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QUATERNARY INVESTIGATIONS OF THE TOPSAILS, NORTH-CENTRAL NEWFOUNDLAND

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ABSTRACT

The 2015 field season was the continuation of a multi-year till-geochemical and regional geological mapping program initiated in 2013. Quaternary investigations focused on till-geochemical sampling, ice-flow, and surficial mapping of the Topsails (NTS map areas 12H/02, 12H/03 and 12A/14) in north-central Newfoundland. Regional till (glacial diamicton) sampling was conducted at a spacing of 1 sample per 1 km^2, along forest-resource roads. In remote areas, where helicopter support was required, the sample density was 1 sample per 4 km^2.

Eleven new striae sites indicate three ice-flow orientations: east–west, north-northwest and west. These orientations support previous interpretations of a radial ice-flow model for the Topsails. Crosscutting striae were not observed on any bedrock surfaces; thus, chronological differentiation of ice-flow events could not be refined.

Most of the study area is covered by varying amounts of glacial till (diamicton), which forms thick plains and blankets, along with hummocky moraine, in NTS map areas 12H/02 and 03. Recessional–ablation till ridges are located in the Chain Lakes valley, and document ice retreat toward the southwest. Thin till veneers, blankets and eroded till, where meltwater channels have cut into the till, dominate the western part of the study area (NTS 12A/14). Glaciofluvial sand and gravel deposits are located in Kitty's Brook valley, at the south end of Goose Pond, on the south side of Grand Lake and in the valleys draining the west side of the study area .

INTRODUCTION

Quaternary fieldwork on the Topsails and highlands west of Hinds Lake, collectively known as 'the Topsails' in this report, in north-central Newfoundland was conducted during the 2015 field season as part of a multi-year program. Initiated in 2013, the purpose of the program is to provide surficial mapping, ice-flow history, and till-geochemical coverage for the Island of Newfoundland. The purpose of this fieldwork was twofold: to contribute additional data to the provincial surficial and till-geochemical databases, and to stimulate mineral exploration activity in the study area. The results from this field season will complement data collected from similar projects in the surrounding areas: Sheffield Lake–Springdale (Organ, 2014a), Buchans–Roberts Arm Belt (Liverman *et al.*, 1996), Red Indian Lake (Smith, 2009, 2010; Smith *et al.*, 2009; Organ, 2014b) and Hodges Hill (Liverman *et al.*, 2000).

LOCATION, ACCESS AND PHYSIOGRAPHY

Fieldwork was conducted over an area of 2500 km^2, encompassing three, 1:50 000-scale NTS map areas: the Topsails (NTS map area 12H/02) and Rainy Lake (NTS 12A/14), and the area southeast of Grand Lake (NTS 12H/03; Figure 1).

From the Trans-Canada Highway, access to the Topsails *via* the T'Railway (old railway bed) is gained either *via* Route 401 to Howley, or by travelling south on the Buchans Highway (Route 370) and turning right at kilometre 14 and continuing on the forest-resource road to Millertown Junction. In the southeastern part of NTS map area 12H/03, access is restricted to a small portion of the T'Railway and a number of forest-resource roads that also provide access to NTS 12A/14. Access by ATV and truck is limited within the overall study area; as a result, most of it was reached by helicopter.

The Topsails (NTS 12H/02) is a plateau comprising locally derived, thick glacial diamicton blankets and hummocky terrain, interspersed by bogs (Plate 1) that range between 450 and 500 m above sea level (asl). Three bedrock tors, known as the Gaff, Main and Mizzen Topsails, rise up to 120 m above the plateau. The southwestern corner of NTS 12H/02 is called the 'Hinds Plains'; exposed bedrock is

