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ICE-FLOW HISTORY AND REGIONAL TILL-GEOCHEMISTRY SAMPLING OF THE SOUTHERN PART OF THE RED INDIAN LAKE BASIN[1]

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ABSTRACT

This was the first year of a multi-year till-geochemistry and regional surficial mapping program in the central volcanic belt, Newfoundland, in support of mineral exploration activity in this area. The first year focused on the southern part of the Red Indian Lake basin, mostly within the Tulks Volcanic Belt of volcanic rocks that have been the focus of considerable mineral exploration activity, but also extending to Victoria Lake in the south and east, and Star Lake in the west. Field work included mapping of ice-flow indicators and till sampling. Future work will extend northward toward Buchans and Millertown, and will include description and interpretation of Quaternary stratigraphy and surficial mapping, as well as ice-flow mapping and till sampling.

Ice-flow mapping in the southern part of the Red Indian Lake basin showed two regionally extensive events. The earliest ice flow was southward from a likely source in The Topsails, followed by a westward to southwestward flow event from a northwest–southeast-trending ice divide located between Lake Ambrose and Snowshoe Pond, north of the study area. Both ice-flow events are interpreted as late Wisconsinan.

Regional till 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. A total of 439 samples were collected.

INTRODUCTION

This year's survey (2007) was the first of a multi-year programme of till sampling and surficial mapping in the central volcanic belt, supported, in part, by the Government of Canada's, Targeted Geoscience Initiative (TGI 3) Program. This geological district has a long history of mining and mineral exploration, including the Buchans Cu–Pb–Zn Mine that operated between 1928 and 1984, and the Duck Pond Cu–Zn Mine that opened in 2007. The initial phase of the 2007 survey focused on the southwest part of the central volcanic belt, and included parts of the Tulks Volcanic Belt (TVB) of the Victoria Lake supergroup (VLS). This area contains significant volcanogenic massive sulphide deposits that have been the focus of considerable mineral exploration activity (Hinchey, 2007). The surficial mapping and till geochemistry program will support current exploration efforts, and may also stimulate mineral exploration activity in more inaccessible parts of the area. Field work in 2007 consisted of till sampling and mapping of ice-flow indicators over an area of the southwestern Red Indian Lake basin (NTS map areas 12A/6, 12A/10, 12A/11; Figure 1). In the subsequent years of this project, the coverage of till sampling will extend northeastward through the Tulks Belt, south of Red Indian Lake and in the Buchans area, north of the lake. Future work will include surficial geological mapping, description and interpretation of Quaternary stratigraphy and mapping of ice-flow indicators.

LOCATION, ACCESS AND PHYSIOGRAPHY

The study area consists of all, or parts, of NTS map areas 12A/6, 12A/10, and 12A/11, located at the southwest end of Red Indian Lake, central Newfoundland (Figure 2). Most of the area is between 250 and 350 m asl, with the highest point being about 550 m asl, on the highland between Star Lake and Red Indian Lake. The eastern part of the area is characterized by a gentle topography and few bedrock outcrops and thick (commonly >2 m) cover of Quaternary sediment. In contrast, the west is more rugged, having thinner sediment cover and more bedrock outcrop. This area marks the eastern extent of the Annieopsquotch Moun-

[1]Contribution to the Geological Survey of Canada Targeted Geoscience Initiative (TGI 3)

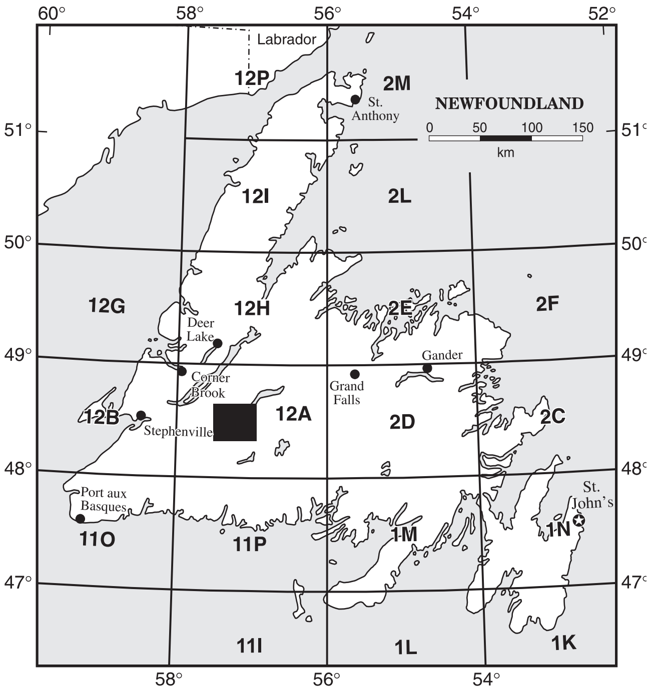


Figure 1. *Location of study area.*

tains, which reach elevations of about 600 m asl, just west of the study area.

