

## BOULDER TRACING AND TERRESTRIAL COSMOGENIC SAMPLING IN NORTH-CENTRAL NEWFOUNDLAND

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### ABSTRACT

*Ice flowed east, northeast, and north to northwest during glacial retreat (following the last glacial maximum) and deposited basal till of variable thicknesses (0–20 m) that cover orogenic gold occurrences in northeastern Newfoundland. Both ice-streaming and cold-based ice conditions resulted in multiple ice-flow directions and variable dispersal distances because of ice moving at different velocities through time; this resulted in complicated interpretations of the dispersal trains within staked mineral-resource properties. This is documented by truncated regional till-dispersal trains for gold pathfinders, such as As and Sb. In addition, erosion of bedrock from the Mount Peyton Intrusive Suite (MPIS) by each ice-flow event has resulted in its over-representation in nearby tills, hindering pebble dispersal studies, and possibly obscuring till geochemical patterns.*

*To better understand glacial distribution patterns in the area, the paths of twenty-two glacially eroded and dispersed large (>2 m) surface boulders were traced using boulder emplacement angles, and their projected up-ice trajectories. Eighteen of these boulders were submitted for terrestrial cosmogenic nuclide (TCN) dating to determine their exposure ages. The exposure ages will determine the ice-retreat sequence near the present-day coast, as well as confirm whether the latest ice flow occurred during the cold-based conditions of the Younger Dryas.*

*This report presents the preliminary results of boulder dispersal studies, including the boulder lithologies, their distribution and up-ice sources inferred from their emplacement orientation relative to conventional ice-flow indicators (e.g., striations and fabrics). The boulder dispersal distances and orientations are variable over the areas studied, highlighting the importance of establishing local-scale ice-flow patterns within the framework of regional dispersal patterns.*

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### INTRODUCTION AND BACKGROUND

Previous studies have determined a complex ice-flow history for north-central Newfoundland, affecting at least three different ice-flow directions originating from different ice centres (Proudfoot *et al.*, 1988; St. Croix and Taylor, 1990, 1991; Scott, 1994; Brushett, 2010, 2011, 2012). Additionally, ice streaming in the Exploits River Valley and south of Gander Lake (Blundon *et al.*, 2010; Primmer *et al.*, 2015; McHenry and Dunlop, 2016; Norris *et al.*, 2024), as well as late glacial cold-based ground conditions (Eyles, 1977; St. Croix and Taylor, 1991; Mackenzie and Catto, 1993; Munro and Catto, 1999; Liverman *et al.*, 2000) suggest complex glacial flow in the region.

Unlike glacial dispersal models constructed from a single ice-flow orientation (e.g., Strange Lake, *see* Batterson and Liverman, 2000), the multiple ice-flow directions and their erosional intensity result in dispersal patterns that can make identifying bedrock sources up-ice

challenging (*ibid*). Pebble lithologies have traditionally been used to define dispersal patterns, but are difficult to employ in this study due to overrepresentation of widely occurring bedrock units (e.g., the Mount Peyton Intrusive Suite–MPIS) in till from multiple ice-flow movements. Fabric studies, historically employed to understand ice-flow orientations in till (Batterson and Vatcher, 1991; MacKenzie and Catto, 1993; Scott, 1994; Organ, 2022) are limited by exposure of suitable sections (e.g., Batterson, 1999a, b, 2000; Scott and Taylor, 2012, 2014).

To clarify dispersal patterns in north-central Newfoundland (NTS map areas 2E/01, 02, 03, 06, 07, 08, 02D/13, 14 and 15), the dispersal paths of subglacially emplaced boulders sampled in the vicinity of ice paths in the Gander Lake and Exploits River Valley area are investigated. The boulders have been sampled for terrestrial cosmogenic nuclide (TCN) analysis to determine exposure dates to constrain the timing of their deposition. The boulder dispersal paths, and their exposure dates will help determine the

ice-flow sequences responsible for glacial dispersal of mineralized debris from up-ice bedrock units in the region.

## TERRESTRIAL COSMOGENIC NUCLIDE DATING

Terrestrial cosmogenic nuclide dating uses the concentration of specific nuclides (protons and neutrons) in the upper surface of terrestrial materials, to calculate the duration of atmospheric exposure of the surface (Cerling and Craig, 1994; Gosse and Phillips, 2001). It is used in glacial studies of different geomorphological landforms to assist in understanding the evolution of past glacial environments. Applications include dating of boulder exposure to constrain ice retreat and paleoclimate conditions (e.g., Rice *et al.*, 2019; Couette *et al.*, 2023), constraining burial rates using depth profiling in ice-contact deltas (Utting *et al.*, 2016), quantifying till deposition and till mixing in drumlins (Brown, 2012), comparing ice-erosion rates between mountains and valleys (Margreth *et al.*, 2016; Davis *et al.*, 2017; Davies, 2022), determining erosion rates over suspected cold- and warm-based ice affected regions (McMartin *et al.*, 2025), quantifying the duration of ice streaming (Glasser *et al.*, 2014) and describing the exposure and burial history of glacial debris (Corbett, 2013).

Terrestrial cosmogenic nuclides are formed during interactions of galactic cosmogenic rays with atmospheric nuclei, breaking them apart into high energy particles that interact with unconsolidated and consolidated earth materials. The surface interactions create  $^{10}\text{Be}$ ,  $^3\text{He}$ ,  $^{21}\text{Ne}$ ,  $^{26}\text{Al}$ ,  $^{14}\text{C}$  and  $^{36}\text{Cl}$  whose abundances are proportional to the duration of exposure (Cerling and Craig, 1994; Gosse and Phillips, 2001). Of these,  $^{10}\text{Be}$  and  $^{26}\text{Al}$  are the most commonly used because of their well-constrained production rates (Gosse and Phillips, 2001). The nuclides are derived from galactic cosmic rays sourced from the Milky Way galaxy, and a smaller component of weaker rays from the sun (*ibid*).

Galactic cosmic ray intensity in the atmosphere is influenced by the horizontal component of the geomagnetic field and solar activity that varies with latitude, commonly resulting in higher ray penetrations at the poles (Gosse and Phillips, 2001). The abundance of TCNs in surface materials is affected by this and other parameters including; 1) material composition and density, 2) erosion rates (typically minimal for samples younger than 30 ka), 3) topographic shielding from nearby hills and dense tree cover and surface covering such as snow, that prevent cosmic rays from interacting with surfaces, and 4) surface slope, where sharp surfaces can diffuse neutron flux around edges (Cerling and Craig, 1994; Gosse and Phillips, 2001; Davies, 2022). These parameters are considered and calculated to provide a surface exposure

age (e.g., see Balco *et al.*, 2008; online cosmogenic-nuclide calculators (<https://hess.ess.washington.edu/>)). Topographic shielding and the slope are input into the calculation from field observations, while cosmic ray production rates are derived from time independent or dependent scaling models (Balco *et al.*, 2008; Davies, 2022).

Most TCNs are produced within the first couple of centimetres of the surface, (Ivy-Ochs and Kober, 2008), enabling their removal by subglacial processes. However, low erosion rates by cold-based ice can result in inheritance from previous exposure episodes. In this case, the ratio of paired nuclides  $^{10}\text{Be}$  and  $^{26}\text{Al}$ , that decay at different rates, can be used to determine the erosion history (Gosse and Phillips, 2001; Corbett *et al.*, 2013; McMartin *et al.*, 2025).

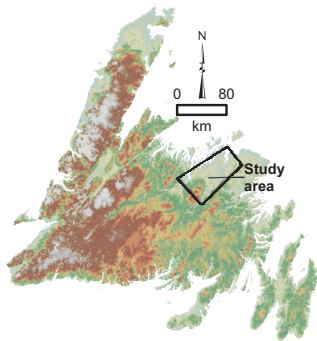
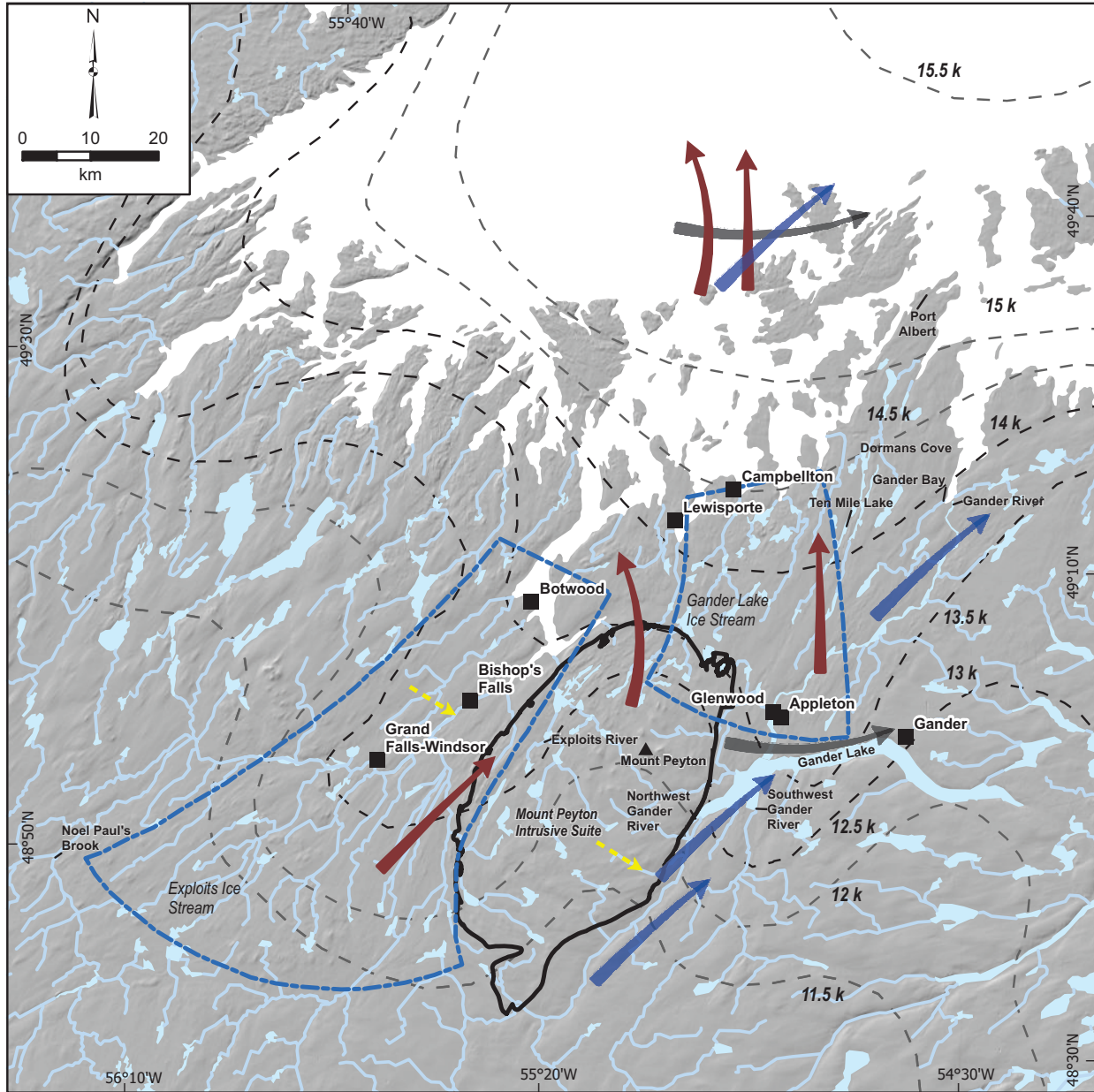
## PHYSIOGRAPHY

Mount Peyton rises 300 m above the plains, bogs and spruce strands to a northeastward roche moutonnée at 471 m in the centre of the study area (Figure 1). It drops off gradually in the southwest and to the southeast toward the Exploits, Great Rattling Brook, Gander and Northwest Gander River valleys. Undulating ridges, valleys and bogs form the terrain between the towns of Gander and Glenwood. West of Mount Peyton, the region is characterized by grassy fens and northeastward-trending ridges east of the Exploits River. Tree-covered ridges and bogs occur north and east of Lewisporte, while sand terraces occur from Botwood, to Birchy Bay in the west and west and east of Gander Bay near the coast. North of Mount Peyton, the terrain is tree and bog covered, with bedrock exposure toward the coast and in quarries. The region south of Gander Lake is tree covered with small ridges and channels, and an interfluvium between the Northwest and Southwest Gander River valleys (Batterson and Vatcher, 1991). Sand terraces occur along the banks of the Northwest Gander River.

