Current Research (2019) Newfoundland and Labrador Department of Natural Resources
Geological Survey, Report 19-1, pages 227-242

QUATERNARY STUDY OF THE PUDDLE POND, STAR LAKE AND RAINY LAKE NTS MAP AREAS (12A/05, 11 AND 14) IN WEST-CENTRAL NEWFOUNDLAND

J.S. Organ and T. Dyke[1]
Terrain Sciences and Geoscience Data Management Section
[1]Department of Earth Sciences, Memorial University of Newfoundland, St. John's, NL, A1B 3X5

ABSTRACT

The 2018 field season continued a till-geochemical and regional surficial geology-mapping program initiated in 2016. Field work focused on till-geochemical sampling, and ice flow and surficial mapping of the southeastern flanks of the Long Range Mountains in west-central Newfoundland. A total of 409 regional-till samples were collected.

Thirty-two new striation sites, record ice-flow directions that range from southwest to west-southwest throughout the study area. In addition a west-northwest flow was recorded from bedrock exposures along Route 480 and in the Southwest Brook valley. This pattern agrees with that of earlier studies, but relative age relationships remaining inconclusive.

Most of the study area is covered by varying amounts of till. It forms blankets, veneers and hummocks in the western part of the study area whereas thick till plains, blankets, eroded till (cut by meltwater channels), hummocks and veneers are found in the northeast. Glaciofluvial outwash (sand and gravel deposits) is present in the Southwest Brook and Lloyds River valleys (NTS map area 12A/05). Eskers are located in the northeast and in Lloyds River valley. Glaciofluvial veneers are associated with meltwater channels in the northeast of the study area.

INTRODUCTION

This paper presents the findings of surficial mapping conducted in 2018 in west-central Newfoundland. The purpose was to map the surficial geology, conduct till-geochemical sampling, and delineate the ice-flow history of this area. The data obtained will assist mineral exploration by delineating prospective areas and clearly determining ice-movement directions. Regional till-geochemical sampling and surficial mapping was completed between Stoney Lake (NTS map area 12A/14) and Star Lake (NTS map area 12A/11); sampling commenced in the Puddle Pond area (NTS map area 12A/05; Figure 1).

The results from this field season complement data collected from similar projects in the surrounding areas; these include Grand Lake (Batterson, 2003; McCuaig *et al.*, 2006), The Topsails (Organ, 2016) and Red Indian Lake (Organ, 2014a; Organ and Amor, 2017; Smith *et al.*, 2009).

LOCATION, ACCESS AND PHYSIOGRAPHY

The northern boundary of the study area is located 13 km south of Grand Lake near Stoney Lake. The study area extends to the southwest to Cormacks Lake (Figure 1). The southern boundary is the western end of Victoria Lake. It covers an area of 2300 km^2, encompassing one full 1:50 000-scale NTS map area (12A/05 – Puddle Pond), as well as parts of NTS map areas 12A/04, 06, 11, 12, 13 and 14 (Figure 1).

From the Trans-Canada Highway (TCH), access to the southwest part of the study area is *via* Route 480 or *via* Route 370 to the forest-resource road that runs along the north shore of Red Indian Lake and continues along the Lloyds River valley. A network of forest-access roads off these main transportation routes provides additional access on NTS map area 12A/05, however, the northeast part of the study area has no road access and was reached by helicopter.

The physiography of the study area is diverse. The study area lies on the southeastern flanks of the Long Range Mountains and is bounded in the south by the northeast–southwest-trending Annieopsquotch Mountains, where elevations are in excess of 400 m and reach a maximum of 678 m asl in the north (east of Indian Lake – NTS map area 12A/12), whereas elevations are typically slightly lower than 400 m asl in the southwest (NTS map area 12A/05;

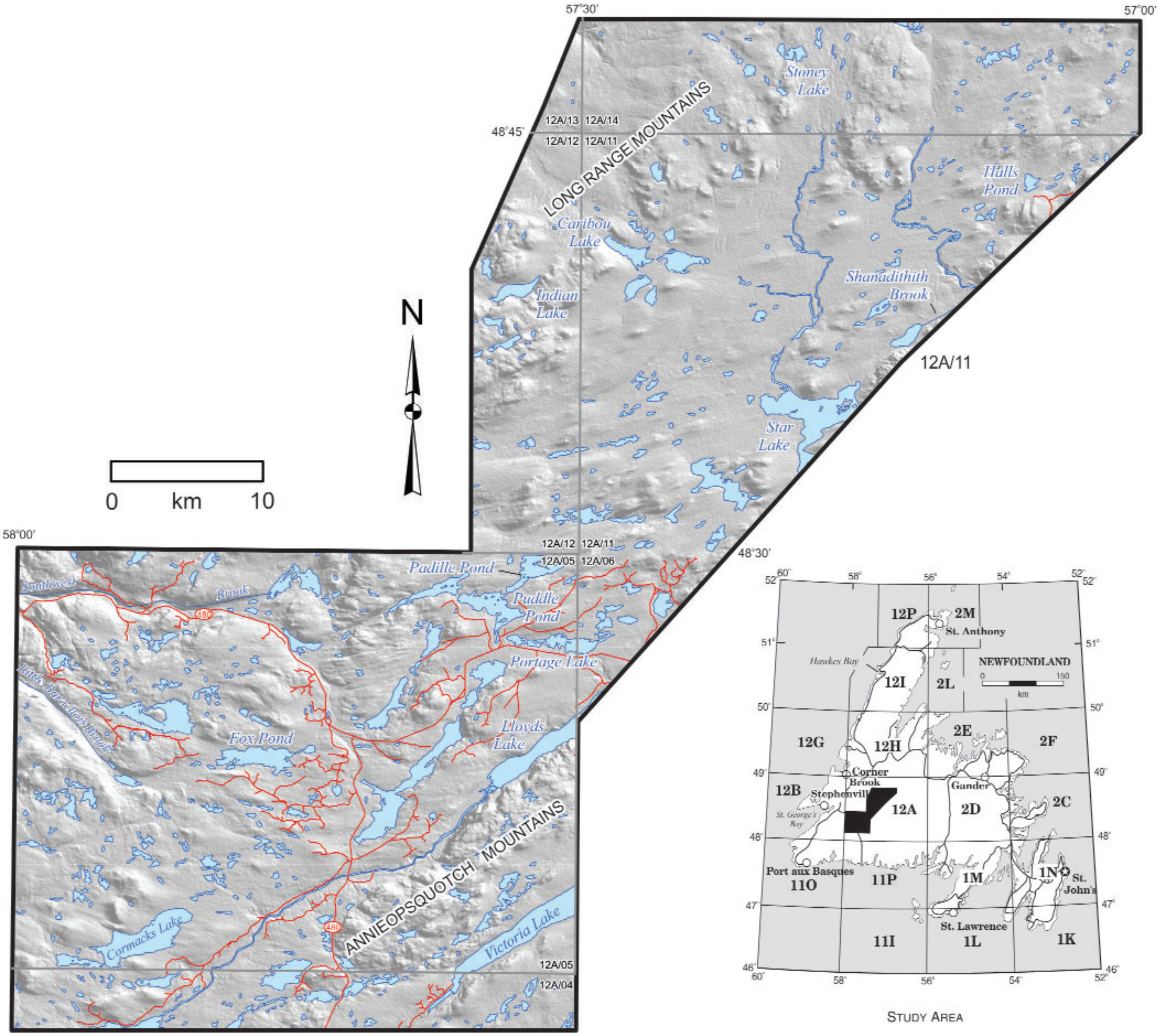

Figure 1. *Map identifying the location of the study area and shows the physiography and place names used in the text. Please note that Fox Pond is an informal name.*

