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SURFICIAL GEOLOGY OF THE HOPEDALE AND SAGLEK BLOCKS BOUNDARY (NTS 14C/12, 13, 14D/09, 16, 14E/01 AND 14F/04): UPDATES FROM SUMMER 2025 FIELDWORK

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ABSTRACT

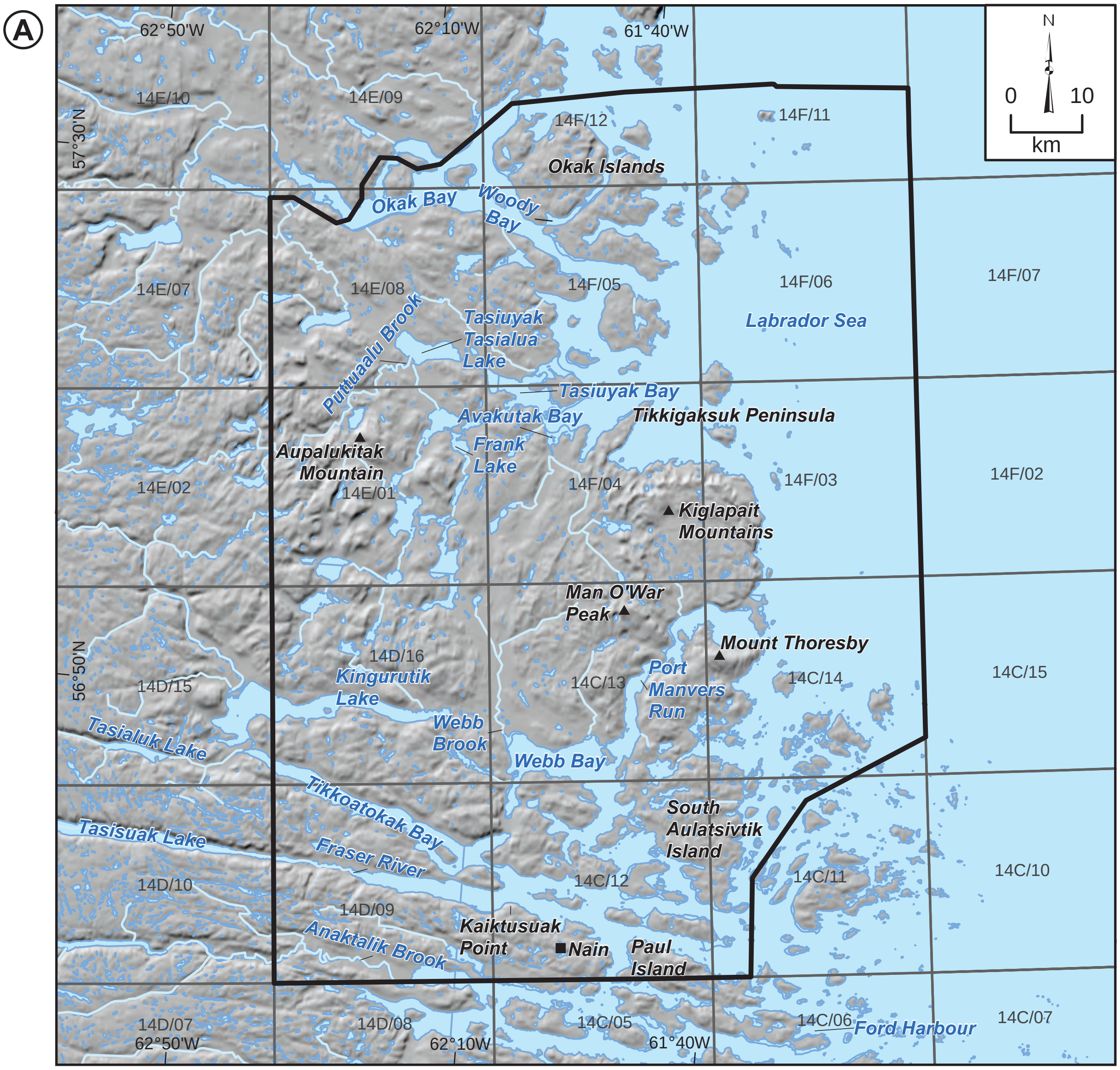
Strategic investment in critical mineral discovery requires robust geoscience data, particularly in regions with high mineral potential but limited coverage. The area north and northwest of the Voisey's Bay Ni–Cu–Co Mine near Nain, northeastern Labrador, has remained poorly studied due to its remote location and challenging conditions. Existing surficial geology data is restricted to a 1:100 000-scale map, inadequate for modern mineral exploration needs, especially given potential critical minerals (Cu, Ni, REEs) concealed beneath glacial sediments. To address the paucity of surficial geology data, a joint Geological Survey of Newfoundland and Labrador (GSNL), Geological Survey of Canada (GSC) and Nunatsiavut Government initiative under Natural Resources Canada's Geomapping for Energy and Mines (GEM) GeoNorth program conducted comprehensive surficial mapping across a ~5000 km^2 study area during the summer of 2025. Helicopter-supported fieldwork included ice-flow-indicator mapping, till sampling for geochemistry and indicator-mineral analysis, and collection of erratic boulders for cosmogenic ^{10}Be exposure dating. Preliminary results document 37 new ice-flow measurements from 34 sites, revealing early northeast-directed ice flow followed by topographically controlled phases. In total, 55 till samples were collected for geochemistry, indicator mineral, till-matrix characteristics and clast lithology analysis. An additional eight cosmogenic samples were collected to constrain deglaciation timing and confirm whether upland summits functioned as nunataks. Results will improve understanding of glacial evolution, support mineral exploration through till-geochemistry data, and provide baseline information for infrastructure development in this critical mineral-rich region.

INTRODUCTION

The drive for strategic investment in critical mineral discovery has increased the need for reliable geoscience data. One region with high critical mineral potential but limited data coverage lies north and northwest of the Voisey's Bay Ni–Cu–Co Mine, near Nain in northeastern Labrador (Figure 1). This part of the Labrador Coast remains poorly studied due to its remoteness, limited access, and challenging weather conditions. From a surficial geology perspective, data coverage is restricted to a 1:100 000-scale surficial sediment map (Klassen *et al.*, 1992).

A robust surficial geology framework is critical for mineral exploration (drift prospecting), infrastructure development (aggregate resource assessment), land-use planning, and environmental baseline studies. Given the potential for critical mineralization (*e.g.*, Cu, Ni, REEs) beneath glacial sediments and increasing mineral infrastructure development in the region (https://www.canada.ca/en/natural-resources-canada/news/2024/12/canada-to-unlock-critical-minerals-rare-earth-development-in-northern-quebec-and-labrador-with-new-funding.html), higher resolution surficial mapping is essential.

To address this data gap, a joint Geological Survey of Newfoundland and Labrador (GSNL), Geological Survey of Canada (GSC) and Nunatsiavut Government initiative under Natural Resources Canada's Geomapping for Energy and Mines (GEM) GeoNorth program was undertaken in summer 2025. The project involved surficial mapping, till sampling and geochronological sampling conducted alongside bedrock mapping within the broader study area (Figure 1). The objectives were to characterize surficial sediments, reconstruct glacial history, and generate till geochemical data to support mineral exploration.



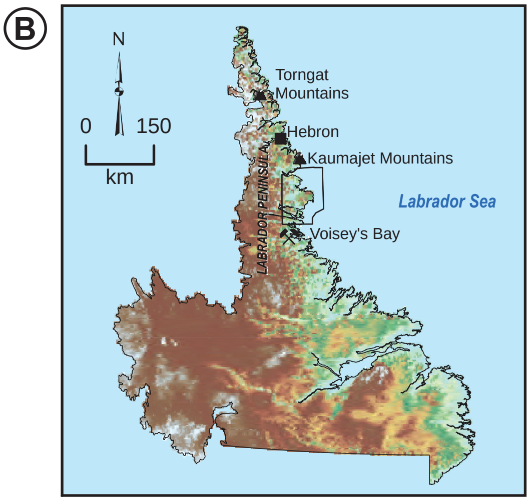


Figure 1. *A) Location of the study area (black box) illustrating the physiography, and place names used in the text; B) Shows the location of Voisey's Bay Ni–Cu–Co Mine south of Nain.*

LOCATION AND PHYSIOGRAPHY

The ~5000 km^2 study area spans National Topographic System (NTS) map sheets 14C/12, 13, 14D/09, 16, 14E/01 and 14F/04 (Figure 1). It extends from the coast to western Tikkoatokak Bay, and from Okak Bay south to the Anaktalik Brook valley. The geographic centre of the study area lies 44 km northwest of Nain, along the western slopes of Webb Brook Valley near Webb Bay and Kingurutik Lake (Figure 1). Nain, the northernmost inhabited community on the Labrador coast, served as the base for field accommodations and logistics. The coastline between Nain and Okak Bay is a classic fjord landscape (Wheeler, 1935, 1958; Andrews, 1961; Andrews and Matthews, 1961). Two of the physiographic zones indicated by Andrews (1961) occur within the study area: 1) the Bay and Island Zone and 2) the Valley Zone. The Bay and Island Zone are characterized by numerous islands and steep, east–west bays carved by north–south–oriented U-shaped troughs (*e.g.*, Port Manvers Run), except around the Kiglapait Mountains Intrusive Complex. Andrews (1961) interprets the Bay and Island Zone as the seaward continuation of ancient river systems that eroded the paragneiss basement. Low-lying areas are filled with modern marine sediments, while exposed bedrock is composed of more resistant intrusions (anorthosite, gabbro, troctolite), is found at higher elevations, and is sporadically overlain by thin till deposits. Mount Thoresby, at 913 m above sea level (asl), is the Bay and Island Zone's highest point.