## BEDROCK GEOLOGY

The tectonostratigraphic and geological units are presented in Figures 2 and 3 (Colman Saad *et al.*, 2000; Honsberger *et al.*, 2022) and are described below.

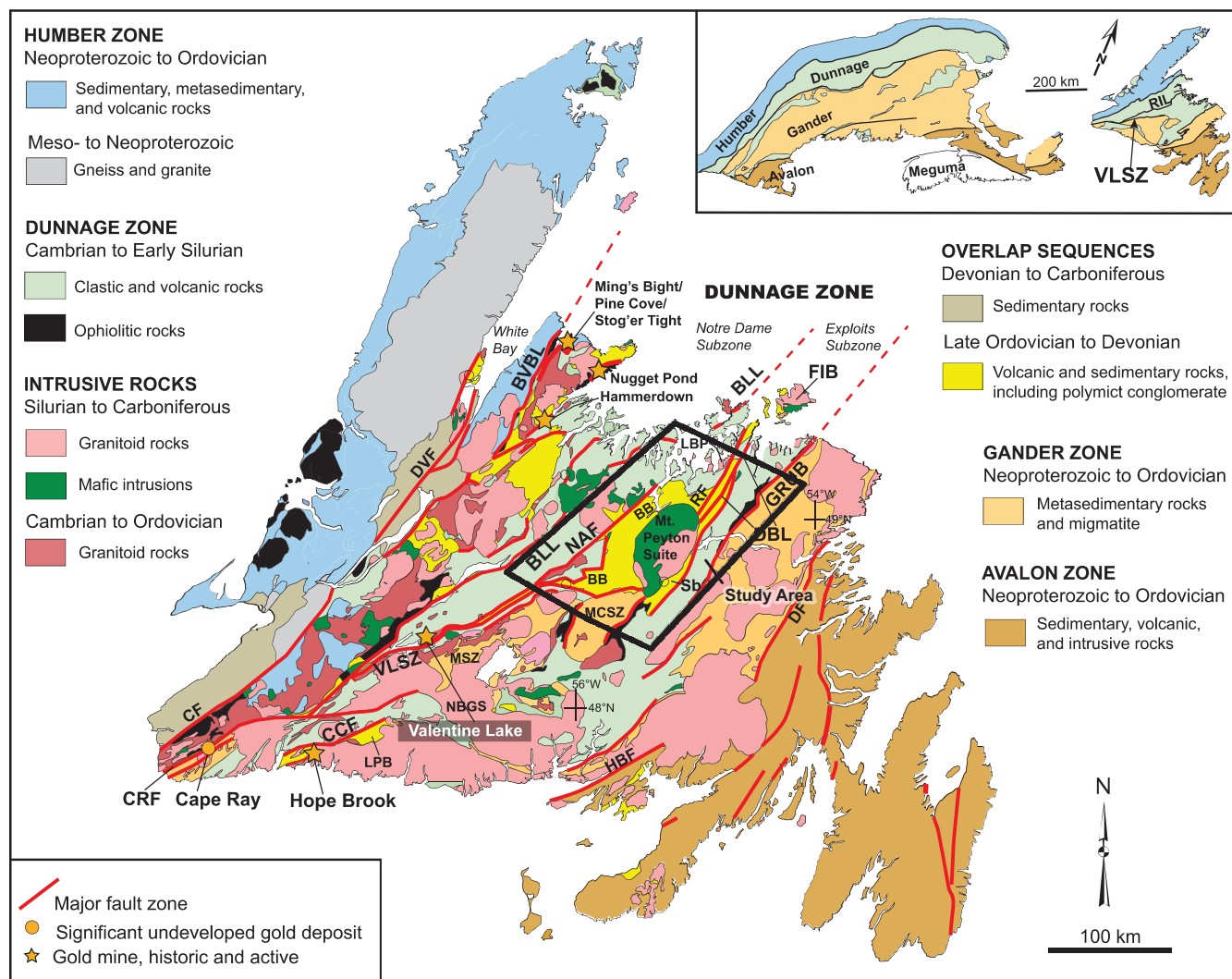
The study area straddles the boundary between bedrock units of the Gander Zone and Exploits tectonostratigraphic subzone in central and north central Newfoundland (Figure 2; Honsberger *et al.*, 2022). It is centred around the MPIS, extending to the Botwood Basin to the west, and the Gander River Complex to the east (Figure 2). It comprises greenschist to upper-amphibolite metamorphosed sedimentary rocks that surround the metamorphic dome of the Mount



**LEGEND**

- Ice streams
  - Isochrones
- Ice-flow directions**
- 4
  - 3
  - 2
  - 1

**Figure 1.** Greyscale digital elevation map of the study area (Government of Newfoundland and Labrador, Department of Forestry, Agriculture and Lands GeoHub, accessed 1/7/2026), with the ice-flow chronology for northeastern Newfoundland along with the positions of ice streams and ice-retreat isochrones (see references in text). The Mount Peyton Intrusive Suite, rising 300 m above the Exploits and Gander River valleys, is outlined in black.

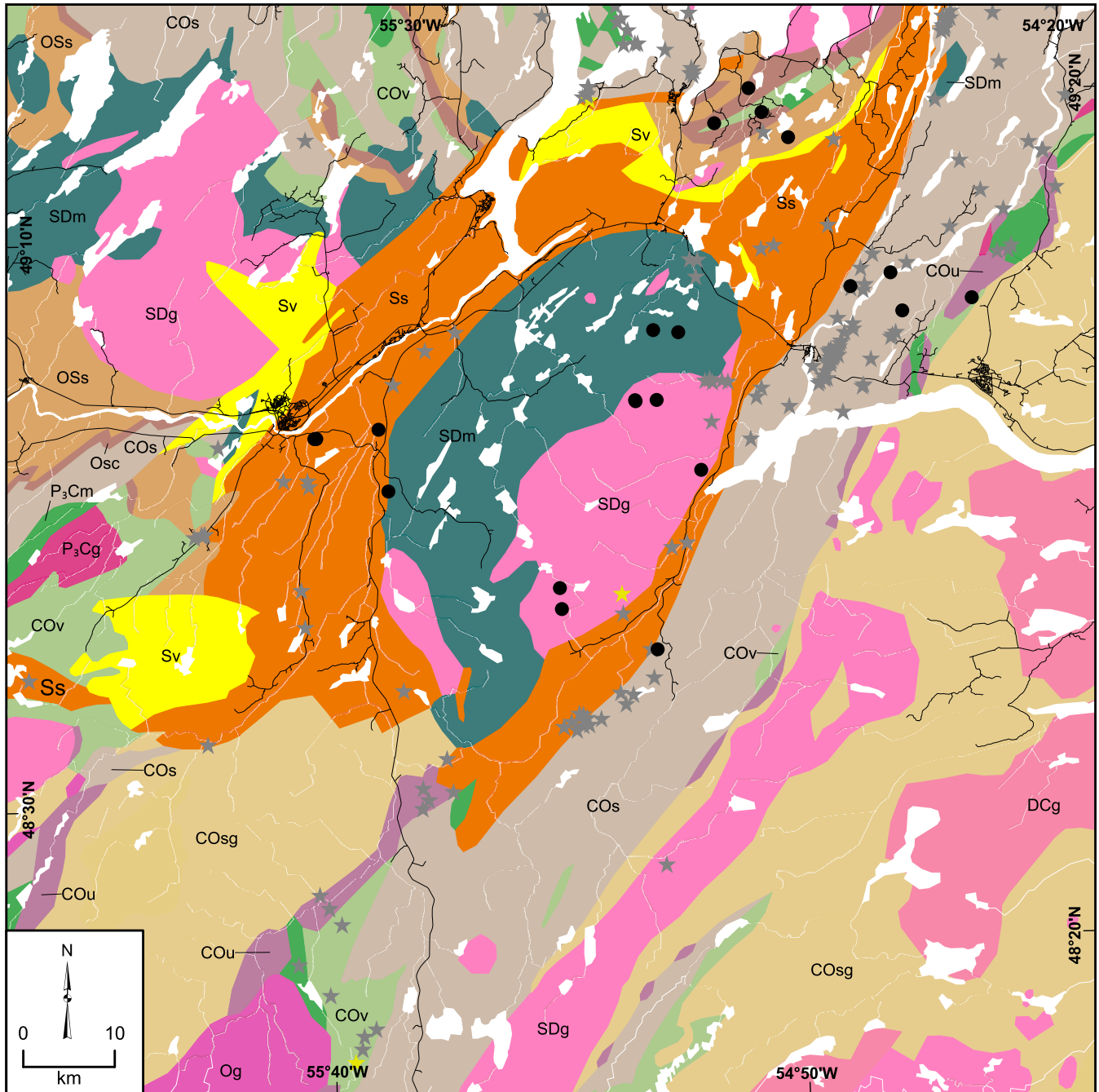


**Figure 2.** Tectonostratigraphic map of Newfoundland showing major faults and gold deposits. Structural divisions are labelled: BB—Botwood basin, BVBL—Baie Verte–Brompton Line, CCF—Cinq Cerf fault, CF—Cabot fault, CRF—Cape Ray Fault Zone, DBL—Dog Bay Line, DF—Dover fault, DVF—Doucens Valley Fault Zone, FIB—Fogo Island Intrusive Suite, GRC—Gander River Complex, HBF—Hermitage Bay fault; LBP—Loon Bay pluton, LPB—La Poile basin, MCSZ—Mount Cormack Subzone, MSZ—Meelpaeg Subzone, NAF—Northern Arm fault, NBGS—North Bay Granite Suite, BLL—Beothuk Lake Line, RF—Reach fault, Sb—Beaver Brook Antimony Mine, VLSZ—Victoria Lake Shear Zone (Honsberger *et al.*, 2022).

Cormack Subzone to the south (Valverde-Vaquero *et al.*, 2006), and the MPIS to the north (Figure 2).

The oldest rocks occur in the west, comprising Neoproterozoic to Cambrian granites and mafic intrusions (Crippleback Lake Intrusive Suite, Lemotte's Lake Granite; Evans *et al.*, 1990, 1994; Rogers *et al.*, 2005, 2006; units P3€g and P3€m, Figure 3). Cambrian to Ordovician ophiolitic rocks (units €Ou, €Om and €Og) occur in several places in central Newfoundland; as a discontinuous band east of Gander River (Gander River Complex; O'Neill and Blackwood, 1989; Currie, 1995), and the Great Bend, Coy

Pond and Pipestone Pond complexes that surround the Mount Cormack Subzone, an ovoid-shaped dome of metamorphosed Cambrian to Ordovician migmatite schists (Unit €Omg), metamorphosed sedimentary rocks (Unit €Osg) and granites (Unit Og; Colman-Sadd and Swinden, 1982, 1984a, b; Colman-Sadd, 1985; Swinden, 1988; Dickson, 1993; 1996; Colman-Sadd *et al.*, 2000; Valverde-Vaquero *et al.*, 2006). Low-grade, metamorphosed sandstones and siltstones of the Jonathan's Pond Formation outcrop east of the Gander River Complex (Unit €Osg; O'Neill and Blackwood, 1989; O'Neill, 1991; Colman Sadd *et al.*, 2000; Figure 3).