Figure 1). The north part of the study area is open and has stunted spruce, common juniper and low crowberry interspersed with bedrock on exposed hilltops; lower elevations are covered with glacial sediment and patchy stands of spruce (Plate 1). In contrast, the southwest contains thicker glacial sediment and thick spruce forest. Major water bodies include Star Lake, Caribou Lake, Lloyds Lake, Cormacks Lake, and Fox Pond* (* denotes informal name; Figure 1). A drainage divide lies within the study area, separating drainage to the west, into the Gulf of St. Lawrence, and to the northeast, into the Atlantic Ocean. The Lloyds River flows northeast into Red Indian Lake and empties *via* the Exploits River into the Bay of Exploits, whereas Little Barachois Brook and Southwest Brook flow west-northwest into St. George's Bay.

BEDROCK GEOLOGY

Riley (1957) conducted the earliest regional bedrock mapping within the study area at a scale of 1 inch to 4 miles. Regional mapping programs were completed in the Star Lake area (NTS map area 12A/11) by Whalen (1993) and Lissenberg *et al.* (2005); in the Puddle Pond area (NTS map area 12A/05) by Dunning and Herd (1979); van Berkel and

Plate 1. *Looking west across a low-lying valley within the Long Rang Mountains. These areas are commonly characterized by eroded till plains, bogs and glaciofluvial veneers associated with meltwater channels. Hills in the distance rise 150 m above the till plain to an elevation of 640 m above sea level.*

Currie (1988); Pehrsson *et al.* (2003) and van Staal *et al.* (2005a); and in the King George IV Lake area (NTS map area 12A/04) by Kean, (1983); Currie and van Berkel (1992) and van Staal *et al.* (2005b). More detailed work within these areas was completed by Dunning and Chorlton (1985); Pehrsson *et al.* (2003) and Hinchey (2013).

The bedrock of the study area is situated within the Laurentian Notre Dame subzone of the Dunnage Zone of the Newfoundland Appalachians. These mostly Ordovician rocks represent intra-oceanic- and back-arc environments linked to the closing of the Cambro-Ordovician Iapetus Ocean (Szybinski, 1995; Williams, 1995).

The southwestern part of the study area is dominated by the Ordovician Cormacks Lake complex (Unit O:CL, Figure 2); a suite of supracrustal rocks including cordierite gneiss, psammite, metavolcanic rocks, and metagabbro (Pehrsson *et al.*, 2003). The Cormacks Lake complex, together with the felsic-intermediate plutonic rocks of the Southwest Brook Complex (Unit O:SW) underlies most of the Puddle Pond area (NTS map area 12A/05). The geology of the southeastern part of this map area near Victoria Lake includes an ophiolite sequence of the Annieopsquotch Complex (Unit eO:N) that includes mafic pillow lavas, gabbro, including layered mafic cumulates (Dunning and Chorlton, 1985). The Annieopsquotch Complex strikes northeast onto NTS map area 12A/11. This map area contains the Star Lake complex (Unit eO:L), another ophiolite sequence containing coarse- to very coarse-grained layered pyroxenite, gabbro, and pegmatitic diorite (Whalen, 1993). Most of NTS map area 12A/11 is underlain by Silurian and Ordovician granodiorites and peralkaline granites of the Topsails igneous suite (Unit eS:T), the Star Lake intrusive suite (Unit eS:R) and the Lewaseechjeech Brook plutonic suite (Unit mO:L), as well as intermediate to felsic gneisses of the Neoproterozoic to Ordovician Caribou Lakes gneiss complex (Unit N-O:C).

MINERAL RESOURCES

Twenty-seven mineral occurrences are located within the study area; these include pyrite (11), gold (7), copper (3), nickel (3), molybdenum (1), silver (1) and zinc (1) (Table 1; Figure 2; GSNL, 2018b). Occurrences of pyrite, copper and silver appear to follow a northeast–southwest trend in the Victoria Lake area, as well as the nickel occurrences southwest of Puddle Pond. Most of these occurrences are associated with rocks of the Southwest Brook complex, Cormacks Lake complex and Victoria Lake Supergroup. The Whalen's Mo occurrence is associated with rocks of the Topsails igneous suite. These rocks may have the potential for additional mineral discoveries. It should be noted that the rocks of Victoria Lake Supergroup are an important exploration target for VMS deposits, particularly to the northwest, south of Red Indian Lake (Hinchey and McNicoll, 2009).

In Figure 2, three nickel deposits, Smith Ni–Cu showing, the Lucky Moose Ni–Cu showing, and the Portage Lake Ni–Cu occurrence, are spatially associated with rocks of the Southwest Brook complex (Unit O:SW). However, work by van Staal *et al.* (2005a) indicates that the age of the mafic and ultramafic host rocks is *ca.* 432 Ma, slightly younger than that of the surrounding rocks (*ca.* 436 Ma). As a result, the younger mafic and ultramafic rocks have been named the Puddle Pond complex (van Staal *et al.,* 2005a). Details of the mineralization of the Smith Ni–Cu showing, the Lucky Moose Ni–Cu showing, and the Portage Lake Ni–Cu occurrence are documented by Hinchey (Figure 1, 2013). Common to all of these nickel occurrences is the presence of copper as a secondary commodity, and their classification as intrusive mafic-magmatic deposits. The nearby Range copper–cobalt occurrence, although close to the nickel deposits, does not contain nickel mineralization and is hosted within the felsic-intermediate rocks of the Southwest Brook complex.

