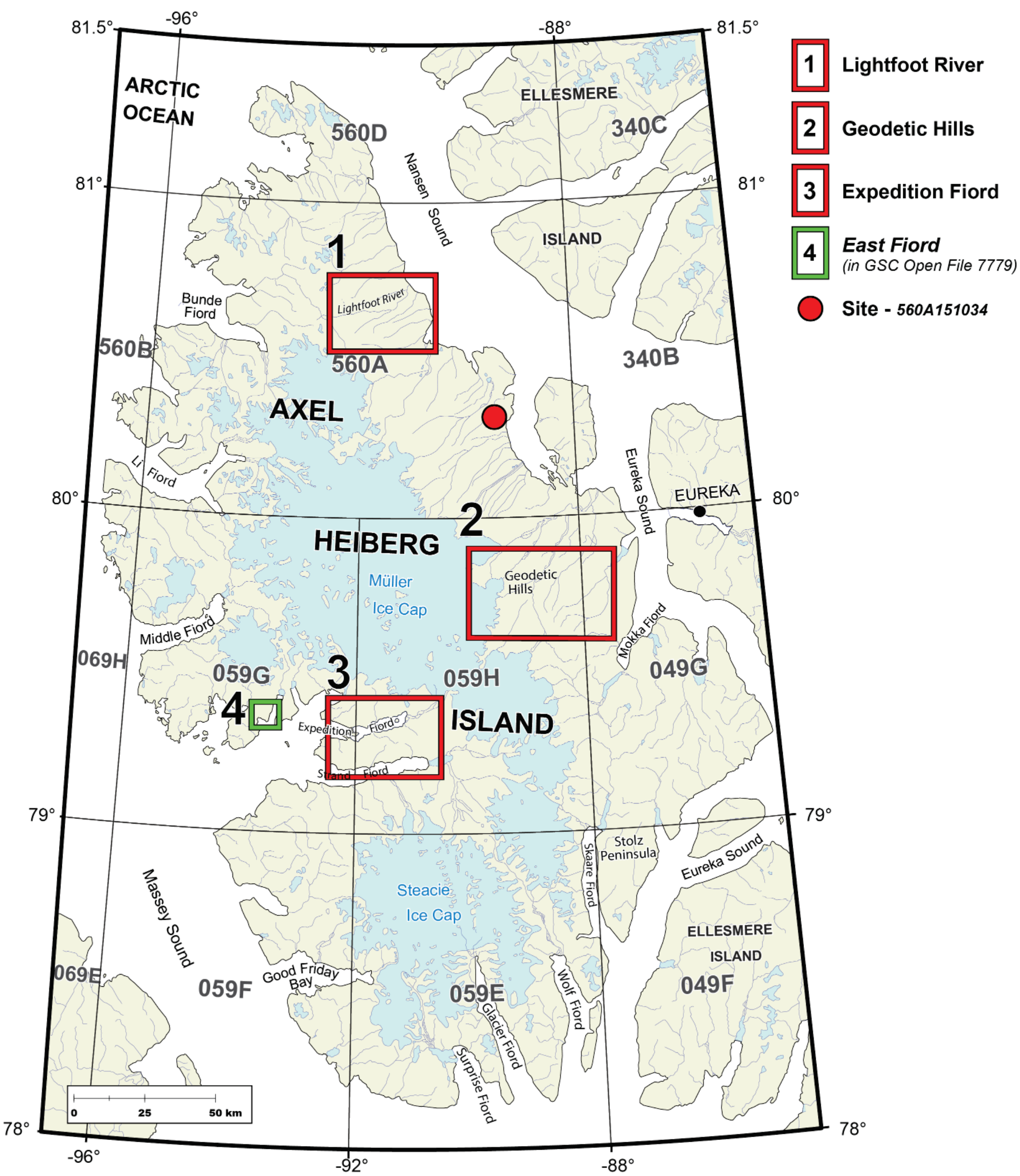


Figure 4. Map of Axel Heiberg Island, Nunavut, with the survey areas highlighted in red for data presented in this report as well as a red circle for site 560A_2015_1034 that did not fit in an area.

SAMPLING LOCALITIES

The rationale for selecting the three areas described below was to carry out additional geochemical surveys in as wide a variety of geological settings as possible.

Area 1: Lightfoot River Dyke Swarm

Previous studies of the Lightfoot River dyke swarm suggest that the dykes consist of gabbroic igneous rocks emplaced during the first phase of the HALIP at ~ 125 Ma (Jowitt et al., 2014). The area was selected for the drainage survey to investigate the potential input of widespread HALIP intrusions on the mineralogy and geochemistry of sediments and waters (**Figure 5**) without the influence and structural controls associated with evaporite structures. A total of 28 sites were sampled, covering an area of approximately 600 km^2. Additional bulk sediment samples for the recovery of heavy minerals were acquired at 12 sites (**Figure 6, 7**).

Area 2: Geodetic Hills

The Geodetic Hills area is characterized by the presence of evaporites in diapirs sourced from the Carboniferous Otto Fiord Formation. Evaporite structures intrude Cretaceous to Triassic sedimentary successions and are intersected by multiple fault structures such as the major NW-SE trending Stolz Thrust Fault (**Figure 8**). The rationale for selecting Geodetic Hills for a drainage survey was to investigate the potential combined effect(s) of evaporite diapirs and faulting on mineral prospectivity. A total of 16 sites, covering an area of approximately 300 km^2, were targeted for the collection of sediment and water samples of which nine sites have an additional bulk sediment sample for the recovery of heavy minerals.

Area 3: Expedition Fiord

The bedrock geology of the Strand Fiord-Expedition Fiord region is more complex than in the other two survey areas. The geology of this area is dominated by Triassic through Lower Cretaceous mudrocks and coarse clastic rocks intruded by HALIP volcanic and intrusive rocks, and overlain by Late Cretaceous through Eocene sediments (**Figure 9**). Regional anticlines, which formed during the Paleogene Eurekan Orogeny, trend north on a regular ~20 km wavelength and probably detach from the autochthonous evaporates sourced in the Carboniferous Otto Fiord Formation (Harrison and Jackson, 2011). A massive sulphide occurrence first reported by industry geologists (Goddard, 2010) and recently investigated by Williamson et al. (2016) and Wilton et. al. (2019) is located near Between Lake in the White Glacier Basin (1018, 1019, **Figure 9**). The rationale for selecting this area for a drainage survey was to evaluate base metal prospectivity on a regional scale in an area characterized by complex geology including evaporites and igneous rock and structures. A total of 27 sites covering an area of approximately 650 km^2 were visited for the collection of sediment and water samples of which 10 sites have an additional bulk sediment sample extracted for the recovery of heavy minerals.

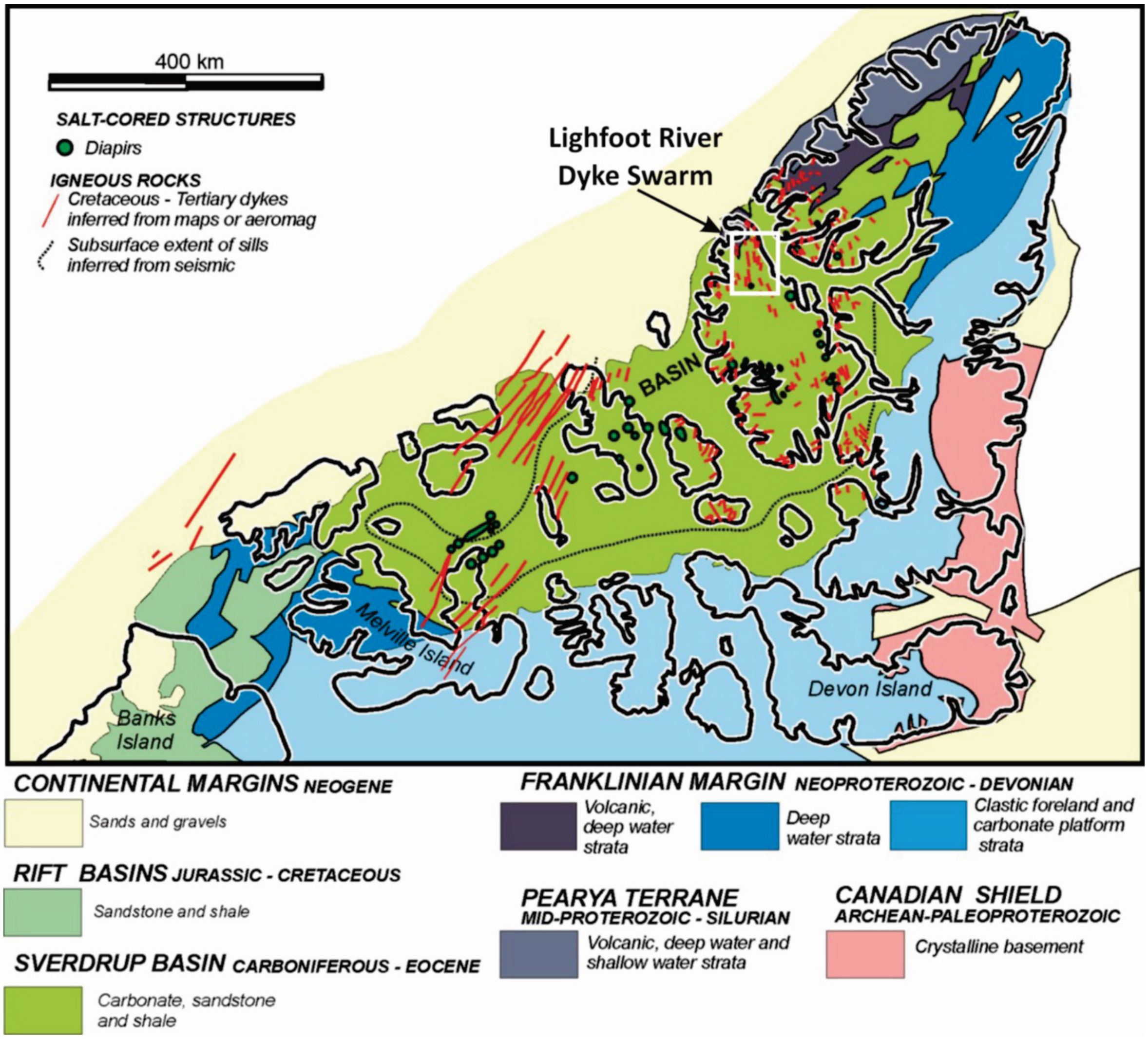


Figure 5. Simplified geological map of the Sverdrup Basin in the Canadian Arctic Islands. The map illustrates the location of the Lightfoot River Area as a component of regional-scale HALIP dykes. Modified from Saumur et al. (2016).