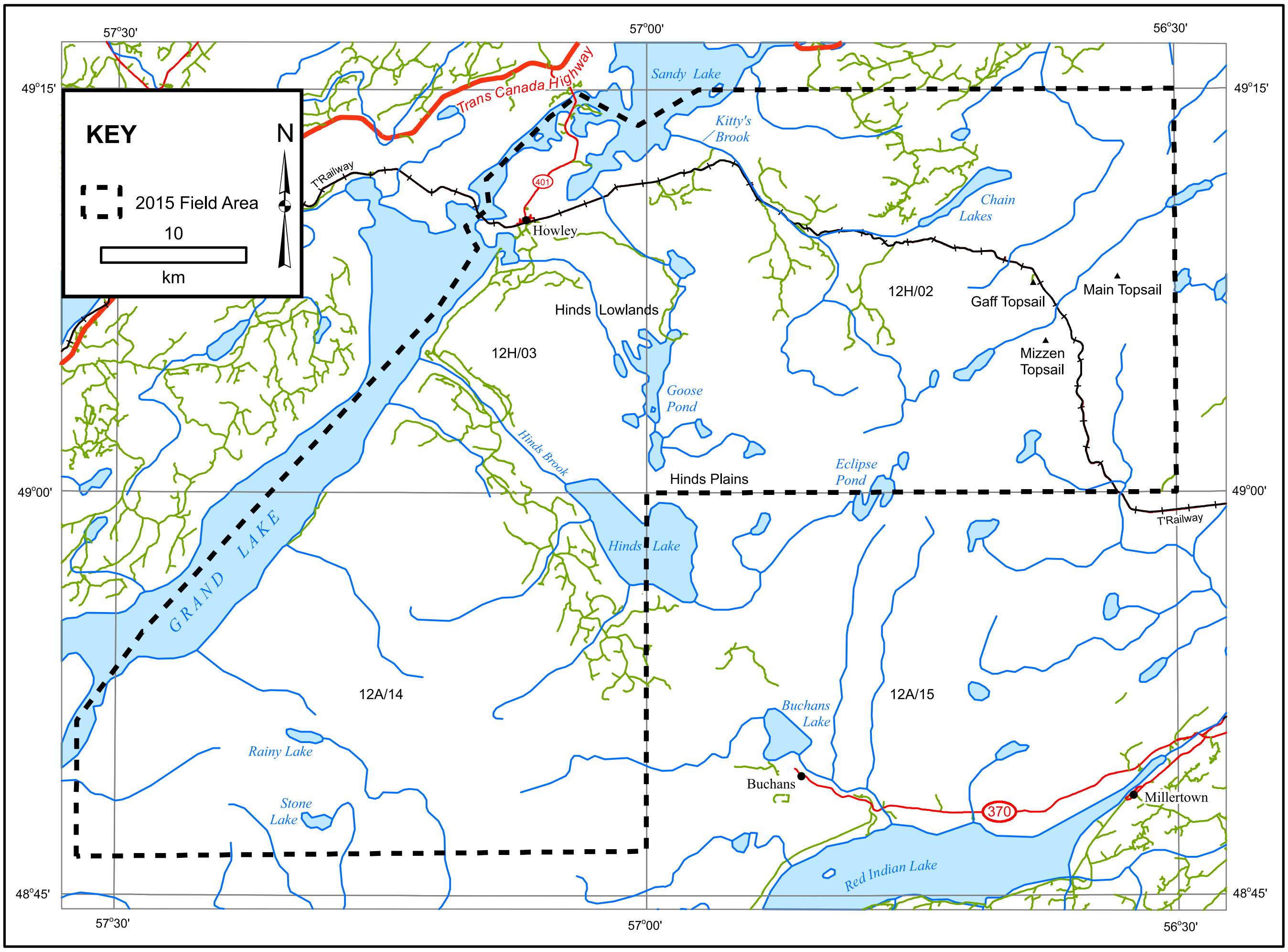


Figure 1. *Location of study area and place names. The extent of the study area is indicated by the black dashed polygon. The green lines show the location of forestry-resource roads. Route 401 is the secondary road to the community of Howley.*

Plate 1. *Looking north toward the Gaff Topsail in NTS map area 12H/02. Till forms blankets and plain deposits, interspersed with bogs.*

more prevalent than in the rest of the map area, and is the highest elevation of the three map areas (666 m asl). The Hinds Lowlands consists of bogs, have an average elevation of 310 m asl, and are situated northwest of Hinds Lake (Figure 1; Plate 2). The western edge of the Topsails, southwest of the Hinds Lowlands, rises to an elevation of 652 m asl (Plate 3). Bedrock exposures are the most prevalent in NTS 12A/14.

BEDROCK GEOLOGY AND MINERAL RESOURCES

The study area lies within the Notre Dame Subzone of the Dunnage Zone of the Newfoundland Appalachians (Figure 2). The Dunnage Zone represents the remnants of the opening and closing of the Iapetus Ocean; it includes volcanic and sedimentary rocks formed in back-arc and island-arc environments, and post-accretion sedimentary deposition during the Silurian and Devonian (O'Reilly *et al.*, 2010). Two groups of predominately granitoid rocks underlie the Topsails. Ordovician gneissic granodiorite, tonalite

Plate 2. *Looking south over the Hinds Lowlands. Bogs are interspersed with glacial diamicton.*

Plate 3. *Looking northwest over the western part of the Topsails, where exposed bedrock and till veneer are common.*