QUATERNARY HISTORY

During the last glacial maximum (LGM) ~21 Ka, Newfoundland was covered with multiple local ice caps, collectively known as the Newfoundland Ice Cap that extended to the continental shelf edge (Grant, 1989; Shaw *et*

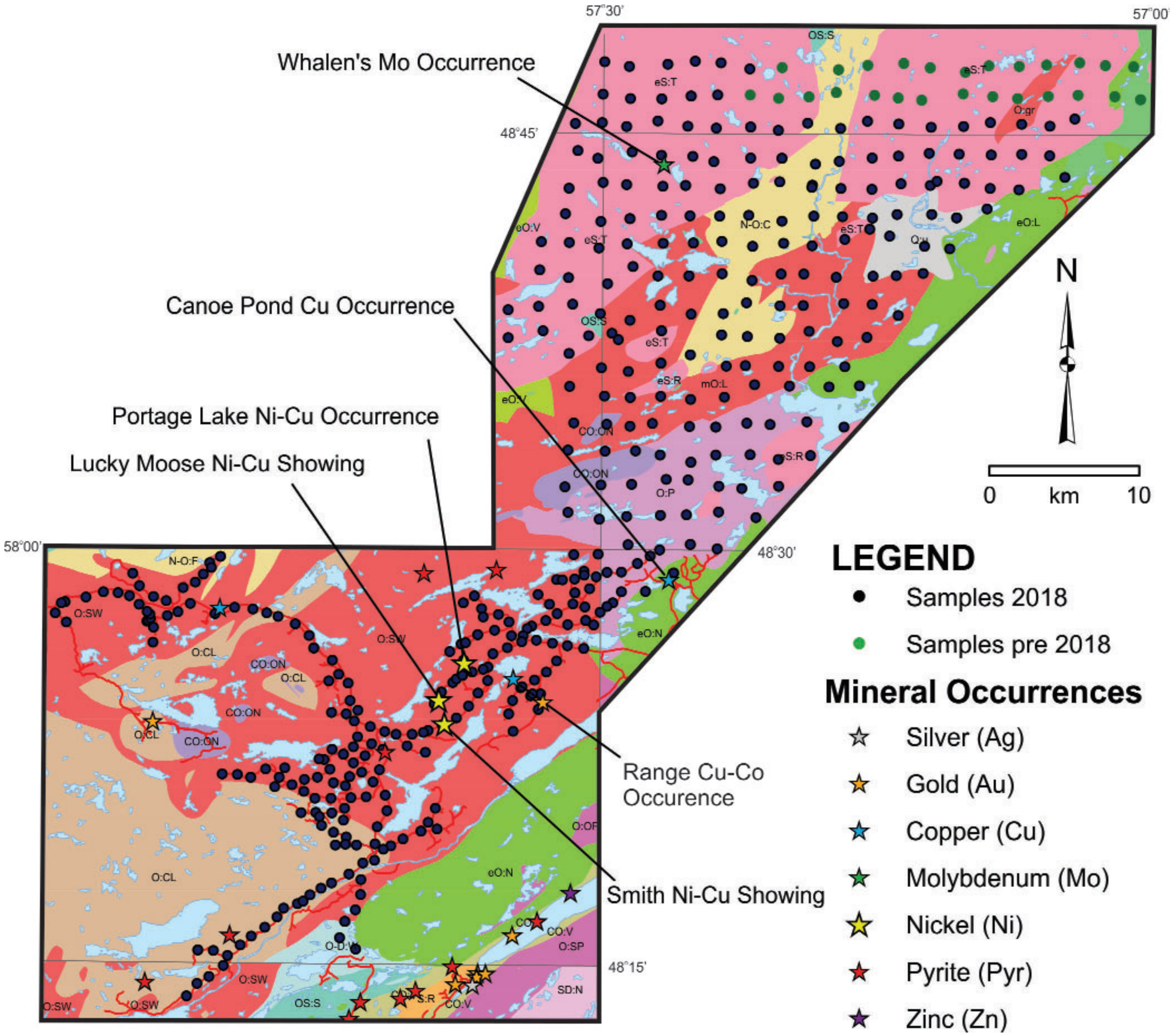

Figure 2. *Bedrock geology of the study area (GNSL, 2018a). Samples collected during the 2018 field season are shown as black dots and those collected prior to 2018 are shown as green dots (Organ, 2016). The locations of mineral occurrences are identified by stars (GNSL, 2018b). Map unit labels accompany map units described in the text.*

al., 2006). Ice divides extended south along the Long Range Mountains through central Newfoundland, and eastward to the Avalon Peninsula. The orientations of these ice divides shifted and changed as deglaciation progressed. Deglaciation became mainly terrestrially based at about 13 Ka, at which time the pattern of retreat became irregular and time-transgressive as a result of varying ice thickness and topographic control (Shaw *et al.*, 2006). Despite being farther inland, the present-day locations of the Inner Humber Arm, and Kippens in St. George's Bay, were ice free 12.6 Ka (Batterson and Sheppard, 2000). Also at this time, in front of a rapidly retreating ice-margin, glacial Lake Howley was formed in the Grand Lake Basin (Batterson, 2003; Shaw *et al.*, 2006). The lake level was controlled by the opening of topographically lower outlets as ice retreated to the northeast. Final drainage of the lake occurred through Junction Brook at about 12.3 Ka, based on the elevation of deltas at the head of Deer Lake (Batterson, 2003). As Grand Lake Basin was deglaciated, the ice margin retreated south into the Long Range Mountains.

South of the Grand Lake Basin, retreat into the interior of central Newfoundland was via Bottom, Southwest and Barachois brooks, with northeastward retreat up the Lloyds

LEGEND

PLEISTOCENE

Q:u	Unconsolidated sediments

LATE SILURIAN TO MIDDLE DEVONIAN

SD:N	Biotite +/- muscovite granodiorite and granite; locally includes biotite -hornblende tonalite

EARLY TO LATE SILURIAN

S:R	Grey, purple, green and red conglomerate

EARLY SILURIAN

eS:	**(R) Star Lake intrusive suite:** Slightly to moderately foliated granite and minor granodiorite intrusions; **(T) Topsails Igneous Suite:** Granite, granodiorite, syenite and gabbro

LATE ORDOVICIAN TO MIDDLE DEVONIAN

O-D:W	Conglomerate, greywacke, siltstone and shale; pebbly sandstone; graphitic shale

LATE ORDOVICIAN TO EARLY SILURIAN

OS:S	Mafic plutons, layered gabbro, hornblende gabbro, lecogabbro, diorite
OS:r	Fine- to medium-grained gabbro intrusive into Ordovician age rocks

MIDDLE TO LATE ORDOVICIAN

O:gr	Moderately foliated granodiorite and minor tonalite
mO:L	**Lewaseechjeech Brook plutonic suite:** biotite-hornblende granodiorite and tonalite

EARLY TO LATE ORDOVICIAN

O:SW	**Southwest Brook complex:** Foliated and massive tonalite, biotite granite, granodiorite, quartz diorite and leucogranite
O:P	Biotite-hornblende granodiorite, and hornblende tonalite, diorite and gabbro
O:in	Biotite granite and granodiorite
O:CL	**Cormacks Lake complex:** Supracrustal rocks consisting of cordierite-gedrite gneiss, psammite, pelite calc-silicate gneiss, and amphibolite

EARLY TO MIDDLE ORDOVICIAN

O:	**(OP):** Weakly foliated, buff to pink, hornblende +/- biotite granodiorite to tonalite; **(SP):** grey, pink or red, biotite granite and granodiorite
O:B	Mafic, intermediate and felsic submarine flows and pyroclastic rocks; volcaniclastic sedimentary rocks
O:HY	Biotite-amphibole subsolvus granodiorite to granite