The area is dominated by several large lakes, including Star Lake, Lloyds Lake, Victoria Lake, and Long Lake. The largest lake is Red Indian Lake (156 m asl; Plate 1) that drains northeastward via the Exploits River into Notre Dame Bay. The lake is fed by numerous rivers and streams, the largest of which is Lloyds River that enters the lake at its southwestern end through a channel incised through bedrock. Other streams at the southwestern end also have incised channels, including Star Brook, Tulks Brook and Costigan Brook. Some of these were likely produced by drainage from proglacial lakes above Red Indian Lake (*e.g.*, Costigan Brook; Plate 2). Several lakes are dammed for hydroelectric power generation, including Red Indian Lake, which is dammed at its northern outlet, and Victoria Lake, which is connected to the Burnt Pond–Granite Lake–Meelpaeg Lake reservoir system. The Victoria River valley now contains an underfit stream, on a broad, flat valley floor, exposing glaciofluvial and postglacial fluvial sediments.

Access to the area is via an extensive network of forest-access and mineral exploration roads; most are suitable for passenger vehicles, although some are only accessible using all-terrain vehicles due to re-vegetation, washouts, removal of bridges and so forth. Some areas were inaccessible to vehicles, and these areas were reached using a helicopter. In particular, sampling of the area around Victoria and Long lakes required helicopter-support.

Plate 1. *View looking northeast along the Red Indian Lake basin.*

Plate 2. *View looking northwest from Costigan Lake. This feature may be a spillway from a proglacial lake in the Costigan Lake basin that flowed into Red Indian Lake. Proglacial lakes have been identified at several places in the Red Indian Lake basin.*

BEDROCK GEOLOGY

Much of the geological description of the study area is derived from Hinchey (2007). The study area is within the Dunnage Zone, of the Newfoundland Appalachians, and is characterized by sedimentary and associated volcanic rocks deposited as island arcs within the Iapetus Ocean during the Cambro-Ordovician period. The Dunnage Zone is separated into two components by the Red Indian Line; to the west is the Red Indian Lake group and the Buchans Group, which formed on the North American continent side, and to the east is the VLS, which formed on the Gondwanan side of the ocean (Figure 3).

The Buchans Group consists of mafic to felsic volcanic and volcaniclastic rocks. Within the study area, the oldest rocks are Neoproterozoic to Early Ordovician siliciclastic