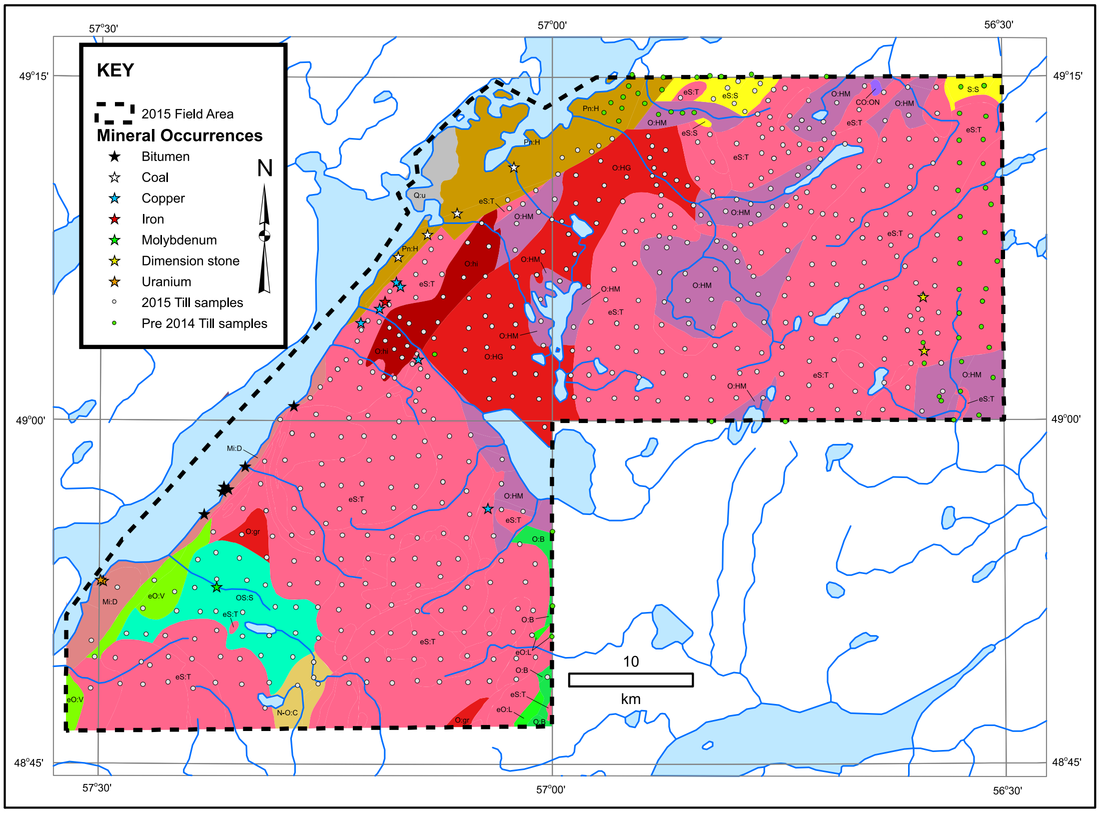
and, minor gabbro make up an older suite of rocks that occur on the western and eastern flanks of the plateau (Taylor *et al*., 1980); these are intruded by the Silurian (~429 Ma), Topsails Intrusive Suite consisting of metaluminous and peralkaline granites. The Hinds Lowlands are underlain by pink, K-feldspar porphyritic Hinds Brook Granite (Whalen and Currie, 1988; Geological Survey of Newfoundland and Labrador, 2015a). The western part of the Topsails, west of Hinds Lake, are made up of Silurian (429 Ma) volcanic rocks of the Springdale Group, and Ordovician intrusive rocks of the Rainy Lake Complex (438 Ma), intruded by rocks of the Topsails Intrusive Suite (Whalen and Currie, 1988). Carboniferous clastic sedimentary rocks skirt the south edge of Grand Lake and are more abundant on the south shore of Sandy Lake (Whalen and Currie, 1988).

The first exploitation of resources was for dimension stone during the construction of the Newfoundland Railway in 1898. Several granite quarries were in operation during this time and the granite used for the construction of bridge abutments (for the railway), and for building the Railway Station in St. John's (Martin, 1983). Following completion of the railway, these quarries remained inactive for most of the 19th century up until the closure of the Newfoundland Railway in the late 1980s (Kerr, 1994). Increased demand for dimension stone, and improved access to the area, led to staking and exploration, and the opening of the Summit Quarry by Classic Stone Inc. (Kerr, 1994). In 2007, Altius Minerals Inc. and JNR Resources staked a large portion of the study area to investigate its potential for volcanic-hosted uranium (O'Reilly *et al.*, 2010). In addition to uranium, the goals of subsequent industrial field seasons included the following up of additional indications of copper and molybdenum mineralization (O'Reilly *et al.*, 2010). Currently there are known showings and indications of bitumen (total 6), copper (5), uranium (2), iron (1), molybdenum (1) and coal (1), most of which are located in NTS map areas 12H/03 and 12A/14 (Geological Survey of Newfoundland and Labrador, 2015b; Figure 2).

QUATERNARY HISTORY

The Newfoundland Ice Cap extended out to the continental shelf during the late Wisconsinan glacial maximum (Grant, 1989; Shaw *et al.*, 2006). Approximately 13 000 years before present (BP), deglaciation became terrestrially based and the deglacial configuration became irregular and time-transgressive because of ice thickness and topography (Shaw *et al.*, 2006). At 12 000 years BP, ice remained over the Topsails (Shaw *et al.*, 2006; Figure 3). As ice continued to retreat, it disintegrated into a number of small isolated ice caps (Grant, 1974), whose model proposes that parts of the Topsails were ice-free, and that ice remained over Hinds Lake and the southern part of the study area, with the centre over Red Indian Lake. Batterson (2003) indicated that late-stage ice remained in the higher elevations on the Topsails during deglaciation on either side of Hinds Lake. Smith (2012) also suggested that late-stage ice caps were located in the high elevations west of Buchans, and north and southwest of Red Indian Lake (Figure 4).

Impounded water from the retreating Newfoundland Ice Cap formed a long, narrow glacial lake, named glacial Lake Howley, at the present-day location of Grand Lake (Batterson and Catto, 2001; Batterson, 2003). The elevation of an outlet at the southwestern end of glacial Lake Howley controlled the water level, while the opening of topographically lower outlets, as the ice retreated to the northeast, controlled subsequent lowering of the water level of the glacial lake. The lake emptied about 12 300 years BP, based on the elevation of deltas and dating of shells at the head of Deer Lake (Batterson, 2003). Evidence of melting ice and standing water is found along the south shore of Grand Lake, in the form of thick glaciofluvial sediments deposited in a glaciolacustrine environment (Batterson, 2000).



