*Current Research (2022) Newfoundland and Labrador Department of Industry, Energy and Technology*
*Geological Survey, Report 22-1, pages 211-235*

# NORTHWEST GANDER SURFICIAL MAPPING PROJECT: PRELIMINARY INVESTIGATIONS

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## ABSTRACT

*Quaternary investigations in the northwest Gander region were initiated in 2021 to study the complex glacial history resulting from multiple ice flows and marine incursions. Fieldwork focused on detailed surficial and ice-flow mapping and characterization of surficial units. Results of these studies are beneficial to early-stage mineral exploration programs undertaken by prospectors and/or the mining/mineral industry.*

*Twenty-six new ice-flow indicators were measured from 20 sites. Relative age relationships identified at a number of sites record two phases of ice flow: Phase 1 – an early east-southeast flow followed, by Phase 2 – a pervasive north-northeast flow that is also recorded by streamline landforms. These results are in keeping with the already established regional ice-flow chronology. It is important to note that Phase 3, seen regionally as two discrete flows (northwest and northeast) exists within the study area but were not recorded from any of the sites this past summer (2021).*

*The surficial geology includes till, organic deposits and glaciofluvial sediments in the Gander River valley, and tributaries; sparse distribution of marine sediment were also recorded. Till is the dominant surficial unit; it has a varying thickness of between 1–6 m and is thinner toward the coast. It forms varying morphologies including veneers, hummocks, eroded and lineated (streamlined) ridges and blankets. Three till units, of unknown lateral extent, were identified at one site. The upper two tills were identified in 30% of sites visited indicating they are more widespread than previously thought. This has important implications for mineral exploration and suggests that knowledge of till units is paramount when conducting sampling programs, and in some areas, sampling techniques may need to be adjusted to accurately reflect the underlying surficial geology.*

## INTRODUCTION

Gold exploration, west of Gander, has increased dramatically in recent years. Exploration in the area follows major geological structural trends hosting orogenic and epithermal gold. The complexity of the Quaternary geology and knowledge gaps, with respect to regional ice-flow events and till composition, pose challenges to exploration. These inadequacies may require explorationists to modify their sampling techniques and analytical methods to achieve optimum results.

The region has experienced multiple phases of ice flow during the Late Wisconsinan as interpreted from glacial striae, subglacial landforms and stratigraphy. The reconstructed irregular retreat pattern of the Newfoundland Ice Sheet (NIS) and extent of marine incursion increases the complexity.

A multi-year project, initiated during the summer of 2021 to better understand the Quaternary glacial history and marine incursion in the region, examines the spatial distribution of large-scale landforms and sediment assemblages. This will be achieved by:

- Using digital elevation models (DEM) to map large-scale subglacial landforms and "ground-truthing" those originally identified by Blundon *et al.* (2009, 2010) and McHenry and Dunlop (2016);
- Refine earlier surveyed maps (*e.g.*, Scott and Taylor, 2012, 2014; Batterson, 2000) by comparing detailed high-resolution digital aerial photography and DEMs to produce new detailed surficial maps;
- Determining stratigraphy by documenting sedimentary structures, colour, texture and interpreting geochemical analyses from sediment exposures, hand-dug and backhoe-excavated pits; and,
- Using the spatial distribution of landforms of marine or glaciomarine origin (raised beaches, deltas, wave-cut platforms and terraces) and sediments (well-sorted silts and clays) to refine the marine limit.

The focus of the 2021 field season was mapping and sediment characterization of glacial diamictons (tills) and surficial sediments, familiarizing with the bedrock geology, determining site accessibility, and identification of areas of thick overburden that would be appropriate for trenching. This report provides a regional overview of the Quaternary history along with preliminary observations from fieldwork conducted north of Gander Lake on NTS map areas 2D/14, 15 and the eastern half of NTS map areas 2E/01, 02, 07 (Figure 1).

## PHYSIOGRAPHY AND LOCATION

The study area is located near Gander in east-central Newfoundland, between Boot Pond in the east and Twin Ponds to the west, and from the mouth of Northwest Gander River in the southwest to Gander Bay in the northeast (Figure 1).

Gander Lake is a prominent feature in the study area, which is roughly 50 km long on its west-trending long axis, 2.5 km wide and 288 m deep. The lake drains into Gander Bay from a western outlet along the 50 km long Gander River. The relatively high depth to width ratio suggests that Gander Lake was a glacial fjord with an eastward outlet to the Atlantic Ocean prior to the Wisconsinan glaciation (Jenness, 1960). South of Gander Lake, gentle undulating topography rises to an elevation of 320 m above sea level (asl). North of Gander Lake, the topography is low-lying (generally less than 100 m asl) and dips toward the coast. Mount Peyton is the highest point (472 m asl), located in the western study area.

### BEDROCK GEOLOGY

The following is a brief summary of the regional bedrock geology (*see* Blackwood, 1982; O'Neill and Blackwood, 1989; O'Neill, 1991; Currie 1995, 1997; Dickson *et al.*, 2000). The study area straddles the north-northeastern boundary between the Exploits Subzone of the Dunnage Zone and the Gander Zone of the Ganderian microcontinent in Newfoundland (Figure 2; Williams *et al.*, 1988; Colman-Sadd *et al.*, 1990; van Stall and Barr, 2012). It is transected by a number of north- to northeast-trending fault zones, including, from west to east, the Reach Fault, the Dog Bay Line and the Gander River Ultramafic Belt (GRUB) fault (Goodwin and O'Neill, 1991; Currie, 1997; Williams *et al.*, 1993). Two other faults have been proposed (*see* New Found Gold Corporation, 2022) including the Appleton fault and the Joe Batts Pond fault, although their northward and southward extensions are not presently known (Figure 2).

The GRUB is now termed the Gander River Complex (CO:X; Figure 2: *see* O'Neill and Blackwood, 1989). In the east, the Gander Group (CO:G; Figure 2) forms the westernmost unit of the Gander Zone and consists of southwest-trending Ordovician sandstone, siltstone, pelite, semipelite and volcanic rocks (Blackwood, 1982). The Gander Group is structurally overlain by the ophiolitic rocks of the Gander River Complex. The Gander River Complex represents the faulted boundary marking the most northwesterly exposures of intra-oceanic Exploits Subzone (ultramafic and mafic rocks) overlying the Gander Zone basement in this area (O'Neill and Blackwood, 1989; Wonderly and Neumann, 1984; Evans, 1996). The Gander River Complex includes gabbro, mafic volcanic and volcaniclastic rocks, variably serpentinized pyroxenite and trondhjemite (O'Neill and Blackwood, 1989; O'Neill, 1991). Gander River Complex rocks are themselves stratigraphically overlain by the quartz-poor sandstone, siltstone, shale and conglomerate of the northeast-trending, Middle to Late Ordovician Davidsville Group (O:D; Figure 2; O'Neill and Blackwood, 1989).

East of the Dog Bay Line, the Davidsville Group is overlain by the Late Silurian to Early Devonian, carbonate-bearing muscovitic sandstone and siltstone of the Indian Islands Group (Williams *et al.*, 1993; Currie, 1995; Dickson *et al.*, 2007; Sandeman *et al.*, 2018). Rocks of the Davidsville and Indian Islands groups only occur south and east of the Dog Bay Line. Their equivalents west and north of the Dog Bay Line are the Exploits, Badger and Botwood groups (Williams *et al.*, 1993; Currie, 1995). Early to Middle Devonian granitic plutons intrude both the Gander Zone and Exploits Subzone rocks (Blackwood, 1982; O'Neill and Lux, 1989). The north and easterly glacial ice-flow directions, determined from previous investigations (Batterson and Vatcher, 1991; Scott, 1994a; Brushett, 2012), suggest that the muscovite–biotite syenogranite of the Hunts Pond Intrusion (mD:H; Figure 2) and the fine- to medium-grained hornblende–biotite monzogranite and diorite–gabbro of the Mount Peyton Intrusive Suite (SD:P; Figure 2) are considered useful indicators of distance and direction of glacial transport.

### MINERAL OCCURRENCES

Mineral exploration initially focused on base-metal showings (Cu, Ni) associated with the ultramafic rocks of the Gander River Complex (Evans, 1996; CO:X; Figure 2). However, the discovery of gold in the Jonathan's Pond area (Blackwood, 1982), and gold anomalies identified in lake sediments (Davenport and Nolan, 1989), resulted in widespread gold exploration in the late 1980s by the mineral industry (Evans, 1996). Exploration for gold during the late 1980s to early 1990s led to discoveries of stibnite (antimony;

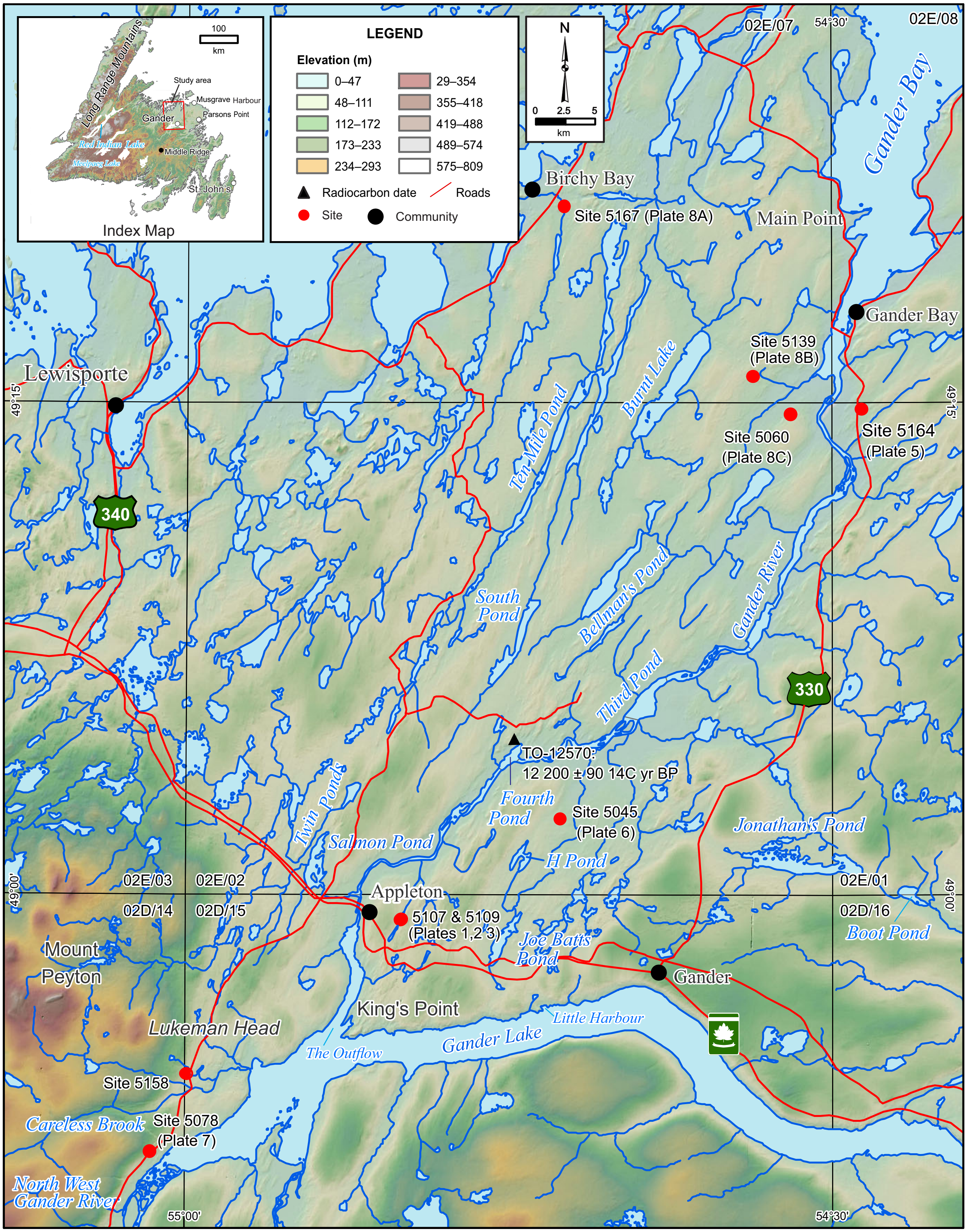

**Figure 1.** *Location of the study area (red box on inset) illustrating the physiography and place names used in the text. Location of Noggin Hill is shown in Figure 6. Red dots show location of sites and plates mentioned in the text. Black triangle shows location of radiocarbon dated* Hiatella artictia *(TO-12570) along the Gander River (McCuaig, 2006).*