EARLY ORDOVICIAN

eO:	**(L) Star Lake ophiolite complex:** pegmatitic hornblende diorite and fine-grained hornblende plagiogranite (tonalite) in diabase dyke complexes; **(K) King George IV Lake Complex:** Dark green, mafic pillow lava and minor pillow breccia; intercalated mafic tuffs and green and red chert; **(N) Annieopsquotch complex:** Basaltic pillow lava and minor red chert; sheeted diabase dykes and rare trondhjemite and breccia dykes; **(V):** Mafic and silicic volcanic rock

LATE CAMBRIAN TO EARLY ORDOVICIAN

CO:	**(OF):** Serpentized ultramafic rock; **(ON):** Ultramafic rocks, gabbro, trondhjemite, diabase, volcanic and sedimentary rocks of the ophiolite suite

EARLY CAMBRIAN TO LATE ORDOVICIAN

O:V	Mafic pillow lava, massive flows, breccia and tuffs
CO:V	Felsic pyroclastic rocks; mafic flows, pillow lava and pyroclastic rocks

EARLY CAMBRIAN TO MIDDLE ORDOVICIAN

CO:m	Diabase and foliated amphibolite

NEOPROTEROZOIC TO EARLY ORDOVICIAN

N-O:F	Metasedimentary gneisses and schists
N-O:C	Biotite-muscovite, migmatitic paragneiss and granodioritic to quartz monzonitic orthogneiss

Figure 2 Legend

River valley. As retreat occurred, meltwater formed glacial Lake Shanadithit (Mihychuk, 1985; Smith, 2012). The paleogeography of glacial lakes Howley and Shanadithit suggests they formed independently of one another. The timing of glacial Lake Shanadithit has not been constrained, due to the lack of radiocarbon dates within the Red Indian Lake Basin. However, drainage through Southwest Brook must have been into an ice-free St. George's Bay, and therefore the formation of glacial Lake Shanadithit was sometime after 12.6 Ka (Smith, 2012). By 12 Ka, ice remained to the south of Grand Lake in the interior (Shaw *et al.*, 2006, Figure 3). As the ice continued to retreat through ablation,

Table 1. List of mineral occurrences located within the study area (GSNL, 2018b)

Map Sheet	MODS #	Latitude	Longitude	Name of Occurrence	Status	Commodity; Secondary Commidities
12A/05	012A/05/Au001	48.39	57.90	Goldquest North Area	Showing	Gold; Silver, Copper
12A/05	012A/05/Cu001	48.46	57.84	Southwest Brook	Indication	Copper; Gold, Silver
12A/05	012A/05/Pyr001	48.27	57.83	Cormacks Lake East	Indication	Pyrite
12A/05	012A/05/Pyr002	48.38	57.69	Burgeo Road	Indication	Pyrite
12A/05	012A/05/Pyr003	48.49	57.66	Bottle Lake North	Indication	Pyrite; Iron
12A/05	012A/05/Ni002	48.39	57.64	Smith Ni Showing	Showing	Nickel; Copper
12A/05	012A/05/Ni003	48.41	57.64	Lucky Moose Showing	Showing	Nickel; Copper
12A/05	012A/05/Ni001	48.43	57.62	Portage Lake	Prospect	Nickel; Copper, Cobalt
12A/05	012A/05/Pyr004	48.49	57.59	Bottle Lake	Indication	Pyrite
12A/05	012A/05/Cu002	48.42	57.58	Range Copper	Prospect	Copper; Cobalt
12A/05	012A/05/Au002	48.41	57.55	Goldrange	Showing	Gold; Silver
12A/05	012A/05/Au003	48.27	57.58	Rich House	Indication	Gold
12A/05	012A/05/Pyr005	48.28	57.56	Victoria Lake Northwest	Indication	Pyrite
12A/05	012A/05/Zn001	48.29	57.52	Unnamed Brook	Showing	Zinc; Lead, Silver
12A/06	012A/06/Cu003	48.48	57.44	Canoe Pond	Showing	Copper; Zinc
12A/11	012A/11/Mo001	48.73	57.44	Whalen's Molybdenum	Indication	Molybdenum
12A/04	012A/04/Pyr005	48.22	57.72	Burgeo Road #2	Indication	Pyrite
12A/04	012A/04/Pyr002	48.23	57.68	Victoria River Southwest	Indication	Pyrite
12A/04	012A/04/Pyr003	48.23	57.66	Yet Another Pond	Indication	Pyrite
12A/04	012A/04/Pyr001	48.25	57.63	Marks Pond Occurence	Indication	Pyrite
12A/04	012A/04/Pyr011	48.24	57.91	King George IV Pyrite #11	Indication	Pyrite
12A/04	012A/04/Au002	48.25	57.61	Victoria Lake South	Showing	Gold
12A/04	012A/04/Au007	48.24	57.63	Newest Discovery	Showing	Gold
12A/04	012A/04/Pyr012	48.23	57.71	King George IV Pyrite #12	Indication	Pyrite; Copper, Zinc
12A/04	012A/04/Au006	48.24	57.61	Ryan's Hammer West	Showing	Gold
12A/04	012A/04/Ag001	48.24	57.61	Woods Brook (Victoria River)	Showing	Silver; Lead
12A/04	012A/04/Au005	48.25	57.60	Ryan's Hammer East	Showing	Gold

Grant's (1974) model suggests the ice disintegrated into at least 15 small isolated ice caps. At this stage, parts of the eastern flanks of the Long Range Mountains were ice free and that ice remained over the Lloyds River valley and Hinds Lake, with a centre over Red Indian Lake. However, with the deglaciation of the Grand Lake Basin between 12.6 and 12.3 Ka, and the formation of glacial Lake Shanadithit, remnant ice during the later stage of deglaciation was confined to the higher elevations on either side of Hinds Lake and remained during the last stage of deglaciation (Batterson, 2003; Smith, 2012). Klassen (1994) and Organ (2016) also suggested that late-stage ice caps were located at high elevations west of Hinds Lake, and northeast and southeast of Red Indian Lake (Figure 4).

Limited Quaternary work in the study area is due to the lack of access to the north, and the southwest being heavily forested. Grant (1975) mapped NTS map area 12A (at 1:250 000 scale), largely from airphoto interpretation. Thick till, till veneer, flutes, drumlins and pockets of glaciofluvial sand and gravel were identified northeast of Puddle Pond. To the southwest, exposed rock, till veneer, till blankets, hummocks and eskers dominate. Landform-classification maps were produced from airphoto interpretation in the late 1980s for NTS map areas 12A/05 and 12A/14 (Kirby *et al.*, 1989a, b). The Star Lake area (NTS map area 12A/11) was mapped using aerial photography but only the southeast corner was field-checked and sampled (Organ, 2014b). Detailed surficial mapping and till sampling adjacent to the study area include the Red Indian Lake Basin (Grant, 1975; Grant and Tucker, 1976; Vanderveer and Sparkes, 1982; Sparkes, 1985; Mihychuk, 1985; Klassen, 1994; Klassen and Murton, 1996; Batterson and Taylor, 2008; Smith, 2009, 2010, 2012, 2013), the Grand Lake Basin (Batterson, 2003; McCuaig *et al.*, 2006) and the Topsails (Prest *et al.*, 1967; Tucker, 1974; Organ, 2016).

