Current Research (2012) Newfoundland and Labrador Department of Natural Resources
Geological Survey, Report 12-1, pages 179-190

QUATERNARY GEOLOGY AND TILL GEOCHEMISTRY OF THE CARMANVILLE (NTS 2E/08), WESLEYVILLE (NTS 2F/04) AND MUSGRAVE HARBOUR (NTS 2F/05) MAP AREAS

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ABSTRACT

During the third year of a multi-year study program, surficial-geology mapping and a regional till-geochemistry sampling survey were conducted in the Carmanville (NTS 2E/08), Wesleyville (NTS 2F/04) and Musgrave Harbour (NTS 2F/05) map areas; 532 samples were collected. Sampling was at a spacing of 1 sample per 1 km² in areas of good access, to one sample per 4 km² where helicopter support was required. Analytical geochemical data collected is expected to be released in late 2012.

Till cover within the study area is extensive inland, and occurs mostly as veneers, eroded veneers, and large areas of hummocks. Along the coast, only small patches of thin diamicton are present and exposed bedrock or vegetated bedrock are common. Marine and glaciofluvial sediments are common along the coast. Postglacial marine limits of 67 m asl in the Hamilton Sound area and 34 m in the Indian Bay area indicate areas where these marine and glaciofluvial sediments may occur and areas where geochemical exploration may be hampered by possible reworking of these sediments by marine processes.

Ice-flow indicators including striations, clast fabrics, roche moutonées, crag-and-tails, and drumlins, were measured, and these indicators identified three ice-flow phases. The earliest was a regional eastward event from a likely source north of Red Indian Lake, the second was northeastward from an ice divide between Middle Ridge and Meelpaeg Lake, and the third was a northwestward flow likely sourced from the Middle Ridge area. In the west, where three ice-flow directions were identified, sediment deposited by earlier eastward ice flow has been reworked by later northward-flowing ice. The dominant ice flow was northwestward in the Carmanville area and east of Island Pond. For the remainder of the study area to the east, the dominant and only ice flow recorded is east-southeastward.

INTRODUCTION

Mapping of the surficial geology and associated sampling for till-geochemistry analyses were completed for the Carmanville (NTS 2E/08), Wesleyville (NTS 2F/04) and Musgrave Harbour (NTS 2F/05) map areas; this was done during the third year of a multi-year till sampling and surficial-geology mapping program in northeast Newfoundland.

Previous exploration in this area centred on gold and base metals of the Gander River Complex, with more recent mineral potential (gold and base metals) being identified in areas underlain by quartz-rich sandstone and quartz breccias of the Gander Group. Only limited Quaternary investigations have been completed in the field area – in the Carmanville area (NTS 2E/08) by Kirby *et al.* (1988), Munro (1993), and Munro and Catto (1993). Given the presence of mineralization and limited Quaternary investigations in the study area, the field program objective was to further our understanding of the region's Quaternary history as it relates to mineral exploration and provide a basis for the evaluation of geochemical data; the study will identify suitable sampling media for further geochemical exploration, especially in the more inaccessible and drift-covered areas that are common throughout the field area. Determination of ice-flow directions will aid in the analysis of geochemical anomalies and provide a better understanding of the regional ice-flow history. These results will supplement that collected from similar projects in surrounding areas, including the Bonavista Peninsula (Batterson and Taylor, 2001), Grand Falls-Mount Peyton area (Batterson and Taylor, 1998), Hodges Hill area (Taylor and Liverman, 2000) and the Gander area (Batterson and Vatcher, 1991; Brushett, 2010, 2011).