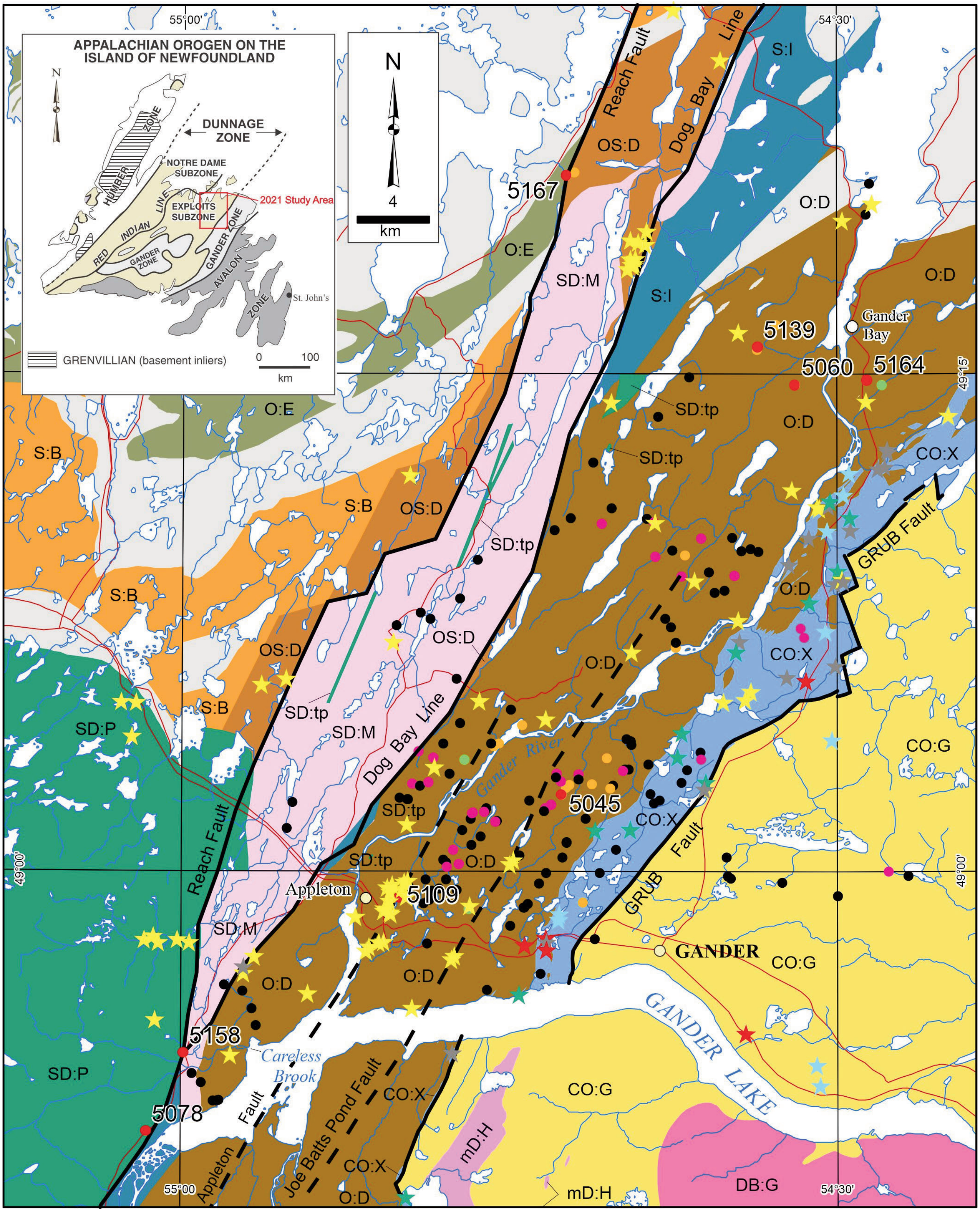

Figure 2. *Caption and legend on page 215.*

**LEGEND**

▨ Bedrock units not mentioned in text

**Lower Devonian to Mississippian**

Gander Lake Granite

DB:G Grey to white K-Feldspar metacrystic, biotite granite

**Middle Devonian**

Hunts Ponds Intrusion

mD:H Foliated, equigranular, muscovite–biotite–garnet granite

**Lower Silurian to Early Devonian**

Ten Mile Lake Formation

SD:M Purple to red shale and thin pink sandstone beds

**Early Silurian to Middle Devonian**

SD: tp: Uralitized and saussuritized gabbro dykes

Mount Peyton Intrusive Suite

P: Equigranular, biotite granite, minor granodiorite, hornblende and pyroxene gabbro, and diabase dykes

**Early to Lower Silurian**

Botwood Group

S:B Subaerial mafic and felsic flows, shallow marine to subaerial red-green and grey sandstone, siltstone and shale

Indian Islands Group

S:I Grey calcareous siltstone and local fossiliferous limestone lenses, grey to black shale pale buff siltstone, limestone and limestone breccia

**Lower Ordovician to Early Silurian**

Badger Group

O:SB Grey, well-bedded greywacke, including conglomerate layers, grey and minor red conglomerate

**Early Ordovician to Early Silurian**

Duder Group

OS:D Dark grey shale and siltstone, melange consisting of blocks of gabbro and volcanic rocks

**Early to Lower Ordovician**

Davidsville Group

O:D Shale, siltstone and sandstone, minor conglomerate, limestone and volcanic rocks

**Early to Middle Ordovician**

Exploits Group

O:E Marine pillow lava and pyroclastic rocks, sandstone, shale and siltstone, argillite, chert, conglomerate

**Lower Cambrian to Middle Ordovician**

Gander River Complex

CO:X Ophiolite complex - pyroxenite, serpentinite, magnesite, gabbro, talc/tremolite zones, volcaniclastic rocks trondhjemite

**Early Cambrian to Middle Ordovician**

Gander Group

CO:G Interbedded psammite, semipelite and pelite

**SYMBOLS**

**Mineral Occurrences**

★ Gold

★ Asbestos

★ Copper

★ Pyrite

★ Antimony; Arsenic; Chromium; Granodiorite; Lead; Limestone; Magnesium; Manganese; Nickel; Platinum; Pyrrhotite; Slate; Tungsten; Zinc

**Sites**

● Observation

● 5600 Sites mentioned in text

● Multiple tills

● Glaciotectonized till

● Glaciofluvial sediment

— Faults

– – – Proposed faults by New Found Gold Corp.(2022)

— Roads

○ Community

**Figure 2.** *Generalized geology of the study area (GSNL, 2021a). Only bedrock units mentioned in text are coloured. Major faults, such as the Reach, Dog Bay Line and Gander River Ultramafic Belt fault zones based on work by Sandeman (personal communication, 2022; Sandeman* et al*., 2017) and Appleton and Joe Batts Pond faults proposed by New Found Gold Corporation (2022) are shown on map. Locations of gold occurrences corresponding with bedrock units described in the text are identified by yellow stars (GSNL, 2021b).*

Gower and Tallman, 1988), and numerous gold showings in the sedimentary rocks of the Davidsville Group (O:D; Figure 2; Evans, 1996). Since then, >200 mineral occurrences have been identified in the study area, over half of which are gold-mineralized zones (Figure 2; GSNL, 2021b). Currently, very little land remains unclaimed within the study area. There are over 300 claims staked by more than 55 prospectors and 20 exploration companies (Newfoundland and Labrador Mineral Lands Division, 2022).

## SURFICIAL GEOLOGY OF THE GANDER REGION

### SURFICIAL SEDIMENTS

Surface-sediment sampling, especially for till geochemistry, has been an important tool for evaluating the mineral potential in this region (Evans, 1996; Dimmell, 2010; Evans-Lamswood, 2020). A thorough understanding of the glacial history, till genesis, and sources of clasts in tills are critical tools for linking geochemical anomalies to their bedrock sources.

Previous researchers have identified sediments interpreted as till (glacial diamicton), glaciofluvial and fluvial sands and gravels, and marine sediments (Figure 3; Batterson, 2000; Scott and Taylor, 2012, 2014; Brushett, 2013a, b; GSNL, 2021c) in the study area. The dominant surficial sediment is till, a mechanically eroded, entrained and poorly sorted glacial sediment with grain size ranging from clay to boulders, deposited by glacial activity.

The most widely distributed till unit identified by previous researchers is a massive, 1–6-m-thick, structurally homogeneous, moderately compact, poorly sorted diamicton with a silty sand matrix. Till composition varies locally; it is relatively siltier in the northern study area (Scott, 1994b) and sandier over the Gander Lake Granite (DB:G; Figure 2) in the southern map area (Brushett, 2010). Till colour varies from reddish-brown (Munsell Colour 5YR 5/3) reflective of the underlying Botwood Group (S:B), to grey-brown (10YR/5/2) when derived from the underlying grey Gander Group (CO:G) rocks (Scott, 1994a; Batterson and Vatcher, 1991).

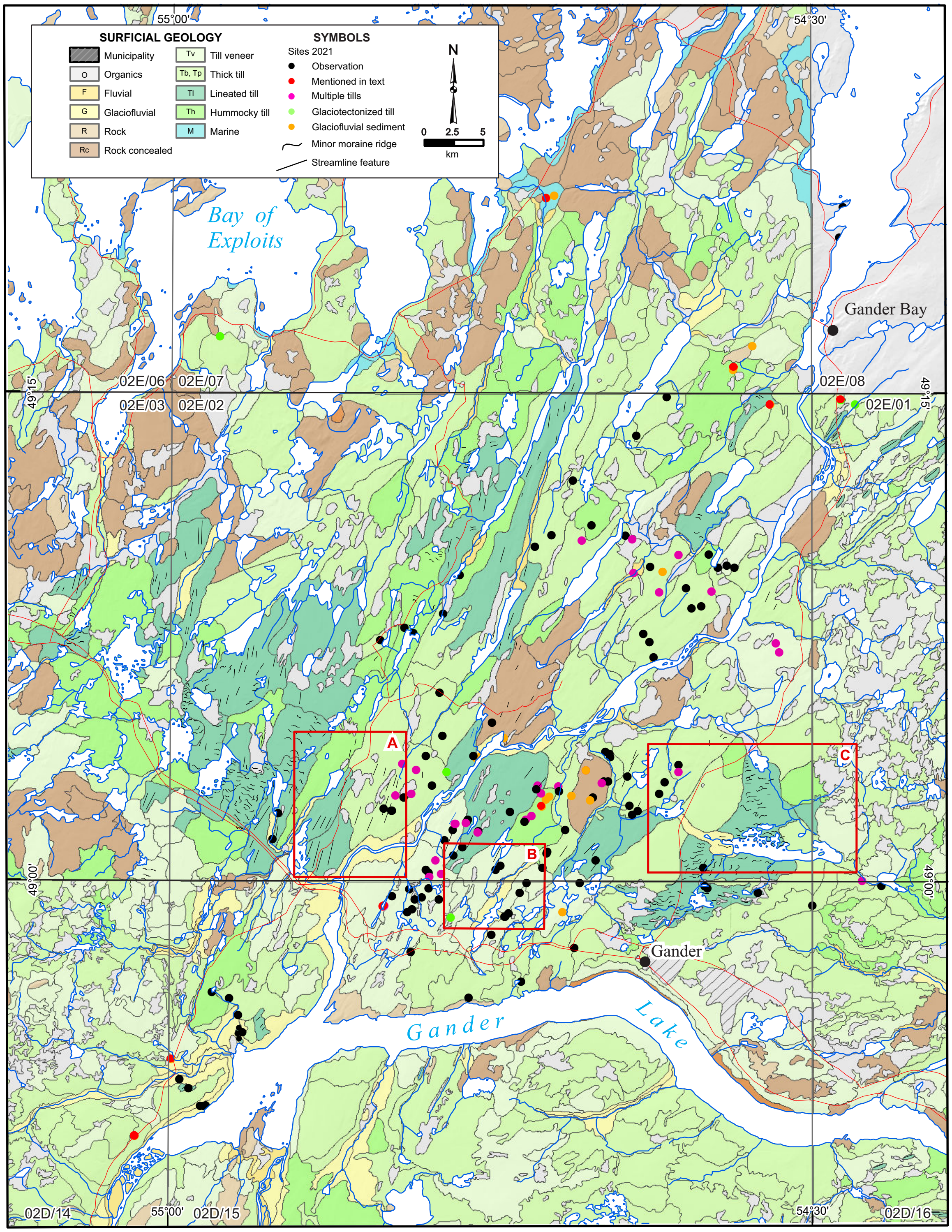

**Figure 3.** *Surficial geology of the study area (Batterson, 2000; Brushett, 2013a; Scott and Taylor, 2012; GSNL, 2021d, e). Note landforms shown on this map are those within the landform database (GSNL, 2021e). Here they are categorized into lineated or streamline features and minor moraine ridges. Notice the higher level of detail in the mapping for NTS map area 2E/01 when compared to 2E/02 and 2D/15. The northeast corner remains grey as detailed mapping is not available digitally. Box A identifies an area of streamlined or lineated till (Tl) and corresponds to mapped flutes, drumlins crag and tails and roche moutonees. Box B shows the location of Joe Batts Pond and the associated glaciofluvial sediments (G) and thin till (Tv: till veneer) or eroded till (Te). Box C shows the location of Jonathan's Pond which is associated with glaciofluvial material (G), eroded till (Te) and till ridges (Tr: ribbed moraine).*

Spatial and stratigraphic variation are poorly understood, as natural exposures of till sections are uncommon and stratigraphic sections exhibiting multiple till units are rare. Batterson and Vatcher (1991) describe a complex stratigraphy comprising four units from a 5 m section near Little Harbour on the north side of Gander Lake. The lowermost unit (Unit 1) is a brown sandy diamicton, interpreted as a subglacial melt-out till, which is overlain by fluvial sands and gravels (Unit 2). Unit 3 overlies the sands and is a moderately compact reddish-brown diamicton interpreted as a subglacial melt-out till. The upper unit (Unit 4) is a loose, coarse-grained, clast-rich supraglacial melt-out till (Batterson and Vatcher, 1991). Hunts Pond Intrusive Suite clasts identified in this unit from the Gillinghams Pond area and are indicative of a northward glacial transport that is consistent with regional striae (Batterson and Vatcher, 1991).

Till forms a number of landforms and surficial map units in the study area (Figure 3) that include: hummocky terrain (map unit Th); lineated terrain (Tl) with landforms such as drumlins; and ridged terrain (Tr) with ribbed moraines. Till is also mapped as: thin veneer (Tv) over bedrock; thick blanket (Tb) or plain (Tp) that mask the underlying bedrock; and winnowed or "washed" deposits (eroded till; Te), often associated with meltwater channels.

Batterson (2000) mapped lineated till (Tl) north of Careless Brook and till ridges (Tr) north of Gander. Scott and Taylor (2012) mapped lineated till west of H Pond and northeast of Salmon Pond, ridged till west of Salmon Pond, and hummocky terrain (Th) north of H Pond and between Salmon Pond and Ten Mile Pond. Along the Gander River, till is typically thin (Tv) and commonly eroded (Te) and as a result is associated with more exposed bedrock (Scott and Taylor, 2012). Lineated till is found on both sides of the Gander River south of Fourth Pond. Thick till plains (Tp) have been mapped west of Gander River (Scott and Taylor, 2012). Shaw and Potter (2015) mapped drumlins (Tl) on the modern sea floor at the mouth of Gander Bay. Subglacial landforms have also been mapped for the NIS by Blundon *et al.* (2009, 2010) and from remote sensing techniques by McHenry and Dunlop (2016).