**Figure 3.** Bedrock map of the study area after Colman-Sadd *et al.* (2000) and associated mineral occurrences with boulder sample sites. Labelled bedrock units are described briefly in the text.

Cambrian to Middle Ordovician, volcanic and volcanoclastic rocks of the Victoria Lake Supergroup outcrop on the western side of the study area (Unit  $\epsilon$ Ov; Evans *et al.*, 1990, 1994; O'Brien *et al.*, 1996, 1997; O'Brien, 2003; van Staal *et al.*, 2005; Rogers *et al.*, 2005, 2006; Valverde-Vaquero *et al.*, 2006). Middle to Late Cambrian to Ordovician deformed metasedimentary rocks of the Davidsville and Bay D'Espoir Groups (units  $\epsilon$ Osg,  $\epsilon$ O<sub>s</sub> and  $\epsilon$ Osm) occur

east, west and southeast of the MPIS (Blackwood, 1980, 1982; O'Neill and Blackwood, 1989; Colman Sadd *et al.*, 2000; Santos, 2024, 2025; Figure 3)

Ordovician turbidites, sandstones, shales and conglomerates and a mélange composed of volcanic and sedimentary rocks, outcrop to the north and west (units OS<sub>s</sub> and OS<sub>c</sub>; Currie, 1995). Ordovician granites including the Snowshoe

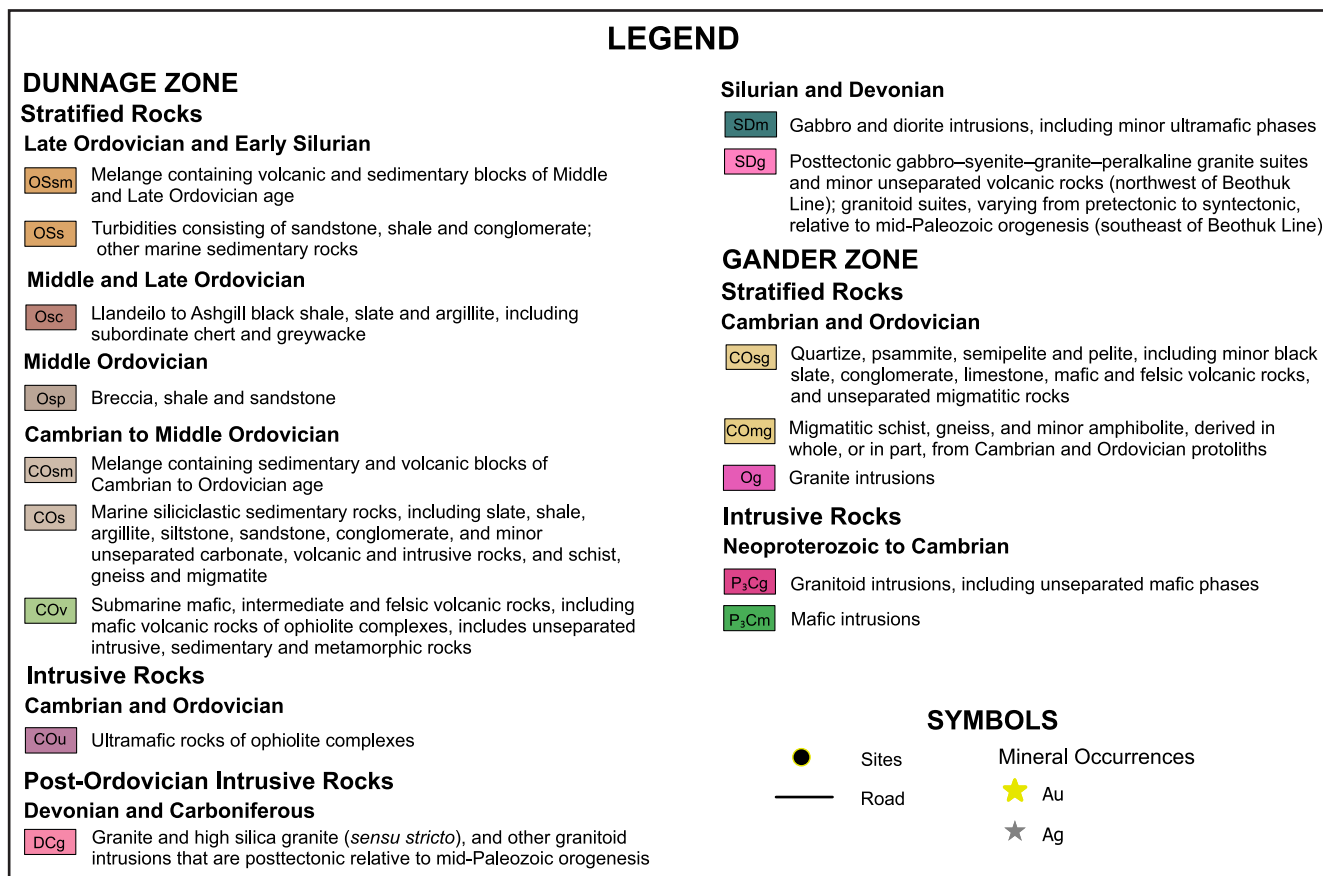


Figure 3. Legend.

Pond and Partridgeberry granites occur southwest and south of the MPIS (Colman-Sadd, 1985; Evans *et al.*, 1994). Ordovician volcanic rocks of the Lawrence Head formation outcrop in the northwest, west of Lewisporte and south of Campbellton (Currie, 1995; O'Brien, 2003; Figure 3).

Silurian volcanic rocks of the Stoney Lake, Charles Lake and Lawrenceton basalts occur on the west and south-west sides of the MPIS (Unit Sv; Colman-Sadd and Russell, 1988; Currie, 1995; Dickson, 2000; Dickson *et al.*, 2000; Honsberger *et al.*, 2024), while the Silurian Indian Islands, Badger and Botwood groups (Unit Ss), composed of siliciclastic and locally calcareous sandstones, siltstones and conglomerates outcrop from the west side of Gander Lake to Grand Falls (Figure 3; Williams, 1993; Currie, 1995; Colman-Sadd *et al.*, 2000; O'Brien, 2003).

The sedimentary rocks have been intruded by Silurian to Devonian granites including the MPIS; a bimodal suite of (mostly coarse grained) gabbros, diorites, monzonites and granites (units SDg and SDm). Young intrusions in this study include coarse-grained leucocratic and peraluminous granites of the Overflow Pond, Hunts Pond, Gander Lake and Middle Ridge granites (Unit SDg) that intrude the

Gander Group, and Davidsville and Bay D'Espoir group sedimentary rocks (Blackwood, 1982; Colman-Sadd *et al.*, 1988; Colman-Sadd, 1989; O'Neill and Colman-Sadd, 1993; Evans *et al.*, 1994; Santos, 2024, 2025; Rogers *et al.*, 2005; Figure 3). A Triassic alkali monzo-gabbro lamprophyre dyke swarm (Unit JK:D) originating from Dildo Pond south of Loon Bay is the youngest bedrock unit in the study (Sandeman and Peace, 2024).

## MINERALIZATION

### GOLD

Gold exploration in north-central Newfoundland started in the late 1980s and early 90s to follow up on anomalous gold concentrations occurring in lake-sediments (Davenport and Nolan, 1988, 1989; Davenport *et al.*, 1988; Tallman and Evans, 1994). Since then, active exploration of orogenic gold and associated base-metal mineralization has led to the emergence of prospective gold belts north of the towns of Appleton (Eccles and Stea, 2017; Atkinson, 2018; Dimmell and Regular, 2021; Sandeman *et al.*, 2023) and from north of Bishop's Falls to south of Grand Falls-Windsor (Barbour and Churchill, 2003; Morgan, 2016; House and Froude,

2020; Honsberger *et al.*, 2022; Figure 2). The gold indications, showings and prospects, as well as the silver and gold occurrences relevant to this study are listed in Table 1 (Mineral Occurrence Database System–MODS, October 2025; Figure 3).

Most of the gold prospects discussed are aligned with northeast-trending structures, such as the Northern Arm Fault west of Mount Peyton, the Reach Fault and Dog Bay Line, north of Mount Peyton, and along the Appleton Fault Zone (AFZ; Honsberger *et al.*, 2022). They occur in quartz veins within sedimentary rocks of the Botwood Basin and Davidsville Group, on the northeast margin of the MPIS, in gabbro units interlayered throughout sediments of the Davidsville and Botwood group, and with the Gander River Complex (Table 1).

The occurrences east of Bishops Falls are hosted in sedimentary rocks of the Botwood Group (Table 1). The Moosehead prospect (MODS # 002E/03/Au 001) includes the minerals pyrite, sphalerite, arsenopyrite, galena, chalcopryrite and abundant antimony-bearing sulphosalts that range in composition from boulangerite to bournonite to chalcostibite (Conliffe *et al.*, 2025). The Moosehead and other showings and prospects hosted in the same rocks south of Moosehead (*e.g.*, Cabin (MODS # 002D/13/Au 004), Moonlight (MODS # 002D/13/Au 005), Twin Ponds (MODS # 002D/13/Au 003)) are all associated with arsenopyrite and pyrite.

Occurrences southwest and south, up-ice of the boulders in this study, hosted in Neoproterozoic granites of the Crippleback Lake Intrusion (MODS # 012A/09/Au 002), are associated with copper and molybdenite (Kean and Evans, 1988; House and Froude, 2020).

Toward Lewisporte, gold occurs in quartz veins in a carbonate-rich mixture of shale, conglomerate and siltstone at the Little Joanna Gold prospect (MODS # 002E/02/Au 021) and in quartz veins in greywacke at the Treasure showing (MODS # 002E/02/Au 016).

Occurrences northeast of Mount Peyton, in the Hurricane (MODS # 002D/14/Au 002), Sabre (MODS # 002D/15/Au 005) and Corsair (MODS # 002D/14/Au 003) prospects, contain elevated As, Au, Sb, Ag and locally Cd, and north of Mount Peyton, monzogranite dykes in the Slip showing contain Au, As, Sb and Ag, and minor enrichment in Cu, Pb, Zn, Mo and Bi, containing pyrite–muscovite–calcite–chalcopryrite ± galena ± arsenopyrite (Sandeman *et al.*, 2017).

Gold occurs around the Beaverbrook Antimony Mine, in quartz veins in sediments of the Indian Islands Group (Figures 2 and 3), including the Cherry Hill (MODS #

002D/15/Au 034) and O'Reilly (MODS # 002D/11/Au021) showings.

The Goose (MODS # 002D/11/Au 011) and Greenwood Pond # 2 (MODS # 002D/11/Au 013) showings are hosted in mafic dykes intruding siltstone and include arsenopyrite, chalcopryrite, pyrrhotite, pyrite and tourmaline (Landry *et al.*, 2025). Silver and lead are indicated in the Clarks Brook West (MODS # 002D/14/Au 008) and Careless Cove (MODS # 002D/15/Au 006) showings.

A cluster of occurrences, including the Dropkick (MODS # 002E/02/Au 031), Golden Dome (not in MODS yet), Keats West (MODS # 002D/15/Au 032), Keats (MODS # 002D/15/Au 010) and Iceberg Zone (MODS # 002D/15/Au 038) prospects (Table 1, Figure 3) occur along the Appleton Fault Zone (AFZ), north of Appleton. These prospects are in quartz veins hosted in Davidsville group shales, siltstones and sandstones, and include arsenopyrite, stibnite, boulangerite, pyrite and chalcopryrite, with elevated As and Sb (Landry *et al.*, 2025; Conliffe *et al.*, 2025). East of the AFZ, base metals (lead, zinc and copper) are associated with the H-Pond prospect (MODS # 002E/02/Au 008; Mullen, 2004). Near Duder Lake, the Goldstash (MODS # 002E/07/Au 002) and Corvette (MODS # 002E/07/Au 004) prospects occur in altered gabbro, and include arsenopyrite and pyrite, with elevated arsenic and antimony geochemistry (Evans, 1996).