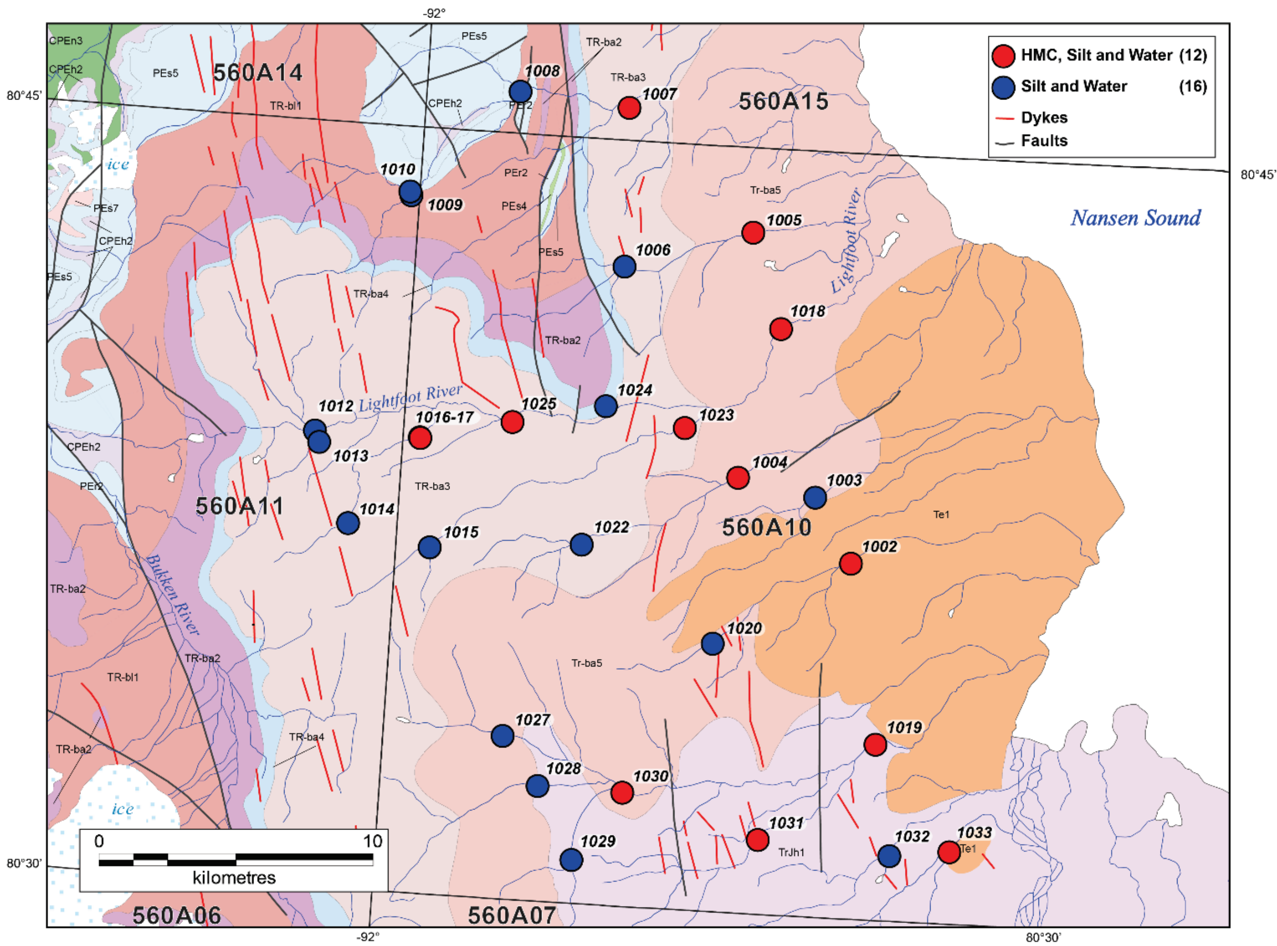


Figure 6. Sample location map of the Lightfoot River area. The Lightfoot River study area, located E-NE of the Bukken River headwaters has a plateau like landscape with sharply incised valleys. It is characterized by the absence of evaporitic diapirs, the predominance of shales, limestones and siltstones of the Blaa Mountain Formation, shale and siltstone of the Blind Fiord Formation, the late Triassic/Early Jurassic Heiberg sandstone, siltstone Formation and the presence of the Lightfoot River dyke swarm (Figure 5). See Figure 7 for a legend of geological units.

PALEOGENE

Paleogene and Eocene

Te1	Eureka Sound	Sandstone, siltstone, conglomerate shale; minor coal

Eureka Sound-West Group

TeW6	Iceberg Bay_Coal member	Sandstone, quartz arenite; minor grey shale, coal
TeW5	Iceberg Bay_Lower member	Sandstone, quartz arenite; minor siltstone, grey shale
TeW4	Strand Bay_Upper Part	Medium to dark grey shale; minor sandstone, quartz arenite; minor coal
TeW3	Strand Bay_Lower Part	Medium to dark grey shale
TeW2	Strand Bay	Medium to dark grey shale; minor sandstone, quartz arenite; minor coal

CRETACEOUS

Late Cretaceous to Early Paleogene

Expedition Group

KTe5	Upper member	Sandstone, quartz arenite, fine- to medium grained; minor siltstone, shale and coal
KTe4	Lower member	Sandstone, quartz arenite, fine- to medium-grained; minor siltstone, shale and ironstone

Late Cretaceous

Kk	Kanguk	Dark coloured shale, minor sandstone, siltstone and mudstone

Early and Late Cretaceous

Hassel Group

Kh5	Strand Fiord	Dark grey to black mafic flows and pyroclastic rocks; weathering red; minor coal, shale and conglomerate
Kh2	Bastion Ridge	Dark grey silty shale; minor siltstone; minor sandstone; minor ironstone and volcaniclastic sandstone.
Kh1	Hassel	Sandstone, quartzose, fine- to coarse-grained; siltstone; minor shale; local mafic volcanic flows
Kg1	Queen Elizabeth swarm	Gabbro; minor granitoid and hybrid rocks, diabase

Early Cretaceous

Christopher Group

Kc5	Macdougall Pt. member	Dark grey to brownish black shale, minor limestone concretions, volcaniclastic sandstone
Kc4	Invincible Pt. member, Junction beds	Grey to greenish grey sandstone, feldspathic quartz arenite; siltstone
Kc2	Invincible Pt. member	Dark greenish grey and brownish grey shale, grading upwards to lesser sandstone; local volcaniclastic sandstone
Kc1	Christopher	Dark coloured shale, minor siltstone, sandstone and mudstone
Ki1	Isachsen	Sandstone, minor shale, siltstone and conglomerate

JURASSIC AND CRETACEOUS

Late Jurassic and Early Cretaceous

JKd1	Deer Bay	Dark coloured shale, minor siltstone, sandstone and mudstone

JURASSIC

Late Jurassic

Ja1	Awingak	Sandstone, partly shaly; local coal

JURASSIC AND CRETACEOUS

Early Jurassic to Early Cretaceous

JKsv2	Savik	Awingak Formation: Sandstone, siltstone, minor shale; Savik Formation: sandstone, dark coloured shale, siltstone; Borden Island Formation: sandstone
JKsv1	Savik	Jameson Bay formation: medium to dark grey shale and siltstone; red weathering ironstone nodules; Sandy Point formation: thin ledge of very fine to fine grained, burrowed sandstone with ironstone

TRIASSIC AND JURASSIC

Late Triassic and Early Jurassic

TrJh1	Heiberg	Sandstone, siltstone; minor shale

TRIASIC

Middle and Late Triassic

Blaa Mountain Group

Tr-ba5	Barrow	Medium to dark grey shale and siltstone
Tr-ba4	Gore Point	Medium to dark grey limestone; medium grey, brown weathering, calcareous siltstone with minor shale
Tr-ba3	Hoyle Bay	Medium to dark grey shale and siltstone, very fine to fine grained sandstone
Tr-ba2	Murray Harbour	Gravel, sand and mud
Tr-ba1	Blaa Mountain	Dark coloured shale,siltstone, light grey calcareous siltstone; minor sandstone

Early Triassic

Tr-bl1	Blind Fiord	Siltstone; minor shale, sandstone and conglomerate

PERMIAN

Guadalupian

Sabine Bay Group

PEs7	Trold Fiord	Siltstone, sandstone; minor bioclastic limestone, conglomerate and chert
PEs5	Degerbols	Light coloured limestone and chert
PEs4	Esayoo	Basalt flows, minor pyroclastic rocks

Cisularian

PEr2	Raanes Great Bear Cape	Light grey chert, weathers white; cherty, medium bedded limestone

CARBONIFEROUS AND PERMIAN

CPEh2	Hare Fiord Trappers Cove	Dark grey to black shale and chert; minor limestone
CPEn3	Nansen	Light coloured limestone, minor sandstone, siltstone and shale

CARBONIFEROUS

Co1	Otto Fiord	Anhydrite, gypsum, minor limestone and shale
Co2	Otto Fiord	Gypsum, with included blocks and masses of anhydrite, dolomite and limestone

Figure 7. Geological legend for figures 6, 8 and 9. Modified from Harrison et al. (2015a, 2015b, 2015c).