Figure 4 shows landforms interpreted by McHenry and Dunlop (2016) who identified significantly more lineated features (drumlins, crag-and-tail, drumlinoid hills and glacially moulded bedrock (Tl) and ribbed moraine (Tr) than previous researchers (*see* landforms on Figure 3). Whereas this interpretation is based on remote sensing and has not been examined in the field, it suggests that glacial deposits have been deposited and/or reworked by several distinct ice-flow directions, and therefore may present challenges to using till geochemistry and dispersal trains to vector back to mineral occurrences.

Clast fabric, the orientation of clasts within till, has been used to define the depositional context and overlying ice-flow orientation for diamictons (*see* Dowdeswell and Sharp, 1986; Dreimanis, 1988). Clast-fabric studies have focused on the area north of Gander Lake on NTS map area 2D/15 (Batterson and Vatcher, 1991), and between Salmon Pond and Birchy Bay on NTS 2E/02 and 2E/07 (Scott, 1994a). Strongly oriented clast fabrics associated with lineated till and till plains (*e.g.*, southern Ten Mile Lake area, Little Harbour) indicate subglacial till deposition by multiple ice-flow phases (Batterson and Vatcher, 1991; Scott, 1994a), whereas poorly orientated fabrics in hummocky terrain (*e.g.*, northeast of Ten Mile Lake) are interpreted as deposits from glaciogenic debris flows and are not indicative of ice-flow (Batterson and Vatcher, 1991; Scott, 1994a). South of Birchy Bay, the clast orientations and striae both suggest northerly flow. In contrast, fabrics near Bellman's Pond suggest a southeast flow but striae are oriented north-northeastward, indicating that sediment dispersal was controlled by the earlier southeastward flow and the later north-northeast flow did not influence sediment dispersal in this area (Scott, 1994b). Glaciofluvial sediments are typically confined to valleys, such as Careless Brook, Gander River valley, north of Burnt Lake, South Pond and Joe Batts Pond, and west of Jonathan's Pond (Ricketts and McGrath, 1990; Batterson, 2000; Scott and Taylor, 2012, 2014). These deposits form flat-topped landforms between 50–64 m asl. Ricketts and McGrath (1990) interpreted these as deltaic deposits in Birchy Bay, and ice-contact deltaic deposits near Burnt Lake and Gander River. Glaciofluvial sediments in the area of The Outflow have surface elevations of 60 m asl (Batterson and Vatcher, 1991). Marine deposits were mainly mapped near the coast, with the exception of the small deposits along Gander River (McCuaig, 2006). Munro and Catto (1993) mapped marine sediments and beach ridges in the Musgrave Harbour area up to an elevation of 57 m asl. Marine silts and clays were identified at 24 m asl by McCuaig (2006) along the Gander River near Fourth Pond. Clay and sands identified at Lukeman Head (64 m asl) were interpreted by Batterson and Vatcher (1991) as lacustrine or glaciolacustrine sediments.

## ICE-FLOW CHRONOLOGY

The NIS on the Island of Newfoundland comprised multiple local ice-dispersal centres. The NIS extended to the edge of the continental shelf during the late glacial maximum during the Late Wisconsinan (approximately 18 ka BP; Grant, 1989; Shaw *et al.*, 2006; Dalton *et al.*, 2020). At this time, major ice divides extended east from the Long Range Mountains through central Newfoundland, where they bifurcated; one divide extended northeastward, north of Gander, and the other eastward toward the Avalon Peninsula (Figure 5A; Shaw *et al.*, 2006).

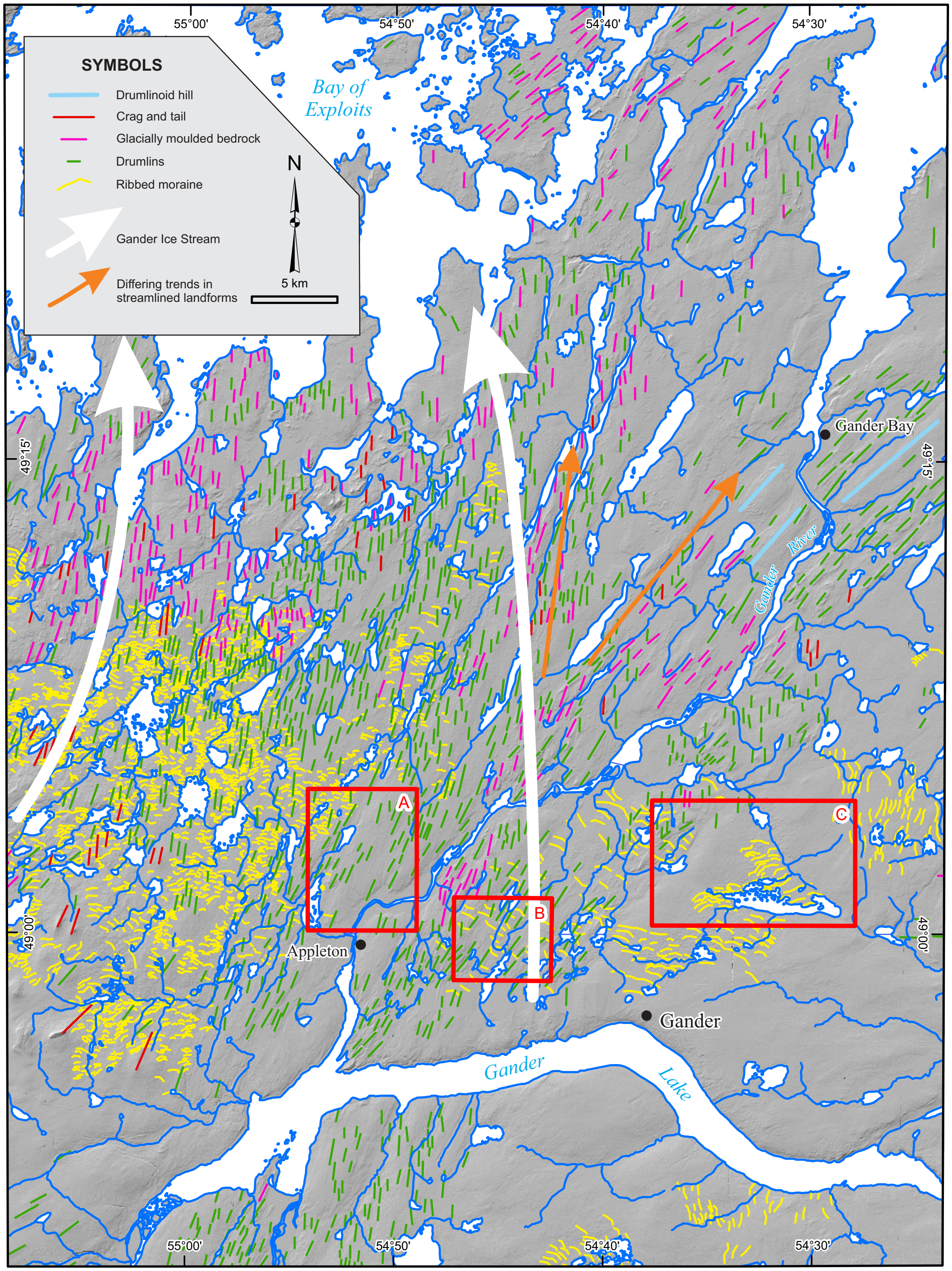

**Figure 4.** *A portion of the subglacial imprint map produced by McHenry and Dunlop (2016) showing linear features corresponding to subglacial landforms inferred from DEM and remote sensing analysis of Newfoundland, including drumlins (green), drumlinoid hills (blue), ribbed moraine (yellow), crag-and-tails (red), and glacially moulded bedrock lineations (pink). McHenry and Dunlop (2016) used the GSNL landform dataset to check remote sensing techniques used to the map production. Notice the two trends in the orientation of drumlins and crag-and-tail landforms in the northeastern 2E/02 map area (denoted by the two orange arrows). The white arrows delineate the edges of the Gander Ice Stream as proposed by Blundon* et al. *(2009, 2010). Red boxes show location of inset boxes used in Figure 3 and highlights the increase in landforms mapped by McHenry and Dunlop (2016).*

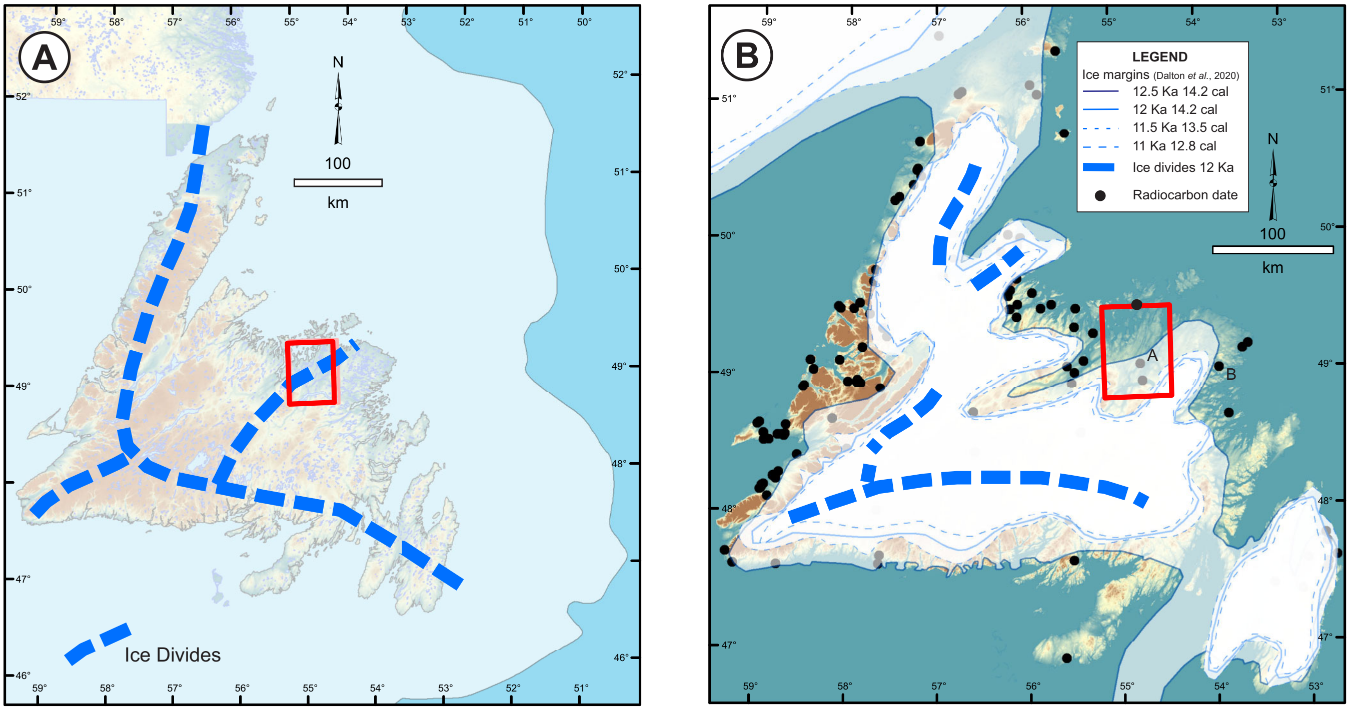

**Figure 5.** *A) Map of the Island of Newfoundland showing the glacial maximum extent of the NIS during the Late Wisconsinan (18 ka BP). Red Box shows the location of the study area. Ice extends off shore with ice divides (dashed blue lines) down the Long Range Mountains through central Newfoundland, where they bifurcated; one divide extended northeastward, north of Gander, and the other eastward toward the Avalon Peninsula (Shaw* et al.*, 2006; Dalton* et al.*, 2020). B) Ice extent sequence, during deglaciation of the Island of Newfoundland between 12.5 and 11 ka BP given by the 12.5, 12, 11.5 and 11 ka isochrones showing ice margins (Dalton* et al.*, 2020). Blue dashed lines and solid lines show extent at time periods while black dots show locations of radiocarbon dates constraining the ice margin at this time (Shaw* et al.*, 2006; Dalton* et al.*, 2020). The dot labelled A shows the location of,* Hiatella arctica*, in silt and clay along the Gander River at 24 m asl (12 200 ± 90 BP – Sample Number: TO-12570; McCuaig, 2006) whereas the dot labelled B shows the location of radiocarbon dated material at Parsons Point (*Balanus sp.*, 12 400 ± 240 BP – Sample Number: GSC-4182; Shaw and Edwardson, 1984) at 2 m asl. Note that most of the study area is ice-free, with ice persisting over eastern Gander Lake, northwest of Gander and near Mount Peyton.*

Three ice-flow phases were inferred from the surficial geology, geomorphology, and striation record in northeastern Newfoundland, all interpreted to be Late Wisconsinan (Figure 6; Vanderveer and Taylor, 1987; Proudfoot *et al.*, 1988; St. Croix and Taylor, 1991; Batterson and Vatcher, 1991; Scott, 1994a; Brushett, 2010, 2011; GSNL, 2021d). The oldest phase, a regional east-southeastward ice flow, is recorded in striae and, less commonly, east-southeastward-moulded bedrock, generally observed east of the study area. The second ice-flow phase is a north to northeast flow, which is captured by striae and numerous streamlined landforms; it forms the dominant ice-flow phase identified within the study area (Vanderveer and Taylor, 1987; St. Croix and Taylor, 1990, 1991; Batterson and Vatcher, 1991; Scott, 1994a, b; Munro and Catto, 1999; Brushett, 2010, 2011, 2012, 2013a, b; McHenry and Dunlop, 2016). The distribution of elongated streamlined forms with a north-northeast orientation (second ice-flow phase) led Blundon *et al.* (2009, 2010) to propose that these features formed during a phase of fast-moving ice, termed the Gander Ice Stream (Figure 4). The youngest third phase produced two discrete local ice-flows: a northeast flow west of the Bay of Exploits; and a north-northwest flow seen throughout the study area (St. Croix and Taylor, 1991; Scott, 1994a). An ice-spreading centre near Red Indian Lake was likely the source for the earliest phase of flow to the east-southeast, whereas a shift to the north-northeast flow was generated from spreading centre near Meelpaeg Lake and Middle Ridge (Proudfoot *et al.*, 1988; St. Croix and Taylor, 1991). The youngest phase was interpreted as topographically controlled ice flow originating from Middle Ridge or possibly a spreading centre near Gander (St. Croix and Taylor, 1991; Brushett, 2010).