Inland of the Bay and Island Zone, the Valley Zone consists of major U-shaped valleys – such as the Fraser River, Tasiuyak Lake, Anaktalik Brook, Tikkoatokak Bay/Tasialuk Lake and Webb Bay/Kingurutik Lake systems that drain eastward into the Labrador Sea. These valleys extend up to 80 km inland, dividing the region into distinct uplands (Andrews, 1961). Additional north–south troughs (*e.g.*, Webb Brook Valley) cut across the dominant east–west drainage. Webb Brook flows south into Webb Bay, while farther north, west of the Kiglapait Mountains, drainage flows into Avakutak and Tasiuyak bays. The broad valley floors are structurally controlled and filled with marine clays and sands (Wheeler, 1935, 1958). Narrow, steep tributary valleys contain glacial debris and colluvium. Upland areas, including Aupalukitak and the Kiglapait Mountains, rise to ~914 m asl (generally 457 to 762 m) and are characterized by exposed bedrock with sporadic till veneer, although with pockets of localized till blanket, hummocky terrain, and small moraines.

BEDROCK GEOLOGY AND MINERAL OCCURRENCES

The following is a broad summary of the study area's bedrock geology, main bedrock units and mineral occurrences (Figures 2 and 3). For a more detailed description of the bedrock geology, *see* Hinchey *et al.*, (*this volume*) and references therein.

The geologically complex northern Labrador region consists of four lithotectonic domains, including the Archean Hopedale and Saglek blocks of the North Atlantic Craton (collectively forming the Nain Province), and the Falcoz and Torngat domains of the Southeastern Churchill Province (SECP; Hinchey *et al.*, 2024). The juxtaposition of the Hopedale and Saglek blocks is marked by a poorly defined high-strain zone, commonly described as north–northeast trending and active as late as *ca.* 2.56 Ga (Connelly and Ryan, 1996; Wasteneys *et al.*, 1996). However, more recent interpretations propose that block juxtaposition occurred earlier, between 2.73 and 2.70 Ga (Hinchey *et al.*, 2024) and may be east–west directed (Hinchey *et al., this volume*).

The Paleoproterozoic Torngat Domain is situated between the Archean Falcoz Domain of the SECP and the Saglek Block. In the map area, the Torngat Domain comprise two units: the Lac Lomier Complex and Tasiuyak sub-assemblage (Hinchey *et al., this volume*). The region was affected by the 1.90–1.73 Ga Torngat orogeny (Scott 1998; Wardle *et al.*, 2002; Godet *et al.*, 2021). During this event, rocks of the Tasiuyak sub-assemblage and Lac Lomier Complex, together with the adjacent eastern Falcoz Domain, experienced transpressional deformation and high-grade metamorphism (*see* reviews in Hinchey *et al., this volume*). The entire region was later intruded by voluminous Mesoproterozoic anorthosite–mangerite–charnockite–granite (AMCG) plutonism of the Nain Plutonic Suite, dominated by anorthosite, iron-rich gabbro, troctolite, and associated granitoid intrusions (Hinchey *et al., this volume*).

The Saglek Block is dominated by Eoarchean to Paleoarchean tonalite–trondhjemite–granodiorite orthogneisses interleaved with supracrustal belts and intruded by younger granitoids (Ryan and Martineau, 2012; Sałacińska *et al.*, 2019; Whitehouse *et al.*, 2019; Wasilewski *et al.*, 2022; Keluskar *et al.*, 2024). Lithological units include (unit numbers are shown in brackets and refer to Figure 2): Metasedimentary gneisses (Unit 1), meta-anorthosite bedrock (Unit 2), quartzofeldspathic gneiss (Unit 3), mafic gneiss (Unit 4), paragneiss (Unit 5) and metaplutonic rocks (Unit 6). These rocks are situated within Webb Brook Valley, north to the Okak Islands. Mostly Paleoproterozoic units include layered ultramafic leucogabbronoritic to anorthositic rocks (Unit 7), quartzofeldspathic and layered mesocratic rocks (Unit 8), anorthosite (Unit 9) and granitoid rocks (Unit 10). The Mesoproterozoic rocks of the Nain Plutonic Suite are extensive within the study area. Anorthosite as well as norite, leuconorite, gabbro and troc-

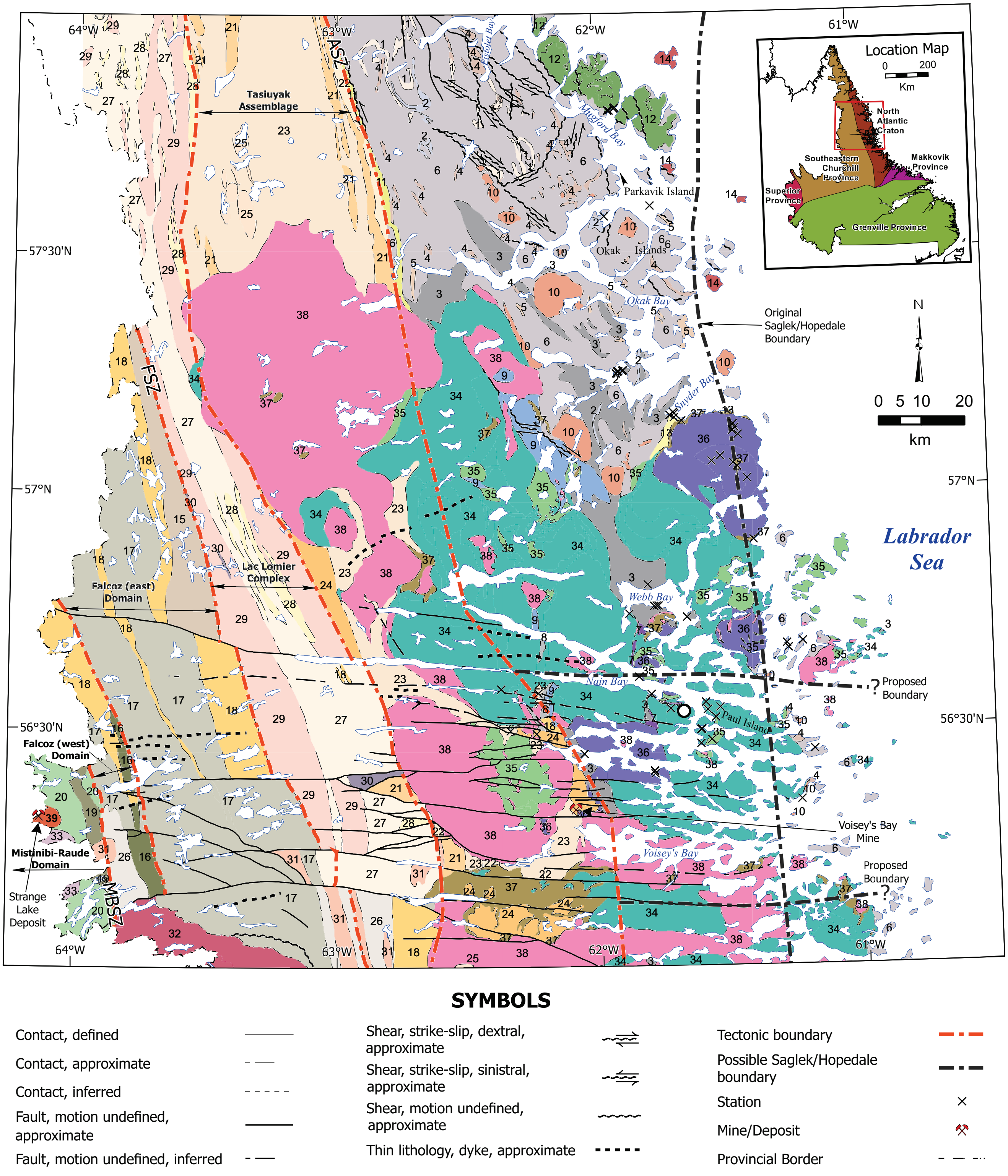


Figure 2. *Bedrock geology and mineral occurrences within the study (taken from Hinchey* et al., this volume).