Farther east, the Jonathans Pond prospect (MODS # 002E/02/Au 001) is hosted in gabbro and altered ultramafic rocks of the Gander River Complex, and contains pyrite and arsenopyrite (Evans, 1996).

## OTHER

Although gold is the main commodity of interest, there is potential for critical minerals such as coltan, spodumene and cassiterite, as well as gemstones (*e.g.*, beryl) from indications and showings in evolved granites of the Gander Zone including the Middle Ridge, Hunt's Pond and related granites (Conliffe *et al.*, 2024).

Ultramafic rocks of the Gander River Complex are also prospective for base-metal mineralization (*e.g.*, awarurite, chalcopryrite, chromite; Blackwood, 1980; Wilton *et al.*, 2017) as well as gold and PGE-bearing minerals and metals (platinum; Blackwood, 1980; Evans, 1996; Bouzane, 2002).

## REGIONAL QUATERNARY FRAMEWORK

This section is limited to discussions of the Late Wisconsinan glaciation, as earlier glacial events have not been documented to date (Batterson and Liverman, 2000). Ice flow from isolated ice centres overlying higher ground

**Table 1.** Mineral Occurrence Database (MODS) listings for gold prospects, showings and indications within and proximal up-ice of the study area. Coordinates are presented in the NAD 27 datum

MODS Number	Name(s)	Commodity	Ore Minerals	Gangue minerals	Stratigraphic Unit	Status	Latitude	Longitude
002D/13/Au 007	320 Vein Pit			Arsenopyrite, Pyrite	Victoria Lake and Tally Pond Gp Volcanics	Showing	48.82327381	55.78249498
002E/02/Au 013	Appleton #1	Arsenic			Gander River Com	Showing	49.0850771	54.58652648
002E/02/Au 014	Appleton #2	Arsenic				Showing	49.05258871	54.80675762
002D/11/Au 007	A-Zone Extension			Arsenopyrite, Pyrite	Davidsville Gp	Prospect	48.64120084	55.22064929
002D/11/Au 006	Aztec			Pyrite	Davidsville Gp	Prospect	48.64192028	55.22646135
002E/02/Au 002	Big Pond/ Blue Peter			Arsenopyrite, Pyrite		Prospect	49.11525838	54.83825613
002D/15/Au 003	Bowater			Pyrite, Arsenopyrite	Davidsville Gp	Prospect	48.97724444	54.86678304
002D/13/Au 004	Cabin/P1/P2			Arsenopyrite, Pyrite	Botwood Gp	Showing	48.87541334	55.62395682
002D/15/Au 006	Careless Cove	Silver		Arsenopyrite, Pyrite	Davidsville Gp	Prospect	48.90771445	54.96200285
002D/15/Au 034	Cherry Hill				Davidsville Gp	Showing	48.720517	55.173052
002E/02/Au 007	Clydesdale			Pyrite, Arsenopyrite		Showing	49.09694272	54.920043
002D/14/Au 001	Commanche/ Apache			Arsenopyrite, Pyrite	Mt Peyton Intrusive Suite	Showing	48.96573146	55.00254149
002D/14/Au 003	Corsair			Arsenopyrite, Pyrite	Mt Peyton Intrusive Suite	Prospect	48.96571673	55.02781908
002E/06/Au 014	Crooked Line #1	Arsenic		Arsenopyrite, Pyrite	Thwart Island Gabbro	Showing	49.27273058	55.03632212
002E/06/Au 017	Crooked Line #2	Arsenic		Arsenopyrite, Pyrite	Thwart Island Gabbro	Indication	49.26789576	55.0382049
002E/06/Au 018	Crooked Line #3	Arsenic		Pyrite, Arsenopyrite	Thwart Island Gabbro	Indication	49.26562971	55.03455588
002D/15/Au 007	Dome			Arsenopyrite, Pyrite, Quartz	Hunt's Cove Fm– Davidsville Gp	Prospect	48.99142717	54.8313176
002D/13/Au 008	Far West			Arsenopyrite, Pyrite	Victoria Lake and Tally Pond Gp Volcanics	Prospect	48.82153108	55.79299988
002D/11/Au 011	Goose/Paul's Pond			Arsenopyrite, Pyrite, Pyrrhotite	Davidsville Gp	Prospect	48.65027479	55.15692277
012A/16/Au 004	GP04-41 Zone					Showing	48.90931195	57.37701885
002D/12/Au 001	Great Rattling Brook			Pyrite	Pipestone Pond Com	Showing	48.61787095	55.77751072
002D/11/Au 012	Greenwood Pond #1			Arsenopyrite, Pyrite	Davidsville Gp	Showing	48.62923073	55.24970693
002D/11/Au 013	Greenwood Pond #2			Arsenopyrite, Pyrite	Davidsville Gp	Showing	48.62578706	55.23041962
002D/11/Au 014	Greenwood Pond #3			Arsenopyrite, Pyrite	Davidsville Gp	Showing	48.63089926	55.21191818
002D/11/Au 015	Greenwood Pond #4			Arsenopyrite, Pyrite	Davidsville Gp	Showing	48.63646868	55.19407532
002D/11/Au 016	Greenwood Pond #5			Arsenopyrite, Pyrite	Davidsville Gp	Showing	48.63507171	55.21991476
002D/11/Au 017	Greenwood Pond #6			Arsenopyrite, Pyrite	Davidsville Gp	Showing	48.62995054	55.22036639
002D/11/Au 018	Greenwood Pond #7			Arsenopyrite, Pyrite	Davidsville Gp	Showing	48.63769575	55.21507146
002D/11/Au 008	Hornet			Pyrite	Davidsville Gp	Showing	48.6340046	55.23827606
002D/14/Au 002	Hurricane	Silver		Arsenopyrite, Pyrite	Mt Peyton Intrusive Suite	Prospect	48.96418085	55.01694941
002D/15/Au 013	Jasperoid			Quartz, Calcite, Jasperoid	Indian Islands Gp	Showing	48.94879538	54.9201151
002E/02/Au 004	Knob Hill/Andromeda			Pyrite	Davidsville Gp	Showing	49.14581374	54.60860317
002D/15/Au 015	Lachlan					Indication	48.95783954	54.7917907
002D/11/Au 010	LBNL			Arsenopyrite	Davidsville Gp	Showing	48.65954153	55.14572079
002D/15/Au 016	Letha			Quartz		Showing	48.96230532	54.85657421
002D/13/Au 005	Moonlight			Arsenopyrite, Pyrite	Botwood Gp	Showing	48.8696251	55.62138828
002E/03/Au 004	Neyle's Brook Gold			Arsenopyrite	Mount Peyton Gabbro	Showing	49.08504409	55.04633821
002D/11/Au 020	North Paul's Pond				Davidsville Gp – Outflow Fm	Showing	48.67585497	55.11428519
002D/11/Au 021	O'Reilly			Quartz	Indian Islands Gp	Showing	48.73933308	55.15804779
002D/12/Au 002	Paradise Lake			Quartz		Showing	48.73151515	55.6305131
002E/06/Au 002	Porter			Pyrite, Arsenopyrite	Porterville Gabbro	Showing	49.25671294	55.19078724
002E/06/Au 001	Powderhouse Cove			Pyrite, Arsenopyrite	Dunnage Melange	Showing	49.32708878	55.03819298
002E/02/Au 029	Pristine					Prospect	49.0561329	54.78601442
002D/15/Au 014	Road Breccia			Quartz, Siderite	Indian Island Gp	Showing	48.95737058	54.94401016
002D/11/Au 009	Road Gabbro			Arsenopyrite, Pyrite,	Davidsville Gp	Showing	48.66164425	55.16465654
002D/15/Au 009	Road Showing			Arsenopyrite, Pyrite	Davidsville Gp	Prospect	48.98741281	54.82834793
002D/11/Au 019	Rolling Pond	Antimony, Arsenic, Barium		Quartz, Pyrite, Geothite	Botwood Gp	Prospect	48.66766669	55.48599422
002E/02/Au 011	Root Showing	Arsenic		Pyrite, Arsenopyrite		Indication	49.12622552	54.57527608
002D/15/Au 005	Sabre	Silver		Pyrite, Arsenopyrite	Mt. Peyton Intrusive Suite	Showing	48.96422886	54.99372066
012A/16/Au 005	Shawn's Shot			Arsenopyrite	Harpoon Brook Belt – Victoria Lake Gp	Showing	48.86408827	56.22745588
002E/03/Au 005	SS Showing			Arsenopyrite, Pyrite	Mount Peyton Gabbro	Showing	49.06790431	55.03774154
002E/06/Au 016	St. John's Harbour #2	Arsenic		Arsenopyrite		Showing	49.31932867	55.14569808
002E/03/Au 003	Sugar Mountain	Arsenic		Pyrite, Arsenopyrite, Quartz, Calcite	Lawrencetown Fm– Botwood Gp	Showing	49.01840162	55.39913246
002E/02/Au 018	The Lucky Moose	Arsenic		Arsenopyrite, Quartz	Outflow Fm–Davidsville Gp	Showing	49.23567931	54.67243403
002E/02/Au 016	Treasure			Arsenopyrite	Botwood Gp	Showing	49.20814881	54.93126593
002E/02/Au 006	Virginia Holdings			Pyrite	Davidsville Gp	Showing	49.02374952	54.82786092
002E/06/Au 005	Frying Pan Island East		Arsenopyrite	Quartz, Pyrite, Pyrrhotite	Thwart Island Gabbro	Showing	49.29809342	55.1159181
002E/06/Au 006	Frying Pan Island West		Arsenopyrite	Quartz, Pyrite, Pyrrhotite	Thwart Island Gabbro	Showing	49.29813207	55.11994681
002E/06/Au 010	St. John's Bay		Arsenopyrite	Quartz, Pyrite, Pyrrhotite	Thwart Island Gabbro	Showing	49.33538512	55.14787536
002E/06/Au 009	St. John's Harbour #1		Arsenopyrite	Quartz, Pyrite, Pyrrhotite	Thwart Island Gabbro	Showing	49.32315894	55.13998068
002E/06/Au 008	Thwart Island East		Arsenopyrite	Quartz, Pyrite, Pyrrhotite	Thwart Island Gabbro	Showing	49.31130246	55.13050735
002E/06/Au 007	Thwart Island Harbour		Arsenopyrite	Quartz, Pyrite, Pyrrhotite	Thwart Island Gabbro	Showing	49.29730963	55.13692381
002E/06/Au 011	Thwart Island North #1		Arsenopyrite	Quartz, Pyrite, Pyrrhotite	Thwart Island Gabbro	Showing	49.35204634	55.17792897
002D/15/Au 002	Bullet	Lead, Antimony, Copper	Boulangerite, Chalcopyrite	Arsenopyrite, Pyrite	Davidsville Gp	Prospect	48.96488497	54.84558598
002D/15/Au 004	The Knob	Copper, Lead, Antimony	Boulangerite, Chalcopyrite	Pyrite, Arsenopyrite, Quartz	Davidsville Gp	Prospect	48.96431943	54.84902612
002D/15/Au 017	Grouse		Boulangerite, Chalcopyrite, Sphalerite, Galena	Quartz, Arsenopyrite, Pyrite		Prospect	48.96027259	54.85877896
002D/14/Au 006	Island Pond	Antimony	Bourmonite, Sphalerite, Chalcopyrite, Stibnite	Pyrite, Arsenopyrite, Quartz, Calcite	Wigwam Fm–Botwood Gp	Indication	48.96838028	55.49305931