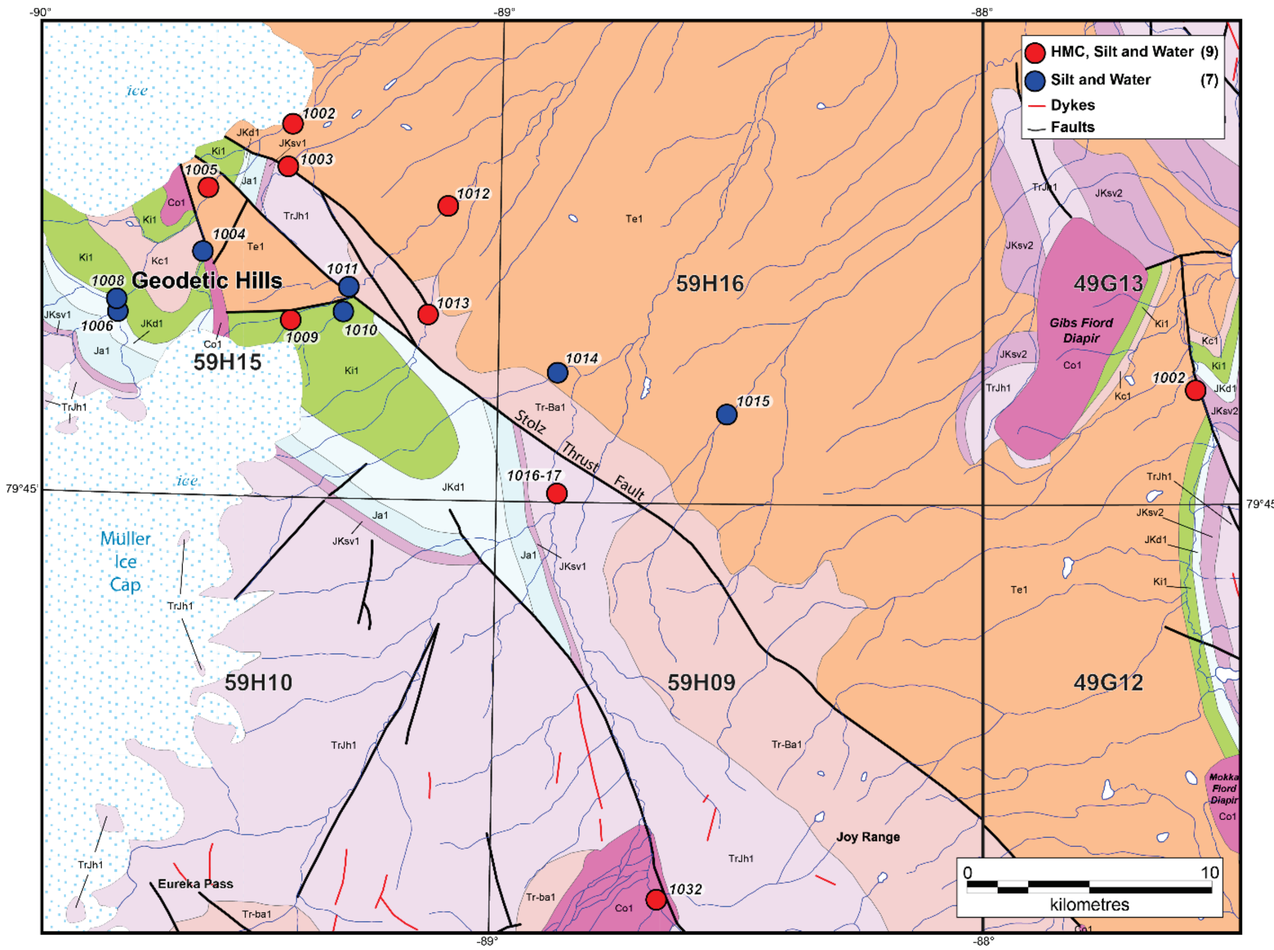


Figure 8. Sample location map of the Geodetic Hills area. The Geodetic Hills area is located west of Gibs Fiord and bordering the Müller Ice Cap has large anastomosing drainages flowing into wide peneplains. It is characterized by the presence of evaporite diapirs intruding Cretaceous and Triassic sedimentary successions as well as multiple fault structures such as the major NW-SE trending Stolz Thrust Fault. The rationale for selecting Geodetic Hills for a drainage survey was to investigate the combined effect(s) of evaporite diapirs and faulting on mineral prospectivity. See Figure 7 for a legend of geological units.

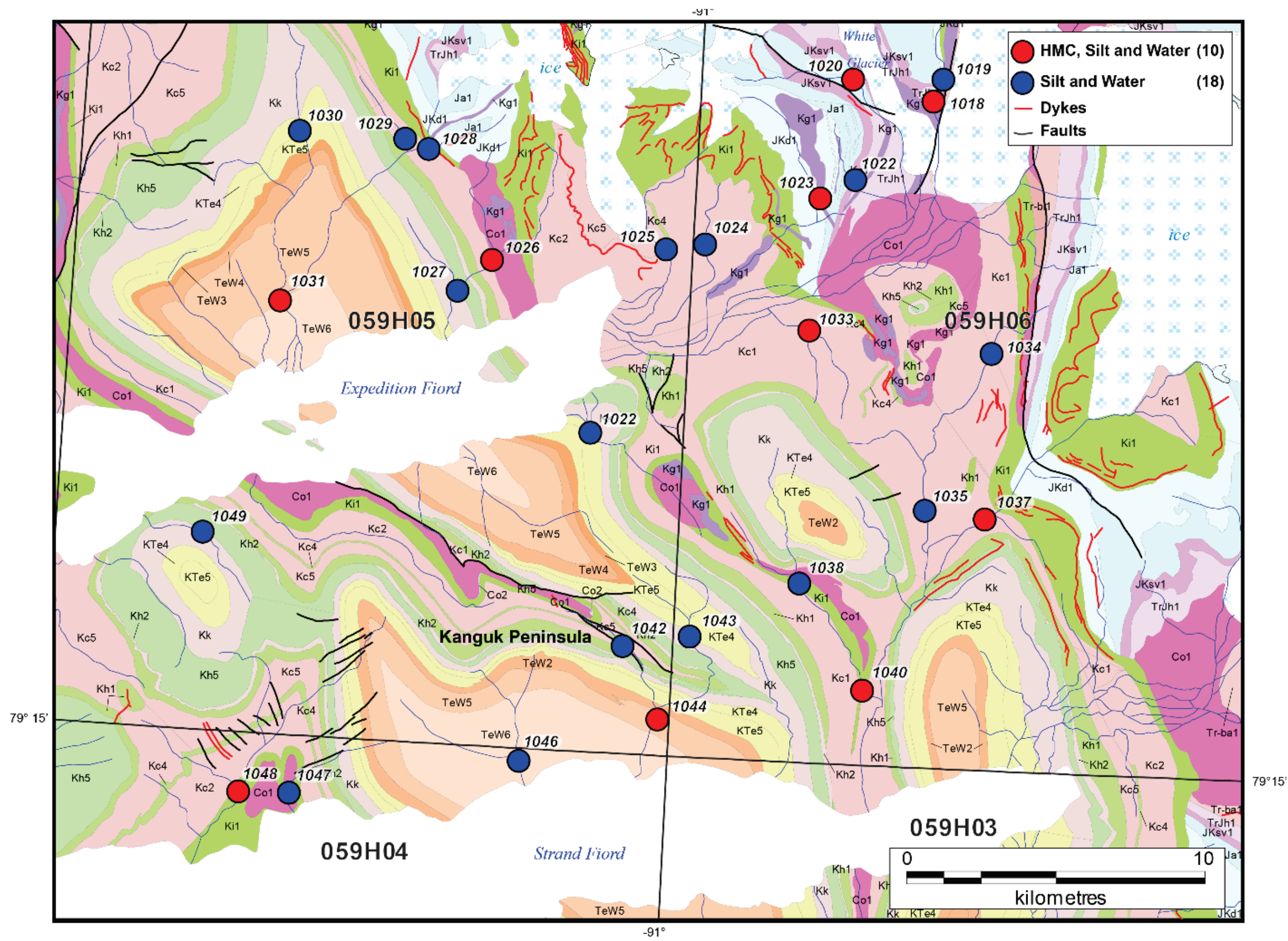


Figure 9. Sample location map of the Expedition Fiord area illustrating the bedrock geology (after Harrison et al., 2015a, 2015b, 2015c). The Expedition Fiord area located in central Axel Heiberg Island covers the north side of Expedition Fiord and the Kanguk Peninsula. The Strand Fiord-Expedition Fiord region is dominated by regional anticlines, which formed during the Paleogene Eurekan Orogeny, trend roughly north on a regular ~20 km wavelength and probably detach on autochthonous evaporate structures sourced in the Carboniferous Otto Fiord Formation. The northeast part of Expedition Fiord borders the Muller Ice Cap and the area generally has a landscape of steep, short drainages. The rationale for selecting this area for a drainage survey was to better understand the relative roles of igneous bedrock, evaporite diapirs and glaciers on the proportions of stream indicator minerals with implications for regional mineral prospectivity. See Figure 7 for a legend of geological units.

FIELD METHODS

Stream Water

Stream water and sediment were collected at each site. Bulk sediment samples collected for the heavy mineral concentrate (HMC) component in the <2 mm fraction were only acquired at selected sites. In total, 72 samples were collected from drainage systems in three areas described above. **Figure 10** illustrates the equipment used for collection of stream sediment and water samples, and field data. Each set of water samples was comprised of three bottles:
g

1- **F**iltered and **A**cidified (FA),
2- **U**nfiltered and **A**cidifed (UA)
3- **F**iltered and **U**nacidified (FU)

On-site, 60 ml of water was collected by filling the syringe from the active part of the stream channel (**Figure 11**). The water was filtered through a single-use Millipore Sterivex-HV® 0.45 µm filter unit attached to a 60 ml sterile plastic syringe into each of the triple rinsed FA and FU 60 ml Nalgene® bottles (**Figure 12**). The UA bottle was filled with 60 ml of unfiltered water. The FA and UA samples were also preserved by acidifying to 0.4% with high-purity 8M HNO_3.

The FA and the UA samples were collected for trace and major element analysis by inductively coupled plasma mass spectrometry and emission spectrometry (ICP-MS and ES). All water samples were analysed at the GSC Inorganic Geochemistry Research Laboratory for trace metals, major cations and anions. The FU samples were analysed for anions, alkalinity and dissolved organic carbon (DOC). *In situ* water measurements were also collected for temperature, pH, Eh, conductivity and dissolved oxygen using a YSI Pro Plus® multi-probe meter. See Appendix A for a full description of Sampling Methods and Analytical Procedures.

Sediment

Stream Silt Sediment (<177 um)

After collection of the water sample, care was taken to ensure active fluvial sediment was collected into a spun-bonded polyester fabric bag from first and second order streams (**Figure 13A**). The sediment represents fine-textured, sandy-silty-clayey, bed load material from relatively low energy fluvial environment. The sediments were collected by hand from several points in the active channel while moving upstream, typically over a distance of 5 to 15 m, to produce a representative composite sample of the drainage basin.