LEGEND

ALL STRUCTURAL PROVINCES

MESOPROTEROZOIC

Strange Lake Igneous Complex (*ca.* 1240 Ma)

39 Arfvedsonite granite; rare-metal-enriched, peralkaline

Nain Plutonic Suite (AMGC; *ca.* 1360 to 1290 Ma)

Felsic Units

38 Various granitic plutons

Intermediate Units

37 Various intrusions that are gabbroic to dioritic and iron-rich

Mafic Units

36 Various troctolitic intrusions, includes troctolite, norite, olivine gabbro

35 Various gabbroic intrusions, includes norite, gabbro and gabbronorite

34 Various anorthosite intrusions, includes norite and leuconorite, lesser gabbro and troctolite, local labradorite

Napeu Kainut Suite

33 Quartz monzonite to granite, rapakivi textured

Mistastin Lake Batholith (*ca.* 1.44 to 1.42 Ga)

32 Quartz monzonite to granite, minor associated anorthosite to leuconorite

SOUTHEASTERN CHURCHILL PROVINCE

PALEOPROTEROZOIC

Falcoz Domain (east)/Torngat Domain

Age unknown

31 Granitic rocks with variable deformation from massive to mylonitic

***ca.* 1.89 Ga Magmatism**

30 Metagabbro, derived from gabbro, ultramafic–gabbroic–leucogabbroic layered mafic intrusions; massive to well-layered

***ca.* 1.92-1.86 Ga Magmatism**

Torngat Domain

Lac Lomier Complex (*ca.* 1.88–1.86 Ga)

29 Orthopyroxene granite to tonalite; augen metamonzogranite, minor amphibolite

28 Undivided, garnetiferous quartzofeldspathic paragneiss, includes lithologies similar to the Tasiuyak Assemblage

27 Quartzofeldspathic gneiss, migmatite, minor metagabbro

***ca.* 1.92–1.90 Ga Magmatism**

26 Quartzofeldspathic gneiss and migmatite derived largely from tonalitic to granitic intrusive rocks

Tasiuyak Assemblage

***ca.* 1.85 Ga Magmatism**

25 Granite, anatectic, megacrystic, <10% biotite and recrystallized garnet

***ca.* 1.90–1.80 Ga**

24 Orthopyroxene metatonalite to orthopyroxene-bearing orthogneiss

<1.940 Ga

23 Pelitic paragneiss, granulite facies, locally mylonitic, strongly deformed

<1.89 Ga

22 Migmatitic orthogneiss; hornblende–biotite tonalitic orthogneiss, variable to granite; fine- to medium-grained, layered

21 Orthopyroxene orthogneiss, undivided homogeneous

Mistinibi–Raude Domain

***ca.* 2.30 Ma Magmatism**

Pelland Suite

20 Metagabbronorite, foliated to gneissic

ARCHEAN OR PALEOPROTEROZOIC

Mistinibi–Raude Domain

19 Mafic gneiss derived from gabbro, ultramafic–gabbroic–leucogabbroic layered mafic intrusions.

Falcoz Domain (east and west)/Torngat Domain

18 Paragneiss with lesser garnetiferous leucogranitic anatexite; pelitic and psammitic gneisses; lesser metacarbonate and mafic rocks

17 Orthogneiss, strongly foliated to migmatitic, granulite to amphibolite-facies

16 Mafic gneiss

Falcoz Domain (east)

***ca.* 2.68–2.57 Ga**

15 Tonalitic to granitic orthogneiss, locally migmatitic, varies from massive to weakly foliated to strongly foliated, migmatitic gneiss

NORTH ATLANTIC CRATON

PALEOPROTEROZOIC

***ca.* 1.77 Ga Intrusive Units**

Granitic Members

14 Leucogranite, massive, medium- to coarse-grained

Supracrustal Units

Snyder Group

13 Metasedimentary units. Quartzite, pelite, quartz–pebble conglomerate, siltstone, marble, calcareous quartzite

Mugford Group

12 Massive and pillowed basalt, volcanic breccia, minor interbedded argillite and chert

Ramah Group

11 Metasedimentary schist; pelite, quartzite, greywacke, minor amounts of calc-silicate and conglomerate

***ca.* 2.13–2.00 Ma Intrusive Units**

10 Granitoid rocks, varying from quartz diorite to leucogranite; weakly foliated to gneissic

9 Anorthosite, leuconorite to gabbronorite, foliated

ARCHEAN OR PALEOPROTEROZOIC

8 Undivided quartzofeldspathic and layered mesocratic rocks

7 Layered ultramafic, leucogabbronoritic to anorthositic rocks; minor quartzofeldspathic gneiss

ARCHEAN

Neoarchean

6 Undivided, polydeformed, metaplutonic rocks of several generations, locally gneissic

Meso- to Neoarchean

5 Paragneiss; undivided metapelite, quartzite, marble and calcsilicate rocks; locally migmatitic

Mesoarchean (3.2–2.8 Ga)

4 Undivided mafic gneiss intercalated with metasedimentary rocks

3 Quartzofeldspathic gneiss to migmatite, derived from tonalitic to granitic intrusive rocks

Eoarchean to Mesoarchean

2 Meta-anorthosite to gabbro; minor leucogabbro

Eoarchean

1 Metapelitic, semipelite, carbonate, quartzite; includes undivided members of the Upernavik and Nulliak assemblages; migmatitic

Figure 2. *Legend.*

tolite, are the most abundant units in the study area (units 34–37). The granitic phases (Unit 38) of the Nain Plutonic Suite are less abundant.

MINERAL OCCURRENCES

Before the 1990s, exploration within the Nain area was limited to broad-scale base-metal prospecting programs. However, the discovery of the world-class Voisey's Bay Ni–Cu–Co deposit, south of Nain within the Nain Plutonic Suite, has led to increased exploration and geological mapping for both base metals and rare-earth elements, and more recently other critical minerals, such as vanadium and titanium.

A total of 169 mineral occurrences are located within the study area (Figure 3). These include gemstones (amazonite, labradorite and topaz), chromium, copper, fluorine, iron, molybdenum, nickel, palladium, pyrite, pyrrhotite and titanium (GSNL, 2025). Approximately 48% of occurrences (predominantly Ni, Cu) are hosted by anorthositic and troctolitic rocks of the Nain Plutonic Suite.

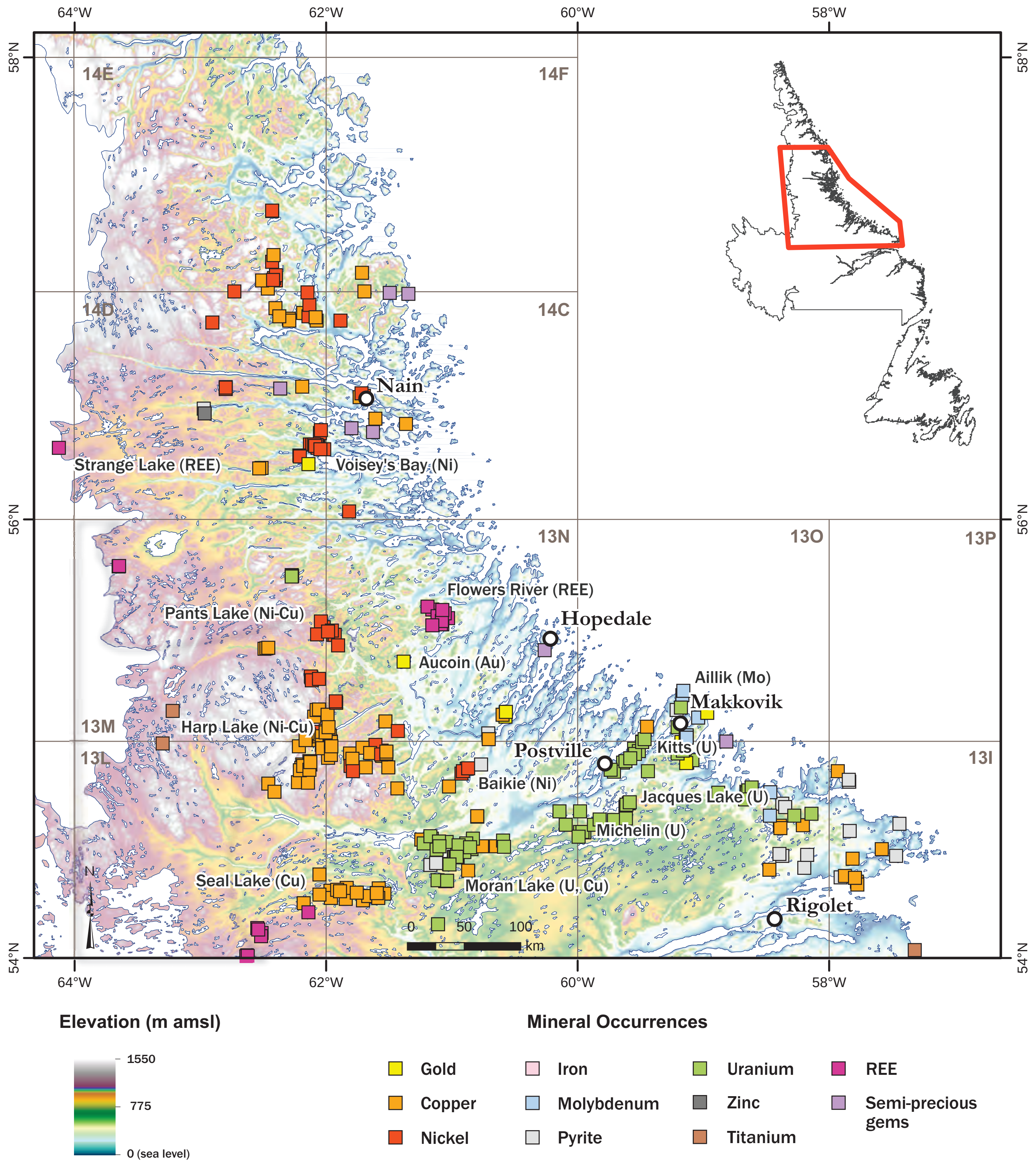


Figure 3. *Regional digital elevation model with mineral occurrence as recorded by the Geological Survey of Newfoundland and Labrador's Mineral Occurrence database (MODs, Geological Survey of Newfoundland and Labrador, 2025).*

QUATERNARY AND GLACIAL HISTORY

ICE-FLOW HISTORY

Robert Bell first identified two distinct weathering zones in the Torngat Mountains (Bell, 1884) with the upper zone characterized by felsenmeer sitting above freshly glaciated rock surfaces and glacial deposits, suggesting that this marked the limit of ice elevation during glaciation. Similar observations of distinct weathering zones were made in the Torngat Mountains by Daly (1902) and Coleman (1920); Coleman (1920) further suggested that the weathered bedrock near the upper part of the Torngat mountains had been ice-free and included not just large portions of the Torngats, but also the Kaumajet and Kiglapait mountains, farther to the south.

