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SURFICIAL GEOLOGICAL SURVEY IN SUPPORT OF MINERAL EXPLORATION, GREAT NORTHERN PENINSULA: PRELIMINARY RESULTS FROM THE ST. JULIEN'S MAP AREA

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ABSTRACT

Multi-year surficial mapping and till sampling program, initiated on the Great Northern Peninsula in 2018 continued into the 2019 field season and the St. Julien's map area was selected for follow-up work. Additional surficial mapping in 2019, till sampling and ice-flow indicator measurements taken during the 2018 and 2019 field seasons, in conjunction with work by previous authors, have resulted in a better understanding of the regional ice flow. Three distinct ice-flow movements have been identified in the study area: an early northeast movement, a subsequent east-southeast movement and the final southeast movement. Preliminary surficial mapping identified a silty sandy till of variable thickness, sand and gravel, colluvial cones, and beach ridges.

INTRODUCTION

A regional surficial mapping and till sampling program was initiated in 2018 on the Great Northern Peninsula (GNP), which is one of the last parts of the Island of Newfoundland whose surficial geology is yet to be mapped in detail, *i.e.*, at 1:50 000. Follow-up studies in the St. Julien's map area (hereafter referred to as the "study area") were completed during the 2019 field season. The study area has a complex bedrock geology, is host to numerous occurrences of base and precious metals, including Zn (± Pb), Cu, Ni and Ag, and was subjected to more than one ice-flow event during the Late Wisconsinan Glaciation. The last few years have also seen renewed exploration activity in this region (*e.g.*, Altius Minerals Corporation, 2018), and hence a need to assess the suitability of reconnaissance surficial geochemistry to detect surficial geochemical dispersal from known and unknown mineralization. This current research report presents an overview of fieldwork conducted during the 2019 field season. Interpretations of ice-flow dynamics and surficial geology are based on data collected by the author during both the 2018 and 2019 field seasons.

PREVIOUS WORK

The surficial geology of the GNP was mapped at a reconnaissance level by Grant (1986, 1989, 1992). Putt *et al.* (2010) did a comprehensive study of the ice-flow dynamics on the GNP; however, no detailed mapping (1:50 000 scale) has ever been completed. Previous regional geochemical sampling includes a lake-sediment sampling survey (Butler and Davenport, 1982). Ricketts and Vatcher (1996) also completed an aggregate assessment report for the study area.

OBJECTIVES

This year's fieldwork objectives were to: 1) map the surficial geology of the study area, and measure ice-flow indicator features to reconstruct the regional glacial history; and 2) sample till, where present, to characterize regional background till geochemistry and, in doing so, identify any surficial geochemical anomalies present that may be associated with known and unknown mineral occurrences.

LOCATION, ACCESS AND PHYSIOGRAPHY

The study area is located on the northern tip of the GNP in northwestern Newfoundland, between latitudes 51°15′N and 51°00′N and longitudes 56°00′W and 55°30′W (Figure 1). Most of the study area is easily accessible from Highway 438, which connects to the Trans-Canada Highway and to routes 432, 433, 435, 436 and 437.

The St. Julien's map area is characterized by undulating topography and the relief is generally low. The lowlands are characterized by peat, muskeg and bog, a variable glacial sediment cover and balsam fir, black spruce and cedar trees and overstory. The higher elevation regions are characterized by exposed rock, bog and spruce and fir trees. The region has a subarctic climate (Köppen climate classification Dfc; Peel *et al.*, 2007).

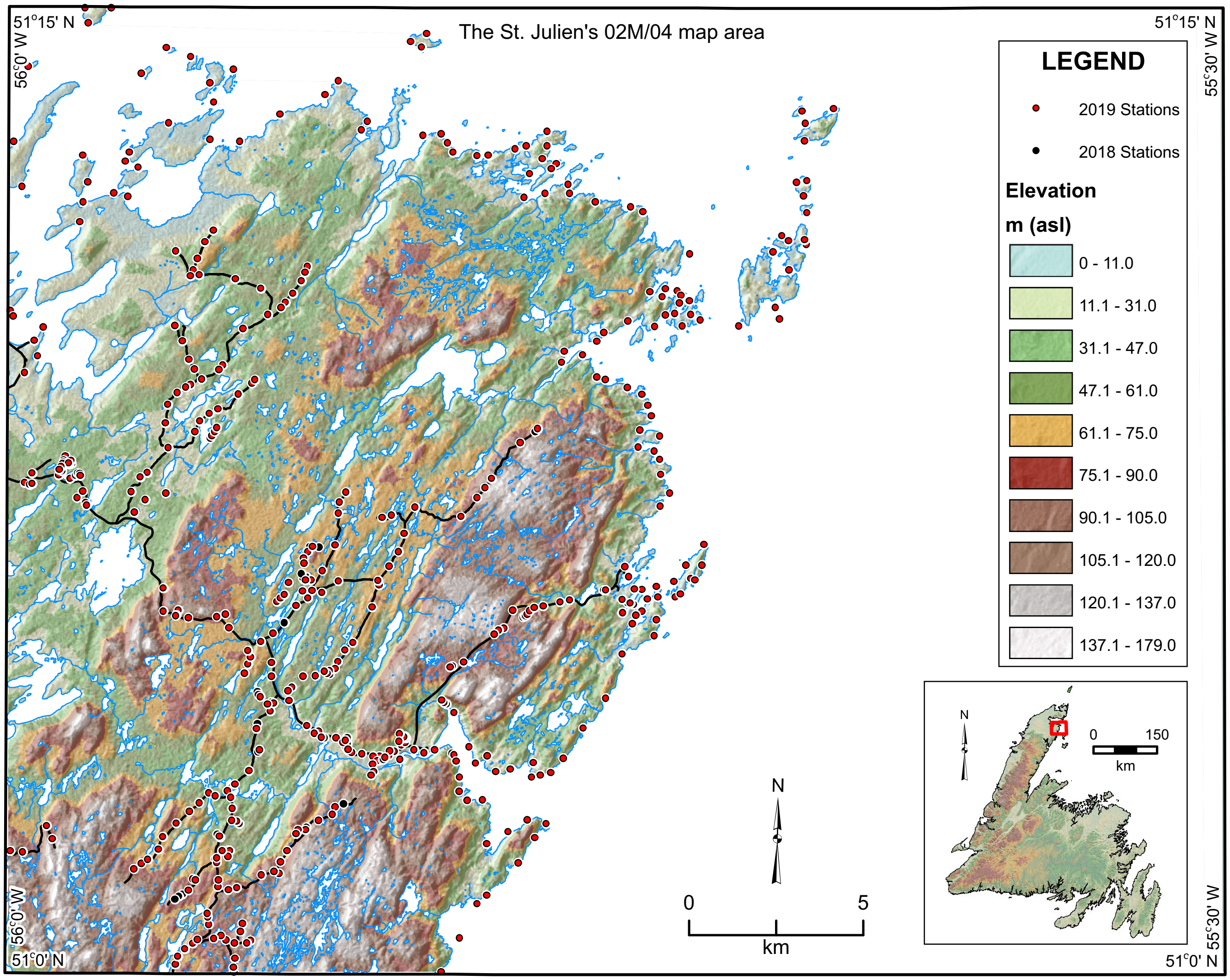

Figure 1. *Digital elevation model and location of study area, showing 2018 and 2019 field stations.*

BEDROCK GEOLOGY

The bedrock geology of the study area has been summarized after Stouge and Godfrey (1982), Williams and Smyth (1983), Botsford (1988), Knight and Edwards (1986a, b), Colman-Sadd *et al.* (1990), Waldron and Stockmal (1994), Hinchey *et al.* (2015) and King and Conliffe (2017). It is situated within the Humber (tectonostratigraphic) Zone and consists of allochthonous sedimentary and volcanic rocks and autochthonous platform sedimentary rocks, all underlain by Grenvillian (*ca.* 1 Ga) basement rocks (Waldron and Stockmal, 1994; Figure 2). The oldest sedimentary rocks in the study area are autochthonous sandstone, shale and limestone, associated with early rifting, of the Neoproterozoic to Middle Cambrian Labrador Group. They are overlain by Middle Cambrian to Early Ordovician carbonates of the Port au Port and St. George groups, both of which represent deposition on a carbonate platform on the Laurentian margin (Hinchey *et al.*, 2015). The top of the St. George Group is marked by a major unconformity, which represents the transition from passive margin sedimentation to the formation of a marine foreland basin at the beginning of the Taconic Orogeny (Knight and Edwards, 1986a, b). The foreland basin succession consists of shallow to deep-water subtidal sequences, including carbonates of the Middle Ordovician Table Head Group, overlain by deeper water sediments of the Middle to Late Ordovician Goose Tickle Group.