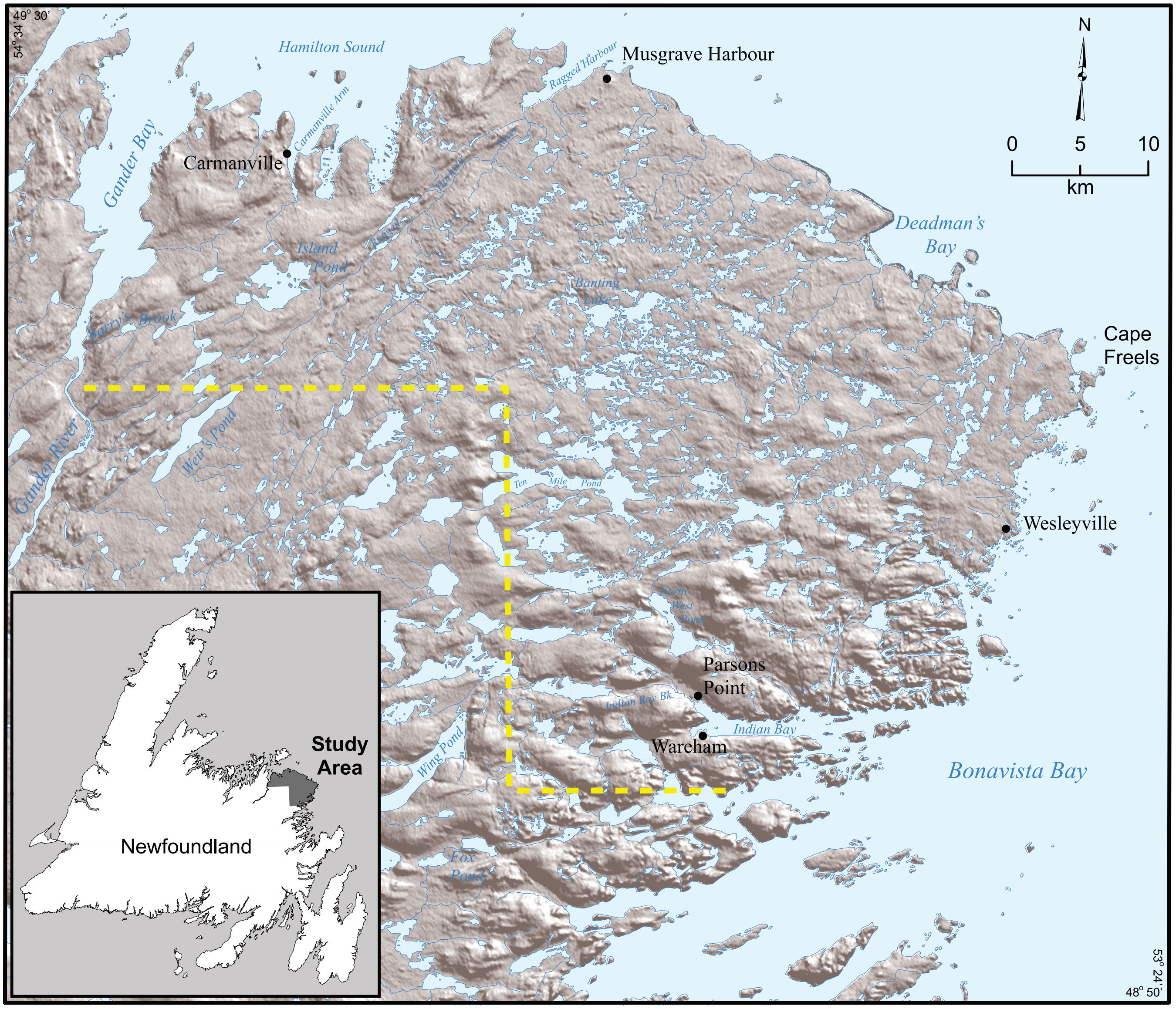


Figure 1. *Shuttle Radar Topography Mission (SRTM) image of the study area showing physiography and places mentioned in the text. Extent of study area is marked by dotted yellow lines.*

LOCATION, ACCESS AND PHYSIOGRAPHY

Fieldwork was conducted over three 1:50 000-scale map areas in northeastern Newfoundland: Carmanville (NTS 2E/08), Wesleyville (NTS 2F/04), and Musgrave Harbour (NTS 2F/05). The field area is approximately 1996 km^2 and extends from Gander Bay in the west to Indian Bay in the southeast (Figure 1). Access to most of the field area is *via* paved roads (*e.g.*, the Trans-Canada Highway (TCH), Route 330 (Gander Bay Road), and Route 320 (Gambo to Wesleyville) or unpaved logging roads. All-terrain vehicles were used along smaller trails and remote areas were accessed by helicopter.

Much of the study area is characterized by low relief except in the southeast, where numerous hills (maximum elevation of 225 m asl) and narrow, steep-sided valleys produce a rugged terrain. These hills and valleys, and low-lying ridges extend across the area and have a southwest–northeast trend, reflecting the structure of the underlying bedrock. The area has varying thicknesses of glacial sediments, generally thinning toward the coast where barren rock exposures and low shrub/alder beds dominate the landscape. Ponds and bogs are common. Boulder fields composed of erratics of local megacrystic granites are common in the eastern portion of the area.

BEDROCK GEOLOGY

The bedrock geology of the study area encompasses two tectonostratigraphic zones, the Dunnage and Gander zones, separated by a boundary defined by the Gander River Complex, which may represent remnants of the Iapetus ocean crust (Williams *et al.*, 1988; Figure 2). Rocks of the Gander River Complex are restricted to a thin, northeast- to southwest-trending belt in the western portion of the study area, and are composed mainly of locally serpentinized pyroxenite, but also include local exposures of carbonate, talc and gabbro (O'Neill, 1990). To the west of the Gander River Complex, is the Davidsville and Botwood groups that are composed of Middle Ordovician quartz-poor sandstone, siltstone, shale and conglomerate rocks (O'Neill, 1990). Rocks of the Botwood Group are nonconformable over the Gander Group, which comprises a north-northeast-trending belt of Ordovician metasedimentary rocks of the Indian Bay Big Pond and Jonathans Pond formations (Blackwood, 1982; O'Neill, 1990). The Indian Bay Big Pond Formation consists of grey to purple, pebble and cobble conglomerate interbedded with grey quartz-rich sandstone, maroon siltstone, and greyish-green pelite. The Jonathans Pond Formation consists of interbedded psammite, semipelite and greyish-green pelite predominantly metamorphosed to greenschist or amphibolite facies. Exposures of gabbro and biotite or hornblende granite in the Wing Pond, Gull Pond, and Square Pond areas and of ultramafic rock near Square Pond and Butts Pond are associated with the Wing Pond Shear Zone (O'Neill, 1991). Prior to the 1980s, rocks of the Gander River Complex were the main focus of mineral exploration. More recently, exploration activity has centred on areas underlain by quartz-rich sandstones and quartz breccias of the Indian Bay Big Pond and Jonathans Pond formations, where gold is the main target of exploration (Evans, 1993).