Early ice retreat in northeastern Newfoundland was facilitated by calving along deep channels (Shaw, 2003) that shifted the configuration of the ice divides (Shaw *et al.*, 2006). The retreat pattern was irregular and time transgressive due to varying ice thickness and underlying topography.

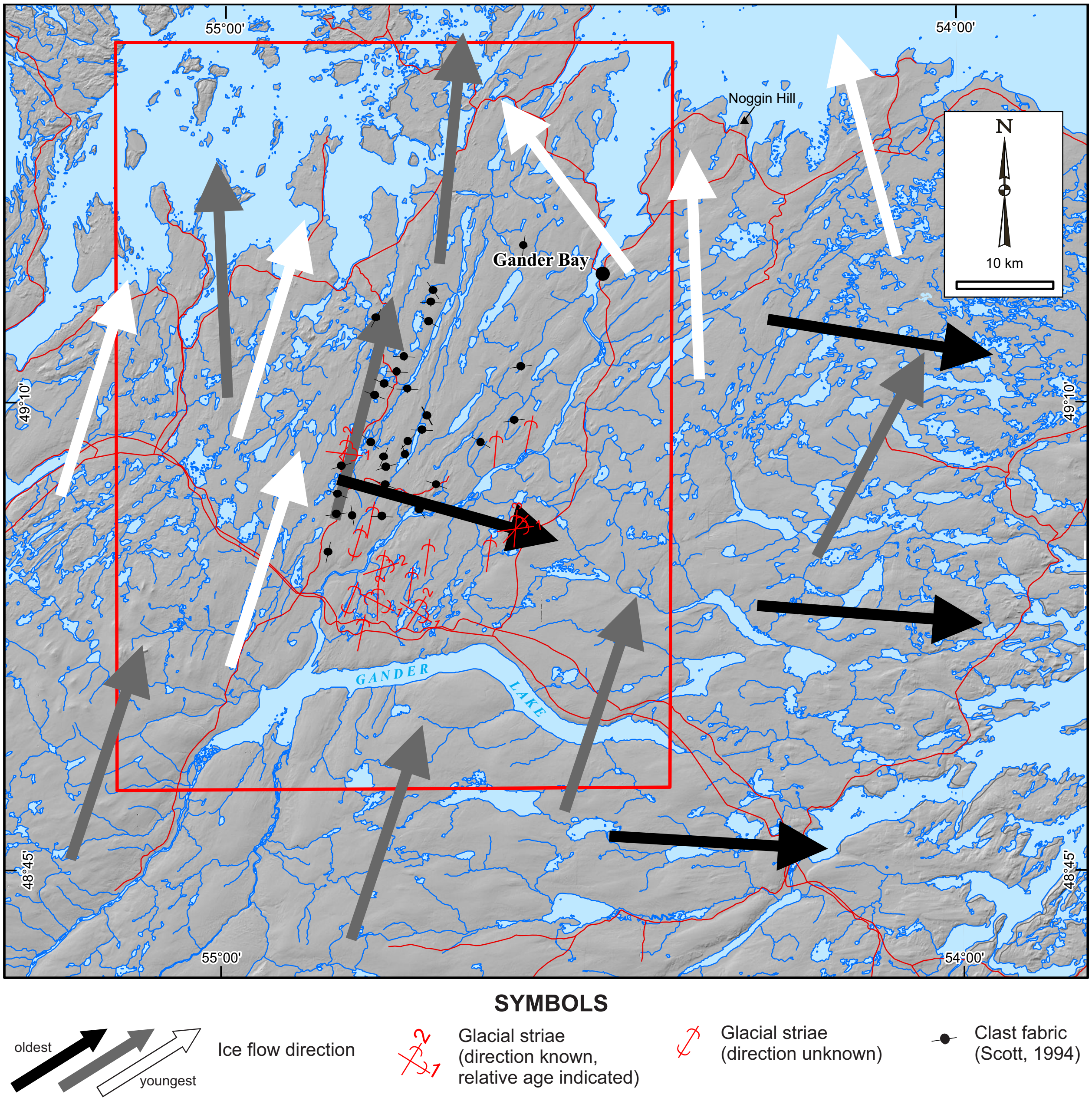

**Figure 6.** *Generalized regional ice-flow history as interpreted by St. Croix and Taylor (1991) from the GSNL striation database (GSNL, 2021d). Black arrows represent the early east to southeastward flow, grey arrows represent a younger north to northeastward flow and the white arrows represent the youngest flows (northwest in the Musgrave Harbour area and a northeastward flow in the west). Striation symbols show selected data collected during the 2021 field season. Relative ages are noted by numbers with 1 being the oldest. Fabric data collected by Scott (1994) is also shown.*

This resulted in the early deglaciation of the Gander River valley and surrounding lowlands and marine inundation; these events are constrained by radiocarbon ages (expressed as uncalibrated $^{14}$C years before present (BP); Figure 5B): a barnacle age from Parsons Point (*Balanus sp.*, 12 400 ± 240 BP – Sample Number: GSC-4182; Shaw and Edwardson, 1984) at 2 m asl and a marine clam, *Hiatella arctica*, in silt and clay along the Gander River at 24 m asl (12 200 ± 90 BP – Sample Number: TO-12570; McCuaig, 2006).

Munro and Catto (1993) indicated that marine limit, northeast of the study area near Musgrave Harbour, could be as high as 67 m asl based on an eroded platform at Noggin Hill, but suggested marine limit was at least 57 m asl based on beach gravels in the area. Massive fine sands, silt and clay laminae, and ripple marks at Lukeman Head, southwest of Gander Lake at 64 m asl, were tentatively mapped as glaciolacustrine sediments (Batterson and Vatcher, 1991). Batterson and Vatcher (*op. cit.*) indicate that no raised features were found east of King's Point on Gander Lake, suggesting that this area may have been occupied by ice. McCuaig (2006) has suggested that, based on fossil evidence found in the Gander River (*see* above), Gander Lake may have been open to the sea following deglaciation which, in turn, indicates an alternative marine-deposition environment for the laminated silts and clays identified at Lukeman Head. The elevation and locations of these marine sediments suggest a marine limit of 64 m asl may be more representative for the study area and indicate that the Gander River and western part of Gander Lake may have been below sea level at 12ka BP, whereas the eastern half of Gander Lake and south of Mount Peyton remained covered in ice (Figure 5B; Shaw *et al.*, 2006; Dalton *et al.*, 2020).

Discrete glaciofluvial deposits, washed and eroded till veneers and ridged tills mapped west of Jonathan's Pond and surrounding Joe Batts Pond (Scott and Taylor, 2012) are consistent with an ice-contact environment around 12 ka (Figure 3). The Gander region was completely deglaciated by about 10 ka (Dalton *et al.*, 2020).

## FIELD METHODS: OBSERVATIONS, SAMPLING AND ANALYSIS

Field observations pertaining to the surficial geology and ice-flow indicators were collected from 168 sites during the 2021 field season. At each site, GPS location, elevation, sediment type, matrix composition, clast information (size, composition, angularity, concentration of clasts) and striae measurements (where present) were recorded.

Natural exposures of till profiles are rare; observations were made from hand-dug pits, ditches or machine-excavated pits. Observations of till and till stratigraphy were collected in each of the various till (map) units (till veneer, till blanket, eroded till, hummocky till and lineated till).

Clast-fabric measurements were recorded at two sites; this involved measuring the orientation and plunge of 25 elongated pebbles having a length to breath ration of greater than 3:2. Clasts were measured within a small area (<1 m$^2$), away from contacts and large boulders. Results were plotted on an equal-area stereonet using GeOrient, ver 9.5.1 (Holcombe, 2015). Following the methods of Woodcock (1977) and the statistical analysis within the GeOrient program calculate the shape (K), strength (C) of the clast fabric along with normalized eigenvalues (S1, S2 and S3). The normalized S1 eigenvalue signify if clasts have a random orientation (0.33) or a unidirectional orientation (>0.75). Girdle distributions are indicated when K values are less than 1. Clast-fabric measurements provide a three-dimensional view of clasts within a diamicton and when used in conjunction with sedimentological data can aid in determining if diamictons represent primary (*e.g.*, meltout, lodgement) or secondary tills (*e.g.*, gravity-flow deposits). Fabrics measured in primary basal tills (S1>0.6, K>1.0) provide data on potential ice-flow direction. Woodcock (1977) and Dowdeswell and Sharp, (1986) detail how clast fabrics are classified through statistical and graphical methods and how their characteristics relate to depositional environments.

Till sampling was only conducted at sites with more than one till unit identified in the profile. At these sites, 2–3 kg till matrix samples were collected from C or BC horizons. Till colour was classified using the Munsell Soil Color Chart and dried till samples. Pebbles were also collected to infer clast provenance, which is useful for determining till transport distance and direction. Care was taken to clean sampling tools between sites, to avoid cross-contamination. Duplicate samples were collected after every 20 samples to determine site variability and analytical reproducibility.

Till samples were processed and analyzed for matrix texture (sand, silt and clay) at the Geochemical laboratory of the Geological Survey of Newfoundland and Labrador (St. John's, NL). Samples were air-dried and dry-sieved through 63 μm (230 mesh) stainless-steel sieves to recover the silt and clay fraction for geochemical analysis. Minor- and trace-element content will be analyzed using ICP-OES analysis for some elements; INAA analysis for other elements will be completed at Bureau Veritas Laboratories (Mississauga, ON). For details of the preparation and analytical methods for till samples, *see* Finch *et al.* (2018).

## PRELIMINARY RESULTS

### ICE-FLOW INDICATORS

Twenty-six new erosional ice-flow indicators (striae and grooves) were measured from 20 sites (Figure 6). Five sites contained multidirectional ice-flow measurements. Relative age relationships were determined from crosscutting and lee-side preservation relationships. All striations were fresh and unweathered, and are therefore tentatively interpreted as Late Wisconsinan.

The regional ice-flow history is determined by looking at the spatial distribution of these relative age relationships for all striae and macro-scale landforms. The new data record two ice-flow phases:

- *older, east to east-southeast flow (Phase 1)* recorded east and west of Joe Batts Pond, and north of Salmon Pond. Often preserved as grooves on lee surfaces; and,

- *younger, north to northeast flow (Phase 2)* is the most pervasive flow identified. This flow correlates with macro-scale streamline landforms such as crag-and-tail hills, flutes and drumlins as mapped by Scott and Taylor (2012, 2014) and McHenry and Dunlop (2016).

The two-phase interpretation is consistent with previous interpretations by Vanderveer and Taylor (1987), St. Croix and Taylor (1990, 1991), Batterson and Vatcher (1991), Scott, (1994a, b), Munro and Catto (1999) and Brushett (2010, 2011, 2012, 2013a, b). The regional Phase 3 ice flow was not recorded during the 2021 field season.

## LANDFORMS

Detailed aerial-photograph interpretation has not yet been conducted. This current section is based on interpretation of a 5-m digital elevation model (DEM; GIS and Mapping Division, 2021) and limited field observations from the 2021 field season.

The hill-shade image created from the DEM (Figure 7) shows a range of surface textures and patterns that when used in conjunction with fieldwork observations allow for landforms (ridges - Tr, hummocks - Th, and lineated features - Tl) and surface morphologies (veneers - Tv, blankets - Tb, plains - Tp, and eroded - Te) to be distinguished.

Glacial ice exploited the northeast-trending bedrock structures, forming streamlined, lineated landforms that parallel the glacial ice flow (Figure 7). Lineated features such as crag-and-tails are discernable on the DEM north of The Outflow, with flutings and drumlins (lineated till) north and northeast of Appleton. The latter are rounded to flat-topped features that are likely bedrock cored and have variable lengths (160–2000 m), widths (50–200 m), and heights (10–30 m). Sections through two streamlined landforms (Sites 5043 and 5174 – Figure 7) suggest that they are composed of at least two tills (B and C, *see* below). The orientation of these features parallel the Phase 2 ice flow.