Legend

Post-Ordovician Units (Overlap Sequences)

Pleistocene

Q:u	**Surficial deposits:** Unconsolidated sediments

Pennsylvanian

Pn:H	**Howley Formation:** Grey to red sandstone, pebble-cobble conglomerate and siltstone

Mississippian

Mi:D	**Deer Lake Group:** Red and grey conglomerate, sandstone, siltstone and mudstone; grey calcareous dolostone and dolomitic limestone

Early to Late Silurian

S:S	**Springdale Group:** Mafic flows and pyroclastic rocks; red sandstone, conglomerate and shale

Post-Ordovician Units (Intrusive Rocks)

Early Silurian

eS:T	**Topsails Igneous Suite:** Granite, granodiorite, syenite and gabbro
eS:S	**Sheffield Lake Complex:** Variably welded, fine-grained ash-flow tuffs

Late Ordovician to Early Silurian

OS:S	**Southern Long Range mafic intrusions:** Mafic plutons, layered gabbro, hornblende gabbro, lecogabbro, diorite, quartz diorite, and minor granodiorite

Iapetus Ocean
(Dunnage Zone (Notre Dame Subzone))

Middle to Late Ordovician

O:gr	Massive to moderately foliated granodiorite and minor tonalite

Early to Late Ordovician

O:hi	Pink, fine-to medium-grained, biotite+/- muscovite granite and aplite
O:HG	**Hinds Brook Granite:** White to pink, medium- to coarse-grained, biotite-amphibole K-feldspar-porphyritic two-feldspar granite

Early to Middle Ordovician

O:B	**Buchans Group:** Mafic, intermediate and felsic submarine flows and pyroclastic rocks
O:HM	**Hungry Mountain Complex:** Tonalite, granodiorite, diorite, gabbro, amphibolite

Early Ordovician

eO:L	**Star Lake ophiolite complex:** Local pods and dykes of pegmatitic hornblende diorite and fine-grained hornblende plagiogranite (tonalite) in diabase dyke complexes
eO:V	**Glover Formation:** Mafic and silicic volcanic rock and high level intrusions with minor volcaniclastic sedimentary rock

Late Cambrian to Early Ordovician

CO:ON	**Unnamed ophiolite (Notre Dame Subzone):** Ultramafic rocks, gabbro, trondhjemite, diabase, volcanic and sedimentary rocks

Neoproterozoic to Early Ordovician

N-O:C	**Caribou Lake gneiss complex:** Biotite-muscovite, migmatitic paragneiss and granodioritic to quartz monzonitic orthogneiss

Figure 2. *Bedrock geology of the study area (Geological Survey of Newfoundland and Labrador, 2015a). Samples collected during the 2015 field season are shown as white dots, and those collected prior to 2015 are shown as green dots (Organ, 2014a). The locations of mineral showings and indications are identified by stars (Geological Survey of Newfoundland and Labrador, 2015b).*

Figure 3. *Pattern of deglaciation on the Island of Newfoundland at 12 000 years BP; blue dashed lines show location of ice divides (Shaw* et al.*, 2006). Black box shows location of study area.*

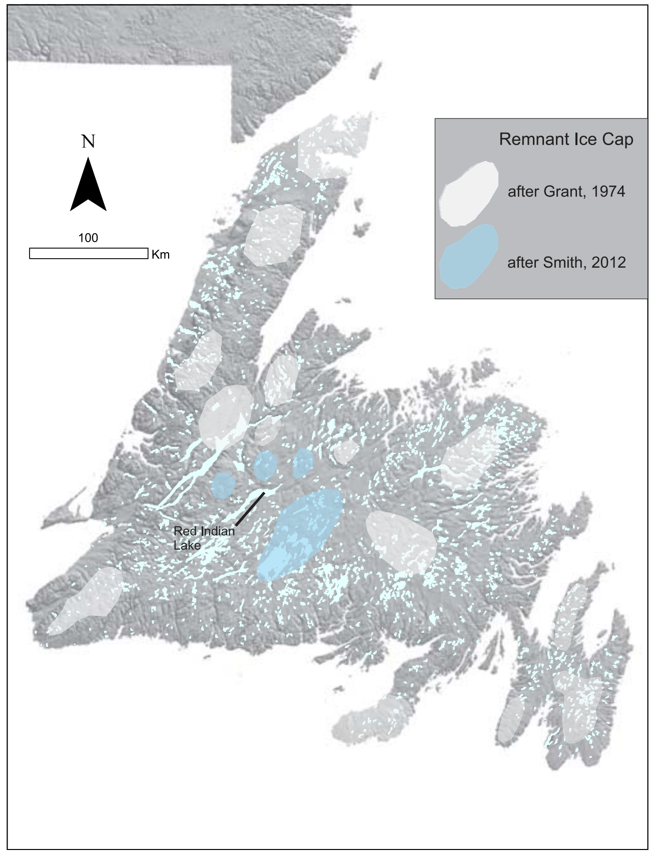


Figure 4. *Map of Newfoundland showing the approximate location of remnant ice caps as proposed by Grant (1974) as the Newfoundland Ice Cap disintegrated. Only those in central Newfoundland, coloured blue, have been modified by Smith (2012).*

Prest *et al.* (1967) first mapped large boulder ridges within the valleys of Kitty's Brook and the Chain Lakes. These ridges, trending southeast to northwest in Chain Lakes, and south to north in Kitty's Brook, are up to 1.6 km in length, 9–12 m high and with crests 90–300 m apart and are interpreted as ribbed moraines. During more detailed work involving textural and fabric analyses, Tucker (1974) concluded that the ridges were composed of till, and thus they were interpreted as recessional–ablation moraine deposited during a topographically controlled ice-flow retreat from the valleys onto the Topsails. He also described a small outwash deposit on the north side of Kitty's Brook, that contained both foreset and topset bedding and interpreted as a small delta formed between the till ridges.