Igneous rocks of Late Silurian to Devonian intrude all older rocks throughout the study area. In the west, coarse-grained grey tonalitic–granodioritic rocks of the Fredericton, Rocky Bay, Tim's Pond, Aspen Cove plutons intrude the Davidsville Group. Also intruding the Davidsville Group are massive, medium-grained biotite–muscovite granite and aplite of the Island Pond and Ragged Harbour plutons (Currie, 1995). The northeasternmost part of the Gander Zone is underlain by gneisses and migmatites of the Hare Bay gneissic complex. Silurian and Devonian megacrystic granites intrude the migmatites and gneisses (Jayasinghe, 1978). The Silurian granites include: Wareham granite, North Pond granite, Business Cove granite, Cape Freels granite and unnamed intrusions, all of which exhibit a regional northeast-trending foliation paralleling the Dover Fault, which separates the Gander Zone from the Avalon Zone. These Silurian granites are primarily medium to coarse grained, locally garnetiferous, K-feldspar biotite granites. Numerous beryl and chrysoberyl occurrences have been discovered, mostly within pegmatite veins (Hill, 1984). The Devonian granites include the Newport granite and Deadman's Bay granite, which are massive, medium- to coarse-grained biotite granite (Jayasinghe, 1978).

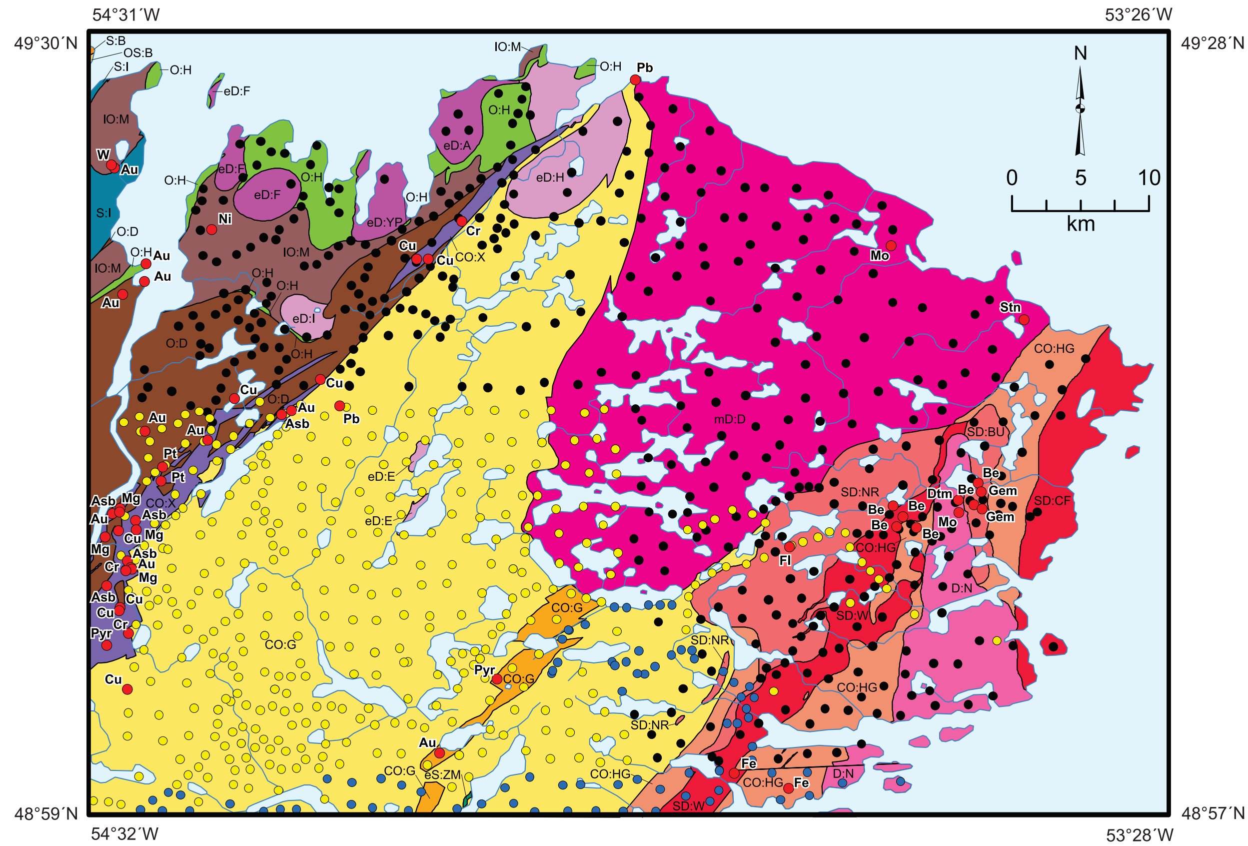
SURFICIAL GEOLOGY

The surficial geology is characterized by thin till cover and valleys containing glacial outwash derived from melting ice inland, originally described by Jenness (1960) as the 'outer drift zone.' Jenness (1960) suggested this zonation evolved as a result of rapid ice retreat from its terminal position on the northeast coast. Only one till unit has been recognized and its composition varies from a brownish-grey silty-sand to sandy grey till where it overlies the Gander Group (Butler *et al.*, 1984; Batterson and Vatcher, 1991), to a grey to pinkish-grey sandy till where it overlies granite (Jenness, 1960; Batterson and Vatcher, 1991).

