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QUATERNARY GEOLOGY OF WEIR'S POND AND SURROUNDING AREAS (NTS MAP AREAS 2D/15, 2E/01, 2E/02 AND 2F/04)

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ABSTRACT

Surficial-geology mapping and a regional till-geochemistry survey were conducted in the Weir's Pond and surrounding areas (NTS map areas 2D/15, 2E/01, 2E/02 and 2F/04) during the second year of a multi-year till-geochemistry and surficial-mapping program in northeast Newfoundland. Mapping identified landforms and sediment types and included the measurement of paleo ice-flow indicators, as a means of reconstructing the region's ice-flow history. Five hundred and two samples were collected. Sampling was at a spacing of 1 sample per 1 km^2 in areas of good access to 1 sample per 4 km^2 where helicopter support was required.

The study area is dominated by till, of varying thicknesses, and organic deposits. Till cover is generally extensive and it conceals much of the bedrock, creating a gently undulating topography. Glaciofluvial deposits are found along the Southwest Gander River valley, the area of the Outflow and the Gander River valley.

Ice-flow indicators, predominantly striations, show that the area was affected by two ice-flow phases, both of which are tentatively assigned as late Wisconsinan. The earliest phase was eastward throughout the field area, likely from a source north of Red Indian Lake. The most recent phase was north-northeastward, likely sourced from the Middle Ridge area. Evidence for this phase is constrained to the western portion of the study area; the remainder was likely covered by stagnant ice and became ice-free sometime before 12.2 ka (11 300 calendar years) BP).

INTRODUCTION

Mapping of the surficial geology and associated sampling for till geochemistry, were completed for the Weir's Pond and surrounding areas, during the second 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 in rocks of the Gander River Complex, with more recent mineral potential being identified in areas underlain by quartz-rich sandstone and quartz breccias of the Gander Group (Evans, 1993). Only limited Quaternary investigations have been completed in the field area – in the Weir's Pond area (parts of NTS map areas 2E/01 and 2D/16) by Butler *et al.* (1984) and the Gander area (NTS map area 2D/15) by Batterson and Vatcher (1991). Given the presence of mineralization and limited Quaternary investigations in the study area, this field program objective is 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; it will identify suitable sampling media for further geochemical exploration, especially in the more inaccessible and drift-covered areas that are common throughout. A better understanding of the regional ice-flow history is also important for overall ice reconstruction in Newfoundland and the results from this project 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 (Brushett, 2010; Batterson and Vatcher, 1991).

LOCATION, ACCESS AND PHYSIOGRAPHY

Fieldwork was conducted over several 1:50 000-scale map areas in northeastern Newfoundland: all of Weir's Pond (NTS map area 2E/01) and parts of Gander (2D/15), Gander River (2E/02), and Wesleyville (2F/04), covering an area of approximately 1200 km^2. The field area extends from the Southwest Gander River area to the Rocky Ridge Pond area in the northeast (Figure 1). Access to most of the field area is *via* paved roads (*e.g.*, Trans-Canada Highway (TCH), Route 330 (Gander Bay Road), and Route 320 (Gambo to