Late-stage thrusting during the Taconic orogeny resulted in the emplacement of the Hare Bay Allochthon (Waldron and Stockmal, 1994). This consists of structural slices of transported rocks consisting of an ophiolite complex (Colman-Sadd *et al.*, 1990; Hinchey *et al.*, 2015) and sedimentary rocks deposited: a) in rift basins; b) on the continental shelf slope; c) onto the adjacent sea floor; and d) in the foreland basin. These transported rocks are all separated by thin zones of shale mélange (the Milan Arm Mélange; Williams and Smyth, 1983). The sedimentary units include pyritiferous shale, sandstone and carbonates of the Northwest Arm Formation, and highly prospective greywacke, slate and basalts of the Maiden Point Formation (*see* Mineral Occurrences section; Colman-Sadd *et al.*, 1990; Hinchey *et al.*, 2015). The ophiolite complex is mapped on Fischot Island and comprises the Green Ridge amphibolite and the Goose Cove schist.

MINERAL OCCURRENCES

Several Cu, Ni, Zn and Pb occurrences have been reported in the mineral occurrence database (MODS) for the study area (Geological Survey of Newfoundland and Labrador, 2016a). Of these, the most recently explored are tabulated (Table 1).

QUATERNARY FRAMEWORK OF THE GREAT NORTHERN PENINSULA

Reconnaissance-level mapping (at 1:125 000 scale) of the Blanc-Sablon region of Québec and the northern portion of the GNP was first completed by Grant (1986, 1989, 1992), who studied the regional ice-flow dynamics and Quaternary glacial stratigraphic record, documented the surficial sediments and marine limits, recorded the regional and local ice-flow regimes and reconstructed paleo shorelines. Grant (1992) established that the glaciers that affected the GNP were part of the Appalachian Ice Complex (characterized by smaller ice caps originating within the Long Range Mountains), and the Laurentide Ice Sheet (LIS), resulting in a complex ice-flow history for the region (Figure 3). Shaw *et al.* (2006) compiled regional studies into an integrated model for the late Wisconsinan in Atlantic Canada. Putt *et al.* (2010) examined the ice-flow dynamics on the GNP by undertaking a comprehensive ice-flow mapping program encompassing all of NTS map area 12P and parts of 2M and 12I. Based on this work, the chronological sequence of events is as follows (ages are in radiocarbon years).

The last glaciation to have affected the study area, referred to as the Long Range Zone (Grant, 1992), is correlated with the late Wisconsinan (25–10 ka). At the late Wisconsinan maximum, the LIS crossed the Strait of Belle Isle and covered the west coast of the GNP, eventually merging with the Newfoundland Ice Cap (NIC), originating in the Long Range Mountains, (Grant, 1992; Shaw *et al.*, 2006). The last glacial maximum was likely between 19.5 and 15 ka BP (Shaw *et al.*, 2006).

Putt *et al.* (2010) recorded striations indicating ice flow to the west (oldest), east-southeast (second oldest) and

Table 1. Copper showings and indications in the St. Julien's map area

Name	Status	Inventory No.	Other Names	Host Rocks	Ore Minerals	Grades/Mineralization Description	References
White Arm Cu	Indication	002M/04/Cu showing #01 to 10	Sail Pond Ag–Cu–Pb–Zn–Sb	St. George Group	chalcocite, tetrahedrite, pyrite boulangerite, bornite, covellite, mimetite, tennantite, sphalerite and glaena	up to 2030 g/t Ag and 7.08% Cu	Altius Minerals Corp., 2018; Newfound Gold Corp., 2018
St. Julien's Ni and Cu	Showings	002M/04/Ni001, 002 (#1 and 2) and 014 to 017 showings (#1 to 4)	N/A	Hare Bay Allochthon (Maiden Point Formation)	chalcopyrite	Copper (occurring primarily as chalcopyrite), Ni, Co and Ag mineralization occurs in quartz veins 5-15 cm thick	Geological Survey of Newfoundland and Labrador, 2016A
Copper Co	Showing	(002M/04/Cu001 (showing #2)	N/A	Hare Bay Allochthon (greywacke of the Maiden Point Formation)	chalcopyrite	Copper (occurring primarily as chalcopyrite), Ni, Co and Ag mineralization occurs in quartz veins 5-15 cm thick	Geological Survey of Newfoundland and Labrador, 2016a
Fischot Island Cu	Indications	(002M/04/Cu013)	N/A	Green Ridge Amphibolite	chalcopyrite	Up to 2.2% Cu; The Cu mineralization occurs as structurally controlled stockwork veins of chalcopyrite within amphibolites	Galeschuk, 2010