Hummocky terrain around H Pond and in the area north of Careless Brook has a stippled, irregular texture in the hill-shaded DEM. Hummocks are rounded, average ≤70 m in diameter with 3–5 m relief, and are composed of sandy

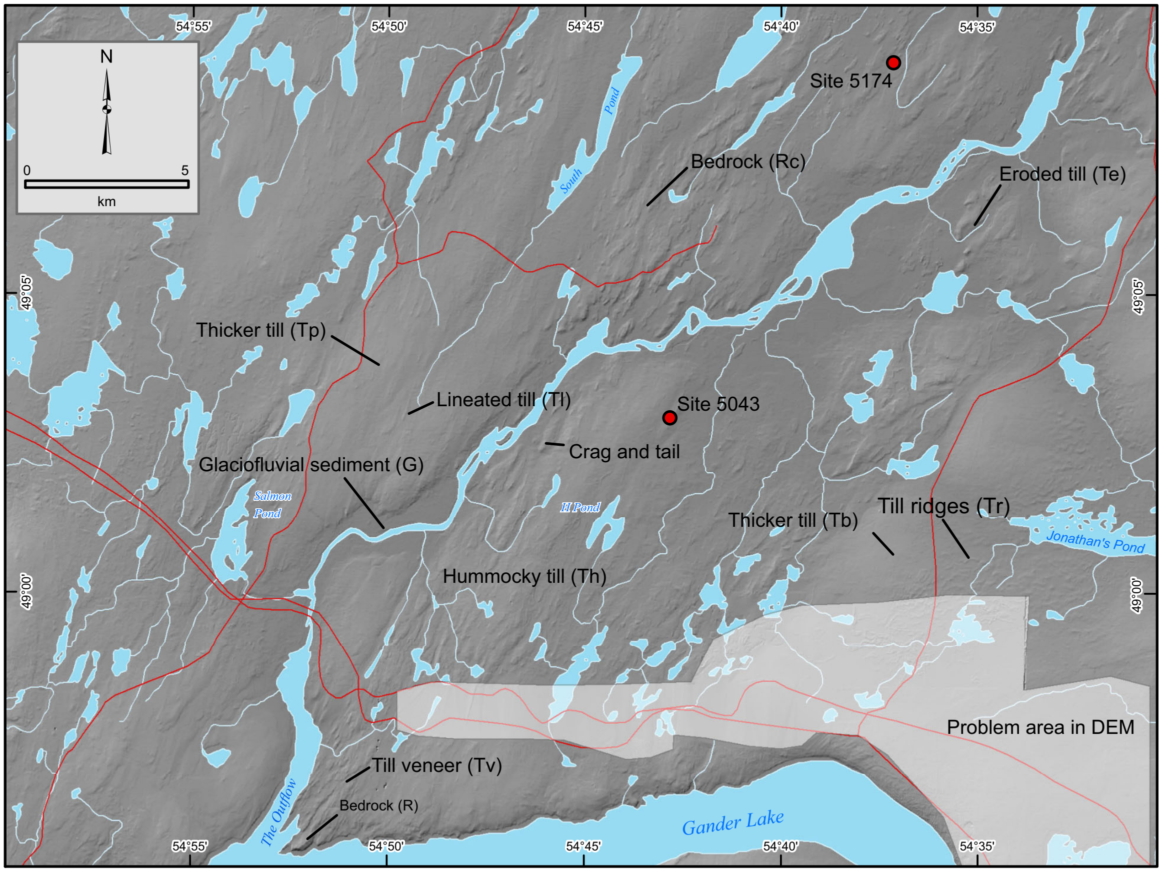

**Figure 7.** *Hillshaded image generated from the provincial DEM (GIS and Mapping Division, 2021) showing the range of textures and patterns that distinguish landforms and sediment types. Red dots show locations of sites mentioned in the text.*

diamicton. Imagery and DEM interpretation indicate this landform may also be found adjacent to till ridges north of Gander Airport and Jonathan's Pond. Till ridges in this area range from 50–1000 m long, 50–150 m wide and typically 3–6 m high. The ridges adjacent to Jonathan's Pond have long axes oriented roughly east–west, whereas ridges north of Gander airport are irregularly oriented.

As seen in Figure 7, thicker sediment represented by smoother textures and morphologies such as blankets and plains are dominant in the southern portion of the field area particularly between Salmon Pond and South Pond, whereas rougher textures indicative of thinner sediment (veneer) cover and bedrock exposures. Bedrock is apparent along the east side of The Outflow, north of Fourth Pond and north of Jonathan's Brook.

## SURFICIAL SEDIMENTS

The surficial geology of the study area consists mostly of glacial, glaciofluvial sediments (till or diamicton, as well as sands, and gravels respectively) and postglacial organic deposits (bogs).

The following section describes the sediment types as they relate to landform morphologies observed in the field.

### Till

Till was identified at over 75% of sites visited and is the most widely distributed sediment within the study area. Till is variable in thickness, texture, colour and morphology reflecting the bedrock lithology, and depositional processes. Till cover is relatively thin, particularly in areas adjacent to bedrock and close to the coast, ranging from 10s of centimetres to a few metres thick. Thicker deposits of up to 6 m are seen in excavated quarries, particularly in the southern part of the study area. Texture of the till matrix is described as a silty sand, however, sandy silt matrix was recorded at only 8% of sites east of the Gander River. The colour of dried till samples varies from light yellowish brown (2.5Y6/3) to light olive brown (2.5Y5/3) to pale brown (2.5Y7/3). Till deposits exhibit a number of morphologies and landforms including veneer, blanket, hummock, eroded and lineated ridges (the location of which have been described above). Three distinct tills were identified in the study area; however, their lateral extent is unknown because the stratigraphic relationship between all three tills (A, B, and C) was only observed at Site 5107, located approximately one kilometre northeast of the town of Appleton (Figure 1). Site 5107 is located on the west side of a small hill approximately 70 m east of a body of water. An excavated pit, 3 m deep by 5 m wide, provided an east–west-orientated section through the three tills shown in Plate 1A. Another excavated pit, Site 5109, is located upslope, 80 m to the northeast, and provides an east–west cross-section of 2.5 m of till along with the bedrock sediment interface. Site 5109 exposes the upper two tills (B and C) seen at Site 5107 (Plate 1B). Typical characteristics of each till unit and their stratigraphic relationships are discussed below. Till A was only identified at one location, while the upper two tills (B and C) were identified at 30% of sites and are commonly associated with till veneer, till blanket and lineated till map units. Tills B and C were described north of Gander Lake to the north end of Bellman's Pond and from South Pond in the west to Boot Pond in the east. It is common to see a textural change (reduction in fine-textured matrix sediment) in the surface till indicative of differential bedrock erosion or erosion/winnowing of the matrix by meltwater. In these areas, it is difficult to determine which till unit is represented.

#### *Till A*

Till A was only observed in the pit at Site 5107. Due to the depth and inaccessibility of this pit, the description is based on observations made from the pit rim and from material recovered by the excavator. It is the lowermost till in the study area, approximately 50 cm was exposed in section. Till A is a yellowish brown (2.5Y6/3 [dry]), poorly sorted, very compact, silty sand diamicton. Clasts are very angular to rounded, 0.2–20 cm in diameter (average 1 cm). Approximately 5% of clasts are striated. The till is very compact – the degree of induration (Plate 2) caused difficulties for the excavator. Clasts are primarily derived from the underlying Davidsville Group (O:D), however, granites presumed to be from the Mount Peyton Intrusive Suite (SD:P), are also present. Preliminary interpretation, based on compaction and clast characteristics, suggest it is a subglacial till; the upper contact with Till B is gradational.

#### *Till B*

Till B is poorly sorted, has a silty sand matrix (Plate 1) and is the middle unit at Site 5107, and it is approximately 150 cm thick. In the field till ranges from brown, to brown-grey to reddish brown, but when dried, the Munsell colours are pale brown (2.5Y7/3), light yellowish brown (2.5Y6/3) to light olive brown (2.5Y5/3), reflecting the underlying lithological bedrock units. Till B is massive, moderately to very compact, and displays strong fissility, indicative of shear stresses (Evans *et al.*, 2006; Plate 3). The clast content is typically low (1–20%) to moderate (21–40%) and clasts diameters are 0.2–40 cm, averaging 3 cm and are typically subangular, but range from very angular to subrounded; striated and faceted clasts are common. Clast provenance is primarily sedimentary reflecting units of the Davidsville Group (O:D), with <5 % pink granite and grey-black diorite of the Mount Peyton Intrusive Suite (SD:P). The till is often only

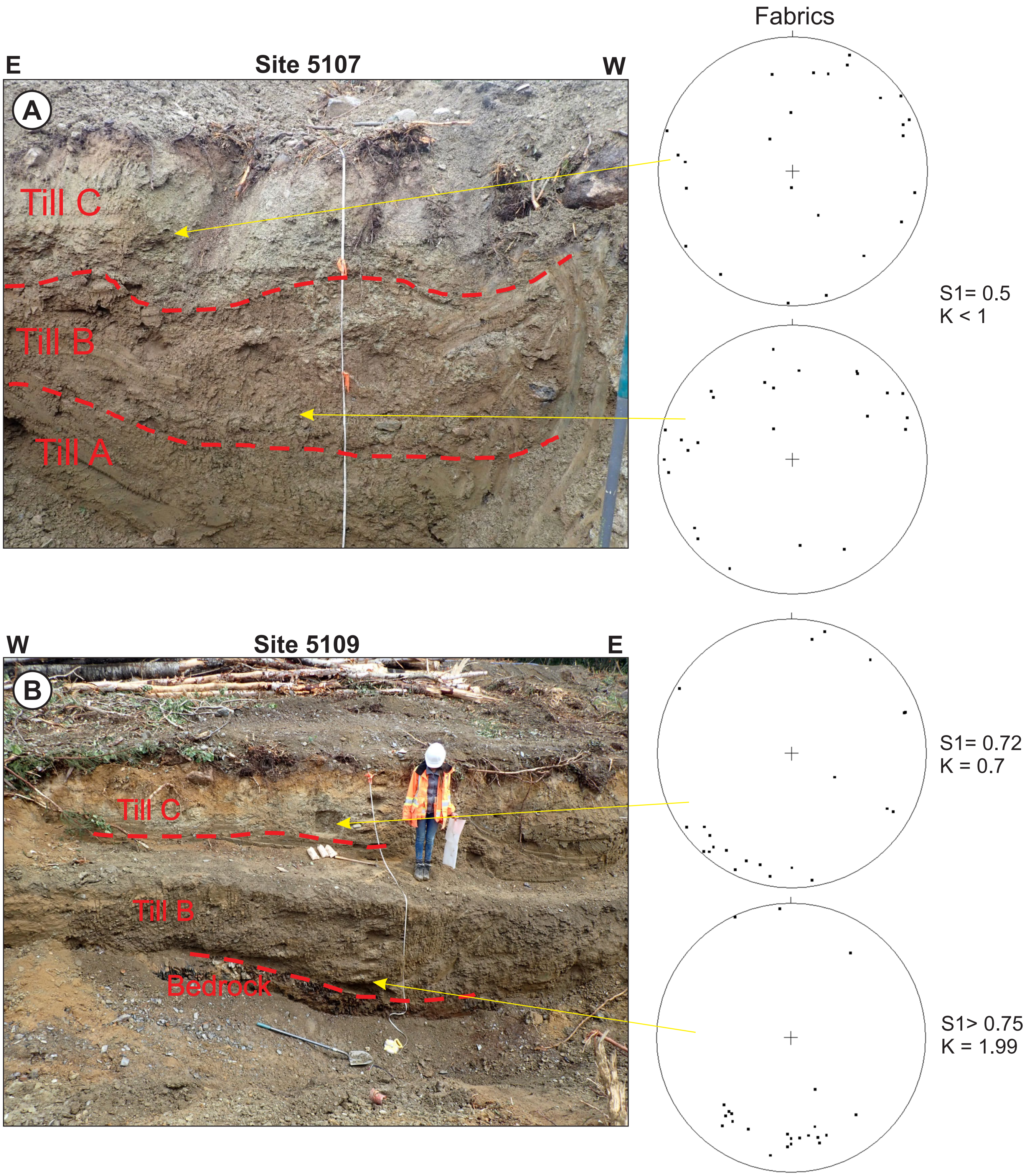

**Plate 1.** *A) A 3 m  east–west section from a backhoe dug hole located a kilometre north of Appleton (Site 5107). Photo is taken looking south. Units were determined based on colour, texture and compaction. The boundary between these three units is gradational and is shown with a dotted lines. Location of measured clast fabrics are shown by yellow arrows while fabrics are plotted on equal-area stereonets on the right; B) A 2.5 m east–west section at Site 5109 located 80 m the northeast of Site 5109, showing till Band C overlying bedrock.*

**Plate 2.** *Compact sediment representing Till A sampled from 3 m at Site 5107. Appears lithified, clasts range from 0.2–20 cm.*

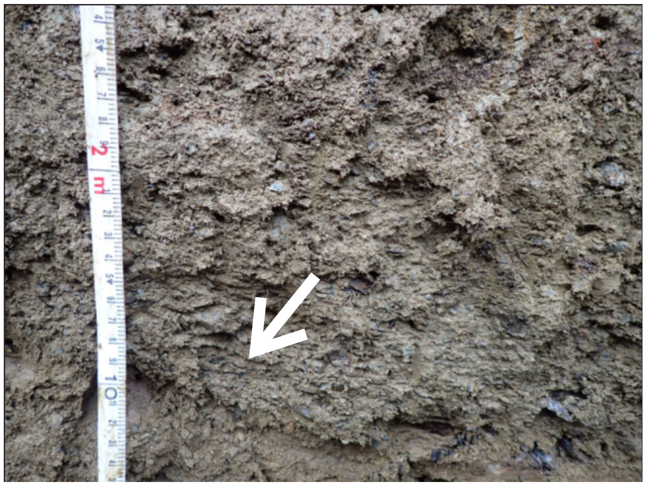

**Plate 3.** *Both Till C and Till B show a moderately to strong fissility (arrowed) as shown here. Culshaw* et al. *(1991) define fissility as a till that appears to have a lineated look and the sediment breaks into small lenticular flakes, this is attributed to greater shear stresses caused by ice movement.*

found at the bottom of hand-dug pits. It is associated with till veneer, lineated till, till blanket and eroded till. The upper contact with Till C varies; some sites have a gradational contact, whereas others are sharp and often denoted by a marked colour change. Preliminary interpretation, based on compaction and fissility, would indicate it is subglacial lodgement till.