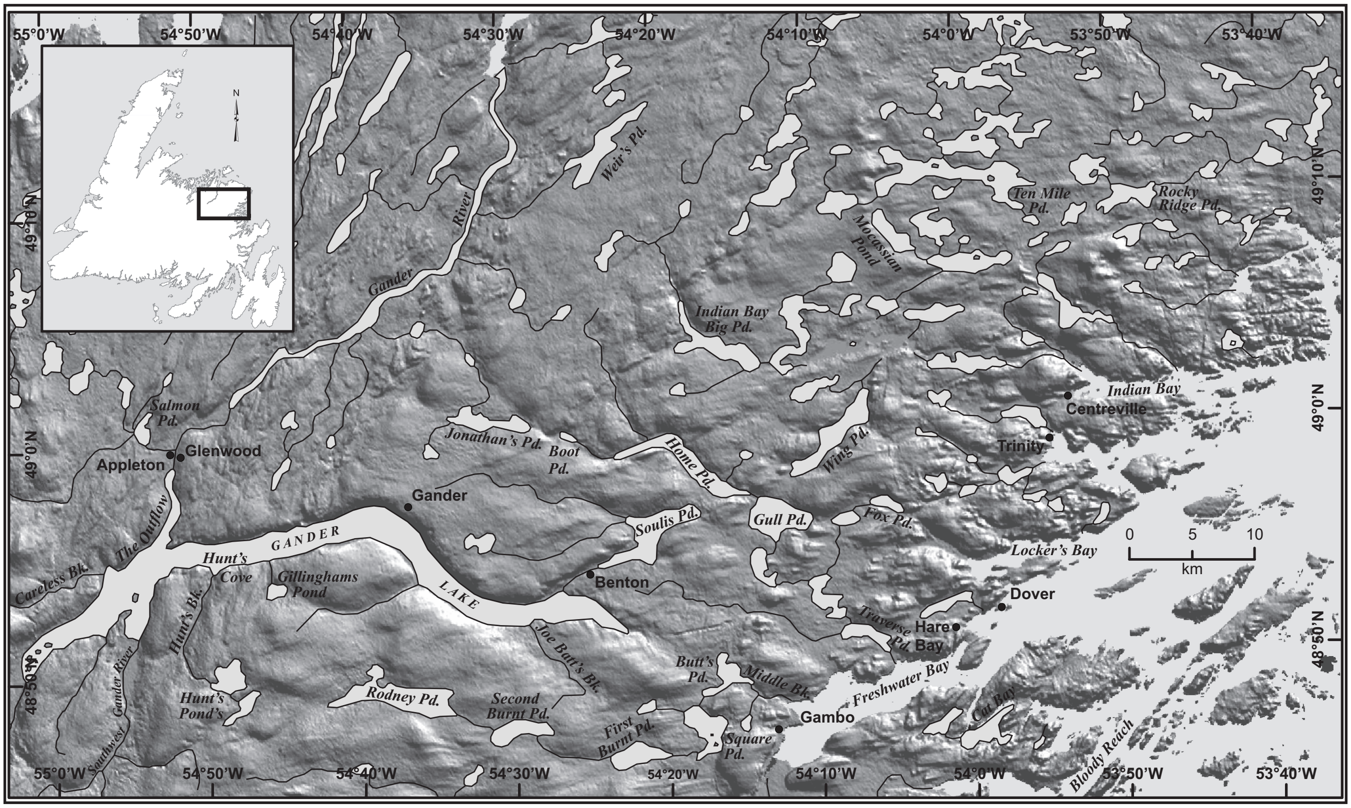

Figure 1. *Shuttle Radar Topography Mission (SRTM) image of study area showing physiography and places referenced in text.*

Wesleyville) or unpaved logging roads. All-terrain vehicles were used along smaller trails and the old railway bed. Remote areas were accessed by helicopter.

Much of the study area is characterized by low to moderate relief with varying thicknesses of glacial cover, numerous elongate low-lying ridges, and boggy areas. Maximum elevations reach 250 m asl south of Gander Lake. North of the Gander Lake basin, in areas underlain by bedrock of the Gander Group, the topography is typically flat and featureless. Surficial cover is thin, particularly along the TCH where bedrock is frequently exposed. The area south of the Gander Lake basin is dominated by a hilly topography and thicker sediment cover, hummocky terrain and rare bedrock outcrops.

In the west of the study area, the Southwest Gander River valley is up to 6 km wide and dominated by glaciofluvial and alluvial sediments. Eroded and terraced outwash sediments are present up to approximately 100 m asl, or 60 m above present river levels. Extensive outwash sediments also occur around the Careless Brook and Hunt's Brook valleys and the area of The Outflow. Terraces up to 40 m high are present around the Careless Brook valley.

Gander Lake, a dominant feature in the area, is a long, narrow lake reaching a maximum depth of at least 288 m (O'Connell and Dempson, 2002). Hills to the south of the lake rise to 215 m asl, giving a maximum relief of 503 m for the trough. The steep sides, shape of the basin and alignment with known ice-flow directions are consistent with the description of fjords of glacial origin as suggested by Jenness (1960).