GLACIAL HISTORY

Previous work on the glaciation of Newfoundland suggests that during the last glacial maximum (LGM; ~21 ka BP), Newfoundland was covered with multiple local ice caps producing almost complete glacial cover extending out to the continental shelf edge (Grant, 1989; Shaw *et al.*, 2006). The sequence of deglacial events following the LGM are based mostly on striation and landform data, which depict a first-order ice divide extending south and southeast across Newfoundland along the axis of the Long Range Mountains, east through central Newfoundland and across the Avalon Peninsula. Early ice retreat was facilitated by calving along deep (>600 m) channels, particularly off northeast Newfoundland. This created a second-order ice divide along the axis of the Cape Freels peninsula that separated ice flow in Notre Dame and Trinity basins (Shaw, 2003). Ice retreat continued *via* calving embayments until ~13 ka BP, when ice margins reached coastal areas and the configuration of ice divides shifted as deglaciation became land-based; retreat of isolated ice caps continued by ablation, predominantly through melting (Shaw *et al.*, 2006). At least fifteen of these remnant ice caps were present, five of which had the potential to influence ice flow in northeastern Newfoundland. These ice caps were located near Red Indian Lake, Meelpaeg Lake, Middle Ridge, north of Grand Falls (in the Twin Ponds area) and in the Gander area (Grant, 1974; Figure 3).

A radiocarbon date of ~12.0 ka (marine barnacles) was obtained from silty clay at Parsons Point (GSC-4182). This sample was at 2 m asl, indicating that Bonavista Bay was ice free at this time and that relative sea level was above pres-



DUNNAGE ZONE

Early Silurian to Early Devonian

S:B — *Botwood Group:* subaerial mafic and felsic flows and pyroclastic rocks, shallow marine to subaerial red, green and grey sandstone, siltstone, shale, and minor conglomerate

Early to Late Silurian

S:I — *Indian Islands Group:* grey calcareous siltstone with local fossiliferous limestone, overlain by grey to black shale containing thin beds of siltstone; discontinuous basal unit of coral-bearing limestone and limestone breccia

Late Ordovician to Early Silurian

OS:B — *Badger Group:* grey, well-bedded greywacke, including conglomerate layers, overlain by grey and minor red conglomerate

Middle to Late Ordovician

IO:M — *Main Point Formation:* graptolitic, black shale containg bedded chert and chert lenses

Early to Late Ordovician

O:D — *Davidsville Group:* shale and thinly bedded siltstone and sandstone, probably distal turbidites; thickly bedded sandstone and minor shale and conglomerate, likely representing more proximal turbidites; minor limestone and felsic and mafic volcanic rocks

O:H — *Hamilton Sound Group:* siltstone, shale and minor sandstone; melange of siltstone, sandstone and mafic volcanic blocks in black shale matrix; volcaniclastic rocks, pillowed and massive basalt, and mafic dykes

Late Cambrian to middle Ordovician

CO:X — *Gander River Complex:* ophiolite complex that includes pyroxenite, serpentinite, magnesite, gabbro, talc/tremolite zones, mafic flows and volcaniclastic rocks, trondhjemite and quartz porphyry

GANDER ZONE

Early Cambrian to Middle Ordovician

CO:G — *Indian Bay Big Pond Formation:* medium- to thick-bedded, buff, grey and maroon sandstone; thinly bedded, maroon and green siltstone and black pelite; brown-weathering, possibly tuffaceous semipelite

CO:G — *Jonathans Pond Formation:* quartzite, psammite, semipelite and pelite, including minor black slate, conglomerate, limestone, mafic and felsic volcanic rocks, and unseparated migmatitic rocks

CO:HG — *Hare Bay Gneiss:* migmatite, gneiss and shist

eS:ZM — *Wing Pond Shear Zone*: locally foliated, medium- to coarse-grained hornblende gabbro

Silurian to Devonian

eD — *Frederickton (F), Rocky Bay (YP), and Aspen Cove (A) plutons*: coarse-grained grey tonalite granodiorite

eD — *Island Pond (I), Ocean Pond (E) and Ragged Harbour (H) plutons*: massive, medium-grained biotite-muscovite granite and aplite

SD — *North Pond Granite (NR), Business Cove Granite (BU)*: medium- to coarse-grained garnetiferous K-feldspar biotite granite

SD — *Wareham Granite (W), Cape Freels Granite (CF)*: medium- to coarse-grained garnetiferous K-feldspar biotite granite

mD:D — *Deadmans Bay Granite*: massive, medium- to coarse-grained biotite granite

D:N — *Newport Granite*: massive, medium- to coarse-grained biotite granite

Mineral Occurence — 2009 Sample Location

2010 Sample Location — 2011 Sample Location

Figure 2. *Bedrock geology of the study area (mostly taken from Colman-Sadd and Crisby-Whittle, 2005). Black dots show location of till samples collected during the 2011 field season. Red dots show location of mineral occurrences.*

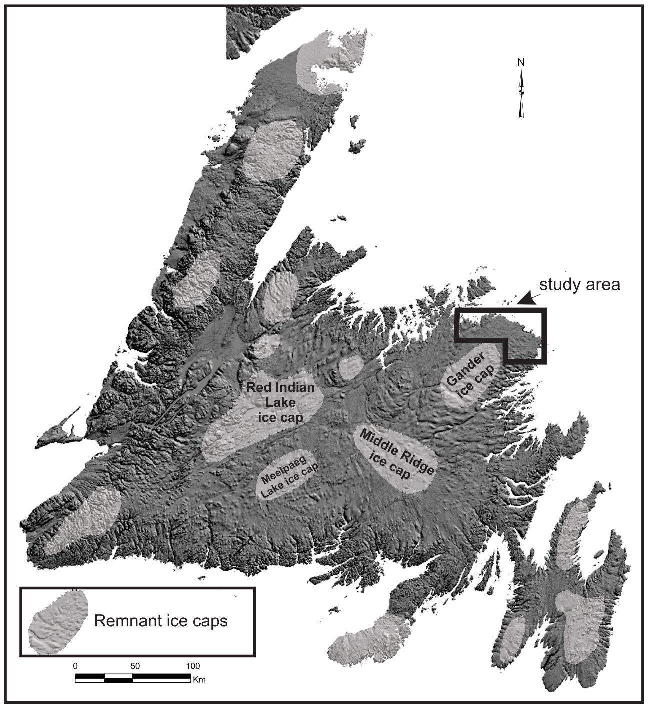


Figure 3. *Approximate locations of remnant ice caps during the deglaciation of Newfoundland (modified from Grant, 1974).*