Bulk Stream Sediments (For Heavy Mineral Concentrates)

The ideal site for collecting bulk stream sediment, to be processed for a heavy mineral concentrate fraction, is a reasonably well-sorted, high-energy, mid-channel depositional environment where a generous amount of gravel allows the entire sample to be taken from the same hole dug into the streambed. Over the course of the field campaign, samples were collected from a variety of environments including large gravel bars (longitudinal, transverse and point bars) in rivers, boulder traps, and tiny pools of sediment in rocky narrow streams. Where possible, the upstream head of active longitudinal bars was preferentially selected.

Roughly 12–15 kg of ≤2 mm stream sediment was collected by wet-sieving stream material on site into a 20 litre (5 gallon) pail lined with a pre-labeled, heavy duty polyethylene bag measuring 46x61 cm (18x24 inches, 4 Mil) (**Figure 13B**). The bag was securely closed with a coloured cable-tie. The sample was then placed into a second polyethylene bag for greater protection and securely closed with a second coloured cable-tie looped through a Tyvek tag pre-labeled with the sample number. At the end of each day, samples were catalogued and packed into 20 l (5 gallon) pails for direct shipping to Overburden Drilling Management Inc. where they underwent processing and analysis.

Figure 10. Samples collected and field equipment used at a typical bulk stream sediment and water site. [1] tablet used for field data capture; [2] multi-parameter water meter; [3] 2 x 60 ml water samples; [4] silt sediment sample (~1 kg); [5] bulk sediment sample (~15 kg of <2 mm); [6] shovel; [7] 10 mesh (2 mm) sieve; [8] gold pan; [9] 5 gallon pail.

Figure 11. Filtering water sample with a 0.45 µm filter into a 60 ml HDPE bottle.

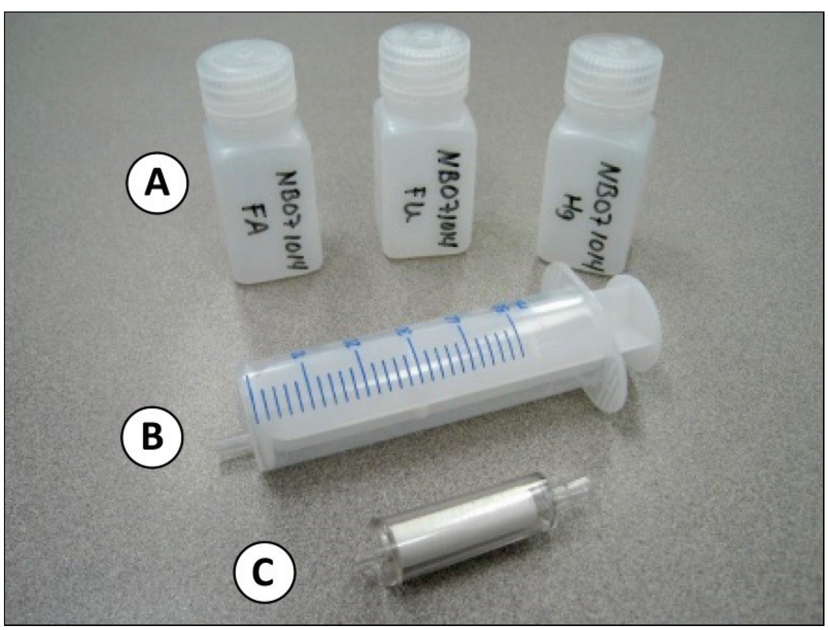


Figure 12. Equipment used for filtering stream water samples on site. A) 60 ml Nalgene® bottles B) 60 ml syringe and C) Millipore® 0.45 µm capsule filter.

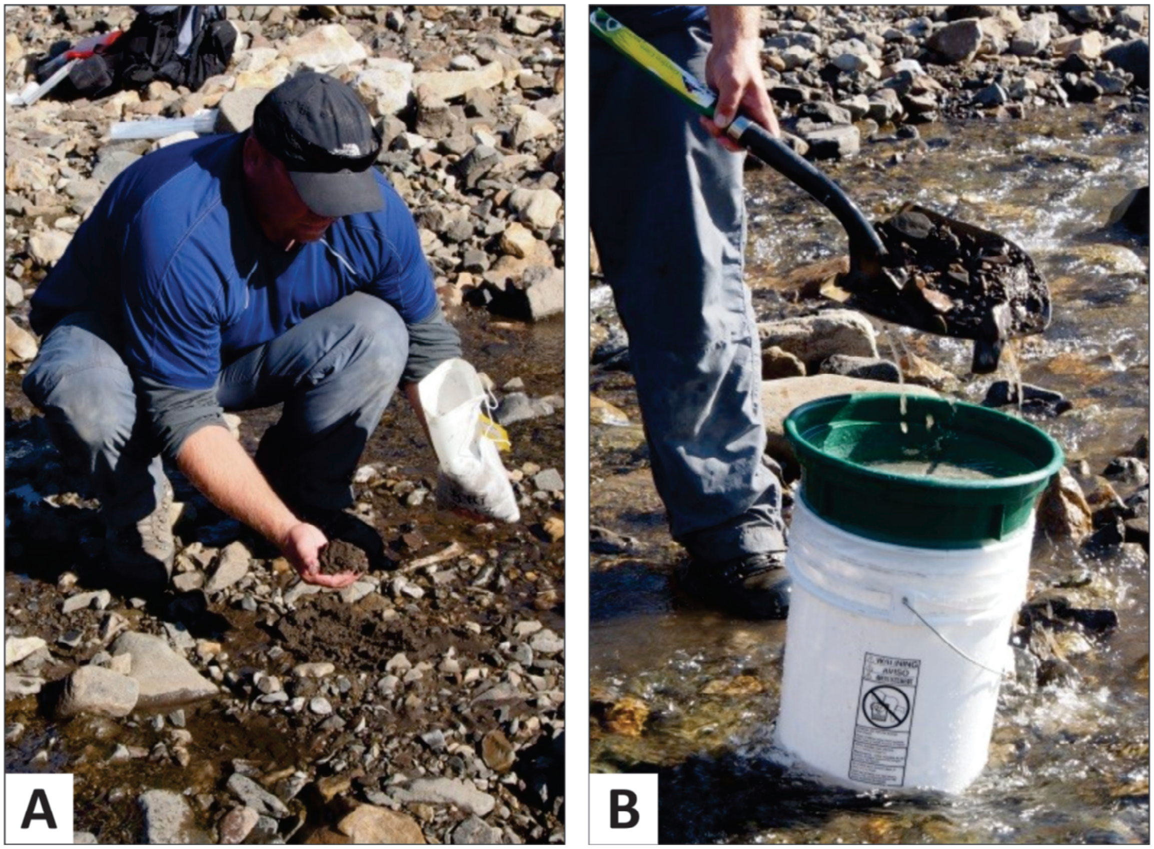
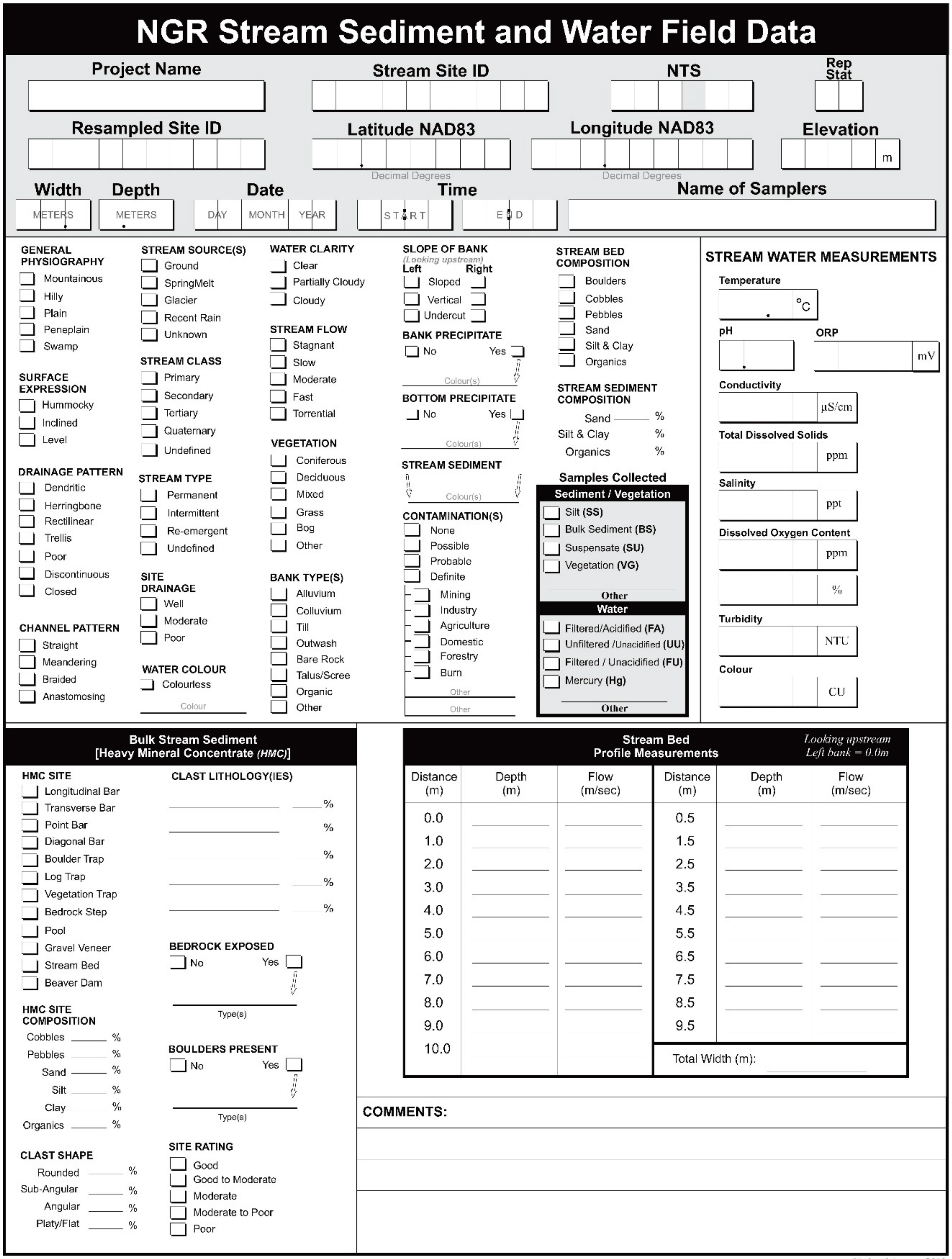


Figure 13. **A**. Approximately 1 kg of wet silt and clay is collected from lower energy part of streams into a cloth bag.
B. Approximately 12-15 kg bulk sediment for heavy minerals is collected by wet sieving with a 2 mm mesh sieve in higher energy part of streams into large plastic bags.