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 north-northeast to south-southwest belt across the western portion of the area and 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 lies the Davidsville and Botwood groups, which are composed of Middle Ordovician quartz-poor sandstone,

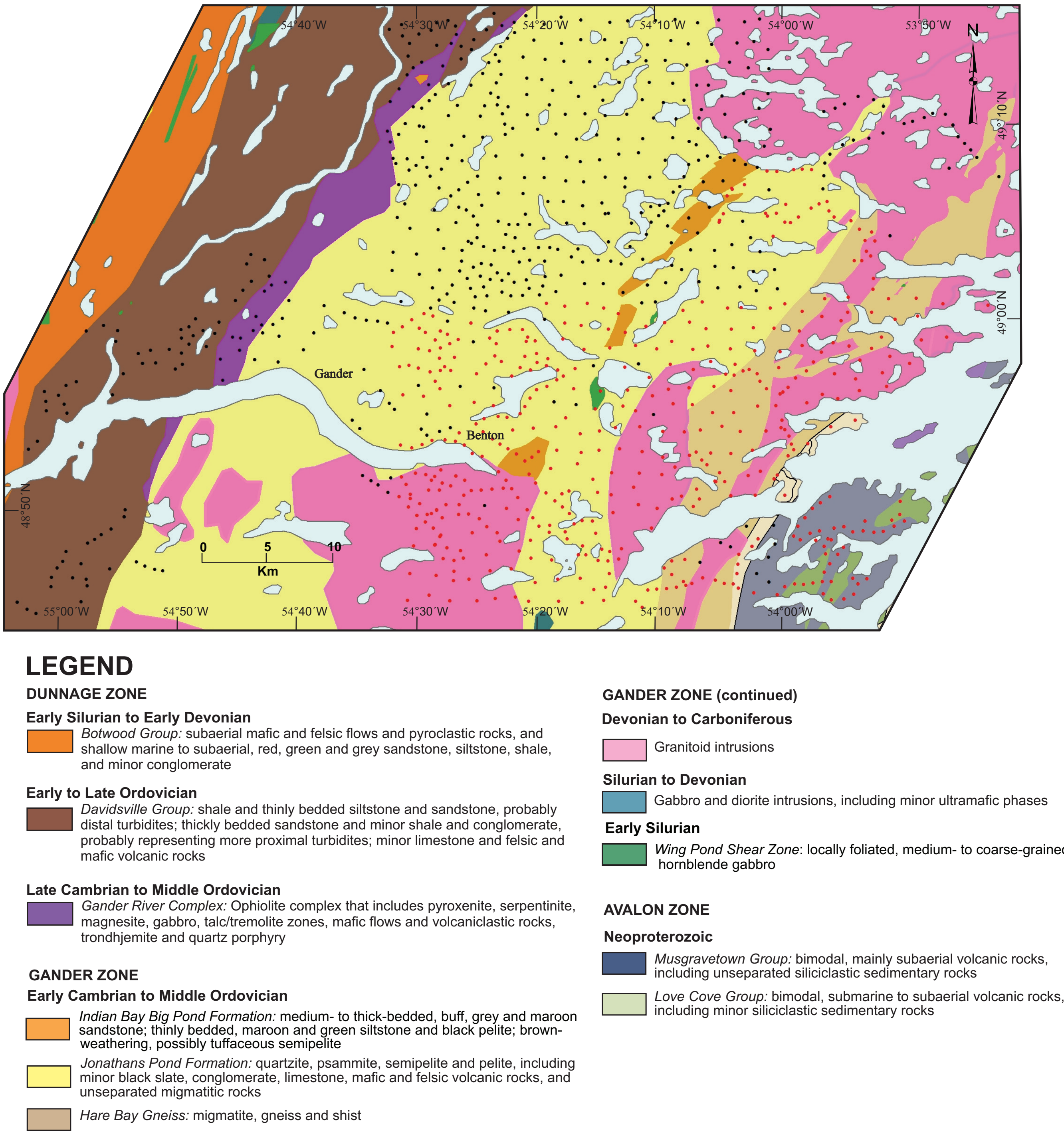

Figure 2. *Bedrock geology of the study area (mostly taken from Colman-Sadd and Crisby-Whittle, 2005). Black dots show the location of till samples collected during the 2010 field season. Red dots show the location of till samples collected during the 2009 field season.*

siltstone, shale and conglomerate rocks (O'Neill, 1987). 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 (O'Neill and Knight, 1988; O'Neill, 1991). The Gander Group grades eastward into amphibolite-facies rocks of the Square Pond Gneiss and Hare Bay Pond Gneiss (O'Neill, 1987). 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).