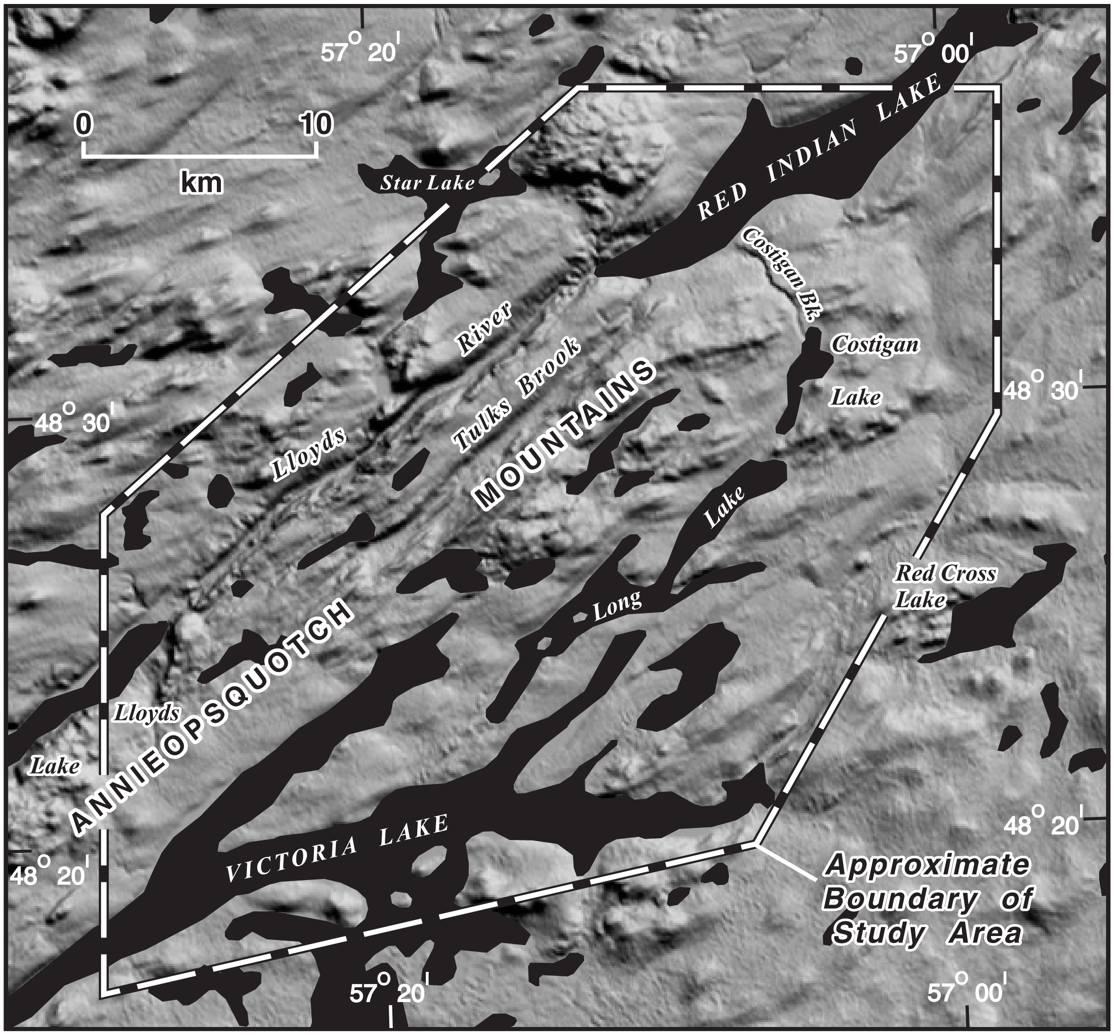
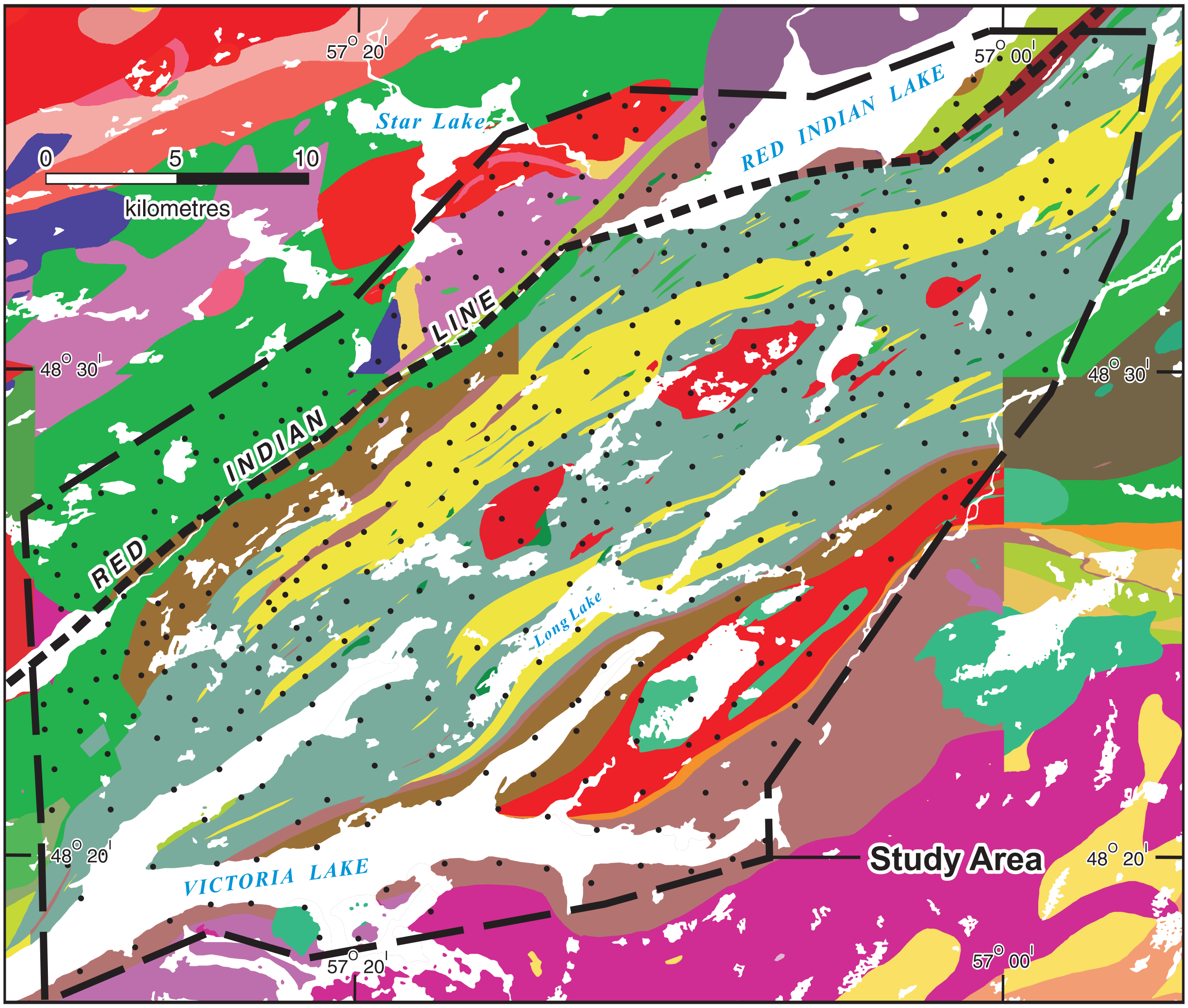