ent level (Shaw and Forbes, 1990). The Gander area was likely ice free by ~11.5 ka BP (marine macrofauna radiocarbon dates from the lower Gander River valley and Exploits River valley) (Batterson and Taylor, 1998; McCuaig, 2006).

ICE-FLOW HISTORY

Regional ice-flow directions determined from glacial erosional evidence, mostly striations, indicate the existence of three separate ice-flow events in northeastern Newfoundland during the last, late Wisconsinan glaciation (St. Croix and Taylor, 1990, 1991). The earliest ice flow was east-southeastward. Evidence for this flow is widespread throughout the area and has been identified in the Gander River and Gander Bay areas (St. Croix and Taylor, 1991), around Gander Lake (Vanderveer and Taylor, 1987; Batterson and Vatcher, 1991; St. Croix and Taylor, 1991) and eastward into the Bonavista Bay area (Jenness, 1960; Butler *et al.*, 1984; St. Croix and Taylor, 1991). The probable source of this ice-flow event was from north of Red Indian Lake, based on the presence of eastward striations in the Northwest Gander River area (Proudfoot *et al.*, 1988), the Grand Falls–Glenwood area (Batterson and Taylor, 1998) and the Red Indian Lake area (Rogerson, 1982; Vanderveer and Sparkes, 1982; Smith, 2009, 2010).

The eastward ice-flow event was followed by north-northeast ice flow. Evidence for this northward ice flow is present throughout most of northeastern Newfoundland (Vanderveer and Taylor, 1987; St. Croix and Taylor, 1990, 1991; Batterson and Vatcher, 1991; Scott, 1994; Batterson and Taylor, 1998). This event crossed Gander Lake and flowed northward into Hamilton Sound; evidence for this flow is sparse east of Gander Lake. The source of this ice flow is likely an ice divide situated between Middle Ridge and Meelpaeg Lake (Proudfoot *et al.*, 1988; St. Croix and Taylor, 1990, 1991).

The third ice-flow event was northwestward and consistently crosscuts the earlier northeastward ice flow when observed on the same outcrop (Vanderveer and Taylor, 1987; Taylor and St. Croix, 1989; St. Croix and Taylor, 1991). This ice flow is likely related to a Middle Ridge ice centre (Grant, 1974; St. Croix and Taylor, 1991).

FIELD PROGRAM

METHODS

A total of 532 samples were collected from the C- and BC- horizons, mostly from hand-dug pits (40 to 60 cm depth) and roadcuts (50 to 100 cm depth). Mudboils were sampled at shallower depths (average 30 cm). In rare cases, where there was a lack of surface sediment, samples were collected from bedrock detritus. Fluvial and glaciofluvial sediments were avoided during sampling, because of the possibility of reworking and the difficulty in defining distances and directions of transport. A sample was collected every 1 km^2 in road-accessible areas, and every 4 km^2 in more remote areas, where helicopter support was required. Duplicate samples were taken every 20 samples to test for field reproducibility of geochemical data. Samples are analyzed in the Geological Survey's geochemical laboratory for a suite of elements determined from ICP-OES and ICP-MS, and at an external laboratory for other elements, including gold, using INAA techniques. Data release of these results is anticipated by mid to late 2012.

Clast fabrics were measured in 9 diamicton exposures. The orientation and plunge of the A axis of 25 elongate (length:width ratio >3:2) clasts were taken in each diamicton unit. These data were analyzed using GeoOrient version 9.4.4 (Holcombe, 2009) and plotted on an equal area stereonet. The mean orientation of the clasts and the strength of that orientation were established using the methods outlined by Woodcock (1977). This involves determining the orientation of a principal eigenvalue (S1), which measures the degree to which the clasts are aligned and ranges from 0.33 (random) and 1.0 (unidirectional). The K-values represent the nature of the distribution of the fabric, with values greater than 1 representing cluster distributions and values less than 1 representing girdle distributions. Strong fabrics (*i.e.*, those with S1>0.6 and K>1.0) indicate unimodal fabric alignment and are generally indicative of primary basal tills and provide data on potential ice-flow direction (Dowdeswell and Sharp, 1986).

Bedrock outcrops were examined for striations and other ice-flow indicators and 49 striations were recorded from 33 sites. Ice-flow direction, where possible, was also determined from the bedrock morphology using features including stoss and lee, nailheads, chattermarks, and crag-and-tails. Sites with two or more striation directions are interpreted to be the result of either separate glacial phases or different ice-flow directions within one flow phase.

RESULTS

ICE-FLOW PATTERNS

Striations in the area are best preserved in fine-grained metasedimentary rocks of the Gander Group, in contrast to the easternmost part of the field area, where coarser granites have poor striation preservation potential and fewer striations were observed. Sites recording multiple ice-flow directions were observed at 10 sites, where relative age relationships were determined from crosscutting relationships and by preservation of older striations in the lee of younger ones. These, combined with data from previously known sites (Taylor and St. Croix, 1989; St. Croix and Taylor, 1990, 1991; Brushett, 2010, 2011) indicate the occurrence of three separate ice-flow phases (Figure 4).