The Gander Group rocks are intruded by several Devonian granitic plutons, the most extensive being the Gander Lake Granite, a predominantly massive, K-feldspar megacrystic biotite granite, which underlies much of the study area south of Gander Lake. Other plutons include a fine-grained, equigranular, pink- to red-weathering granite containing gabbroic intrusions of the Mount Peyton intrusive suite to the west (Blackwood, 1982) and a medium- to coarse-grained, white- to pink-weathering, muscovite granite in the Gillingham's Pond area that may be correlative with the Middle Ridge Granite to the southwest (O'Neill, 1990).

Rocks of the Gander River Complex and Dunnage Zone, occurring to the west of the study area, could potentially be used as indicators of glacial transport directions and distances. Historically, rocks of the Gander River Complex have been the main focus of mineral exploration in the area, primarily for gold and base metals. More recently, exploration activity has been centred in areas underlain by quartz-rich sandstones and quartz breccias of the Indian Bay Big Pond and Jonathans Pond formations where gold is the main exploration target (Evans, 1993).

SURFICIAL GEOLOGY

The study area is dominated by varying thicknesses of sediment and predominantly lies within the 'outer drift zone' described by Jenness (1960). This zone is characterized by thin till cover and valleys containing glaciofluvial sediments, derived from melting ice, inland. It is separated from an 'inner drift zone' by a discontinuous 'boulder-till moraine' that generally contains thicker till cover and has a hummocky or ribbed topography, which suggests that the inland ice stagnated. The boundary of this zone crosses part of the field area to the south of Gander Lake. Jenness (1960) suggested that this zonation evolved, as a result of rapid ice retreat from its terminal position on the northeast coast, to a major stillstand position marked by the moraine; only one till unit has been recognized. Its composition varies from a reddish-brown silty-sand till to grey sandy till where it overlies the Gander Group (Batterson and Vatcher, 1991; Butler *et al.*, 1984), to a grey to pinkish-grey sandy till where it overlies rocks of the Musgravetown Group or granite (Jenness, 1960). Extensive glaciofluvial sand and gravel deposits, up to 60 m higher than present river levels, are common in the western part of the field area, particularly in the Southwest Gander River valley, the area of the Outflow and the Gander River valley (Batterson and Vatcher, 1991; Batterson *et al.*, 2001).

GLACIAL HISTORY

Previous work on the glaciation of Newfoundland suggested 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 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 (Figure 3). Early ice retreat was facilitated by calving along deep 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, where depths greater than 600 m have been reported (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; Figure 3). 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). The Gander area was likely ice-free by ~11.5 ka BP, based on radiocarbon dates from marine macrofauna found in the lower Gander and Exploits river valleys (Batterson and Taylor, 1998; McCuaig, 2006).

ICE-FLOW HISTORY

Regional ice-flow directions determined from glacial erosional evidence, mostly striations, indicate the existence of at least two separate ice-flow events in northeastern Newfoundland during the last, late Wisconsinan glaciation. Relative ages are determined from crosscutting relationships and leeside preservation (Taylor and St. Croix, 1989; St. Croix and Taylor, 1990, 1991; Batterson *et al.*, 1991).

The earliest ice-flow event was eastward (90° ± 20°). This flow was identified at Gander Lake (Vanderveer, 1985; 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

Figure 3. *Glacial extent at ~13 ka BP. Last glacial maximum (dotted black line), major ice divides (thick blue dashed lines) and generalized ice-flow lines (thin blue lines; modified from Shaw* et al.*, 2006).*

Taylor, 1991). This flow parallels Gander Lake in its central part and along the southeast-oriented portion of the lake. 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 (Vanderveer and Sparkes, 1982).

The eastward ice-flow event was followed by north-northeast ice-flow. Evidence for this northward ice-flow is widespread 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 flow roughly parallels the Southwest Gander River valley and the Outflow and obliquely crosses Gander Lake. Evidence for this ice flow is sparse east of Gander Lake. The source of this ice flow is likely from an ice divide situated between Middle Ridge and Meelpaeg Lake (Proudfoot *et al.*, 1988; St. Croix and Taylor, 1990, 1991).