### *Till C*

Till C is the uppermost till at Site 5107, and is the common surface till in the study area. It is a massive, pale brown (2.5Y7/3), silty sand diamicton having a very fine- to fine-grained matrix. Clast content is low (1–20%), tend to be subangular, ranging from very angular to subrounded, and are often striated. Clast lithology is dominantly shale, siltstone and sandstone of the Davidsville Group (O:D), but muscovite–biotite syenogranite of the Hunts Pond Intrusion have been transported up to ~17 km north of their presumed bedrock sources south of Gander Lake. The thickness of Till C is generally thin ranging from 20–100 cm above the contact with Till B. Till C is typically loose and moderately fissile. This till is associated with till veneer, lineated till, till blanket and eroded till. Preliminary interpretation of this unit is a melt-out till.

### *Clast Fabrics*

Two clast fabrics, an upper and lower, were recorded at each site (Sites 5107 and 5109). Fabric measurements at Site 5107 were collected between 50–70 cm (Till C) and 130–160 cm (Till B) depth (with surface being 0 cm). Stereonet plots show that both the upper and lower fabrics at site 5107 have an eigenvalue S1 value of 0.5 and 0.52 and K values of 0.66 and 0.29, respectively, indicating a weak or no preferred orientation of clasts forming a girdle distribution. Dowdeswell and Sharp's (1986) graphical representation of S1 *vs.* S3 eigenvalues and girdle distribution suggests that both Till B and Till C at Site 5107 are secondary tills and were remobilized as sediment gravity flows. It may be that these two till units are the same unit at this location; this will be confirmed, either way, using geochemical and textural analysis.

Two clast fabrics were collected from Site 5109, between 70–90 cm (Till C) and 250–260 cm (Till B) depth. The lower clast fabric was measured just above the bedrock sediment interface within Till B at 250–260 cm depth. The S1 eigenvalue of >0.75 and a K value of 1.99 indicates a strong orientation of clasts that cluster toward 183 (mean principle direction). The upper fabric (70–90 cm) Till C has a S1 eigenvalue of 0.72 and K value of 0.7, which indicates a moderate to strong orientation of clasts toward 214 (mean principle direction). The strong S1 and K values indicate that clasts orientations within these fabrics parallels ice flow that corresponds to the Phase 2 – north-northeast flow. Dowdeswell and Sharp's (1986) graphical representation of S1 *vs.* S3 eigenvalues and girdle distribution suggests that both Till B and Till C are representative of lodgement till and/or deformation till.

### *Eroded Till*

Eroded till is observed throughout the study area, from Main Point in the north to Northwest Gander River in the south. The distinguishing characteristic of eroded till is the lack of silt and fine material in the matrix. Eroded till, often associated with a coarser matrix and higher clast content, appear as possibly winnowed or washed (Plate 4). Clasts are often striated and faceted and have a more angular appearance than clasts in glaciofluvial sediments. Determining the thickness of this unit was difficult, due to poor exposures and difficulty digging. At some sites, the upper 60 cm showed features associated with "eroded till" and unmodified, silty till below. The location of the eroded till unit ranges in elevation between 32 and 114 m asl. More than 75% of sites are either at or below the marine limit of 64 m asl indicating that marine processes may be the erosion mechanism. The remainder of the sites above 64 m are associated with hummocky terrain or are in close proximity to meltwater channels.

**Plate 4.** *Shallow test pit showing till that is eroded. The grey till is poorly sorted, and contains little to no silt.*

### *Glaciotectonized Till*

Glaciotectonized till was observed at several locations. This unit exhibits deformation features formed in response to glacial movement (Phillips, 2018). These deposits are typically thin, <1.0 m, and are clast-supported with 95% of clasts derived from the underlying bedrock (Plate 5). Glaciotectonic till sites are associated with siliciclastic marine sediments, such as the siltstone and shale of the Hunts Cove and Outflow formations of the Davidsville Group (O:D). Further discussion of glaciotectonized till at other sites, including detailed descriptions of its features, can be found in Campbell *et al.* (*this volume*).

**Plate 5.** *A north–south section showing glaciotectonic till overlying siliciclastic marine shale of the Hunts Cove Formation of the Davidsville Group. Bending of the underlying bedrock (arrowed) shows general glacial movement to the north.*

## GLACIOFLUVIAL DEPOSITS

Sands and gravels interpreted as glaciofluvial deposits were identified in topographic lows, along the Gander River and northeast of H Pond. Large glaciofluvial deposits west of Gander Lake and inland of the coast between Gander Bay and Birchy Bay were also identified. These deposits occur at elevations ranging from 36 to 108 m asl. Deposits have a variable composition, and range in thickness from <1 to 15 m (Plates 6–8). Glaciofluvial deposits along Gander River and northeast of H Pond appear to be <2 m thick and are poor to moderately sorted, coarse sand to pebble gravel with minor fine-grained sediments (Plate 6). Clasts range from very angular to subround. Sands and gravels commonly occur adjacent to or overlying glacial diamicton. In contrast, till overlying sand may indicate deposition in a fluctuating ice-marginal environment. Sand and gravel deposits are common along ice margins in confined channels or in a proglacial environment.

Larger deposits, such as the 10–15 m sections near Careless Brook (Sites 5078 and 5158), have alternating lenses of both poorly sorted boulder gravel and moderately to well-sorted fine-grained sand. They are interpreted as glaciofluvial outwash deposits. Plate 7A shows the southern end of the 15 m exposure that is composed of a poorly sorted boulder gravel with a coarse-grained sand to granule gravel matrix. This boulder gravel unit thins northward, and multiple moderate to well-sorted sand and gravel beds are identified below the boulder gravel unit. Plate 7B shows a section 15 m to the north of Plate 7A having sand and gravel beds below the boulder gravel. These units appear to dip toward the southwest. The upper brown unit is approximately 15–20-cm-thick fine- to medium-grained sand that conformably overlies a 40–50 cm bed of poorly sorted granule to pebble gravel. The lower contact of the gravel is erosional and truncates a lower, pebbly, fine-grained sand deposit. The gravel unit is interpreted as channel-fill

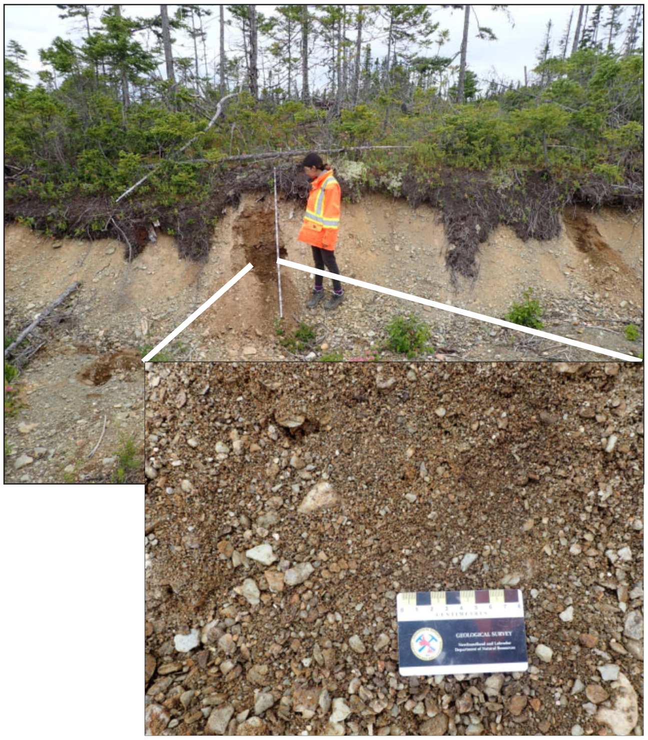

**Plate 6.** *A two metre section located north of H Pond (Site 5045) showing granule to pebble gravel that has a coarse sand matrix.*

deposited in a high energy environment, likely proximal to the meltwater source; the sharp contacts and texture changes between the gravel and sandy bounding beds indicate rapid changes in flow energy; this sequence is interpreted as deposition in an ice-proximal glacial meltwater system.

### ORGANIC DEPOSITS

Organic deposits are found throughout the study area. Bogs occur in poorly drained areas or topographic lows, such as east of Third Pond. Organic deposits west of Gander River are elongated along a north to northeast long axis. The thickness of these deposits has not been determined.

## DISCUSSION

Ice-flow directions recorded by glacial striae are linked to Phases 1 and 2 of the regional chronology outlined by St. Croix and Taylor (1991). The regional chronology documents three phases, from oldest to youngest, including: 1) an east to east-southeast flow; 2) a north-northeast flow, and; 3) a northwest flow in the eastern study area, contemporaneous with a northeast flow to the west of the study area.

It is interesting to note the relationships between striae, streamlined landforms and orientations indicated by clast fabrics; whereas striae and clast fabrics record all three regional ice-flow phases, landforms representing the east to east-southeast flow (Phase 1) are rare and are best seen east of Jonathan's Pond. This may be explained by the prevalence of the Phase 2 north-northeast flow that changed the landscape as shown by the abundance of striae and north-northeast streamlined landforms, west of Gander. The lack of northwest landforms may suggest that only localized, Phase 3 ice flow was less erosive. Areas that require further investigation to document stratigraphy to better understand the glacial history include areas where: i) landforms and the

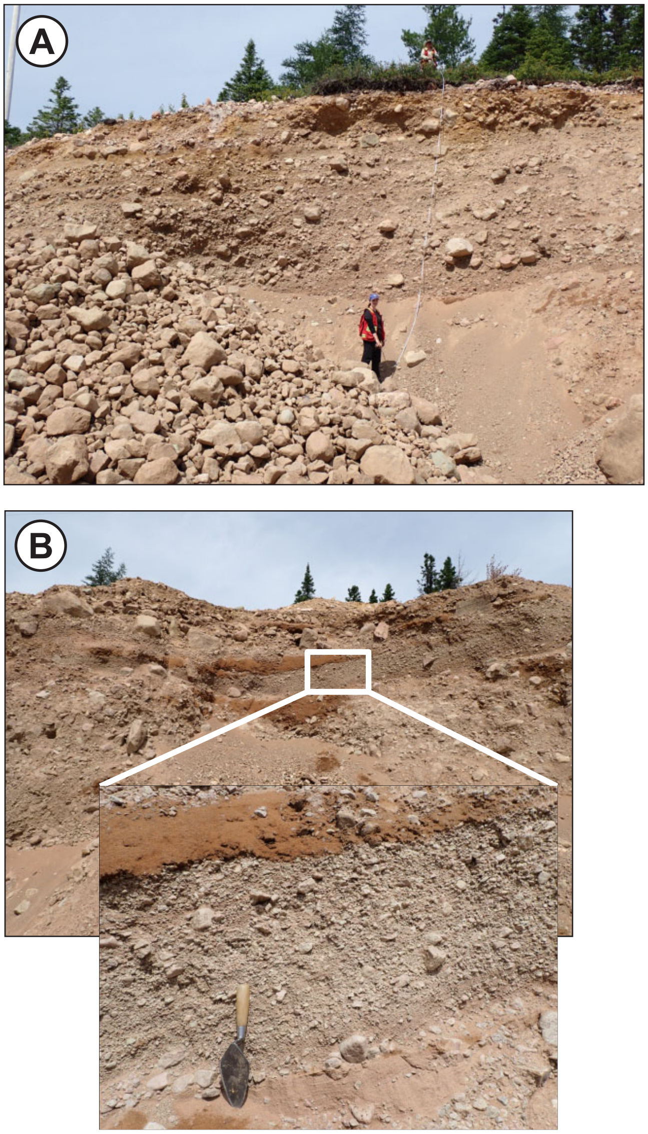

**Plate 7.** *A) South end of a 15 m section at Careless Brook showing poorly sorted boulder gravel deposited in a high energy glaciofluvial environment. B) Located 15 m north of the boulder gravel, picture shows sharp contacts between fine- to medium-grained sand overlying granule to pebble gravel and underlying truncated fine-grained sand.*

**Plate 8.** *A) Section in an active gravel pit south of Birchy Bay. Section is approximately 5 m high, although the top has been removed. The sections is primarily composed of coarse sand with beds of pebble to cobble gravel that dip toward the west-northwest; B) North–south orientated section in gravel pit east of Burnt Lake. Section is approximately 25 m high and is composed of bedded medium to coarse sands and gravel; C) Looking west, this east–west section located 1.5 km west of the Gander River. Section is approximately 13 m high and is composed of fine and medium sand with beds of granule and pebble gravel.*

striae record disagree, ii) landforms from multiple phases overprint each other; and, iii) landforms diverge.

Stratigraphic exposures with multiple till units were recorded throughout the field area, and are more widespread than previously documented. Additional field mapping will refine the lateral extent of these units further. The discontinuous nature of these units is directly related to both the processes that emplaced them, and to the subsequent changes in ice-flow direction, reworking, and deglaciation.

Till A is a subglacial till and likely correlates to Batterson and Vatcher's (1991) Unit 1. The compactness and fissility of Till B suggest subglacial deposition (Evans *et al.*, 2006) similar to Unit 3 of Batterson and Vatcher (1991). The high degree of fissility and compaction possibly relates to high shear stresses incurred by the overriding ice movement and is typically associated with lodgement and deformation tills (Lian *et al.*, 2003; Benn and Evans, 2010) This is supported by fabric data at Site 5109 indicating that Till B is a subglacial till emplaced by lodgement and/or deformation processes. Deformation, and lodgment till comprises mega-scale glacial lineations associated with ice streaming (Cofaigh *et al.*, 2013). Similarly strong fissility is noted in the Hartlan Till, Nova Scotia, which is also associated with ice streaming (J. Gosse, personal communication, 2021). Till C is typically a loose sediment unit containing non-locally derived pebbles from the Hunts Pond Intrusive Suite. It is interpreted as a supraglacial melt-out till deposited during deglaciation. Similar characteristics are exhibited by Unit 4 of Batterson and Vatcher (1991). At Site 5109, Till C is interpreted as a lodgement till based on sediment and fabric measurements. Geochemical analytics will help differentiate between the multiple tills observed, and confirm the association between these and the till units described by Batterson and Vatcher (1991).