ICE-FLOW HISTORY

Striae indicate that ice flow was radial from an ice-dispersal centre on the Topsails (Taylor and Vatcher, 1993; Batterson, 2003). The flow directions are shown on Figure 5 and have been documented by Vanderveer and Sparkes (1982; southwesterly), Taylor and Vatcher (1993; northerly), Klassen (1994; northwesterly), Batterson (2003; northwesterly and westerly), McCuaig *et al.* (2006; westerly), Smith (2009; southerly), Smith (2010; northeasterly) and Organ (2014a; northeasterly). The relationship between the ice flows remains largely unknown, as only one age relationship has been observed: a northwesterly flow followed by a southwesterly flow in Hinds Brook, documented by Batterson (2003) on the Topsails. Batterson (2003) consequently suggested that an ice-dispersal centre was located on the Topsails with an ice divide along the southwest margin of the Topsails, south of Hinds Lake, producing southeasterly and northwesterly flow. However, the relative timing of the radial flow, ice divide and relationships between the flows remain unresolved.

SAMPLING METHODS AND ANALYSIS

The till-geochemical sampling was completed in NTS map area 12H/02, and parts of NTS 12H/03 and 12A/14 (Figure 2). Approximately 1 kg of till was collected, and placed in a Kraft paper bag, from the C- or BC-soil horizons of 389 hand-dug pits (average sample depth, 54 cm), 48 ditches (average sample depth, 77 cm), 23 mudboils (average sample depth, 42 cm), 4 river sections (average sample depth, 88 cm) and 79 roadcuts (average sample depth, 85 cm). Sample spacing was determined by access along exist-

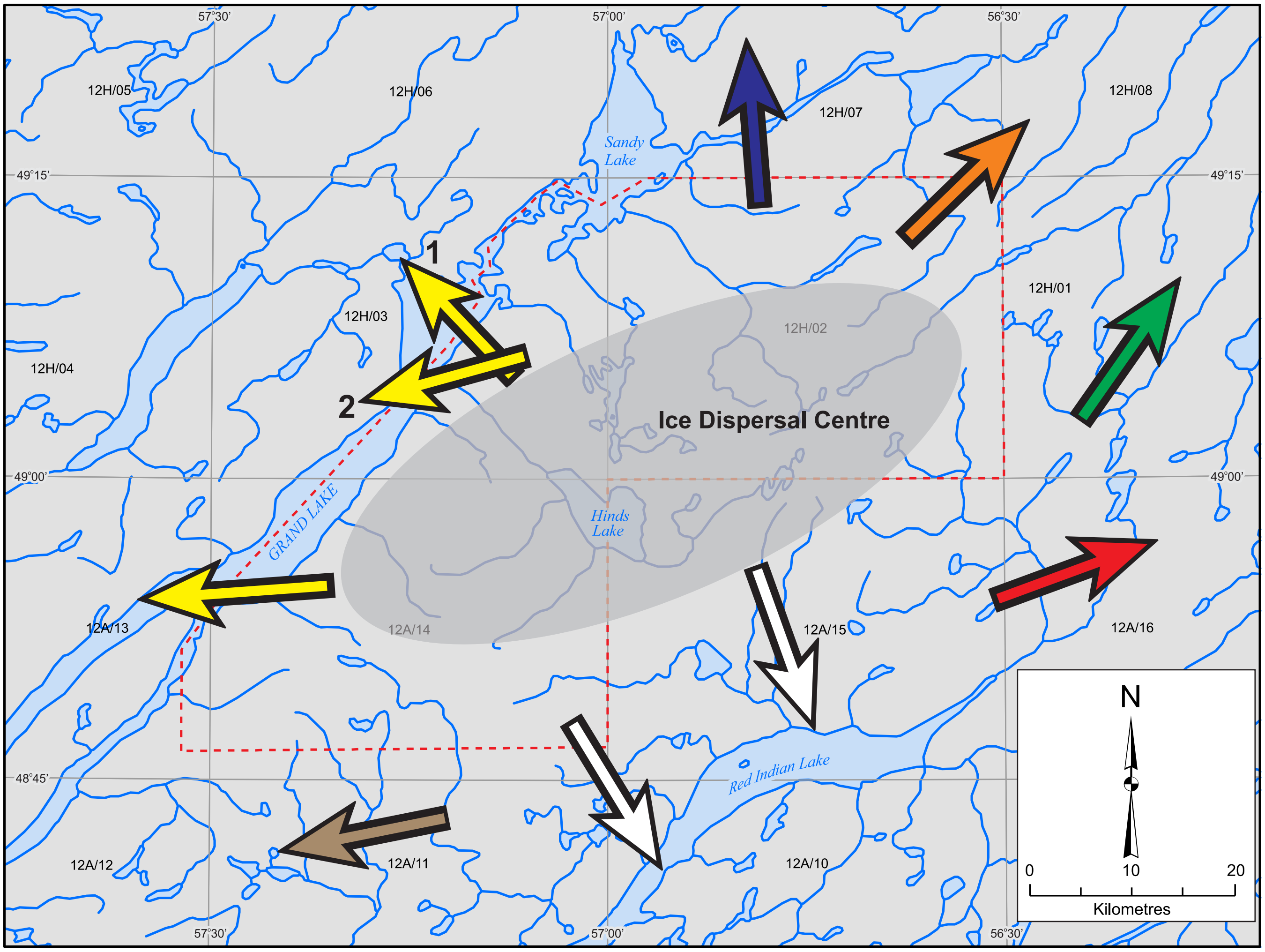


Figure 5. *Regional ice-flow patterns identified within the study area from previous reports; Vanderveer and Sparkes (1982; brown arrow), Taylor and Vatcher (1993; dark blue arrow), Batterson (2003; yellow arrows), Smith (2009; white arrows), Smith (2010; red arrow), Smith (2012; green arrow) and Organ (2014a; orange arrow). The only age relationship known is that a northwesterly flow (1) is postdated by a west-southwesterly flow (2).*

ing roadways and the availability of the appropriate sampling medium. Along forest-resource roads, sample density was one sample every 1 km^2 and in remote areas, only accessible *via* helicopter, the sampling density decreased to one sample per 4 km^2. Duplicate samples were collected at a frequency of 1 in 10 to estimate the natural inhomogeneity of the sample medium.