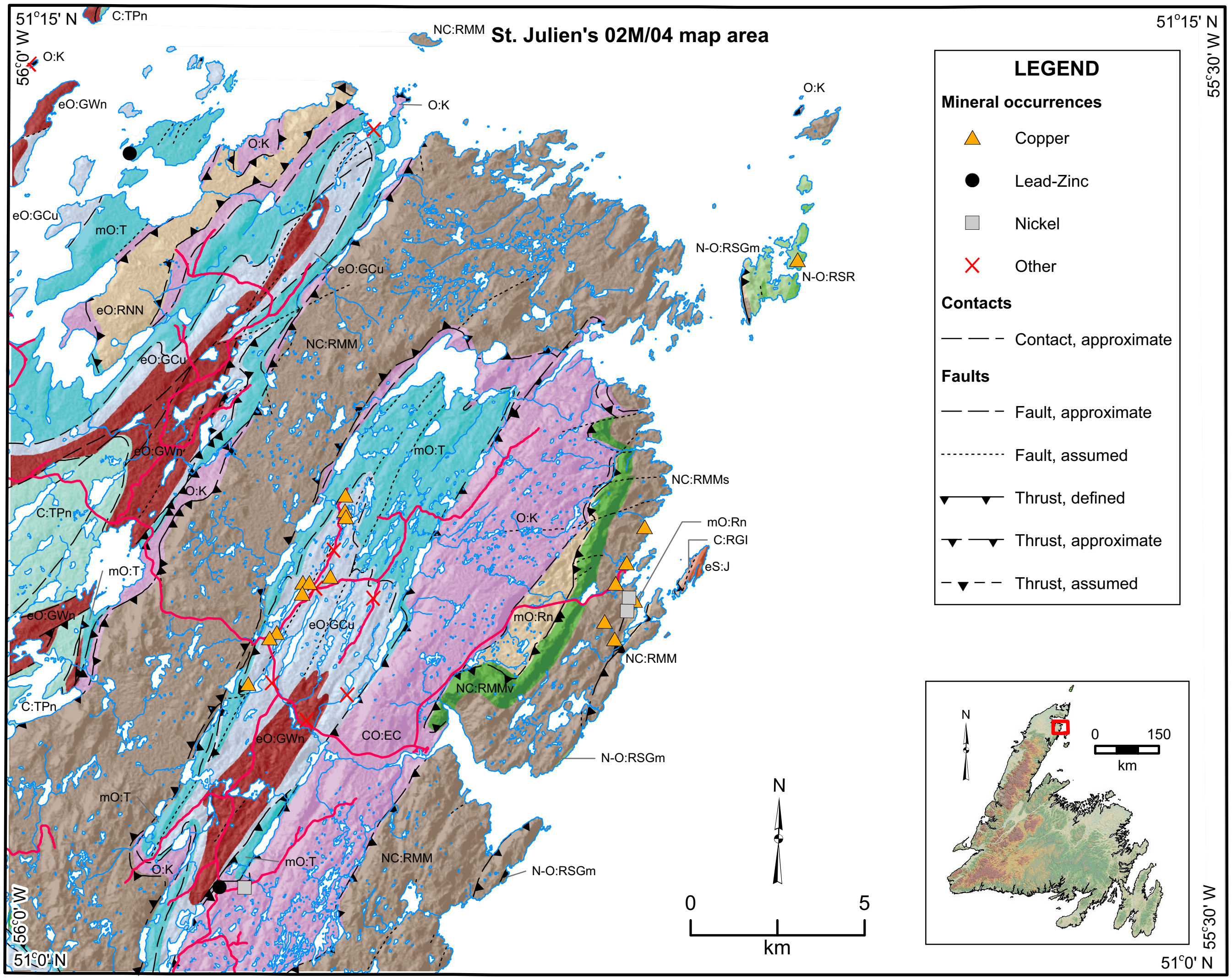

Figure 2. *Bedrock geology and relevant mineral occurrences in the study area. Bedrock geology modified after Colman-Sadd* et al. *(1990).*

southwest (youngest). They interpreted these as suggesting that during the late Wisconsinan Glaciation, ice originating from the Long Range Mountains flowed west, whereas the LIS flowed southeast, across the Strait of Belle Isle. The ice masses coalesced on the western part of the GNP, deflecting the glaciers originating in the Long Range Mountains to the southwest. Putt *et al.* (2010) described striations, suggesting a dominant southeast flow. They also observed clusters of anorthosite boulders (on raised beaches) in the northeastern part of the GNP, which were interpreted as showing the LIS advancing southeast onto it.

Ice retreat may have commenced between 13–10 ka BP (Grant, 1992), whereby ice sheets disintegrated primarily *via* ablation and ice stagnation, becoming isolated and shrinking into multiple ice-caps (Grant, 1989, 1992; Shaw *et al.*, 2006). As deglaciation proceeded, ice sheets became topographically controlled as they retreated toward the Long Range Mountains (Grant, 1992; Shaw *et al.*, 2006).

By 12 ka BP, ablating ice of the NIC in western Newfoundland was discharging into the Gulf of St. Lawrence and the Strait of Belle Isle was ice free (Shaw *et al.*, 2006); however, smaller ice caps, (such as the ice cap originating in the White Hills north of the study area), persisted until approximately 11 ka BP (Shaw *et al.*, 2006). The Goldthwait Sea marine limit was also established by 12 ka BP in the GNP between 125 to 175 m above modern day sea level (Grant, 1992; Dyke *et al.*, 2005). The suggested positions of the marine limit are based on marine shells, whose 14C dates were compiled by Grant (1992). The marine limit in the study area is somewhat variable; Grant (1992) recorded the marine limit at 122 m asl in the north-central portion of the map area, at 137 m asl in Croque in the southeast of

LEGEND

Post-Ordovician Units

Overlap Sequences

Early Silurian

St. Julien Island Formation

eS:J Red to purple polymictic conglomerate and minor greywacke

Laurentian Margin

Humber Zone (Shelf and Related Rocks)

Middle to Late Ordovician

Goose Tickle Group

Black Cove Formation

O:K Lower dark grey to black, graptolitic shale (Black Cove Formation) overlain by American Tickle Formation of dark grey shale interbedded with green-grey sandstone, siltstone and yellow- and grey-weathering, thin bedded limestone, dolomitic limestone and dolostone, and locally shale-pebble conglomerate; shales are metamorphosed to slates and phyllites in more deformed areas; thick intervals of massive-bedded, green-grey and green sandstone and pebbly sandstone known on Port au Port Peninsula only as the Mainland Sandstone; lenses of very thick limestone conglomerate and breccia and beds of limestone conglomerate overlain by calcarenite and calcisiltite (Daniel's Harbour Member); all units dismembered into melange-like deposits locally

Middle Ordovician

Table Head Group

Table Point Formation

mO:T Largely comprises dark grey to light grey, thick to massive bedded, stylonodular, fossiliferous, dominantly fine grained, argillaceous and dolomitic limestone; locally grainstone; locally interbedded with fenestral limestone and dolostone near the base; minor sponge-bryozoan bioherms and large slump units and locally a conglomeratic aspect (Table Point Formation) overlain locally by fine-grained, fossiliferous and graptolitic, parted, stylonodular and ribbon limestone and shale (Table Cove Formation); carbonate conglomerate and megaconglomerate interbedded with calcarenite, ribbon limestone and green-grey to black shale occurs locally at the top on Port au Port Peninsula (Cape Cormorant Formation)

Early to Middle Ordovician

St. George Group

Catoche Formation

eO:GCu Undivided Catoche Formation, which includes Costa Bay Member where present; bedded, bioturbated, dolomitic limestone with some microbial mound beds, locally replaced by sucrosic dolomite

Watts Bight Formation

eO:GWn Dark grey to black, thick bedded, fine- to medium-crystalline dolostone characterized by light grey to cream mottling, and large microbial mounds, chert, dolarenite, thin beds of buff weathering, microcrystalline dolostone, gastropods and cephalopods locally; light grey limestones locally at top of formation composed of large thrombolite mounds and grainstone in Hare Bay region; the dolostones feather out eastward as the unit approaches the Hare Bay allochthon into dark grey to black to light grey to grey, fabric and dolomite-mottled, cherty thrombolitic, stromatolitic, bioturbated, clean and dolomitic limestone

Middle Cambrian to Late Ordovician

Epine Cadoret Formation

CO:EC Black and grey slate, and minor brown weathering sandstone; may be equivalent to either Ordovician Goose Tickle Group or Cambrian March Point Formation

Middle Cambrian to Early Ordovician

Port au Port Group

Petit Jardin Formation

C:TPn Yellow or buff to white weathering, light grey to white, microcrystalline to finely crystalline dolostones and lesser red, green and grey shale interbeds; stromatolite mounds common; locally oolitic and stromatolitic limestones in the middle of the formation; cherty dolostones towards the top

Neoproterozoic to Early Ordovician

Hare Bay Allochthon

Irish Formation

C:RGI Sandy limestone; brown thinly bedded siliceous limestone and slate; basal unit of sheared and brecciated quartzite with minor interbedded greenschist

Neoproterozoic to Middle Cambrian

Labrador Group

Hawke Bay Formation

C:LHm Rusty weathering, green-grey to grey phyllites with thin, rusty weathering, white, quartz arenites and a few beds of ribbon limestone in parautochthon adjacent to Hare Bay Allochthon

Humber Zone (Slope and Related Rocks)

Neoproterozoic to Early Ordovician

Fleur de Lys Supergroup

N-O:FMg Meta-greywacke, pebbly psammitic and semipelitic schist

Hare Bay Allochthon

Maiden Point Formation

NC:RMMv Mafic agglomerate and tuff, massive basaltic flows, and local pillow lava

NC:RMMs Coarse-grained greywacke; red, green, purple and black slate, quartz pebble conglomerate, and minor limestone conglomerate

NC:RMM Coarse-grained greywacke; red, green, purple and black slate, quartz pebble conglomerate, and minor limestone conglomerate; mafic agglomerate and tuff, massive basaltic flows, and local pillow lava; minor medium- to coarse-grained diorite and gabbro, and unseparated mafic dykes and sills

Northwest Arm Formation

eO:RNN Pyritiferous, green and black shale, grey and black bedded chert, grey limestone including limestone breccia, calcarenite, calcisiltite, thinly bedded ribbon limestone and shale, grey sandstone and thick dark grey, locally gritty sandstone, and intraclastic conglomerate composed of intraformational lithoclasts; the formation was disarticulated during emplacement of the Hare Bay Allochthon

Milan Arm Melange

mO:Rn Melange beneath transported slices of allochthon; consists of black and green shale matrix with sandstone, volcanic, intrusive and ultramafic blocks

Iapetus Ocean

Dunnage Zone (Notre Dame Subzone)

Green Ridge Amphibolite

N-O:RSR Well foliated amphibolite and garnetiferous amphibolite, minor marble and foliated gabbro; includes pyroxene-bearing amphibolite at the White Hills Peridotite contact; has a gradational metamorphic contact with the Goose Cove Schist

Goose Cove Schist

N-O:RSGm Greenschist derived mainly from thinly layered tuffs, mafic agglomerate and flows; includes black and green pelitic schist, thin marble beds and deformed gabbro sills; has gradational contacts with both the Green Ridge Amphibolite and the Ireland Point Volcanics

Legend for Figure 2.