Table 1. Continued

MODS Number	Name(s)	Commodity	Ore Minerals	Gangue minerals	Stratigraphic Unit	Status	Latitude	Longitude
002E/02/Au 015	Cracker	Copper	Chalcopyrite	Pyrite	Outflow Fm– Davidsville Gp	Showing	49.08582891	54.7728601
002E/06/Au 004	Burnt Bay	Copper, Lead	Chalcopyrite, Galena	Quartz, Pyrite, Pyrrhotite, Arsenopyrite	Thwart Island Gabbro	Showing	49.26957634	55.03281814
002E/06/Au 003	Stanhope Cove	Silver, Lead, Copper	Chalcopyrite, Galena	Quartz, Pyrite, Pyrrhotite, Arsenopyrite	Thwart Island Gabbro	Showing	49.2913825	55.0749974
002D/14/Au 004	Peyton	Silver, Copper, Lead, Zinc	Chalcopyrite, Galena, Sphalerite	Arsenopyrite, Pyrite	Mt Peyton Intrusive Suite	Prospect	48.96739782	55.02092091
012A/09/Au 002	Island Pond	Copper, Molybdenum	Chalcopyrite, Molybdenite	Pyrite, Sericite, Carbonate	Crippleback Lake Qtz Monzonite	Showing	48.73759318	56.16902411
002E/02/Au 010	Grid 69 Gold	Zinc, Copper	Chalcopyrite, Sphalerite	Pyrite	Davidsville Gp	Prospect	49.07650221	54.72230834
002E/02/Au 017	Jonathan's Second Pond	Arsenic, Antimony	Chalcopyrite, Stibnite	Arsenopyrite, Pyrite	Gander River Com	Showing	49.08609822	54.57002705
002E/01/Au 004	Burseys Hill	Talc, Chromium	Chromite	Pyrite	Gander River Com	Showing	49.14657657	54.49611514
002E/03/Au 001	Moosehead	Lead, Copper, Zinc, Antimony	Galena, Chalcopyrite, Sphalerite, Boulangerite, Bourmonite	Quartz	Botwood Gp–Wigwam Fm	Prospect	49.00105944	55.44467102
002D/13/Au 003	Twin Ponds/P3	Antimony, Lead, Zinc	Galena, Sphalerite	Arsenopyrite, Pyrite	Botwood Gp	Showing	48.8755121	55.65905847
002D/13/Au 002	Rip Van Winkle	Antimony, Cobalt	Galena, Stibnite, Sphalerite, Chalco- pyrite, Bornite	Pyrite, Arsenopyrite	Lemotte's Lake Sequence	Showing	48.90929318	55.75540459
002E/02/Au 023	1744 Zone		Gold	Quartz	Hunts Cove Fm– Davidsville Gp	Prospect	49.00836414	54.74161094
002D/15/Au 028	515 Zone		Gold	Quartz	Davidsville Gp– Hunts Cove Fm	Prospect	48.98486084	54.83664643
002D/15/Au 029	533 Zone		Gold	Quartz	Davidsville Gp– Hunts Cove Fm	Showing	48.98205891	54.83883162
002D/15/Au 030	538 Zone		Gold	Quartz	Davidsville Gp– Hunts Cove Fm	Showing	48.9824624	54.84212183
002E/02/Au 019	Bellman's Pond		Gold	Pyrite, Arsenopyrite	Outflow and Hunt's Cove Fm–Davidsville Gp	Showing	49.17525486	54.63853786
002D/15/Au 034	Bullseye		Gold	Quartz	Hunts Cove Fm– Davidsville Gp	Prospect	49.00964476	54.81794469
012A/16/Au 006	Christopher Zone		Gold	Quartz	Noels Paul's Gp–Stanley Waters Fm	Prospect	48.90321236	56.15694834
002D/14/Au 005	Clark's Brook East		Gold	Pyrite, Quartz	Indian Islands Gp	Prospect	48.80739487	55.06061025
002D/14/Au 008	Clark's Brook West	Silver, Lead	Gold	Quartz	Indian Islands Gp	Showing	48.80332405	55.0834701
002D/15/Au 021	Cokes 1		Gold			Prospect	48.98033209	54.84558969
002D/15/Au 022	Cokes 2		Gold			Prospect	48.98137828	54.84476552
002E/02/Au 028	Doyle Zone		Gold	Quartz	Davidsville Gp– Hunts Cove Fm	Prospect	49.05594781	54.78621428
012A/09/Au 003	Elliott		Gold	Quartz, Pyrite, Arsenopyrite, Specularite	Botwood Gp	Showing	48.68330731	56.04127373
012A/16/Au 011	Gabbro Zone		Gold	Pyrite, Quartz	Victoria Lake Supergroup	Showing	48.80013027	56.29245328
002D/13/Au 012	Gerry's Pit		Gold		Victoria Lake Gp– Tally Pond Volcanics	Showing	48.82378214	55.78207394
002E/02/Au 022	Glass		Gold		Hunts Cove Fm– Davidsville Gp	Showing	49.00582429	54.74652563
002D/15/Au 027	Golden Joint		Gold	Quartz	Hunts Cove Fm– Davidsville Gp	Prospect	48.98860095	54.83411958
002D/15/Au 023	Hornet		Gold			Prospect	48.9851685	54.84106179
002D/15/Au 038	Iceberg Zone		Gold	Quartz	Davidsville Gp	Prospect	48.98748062	54.83482429
002E/02/Au 001	Jonathans Pond/Westfield		Gold	Arsenopyrite, Pyrite	Gander River Com	Prospect	49.09048045	54.56537489
002D/15/Au 010	Keats		Gold	Arsenopyrite, Pyrite	Davidsville Gp	Prospect	48.97890874	54.86019791
002D/15/Au 033	Keats North		Gold	Quartz		Prospect	48.98648176	54.83576975
002D/15/Au 032	Keats West		Gold	Quartz	Davidsville Gp	Prospect	48.98770799	54.83879225
002D/15/Au 020	Little	Antimony	Gold	Quartz, Pyrite, Arsenopyrite	Davidsville Gp– Hunts Cove Fm	Prospect	48.9898971	54.84087107
002E/02/Au 021	Little Joanna Gold		Gold	Quartz	Botwood Gp–Wigwam and Lawrenceton Fm	Prospect	49.19910823	54.82603628
002D/15/Au 026	Logan		Gold			Showing	48.95612991	54.79365577
002D/15/Au 035	Lotto North		Gold	Quartz		Prospect	48.99887669	54.82512854
002E/02/Au 024	Midway		Gold	Quartz	Davidsville Gp–Outflow Fm	Prospect	49.07224652	54.7912271
002D/13/Au 006	Paradise Lake	Arsenic, Zinc	Gold	Quartz	Botwood Group	Prospect	48.76797958	55.635251
002D/15/Au 019	Power Line	Arsenic	Gold	Arsenopyrite, Quartz	Davidsville Gp– Hunts Cove Fm	Showing	48.9919167	54.84254728
002E/03/Au 008	Red Cliff Shear		Gold	Arsenopyrite, Quartz,	Porterville Gabbro	Showing	49.24661474	55.20026627
002D/15/Au 036	Rocket		Gold	Quartz		Prospect	48.96769062	54.85226973
002D/15/Au 025	Sunday Zone		Gold	Quartz, Pyrite	Davidsville Gp	Showing	48.99566328	54.82695011
002D/15/Au 037	TCH		Gold	Quartz	Hunt Cove Fm– Davidsville Gp	Prospect	48.97179162	54.8468871
002E/03/Au 006	Tetfords Point/Hammer	Antimony	Gold	Quartz, Arsenopyrite, Pyrite	Porterville Gabbro	Showing	49.24999957	55.19292896
002E/03/Au 002	The Slip/Turnabout and Fairplay	Copper, Lead	Gold	Pyrite	Mt Peyton Intrusive Suite	Showing	49.08458651	55.03475579
002D/15/Au 031	Tuesday Zone		Gold	Quartz	Davidsville Gp	Prospect	48.99361666	54.82958199
002E/03/Au 007	Twin		Gold	Pyrite, Arsenopyrite	Porterville Gabbro	Showing	49.24867372	55.19443392
002E/06/Au 019	Whitehouse	Antimony	Gold	Quartz, Arsenopyrite, Pyrite	Porterville Gabbro	Showing	49.2564898	55.19262325
002D/15/Au 018	Zone 26		Gold			Prospect	48.99333854	54.83920481
002E/02/Au 026	Zone 36		Gold	Quartz		Prospect	49.00141127	54.82356876
002E/02/Au 025	Big Vein	Antimony	Gold, Boulangerite	Pyrite, Arsenopyrite	Davidsville Gp– Hunts Cove Fm	Prospect	49.05066604	54.78851561
002E/02/Au 030	Big Dave	Antimony, Copper	Gold, Boulangerite, Chalcopyrite	Quartz	Hunts Cove Fm– Davidsville Gp	Prospect	49.01286049	54.80487988
002E/02/Au 027	Golden Glove	Copper	Gold, Chalcopyrite	Quartz, Pyrite	Davidsville Gp– Hunts Cove Fm	Prospect	49.01800334	54.80518708

Table 1. Continued

MODS Number	Name(s)	Commodity	Ore Minerals	Gangue minerals	Stratigraphic Unit	Status	Latitude	Longitude
002D/15/Au 011	Lotto Zone	Copper	Gold, Chalcopyrite	Arsenopyrite, Pyrite	Davidsville Gp	Prospect	48.9947249	54.82967054
002D/15/Au 008	Baseline Showing	Copper, Antimony, Arsenic	Gold, Chalcopyrite, Boulangerite	Arsenopyrite, Pyrite	Davidsville Gp	Prospect	48.97945065	54.84031116
002D/15/Au 024	Lake Side No 1	Copper, Lead	Gold, Chalcopyrite, Galena	Quartz, Pyrite, Arsenopyrite	Davidsville Gp–Hunts Cove Fm	Showing	48.93163274	54.82350527
002D/12/Au 003	Williams Gold	Copper, Zinc, Lead, Antimony	Gold, Chalcopyrite, Sphalerite, Galena, Stibnite	Quartz	Botwood Gp–Outflow Fm	Showing	48.70355837	55.11773548
002D/15/Au 001	The Outflow/Mustang and Piper	Arsenic, Antimony	Gold, Stibnite	Arsenopyrite, Pyrite, Quartz	Davidsville Gp	Prospect	48.93877841	54.90324631
002D/14/Au 007	Yellow Fox	Silver, Lead, Antimony	Gold, Stibnite	Pyrite, Arsenopyrite	Mt Peyton Intrusive Suite	Showing	48.92548707	55.01956106
012A/09/Au 001	Shoulderblade Lake	Iron, Molybdenum	Molybdenite	Pyrite, Arsenopyrite, Hematite, Quartz	Tulks Hill Fm–Victoria Lake Gp	Showing	48.7080252	56.16067601
002E/02/Au 003	Third Pond	Molybdenum, Lead	Molybdenite, Galena	Pyrite	Davidsville Group	Showing	49.11035479	54.65621539
002E/02/Au 009	T Rex		Sphalerite	Arsenopyrite, Pyrite, Quartz	Hunts Cove Fm–Victoria Lake Gp	Showing	49.09384307	54.93932308
012A/16/Au 001	Tom Joe (Brook)	Arsenic	Sphalerite	Quartz, Pyrite, Arsenopyrite	Hunts Cove Fm–Davidsville Gp	Showing	48.82448514	56.16760206
002E/02/Au 008	H Pond	Zinc, Copper, Lead, y Antimon	Sphalerite, Chalcopyrite, Galena, Boulangerite	Quartz	Hunts Cove Fm–Davidsville Gp	Prospect	49.00376238	54.74920309
002D/15/Au 012	Pocket Pond	Zinc, Copper, Lead, Antimony	Sphalerite, Chalcopyrite, Galena, Boulangerite	Quartz, Pyrite, Arsenopyrite	Victoria Lake and Tally Pond Gp Volcanics	Prospect	48.98279883	54.77975312
002D/13/Au 009	Spring Pit		Stibnite	Arsenopyrite, Pyrite	Victoria Lake Gp–Tally Pond Volcanics	Prospect	48.82451384	55.77726053
002D/13/Au 001	Discovery Pit; Twilite Zone	Antimony, Lead, Copper, Zinc	Stibnite, Galena, Chalcopyrite, Sphalerite	Pyrite, Arsenopyrite, Quartz	Victoria Lake Gp–Tally Pond Volcanics	Prospect	48.82407137	55.77795249
002D/13/Au 011	Paddy's Pit	Antimony, Lead, Copper, Zinc	Stibnite, Galena, Chalcopyrite, Sphalerite	Pyrite, Arsenopyrite, Quartz	Victoria Lake Gp–Tally Pond Volcanics	Prospect	48.82411232	55.78182071