Figure 3. *Pattern of deglaciation on the Island of Newfoundland at 12 Ka. Blue dashed lines show location of ice divides (Shaw* et al.*, 2006). Red box shows location of study area.*

REGIONAL ICE FLOW

A radial regional ice-flow pattern was documented in the Long Range Mountains between Grand Lake and the Topsails (Vanderveer and Sparkes, 1982; Sparkes, 1985; Klassen, 1994; Taylor, 1994; Batterson, 2003; McCuaig *et al.*, 2006; Smith, 2009, 2010; Organ 2016; Figure 5). This pattern is based on striae, and streamlined landforms such as roches moutonnées, crag and tails, flutes and drumlins. The study area was influenced by an early stage southerly flow of ice from the Long Range Mountains. This was later followed by a southwest to westerly flow from an ice divide east of Costigan Lake (Batterson and Taylor, 2008; Smith, 2010; GSNL, 2018c). Ice retreated to a number of small, late-stage ice caps in the higher elevations on either side of Hinds Lake, as well as northeast and southeast of Red Indian Lake (Klassen, 1994; Batterson, 2003; Smith, 2012; Organ, 2016).

FIELD METHODS: OBSERVATION, SAMPLING AND ANALYSIS

Field observations pertaining to the surficial geology and ice-flow indicators were collected from 436 sites during the 2018 field season. At each site, GPS location, elevation, sediment type, matrix composition, clast information (size, composition, angularity, concentration of clasts) and striae measurements (where present) were recorded.

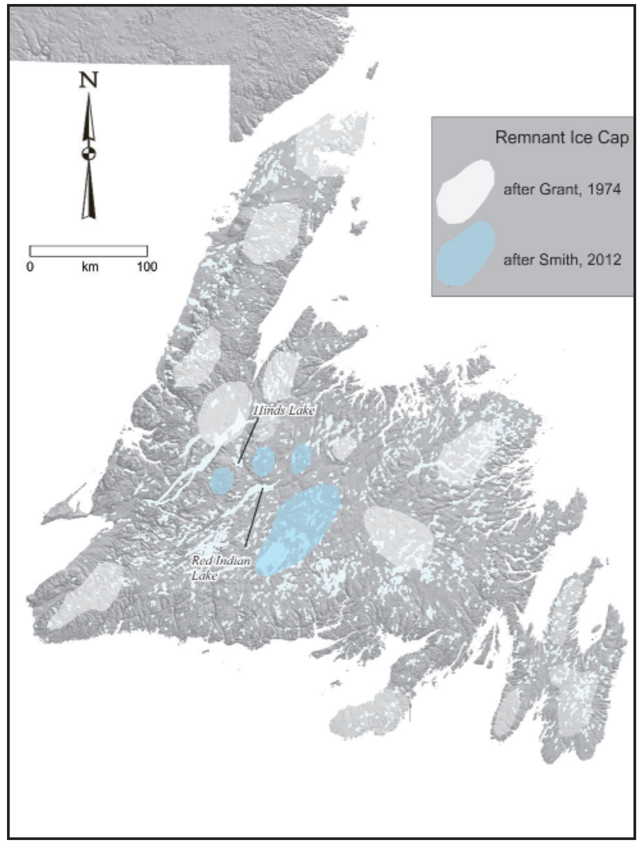

Figure 4. *Map of Newfoundland showing the approximate locations of remnant ice caps as the Newfoundland Ice Cap disintegrated, as proposed by Grant (1974). Only those in central Newfoundland coloured blue have been modified by Smith (2012).*

A total of 409 till samples were collected (Figure 2). A helicopter was used to provide access for the collection of 215 till samples at a density of one in each 4 km^2 cell of a predetermined grid. An additional 194 till samples were collected along Route 480 and forestry access roads, *via* truck and ATV, at a spacing of one sample every linear kilometre. Samples of 1 kg were taken from the C and BC horizons of hand-dug pits and placed in Kraft paper bags. Care was taken to clean sampling tools to avoid cross-contamination. To test site variability and reproducibility of results, duplicate samples were taken at a frequency of 1 in 12 from a second hand-dug pit 2–3 m away from the original pit.

Samples were processed and analyzed in the Geochemical Laboratory of the Geological Survey of Newfoundland and Labrador (GSNL) in St John's, where they were they were air-dried to 60°C and dry-sieved through 63 μm (250 mesh) stainless-steel sieves to recover the silt and clay fraction for analysis. Minor and trace-element content will be analyzed using ICP-OES analysis, whereas INAA analysis will be completed at Maxxam Analytics