METHODS AND RESULTS – 2010

REGIONAL TILL GEOCHEMISTRY

A total of 502 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. Samples were 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. Samples will be analyzed at the Geological Survey's geochemical laboratory, for a suite of elements determined from ICP-ES, and at an external laboratory for other elements, including gold, using INAA techniques. Data release is anticipated by mid- to late-2011.

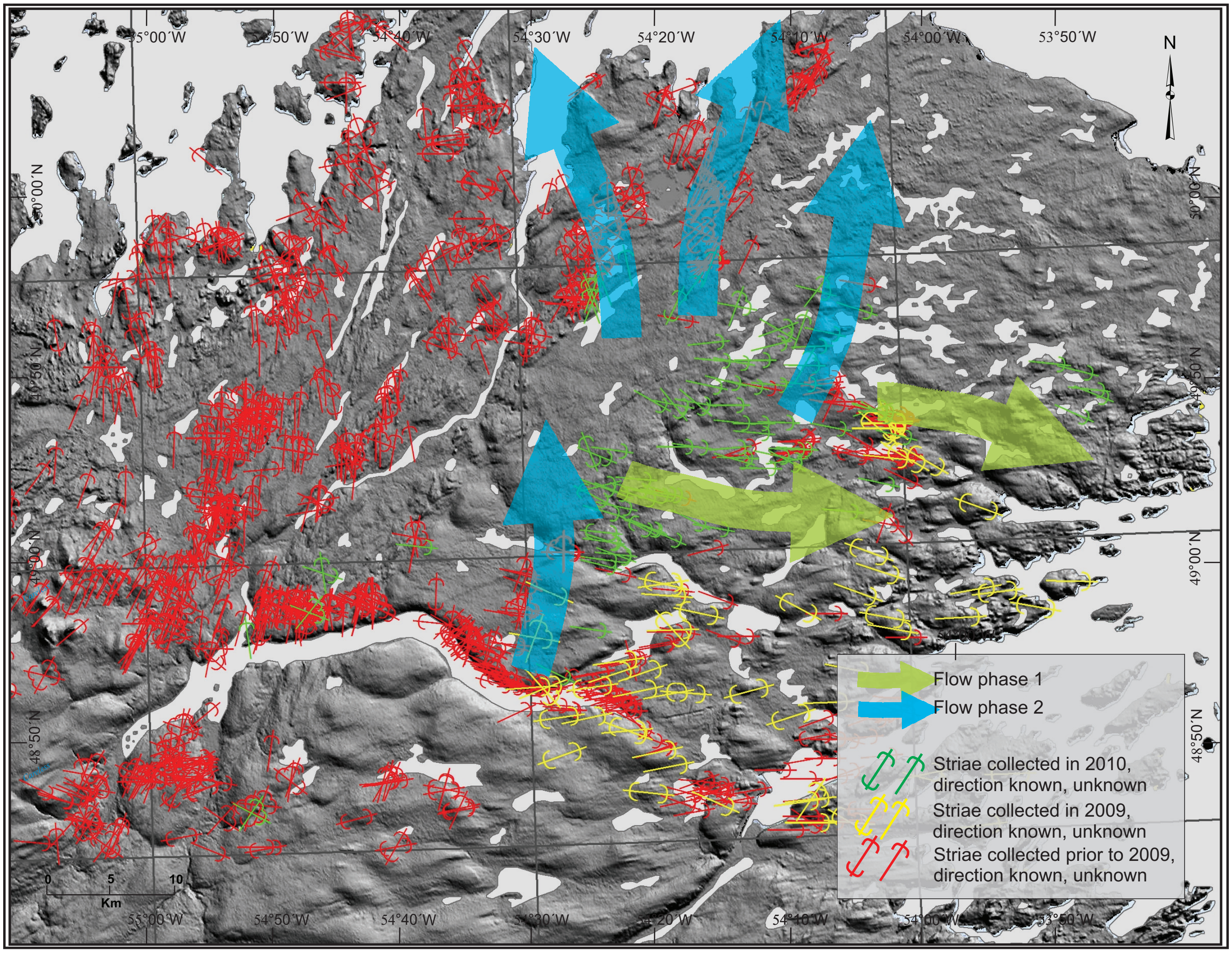

Figure 4. *Ice-flow patterns overlain on SRTM image. At least two ice-flow events affected the study area. The first (Flow phase 1) was a regionally extensive eastward flow, likely from a source north of Red Indian Lake. Stagnant ice was likely present in the eastern part of the study area for some time and deflected the later northward ice-flow event, sourced from the Middle Ridge area.*