Wheeler (1935) revealed small lateral moraines west of Okak Bay indicating glacial advance during deglaciation and documented potholes on the Kiglapaits summit and near Anaktalik Bay above 450 m asl, suggesting significant ice cover over these peaks. Early debate centred on whether ice inundated all of the coastal summits or nunataks persisted. Odell (1938) provided evidence of glacial smoothing above 1400 m and correlated upper felsenmeer weathering zones to post-Pleistocene frost shattering, although acknowledged the felsenmeer could predate postglacial times, perhaps unintentionally indicating polythermal subglacial conditions. Flint (1943) suggested climactic shifts lowered the regional snowline, forming small cirque systems along coastal mountains where ice built up and flowed westward, similar to Scandinavian glacial inception. Dahl (1947) disagreed with Odell (1938), suggesting ice had not covered all coastal peaks based on field observations. Flint (1943) inferred the mountains in the area would be the source of ice build-up in the region with ice flowing westerly from the ice-covered peaks along the coast (Torngat, Kaumajet and Kiglapait mountains), similar to the glacial inception observed in Scandinavia. However, Ives (1957, 1958a, b) provided definitive field evidence that ice movement was consistently west to east, indicating “instantaneous glacerization of the Labrador Peninsula” rather than coastal ice build-up. Ives (1957) also noted Odell’s (1938) glacial smoothing observations reflected bedrock structure rather than erosional features, reiterating that felsenmeer represented ice-free areas.

Through their extensive work in the Torngat Mountains, Ives (1957, 1958a, b) was the first to build a general ice-flow chronology for the mountainous coastal Labrador region, primarily defined by the previously reported weathering zones:

1) Torngat Phase: The oldest glaciation in the region, inundation of all mountain peaks from an inland ice sheet moving toward the coast.

2) Koroksoak Phase: Ice continued to flow east (from the Québec side), and the ice sheet’s elevation decreased, resulting in the formation of major outlet glaciers throughout the coastal mountain ranges, with nunataks becoming exposed (Man O’War Peak, Mt. Thorsby, Kaumajet and Kiglapait mountains).

3) Saglek Phase: Continued degradation of the ice sheet increased topographic control over the ice-flow direction, leading to the formation of multiple lateral moraines and kame terraces. (Figure 4).

Ives’ (1957, 1958a, b) rebuttal of Flint’s (1943) east-coast ice sheet inception was supported during follow-up fieldwork by Wheeler (1958) and Tomlinson (1959, 1963). Andrews’ (1961) M.Sc. thesis also rebutted Flint’s (1943) east-coast ice sheet inception model providing evidence that the mountain summits were inundated by east/east-northeast ice that flowed independently of topography (Torngat Phase). During the Koroksoak phase, Andrews (1961) proposed ice thickness reached only an elevation of 915 m, leaving some of the higher peaks (Man O'War peak, Mount Thorsby) as nunataks. This phase was again postulated to have been followed by an interglacial period where continued felsenmeer formation occurred (Andrews, 1961). The Saglek Glaciation was characterized by complete glacial inundation south of Nain, but only to a maximum vertical extent of 518 m asl, as evidenced by the high lateral moraines and cirque-valley glaciers. During this investigation, Andrews (1961) identified an area of thick (>15 m) rhythmite deposits just north of the study area, on the west end of Tasiuyak Tasialua Lake. These rhythmite deposits were deposited beneath end moraine deposits, suggesting a late-stage readvance at some point during deglaciation and marine inundation of the lowlands.

A subsequent Ph.D. by Johnson (1963) focused on the deglaciation and emergence of the Webb Bay and Port Manvers Run area along the coast. Through this work, Johnson (1963) documented erratics at the highest summits, confirming complete inundation of the coastal range, but indicated areas of felsenmeer, “nunatak forms”, and botanic evidence of incomplete inundation of the landscape during a subsequent glaciation. Through the distribution of moraines and outwash deltas, Johnson (1963, 1969) developed a succinct model of deglaciation for the coast whereby, after maximum ice thickness (~975 m asl) during the Koroksoak Phase, the ice sheet underwent progressive downwasting marked by moraine formation, a brief re-advance, and increasingly meltwater-dominated conditions, ultimately disintegrating and becoming restricted to low-lying areas.

Following the completion of the aforementioned foundational work, little additional research on the region's gla-

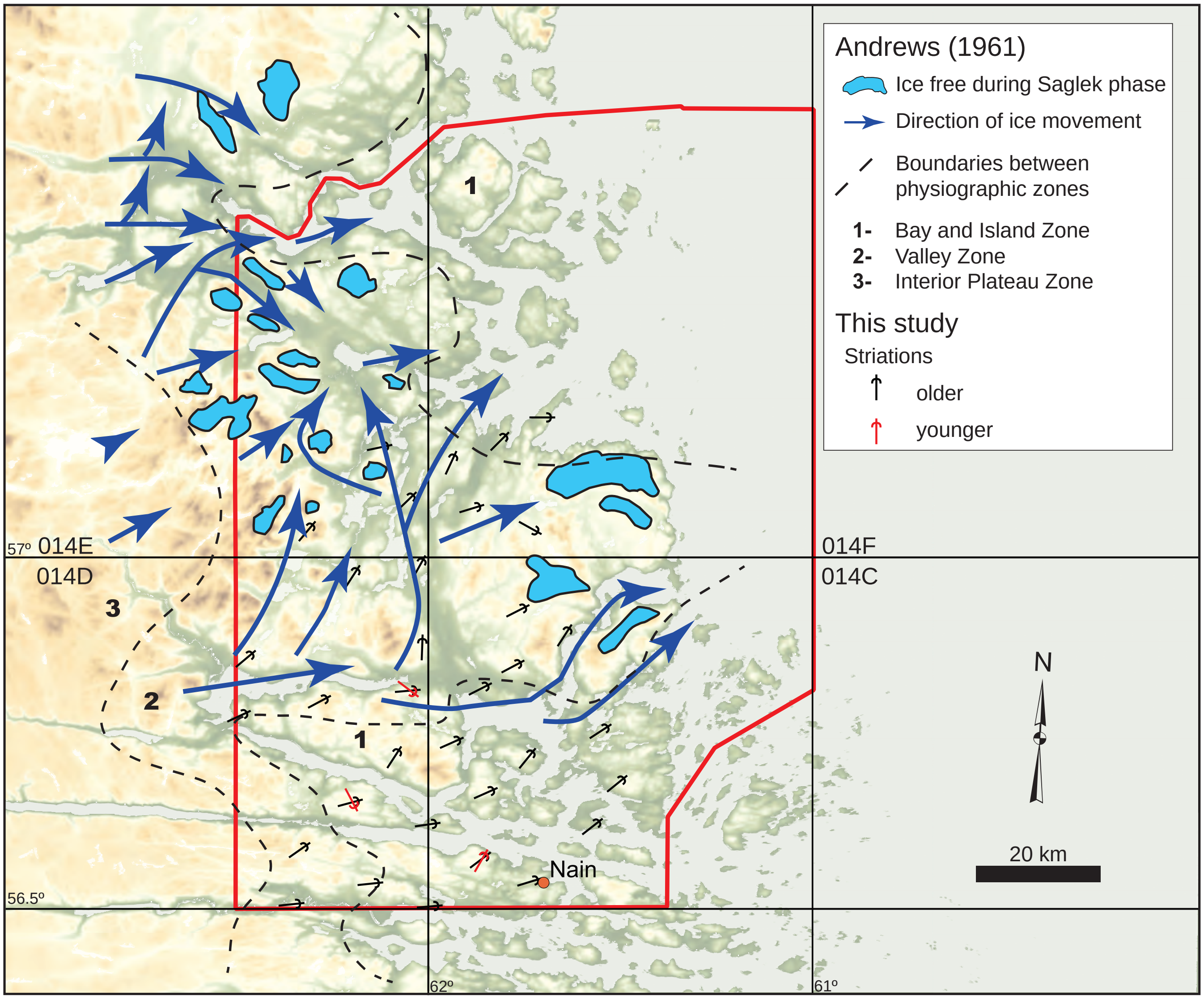


Figure 4. *Glacial reconstruction (dark blue arrows) of the Saglek phase by Andrews (1961, 1963) including areas hypothesized to have been ice free during the last phase of glaciation. Our additional ice-flow indicators from this season's field work in black (older) and red (younger).*

cial history has been conducted. Numerous studies focused on the glacial history of the Torngat Mountains to the North (Ives, 1957, 1976; Løken, 1960, 1962a, b; Evans, 1984; Clark, 1984; Evans and Rogerson, 1986; Clark *et al.*, 2003; Marquette *et al.*, 2004), to the west on interior regions of the Québec–Labrador sector (Dubé-Loubert, 2017, 2018, 2021; Rice *et al.*, 2019, 2020, 2024a, b), and south along the coast (Gray, 1969; Fulton and Hodgson, 1979; Klassen and Thompson, 1993; Couette *et al.*, 2023; Campbell, 2024). However, several outstanding questions remain for the current study area, particularly the patterns and distributions of surficial sediments, the timing of ice-free uplands, and the effectiveness of late-stage ice flows in dispersing glacial sediments.