Deglaciation of the NIS sheet was irregular and time-transgressive due to variations in ice thickness and local topography. In the topographic lowland northwest of Gander, ice retreated southward to south-southwestward. Glaciofluvial sands and gravels were deposited along the valley sides and bottom in front of the actively retreating ice margin; their distribution may provide insight into the extent and synchronization of ice retreat and subsequent marine incursion in this area (Ricketts and McGrath, 1990). Ricketts and McGrath (*op. cit.*) observed deltaic sand and gravel deposits along a northwest–southeast transect between Birchy Bay and Gander River at elevations between 50–64 m asl. In the GIS model, deltaic deposits generally plot at or below 64 m asl (Figure 8), but precise elevations could not be established with a handheld GPS while in the field. Future work aims to refine the sea-level history as refining marine limit is important to quantify for mineral exploration; winnowing and removal of fine-grained materials by marine processes make tills under the marine limit less suitable for geochemical exploration.

## IMPLICATIONS FOR MINERAL EXPLORATION

An improved understanding of the ice-flow history, ice retreat and the resulting landscape morphology will improve drift-prospecting strategies within the northwest Gander region. The following are important considerations:

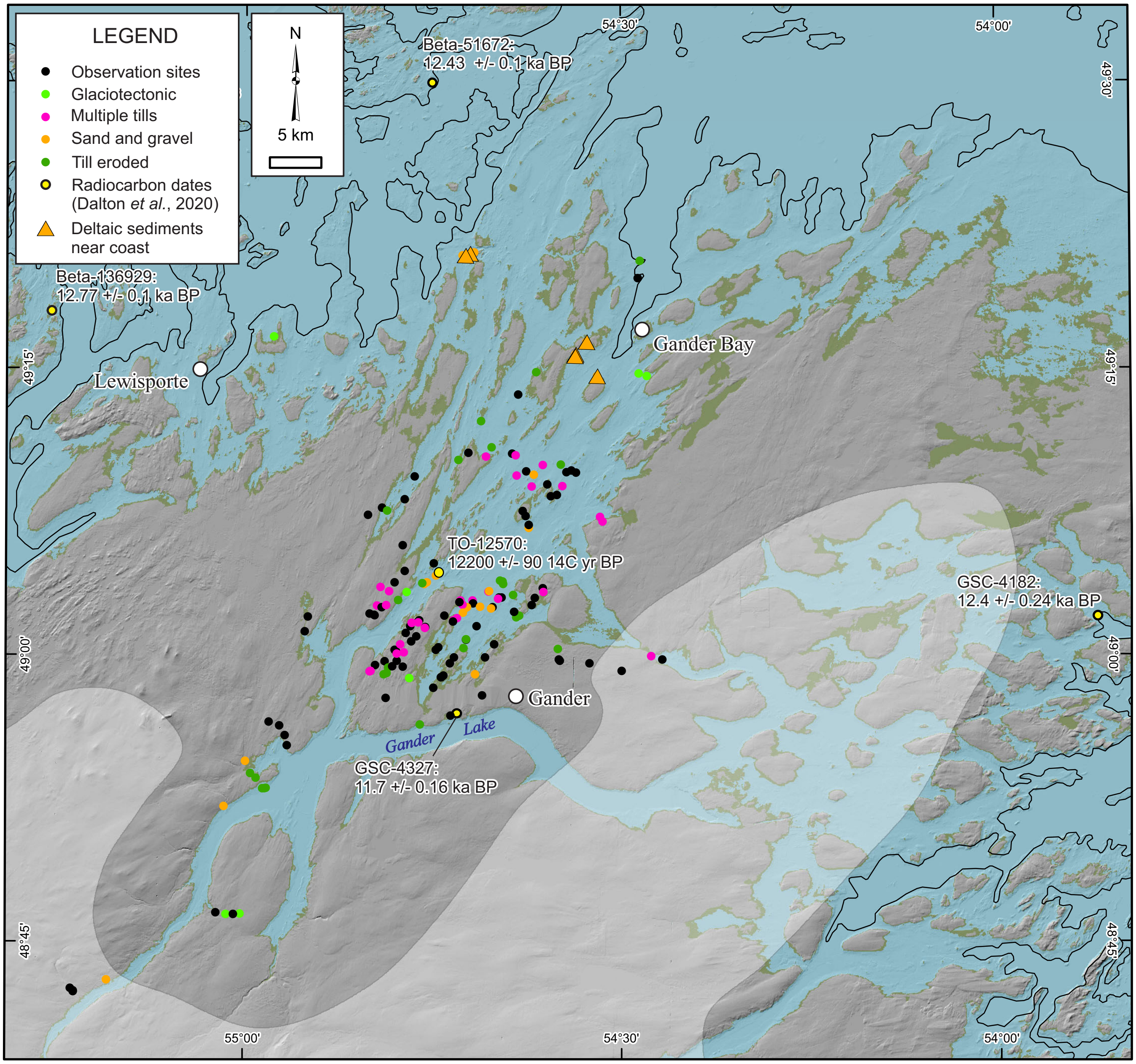

**Figure 8.** *Map showing the field area and the distribution of glaciofluvial sands and gravels (orange triangles) associated with deltaic deposition along with marine incursion at 57 m asl (blue) as suggested by Munro and Catto (1999) and marine incursion at 64 m asl (olive-green). Notice the difference affected by the higher marine limit. The modern coastline is outlined by the black line. Ice cover is shows as white polygon, the approximate ice margin is for 12 ka and is modified from Dalton* et al. *(2020).*

1) Understand the characteristics and depositional environments of the geological materials sampled.
    a) Sediments with a silty matrix, deposited in direct contact with active ice (*i.e.*, till), are optimal sampling units for drift-prospecting surveys. Subglacial till tends to best represent local, underlying bedrock, whereas supraglacial sediment may contain debris that has travelled longer distances.
    b) Sediments deposited from stagnating ice, corresponding to the hummocky terrain map unit, are less suitable for drift prospecting, as melt-out debris (*e.g.*, mineralized boulders) may include both local and distally derived material (Proudfoot *et al.*, 1988; Geological Survey of Canada, 2017). Due to varying amounts of reworking and winnowing by meltwater, sediments forming hum-

mocky terrain tend to have a coarser matrix (*i.e.*, higher sand to silt ratio) and more sorting than till deposited by active ice. It is recommend that till-sampling programs avoid hummocky areas such as north of Salmon Pond and H Pond, and if sampling is required, collect samples between the hummocks (Proudfoot *et al.*, 1988; Geological Survey of Canada, 2017).

2) Multiple tills (Tills B and C) are more widespread than previously identified and the lateral continuity of till units remains uncertain.
   a) In the study area, the uppermost till (Till C) is likely a supraglacial till that may contain far-travelled sediment, whereas the compact and fissile brown-reddish till (Till B) was likely deposited subglacially.
   b) The variable thickness of the upper till, Till C (20–80 cm), may result in sampling of multiple, diachronous till units if a sampling campaign is conducted at a consistent depth without considering till stratigraphy.

3) To use till geochemistry to determine sources of geochemical anomalies and potential mineralization in bedrock, ice-flow direction and debris transport distance must be considered.
   a) The study area was affected by three ice-flow events, only two of which were identified in newly identified striae sites. The older, east to southeast flow is recognized only in the west-central study area; the younger, north-northeast flow is recognized more commonly in striae and landforms throughout the study area. The youngest ice-flow, ice flow to the northeast and northwest, while not identified this summer has been identified regionally. McClenaghan and Paulen (2018) report that multiple ice flows in an area can produce complex dispersion train patterns, or remove them entirely.
   b) Till fabrics (pebble orientations) collected by Scott (1994a) record all three ice-flow phases and suggest that the youngest ice-flow may not have affect sediment dispersal of the uppermost till.
   c) Glacial transport distances in Newfoundland may be 10s of kilometres in the Gander (Batterson and Vatcher, 1991) and Baie Verte areas (Batterson and Liverman, 2000).

4) Avoid sampling sediment that is moderately to well-sorted or lacking silt, such as eroded till, glaciofluvial sands and gravels, or lacustrine and marine sediments. These sediments will be difficult to trace to source, or may have experienced postglacial re-entrainment and redeposition. Such sediment may be common below the currently proposed marine limit (64 m asl), close to the coast, or along Gander River, Burnt Lake or Ten Mile Lake.

## FUTURE WORK

Future work in the study area will focus on detailed mapping and stratigraphy. This will provide a better understanding of the distribution of all surficial units, help refine marine limit, and determine the stratigraphic relationships between multiple till units in the region. Anticipated results will not only improve regional Quaternary ice sheet dynamics, but will also enable exploration companies to refine sampling techniques and target mineral sources effectively.

## ACKNOWLEDGMENTS

Heather Campbell and Hamish Sandman are thanked for insightful discussions on the Quaternary and bedrock geology of the region. Daniella Mendoza Marin is acknowledged for providing enthusiastic office and field support. Gerry Hickey is thanked for his readying of field gear and logistical support. Tom Burry from the Department of Fisheries, Forestry and Agrifoods is recognized for logistical support in Gander. Critical reviews and discussion of this manuscript were provided by Andrea Marich and Sara Jenkins. Much appreciation is given to the mineral exploration companies operating in the field area, especially the staff at New Found Gold Corporation and Labrador Gold Corporation, for their discussion of ongoing Quaternary issues and for providing access to their claims and trenches.

## REFERENCES

Batterson, M.J.
2000: Landforms and surficial geology of the Gander map sheet (NTS 2D/15), Newfoundland. Map 2000-19. Government of Newfoundland and Labrador, Department of Mines and Energy, Geological Survey, Open File 2D/15/0350.

Batterson, M.J. and Liverman, D
2000: Contrasting styles of glacial dispersal in Newfoundland and Labrador: Methods and case studies. *In* Current Research. Government of Newfoundland and Labrador, Department of Mines and Energy, Geological Survey, Report 2000-1, pages 1-31.

Batterson, M.J., Taylor, D.M. and Sheppard, K.
2001: Till geochemistry of the Gander map area. Government of Newfoundland and Labrador, Department of Mines and Energy, Geological Survey, Open File 2D/15/0398, 54 pages.

Batterson, M.J. and Vatcher, S.
1991: Quaternary geology of the Gander (NTS 2D/15) map area. *In* Current Research. Government of Newfoundland and Labrador, Department of Mines and Energy, Geological Survey Branch, Report 91-1, pages 1-12.

Blackwood, R.H.
1982: Geology of the Gander Lake (2D/15) and Gander River (2E/2) area. Government of Newfoundland and Labrador, Department of Mines and Energy, Mineral Development Division, Report 82-4, 56 pages.

Blundon, P., Bell T. and Batterson, M.
2009: An evaluation of SRTM digital elevation data for glacial landform mapping in Newfoundland. *In* Current Research. Government of Newfoundland and Labrador, Department of Natural Resources, Geological Survey, Report 09-1, pages 289-303.

2010: Ice streaming in the Newfoundland Ice Cap: Implications for the reconstructing of ice flow and drift prospecting. *In* Current Research. Government of Newfoundland and Labrador, Department of Natural Resources, Geological Survey, Report 10-1, pages 143-157.

Brushett, D.
2010: Quaternary geology of the Gander Lake and Gambo map areas (NTS 2D/16 and 2C/13). *In* Current Research. Government of Newfoundland and Labrador, Department of Natural Resources, Geological Survey, Report 10-1, pages 159-170.

2011: Quaternary geology of Weir's Pond and surrounding areas (NTS map areas 2D/15, 2E/01, 2E/02 and 2F/04). *In* Current Research. Government of Newfoundland and Labrador, Department of Natural Resources, Geological Survey, Report 11-1, pages 33-42.

2012: Quaternary geology and till geochemistry of the Carmanville (NTS 2E/08), Wesleyville (NTS 2F/04) and Musgrave Harbour (NTS 2F/05) map areas. *In* Current Research. Government of Newfoundland and Labrador, Department of Natural Resources, Geological Survey, Report 12-1, pages 179-190.

2013a: Surficial geology of the Weir's Pond map area (NTS 2E/01). Map 2013-05. Government of Newfoundland and Labrador, Department of Natural Resources, Geological Survey, Open File 2E/01/1733.

2013b: Surficial geology of the Wesleyville map area (NTS 2F/04 and part of 2F/03). Map 2013-013. Government of Newfoundland and Labrador, Department of Natural Resources, Geological Survey, Open File 2F/0043.

Campbell, H.E., Sandeman, H. and Organ, J.
This volume: Glaciotectonic deformation along a 70 km section of the Dog Bay Line: Beaver Brook Antimony Mine to Ten Mile Lake.

Cofaigh, C.O., Stokes, C.R., Lian, O.B., Clark, C.D. and Tulacyzk. S.
2013: Formation of mega-scale glacial lineations on the Dubawnt Lake Ice Stream Bed: 2. Sedimentology and stratigraphy. Quaternary Science Reviews. Volume 77, pages 210-227.

Colman-Sadd, S., Hayes, J.P. and Knight, I.
1990: Geology of the Island of Newfoundland. Newfoundland and Labrador Geological Survey, Map 90-001.

Currie, K.L.
1995: Geology, Gander River, Newfoundland. 1:50 000 scale map. Geological Survey of Canada. Open File 3162. 1 Sheet. DOI: 10.4095/205322

1997: Geology, Gander River-Gander Bay region, Newfoundland. Geological Survey of Canada, Open File 3467. DOI: 10.4095/209111

Culshaw, M.G., Cripps, J.C., Bell, F.G. and Moon, C.F.
1991: Engineering geology of Quaternary soils: I. Processes and properties. *In* Quaternary Engineering Geology. *Edited by* A. Forster, M.G. Culshaw, J.C. Gripps, J.A. Little and C.F. Moon. Geological Society, Engineering Geology Special Publication No 7, pages 3-38.