Data Collection

Site locations, field observations, stream water physico-chemical measurements, sample type, and any more specific comments were recorded on a digital field card using a digital tablet at each sampling station. The field card **(Figure 14)**, was adapted from the stream sediment and water survey field data collection card developed by Garrett (1974) for the GSC National Geochemical Reconnaissance program and converted to a digital format to be used with a tablet in-situ.



NGR Stream Sediment and Water Field Data

Project Name | Stream Site ID | NTS | Rep Stat

Resampled Site ID | Latitude NAD83 (Decimal Degrees) | Longitude NAD83 (Decimal Degrees) | Elevation (m)

Width (METERS) | Depth (METERS) | Date (DAY, MONTH, YEAR) | Time (START, END) | Name of Samplers

GENERAL PHYSIOGRAPHY
- Mountainous
- Hilly
- Plain
- Peneplain
- Swamp

SURFACE EXPRESSION
- Hummocky
- Inclined
- Level

DRAINAGE PATTERN
- Dendritic
- Herringbone
- Rectilinear
- Trellis
- Poor
- Discontinuous
- Closed

CHANNEL PATTERN
- Straight
- Meandering
- Braided
- Anastomosing

STREAM SOURCE(S)
- Ground
- SpringMelt
- Glacier
- Recent Rain
- Unknown

STREAM CLASS
- Primary
- Secondary
- Tertiary
- Quaternary
- Undefined

STREAM TYPE
- Permanent
- Intermittent
- Re-emergent
- Undefined

SITE DRAINAGE
- Well
- Moderate
- Poor

WATER COLOUR
- Colourless
- Colour

WATER CLARITY
- Clear
- Partially Cloudy
- Cloudy

STREAM FLOW
- Stagnant
- Slow
- Moderate
- Fast
- Torrential

VEGETATION
- Coniferous
- Deciduous
- Mixed
- Grass
- Bog
- Other

BANK TYPE(S)
- Alluvium
- Colluvium
- Till
- Outwash
- Bare Rock
- Talus/Scree
- Organic
- Other

SLOPE OF BANK *(Looking upstream)* Left / Right
- Sloped
- Vertical
- Undercut

BANK PRECIPITATE
No / Yes — Colour(s)

BOTTOM PRECIPITATE
No / Yes — Colour(s)

STREAM SEDIMENT
Colour(s)

CONTAMINATION(S)
- None
- Possible
- Probable
- Definite
  - Mining
  - Industry
  - Agriculture
  - Domestic
  - Forestry
  - Burn
  - Other
  - Other

STREAM BED COMPOSITION
- Boulders
- Cobbles
- Pebbles
- Sand
- Silt & Clay
- Organics

STREAM SEDIMENT COMPOSITION
- Sand ____ %
- Silt & Clay ____ %
- Organics ____ %

Samples Collected

Sediment / Vegetation
- Silt **(SS)**
- Bulk Sediment **(BS)**
- Suspensate **(SU)**
- Vegetation **(VG)**
- Other

Water
- Filtered/Acidified **(FA)**
- Unfiltered /Unacidified **(UU)**
- Filtered / Unacidified **(FU)**
- Mercury **(Hg)**
- Other

STREAM WATER MEASUREMENTS
- Temperature ____ °C
- pH
- ORP ____ mV
- Conductivity ____ µS/cm
- Total Dissolved Solids ____ ppm
- Salinity ____ ppt
- Dissolved Oxygen Content ____ ppm ____ %
- Turbidity ____ NTU
- Colour ____ CU

Bulk Stream Sediment [Heavy Mineral Concentrate *(HMC)*]

HMC SITE
- Longitudinal Bar
- Transverse Bar
- Point Bar
- Diagonal Bar
- Boulder Trap
- Log Trap
- Vegetation Trap
- Bedrock Step
- Pool
- Gravel Veneer
- Stream Bed
- Beaver Dam

HMC SITE COMPOSITION
- Cobbles ____ %
- Pebbles ____ %
- Sand ____ %
- Silt ____ %
- Clay ____ %
- Organics ____ %

CLAST SHAPE
- Rounded ____ %
- Sub-Angular ____ %
- Angular ____ %
- Platy/Flat ____ %

CLAST LITHOLOGY(IES)
- ____ %
- ____ %
- ____ %
- ____ %
- ____ %

BEDROCK EXPOSED
No / Yes — Type(s)

BOULDERS PRESENT
No / Yes — Type(s)

SITE RATING
- Good
- Good to Moderate
- Moderate
- Moderate to Poor
- Poor

Stream Bed Profile Measurements — *Looking upstream Left bank = 0.0m*

Distance (m)	Depth (m)	Flow (m/sec)	Distance (m)	Depth (m)	Flow (m/sec)
0.0			0.5		
1.0			1.5		
2.0			2.5		
3.0			3.5		
4.0			4.5		
5.0			5.5		
6.0			6.5		
7.0			7.5		
8.0			8.5		
9.0			9.5		
10.0			Total Width (m):		

COMMENTS:

Updated August, 2010

Figure 14. Field data card adapted from Garrett (1974) to be used in digital format on portable field tablets.

ANALYTICAL PROCEDURES

The analytical procedures are described in Appendix A for water, silt and heavy mineral fractions.

FIELD PHOTOGRAPHS

Field photographs of the sampling sites are included with this report and available in Appendix B. At each site, two photos were taken, a panoramic view and a close up view of the sampling site. The photos are labeled with the site ID followed by the mention "Site" for the large upstream view and "Detail" for the close up view of the sampling site.

QUANTITATIVE MODAL MINERALOGY OF HMCs, EXPEDITION FIORD

The results for Areas 1 and 2 will be discussed in a separate publication. For the purposes of this report, we highlight a pilot study of the HMCs in Area 3, Expedition Fiord.

The geology of the Expedition Fiord area exhibits a complex and unique fold interference pattern known as wall-and-basin (WAB) structure. The WAB structural pattern results from a combination of salt tectonics coeval with sedimentation and volcanism within the Sverdrup Basin, and subsequent shortening during the Eurekan Orogeny (Jackson & Harrison, 2006; Harrison & Jackson, 2014). This fold interference pattern exerts a first order control on the geomorphology of the area as plateaus and ridges tend to consist of either physically resistant HALIP lava flows or sills and, to a lesser extent, quartz-rich sandstone units of the Isachsen Formation. Rivers and their valleys exploit physically weak, fine-grained siliciclastic units.

A total of ten bulk stream sediment samples were collected in the Expedition Fiord area (**Figure 9**). Each sample was wet-sieved on site to <2 mm and then processed and refined into various non-magnetic heavy mineral fractions (>3.2 specific gravity). From the resulting <0.25mm non-magnetic HMC fraction, the samples are further refined following the methodology of Wilton and Winter (2012) to recover the 125 to 180 µm fraction for mounting in epoxy pucks for SEM-MLA analysis. The MLA-SEM consists of a fast SEM and associated sophisticated MLA software that allows the Energy Dispersive X-ray (EDX) component of the SEM to quantitatively define the abundance, association, size and shape of minerals in an automated, systematic fashion (Wilton et al. 2017; Wilton and Winter 2012).

RESULTS

The samples consist of two groups based on their broad geographic locations: Expedition Fiord and Kanguk Peninsula. These groups also correlate with distinct mineral-assemblages identified by MLA-SEM analysis. The Expedition Fiord group consists of samples 1018, 1020, 1023, 1026 and 1031, located on the North side of Expedition Fiord. Sampling sites 1020 and 1018 are closest to White Glacier, with 1018 located ~100 m downstream from the Between Lake showing (**Figure 15A**). Samples from the second group, 1033, 1037, 1040, 1044 and 1048, are primarily located on the Kanguk Peninsula between Expedition Fiord and Strand Fiord.

Figures 16A and 16B illustrate the average value, in area percent, of the top seven mineral phases in the samples from both areas. These top mineral phases constitute 68% and 67% of the Expedition Fiord and Kanguk Peninsula groups, respectively. The main mineral assemblage of the Exploration Fiord group is clinopyroxene-pyrite-ilmenite with augite as is the primary mineral phase comprising 30.9% of the sample, pyrite 16.7% and ilmenite 9.2%. Hornblende, oxidized pyrite, siderite and tourmaline account for the other top minerals (See Appendix D for a full account of the mineralogy). The main mineral assemblage in the Kanguk Peninsula samples as identified by the SEM-MLA is pyrite, oxidized pyrite, siderite and tourmaline. Pyrite is the primary mineral phase comprising 37.4% of the sample mineralogy, oxidized pyrite 8.0%, tourmaline 6.9% and siderite 5.9%. Various other minerals (e.g., augite, ilmenite, hornblende) constitute the remaining top mineral phases.