ICE-FLOW PATTERNS

The glacial erosional evidence, mostly striations, indicates that two separate ice-flow phases affected the field area. They 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. A total of 104 striations were recorded from 86 sites during the field season and are generally consistent with previously described regional ice-flow patterns (Brushett, 2010; St. Croix and Taylor, 1990, 1991). Sites recording multiple directions were observed at 9 site locations where relative-age relationships were determined from crosscutting data and by preservation of older striations in the lee of younger ones; however, relative age relationships were only determined at 7 sites.

The earliest ice-flow phase was generally eastward (~114° ± 44°) and was found across the entire study area (Figure 4). These eastward striations range between 70° to 158°; it is possible that these are separate ice flows, however, there are no consistent age relationships on which to base this interpretation, and without these age relationships, these striations are interpreted as a single ice-flow phase that shows increased variability toward the coast, which likely reflect topographic influence as thinning ice was drawn-down toward the coast.

Evidence for northward ice-flow (~6° ± 14°) occurs in the western portion of the study area (Figure 4). Where striations related to both the northward and eastward ice-flow phases are observed, the northward flow is interpreted to be the younger of the two, consistent with regional ice-flow relationships events recorded to the west of the study area.

SURFICIAL GEOLOGY

Surficial mapping consisted of 1:50 000-scale airphoto interpretation verified through detailed ground-checking. Most of the study area is covered by diamicton, mostly as veneers or blankets, and large areas of hummocks. Extensive areas of glaciofluvial sand and gravels are found along the Southwest Gander River valley, the area of The Outflow and into the modern Gander River valley. Wetlands are found throughout the study area, some forming bogs up to 10 km long.

Till

Much of the study area is covered by diamicton of varying thicknesses. Thicker till cover occurs in the western part of the study area (Plate 1), and in the east, till generally occurs as a veneer where bedrock is exposed (Plate 2). Only a single stratigraphic unit of diamicton was noted. Sedimentary structures were not generally noted, but this may be due to poor exposure. Diamicton texture and colour varies throughout the field area and reflects the underlying bedrock geology. Diamicton underlain by the Botwood Group are generally reddish-brown, whereas diamicton underlain by the Gander Group are generally light brownish-grey to grey. The matrix is predominantly silty sand, poorly sorted and slightly to moderately compacted. Diamicton are also underlain by several granitic plutons. In these areas, the diamicton is typically pinkish-grey and generally has a coarser, sandier matrix. Clasts are granule- to boulder-sized clasts (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. Angular, fragile shale clasts are common in areas underlain by rocks of the Gander Group, whereas granite clasts are generally subrounded. Clast content varies between 30 to 70% and averages about 50%. The characteristics described above (subrounded clasts, striated and fragile clasts, and silt coatings) are interpreted to represent deposition as subglacial melt-out till (Dreimanis, 1988). These sediments are commonly associated with stagnating glaciers.

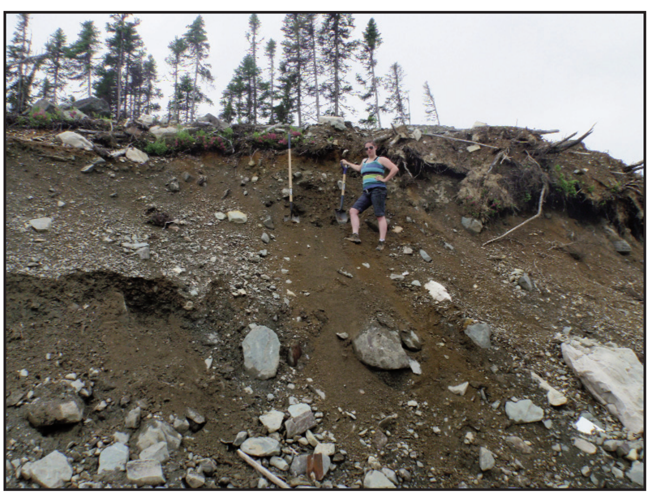

Plate 1. *Thick till blanket in the Boot Pond area. Only one till unit was observed in exposures throughout this area.*