Flow Phase 1 was east to southeastward (~105° ± 30°) and is generally well preserved across the study area, and commonly preserved on the leeside surfaces of outcrops where one or more subsequent ice-flow phases are preserved (Figure 4). Eastward-oriented striations range from 075 to 136°; this variability becomes more pronounced toward the coast and likely reflects topographic control.

Flow Phase 2 has a northeast–northward orientation (~025° ± 13°) and is common in the western portion of the study area (Figure 4). Where striations related to both the northeastward and eastward ice flows are observed, the northeastward flow is interpreted to be the younger of the two.

Flow Phase 3 was northwestward (~342° ± 17°), and is also preserved in the western portion of the study area. Crosscutting relationships indicate that the northwestward flow is younger than the northeastward flow. Where all three directions were preserved, striations from the eastward flow were crosscut by striations from the northeastward ice flow and both of these were overprinted by striations from the northwestward flow.

Geomorphic evidence for ice flow includes rôches moutonées, crag-and-tail hills, and drumlins. All of these landforms occur northwest of Weir's Pond and have a north-northeast orientation (~028° ± 10°), which were likely shaped by northeast-flowing ice. These findings are consistent with those previously mapped (Kirby *et al.*, 1988; St. Croix and Taylor, 1990; Munro, 1993; Munro and Catto, 1993). In the eastern part of the study area, where only the earlier eastward ice flow is represented, eastward-trending rôches moutonées and crag-and-tail hills are present. These landforms are most common closer to the coast where exposed bedrock or thin till veneers are common. No geomorphic evidence for Flow Phase 2 and 3 was noted in the eastern part of the study area. Whereas it is possible that these flow phases had little influence on reshaping the landscape, it is more likely given the absence of any striation or geomorphic evidence that these flow phases did not cross the area at all.

SURFICIAL GEOLOGY

The surficial geology and geomorphology of the area are variable, with a strong contrast between coastal areas and inland. The coast is mostly rock or rock concealed by a thin veneer of vegetation. In the coastal margin, extending up to 6 km inland, the topography is rugged, having mostly exposed or vegetated bedrock interspersed with areas of bog and fen (up to 10 km long) and only small patches of thin diamicton (Plate 1). Inland, most of the study area is covered by diamicton, mostly as veneers, eroded veneers, and large areas of hummocks (Plate 2).

Only a single stratigraphic unit of diamicton was identified. Diamicton texture and colour vary and reflect the underlying bedrock geology. Diamicton underlain by the Gander Group is generally light-brownish grey to grey. The matrix is predominantly silty sand, poorly sorted and slightly to moderately compacted. Diamicton underlain by granite is typically pinkish grey with a coarser, sandier matrix. Sedimentary structures were not generally noted, but this may be due to poor exposure. Clasts are granule to boulder sized (up to 3 m diameter) and are generally subrounded to angular. Clasts are commonly striated and have thin silt coatings on their upper surfaces.

Clast lithology and shape are generally controlled by the underlying bedrock. Fragile (*e.g.*, well-bedded, soft, shale) clasts are common in areas underlain by bedrock of the Gander Group, whereas granite clasts are generally subrounded. Clast content varies between 30 to 70 percent and averages about 50 percent. Ultramafic and associated volcanic rocks of the Gander River Complex are restricted to a thin belt through the western part of the area, making them useful indicators of glacial transport directions and dis-