flowed into bays along the coast. Major ice divides resulting from off-shelf drainage include an east–west ice divide extending from the Great Northern Peninsula toward Grand Banks (Grant, 1989; Shaw *et al.*, 2006; Shaw and Longva, 2017). A northeastern splay of this divide was at the centre of Mount Peyton, running parallel to the Gander River and into Gander Bay (Shaw *et al.*, 2006). Ice extended to the continental shelf *ca.* 18 ka before present (BP) at the late glacial maximum (Shaw *et al.*, 2006). Ice retreat in the region commenced via calving and ice streaming along the north and northeastern coast, and later by ablation and ice stagnation. By 8000 ka, the island was ice free (Grant, 1989; Batterson and Liverman, 2000; Dyke, 2004; Shaw *et al.*, 2006; Dalton *et al.*, 2023).

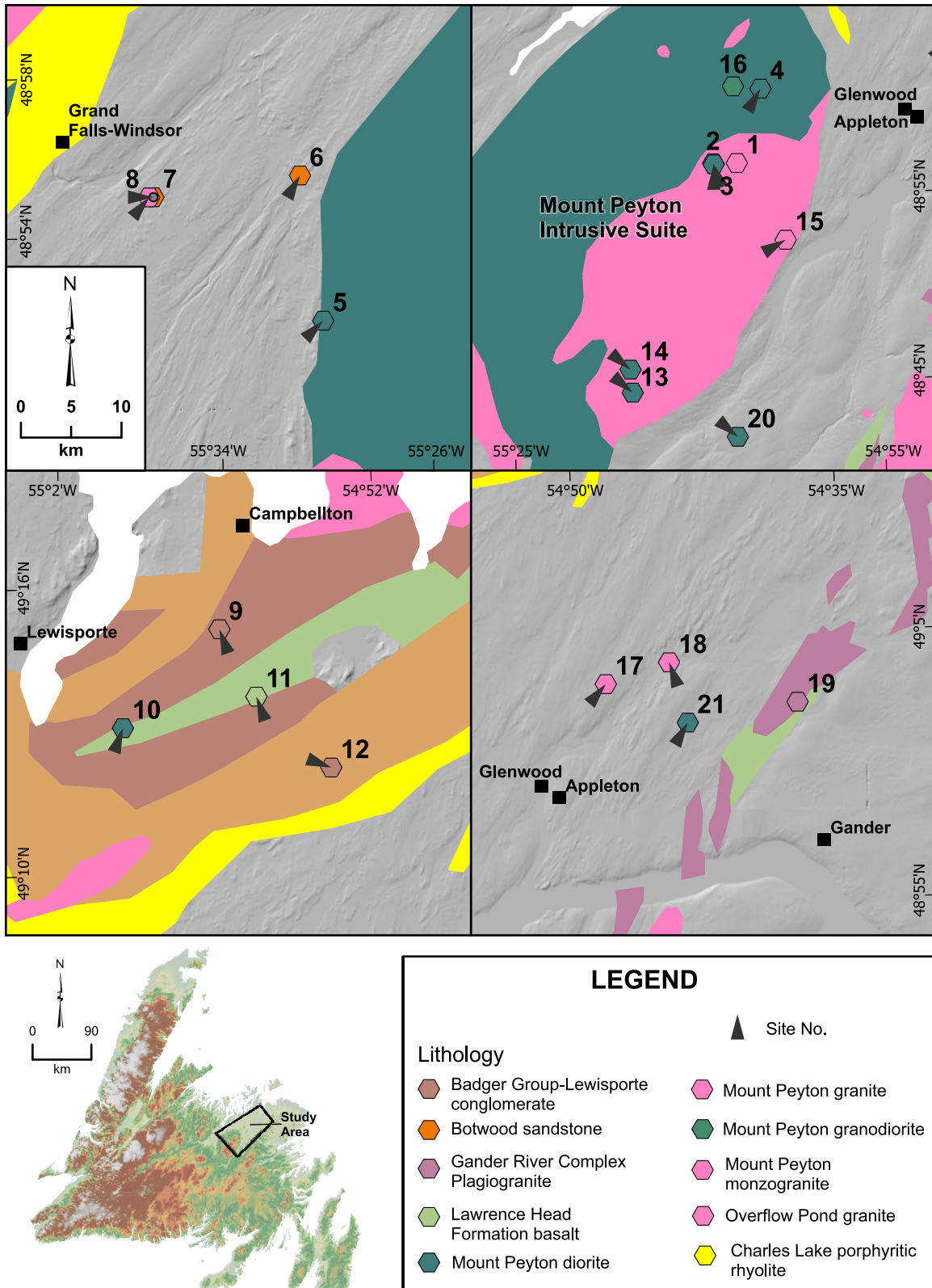
## ICE FLOW

In north-central Newfoundland, an eastward to south-eastward ice flow was recognized based on the distribution of distinctive boulders sourced from the MPIS at the eastern outlet of Gander Lake (Murray, 1882). Striations from this earliest ice flow are overprinted by northeast and northward striations along the shores of Gander Lake (Figure 1), toward Ten Mile Lake and near Gander Bay (St. Croix and Taylor, 1990, 1991; Scott, 1994; Munro and Catto, 1999; Brushett, 2010, 2011, 2012; Figure 1). An ice centre near Beothuk Lake southwest of the MPIS is hypothesized as the source of this ice flow (Proudfoot *et al.*, 1988; St. Croix and Taylor, 1991). This ice flow is thought to have occurred after the Late Glacial Maximum ~18 ka at the onset of deglaciation (St. Croix and Taylor, 1991).

Eastward ice flow was followed by a widespread north-eastward ice flow (Figure 1) that sculpted landforms and left

striations on the western, northern and eastern ends of the MPIS and in the Exploits River Valley from Noel Paul's Brook to Port Albert, as well as southwestern part of the Gander River Valley from Middle Ridge to Dorman's Cove (Proudfoot *et al.*, 1988; St. Croix and Taylor, 1990, 1991; Batterson and Vatcher, 1991; Scott, 1994; Brushett, 2010, 2011, 2012; Blundon *et al.*, 2010; Norris *et al.*, 2024). The inferred source of the ice flow is between Meelpaeg Lake and Middle Ridge (Proudfoot *et al.*, 1988; St. Croix and Taylor, 1990, 1991; Brushett, 2010). West of Mount Peyton, northeastward striations, and macro-scale glacially sculpted landforms locally converge into the Exploits Ice Stream (Figure 1; Blundon *et al.*, 2010; Primmer *et al.*, 2015; Norris *et al.*, 2024).

North-northeastward to northward striations (hereafter termed northward) are overprinted by a later northwestward flow, over the western and northern MPIS toward Lewisporte and from south of Gander Lake to Fox Pond, originating from an ice centre near Middle Ridge (St. Croix and Taylor, 1990, 1991; Scott, 1994; Munro and Catto, 1999; Brushett, 2010). This northwestward flow is identified in fabrics south of Ten Mile Lake and west of Gander River, near Appleton and on the northern shoreline of Gander Lake to Gander Bay, (Batterson and Vatcher, 1991; Scott, 1994; Organ, 2022). The landforms and striations converge around Gander Lake, heading northwest toward Lewisporte and Campbellton and Gander Bay forming the Gander Lake Ice Stream (Figure 1; Blundon *et al.*, 2010; Primmer *et al.*, 2015; Norris *et al.*, 2024; Figure 4). Northwest ice flow identified east of Gander Bay possibly occurred during the Younger Dryas as indicated by north-westward fabrics in till overlying over a deglacial delta (Munro and Catto, 1999). Northward ice flow is recorded in



**Figure 4.** Boulder site distribution in the study area; a legend with colours marking their inferred lithologies and localities relative to bedrock units. The angle of the arrows indicates the orientation of the boulder determined by its morphology and the orientation of surface erosion marks (i.e., grooves).

striations and fabrics near the Moosehead Prospect (Batterson and Liverman, 2000; Morgan, 2016), with multiple stacked lodgment tills that indicate a north-northwestward and a northward flow near Notre Dame Junction (*e.g.*, MacKenzie and Catto, 1993).

Late, local east-southeastward oriented ice flow is indicated by striations (Batterson and Vatcher, 1991; St. Croix and Taylor, 1991; Taylor and Liverman, 2000; Figure 1) and is hypothesized to have originated west of Badger (St. Croix and Taylor, 1991). Overprinting striations are rare but eastward striations crosscut a few northeast striations near Grand Falls-Windsor, and it has been postulated that this late eastward ice flow advanced briefly during the Younger Dryas (St. Croix and Taylor, 1991).

## GLACIAL DEPOSITS

Glacial deposits consist of 1) till that is distributed across the entire study area but is locally lineated under the Gander Lake and Exploits Ice streams with variably oriented ridges, 2) glaciofluvial channel, ice-contact ridges and ice-marginal delta and outwash deposits, that occur along the Northwest Gander and Exploits rivers, 3) marine deposits, with deltas occurring on the east side of Notre Dame Bay, and marine muds in the Northwest Gander and Gander River valleys (Batterson, 1999a, b, 2000). Older sections are partially preserved, partially recording two to three glacial and deglacial layers near Moosehead (Morgan *et al.*, 2016), Notre Dame Junction (MacKenzie and Catto, 1993), south and north of Gander Lake (Batterson and Vatcher, 1991), in Appleton (Organ, 2022), and toward Ten Mile Lake (Scott, 1994).

Deglaciation is marked by the positions of ice-contact deltas identified in Birchy Bay and along the Northwest Gander River, in Botwood and Lewisporte (Ricketts and McGrath, 1990; Liverman *et al.*, 2000; Kirby *et al.*, 2011). Maximum marine levels are indicated by delta heights of ~64 m on the banks of the northwest Gander River (Batterson and Vatcher, 1991; McCuaig, 2006; Organ, 2022). Ice-wedge casts are noted at the deltas in Botwood, Gander River and Birchy Bay (Eyles, 1977; Mackenzie and Catto, 1993; Liverman *et al.*, 2000). Recent and historical studies indicate past-permafrost and glaciotectionic deformation features in till sections from south of Gander Lake to west of Gander Bay (Munro and Catto, 1999; Campbell *et al.*, 2022, 2024).

## FIELD WORK

### BOULDER SAMPLING

Field work was completed in the summer and fall of 2025, where samples from fifteen boulders were collected

overlying streamlined till-covered ridges, streamlined bedrock ridges, and bogs on the eastern and western flanks of Mount Peyton and north of Lewisporte in the Gander Lake and Exploits Ice Stream, as well as samples from four polished bedrock outcrops (Figure 4; sites 1, 7, 16 and 19), three of them up-ice, to compare their exposure dates to down-ice boulders (Figure 4, Table 1).