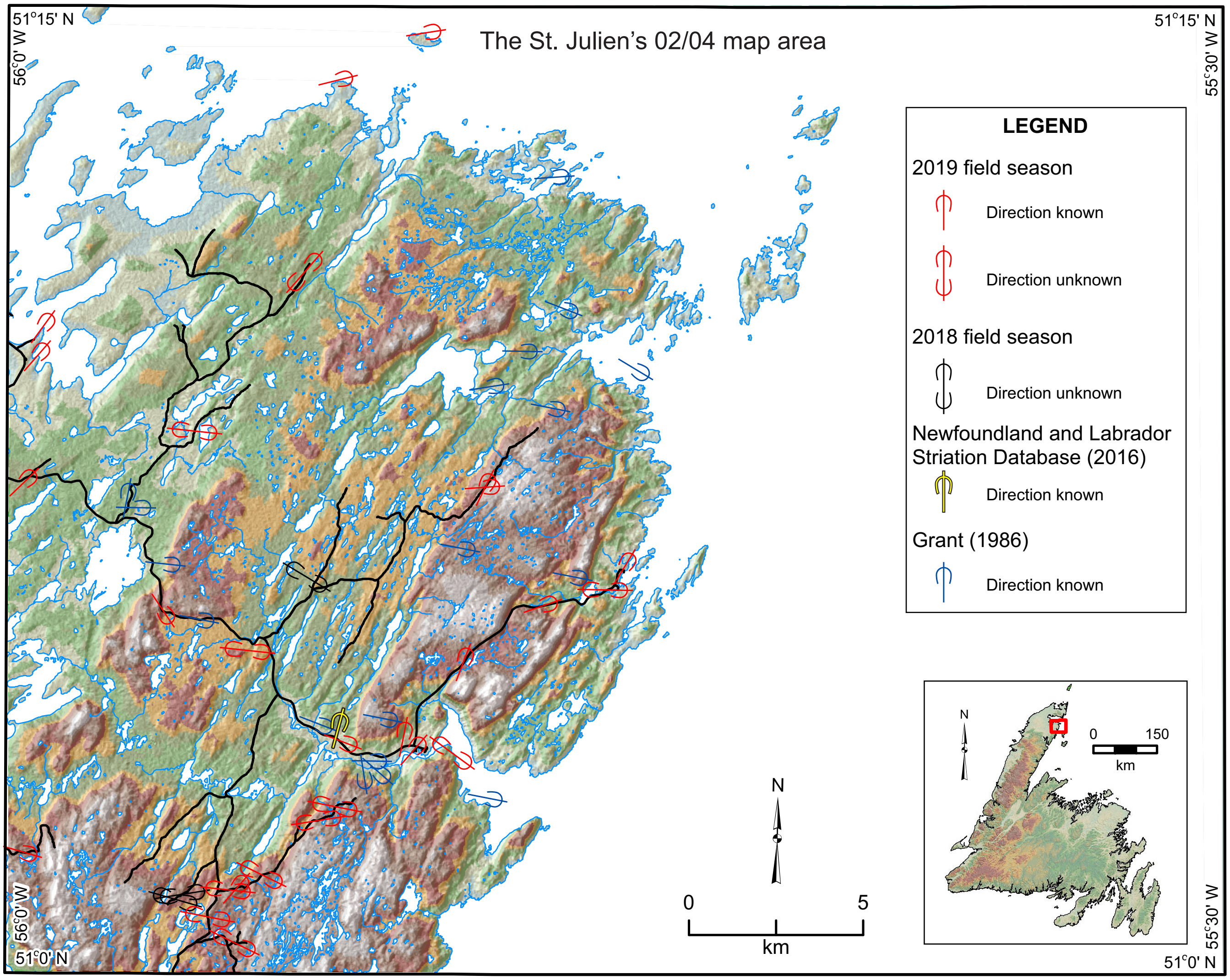

Figure 3. *Select striation measurements from previous studies in the study area, as well as the 2018 and 2019 field seasons. The colours distinguish each study. Data retrieved from Grant (1992), Putt* et al. *(2010) and Geological Survey of Newfoundland and Labrador's striation database (2016b).*

the study area, and at 62 m asl in Conche, which is south of the study area. Grant (1992) identified a large arcuate moraine (the Ten Mile Lake Moraine), whose eastern edge terminates in the west-central portion of the study area, that he suggested (based on 14C dates) was formed in a re-advance related to the globally recognized Younger Dryas cooling period. Deglaciation was mainly complete by 10 ka BP (Grant, 1992; Shaw *et al.*, 2006).

Deglaciation of the region resulted in isostatic rebound of the Earth's crust and changes in sea level (Grant, 1992). Liverman (1994) integrated marine shell dates with modelling of sea-level change curves (after Quinlan and Beaumont, 1981, 1982) to calculate the rate of isostatic rebound of the Earth's crust within the Island of Newfoundland. Based on the age of marine shells recovered from the tip of the GNP, it was demonstrated that by 8.5 ka BP, the study area was still submerged and that after deglaciation of the GNP, the crust either underwent continued emergence (or isostatic uplift) or a more complex pattern of emergence, submergence and later re-emergence.

FIELDWORK

MAPPING

Till sampling and surficial geology mapping were completed *via* boat, truck, all-terrain vehicle (ATV) and foot traverse between June and August, 2019. Surficial geology was mapped with the aid of a Trimble GPS unit. Google Earth™ digital hill shade imagery, derived from shuttle radar topography mission (SRTM) data, and orthoimagery, sourced from the Department of Forestry were also used to study macro-scale ice-flow indicator features (streamlined bedrock, flutings, rôches moutonnées). Information entered at mapped stations consists of GPS coordinates, elevation, sediment type and characteristics and geomorphic signature. Orientation measurements of macro-scale features such as rôches moutonnées and streamlined bedforms, and micro-scale features consisting of striations and grooves were also made at suitable sites.

SAMPLING

Eight samples were collected during the 2019 field season. Additionally, select sites in the study area were briefly visited during the 2018 field season to collect till samples in (now back-filled) trenches dug around the Sail Pond deposit. Lack of suitable till contributed to the sparse sample coverage. Till sampling followed the protocol of the Geological Survey of Newfoundland and Labrador (GSNL). Most of the samples collected were of C-horizon material; however, at a few sites, the B/C horizon was sampled. C-horizon till is the optimal surficial medium to sample as it is mostly unaffected by physical and chemical weathering processes such as surface washing, pedogenesis, remobilization *via* gravity and/or element mobility *via* hydromorphic dispersion (Levson, 2001). At each site, the sediment face was cleaned and dug out to expose till and 2 to 3 kg of material were collected. Information collected at each sample site consisted of: a) GPS coordinates; b) site description including observations such as evidence of anthropogenic activity in the vicinity; c) till colour; d) relative percentages of clasts and matrix (clay, silt and sand); e) elevation; f) clast features (*e.g.*, faceting, scour marks, micro-striae); and g) till properties such as fissility and jointing, as well as the presence of carbonate, identified using diluted HCl acid. Weathering and soil-horizon information were also recorded, and photographs taken at each site. The potential influence of marine incursion on till composition was also taken into account (Grant, 1992), and each sample was thoroughly checked to ensure that no shells were present. It is, however, significant that all of the 2019 sample locations, and all except one of the 2018 locations, were at an elevation of <100 m asl and were likely below the marine limit for the region (*see* above).