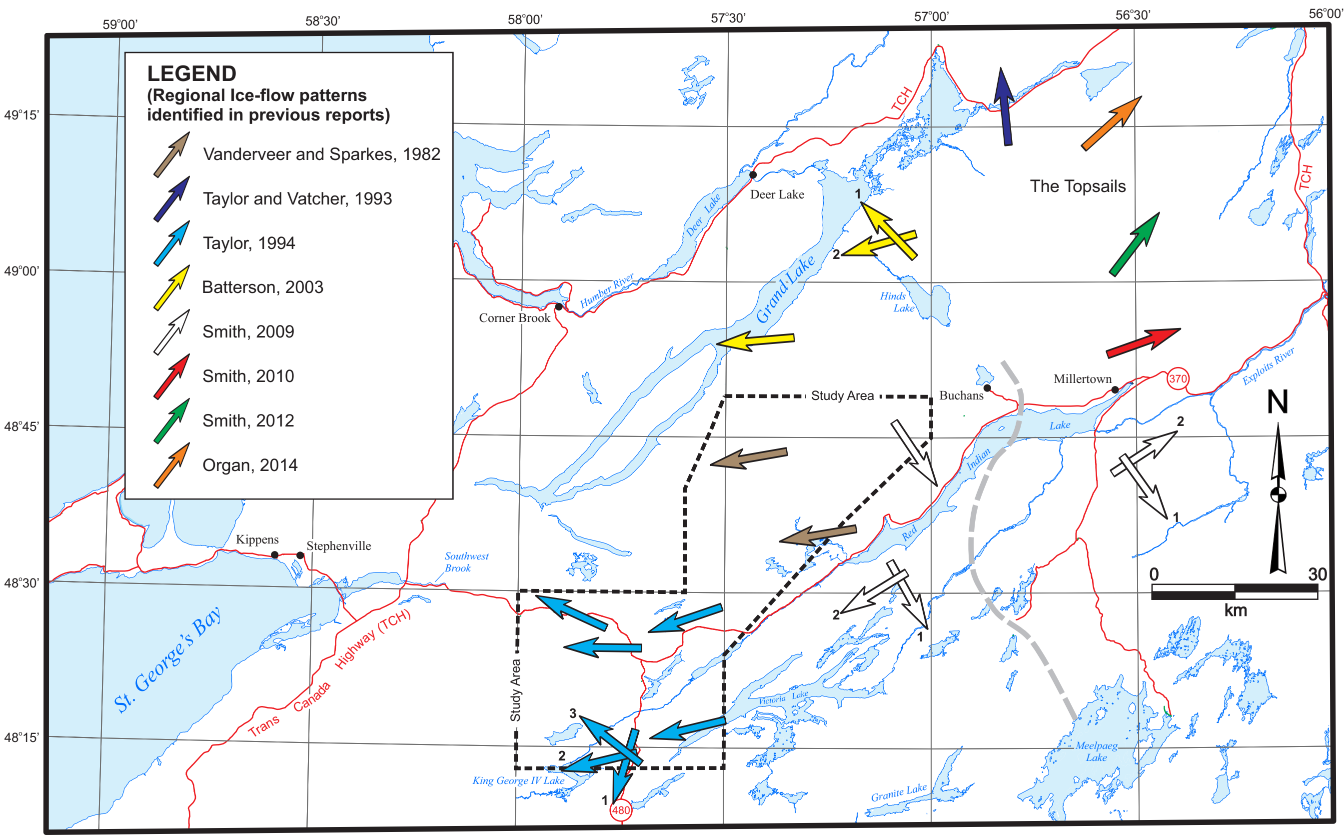

Figure 5. *Regional ice-flow patterns identified within the study area from previous reports. The numbers at the end of the arrows denote the age relationship, where known, with 1 being the oldest and 3 the youngest. Dotted line is the approximate location of the ice divide proposed by Batterson and Taylor (2008).*

(Mississauga). Further details of the preparation and analytical methods for till samples, *see* Finch *et al.* (2018).

RESULTS

ICE-FLOW INDICATORS

Glacial striae were recorded from 32 new sites (Figure 6). Twenty-four of these measurements were collected within the boundaries of NTS map areas 12A/05 and 12A/06. These were mostly from newly exposed rock surfaces, exposed during road construction. The remaining striae were from sites in NTS map areas 12A/11, 12 and 14. Striae evidence of southwestward to westward ice flow was observed throughout the study area, along with a west-northwestward flow identified at various locations adjacent to the Burgeo Highway (Route 480) and in the Southwest Brook valley. Only two multidirectional sites were identified, and of these, only one has an observable age relationship. This site, located south of Puddle Pond, is interpreted as showing an older west-northwestward flow (290°) followed by a younger westward flow (260°).

Whereas no early southerly flow was recorded from the newly identified sites, the southwest to westerly flow follows the regional trend described earlier (Sparkes, 1985; Taylor, 1994; GSNL, 2018c). In comparison to three previously identified multidirectional sites with age relationships, only the southward flow was determined to be older than both the southwest to westward and west-northwestward flows. There is no agreement as to the age relationship between the southwest to westward and the west-northwestward flows, and as a result it remains inconclusive (GSNL, 2018c).

SURFICIAL GEOLOGY

The surficial geology and geomorphology of the area are complex. This is, in part, shown by the contrast between the Long Range and Annieopsquotch mountains and upland plateau, and the low-lying valleys of the Lloyds River, Southwest Brook and Little Barachois Brook. Surficial sediments were mostly deposited by ice (in the case of till, or glacial diamicton), and glaciofluvial activity (sand and gravel; Smith, 2012). The thickness of till deposits ranges from

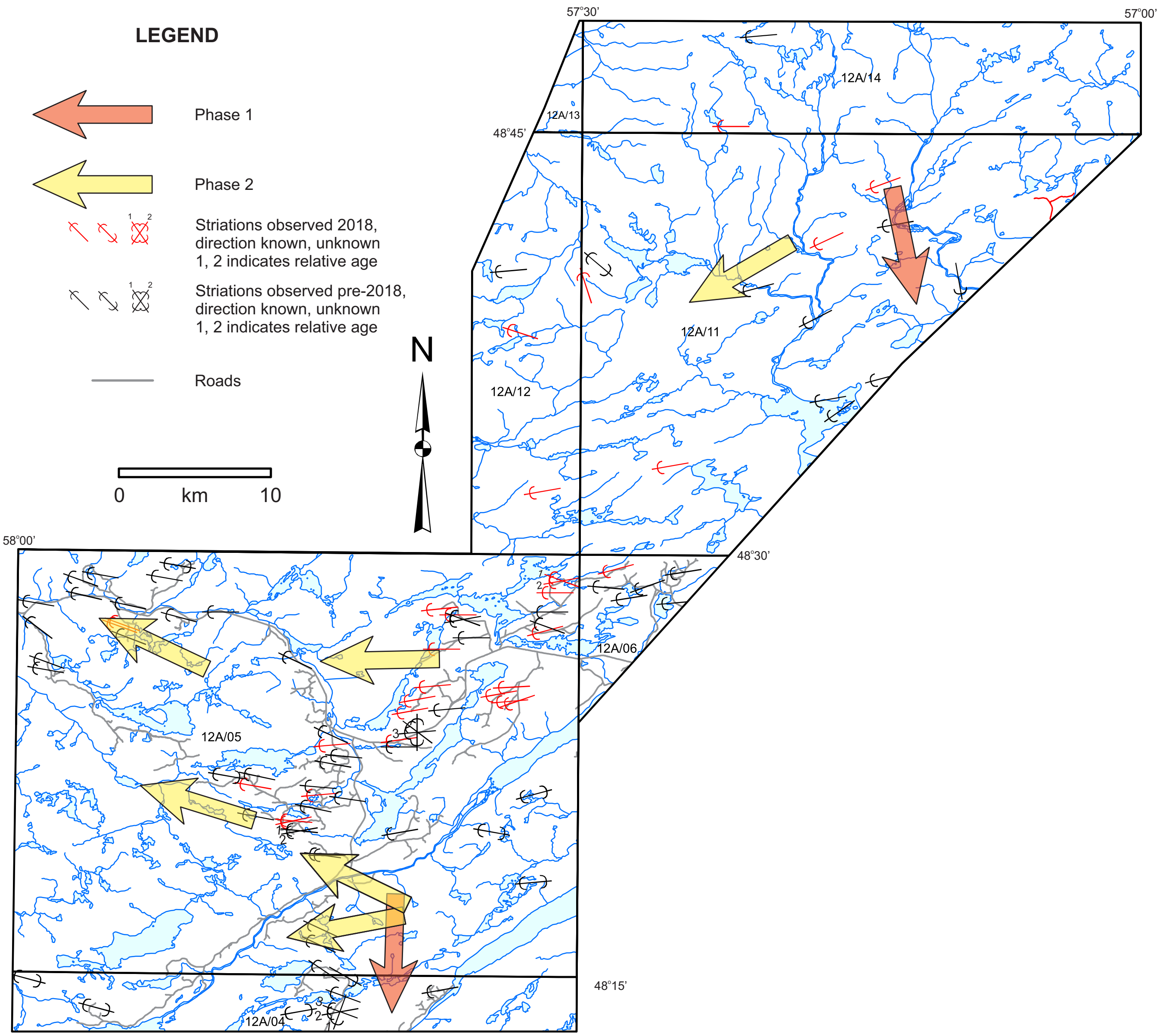

Figure 6. *Locations and orientations of striae identified during 2018 fieldwork (shown in red). Large arrows indicate regional ice-flow chronology. Red arrows indicate an older phase of southward flow followed by a younger phase of west to southwest flow and northwest flow (yellow arrows).*