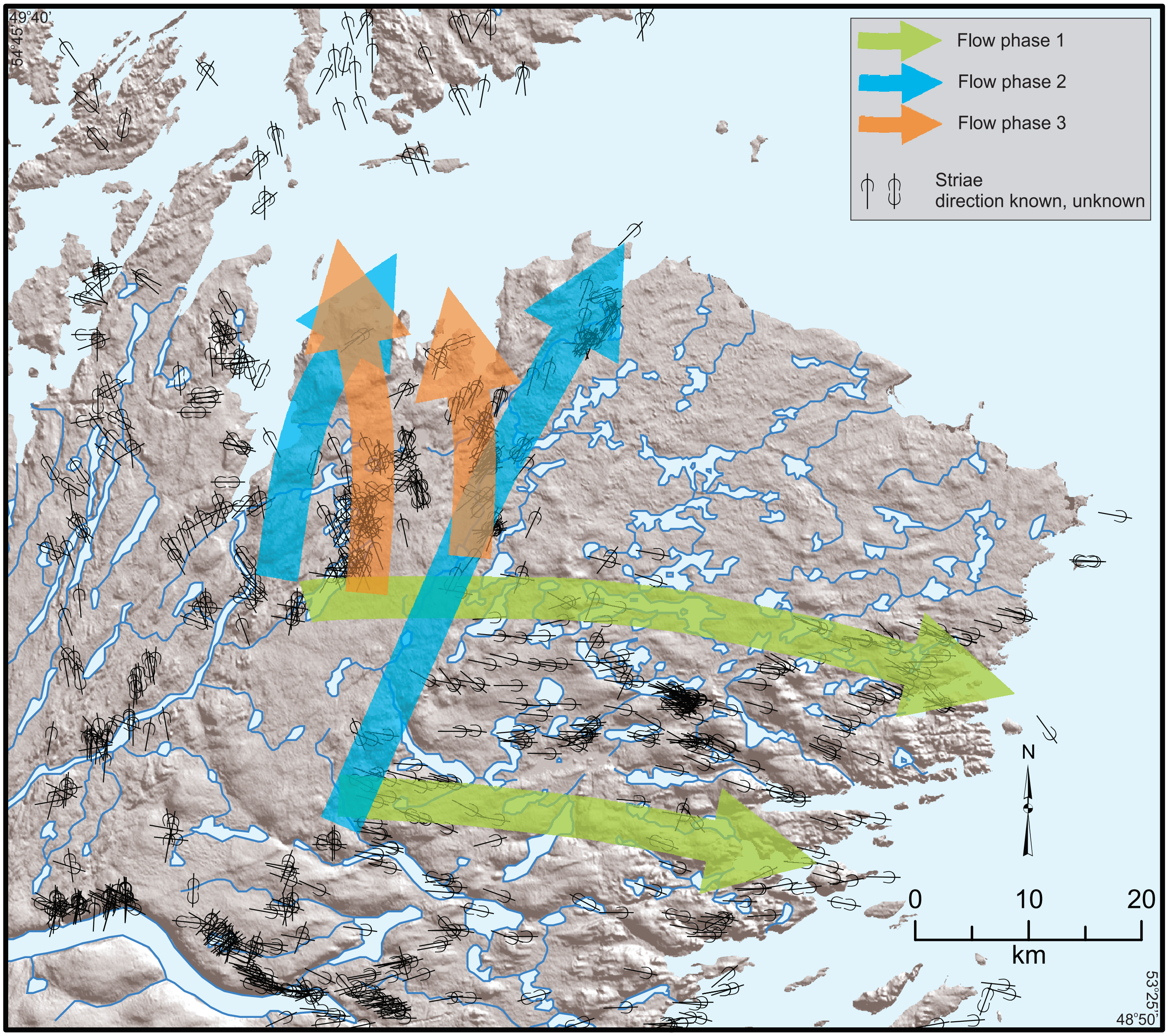


Figure 4. *Ice-flow patterns overlain on SRTM image. Three ice-flow phases affected the study area. The first (Flow Phase 1) was a regionally extensive eastward flow likely sourced from Red Indian Lake. The second (Flow Phase 2) was northeastward from an ice divide between Middle Ridge and Meelpaeg Lake, and the third (Flow Phase 3) was a northwestward flow likely sourced from the Middle Ridge area.*

tances. Clasts associated with the Gander River Complex were located in diamictons in the Carmanville area and east of Island Pond, and indicate northwestward transport. Granitic clasts derived from Gander Lake Granite found in areas underlain by Gander Group in the Island Pond area suggest northward transport.

Clast fabrics are variable. Strong fabrics (S1>0.6, K>1.0) providing data on potential ice-flow directions were only determined at 3 sites. These fabrics indicate northwestward ice flow in the Boot Pond area, and northeastward ice flow in Jonathan's Pond and Home Pond areas. The characteristics described above (subrounded clasts, striated and fragile clasts, well-oriented clast fabrics, and silt coatings) are interpreted to represent deposition as subglacial melt-out till (Dreimanis, 1988).

Hummocky terrain and eroded till, common in the northeast, likely reflect ice stagnation during deglaciation. Hummocks are predominantly composed of till and have a surface cover of boulders, likely derived from a supraglacial source. The Ten Mile Pond area, in particular, is extensively

Plate 1. *Thin till veneer with exposed bedrock in the Indian Bay area. Boulder strewn terrain is also common in this area.*

Plate 3. *Bouldery terrain observed in the Ten Mile Pond area. Large granitic boulders are common in this area, many exceeding 3 m in height.*

Plate 2. *Eroded till veneer and hummocky terrain in the Great Eastern Pond area.*

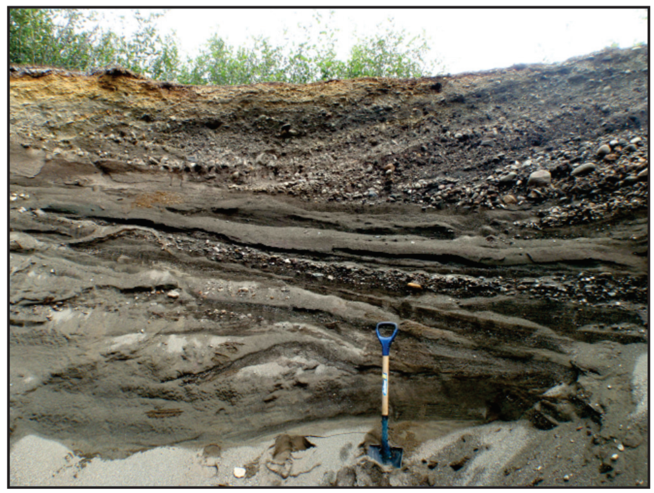


Plate 4. *Glaciofluvial sand and gravels west of Musgrave Harbour.*

covered with large boulders, many exceeding 3 m diameter (Plate 3). Areas of eroded till are commonly associated with many minor meltwater channels.

Glaciofluvial and fluvial deposits are common in the valleys emptying into Bonavista Bay and Hamilton Sound. The largest deposits are in an active quarry in Wareham where horizontal silty clay beds and steeply dipping sand beds are suggestive of the bottomset and foreset beds of a Gilbert-type delta. These are overlain by horizontal poorly sorted, medium- to coarse-grained sand and gravel beds, which are interpreted as topset beds and support a deltaic interpretation. The elevation of the topset beds is 36 m asl, providing a marine limit for the area. Other sand and gravel deposits present in the Indian Bay area include a sandy gravel esker (~500 m long), several small ridges (~100 m long), and gravel terrace deposits and remnants of an eroded terrace along the south side of the brook, which were examined by Ricketts (2011) for their aggregate potential.