ANALYSIS

SAMPLE PREPARATION

Till samples have been submitted to the GSNL laboratory for preparation and analysis. Samples have been dried and sieved to the <63 µm fraction (230 mesh) to recover the silt and clay fraction. This fraction is considered to be the optimal size fraction for analysis because it is time- and cost-effective to sieve.

QUALITY ASSURANCE AND QUALITY CONTROL

Several measures were taken in the field to ensure the integrity of the samples. Sampling tools were cleaned before and after the collection of each new sample to reduce the risk of cross-contamination. Quality assurance methods in the lab consist of the insertion of lab duplicates, and certified reference standards, to monitor precision and accuracy, respectively (*see* Finch *et al.*, 2018).

ANALYTICAL TECHNIQUES

Sieved samples will be analyzed at the GSNL laboratory in St. Johns, where minor- and trace-element content will be analyzed following methods described by Finch *et al.* (2018): inductively coupled plasma-optical emission spectroscopy (ICP-OES) after a (near total) multi-acid (HF/$HCl/HNO_3/HClO_4$) digestion. Samples will also be submitted for instrumental neutron activation analysis (INAA) by Bureau Veritas.

RESULTS AND PRELIMINARY INTERPRETATION

SURFICIAL GEOLOGY

The advance and retreat of glaciers in the study area has resulted in sporadic deposits of glacial sediments of variable thickness. Preliminary field mapping has delineated the following surficial units in the study area:

a) Bare or concealed, sculpted bedrock is the most dominant surficial unit mapped in the study area (Plate 1A, B). At topographic highs it is mapped as concealed rock, with the cover consisting of vegetation (*e.g.*, trees, moss, shrubs). At low elevations and along the coast, it is overlain by a variable veneer (*i.e.*, <1 m) of till, gravel, beach deposits or organics (Plate 1C);

b) Till is the oldest surficial unit mapped in the study area and is associated with the advance of glaciers into the study area (Plates 1D and 2A). It is grey-brown, and present as a veneer in the northwest and central portions of the study area, where it is observed overlying bedrock and rarely exceeds 1 m in thickness. In the west-central portion of the study area, it is observed underlying sand and gravel gravel. It is also mapped as a blanket in the west-central part of the study area;

c) Crude to well-stratified, granule- to boulder-sized gravel and medium-coarse sand, lenses of silty sand as well as a massive, brownish silty till derived from local sedimentary rocks (dolomites), crystalline boulder erratics and quartzite have been mapped in the western corner of the

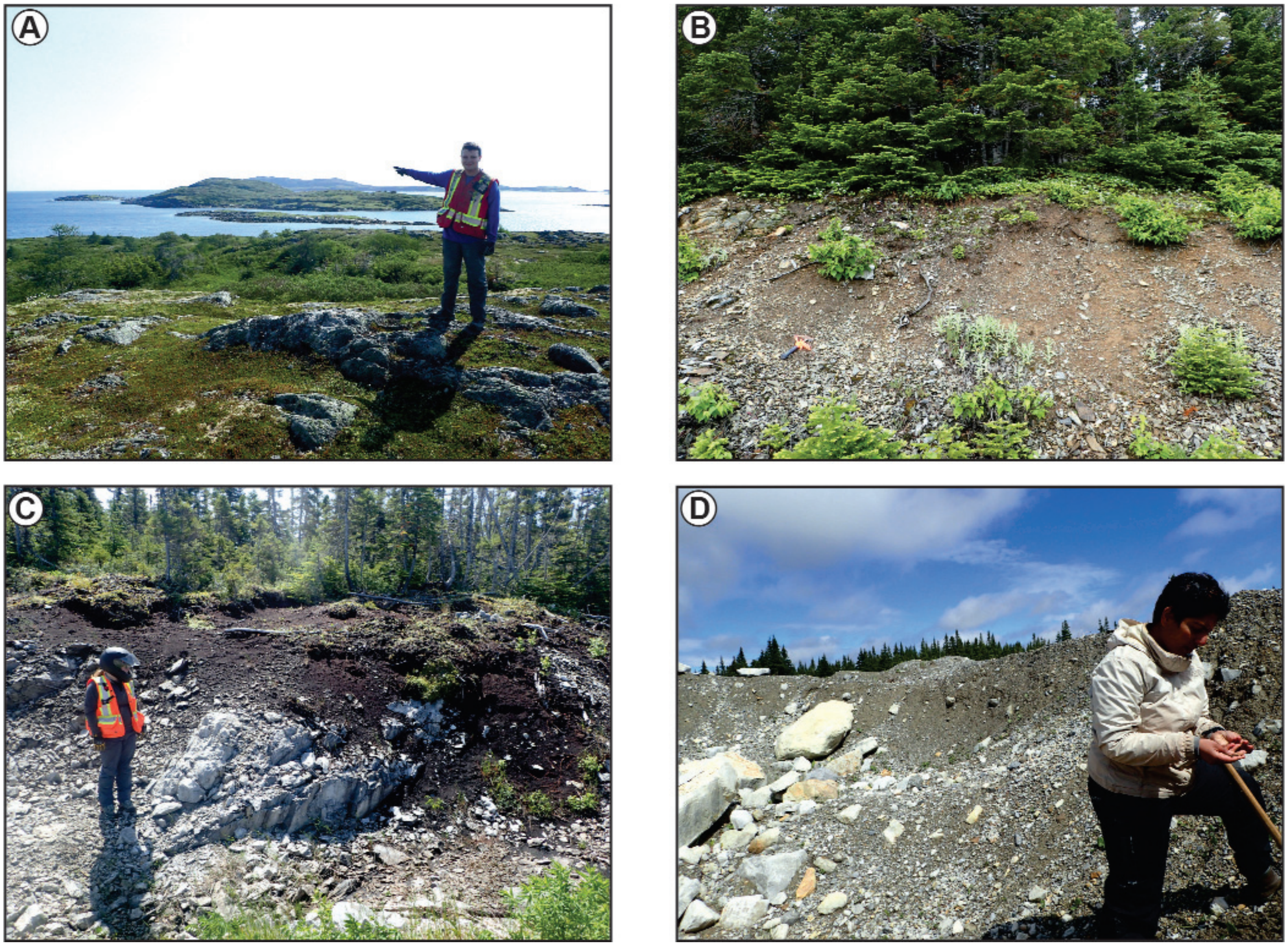

Plate 1. *A) Panoramic view from Grandois, looking northeast toward Goose Island. Ice-flow documented at this site (02M/04/190420) was to the northeast; B)* In situ *shattered bedrock overlain by vegetation is prevalent in the study area; C) Bedrock overlain by organics and vegetation; D) Till blanket mapped at site 02M/04/190170. The till blanket is at least 3 m thick.*

study area (Plate 2Bi, Bii). These deposits (ranging 10–30 m in thickness) are part of the Ten Mile Lake moraine. Grant (1992) also documented broken marine shells dominated by Mya truncata; however no marine shells were observed during the fieldwork;

d) Medium to coarse-grained sand and granule-sized gravel are mapped as littoral/nearshore features and beach deposits along most shorelines (Plate 2C, D). Most of the beach deposits were formed as a result of littoral reworking of frost-shattered bedrock, till, outwash and colluvium;

e) Organic deposits, consisting of muskeg, bog and fen, are prevalent in the coastal lowlands and bedrock depressions inland and can be observed overlying bedrock at many localities (Plate 2E); and

f) Colluvium mainly consisting of clay, silt and sand and granule- to boulder-sized bedrock rubble, is associated with slope failures along the shore in both surficial material and bedrock, and is mapped as colluvial fans and cones along some shorelines (Plate 2F).