veneers of a few centimetres, in areas adjacent to exposed bedrock in the mountains, to tens of metres (blankets/plains), in upland areas where the topography consists of flat, gently rolling landscape, such as that found southeast of the Long Range Mountains, or in river valleys (Plate 2). In some areas, the thick till blankets/plains are cut by meltwater channels, and are associated with glaciofluvial sand and gravel. An area of streamlined till is located from Padille Pond northeast to Shanadithit Brook. Hummocky terrain include localities west of Indian Lake, northeast of Portage Lake and southeast of Fox Pond. Large postglacial organic deposits (bogs and string bogs) cover large areas of NTS map area 12A/11.

Diamicton

Only one unit of glacial diamicton was identified and is interpreted as being stratigraphically continuous throughout the study area. The diamicton is matrix-supported, and the variable coloured matrix is composed of silty to fine-grained sand (Plate 3). Dark-yellowish-brown (Munsell soil colour 10YR4/4) matrix predominates; however, a brown–dark

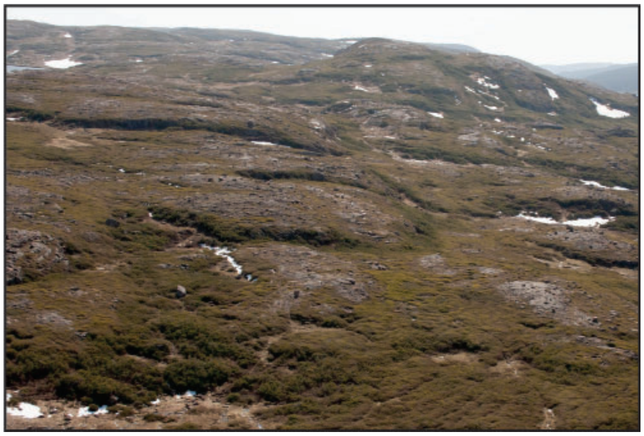

Plate 2. *West of Star Lake, bedrock overlain by boulders and thin glacial diamicton deposits (less than 1.5 m).*

Plate 3. *Looking north at a 3 m section located in NTS map area 12A/05 (Site 226). The diamicton is composed of dark-greyish-brown (2.5Y4/2) silty to fine-grained sand (*see *inset). Clast content at this location is generally low with angular to subrounded clasts with diameters of up to 70 cm.*

brown (10YR4/3) matrix is observed in the northern part, and a dark-greyish-brown matrix (7.5Y3/3) is common in till observed northeast of Route 480 in NTS map area 12A/05. Clast content is typically low (20%); however, till at some sites contains up to 40% clasts. Till observed at over half the sites have clasts, the angularity of which ranges from angular to subround, with a median of subangular. Clasts observed on the surface range from pebble to boulder sized (350 cm diameter). Striated clasts were observed at 23%, and faceted clasts at 1.6% of the 436 sites visited. Determination of clast lithology tends to reflect that of the underlying local bedrock, whereas their size and angularity suggest that they were transported short distances.

In some areas, the upper surface of the till has been modified, or cut into, by flowing water and are mapped as eroded till. The diamicton matrix of the upper 30 cm consists of medium- to coarse-grained sand, and it appears that the silt and very fine-grained sand has been washed away. Areas of eroded till were found associated with meltwater channel(s), and armoured boulder surfaces. The meltwater channels are up to 10 km in length, 300 m wide and 6 m deep (Plate 4); single meltwater channels are not common. Areas of multiple channels are up to 2 km wide, and in places resemble a braided river. Most of these channels follow present-day topography, but some, channels were observed cutting across the hillside and transverse to slope. Meltwater generally follows topography, and flows away from the ice margin incising the sediment and forming proglacial channels, either singularly or as a network (Benn and Evans, 1998). However, some channels develop transverse to slope and are known as lateral meltwater channels. Dyke (1993) explains that these form as the result of either (1) meltwater being deflected along the margin as a result of high subglacial pressure, (2) meltwater from spring snow melt on surrounding ice-free slopes, and with meltwater drainage along the margin while the substrate is still frozen; or (3) cold-based conditions in the marginal zone. These meltwater channels are similar to those identified by Batterson (2003) and Organ (2016) to the north, which were interpreted as being ice-marginal or proglacial channels, depending on the orientation of the channel with respect to the slope. These channels were carved by meltwater produced during the last stages of deglaciation.

Hummocky terrain is present in the following localities west of Indian Lake (Plate 5), northeast of Portage Lake and southeast of Fox Pond. In general, the hummocks seen in the study area are composed of till that typically has a sandier

Plate 4. *Looking northeast across an eroded till plain in a broad flat valley 4 km west of Halls Pond in NTS map area 12A/11/ Meltwater channels indicated by light-coloured vegetation (red arrows).*

Plate 5. *Boulder-strewn hummocky terrain west of Indian Lake. This terrain is indicative of stagnating ice along a passive margin.*

matrix than that described above. The surface of the hummocks is characterized by high concentrations of angular–subangular cobbles, and boulders up to 250 cm in diameter. The sandiness of the matrix material, and the high concentration of large angular clasts in the upper confines of this unit, suggest that it was formed by stagnating ice during deglaciation. Similar areas of hummocky till were mapped to the northeast in the Chain Lake (Organ, 2016) and Sheffield Lake areas (Organ, 2014c), as well as to the southeast in the Meelpaeg Lake area (Smith, 2010).

An area of streamlined terrain is located in the middle of NTS map area 12A/11, from Padille Pond northeast to Shanadithit Brook. This is characterized by very subtle elongate vegetated ridges rising only a few metres from the surrounding bogs. The ridges have widths of 100–200 m and lengths of up to 1000 m and are oriented west-southwest, parallel to the dominant ice-flow direction. The till within these ridges has a silty fine-grained sand matrix, comparable to the regional till described above. This corresponds to the same area in which Organ (2014b) had mapped these streamline features as flutes.