Plate 2. *Thin till veneer having exposed bedrock in the Wing Pond area. Hummocky and boulder strewn terrain are also common in this area.*

Hummocky terrain is present in areas south of Gander Lake, and in the Ten Mile Pond–Moccasin Pond areas in the northeastern part of the study area. These areas commonly have a surface cover of boulders, likely derived from a supraglacial source. The Ten Mile Pond area, in particular, is extensively covered with large boulders, many exceeding 3 m in height (Plate 3).

Plate 3. *Bouldery terrain observed in the Ten Mile Pond–Moccasin Pond area. These areas are extensively covered with large granitic boulders, many exceeding 3 m in height.*

Glaciofluvial–Glaciomarine–Marine Sediments

Glaciofluvial and fluvial deposits are common in the valleys around the Gander River. The largest deposits are found along the Southwest Gander River valley, the area of The Outflow into the modern Gander River valley. These deposits are typically made up of poorly sorted medium- to coarse-grained sands and gravels (Batterson and Vatcher, 1991) and are consistent with deposition within glacial meltwater streams, which typically have rapid changes in discharge. Steeply dipping beds of sand and gravel present at Hunt Ponds are also consistent with deposition in an ice-contact environment.

Glaciofluvial sediments in The Outflow commonly overlie diamicton and are up to 60 m asl or 35 m above the current river level. No evidence of glaciofluvial sediments at this elevation have been observed elsewhere around the shores of the lake, which suggests that water levels were higher in the area of The Outflow.

Organic Deposits

Organic deposits, common within the study area, are generally associated with poorly drained areas. Numerous bogs are found in valleys along the Gander River, low-lying areas in the interior of the region and in depressions associated with hummocky moraine.

GLACIAL HISTORY AND IMPLICATIONS FOR MINERAL EXPLORATION

The study area has been covered by flowing ice, sourced from two distinct areas during the last, late Wisconsinan glacial period. The first ice-flow event was a regional eastward flow that extended into Bonavista Bay. This flow is recorded across much of northeast Newfoundland and likely had a source area 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; Scott, 1994).

The eastward ice-flow event was followed by a north to northeastward ice flow, likely sourced from the Middle Ridge area (Rogerson, 1982). The northward flow is only present in the western portion of the field area, where it is typically associated with thicker till cover. This is particularly apparent in the Boot Pond area, where till thickness is greater than 2 m. Striations found on isolated bedrock exposures also indicate a northward ice flow; east of this area no striation or landform evidence of the 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, previously postulated by Grant (1974). Landform evidence supporting the presence (and possible extent) of stagnant ice includes hummocky moraine at the eastern end of Gander Lake, hummocky topography south of Gander Lake and in the Ten Mile Pond area, and esker-like ridges at the eastern end of Gander Lake, Joe Batt's Brook, and Fox Pond.

The area became ice-free sometime before 12.2 ka (11 300 calendar years) BP; this date is based on marine shells, from the Gander River valley (McCuaig, 2006). To date, no radiocarbon dateable material has been found in the Freshwater 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. Despite the presence of two ice flows, only one till unit was observed; but fieldwork was limited to natural exposures up to 2 m thick. Evidence for the northward flow was observed in areas where previously only eastward flow was documented. This suggests that two ice-flow directions have to be taken into consideration for mineral-exploration purposes.
2. Sampling in glaciofluvial, fluvial and marine settings should be avoided due to the possibility of sediment reworking, and the difficulty in defining distances and directions of transport. These areas include the Southwest Gander River valley, the Outflow, and Gander River valley.
3. Hummocky deposits in the Ten Mile Pond area likely formed in a stagnating environment and may contain a greater proportion of supraglacial (and more far travelled) sediment then basally deposited till.

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