A total of 543 samples were submitted to the Geochemical Laboratory of the GSNL for analysis by ICP-OES and ICP-MS. Samples will be sent to an external laboratory to analyze for gold, and other elements, by INAA. Data release is in 2016.

RESULTS

ICE-FLOW HISTORY

Eleven new, single ice-flow indicators were measured, and nine striae were identified in NTS map area 12A/14, where bedrock was more prevalent, whereas the remaining two were located in NTS 12H/02 and 12H/03 (Figure 6).

Three main ice-flow directions are recorded: an east–west orientation in the southwest corner of NTS map area 12H/02; a north-northwest flow on the west side of Hinds Lake (NTS 12A/14) and a westerly flow south of Rainy Lake (NTS 12A/14). No multidirectional sites or age relationships were identified.

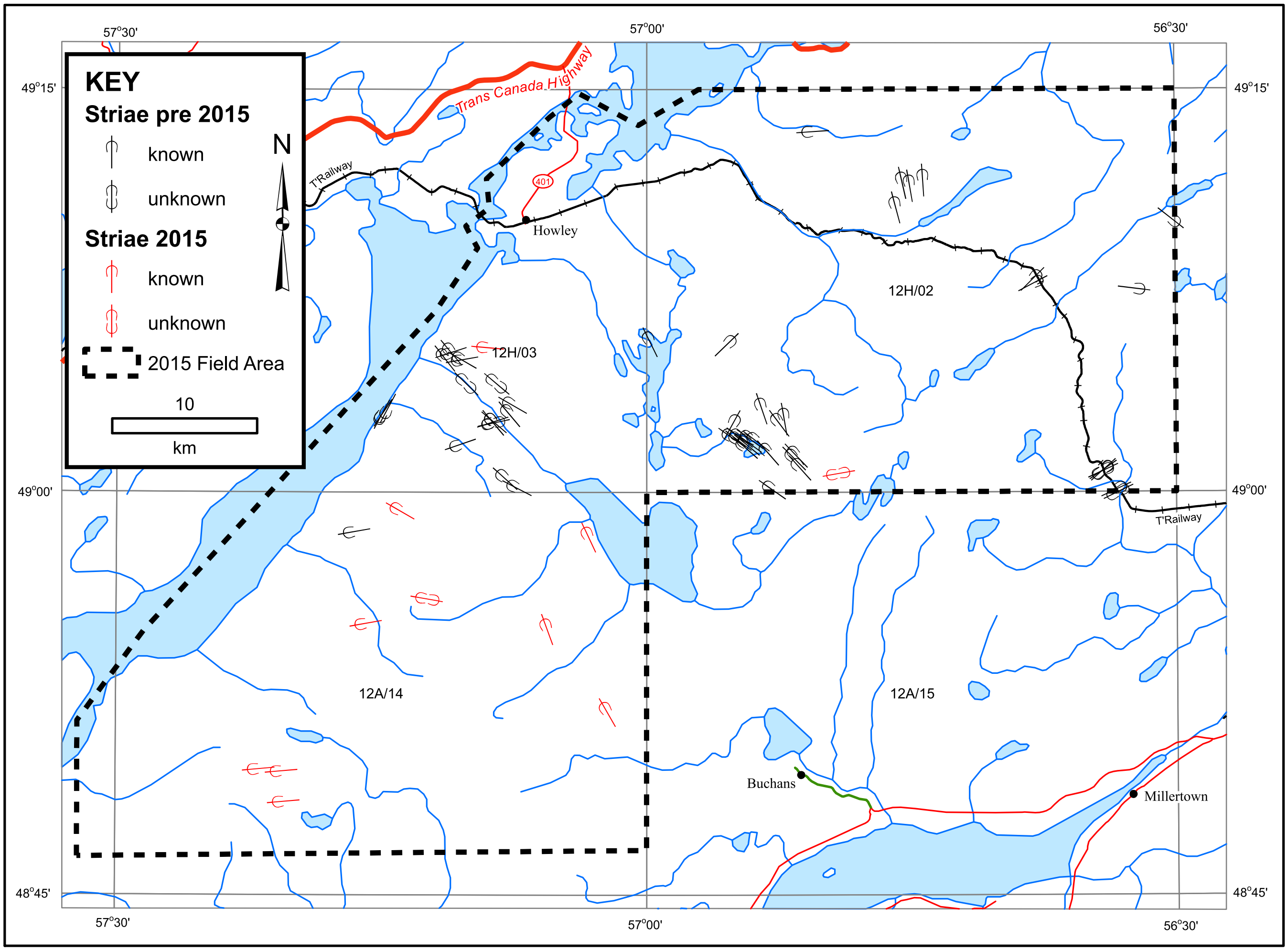


Figure 6. *Locations and orientations of new striae, shown in red, identified during 2015 fieldwork.*

The striae recorded generally support earlier ice-flow patterns recorded and described by Batterson (2003), McCuaig *et al.* (2006) and Smith (2009). The ice-flow chronology could not be refined further because of a lack of multidirectional striae sites and relative age relationships.