Dalton, A.S., Margold, M., Stokes, C.R., Tarasov, L., Dyke, A.S. (+ 66 authors)
2020: An updated radiocarbon-based ice margin chronology for the last deglaciation of the North America Ice Sheet Complex. Quaternary Science Reviews, Volume 234, 23 pages. DOI: 10.1016/j.quascirev.2020.106223

Davenport, P.H. and Nolan, L.W.
1989: Mapping the regional distribution of gold in Newfoundland using lake sediment geochemistry. *In* Current Research. Government of Newfoundland and Labrador, Department of Mines, Geological Survey of Newfoundland, Report 89-1, pages 259-266.

Dickson, W.L., McNicoll, V.J., Nowlan, G.S. and Dunning, G.R.
2007: The Indian Islands Group and its relationships to adjacent units: recent data. *In* Current Research. Government of Newfoundland and Labrador, Department of Natural Resources, Geological Survey, Report 07-1, pages 1-9.

Dickson, W.L., O'Brien, B.H. and Colman-Sadd, SP.
2000: Geology of the Botwood map area (NTS 2E/3), central Newfoundland. Map 2000-11, version 2.0. Government of Newfoundland and Labrador, Department of Mines and Energy, Geological Survey, Open File 2E/03/1067.

Dimmell, P.M.
2010: First year assessment report on prospecting for licence 15923M on claims in the Gander River area, central Newfoundland. Newfoundland and Labrador Geological Survey, Assessment File NFLD/3153, 19 pages.

Dowdeswell, J.A. and Sharp, M.S.
1986: Characterization of pebble fabrics in modern glacigenic sediments. Sedimentology, Volume 33, pages 699-710. DOI: 10.1111/j.1365-3091.1986.tb01970.x

Dreimanis, A.
1988: Tills, their genetic terminology and classification. In Genetic Classification of Glacigenic Deposits. *Edited by* R.P. Goldthwait and C.L. Matsch. Rotterdam, Balkema, pages 17-84.

Evans, D.T.W.
1996: Epigenetic gold occurrences, easter and central Dunnage Zone, Newfoundland. Government of Newfoundland and Labrador, Department of Mines and Energy, Geological Survey, Mineral Resource Report 9, 135 pages.

Evans, D.J.A, Phillips, E.R., Hiemstra, J.F. and Auton, C.A.
2006: Subglacial till: Formation, sedimentary characteristics and classification. Earth-Science Reviews, Volume 78, pages 115-176. doi.org/10.1016/j.earscirev.2006.04.001

Evans-Lamswood, D.
2020: Technical report on the Queensway Gold Project, Newfoundland, Canada. New Found Gold Corporation, Toronto, Ontario, 482 pages.

Finch, C., Roldan, R., Walsh, L., Kelly, J. and Amor, S.
2018: Analytical methods for chemical analysis of geological materials. Government of Newfoundland and Labrador, Department of Natural Resources, Geological Survey, Open File NFLD/3316, 67 pages.

Geological Survey of Canada
2017: Till sampling and analytical protocols for GEM projects: from field to archive. Geological Survey of Canada, Open File 6850 (revised), 84 pages. DOI:10.4095/300281

Geological Survey of Newfoundland and Labrador (GSNL)
2021a: "Generalized Bedrock Geology." Newfoundland and Labrador GeoScience Atlas OnLine. Last update: January 2013, http://geoatlas.gov.nl.ca/. [October 2021].

2021b: "Mineral Occurrence Database System (MODS)." Newfoundland and Labrador GeoScience Atlas OnLine. Last update: December 2021. http://geoatlas.gov.nl.ca/. [December 2021].

2021c: "Surficial Geology – Detailed 1:50 000 scale." Newfoundland and Labrador GeoScience Atlas OnLine. Last Update: June 2021. http://geoatlas.gov.nl.ca/. [October 2021].

2021d: "Striation Database." Newfoundland and Labrador GeoScience Atlas OnLine. Last update: June 2021. http://geoatlas.gov.nl.ca/. [October, 2021].

2021e: 'Landform Newfoundland and Labrador GeoScience Atlas OnLine. Last update: June 2021. http://geoatlas.gov.nl.ca/. [October, 2021].

GIS and Mapping Division
2021: 5 m Digital Elevation Model for the Island of Newfoundland. GEOHub Last update Feb 9, 2021. Fisheries, Forestry and Agriculture. [March 2021].

Goodwin, L.B. and O'Neill, P.P.
1991: The structural evolution of the northern segment of the Dunnage Zone-Gander Zone boundary, Newfoundland. *In* Current Research. Government of Newfoundland and Labrador, Department of Mines and Energy, Geological Survey Branch, Report 91-1, pages 97-107.

Gower, D. and Tallman, P.
1988: Second year assessment report on geological, geochemical, geophysical, trenching and diamond drilling exploration for licence 2892 on claim blocks 4515-4517 and 4520 and licence 2917 on claim blocks 4553-4454 and claim 15549 in the Gander River Outflow and Careless Coves areas. Newfoundland.

Newfoundland and Labrador Geological Survey, Assessment File 2D/15/0198, 253 pages.

Grant, D.R.
1989: Quaternary geology of the Atlantic Appalachian region of Canada; Chapter 5. *In* Quaternary Geology of Canada and Greenland. *Edited by* R.J. Fulton. Geological Survey of Canada, Geology of Canada, no.1 (also Geological Society of America, The Geology of North America, v. K-1). Pages 393-440.

Jenness, S.E.
1960: Late Pleistocene glaciation of eastern Newfoundland. Bulletin of the Geological Society of America, Volume 71, pages 161-179. doi.org/10.1130/00167606(1960)71[161:LPGOEN]2.0.CO;2

Lian, O.B., Hicock, S.R. and Dremanis, A.
2003: Laurentide and Cordilleran fast ice flow: Some sedimentological evidence from Wisconsinan subglacial till and its substrate. Boreas, Volume 32, pages 102-113.

McClenaghan, M.B. and Paulen, R.C.,
2017: Chapter 20: Application of Till Mineralogy and Geochemistry to Mineral Exploration. *In* Past Glacial Environments Second Edition. *Edited by* J. Menzies and J.J.M. van der Meer. Queen Mary University of London, London, United Kingdon, pages 689-751. DOI:10.1016/B978-0-08-100524-8.00022-1

McCuaig, S.
2006: Glacial spillway deposits in the Gander Lake–Gambo area. *In* Current Research. Government of Newfoundland and Labrador, Department of Mines and Energy, Geological Survey, Report 06-1, pages 209-219.

McHenry, H. and Dunlop, P.
2016: The subglacial imprint of the last Newfoundland Ice Sheet, Canada. Journal of Maps, Volume 12, Number 3, pages 462-483. doi.org/10.1080/17445647.2015.1044038

Munro, M. and Catto, N.
1993: Quaternary geology of the Carmanville map area (NTS2E/8). *In* Current Research. Government of Newfoundland and Labrador, Department of Mines and Energy, Geological Survey Branch, Report 93-1, pages 149-159.

1999: Quaternary geology and glacial history of the Carmanville map area (NTS 2E/8). Government of Newfoundland and Labrador, Department of Mines and Energy, Geological Survey, Open File 002E/08/1066, 52 pages.

New Found Gold Corporation.
2022: Queensway Project. https://newfoundgold.ca/project/queensway-project/. [January 2022]

Newfoundland and Labrador Mineral Lands Division.
2022: "Map Staked Claims". Newfoundland and Labrador GeoScience Atlas OnLine. Last update: updated in real time. https://geoatlas.gov.nl.ca/. [January 2022].

O’Neill, P.
1991: Geology of the Weir’s Pond area, Newfoundland (NTS2E/1). Government of Newfoundland and Labrador, Department of Mines and Energy, Geological Survey Branch, Report 91-3, 144 pages.

O'Neill, P.P. and Blackwood, R.F.
1989: A proposal for revised stratigraphic nomenclature of the Gander and Davidsville groups and the Gander River ultrabasic belt, of northeastern Newfoundland. *In* Current Research. Government of Newfoundland and Labrador, Department of Mines, Geological Survey, Report 89-1, pages 127-130.

O’Neill, P. and Lux, D.
1989: Tectonothermal history and 40Ar/39Ar geochronology of northeastern Gander Zone, Weirs Pond area [2E/1]. *In* Current Research. Government of Newfoundland and Labrador, Department of Mines, Geological Survey of Newfoundland, Report 89-1, pages 131-139.

Phillips, E.R.
2018: Chapter 13: Glacitectonics. *In* Past Glacial Environments Second Edition. *Edited by* J. Menzies and J.J.M. van der Meer. Queen Mary University of London, London, United Kingdom, pages 467-502.

Proudfoot, D.N., Scott, S., St. Croix, L., Taylor, D.M. and Vanderveer, D.G.
1988: Glacial striations in southeast-central Newfoundland. Map 88-102. 1:250 000 scale. Government of Newfoundland and Labrador, Department of Mines, Mineral Development Division, Open File NFLD 1725.

Rickets, M.J. and McGrath, J.
1990: Granular aggregate-resource mapping of the Gander Lake (NTS2D/15), Gander River (NTS 2E/2) and Comfort Cove – Newstead (NTS2E/7) map areas. *In* Current Research. Government of Newfoundland

and Labrador, Department of Mines and Energy, Geological Survey Branch, Report 90-1, pages 65-75.

Sandeman, H.A.I., Dunning, G.R., McCullough, C.K. and Peddle. C.
2017: U–Pb geochronology, petrogenetic relationships and intrusion-related precious-metal mineralization in the northern Mount Peyton intrusive suite: Implications for the origin of the Mount Peyton trend, central Newfoundland (NTS 2D/04). *In* Current Research. Government of Newfoundland and Labrador, Department of Natural Resources, Geological Survey, Report 17-1, pages 189-117.

Sandeman, H.A.I., Peddle, C. and Newman R.
2018: Beaver Brook antimony mine revisited: An update on operations and new structural and geological observations. *In* Current Research. Government of Newfoundland and Labrador, Department of Natural Resources, Geological Survey, Report 18-1, pages 123-132.

Scott, S.
1994a: Surficial geology, and drift exploration of Comfort Cove-Newstead and Gander River map areas (NTS 2E/7 and 2E/2). *In* Current Research. Government of Newfoundland and Labrador, Department of Mines and Energy, Geological Survey Branch, Report 94-1, pages 29-42.

1994b: Placer gold studies, drift exploration and surficial geology of the Gander River and Comfort Cove – Newstead map sheets (NTS 2E/02 and 2E/07). Government of Newfoundland and Labrador, Department of Mines and Energy. Open File 002E/1093, 151 pages.

Scott, S. and Taylor, D.M.
2012: Surficial geology of the Gander River map area (NTS 2E/02). Map 2012-19. Government of Newfoundland and Labrador, Department of Natural Resources, Geological Survey, Open File 2E/02/1717.

2014: Surficial geology of the Comfort Cove – Newstead map area (NTS 2E/07). Map 2014-04. Government of Newfoundland and Labrador, Department of Natural Resources, Geological Survey, Open File 2E/07/1744.

Shaw, J.
2003: Submarine moraines in Newfoundland coastal waters: Implications for the deglaciation of Newfoundland and adjacent areas. Quaternary International 99-100, pages 115-134.

Shaw, J. and Edwardson, K.A
1984: Surficial sediments and post-glacial relative sea-level history, Hamilton Sound, Newfoundland. Atlantic Geology, Volume 30, pages 97-112.

Shaw, J. and Potter, D.P.
2015: Surficial geology, coastal waters, Island of Newfoundland, Newfoundland and Labrador. Geological Survey of Canada, Bulletin 605, 118 pages.

Shaw, J., Piper, D.J.W., Fader, G.B., King, E.L., Todd, B.J., Bell, T., Batterson, M.J. and Liverman, D.G.E.
2006: A conceptual model of the deglaciation of Atlantic Canada. Quaternary Science Reviews, Volume 25, pages 2059-2081.

St. Croix, L. and Taylor, D.M.
1990: Ice flow in north-central Newfoundland. *In* Current Research. Government of Newfoundland and Labrador, Department of Mines and Energy, Geological Survey Branch, Report 90-01, pages 85-88.

1991: Regional striation survey and deglacial history of the Notre Dame Bay area, Newfoundland. *In* Current Research. Government of Newfoundland and Labrador, Department of Mines and Energy, Geological Survey Branch, Report 91-01, pages 61-68.

Vanderveer, D.G. and Taylor, D.M.
1987: Quaternary mapping in the Gander River area, Newfoundland. *In* Current Research. Government of Newfoundland and Labrador, Department of Mines and Energy, Mineral Development Division, Report 87-01, pages 39-43.

van Staal, C. and Barr, S.M.
2012: Lithospheric architecture and tectonic evolution of the Canadian Appalachians and associated Atlantic margin: Chapter 2. *In* Tectonic Styles in Canada: The Lithoprobe Perspective. *Edited by* J.A. Percival, F.A. Cook and R.M. Clowes. Geological Association of Canada, Special Paper 49, pages 41-95.

Williams, H., Colman-Sadd, S.P. and Swinden, H.S.
1988: Tectonic-stratigraphic subdivisions of central Newfoundland. *In* Current Research, Part B. Eastern and Atlantic Canada, Geological Survey of Canada, Paper 88-1B, pages 91-98.

Williams, H., Currie, K.L. and Piasecki, M.A.J.
1993: The Dog Bay Line: A major Silurian tectonic boundary in northeast Newfoundland. Canadian Journal of Earth Sciences, Volume 30, pages 2481-2494.

Wonderly, P.F. and Neuman, R.B.
1984: The Indian Bay Formation: fossiliferous Early Ordovician volcanogenic rocks in the northern Gander Terrane, Newfoundland, and their regional significance. Canadian Journal of Earth Sciences, Volume 21, pages 525-532.

Woodcok, N.H.
1977: Specification of fabric shapes using an eigenvalue method. Bulletin of the Geological Society of America, Volume 88, pages 1231-1236.