The only existing surficial map for the area is the 1:100 000 compilation of the Labrador Peninsula by Klassen *et al.* (1992). More detailed maps (1:50 000) have been completed for areas to the southwest of the study area in NTS map areas 14D/07 (Batterson, 2001a), 14D/10 (Batterson, 2001b) and, a granular aggregate resource map for 14D/08 (Batterson, 2012).

TIMING AND PATTERN OF DEGLACIATION AND MARINE INUNDATION

Early ice sheet studies recorded marine inundation elevations, with Daly (1902) observing shorelines at 88 m asl in Ford Harbour (Torngats) and 80 m asl at Hebron. Tanner

(1944) noted 102 m asl on South Aulatsivik Island but 70 m asl in the Mugford range south of Hebron. Taken together, this suggests marine inundation was more extensive (*i.e.*, to a higher elevations) farther south along the coast from the Torngat Mountains. Wenner (1947) first constrained deglaciation timing using pollen samples and radiocarbon (^{14}C) dating, estimating coastal deglaciation around 10 k years BP. Johnson (1969) produced a robust deglacial reconstruction using ice-contact features, moraines, kame terraces and glaciofluvial features, associating moraines with temporary readvances. Short (1981) reported ages of 9.85 ± 1.21 and 8.01 ± 0.39 k calibrated years (cal) BP from organic pond sediments west of Nain. McNeely (1989) obtained a ^{14}C age of 7.93 ± 0.3 k years BP from a *Mya Truncata* shell on South Aulatsivik Island. Hemming and Hajdas (2003) showed the ice sheet extended into the Labrador Sea south of 55°N around 26 ^{14}C k years BP, retreating to the coastline by 14 ^{14}C k years BP. Recq *et al.* (2020) determined glaciomarine rhythmites on South Aulatsivik Island to be 9.4 and 9.2 k cal. BP old, with marine inundation observed up to 76 m elevation. Large-scale ice sheet reconstructions for the area have been detailed and compiled by Dyke and Prest (1987), Occhietti *et al.* (2011), Dyke (2004) and most recently by Dalton *et al.* (2023). The most recent reconstruction by Dalton *et al.* (2023) places the ice margin along the coast ~3 k earlier than Dyke (2004), though both indicate oversimplified step-wise retrogression due to limited geochronological constraints.

METHODS

To address the outstanding questions regarding the glacial evolution of the landscape and to assist in determining the buried mineral potential of the Labrador Coast, a >5000 km^2 area, north-northwest of the community of Nain (Figure 1) was selected for a joint GSC–GSNL surficial mapping and sampling program. Due to the remote location and the region's lack of infrastructure, fieldwork was conducted by helicopter. The surficial portion of the activity used surficial mapping techniques, till sampling, ice-flow indicator mapping, and geochronological sampling to improve our understanding of the region's glacial evolution and to assess the buried mineral potential of the area. Each of these methods is outlined in detail below.

ICE-FLOW AND SURFICIAL MAPPING

Outcrop-scale ice-flow indicators (*e.g.*, striations, grooves, rat tails and mini crag-and-tails; Plate 1) were measured during this summer’s field work to improve ice-flow chronology and vectors. The directions of striations and grooves were determined from the shape of the outcrops, including plucking directions. Where multiple sets of ice-flow indicators were identified, relative ages were determined through the examination of older ice-flow indicators in protected lee-side positions on bedrock outcrops (*e.g.*, Veillette and Roy, 1995; McMartin and Paulen, 2009).

TILL SAMPLING

Till samples were collected across the study area for indicator mineral studies, till matrix geochemistry analysis, sediment characteristic determination (*i.e.*, grain size, Munsell colour, *etc.*), and pebble lithology counts (Figure 5). Samples were collected at a spacing of ~1 sample per ~10 km, using protocols established by the Geological Survey of Canada (McClenaghan *et al.*, 2020, 2023; Paulen and McClenaghan, 2024; Paulen *et al.*, 2025). Sampled till was determined to be of subglacial origin based on it being poorly sorted, the abundance of striated and faceted clasts within the sediment, and a high degree of compaction. Where frost boils were present, they were targeted for till sample collection, scraping the top 10–20 cm off and hand-digging down to collect a sample (Plate 2A). In the absence of frost boils, hand-dug pits were dug into soil profiles where the C-horizon soil developed in till and considered unoxidized was targeted (Plate 2B). Sample depths ranged from 30–80 cm with an average depth of 70 cm for sample collection. During sample collection, larger clasts (>64 mm) were removed by hand, to maximize the material collected for the size fractions required during analyses. At each sample location, a ~3 kg sample was collected for till-matrix geochemistry analysis, and an additional ~10 kg sample was collected for indicator mineral recovery and clast (>2 mm) separation (Plate 2C).

SAMPLE PROCESSING

The 3 kg samples were submitted to the Sedimentology Laboratory at the GSC for geochemical sample preparation and determination of till matrix characteristics. Once received, samples were laid out to dry and, if required, disaggregated inside a plastic bag using a small rubber mallet. After drying, an ~800 g split was archived, and the remainder of each sample was subjected to matrix grain-size analysis, Munsell colour determination, and dry sieving in preparation for geochemical analysis. Matrix grain-size analysis (% sand, silt and clay) was conducted using a Lecotrac LT-100 Particle Size Analyzer. The Munsell colour of each sample (moist) was determined using a spectrophotometer linked to IQC colour software. Dry sieving was completed using stainless steel US standard sieves to recover the <0.063 and 1.0–2.0 mm fractions following GSC sieve cleaning protocols throughout (Grenier *et al.*, 2015).

To minimize cross-contamination between sites, tools used for sampling were cleaned between sites following methods outlined by McClenaghan *et al.* (2023). To evaluate the accuracy and precision of the analytical laboratories, blanks, duplicates and standard samples were inserted into