Glaciofluvial Deposits

Glaciofluvial sediments are present in NTS map area 12A/11 adjacent to the Long Range Mountains, as well as in the Lloyds River and Southwest Brook valleys of NTS map area 12A/05. Glaciofluvial veneers overlie till blankets and plains, or within meltwater channels. These veneers are 30–50 cm thick, and their matrix is composed of moderately sorted coarse-grained sand to granule gravel. Clasts range from 3–90 cm in diameter, are subangular to subrounded and often armour the sediment surface. These characteristics are consistent with deposition in meltwater streams that have variable amounts of suspended sediment and bedload, along with fluctuating discharges (Benn and Evans, 1998).

There are three eskers, with associated thicker glaciofluvial sediments, in the northwest corner of NTS map area 12A/11 between Star Lake and Caribou Lake (Organ, 2014b; Plate 6). These features are segmented, in places, and are each less than 2 km long, 10 m high and 20–60 m wide. The two eskers near Caribou Lake are complex glaciofluvial systems, having bifurcating ridges and glaciofluvial hummocks.

Plate 6. *Looking north from the northeast end of Caribou Lake at a segment of an east–west-oriented esker (red arrow). The esker is approximately 5 m high, 20 m wide and 100 m long.*

A 4-km-long esker is present along the north bank of the upper Lloyds River. It is 60–100 m wide and less than 10 m high. The composition of this esker ranges from well-sorted silty very fine-grained sand, to coarse-grained sand, to granule–gravel matrix, to a clast-supported cobble gravel. On the surface, the clast concentration varies along the esker's length, ranging from very few to abundant subangular to subrounded boulders up to 80 cm in diameter.

Organic Deposits

Organic deposits (bogs) are found throughout the study area and are most extensive northeast of Puddle Pond, where they are interspersed with till deposits. These bogs appear to be thicker than 1.5 m and have been mapped as blanket or ridge bogs. To the southwest, organic deposits are much less prevalent.

QUATERNARY HISTORY

During the Late Wisconsinan glacial maximum the study area was covered by the Newfoundland Ice Cap. Ice flow was radial from an ice centre in the Hinds Lake area, between the Long Range Mountains and the Topsails (Batterson, 2003). Shifting ice centres and ice divides add complexity to the ice-flow history. The study area lies to the west of Hinds Lake ice centre and was influenced by south-flowing ice, followed by southwestward to westward flow from an ice divide located east of Costigan Lake. The relationship with the younger southwest to west flow, and the west-northwest flow identified along Route 480 and in the Southwest Brook valley, remains unclear.

The St. George's Bay area, west of the study area, was ice-free by 12.6 Ka as indicated by radiocarbon dated *Hiatella Arctica* shells (GSC-5942) at Kippens (Batterson and Sheppard, 2000). Ice retreat from this location was northeastward toward Corner Brook, as well as to the southwest along Bottom, Southwest and Little Barachois brooks toward the interior. Radiocarbon dates of two samples collected along Route 480 (Burgeo Highway) indicate that the western part of the study area was ice-free prior to 11.5–11.3 Ka (GSC-4499: McNeely and Jorgensen, 1992; GSC-5257: McNeely, 2002).

Till, recorded striae, and streamlined features including crag and tails, roches moutonnées and flutes, are indicative of active east-southeastward and east-northeastward retreat toward the interior (*i.e.*, the Lloyds River valley and Star Lake). The broad area of streamlined features from Shanadithit Brook toward the southwest to Padille Pond has well-defined boundaries, and is suggestive of ice streaming; however, further work is needed to support this hypothesis. Blundon *et al.* (2010) did identify seven ice-streams within the Newfoundland Ice Cap, to the east and south of the study area, using a multi-scale mapping approach.

With active northeastward retreat of the ice margin, and the formation of glacial Lake Shanadithit in the Red Indian Lake Basin, ice divided, resulting in retreat into the Long Range Mountains to the north and toward Meelpaeg Lake in the south (Smith, 2012).

Not all areas were influenced by active ice; areas of hummocky terrain, and those associated with meltwater channels, particularly those in the northern part of the study area, formed as a result of stagnating ice. During the late stages of deglaciation, ice stagnated and melted *in situ*, at the higher elevations. This formed copious amounts of meltwater that carved proglacial and ice-margin meltwater channels into the underlying glacial sediment. Similar channels were identified by Batterson (2003) draining into the south side of Grand Lake, to the north of the study area. The location of these channels indicates that the ice was south of Grand Lake in the Long Range Mountains (Batterson, 2003). Klassen (1994) and Organ (2016) also suggest that there was late-stage retreat northwestward of Buchans and Hinds Lake with ice remaining in the Long Range Mountains.

The timing of this late stage in the deglaciation history is not known, as no radiocarbon dates are available for this part of the Long Range Mountains, but deglaciation probably occurred sometime after the opening of the Grand Lake Basin and the formation of glacial Lake Howley, after 12.6 Ka (Batterson, 2003).

IMPLICATIONS FOR MINERAL EXPLORATION

The ice-flow history, type of ice retreat and the resulting landscape aid in the development of strategies for drift prospecting within the Red Indian Lake Basin as follows:

- This study area has a complex ice-flow history, reflecting ice-flow fluctuations during the last glacial advance and retreat. This must be taken into account when inferring the direction of mineralized dispersal trains.
- Areas of till, containing poorly sorted sediment including silt and clay, are best for conducting drift-prospecting surveys because the sediment was deposited in contact with ice as a result of active retreat.
- Areas of thin veneer, with local boulders, are also favourable for conducting drift-prospecting studies because the till was likely deposited by the last ice-flow event. The relationship between till and the direction of the last ice-flow event allows for geochemical responses in the till, to be more accurately sourced.
- Areas of thicker till may be the result of shifts in the ice-movement direction and the tills' uppermost surface may not necessarily reflect the underlying bedrock. Geochemical and textural analyses of samples taken at regular vertical intervals throughout a section of thick till will help to determine if there are multiple till units.
- Areas of sediment deposited under stagnating ice, such as hummocky terrain, are less suitable for drift prospecting as there is commonly a high proportion of distally derived material. Due to varying amounts of associated meltwater, sediments forming hummocky moraine tend to contain less fines (*i.e.*, their texture is more sandy and less silty) and be better sorted than till in the same area.

FUTURE WORK

Future work will focus on:

- Updating of 1:50 000-scale surficial mapping of NTS map area 12A/11;
- Completion of 1:50 000-scale mapping of NTS map area 12A/05;
- Interpretation of till geochemistry for NTS map area 12A/11 and 12A/05;

ACKNOWLEDGMENTS

Robyn Constantine is thanked her enthusiastic assistance during helicopter sampling. Much appreciation is given to Dave Taylor for his guidance and support with planning and helicopter sampling. Logistical support was provided by Gerry Hickey. Dave Liverman and Steve Amor are thanked for their critical reviews of the manuscript.

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