Samples were collected from flat, glacially eroded surfaces on top of the boulders using both a battery-powered DeWalt saw with a 6" tile-cutting blade for samples collected earlier in the summer, and a gas-powered Stihl saw with a 12" tile-cutting blade for samples collected during helicopter-supported work in the fall. Both topography and tree cover were recorded for each sample, along with the dimensions of the boulder, a field classification of rock type and the orientation of the boulder determined by glacial erosion features on the upper surface of the boulders. The boulder samples were excavated to a depth of 3" with the Dewalt saw, and a depth of 5" with the Stihl gas powered saw. Samples were bagged, taped and put in buckets for transport to the Geological Survey's geochemical laboratory, where they were rinsed of rock powder from the saw, and dried. Lichen was kept on the sample to assist with surface identification as most TCN production is near the surface (*see* TCN dating section, Ivy-Ochs and Kober, 2008)

The samples were cleaned and their identification confirmed for provenance interpretation, before being packed and shipped for TCN exposure dating preparation at the Cosmic Ray Isotope Sciences at Dalhousie University.

The boulders were sampled based on their suitability for TCN exposure dating, and included the following criteria:

- 1) Suitable exposure to the atmosphere, preferably with minimal topographic and vegetation shielding (*e.g.*, surrounding hills and trees)
- 2) Flat-topped and coarse grained, to ensure the equal accumulation of nuclides on the surface
- 3) Greater than 1 m off the ground and larger than 1 m in diameter to ensure minimal snow cover (above the snow line or in windswept areas)
- 4) Abundant quartz, to capture enough nuclides of interest ( $^{10}\text{Be}$ )
- 5) The presence of original glacial features (*e.g.*, sculpted, striated or grooved surfaces on boulder and bedrock surfaces) to indicate original glacial rather than other emplacement modes

The boulder locations, rock classifications and orientations were plotted to compare their alignment with any of the three regional and one local ice flow orientations defined by landforms and striations, or their resultant sum,

in the case of palimpsest flow (*e.g.*, Stea and Finck, 2001). The closest plucked surface of the same bedrock unit up-ice of the boulder and its orientation was determined as the minimum dispersal distance. If the boulder was offset from ice-flow path, the sum of ice flows needed to emplace the boulder into its final position were calculated. Three other large boulders in Table 2 (boulder sites 20, 21 and 22) were not sampled, but are included in this report, as their orientation and lithology assist with dispersal orientations and distances.

## PRELIMINARY RESULTS

Of the 18 boulders, 14 were derived from the MPIS. Boulders at sites 3, 18 and 21 (Table 2) could potentially have been emplaced by eastward flow, followed by northward flow. The four striated and polished bedrock outcrops sampled (sites 1, 7, 16 and 19) included northeastward ice-flow indicators, that are crosscut by northward striations at site 16 (Table 2). The northeastward-oriented garnet-bearing granite (Site 8; Figure 5) is distinctive and is most likely dispersed from the Overflow Pond Granite, 40 km south of the boulder by ice-flow 2, or possibly from a smaller granite of

similar composition, 9 km southwest of Grand Falls-Windsor by ice-flow 4. Another boulder in the same area (Site 22; Table 2; Figure 5) is likely dispersed from the Charles Lake porphyritic rhyolite 4 km to the east by ice-flow 4, based on its orientation, but it could also be sourced from the Stoney Lake Volcanics, 20 km to the southwest (ice-flow 2). Late eastward ice flow is proposed for these boulders as indicated by the striations here (St. Croix and Taylor, 1990; Figure 1).

The rest of the boulder lithologies are sourced from underlying bedrock – including Botwood sandstone, Lewisporte conglomerate and Lawrence Head Formation volcanoclastic rocks (Table 2; Figure 4). Sedimentary and volcanoclastic boulders are dispersed proximally to source (0.2–3 km) as expected, while granitic and rhyolite boulders have been dispersed distal to sources (*e.g.*, 5–40 km). To compare ice-flow orientations and distances, the same rock type is used. The comparisons of ice-flow distances and orientations are calculated only from MPIS boulders with the caveat that most MPIS boulders are underrepresented in the Exploits Ice Stream path (Figure 4).

**Table 2.** Boulder TCN sample site numbers (corresponding to the map), sample numbers, locations, inferred lithology, associated landforms, the orientation of the boulders or striations (if a bedrock TCN sample) and the distance and direction from the inferred source, with up-ice directions determined by boulder orientation and aligned striations, and the associated ice flow event

Site Number on Map	Sample Number	Longitude	Latitude	Elevation (m)	Lithology	Landform	Azimuth of boulder or bedrock striations	Distance and direction from source (km) orientations from boulder and striations	Inferred ice-flow event(s) (chronology from striations)
1	25HC09-01	-55.099002	48.947628	483	MPIS monzogranite (bedrock sample)	NE streamlined ridge	045	Striations NE	2
2	25HC09-02	-55.131185	48.947971	451	MPIS monzogranite	NW streamlined ridge	340	0-4	3
3	25HC09-03	-55.130397	48.946897	447	MPIS diorite	NW streamlined ridge	0	3.5 ESE (110), 3 N	1, 3
4	25HC09-04	-55.064283	49.013532	206	MPIS diorite	Bog	030	5 NNE	3
5	25HC09-05	-55.50142	48.86364	120	MPIS diorite	NE streamlined ridge	045	0.2 NE	2
6	25HC09-06	-55.51434	48.92446	53	Botwood sandstone	NNE streamlined ridge	030	0.24 NE	2
7	25HC09-07	-55.607515	48.916548	100	Botwood sandstone (bedrock sample)	NE streamlined ridge	45	Striations NE	2
8	25HC09-08	-55.610227	48.916482	99	Overflow Pond granite	NE streamlined ridge	040	40NE/6 ENE	2 or 4
9	25HC09-09	-54.949783	49.25116	28	Badger Group–Lewisporte conglomerate	Bog	340	1.5 NW	3
10	25HC09-10	-55.002442	49.217647	100	MPIS diorite	Bog	020	12.5 NNE	3
11	25HC09-11	-54.931086	49.227378	55	Lawrence Head Formation volcanoclastic	Hummocky ridge	340	0.15NW	3
12	25HC09-12	-54.892307	49.20198	42	Badger Group–Lewisporte conglomerate	Hummocky ridge	110	3 ESE	1
13	25HC09-13	-55.24744	48.744665	254	MPIS diorite	Bog	110	4 ESE	4
14	25HC09-14	-55.249645	48.765295	259	MPIS diorite	Bog	110	3 ESE	4
15	25HC09-15	-55.035283	48.877947	184	MPIS granite	ENE streamlined ridge	060	4 NE	2
16	25HCBe001	-55.101651	49.016218	213	MPIS granodiorite (bedrock sample)	NE to NNE streamlined flat bedrock	40	Striations NE and NNE	2
17	25HCBe002	-54.805411	49.054169	94	MPIS granite	Cutover till field	040	20 NE	2
18	25HCBe003	-54.745047	49.066564	60	MPIS granite	Bog	340	20 ESE (110), 15 NNW	1, 3
19	25HCBe004	-54.624858	49.039664	79	Gander River Complex plagiogranite (bedrock sample)	NE bedrock small (< 1 m) ridge	040	Striations NE	2
20	No Sample–Net-Textured Diorite Boulder	-55.106739	48.702944	160	MPIS diorite	NE streamlined ridge	110	15 ENE	1
21	No Sample–North MPIS diorite	-54.729101	49.028839	74	MPIS diorite	NE streamlined ridge	30	14 ESE, 10 NNE	1, 3
22	No Sample–Charles Lake porphyritic rhyolite	-55.607515	48.916548	100	Charles Lake porphyritic rhyolite	NE streamlined ridge	90	20SW or SE	2 or 4

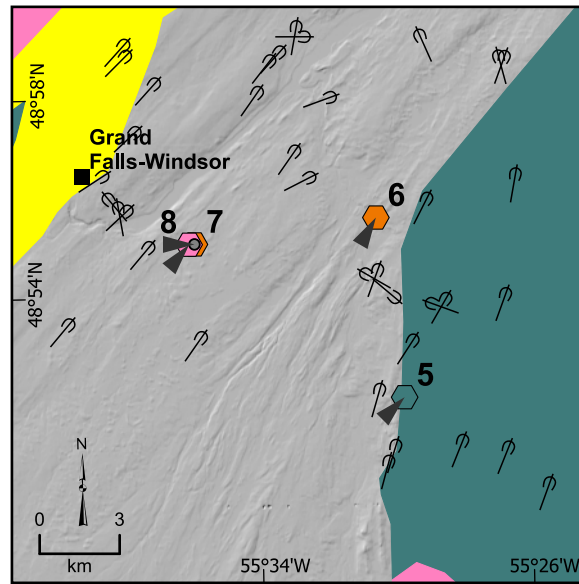


Figure 5. Numbered boulder sites and bedrock locations west of the MPIS.

**Table 3.** Summary table of the range, median and average of MPIS boulder distances with each ice flow

Ice flow	Minimum (km)	Maximum (km)	Median dispersal distance (km)	Average (km)
1 (n=4)	3.5	20	14.5	13.13
2 (n=4)	0.2	20	8.25	9.18
3 (n=5)	2	15	5	7.00
4 (n=2)	3	4	3.5	3.50

East of the MPIS, two distances are indicated for eastward dispersed boulders; these are boulders from sites 20 (15 km), 13 and 14 (3–4 km, Figure 6). The boulder orientations correlate with both earlier (ice-flow 1) and later (ice-flow 4) striations observed nearby. Boulders from sites 13 and 14 are located much closer to their bedrock source than the boulder at Site 20 that is presumed to be dispersed by earlier, rather than the later eastward ice flow.

North of the MPIS, between the Gander and Exploits rivers, northward boulder dispersal ranges between 5 and 15 km as indicated by boulders from sites 4, 10, 18 and 21 (Figures 6, 7 and 8); their orientations correlate with northward striations, suggesting dispersal by ice-flow 3. The boulder at Site 18 is inferred to have been remobilized from early eastward flow (ice-flow 1) by northward flow (ice-flow 3), based on nearby striations. However, the boulders could also have been initially dispersed by northeast (ice-flow 2) flow.

The northwestward orientation of two boulders near Lewisporte (sites 9 and 11, Figure 6) correlate with the striations left by (northwestward) ice-flow 3, the last event indicated in this region. However, the orientation of the boulder at site 12, near Brink's Pond, correlates with early east-southeastward striations (ice-flow 1) near Ten Mile Lake.

While boulder orientations along flow paths can assist with ice-flow reconstructions, exposure ages (from the TCN dating results), expected in late spring, should help constrain the timing of glacial retreat to assist with the interpretation of paleoenvironmental conditions. These results will be combined with historical data (*e.g.*, striations, dispersal patterns and fabrics and  $^{14}\text{C}$  deglacial ages), to refine the ice-flow history, and constrain dispersal conditions (*e.g.*, cold-based or warm-based ground conditions) for each boulder (and its region).

## DISCUSSION

The dispersed boulders in this study seem to be aligned along the three regional ice-flow orientations suggesting

some were protected from erosion by later ice-flow events. This could have implications for reconstructing the ice-flow patterns here, where ice-flow orientation and velocity were likely controlled by marine incursion, sea-ice thickness and calving in the bays (*e.g.*, Shaw *et al.*, 2006). Boulder dispersal patterns are inconsistent between the researched areas. This correlates with earlier studies indicating preservation of all three dispersal orientations in striations and fabrics (Scott, 1994), and of differing erosional intensities, reflected in landforms and till-geochemical dispersal distances (Blundon *et al.*, 2010; Primmer *et al.*, 2015).

Metasedimentary boulders from sites 6, 9, 11 and 12, and a bedrock sample from Site 7 could pose problems for TCN analysis due to the difficulty in separating quartz from feldspar grains. Likewise, the gabbro sample from the boulder at Site 11 may not contain sufficient quartz needed to extract nuclides for analysis.