Plate 2. *(Plate on page 9) A) Till sample (19SH111-1006) collected at the western boundary of the map sheet; Bi) Glaciofluvial medium to coarse sand and granule- to boulder-sized gravel at the western boundary of the map sheet (site 02M/04/190054). The sand and gravel deposit is likely associated with ice stagnation in the area; Bii) Detailed view of the sand and gravel at site 02M/04/190053; C) Vegetated modern shorelines; D) Paleo-shorelines developed on top of bedrock; E) Fen (organics) with underlying water; F) Colluvium mapped along the coast. Rock failure along steep coastal slopes resulting in talus slopes.*

Plate 2. *Caption on page 8.*

ICE FLOW

Small-scale ice-flow indicator features such as striations, grooves and rat-tails, and large-scale ice-flow indicators such as crag and tail, rôches moutonneés and stoss-and-lee relationships were used to interpret the ice-flow history in the study area. Overall, the region has well-preserved glacial features and three distinct ice-flow directions have been identified (Plate 3A–F; Figure 4):

a) A northeast flow.
b) An east-northeast flow.
c) A southeast flow.

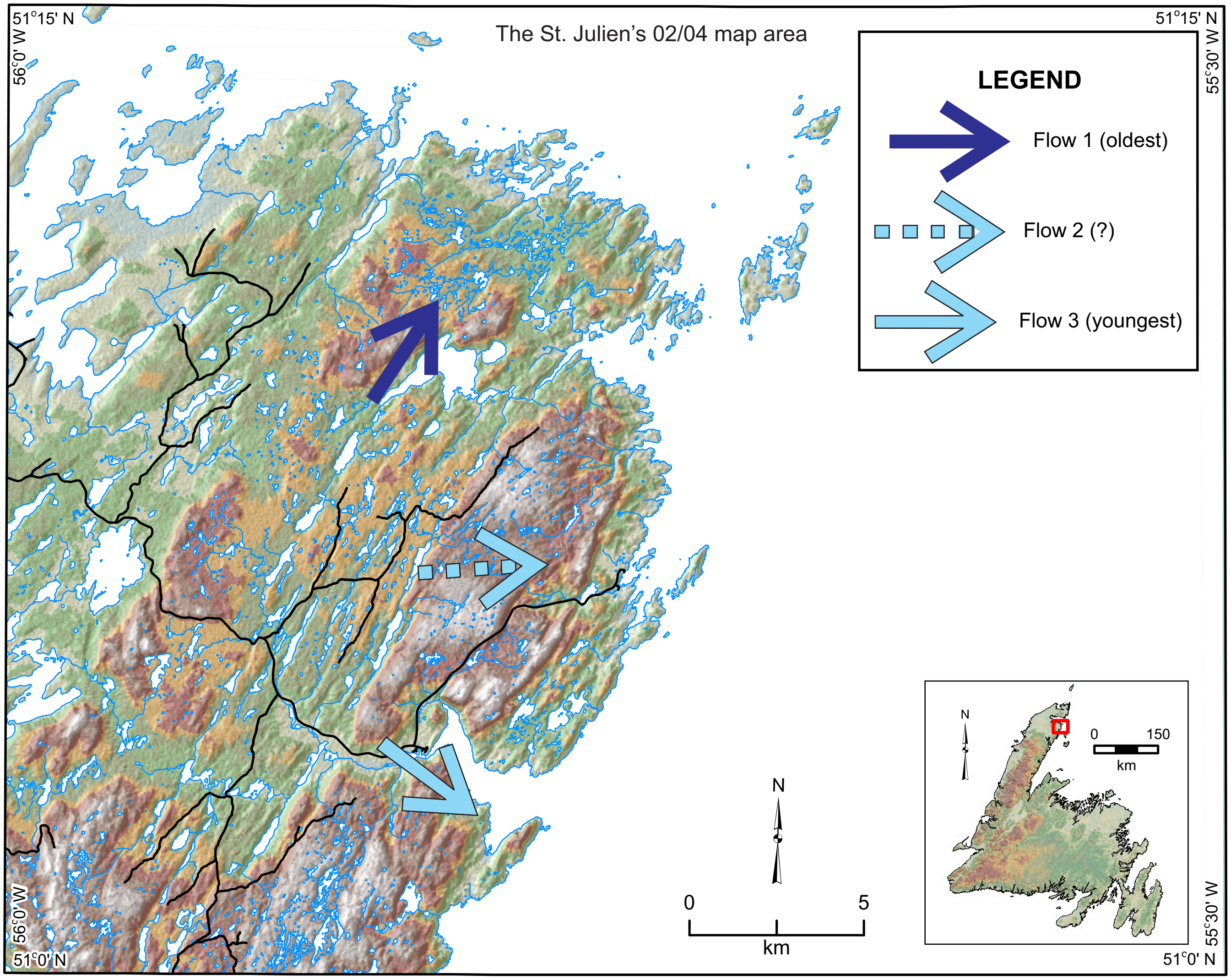

Figure 4. *Glacial movement reconstruction based on previous work by Grant (1992), Putt* et al. *(2010) and the 2018 and 2019 fieldwork.*

Plate 3. *(Plate on page 11) A) Rôche moutonnée indicating ice flow to the southeast, partially concealed by vegetation (145°); B) Rôche moutonnée indicating ice flow to the northeast; C) Striations and grooves observed near Maiden Arm indicating a southeast glacial flow, oriented 125°; D) Well-developed striations and grooves at the southern map boundary, indicating glacial movement to the east-southeast (105°); E) Two sets of ice-flow indicators observed at site (02M/04/190409). Striations and grooves (no. 1) are oriented to the southeast (115°). These earlier striations and grooves are overprinted by later finer striations (no. 2) oriented southeast (135°); F) three sets of striations and grooves at site 02M/04/190042. The oldest grooves (no. 1) are located on the protected side of the outcrop (*i.e.*, protected by later flows) and oriented 035°. Striations, grooves and rat-tails oriented to the east, southeast (095°) are abundant and observed on the top surface. The youngest flow crosscuts the east-southeast flow (095°) and is represented by finer striations (and one groove) imprinted on the top surface, oriented to the southeast (115°).*

Plate 3. *Caption on page 10.*

a) The northeast flow is interpreted to be the earliest and also the dominant flow in the study area. Abundant large-scale features such as rock ridges, rôches moutonneés and stoss-and-lee bedforms and small-scale features such as striations and grooves and rat-tails indicate this ice-movement direction. These features are predominantly oriented 035° and range between 020 and 045°. This finding is based on 2019 fieldwork during which two key sites (02M/04/190042 and 02M/04/190197; Table 2) were identified, where evidence of multiple ice-flow movements is preserved on bedrock. At both sites, the northeast flow was observed on the 'protected' face (*i.e.*, protected from the later east-northeast and southeast movements). This northeast flow has been documented by previous authors (*see* Grant, 1992; Geological Survey of Newfoundland and Labrador, 2016b);

b) The east-northeast flow is manifest primarily in small-scale indicators such as striations, grooves and rat-tail features, as well as a few large-scale indicator features such as rock ridges, having an average orientation of 085° and a range of orientations between 070 and 095°. At one site