SURFICIAL GEOLOGY

Most of the study area is covered by glacial diamicton (till), deposited under the influence of ice and interspersed with bogs. Glaciofluvial sands and gravels, deposited under the influence of flowing water, are located in Kitty's Brook valley, the south end of Goose Pond, the south side of Grand Lake and in the valleys draining the western part of the Topsails. Using aerial photography and ground-checked data, from 546 sites, a map of surficial geology and landforms will be produced at a scale of 1:50 000.

Diamicton Deposits

The morphology and thickness of glacial diamicton are variable. In the east of the study area, in most of NTS map area 12H/02, blanket, plain and hummocky terrain, interspersed with bog, mask the underlying bedrock. Thin veneers of diamicton, associated with concealed and exposed bedrock, are located in the southwestern and northwestern parts of NTS 12H/02, and throughout NTS 12A/14. Northwest–southeast-trending ridges of diamicton are located in the Chain Lakes area in the northern half of NTS 12H/02. Eroded diamicton is characterized by being devoid of fines, and meltwater channels have been carved into thick diamicton north of Hinds Lake and on the western half of NTS 12A/14.

Only one stratigraphically continuous unit of glacial diamicton was identified. The diamicton is typically matrix-supported, and ranges from a matrix of silty very fine- to fine-grained sand to one of fine- to medium-grained sand with little silt (Plate 4). The matrix of the diamicton in NTS map area 12H/02 is often very compact, and has a relatively low (20%) clast percentage and an average clast size of 3

Plate 4. *Till plain with granitic boulders on the surface. Inset shows a typical glacial diamicton within a hand-dug test pit.*

cm. Striated clasts were observed in only 17% of sites, and faceted clasts in 9% of the 546 sites visited. Clasts on the surface range from pebble- to boulder-sized (up to 350 cm). The angularity of the clasts ranges from very angular to subrounded, but is typically subangular. The composition of the clasts reflects that of the local underlying granitic bedrock, and their size and angularity suggest they have only been transported short distances. Blankets and plains containing this diamicton are common on the Topsails, whereas thinner veneers of diamicton are prevalent west of Hinds Lake. Northwest–southeast-trending diamicton ridges are located along Chain Lakes; their orientation changes to north–south along the southern end of Chain Lake. These are flat-topped, and are up to 2.6 km long and 500 m wide (Plate 5). Tucker (1974) provides detailed descriptions of the till ridges.

The characteristics described above (*i.e.*, compactness, striae on clasts, angular clasts and preferentially oriented landforms) indicate that the diamicton was formed by actively retreating ice, and thus is interpreted as till.

Hummocky terrain is common both southeast and northeast of Chain Lakes (Plate 6). In areas of hummocky terrain, the matrix is often sandier than that of the diamicton described above, with fine- to medium-grained sand and little silt. The surface of the hummocks shows a high concentration of angular–subangular cobbles and boulders that have diameters in excess of 200 cm. The sandiness of the matrix material (winnowing of fines from melting glacial water) and the high concentration of large, angular fragments in the upper confines of this unit (resulting from disintegration of ice and subsequent transport of ice-marginal material) suggest that it formed by stagnating ice under a passive margin. Thus, the unit is interpreted to be a recessional–ablation till. Similar areas of stagnating ice are to the east and northeast of Sheffield Lake (Organ, 2014a) and to the south in the Meelpaeg Lake area (Smith, 2010). This is

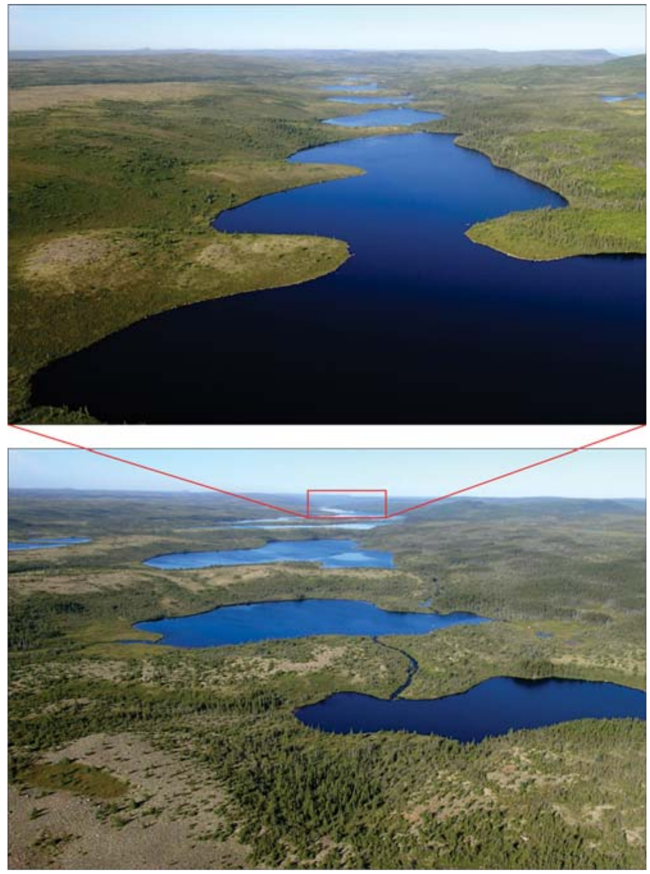


Plate 5. *The lower picture shows northeast extent of Chain Lakes looking southwest at flat-topped till ridges. The inset shown shows till ridges at the southwest extent of Chain Lakes.*

Plate 6. *Boulder-covered hummocky terrain to the east of the Gaff Topsail.*

consistent with Grant's (1974) proposed remnant ice cap over the Sheffield Lake area.