Glaciofluvial sand and gravels are also present west of Musgrave Harbour in areas that are being exploited for aggregate. These deposits range from horizontally bedded finely laminated clay, silt and sand to steeply dipping thick beds of gravel and cobbles and display a textural and structural variability that is typical of glaciofluvial outwash systems (Plate 4). The finer silt to clay deposits are limited to smaller pockets (observed exposures were less than 4 m wide by 3 m high) that are likely the result of small ephemeral kettle lakes forming in this system or an abandoned part of a changing channel. Smaller deposits of poorly sorted sands and gravels occur in Indian Bay Brook, Northwest Brook, Ragged Harbour River and Barry's Brook.

The coastline bordering Hamilton Sound is mostly low lying and rocky and has numerous small gravel beaches. The coastline character changes from Musgrave Harbour to Cape Freels, where it is mostly sand dominated, and has barrier beaches, beach-ridge formation, tombolos and coastal dunes. Organic deposits are commonly associated with coastal sediment systems along the northeast coast, most notably at Cape Freels, Man Point and Deadman's Bay. Peat, both freshwater and salt marsh, is commonly found overlying gravel beach ridges and reaches thicknesses up to approximately 1 m. The maximum marine limit for the western area is 67 m asl, based on marine terraces observed in the Gander Bay area (Munro and Catto, 1993). Marine terraces up to 34 m asl were observed in the Indian Bay area.

GLACIAL HISTORY AND IMPLICATIONS FOR MINERAL EXPLORATION

The study area has evidence of three late Wisconsinan ice-flow events. The first was a regional eastward flow that extended into Bonavista Bay. This flow is recorded across much of northeast Newfoundland and likely had a source north of the Red Indian Lake area (Vanderveer and Sparkes, 1982; Proudfoot *et al.*, 1988; Batterson and Vatcher, 1991; St. Croix and Taylor, 1990, 1991). The eastward ice-flow event was followed by a north to northeastward ice flow, likely sourced from an ice divide between Middle Ridge and Meelpaeg Lake (Rogerson, 1982). A third, northwestward flow is also preserved in the western portion of the study area with a likely source from the Middle Ridge area (Grant, 1974; St. Croix and Taylor, 1991). Both northward ice-flow phases are only present in the western portion of the field area and are typically associated with thicker till cover interpreted as a basal melt-out till. East of this area, no striation or landform evidence of northward flow is observed. Till occurs mostly as a veneer where hummocky and bouldery terrain are common, likely formed by a stagnating remnant ice centre, as postulated by Grant (1974). Landform evidence supporting the presence (and possible extent) of stagnant ice includes hummocky topography in the Ten Mile Pond area, and esker-like ridges at Fox Pond (Brushett, 2010). The area became ice free sometime before 12.0 ka BP based on radiocarbon dates of marine shells from Indian Bay (Shaw and Forbes, 1990) and Gander River valley (McCuaig, 2006). To date, no radiocarbon dateable material has been found in the Bonavista Bay area that could further constrain the region's deglacial history.

Interpretations of till geochemistry and the development of mineral-exploration strategies should consider the following:

1. Three ice-flow directions have to be taken into consideration for mineral-exploration purposes. In the western area, where there is evidence for three ice-flow events, sediment deposited by earlier eastward ice flow has been reworked by later northward-flowing ice. The dispersal pattern of ultramafic clasts associated with the Gander River Complex suggests that the dominant ice flow was northwestward in the Carmanville area and east of Island Pond. Granitic clasts derived from Gander Lake granite found in areas underlain by the Gander Group in the Barry's Brook and Island Pond areas suggest transport northward. For the remainder of the study area to the east, the dominant and only ice flow recorded is east-southeastward.
2. Despite the presence of three ice-flow events, only one till unit, interpreted as a basal melt-out till, was observed. In the eastern area, hummocky deposits are common; these likely formed in a stagnating environment and may contain a greater proportion of supraglacial (and more far travelled) sediment then basally deposited till.
3. Sampling in areas underlain by glaciofluvial or fluvial sediments should be avoided due to the possibility of sediment reworking, and the difficulty in defining distances and directions of transport. These areas include: those below the marine limit of approximately 67 m in the Carmanville area, Hamilton Sound and along the northeastern coast, areas below the marine limit of 34 m in the Indian Bay area and surrounding coast along Bonavista Bay, and valleys containing glaciofluvial and fluvial sands and gravels in the Indian Bay area, Northwest Brook, Ragged Harbour River, south of Carmanville Arm, Barry's Brook, and west of Musgrave Harbour.
4. Hummocky deposits, such as those in the Ten Mile Pond area, likely formed in a stagnating glacial environment and may contain a greater proportion of supraglacial (and thus more far travelled) sediment than basal till, and is thus less likely to be representative of the underlying bedrock.

ACKNOWLEDGMENTS

The author would like to thank Gerry Hickey for logistical support. Nicole Clowe is thanked for providing excellent field assistance. Dave Taylor provided much appreciated guidance and support during helicopter sampling. Jennifer Smith and Krista Hawco are thanked for their enthusiastic assistance during helicopter sampling. Glenn Piercey and Jeff Maloney of Canadian and Universal Helicopters, respectively, are thanked for their piloting skills. Martin Batterson is thanked for his support during the field season and for providing a critical review of this manuscript.

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