Table 2. Striation data collected during the 2019 field season

UNIQUE_ID	SITE_NUM	NTS_MAP	YEAR	GEOLOGIST	UTMEAST	UTMNORTH	UTMZONE	DATUM	ELEV_M	STRUCTURE	STRUC_CONF
02M/04/190025	25	02M/04	2019	Sarah Hashmi	579298.8025	5675907.272	21	NAD 27	19.65451	rat-tail	moderate
02M/04/190026	26	02M/04	2019	Sarah Hashmi	581808.2302	5677305.214	21	NAD 27	-12.47373	stoss and lee	moderate
02M/04/190032	32	02M/04	2019	Sarah Hashmi	570802.2366	5667836.972	21	NAD 27	17.55006	stoss and lee	high
02M/04/190033	33	02M/04	2019	Sarah Hashmi	570947.9921	5668669.085	21	NAD 27	22.04838	stoss and lee	moderate
02M/04/190039	39	02M/04	2019	Sarah Hashmi	581825.4577	5656700.394	21	NAD 27	35.22744	stoss and lee	high
02M/04/190040	40	02M/04	2019	Sarah Hashmi	581253.9817	5656645.755	21	NAD 27	49.13385	stoss and lee	high
02M/04/190042	42	02M/04	2019	Sarah Hashmi	580847.048	5656505.517	21	NAD 27	49.43842	grooves	high
02M/04/190042	42	02M/04	2019	Sarah Hashmi	580847.048	5656505.517	21	NAD 27	49.43842	striations, grooves, rat-tail	high
02M/04/190042	42	02M/04	2019	Sarah Hashmi	580847.048	5656505.517	21	NAD 27	49.43842	striations and grooves	high
02M/04/190044	44	02M/04	2019	Sarah Hashmi	579883.9021	5656723.9	21	NAD 27	45.64921	striations and grooves	high
02M/04/190046	46	02M/04	2019	Sarah Hashmi	579078.2945	5657187.533	21	NAD 27	43.05821	striations	high
02M/04/190046	46	02M/04	2019	Sarah Hashmi	579078.2945	5657187.533	21	NAD 27	43.05821	striations and grooves	high
02M/04/190051	51	02M/04	2019	Sarah Hashmi	574549.7728	5660558.755	21	NAD 27	95.60868	grooves	high
02M/04/190051	51	02M/04	2019	Sarah Hashmi	574549.7728	5660558.755	21	NAD 27	95.60868	Roche Moutonnee	high
02M/04/190054	54	02M/04	2019	Sarah Hashmi	570497.4765	5664184.467	21	NAD 27	78.5537	Roche Moutonnee	high
02M/04/190060	60	02M/04	2019	Sarah Hashmi	570628.3799	5653558.793	21	NAD 27	126.25284	striations, grooves, rat-tails	medium
02M/04/190060	60	02M/04	2019	Sarah Hashmi	570628.3799	5653558.793	21	NAD 27	126.25284	striations and grooves	medium
02M/04/190061	61	02M/04	2019	Sarah Hashmi	570264.5685	5653579.965	21	NAD 27	130.5569	striations and grooves	high
02M/04/190061	61	02M/04	2019	Sarah Hashmi	570264.5685	5653579.965	21	NAD 27	130.5569	striations and grooves	high
02M/04/190094	94	02M/04	2019	Sarah Hashmi	582920.8848	5656632.058	21	NAD 27	20.91516	striations and grooves	high
02M/04/190094	94	02M/04	2019	Sarah Hashmi	582920.8848	5656632.058	21	NAD 27	20.91516	striations and grooves	medium
02M/04/190094	94	02M/04	2019	Sarah Hashmi	582920.8848	5656632.058	21	NAD 27	20.91516	striations	high
02M/04/190095	95	02M/04	2019	Sarah Hashmi	582986.5229	5656582.505	21	NAD 27	23.51442	striations and grooves	medium
02M/04/190095	95	02M/04	2019	Sarah Hashmi	582986.5229	5656582.505	21	NAD 27	23.51442	striations and grooves	medium
02M/04/190095	95	02M/04	2019	Sarah Hashmi	582986.5229	5656582.505	21	NAD 27	23.51442	striations and grooves	medium
02M/04/190120	120	02M/04	2019	Sarah Hashmi	578441.4399	5670380.281	21	NAD 27	71.46452	striations and grooves	high
02M/04/190160	160	02M/04	2019	Sarah Hashmi	575352.6375	5665740.564	21	NAD 27	56.09939	striations and grooves	high
02M/04/190169	169	02M/04	2019	Sarah Hashmi	577003.7607	5659473.702	21	NAD 27	81.8813	striations	high
02M/04/190197	197	02M/04	2019	Sarah Hashmi	583736.35	5664288.924	21	NAD 27	134.20555	rock ridge	high
02M/04/190197	197	02M/04	2019	Sarah Hashmi	583736.35	5664288.924	21	NAD 27	134.20555	striations and grooves	high
02M/04/190198	198	02M/04	2019	Sarah Hashmi	583515.0649	5663993.348	21	NAD 27	124.00805	striations and grooves	high
02M/04/190251	251	02M/04	2019	Sarah Hashmi	574920.6177	5660455.691	21	NAD 27	97.70454	striations and grooves	high
02L/13/190261	261	02L/13	2019	Sarah Hashmi	578132.7691	5649542.893	21	NAD 27	154.96919	striations and grooves	high
02L/13/190262	262	02L/13	2019	Sarah Hashmi	578041.7796	5649742.65	21	NAD 27	146.6702	striations and grooves	high
02L/13/190263	263	02L/13	2019	Sarah Hashmi	577124.4348	5650117.608	21	NAD 27	137.08045	striations and grooves	high
02M/04/190271	271	02M/04	2019	Sarah Hashmi	576761.6937	5651063.171	21	NAD 27	133.88446	striations and grooves	medium
02M/04/190277	277	02M/04	2019	Sarah Hashmi	575987.2575	5651786.17	21	NAD 27	123.69308	striations and grooves	medium
02M/04/190278	278	02M/04	2019	Sarah Hashmi	575970.5953	5651893.441	21	NAD 27	127.19326	striations and grooves	medium
02M/04/190279	279	02M/04	2019	Sarah Hashmi	579583.6572	5655020.091	21	NAD 27	125.25266	striations and grooves	high
02M/04/190281	281	02M/04	2019	Sarah Hashmi	579120.5321	5654631.094	21	NAD 27	125.65787	striations and grooves	high
02M/04/190289	289	02M/04	2019	Sarah Hashmi	577501.3638	5653021.941	21	NAD 27	120.27608	striations and grooves	high
02M/04/190289	289	02M/04	2019	Sarah Hashmi	577501.3638	5653021.941	21	NAD 27	120.27608	rock ridge	high
02M/04/190290	290	02M/04	2019	Sarah Hashmi	576801.2779	5652640.176	21	NAD 27	125.88394	striations and grooves	high
02M/04/190291	291	02M/04	2019	Sarah Hashmi	576562.018	5652580.64	21	NAD 27	133.18662	striations and grooves	high
02M/04/190409	409	02M/04	2019	Sarah Hashmi	579916.0484	5656850.826	21	NAD 27	59.64884	striations (finer)	high
02M/04/190409	409	02M/04	2019	Sarah Hashmi	579916.0484	5656850.826	21	NAD 27	59.64884	striations and grooves	high
02M/04/190410	410	02M/04	2019	Sarah Hashmi	579786.9703	5656880.342	21	NAD 27	47.25028	rock ridge	high
02M/04/190410	410	02M/04	2019	Sarah Hashmi	579786.9703	5656880.342	21	NAD 27	47.25028	striations and grooves	high
02M/04/190420	420	02M/04	2019	Sarah Hashmi	587786.663	5662085.627	21	NAD 27	39.96017	rock ridge	high
02M/04/190421	421	02M/04	2019	Sarah Hashmi	587247.3261	5661404.434	21	NAD 27	41.66628	striations and grooves	high
02M/04/190426	426	02M/04	2019	Sarah Hashmi	585462.1935	5660907.889	21	NAD 27	75.28637	rock ridge	medium
02M/04/190437	437	02M/04	2019	Sarah Hashmi	583212.3466	5659253.593	21	NAD 27	104.81174	rock ridge	high
02M/04/190442	442	02M/04	2019	Sarah Hashmi	580328.5282	5656567.118	21	NAD 27	47.54423	striations and grooves	high
02M/04/190444	444	02M/04	2019	Sarah Hashmi	579935.6712	5656685.217	21	NAD 27	55.54863	striations and grooves	medium
02M/04/190445	445	02M/04	2019	Sarah Hashmi	582893.1157	5659128.878	21	NAD 27	103.41533	rock ridge	high
02M/04/190446	446	02M/04	2019	Sarah Hashmi	582821.2327	5659103.993	21	NAD 27	106.81614	rock ridge	high
02M/04/190448	448	02M/04	2019	Sarah Hashmi	581560.447	5656917.539	21	NAD 27	45.4304	striations and grooves	high
02M/04/190448	448	02M/04	2019	Sarah Hashmi	581560.447	5656917.539	21	NAD 27	45.4304	rock ridge	high
02M/04/190449	449	02M/04	2019	Sarah Hashmi	581586.6825	5657038.821	21	NAD 27	49.9301	striations and grooves	high
02M/04/190450	450	02M/04	2019	Sarah Hashmi	581581.6478	5657054.313	21	NAD 27	50.83016	striations and grooves	medium
02M/04/190451	451	02M/04	2019	Sarah Hashmi	581554.4047	5657085.397	21	NAD 27	55.53046	striations and grooves	medium
02M/04/190451	451	02M/04	2019	Sarah Hashmi	581554.4047	5657085.397	21	NAD 27	55.53046	stoss and lee	medium
02M/04/190452	452	02M/04	2019	Sarah Hashmi	581522.3701	5657072.285	21	NAD 27	60.03082	stoss and lee	high