Areas where the upper surface of the till has been modified, or cut into, are mapped as eroded till. In some areas, the upper 50 cm of material is washed and is devoid of silt and very fine-grained sand. Areas of eroded till are often associated with large meltwater channels (Plate 7) or local armouring of the surface with boulders (Plate 8). The channels are up to 10 km long, 250 m wide and 10 m deep and carved by meltwater produced during the late stages of deglaciation. Batterson (2003) interprets these channels as ice-marginal or proglacial, depending on the orientation of the channel with respect to the slope. The armouring boulders are the result of meltwater winnowing of fines during unchannellized, meltwater sheet flow (Benn and Evans, 1998).

Overall, the diamictons described are much sandier than those described by Smith (2010) to the south, and those to the east described by Organ (2014a). The sandy nature of their matrix is related to underlying granitic bedrock and its mode of erosion, as well as the short transportation distance (Batterson, 2003).

Glaciofluvial Deposits

Glaciofluvial sands and gravel are located along Kitty's Brook, on the west side of Goose Pond, on the south shore of Grand Lake and in the bottoms of waterways draining the western part of the Topsails. These deposits consist of moderately sorted medium- to coarse-grained sand, and poorly sorted pebble to cobble gravels (Plate 9). These characteristics are consistent with deposition in meltwater streams that have variable discharge rates. Glaciofluvial sediments range from thin veneers (<1 m) overlying glacial diamicton, to accumulations tens of metres thick near Howley.

In NTS map area 12H/03, Batterson (2000) identified thick accumulations of glaciofluvial material below 170 m asl and interpreted these sediments as having been carried by glacial meltwater from the retreating ice front, and subsequently deposited in glacial Lake Howley. Tucker (1974) identified foreset and topset bedding on the north side of Kitty's Brook, and interpreted the deposit as a small delta. At the time of Tucker's description, the deposit was being exploited in a borrow pit; the author was unable to locate the pit during the 2015 field season.

Organic Deposits

Organic deposits (bogs) are found throughout the study area and are most prevalent on the Topsails and Hinds Lake Lowlands, where they are interspersed with till deposits

Plate 7. *Meltwater channels in NTS map area 12A/14. Lateral channels drained water from right to left, whereas the channel on the right is perpendicular to the slope and drained downslope (toward the bottom).*

Plate 8. *Armoured boulder surface in the southern part of NTS map area 12A/14.*

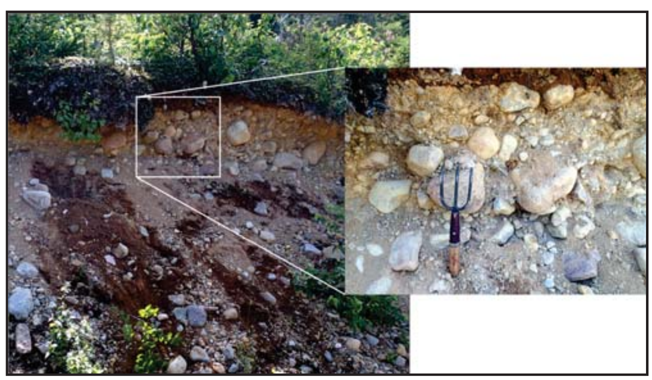


Plate 9. *Pebble to cobble gravels on the south side of Kitty's Brook.*

(Plates 1 and 2). Typically, the deposits are less than a metre thick; however, thicker deposits are present locally.

GLACIAL RETREAT

Field investigations suggest the pattern of retreat on the Topsails is radial, and late-stage remnant ice remaining on the higher elevations east and west of Hinds Lake until sometime after 12 600 years BP (Batterson, 2003). This is indicated by the location and morphology of glacial till, and the presence of glaciofluvial sediment and meltwater channels, and is consistent with retreat patterns observed in previous research in the Grand Lake area (Batterson, 2003), the Red Indian Lake Basin (Smith, 2012), the Chain Lakes (Tucker, 1974), and the Buchans area (Klassen, 1994). The boulder-rich hummocky terrain to the southeast of Chain Lakes suggests that ice stagnated on the Topsails. In the Buchans area, Klassen (1994) and Batterson (2003) indicated that retreat was to the east and west of Buchans and Hinds Lake. The exact location of remnant ice on the highlands on either side of Hinds Lake has not been refined and will be the focus of airphoto mapping. No radiocarbon dates are available for the study area, but deglaciation probably occurred sometime after the opening of the Grand Lake basin, and the formation glacial Lake Howley, after 12 600 years BP (Batterson, 2003).

FUTURE WORK

Further work is required to fully understand the ice-flow history and retreat patterns in the Topsails and will involve:

- The completion of 1:50 000-scale mapping of NTS map areas 12H/02 and 12A/14 to refine the locations of stagnating or remnant ice;
- Detailed ice-flow mapping in the southern portion of NTS 12A/14, and southwestern portion of 12H/02, where bedrock is more prevalent;
- Cosmogenic nuclide dating of boulders to provide minimum age estimates for deglaciation on the Topsails;
- Till sampling and mapping of south of Stoney Lake and south of the current study area (the north part of Star Lake, NTS 12A/11).

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