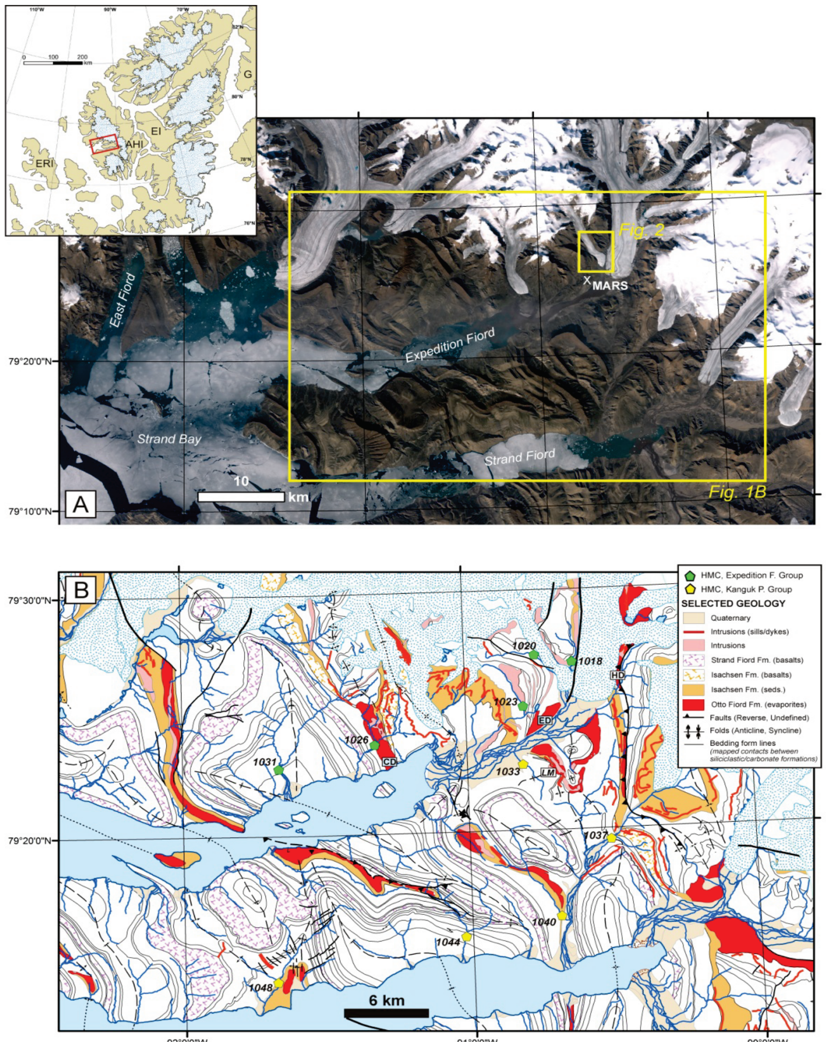


Figure 15. Location of bulk sediment heavy mineral concentrate (HMC) samples illustrated in Figure 16 and discussed in the text. Topographic contours indicate 20 m intervals. Bedrock geology is interpreted from new GEM 2 - HALIP fieldwork, SPOT 7 imagery and after Harrison and Jackson (2011). Figure 1 of Wilton et al. (2019), unedited.
ED, Expedition Diapir; CD, Colour Diapir; HD, Hidden Diapir; LM, Little Matterhorn.

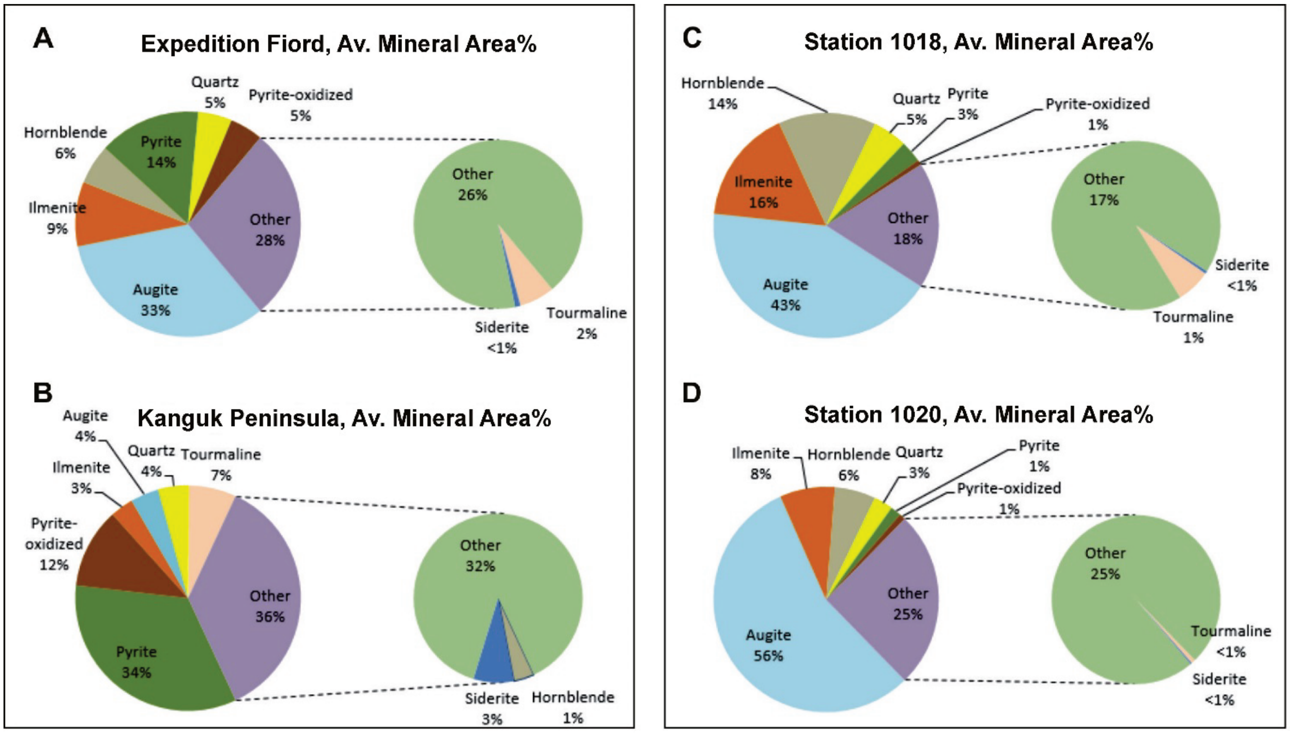


Figure 16. Pie charts illustrating the top eight mineral phases identified by SEM-MLA in the 125 µm to 180 µm fraction in the bulk sediment heavy mineral concentrates sampled in **A.** the Expedition Fiord area, and **B.** the Kanguk Peninsula area. The data are presented as a percent average area of each mineral phase from the five samples in each area. **C.** and **D.** illustrate mineral phases from sites near the Between Lake Showing, by percent average area: **C.** sampling site 1018 and **D.** sampling site 1020 (Figure 15).

Essentially, the two groups reflect the bedrock lithologies of each area through which the streams flowed. The Kanguk Peninsula Heavy Mineral Concentrates (HMC) contain much more sulphide as pyrite and oxidized pyrite than do the Expedition Fiord samples. Therefore, it must be assumed that the Isachsen Formation basalt and sedimentary rocks, Strand Fiord basalts, and (?) evaporites contain more pyrite than the intrusive rocks exposed in the Expedition Fiord area.

Near the Between Lake showing (**Figure 15A**), heavy mineral concentrates from sites 1018 and 1020 (**Figures 16C and 16D**) have a similar main mineral assemblage of clinopyroxene-ilmenite-hornblende but with greater contents than the other Expedition Fiord samples (**Figure 16A**). Notably, they differ from all other samples by their very low pyrite abundances, which only constitute 3.4% and 1.9% in samples 1018 and 1020, respectively, compared to an average 16.7% in the Expedition group and 37.4% in the Kanguk Peninsula group.

Sulphide Content

Sulphides other than pyrite, including sphalerite, chalcopyrite, galena and pyrrhotite, are minor components, constituting on average only 0.9% of the mineral area in the heavy mineral concentrates. Aside from pyrite, pyrrhotite is the main primary sulfide present at all sites except 1018 (near Between Lake), varying between 0.05% and 1.71%, followed by sphalerite, chalcopyrite and galena. Galena overall does not have a significant presence; the largest galena area was 0.04% from site 1018. Interestingly, site 1018 exhibits very little sulphide, accounting for only 0.26% of the sample, actually representing the lowest content for all ten sites examined in this study. The maximum value (1.88%) was obtained from site 1040 on Kanguk Peninsula (**Figure 16B**).

Pyrite grains, as seen in the electron micrographs (**Figures 17 A-C**), typically exhibit framboidal textures with various levels of oxidation. The MLA-SEM cannot distinguish between marcasite and pyrite, and though marcasite typically has a concretionary form, the FeS phases in many samples are definitely framboidal pyrite. Sphalerite, barite, and chalcopyrite occur as infill within framboidal spherules, particularly in the Kanguk Peninsula samples. The presence of intergranular barite suggests that the framboidal pyrite may have been derived from evaporites. Other minerals of interest identified by SEM-MLA include pentlandite with chalcopyrite at site 1018, presumably derived from the Rotten Rock Ridge gabbroic to diabasic sills, and a solitary cobaltite inclusion in quartz-albite (**Figures 17 D and E**).