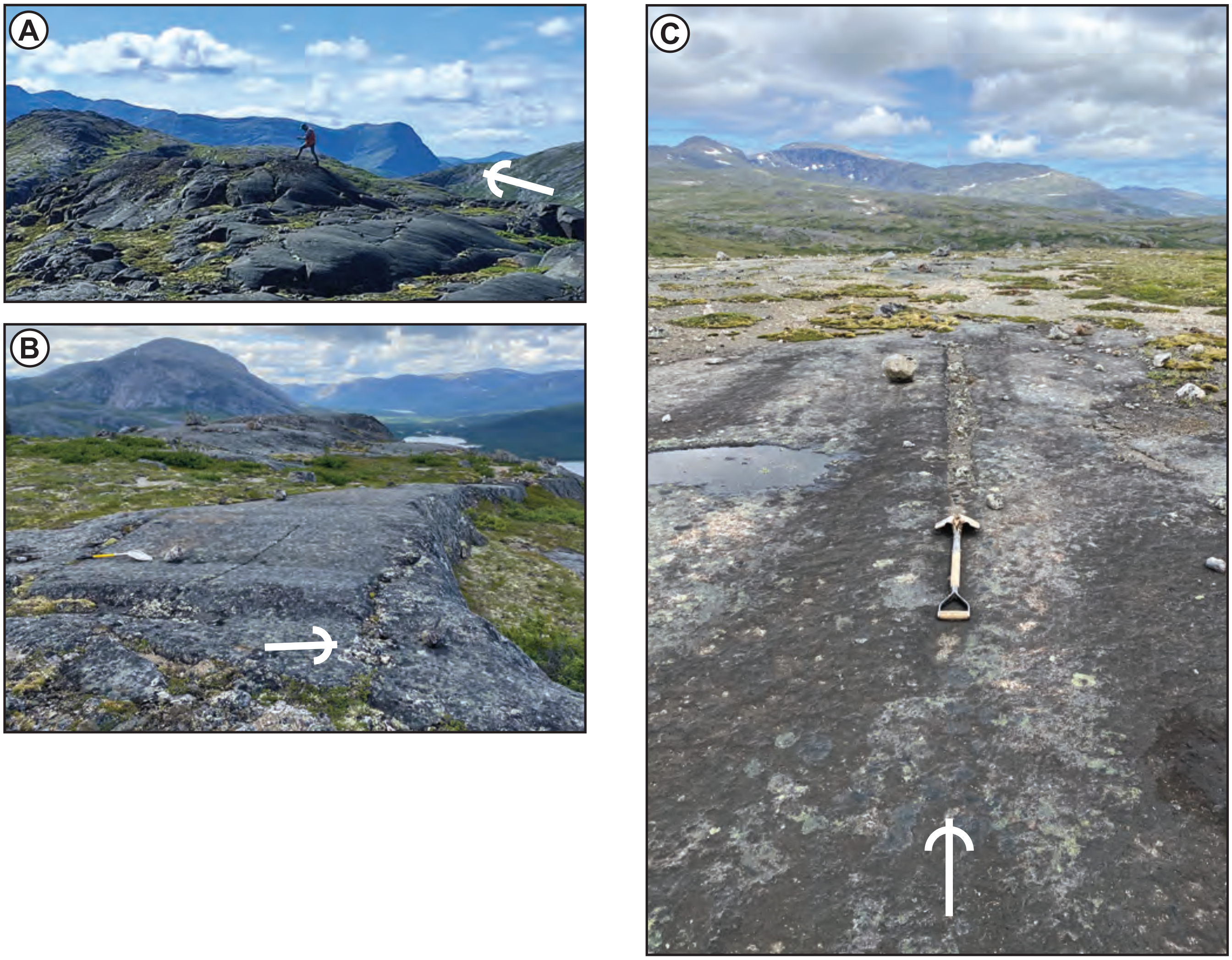


Plate 1. *Examples of ice-flow indicators observed during fieldwork, refer to Figure 5 for locations. Ice flow direction indicated by white arrow. A) Glacially polished and striated stoss side, and plucked lee side of mafic bedrock, from the Tikkigaksuk Peninsula, indicating ice flow toward the east in the direction of the white arrow (Site 25RBA051); B) A large groove with a lee-side plucking edge down ice observed at site 25RBA024; C) Deep weathered groove shown by shovel indicating ice flow to the east-northeast in the direction of the white arrow (Site 25RBA031).*

the batch of routine till samples for quality assurance and quality control (QA/QC). A total of three blanks, two field duplicates and two laboratory duplicates were submitted with the batch of samples submitted for geochemical analyses. Three blanks and two field duplicates (*e.g.*, Plate 2C) were also submitted with the routine batch of samples submitted for indicator mineral separation and identification.

GEOCHEMICAL ANALYSIS

The <0.063 mm fraction for each sample were separated, and the aliquots will be shipped to Activation Laboratories in Ancaster, ON. Samples were submitted for the following digestion methods: 1) lithium borate fusion digestion with analysis by ICP-MS (Package 6), 2) a near total 4-acid digestion with analysis by ICP-ES+MS (Package 7 requested on a 30 g aliquot), and 3) fire assay digestion with analysis by ICP-ES/MS (Package 11) for determination of major, minor, and trace elements using a variety of detection methods. Blind laboratory duplicates were inserted into the batches by the GSC's sedimentology laboratory to monitor analytical precision.

INDICATOR MINERAL SEPARATION AND IDENTIFICATION

The larger ~10 kg samples were submitted to Overburden Drilling Management (ODM), Ottawa, ON, for

Figure 5. *Sample location map showing the distribution of till samples collected (geochemistry and indicator mineral analyses), observations and samples collected for cosmogenic exposure age dating.*

Plate 2. *A) Example of frost boil targeted for till sampling at site 25RBA065; B) Test-pit dug to expose the C horizon for sampling at site 25RBA023; C) Showing sample bags and size for different analysis, the larger for indicator-mineral identification and the smaller for geochemistry and a duplicate sample to assess QA/QC at site 25RBA035; D–F) Examples of how samples are collected for cosmogenic exposure age dating from site 25RBA057 where (D) the erratics are scored in a grid pattern to allow (E) chiseling out of the required sample (F) for exposure age dating.*

indicator mineral separation and identification. At ODM, samples were wet-sieved to remove the >2 mm fraction, which were retained, washed in an oxalic bath to remove stains or cemented till, and returned to the GSC for clast lithology determination. The <2.00 mm fraction were passed over a Deister concentrating table, with the table pre-concentrate recovered and micro-panned to recover gold grains, platinum-group minerals, uranium minerals, zircons and any other heavy minerals (*i.e.*, >3.2 specific gravity; SG). Following tabling, the pre-concentrate is sieved at 0.25 mm, and the 0.25–2.0 mm fraction is further refined using heavy liquid separation in methylene iodide that has been diluted to an SG of 3.2 to recover the >3.2 SG fraction for further examination. Once recovered, the minerals are counted, their size estimated, potentially photographed and/or confirmed using a scanning electron microscope, and returned to the GSC.

GEOCHRONOLOGICAL SAMPLING

To constrain the timing of deglaciation within the study area and better understand the paleo-glaciological evolution of the moraines identified and their relation to regional deglaciation, eight geochronological samples were collected (Plate 2D–F). Cosmogenic ^{10}Be exposure age dating constrains the timing of deglaciation by quantifying the duration of cosmic-ray exposure of a rock surface following the retreat of an overlying ice sheet. High-energy cosmic rays penetrate Earth's atmosphere and produce secondary particles (neutrons, muons, and protons) that reach the surface (Gosse and Phillips, 2001). These particles collide with target atoms in quartz, producing ^{10}Be through spallation reactions (Lal, 1991; Gosse and Phillips, 2001). The concentration of ^{10}Be accumulates predictably over time at production rates that vary with latitude, altitude and shielding (Balco *et al.*, 2008). By measuring ^{10}Be concentrations using accelerator mass spectrometry (AMS), researchers can calculate exposure ages (Gosse and Phillips, 2001). The method assumes continuous exposure, negligible erosion and no inherited nuclides from prior exposure. This technique is widely used for dating glacial landforms, including moraines and erratics, providing critical constraints on ice sheet retreat timing (Briner *et al.*, 2003). Large (>1 m a-axis), stable erratic boulders with >25% quartz from windswept features were the target for sample collection. Samples were collected using a battery-powered concrete saw to cut into the rock and a hammer and chisel to collect the top ~3–5 cm of the rock's surface (Plate 2F). The sample locations were selected to limit topographic shielding; however, as multiple samples were collected from moraine ridges in low-lying valleys, some shielding could not be avoided. Three samples (25RBA062A01, 02, 03) were collected from an upland just south of Umiakoviagusek Lake, which Andrews (1963) identified as being ice free during the Saglek phase. Three additional samples (25RBA057A01, 02, 03) were collected by a nearby terminal moraine to assess the difference in deglacial timing between the two landforms. Two additional samples (25RBA072A01, 25RBA072A02), were collected from a small terminal moraine on the western edge of the Kiglapait Mountains to assess the difference in timing between two moraine formations. Samples were submitted to the Cosmic Ray Isotopes Sciences at Dalhousie (CRISDal) Lab, at Dalhousie University, Halifax, NS, for analysis.

RESULTS

Observations across the study area show a marked transition from a major fjord control on late-stage ice flow in the south to more topographic control on late-stage ice flow in the north of the study area. Evidence of glaciation was observed across the study area, confirming early researchers' suggestion of complete glaciation. Evidence of glaciation was prominent at every site visited, with till deposits recorded and collected at a maximum elevation of 958 m asl (25RBA032) where multiple erratic boulders were observed around the sample location. Interestingly, at two locations, potholes similar to those observed by Wheeler (1935) were observed. At sample location 25RBA044, potholes were recorded at elevations ~613 m asl and at an even greater elevation of ~835 m asl at sample site 25RBA062, suggesting significant ice build-up over these regions as moulins formed above these uplands.

ICE-FLOW INDICATORS

Thirty-seven new ice-flow measurements (striae, grooves, nailhead striae, crescentic chattermarks and lunate fractures) were recorded from 34 sites (Plate 1). The direction was determined for 36 striae (*see* https://geoatlas.gov.nl.ca for striation data) using stoss and lee relationships, while the direction of the remaining striae could not be determined. Three sites contained multi-directional ice-flow indicators (25RBA008, 25RBA012 and 25RBA070). At these locations, crosscutting and lee-side preservation relationships were used to try to establish age relationships. Age relationships were only determined at two sites. The following is a brief description of these sites:

25RBA008: At a location just north of the Fraser River, two sets of striae were measured at this site independently of one another and therefore without a crosscutting relationship. Both sets of striae were well developed and had high directional confidence. The oldest is an east-northeast flow (75°) identified on the stoss side of glacial moulded bedrock. The youngest is a south-southeast flow (152°) measured 50 m to the southeast in a small gully. The gully could represent a slight deviation from the main flow, funnelled into the gully during the oldest phase, or a small meltwater channel that was later utilized by a later flow. Either way, this flow is interpreted as late-stage flow when topography had more control on ice-flow vectors.

25RBA012: Striae identified at the southeast end of Kingurutik Lake were identified on anorthosite bedrock. Two sets of ice-flow measurements were located 150–200 m from each other and as a result no age relationship could be determined. One set of striae was located west of a large anorthosite boulder. This exposure was excellent and numerous striae and nailhead striae recorded an ice-flow direction of 85°. The second set of striae was located 150–200 m south at a higher elevation and recorded an ice-flow direction of 127°. These striae were scarce and only found and recorded on a small smooth patch of polished bedrock.