The boulder dispersal patterns raise questions that may be resolved through the boulder exposure TCN dates. For instance, did ice retreat from the Exploits and Gander Lake ice streams at the same time or was the Exploits Ice Stream flowing only after the regional northeast ice flow? Were boulders closer to the proposed ice centres exposed at the same time as boulders closer to the coast? Do the exposure ages from the eastward and northwestward dispersed boulders reflect early or late eastward flow, and if so, do the dates correlate with the onset of the Younger Dryas in Newfoundland at *ca.* 12-13 ka or are they younger? Or will some of these boulders show older ages, reflecting incomplete erosion of previous nuclides in cold-based ice conditions?

Establishing the exposure ages on the boulders will help build an ice-retreat sequence for each of the ice-flow events. The ice-flow paths can then be reconstructed to determine which ice-flow orientation was the dominant flow for each area.

## IMPLICATIONS FOR EXPLORATION

The varied dispersal orientations and distances west, north and east of the MPIS indicate that resource-property-scale ice-flow studies, including striation measurements, and till fabrics, where possible, can assist interpreting till geochemical dispersal. Gold (grain) dispersal studies, including morphological characterization, have been successful near Appleton (*e.g.*, Dimmell and Regular, 2021). These studies use gold grain morphology and ratios of pristine (proximal) to modified and reshaped (distal) grains to indicate dispersal and distance to source (DiLabio, 1991; Averill, 2001; Girard *et al.*, 2021).

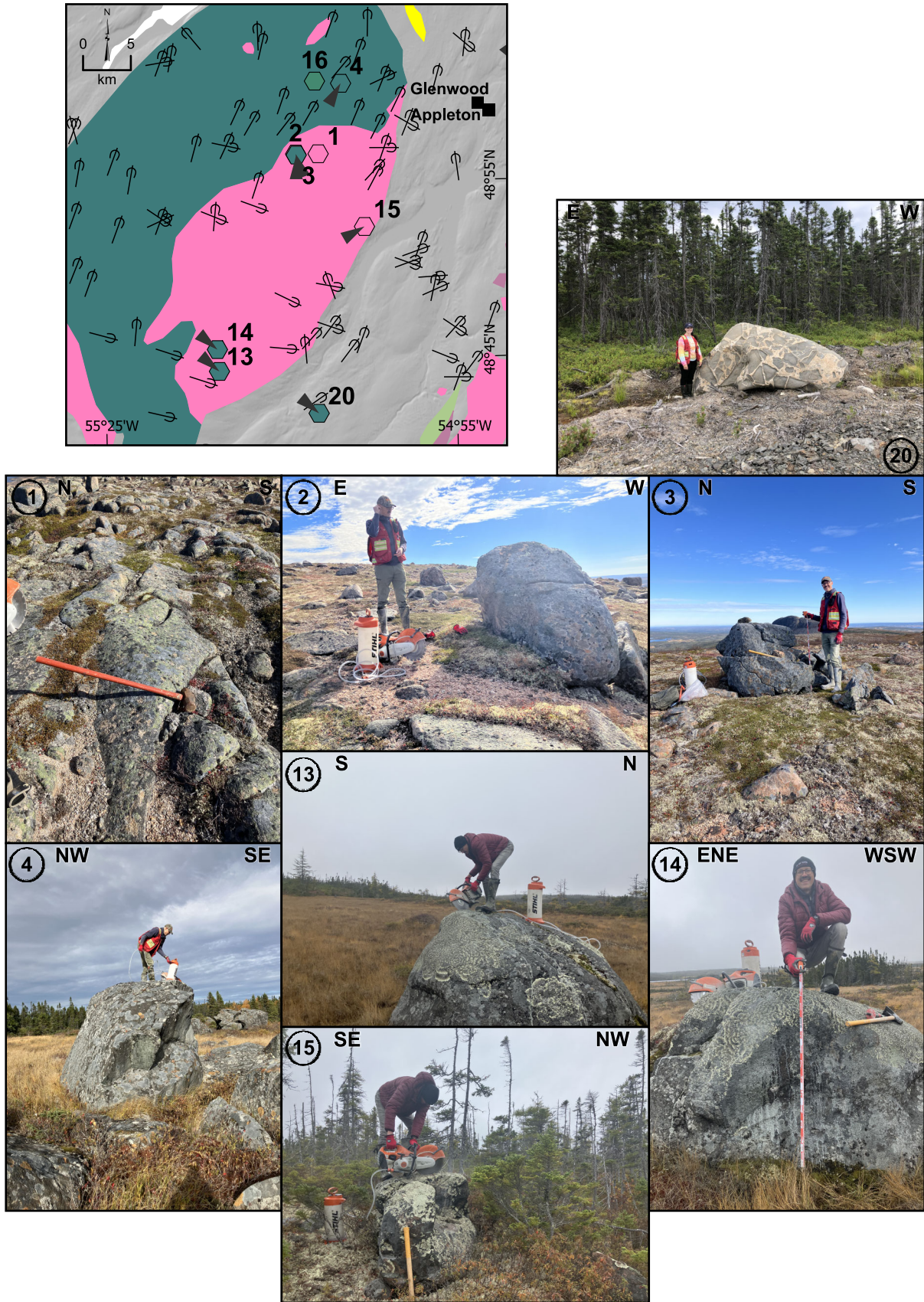


Figure 6. Numbered boulder sites and bedrock site locations southeast and northeast of Mount Peyton.

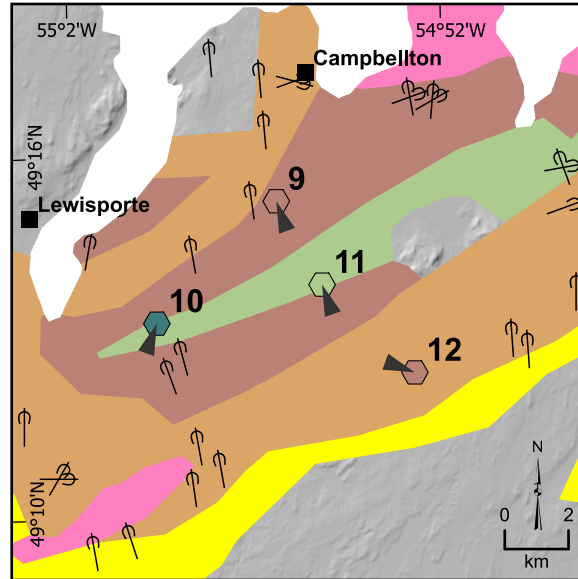


Figure 7. Numbered boulder site locations east of Lewisporte and Campbellton.

While north and northeastward ice flow has dispersed boulders on the eastern margin of the MPIS, eastward dispersal has also been identified. This could be important for understanding dispersal patterns in till down-ice toward the Beaver Brook mine area and toward Paul’s Pond, and possibly the area west of Grand Falls. If the results from the cosmogenic boulder exposure dates occur within the same time frame as the Younger Dryas, then cold-ground conditions could mean that the late flows were less erosive, and the

resulting dispersal distances could be shorter (*e.g.*, <4 km, boulders from sites 13 and 14).

### SUMMARY

This report discussed boulders sampled for TCN exposure dates and reported the boulder locations, their identification and the distances they were dispersed from their likely up-ice sources, as preliminary efforts to build a robust ice-

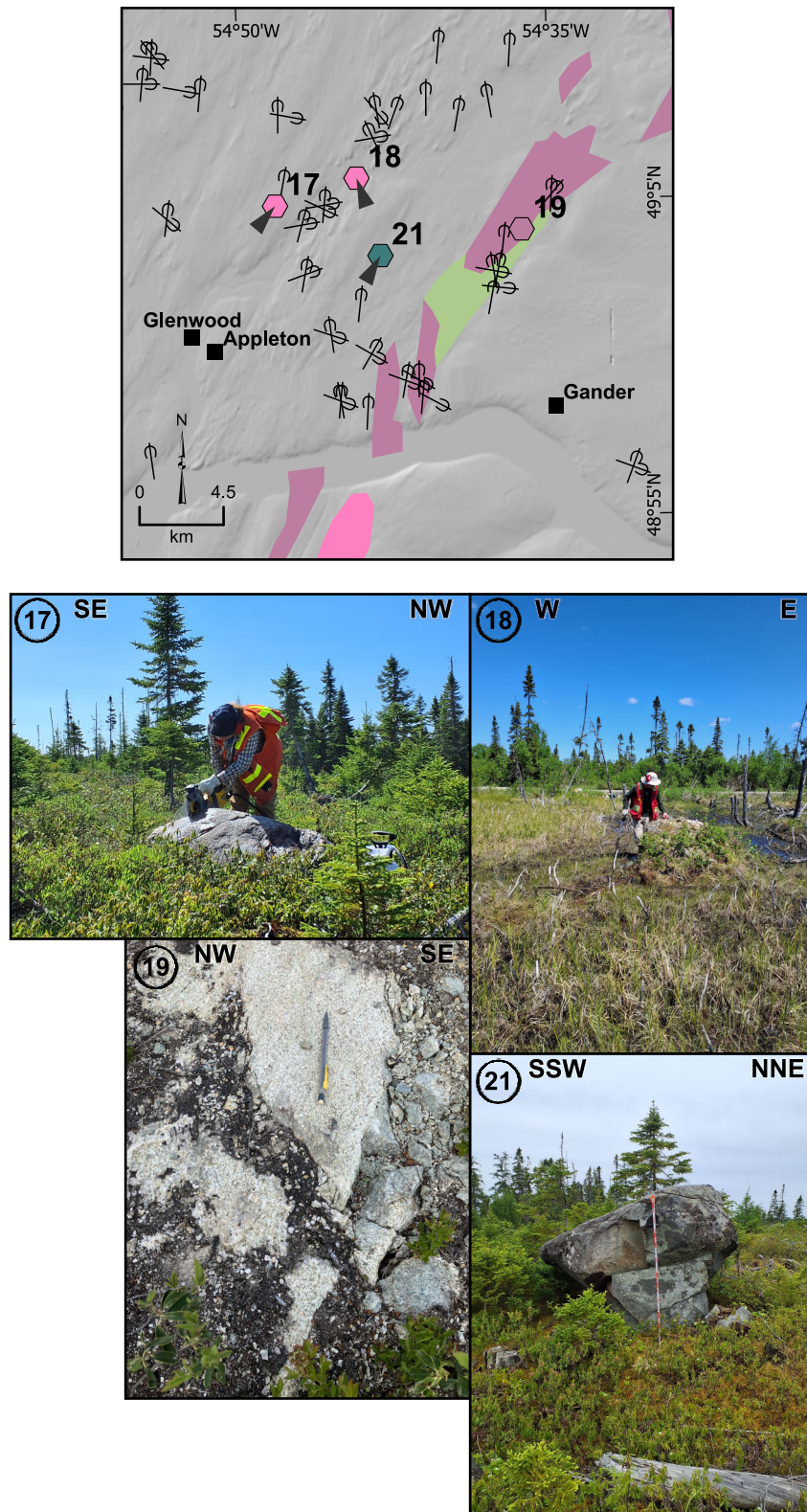


Figure 8. Numbered boulder sites and bedrock site locations north of Appleton.

flow chronology for spatially and temporally distinct ice-flow events in north-central Newfoundland. The varied ice-flow paths and distances indicated by dispersed boulders suggest eastward, northeastward, and northward orientations, and at least one boulder dispersal resulted from a combination of ice-flow orientations and distances. In addition, different dispersal distances were identified, suggesting different ice flow velocities and that erosion was not evenly distributed under ice sheets. This suggests property-scale dispersal studies are important in determining ice-flow orientations and dispersal distances. Gold grains, whose morphologies can assist with proximity, could be effective for these studies.

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