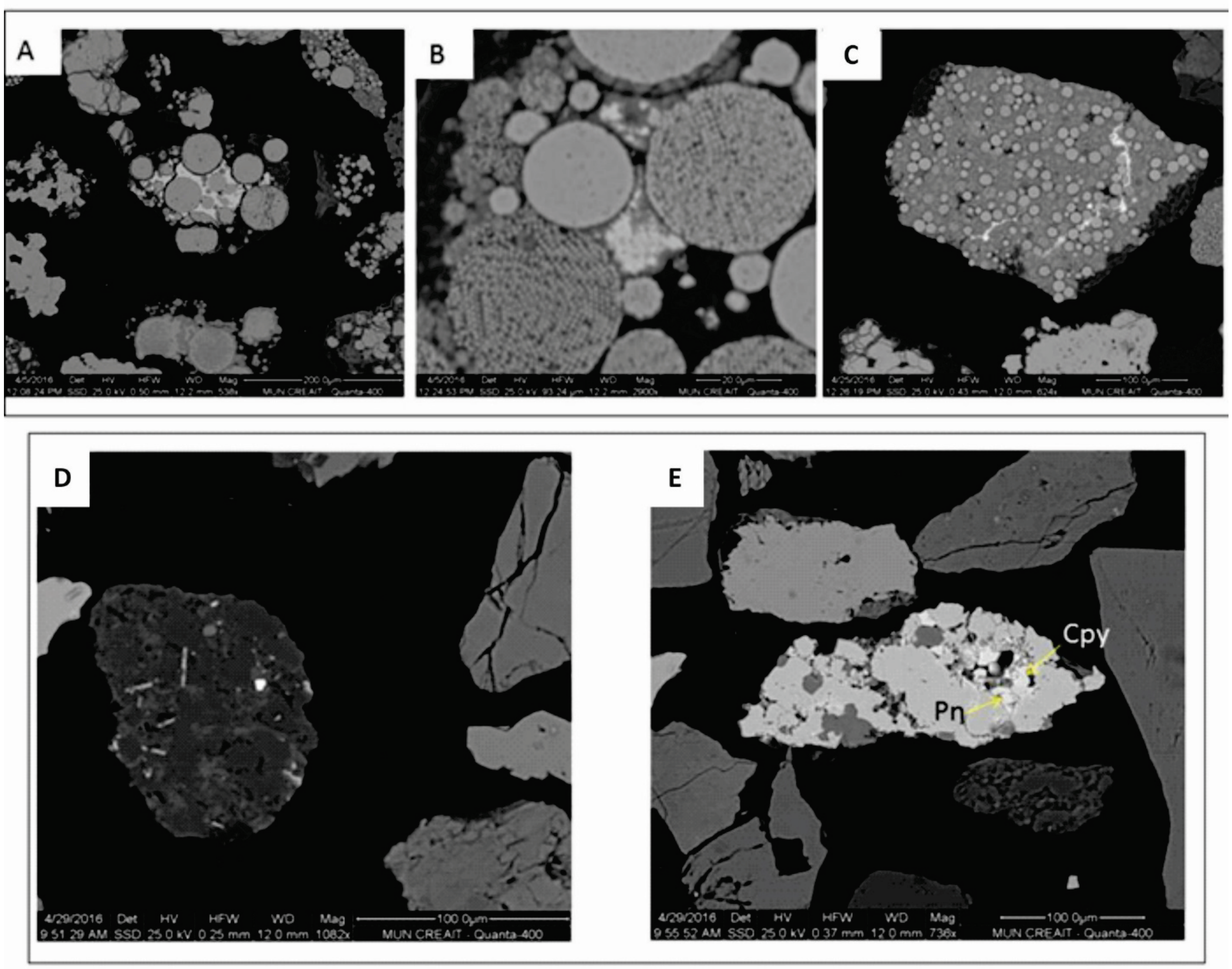


Figure 17. A-C. Back Scatter Electron (BSE) images of typical framboidal pyrite grains in stream sediment Heavy Mineral Concentrate (HMC). **A.** Sample 59H_2015_1040 sphalerite (white) intergranular to pyrite framboids. **B**. Sample 59H_2015_1044 chalcopyrite (white) intergranular to pyrite framboids. **C.** Sample 59H_2015_1037 barite (white) in pyrite framboids. **D-E**. Sample from site 1018, BSE images of possible orthomagmatic sulphide minerals in sample 1018 HMC. **D.** Minute cobaltite (white) grain in quartz and mixed clay minerals. **E.** Pentlandite (Pn) and chalcopyrite (Cpy) in pyrite grain. Note scale bars (in µm) in the lower right corner of each image.

DISCUSSION

Bulk sampling for HMCs in streams is a proven method of evaluating the mineral potential of an area. Heavy mineral concentrates are typically composed of key indicator minerals that indicate the presence of a specific type of mineralization, alteration or lithology (McClenaghan, 2005). **Figure 18** shows the location of the sediment surveys carried out so far on Axel Heiberg Island. An important result of these surveys is a better understanding of local controls by evaporate diapirs on the mineral potential. The 2013 survey in the East Fiord area revealed that sulphides such as chalcopyrite, sphalerite and galena are present at all sites. There is a correlation between higher concentrations of all three minerals and proximity to the East Fiord South and East Fiord North evaporite diapirs (McNeil et al., 2015). Chalcopyrite and sphalerite grains show the greatest range of concentrations with maxima of > 500 grains at some sites. **Figure 19** shows a selection of indicator minerals recovered from the heavy mineral concentrates in the East Fiord area. Preserved crystal faces indicate that grains are weakly physically eroded, suggesting that they have been transported only short distances from their source. Minerals such as cinnabar, red rutile, pyrite and barite show a strong spatial link to the presence of the diapirs. This is also the case in the Expedition Fiord area. Clinopyroxene (62-83% of the HMC sample) and ilmenite (4-19% of the HMC fraction) reflect the presence of widespread HALIP intrusions that form the bedrock in this area. Based on the results described in the previous section, we conclude that these observations also apply to the Expedition Fiord area (**Figure 16**).

Figure 20 shows chalcopyrite grain counts from samples collected in the East Fiord area of Axel Heiberg Island (McNeil et al., 2015) compared to grain counts in stream sediment samples from a similar sedimentary-volcanic lithological package in the Mackenzie Mountains, Northwest Territories (Falck et al., 2012, 2014). Both datasets are normalized to 100 grams of non-magnetic heavy minerals. The number of chalcopyrite grains recovered in the East Fiord area ranks above the 98^{th} percentile with respect to the 189 Mackenzie Mountains samples. The abundance of sulphide minerals recovered in the HMCs is interpreted as an indication of their presence in the local bedrock. In both areas, voluminous mafic igneous rocks intrude predominantly clastic sedimentary successions in a remnant large igneous province, the HALIP (e.g. Jowitt et al., 2014; Williamson, 2017) and the Gunbarrel LIP (Sandeman et al., 2014; Mackinder et al., 2019). However, a comparable result was not found in silt and water samples of the East Fiord area. These differences may be attributed to the fact that at high latitudes, streams only flow for a short period of time in the summer over perennial permafrost. The main source of water in most catchment areas is therefore a short-lived supply of meltwater channeled in fast flowing streams. This type of drainage combined with alkaline pH values of water measured in local streams suggests little chemical dissolution of minerals, thereby inhibiting the transport of metals in solution. The metals may only be mobilized a short distance before quickly precipitating out of solution as carbonate, oxide and hydroxide minerals.

The Strand Fiord-Expedition Fiord region is dominated by regional anticlines which formed during Eurekan Orogeny, trend north on a regular ~20 km wavelength and probably detach on the autochthonous evaporites (**Figure 21**). A 60 km wide area known as the wall-and-basin (WAB) region, has bimodal fold trends and irregular (<10 km) fold wavelengths (Van Berkel et al., 1984). The WAB region is interpreted to detach on a shallow, partly exposed canopy of coalesced allochthonous evaporite sheets (Harrison & Jackson, 2014). A model for salt-allochton controlled base-metal (sedex) accumulation (e.g. Warren 2010) could explain the spatial distribution of base metal showings along the margins of the wall-and-basin region (Williamson et al., 2017). Future work to compare stream and bedrock mineralogy and geochemistry in this area would clarify (1) compositional variations of local bedrock vs. hydrothermal deposits and gossans (Zentilli et al., 2019; Wilton et al., 2019); and (2) their potential association with faults at the periphery of mapped evaporite structures.

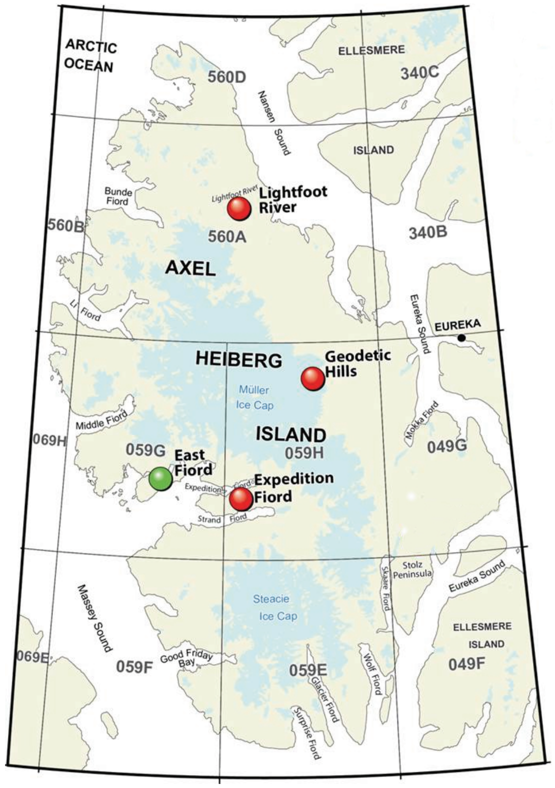


Figure 18. Location of 2013 and 2015 stream sediment surveys on Axel Heiberg Island (McNeil et al., 2017).

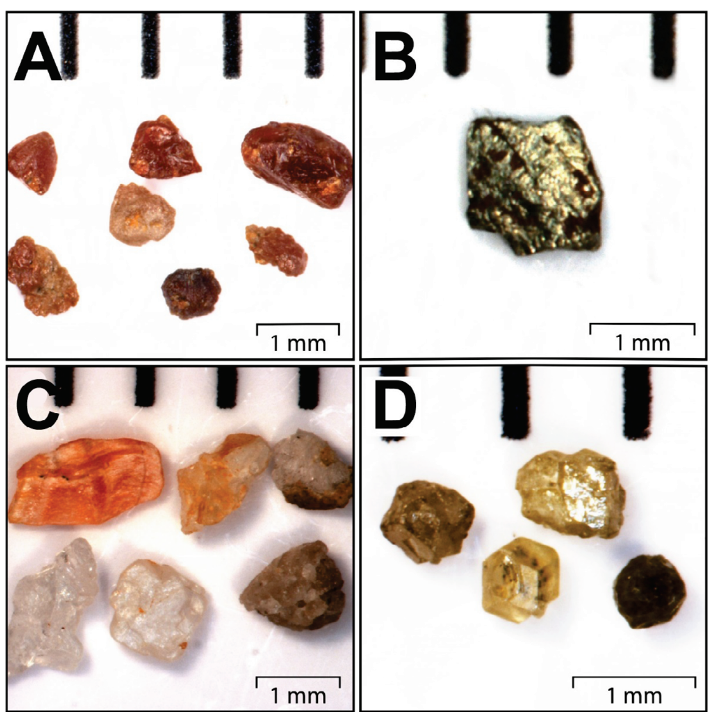


Figure 19. Examples of indicator minerals recovered from the heavy mineral concentrates in samples from the 2013 stream sediment survey at East Fiord (Figure 17; McNeil et al., 2015). **A.** Sphalerite in the 0.5-1.0 mm fraction. **B.** chalcopyrite in the 1.0-2.0 mm fraction. **C.** Barite in the 1.0-2.0 mm fraction. **D.** Andradite in the 0.5-1.0 mm.