25RBA070: South of Kaiktusuak Point in Nain Bay, a multidirectional site recorded both a northeast flow (53°) and a north-northeast flow (30°) at the bottom of a till sampling pit. The northeast flow was designated the oldest as it was preserved in the lee of the north-northeast flow.

Overall, the ice-flow indicators measured across the study area largely conform to ice-flow reconstruction of previous workers (*i.e.*, Andrews and Matthew, 1961; Klassen and Thompson, 1993; Veillette *et al.*, 1999). Outcrop-scale ice-flow indicators suggest an early flow broadly to the northeast across much of the study area, followed by more topographically controlled, locally variable ice-flow phases, with ice funnelling into the lowlands and meandering around bedrock knobs (Figure 4). Given the nature of the fieldwork, there is a bias toward ice-flow measurements in the uplands as many of the lowlands were inaccessible via helicopter-supported work. It is therefore likely that there are potentially even more local variations in ice flow within the valleys and lowlands, which are largely vegetated or covered in thick postglacial deposits (*i.e.*, outwash and marine sediments).

SURFICIAL MAPPING

Hundreds of aerial observations and 55 sample sites were used to describe both the characteristics and distribution of glacial sediments (Figure 5; Plate 3). Sedimentary sections exposed along riverbanks are rare, and as a result,

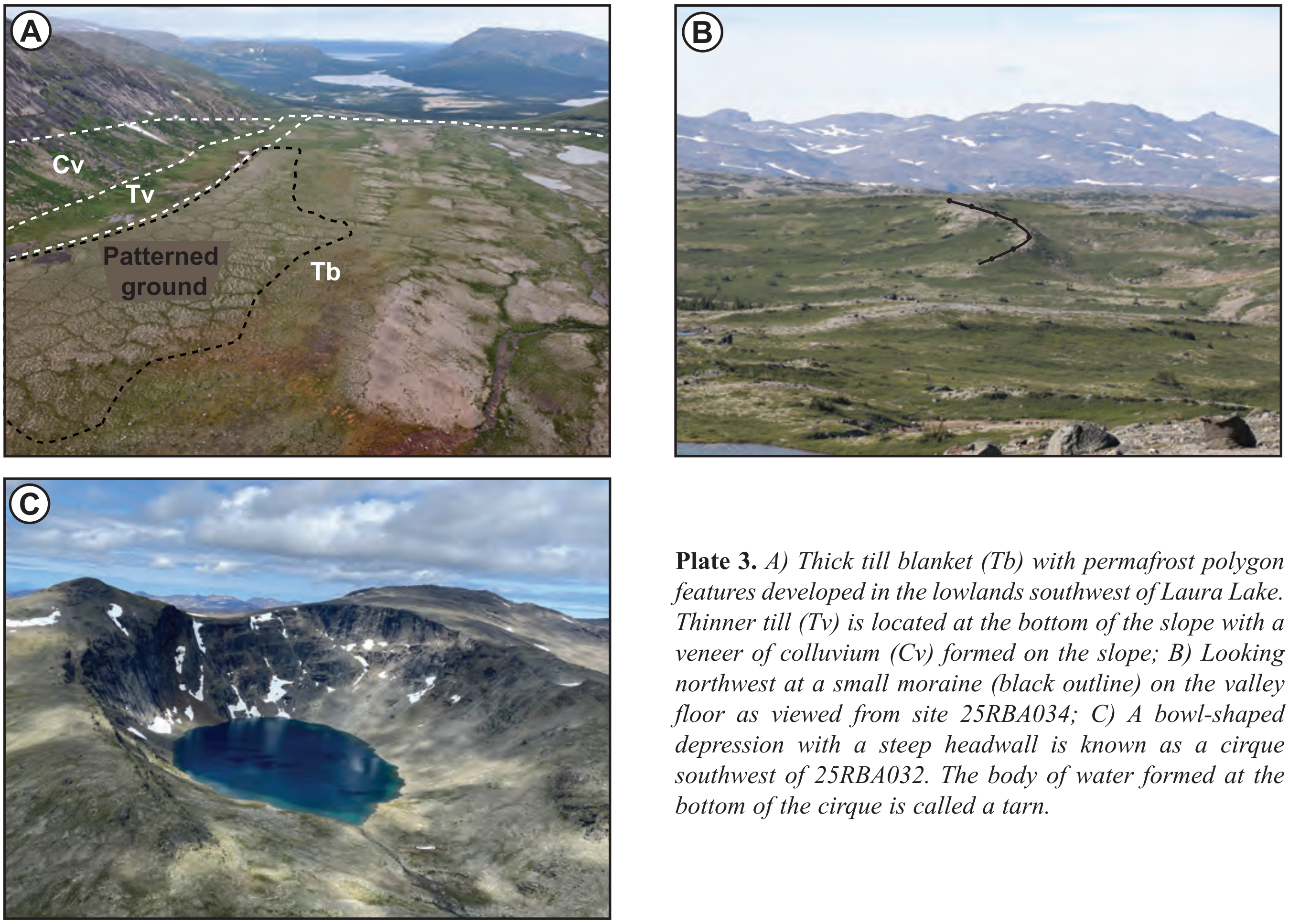


Plate 3. *A) Thick till blanket (Tb) with permafrost polygon features developed in the lowlands southwest of Laura Lake. Thinner till (Tv) is located at the bottom of the slope with a veneer of colluvium (Cv) formed on the slope; B) Looking northwest at a small moraine (black outline) on the valley floor as viewed from site 25RBA034; C) A bowl-shaped depression with a steep headwall is known as a cirque southwest of 25RBA032. The body of water formed at the bottom of the cirque is called a tarn.*

only one stratigraphic unit is described for the study area. Field observations indicate that generally, till across the study area has a matrix that varies between a silty sand and sandy silt. Till veneer and exposed bedrock are the most common units observed across the study area, although thicker pockets of till were observed in many locations, including at topographic highs, but more broadly in the lowlands, above marine limit (Plate 3A).

Numerous moraines, commonly associated with small cirques (Plate 3B, C), were identified, including several minor moraines in addition to those documented by Andrews (1961). While many moraines were viewed from the air, only three were visited during field investigations (25RBA072, 25RBA058 and 25RBA57). The primary reason for visiting these locations was to sample boulders for cosmogenic ^{10}Be surface-exposure age determination. The moraine complex at site 25RBA072 formed a small steep-sided semi-circle feature that is close to 500-m long and 15 to 20 m high. It contains lateral moraines extending up slope that reach 400 m in length. Lateral moraines up to 1000-m long have been identified on the slope of the mountain overhanging Puttuaalu Brook. Others have been found associated with topographic highs and outcropping bedrock southwest of Aupalukitak Mountain.

Erosional streamlined features like sculpted bedrock and roche moutonnées are quite common within the study area. However, depositional streamlined features such as crag-and-tails, drumlins and flutes are less common. Of note is a series of five streamlined features north of Iglusuataliksuak Lake, which range in length from 380 to 1770 m, and 70 to 160 m in width. These landforms are low profile and, given their elongation ratios, suggest pockets of ice streaming within some of the lowland valleys.

Postglacial sedimentation is widespread, particularly within valleys where meltwater was routed through major bedrock troughs (Plate 4A). Large outwash deltas, kettle and kame complexes, and related landforms indicate ice stagnation (Plate 4B, C), which provide key constraints on ice-margin retreat patterns and marine inundation elevations. Postglacial marine sediments and organic deposits are common below 84 m asl, while colluvium and landslide scars occur on steeper slopes.

Evidence of marine inundation is apparent through fine-grained sediments at the base of sections exposed in the small river valleys that drain into Tasiuyak Bay. Marine deltas generally mark the transition between glaciofluvial and marine depositional events. Marked transitions between marine inundation and glaciofluvial deposition are marked where marine sands and clays were identified in Puttuaalu Brook (site 25RBA039) and Avakutak Brook (site 25RBA060) and are overlain by outwash deposits (Plate 4D).

Raised beaches are located relatively close in elevation to the modern-day sea level, such as those found north of Nain at Sandy Point (Plate 4E). Raised beaches identified east of Kingurutik Lake are higher based on the 61 m elevation from the topographic map. The highest beaches identified so far are located in the Anaktalik Brook valley on the delta surface at site 25RBA068. A cobbly gravel beach at this location was measured to be approximately 84 m asl using a GPS (± 5 m).

Organics and well-developed permafrost features are commonly developed on marine sediments; bogs, fens, peat, and palsas are all common in low-lying areas and in depressions within the uplands where drainage is restricted or absent. A well-developed palsa bog is situated northwest of Webb Bay.

TILL SAMPLING

A total of 55 till samples were collected for geochemistry, till matrix characterization, indicator mineral analysis and clast provenance determination. Results for these analyses are forthcoming. In addition to observations at each till sampling location, eight sites were visited to support surficial mapping.