(02M/04/190197), many striations and grooves having this orientation were observed in the protected side slope face (*i.e.*, protected from later glacial movement to the southeast). This east-northeast movement has been documented by previous authors (Williams and Smyth, 1983; Grant, 1992; Geological Survey of Newfoundland and Labrador, 2016b); and

c) The third glacial movement recognized in the study area is a southeast flow, indicated by small-scale glacial indicator features including striations and grooves and a few large-scale features such as rock ridges. Interpreted ice-movement directions vary between 100 and 145°. At a few sites (02M/04/190040, 02M/04/190060, 02M/04/190409), a crosscutting relationship is observed between the east-northeast and this southeast flow.

These three ice-flow movements have been interpreted as showing a sequence of ice-flow events consisting of an early northeast flow, and a subsequent east-southeast flow, followed in turn by a southeast movement. The earliest, northeast, flow is interpreted to have been from glaciers orig-

Table 2. Striation data collected during the 2019 field season

UNIQUE_ID	SENSE	AZIMUTH	RANGE	DIRECTION	BASIS	DIR_CONF	LOCATION	REL_AGE	AGE_BASIS	ABUNDANCE	AGE_CONF
02M/04/190025	known	75	70-80	known	stoss and lee	high	top slope	1			high
02M/04/190026	unknown	80	70-90	known	stoss and lee	high	top slope	1			high
02M/04/190032	known	40	35-45	known	stoss and lee	high	top slope	1			high
02M/04/190033	known	35	30-40	known	stoss and lee	high	top slope	1			high
02M/04/190039	known	40	35-45	known	stoss and lee	high	top slope	1			high
02M/04/190040	known	35	30-40	known	stoss and lee	high	top slope	1			high
02M/04/190042	known	35		known	stossed	high	lee side	1	protected side	few	high
02M/04/190042	known	95		known	stoss and lee	high	top slope	2		abundant	high
02M/04/190042	unknown	105	100-110	unknown		high	side slope	3		many	medium
02M/04/190044	unknown	95		unknown			side slope	1		abundant	high
02M/04/190046	unknown	110		unknown		high	side slope	2	crosscutting	few	medium
02M/04/190046	unknown	125	120-130	unknown			side slope	1		abundant	high
02M/04/190051	unknown	115		unknown	NA	high	side slope	2		few	medium
02M/04/190051	known	145		known	stoss and lee	medium	NA	1		NA	medium
02M/04/190054	known	45		known	stoss and lee	high	NA	1			high
02M/04/190060	known	105		known		high	side slope	1		abundant	high
02M/04/190060	unknown	140		unknown		high	side slope	2	very fine over printing	few	high
02M/04/190061	unknown	95	90-100	unknown		high	side slope	1			high
02M/04/190061	unknown	105		unknown		high	top, flat	1			high
02M/04/190094	unknown	105	100-110	unknown		high	top slope	1			high
02M/04/190094	unknown	120		unknown		high	vertical side slope	1			high
02M/04/190094	unknown	125	120-130	unknown		high	top slope	1			high
02M/04/190095	unknown	115		unknown		high	side slope	1			high
02M/04/190095	unknown	125		unknown		high	vertical side slope	1			high
02M/04/190095	unknown	135		unknown		high	top, side slope	1			high
02M/04/190120	unknown	40	35-45	unknown		high	side slope	1		abundant	high
02M/04/190160	unknown	95	90-100	unknown		high	top surface	1		abundant	high
02M/04/190169	unknown	95	85-105	unknown		high	top slope	1		abundant	high
02M/04/190197	known	25	20-30	known		high	NA	1			high
02M/04/190197	known	85	80-90	known	stossed	high	side slope	2	protected side	many	high
02M/04/190198	unknown	85	80-90	unknown			top slope	1			high
02M/04/190251	unknown	115	110-120	unknown			side slope	1			high
02L/13/190261	unknown	115	110-120	unknown		high	side slope	1			high
02L/13/190262	unknown	110		unknown			side slope	1			high
02L/13/190263	unknown	105	100-110	unknown			side slope	1			high
02M/04/190271	unknown	115		unknown			top slope	1			high
02M/04/190277	unknown	100		unknown			top slope	1			high
02M/04/190278	unknown	95		unknown			top slope	1			high
02M/04/190279	unknown	100		unknown			side slope	1			high
02M/04/190281	unknown	80	70-90	unknown			side slope	1			high
02M/04/190289	unknown	115		unknown			top slope	1			high
02M/04/190289	known	115		known	stoss and lee		NA	1			high
02M/04/190290	unknown	40		known	stossed	high	protected slope	1			high
02M/04/190291	unknown	95	90-100	unknown			top slope	1			high
02M/04/190409	unknown	115		unknown	stoss side	high	top slope	2	crosscutting		high
02M/04/190409	unknown	135		unknown			top	1			high
02M/04/190410	known	110		known	stoss and lee	high	NA	1			high
02M/04/190410	known	110	105-115	unknown	stossed		top slope	1			high
02M/04/190420	known	30	25-35	known	stoss and lee	high	NA	1			high
02M/04/190421	unknown	90	85-95	unknown			top surface	1			high
02M/04/190426	known	70		known	stoss and lee	high	NA	1			high
02M/04/190437	known	20		known	stoss and lee	high	NA	1			high
02M/04/190442	unknown	105	100-110	unknown		high	top slope	1			high
02M/04/190444	unknown	105		unknown		medium	side slope	1			high
02M/04/190445	known	35		known	stoss and lee	high	NA	1			high
02M/04/190446	known	35		known	stoss and lee	high	NA	1			high
02M/04/190448	unknown	80		unknown		high	top slope	1			high
02M/04/190448	known	80		known	stoss and lee	high	NA	1			high
02M/04/190449	unknown	80	75-85	unknown		high	top	1			high
02M/04/190450	unknown	75		unknown		medium	top side	1			medium
02M/04/190451	unknown	30		unknown		medium	top surface	1			high
02M/04/190451	known	35		known	stoss and lee	high	top	1			high
02M/04/190452	known	10		known	stoss and lee	high	top	1			high

inating in the Long Range Mountains to the south. This interpretation is not in agreement with the regional flow model of Shaw *et al.* (2006) and Putt *et al.* (2010), whose findings were based primarily on regional ice-flow models created for all of Atlantic Canada and the GNP, respectively. The conclusions reached here are based almost entirely on ice-flow measurements taken within the St. Julien's map area.

This earlier northeast advance of glaciers originating in the Long Range Mountains was followed by the advance of the LIS, in a southeast direction. Consequently, the LIS coalesced with the glaciers originating in the Long Range Mountains, resulting in the deflection of flow to the east-southeast, followed by a southeast flow out into the ocean. These two movements are in agreement with Grant (1992) who also proposed the east flow to be earlier than the southeast flow.

IMPLICATIONS FOR MINERAL EXPLORATION

The lack of suitable till, probably a consequence of much of the study area lying below the marine limit, presents the main limitation to using till geochemistry and mineralogy as aids to mineral exploration. Further, marine limits need to be better constrained in the region by airphoto interpretation of features such as paleoshorelines, deltas, wave-cut notches and tombolos, which are indicative of water levels post deglaciation.

FUTURE WORK

A 1:50 000-scale surficial geology map will incorporate mapping completed during 2018 and 2019 field seasons. The analytical results of the till sampling as well as surficial and ice-flow maps will be released as an Open File report in 2020.

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