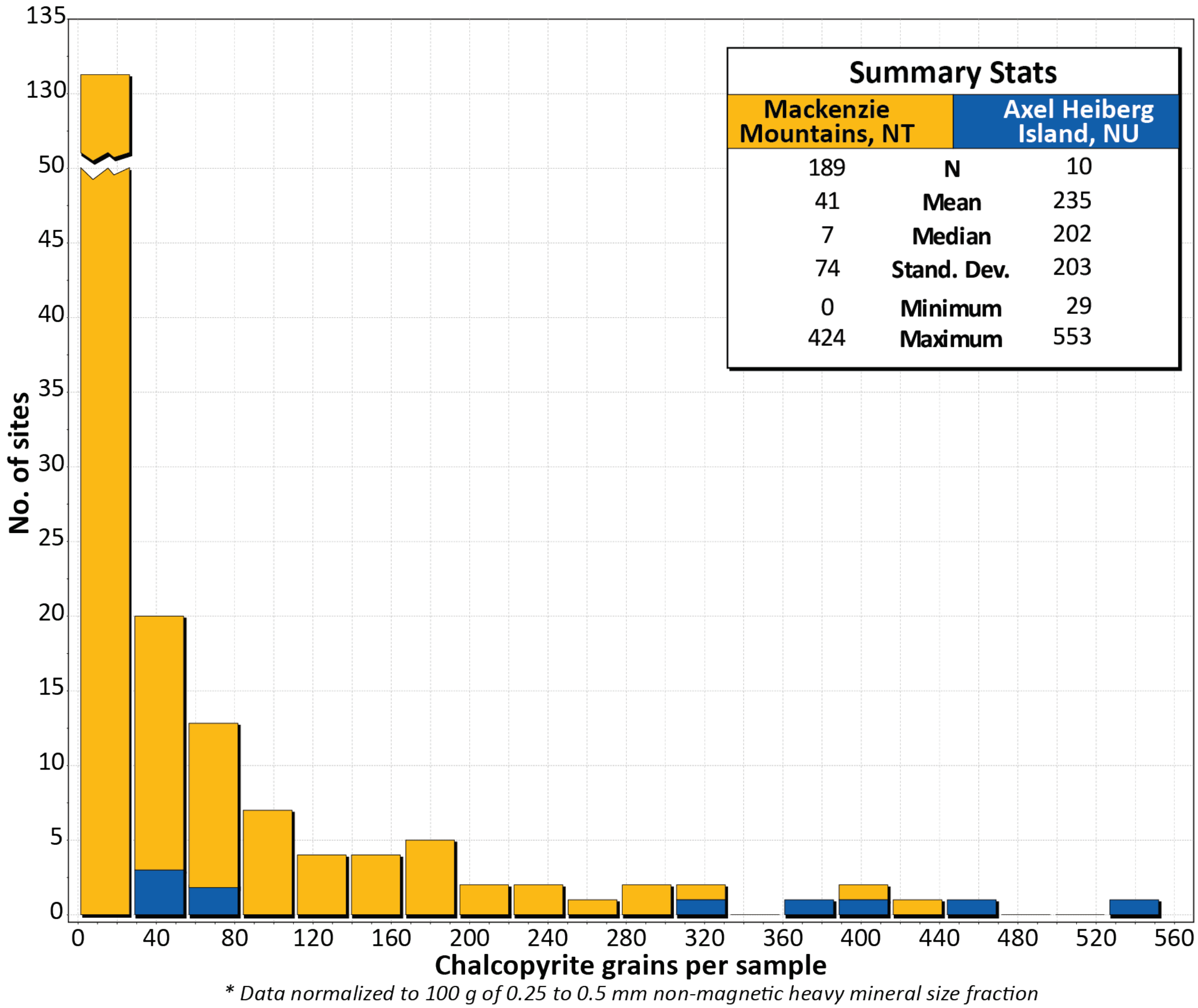


Figure 20. Histogram comparing the abundance of chalcopyrite grains recovered in the heavy mineral concentrates at East Fiord (McNeil et al, 2017) with samples collected in the Mackenzie Mountains (Northwest Territories) where the local geology also consists of intrusive rocks in the Gunbarrel LIP (Falck et al., 2012, 2014; Sandeman et al., 2014; Mackinder et al., 2019).

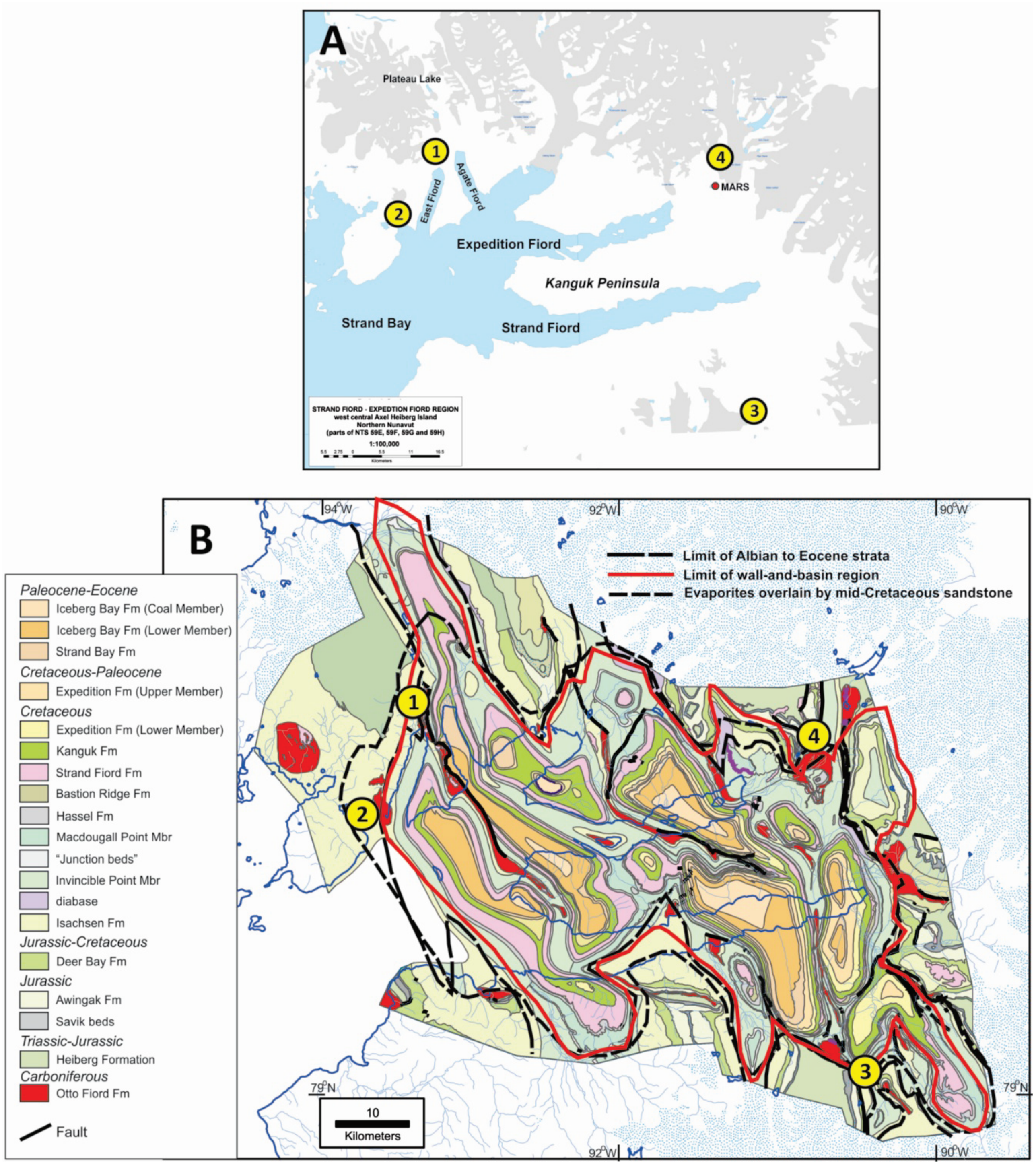


Figure 21. **A.** Location of base metal showings in the Strand Fiord-Expedition Fiord area (Williamson et al., 2017). See text for explanation. MARS: McGill Arctic Research Station located in the White Glacier Basin area, head of Expedition Fiord. **B.** Bedrock geology of the Strand Fiord-Expedition Fiord area showing three proxies to delineate the limits of a salt canopy in this region. The limit of the wall-and-basin (WAB) region is shown by a red line. Modified from Harrison & Jackson (2014).

SUMMARY

Stream sediment surveys carried out in the Lightfoot River and Geodetic Hills areas of Axel Heiberg Island do not show any clear evidence of mineralization. The most promising geochemical and mineral data resulted from a survey in the Expedition Fiord area. We illustrate the prospectivity of the area in a pilot MLA-SEM study of the Heavy Mineral Concentrates (HMC) carried out on stream sediments from drainage systems around Expedition Fiord, near the Between Lake showing and in parts of the Kanguk Peninsula. The samples near Between Lake, 1018 and 1020, were of particular interest because their drainage flowed directly from an area of extensive HALIP exposure and 1018 was also located 100 m downstream from the massive sulphide showing. The Kanguk Peninsula HMC drainage samples flowed from areas with extensive mafic volcanic, sedimentary and evaporite bedrock. These samples were distinct from the other Expedition Fiord samples in that they contained appreciable pyrite that mainly consisted of grains with framboidal pyrite masses. Some the framboids locally contained chalcopyrite, sphalerite, or barite 'cement'. These may have been derived from either the Isachsen Formation sedimentary rocks or the evaporites.

The remaining Expedition Fiord HMC samples consist mainly clinopyroxene with lesser pyrite. The Between Lake samples (i.e., 1018 and 1020) contain even lower pyrite contents, (< 3.4%). The 1018 sample contained a single micro-inclusion of pentlandite which might indicate a minor Ni content in the upstream HALIP sills; no other nickel-bearing sulphides were detected in all the other HMC. A minute grain of cobaltite was solely mapped in sample 1018.

A comparison of data for the East Fiord (2013) and Expedition Fiord (2015) survey areas highlights the presence of sulphides in the HMCs as well as other similarities in the geological setting. Notable differences in water, silt and HMC composition in both areas are not well understood and require further research on (1) the age, composition and volume of mafic intrusions in the two areas; (2) an evaluation of mechanical mixing between igneous and evaporate rocks; (3) compositional variations in streams with distance from glaciers; and (4) the role of conduits for fluid flow in the wall-and-basin evaporite structures in the Strand Fiord-Expedition Fiord area.

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