At 77% of sites, the till is poorly sorted, massive, and with a silty-sandy matrix. Field estimates for fines concentration are low (1 to 10%), while clast concentration ranges from low (<20%) to moderate (21–40%). The clasts within the till range in diameter from 1 to 50 cm and are typically subangular. Clasts are commonly striated, faceted, and can be bullet-shaped. Boulders up to 800 cm in diameter are found on the surface. These especially large erratics are present throughout the study area regardless of till cover. Most of the erratics identified at each site were anorthosites or granites, with some locations having significantly weathered erratics, likely associated with the amount of olivine within the boulders and not an indication of pre-glacial exposure.

The remaining sites (23%) are characterized by till that is matrix-supported, massive, poorly sorted, with sandy-silt, having slightly higher concentrations of fines. The texture of this till has a moderate (11–20%) concentration of fines and low (<20%) clast concentration. Although striated, faceted, and bulleted clasts are present in field observations, they are generally in lower quantities than the silty-sand matrix till relative to the sandy-silt tills. Clasts range from 2 to 70 cm

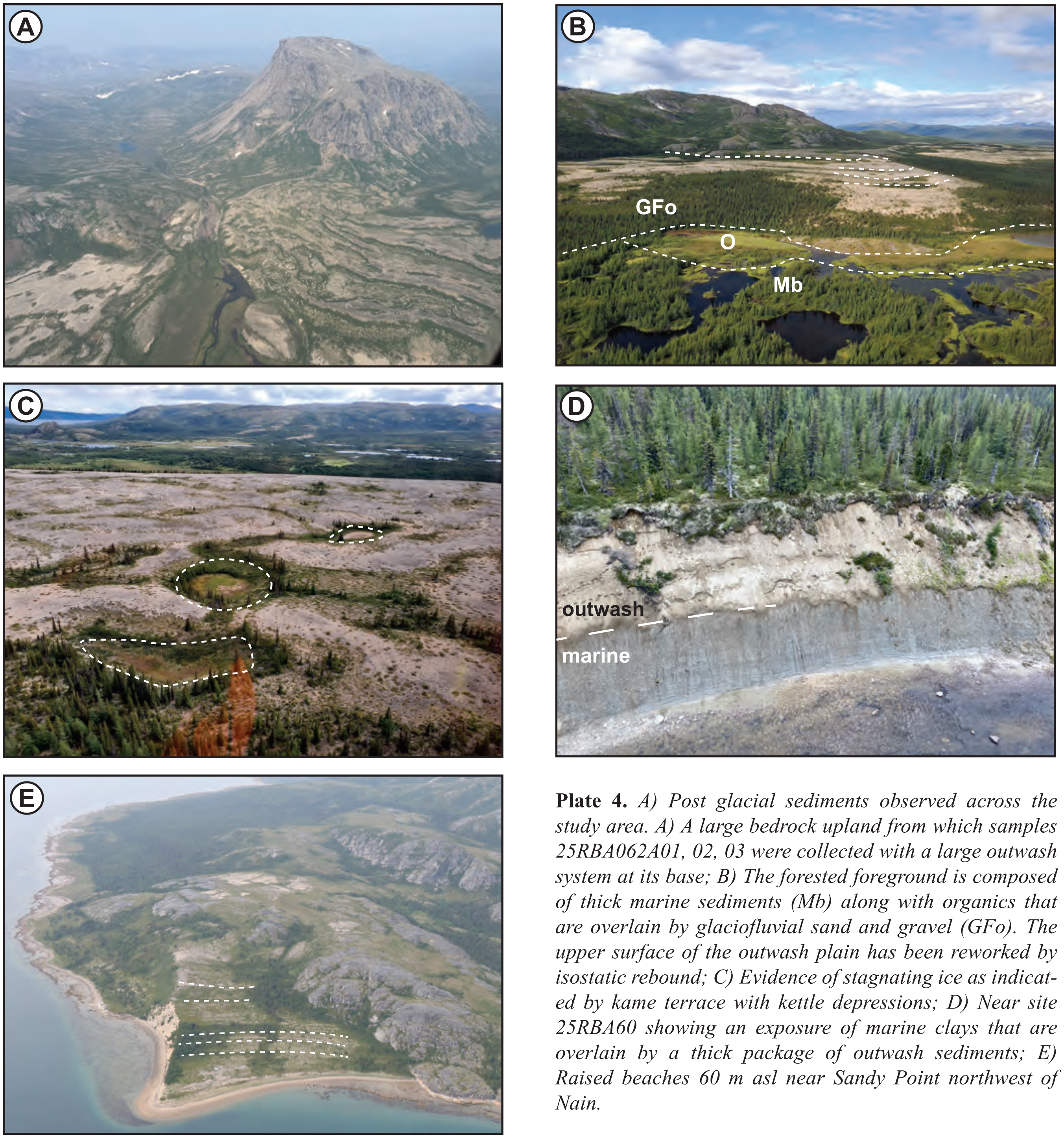


Plate 4. *A) Post glacial sediments observed across the study area. A) A large bedrock upland from which samples 25RBA062A01, 02, 03 were collected with a large outwash system at its base; B) The forested foreground is composed of thick marine sediments (Mb) along with organics that are overlain by glaciofluvial sand and gravel (GFo). The upper surface of the outwash plain has been reworked by isostatic rebound; C) Evidence of stagnating ice as indicated by kame terrace with kettle depressions; D) Near site 25RBA60 showing an exposure of marine clays that are overlain by a thick package of outwash sediments; E) Raised beaches 60 m asl near Sandy Point northwest of Nain.*

in diameter and are angular to subrounded in shape. Sites with a sandy-silt texture are located in the central part of the study area from Kingurutik Lake to Port Manvers Run, associated with anorthosite (Unit 35), quartzofeldspathic gneiss (Unit 3), and granite (Unit 39). In addition, one site is found west of Franks Lake and is associated with granitoid rocks that vary from quartz diorite to leucogranite (Unit 10; Hinchey *et al., this volume*).

At each site, the colour of the till was noted; no clear spatial pattern correlating till colour to bedrock unit is evident. However, more accurate laboratory Munsell colour determination may elucidate this pattern more accurately, as lighting, moisture, and personal bias make field determination of till colour much less consistent.

FUTURE WORK

Surficial geology maps will be created at different scales for different regions of the study area. Maps at a scale of 1:50 000 will be created for NTS map areas 14C/12 and 14D/09 and a 1:100 000 scale map will be created for the NTS map areas 14C/13, 14D/16, 14E/01 and 14F/04. Surficial maps will be created through airphoto interpretation and will be aided by existing digital elevation models for the region. Areas of interest or complex surficial geology were visited during the 2025 field season to confirm mapped interpretation. As part of surficial mapping activities, ice-flow directions will be determined by measuring streamlined glacial landforms (*e.g.*, crag-and-tails, drumlins and large-scale glacial lineations) from satellite imagery and aerial photographs. The surficial mapping will aim to improve our overall understanding of glaciation and provide important constraints on the pattern of deglaciation and the elevation at which marine inundation occurred. Mapping of the terminal and lateral moraines will provide limits to the extent of the ice margin during their deposition. Mapping the distribution of outwash sediments and deltas will also provide important constraints on the position of the ice margin during deglaciation. Delineation of glacially elongated landforms (*i.e.*, flutings, drumlins), will help determine ice-flow direction in areas where striation data was not recorded. The mapped extent of marine sediments will also provide important context for the elevation at which marine inundation occurred across the study area, and whether there was a marked change in marine inundation levels from the northern extent to the southern extent of the study area.

The 55 regional till samples will provide important indicator mineral and geochemical data, as there are currently no publicly available till data within the region. The data will also help to develop a regional framework for dispersal investigations. As it stands, it is unclear at what time during deglaciation the elevated hilltops became ice-free, when the small cirques developed, and when the many moraines across the region were deposited, and whether all three events were contemporaneous.

The erratic boulder samples collected for cosmogenic nuclide analyses will provide critical information for reconstructing the region's glacial history. Specifically, exposure age calculations from the data for the hilltop samples will provide empirical evidence of whether nunataks were abundant during the last phase of glaciation, or if these hilltops only became ice-free near regional deglaciation. These results, paired with the moraine samples, will provide important constraints for evaluating if the moraines in the region were a function of a late-stage glacial advance or developed shortly after the deglaciation of the hilltops. The erratic boulder samples collected from near the Kiglapait Mountains will determine whether these moraine-forming process occurred contemporaneously, or if the elevated hilltops along the coast had glacial dynamics significantly different from those farther inland.

SUMMARY

A joint surficial mapping, till sampling and geochronological sampling activity by the GSNL, GSC and Nunatsiavut Government was conducted across ~5000 km^2 north-northwest of Voisey's Bay to address the lack of detailed geoscience data in this critical mineral-rich region. Helicopter-supported fieldwork documented 37 new ice-flow measurements revealing early northeast-directed flow followed by topographically controlled phases, collected 55 till samples for geochemistry and indicator mineral analysis, and gathered eight erratic boulders for cosmogenic ^{10}Be exposure dating. Field observations confirm complete glaciation to elevations exceeding 950 m asl, with marine inundation reaching ~84 m asl and numerous moraines, cirques and streamlined features identified across the study area. Future results will constrain the timing and pattern of deglaciation, improve understanding of glacial dynamics, and provide essential till geochemistry, indicator mineral, and ice flow data to guide mineral exploration for Cu, Ni and REEs in this understudied region.

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