Figure 2. *SRTM image of the study area and surrounds showing physiography, and places mentioned in text.*

marine rocks of the Fleur de Lys Supergroup. These rocks are in tectonic contact with Early Ordovician ophiolite rocks of the Annieopsquotch Complex (mostly medium- to coarse-grained gabbro and olivine gabbro) and Star Lake ophiolite complex (pegmatitic hornblende diorite, gabbro, diorite, pyroxenite), and subsequently by Early to Late Ordovician biotite–hornblende granodiorite and hornblende tonalite rocks of the Pierre's Pond plutonic suite. The Early Silurian Star Lake intrusive suite completes the intrusive sequence. This suite is mostly composed of slightly to moderately foliated granite and minor granodiorite intrusions. The Buchans Group belt of rocks is capped by the Mississippian Shanandithit formation, which is composed of poorly indurated red and grey sandstone and conglomerate.

The oldest rocks south of the Red Indian Line, within the study area, are Early Cambrian to Early Ordovician quartz monzonite, granodiorite and quartz diorite of the Valentine Lake quartz monzonite (Figure 3). These rocks are overlain by rocks of the VLS, which may be subdivided into the TVB, Long Lake Volcanic/Volcaniclastic Belt, and the Tally Pond Volcanic Belt north of study area (Evans and Kean, 2002). These rocks are mostly felsic volcanics intermixed with mafic volcanic, felsic pyroclastic, volcaniclastic and sedimentary rocks. Hinchey (2007) suggests that the most common rock type of the TVB are light-grey to white, quartz±feldspar porphyritic pyroclastic rocks, felsic ash tuffs through to tuffs and lapilli tuffs, breccias and subvolcanic porphyries. The area hosts a series of plutons, including the Early to Middle Ordovician Snowshoe Pond granite (grey to red biotite granite and granodiorite), and the Early Silurian to Middle Devonian Redcross Lake intrusion (mostly gabbro). The Late Silurian to Middle Devonian North Bay granite suite (biotite±muscovite granodiorite and granite) intrudes the Redcross Lake intrusion.

There has been extensive mineral exploration in the Victoria Lake Supergroup. ASARCO discovered the Tulks Hill deposit in 1961, followed by more detailed work by Abitibi-Price in the 1970s, which led to the discovery of the



Mississippian

Shanandithit Formation: Poorly indurated, red and grey sandstone and conglomerate; minor limestone and siltstone

Late Silurian to Middle Devonian

North Bay Granite Suite: Medium-to coarse-grained biotite +/- muscovite granodiorite and granite

Early Silurian to Middle Devonian

Redcross Lake Intrusion: Medium-grained, grey gabbro and/or diorite; some troctolite, pyroxenite and biotite granite

Early Silurian

Star Lake intrusive suite: Foliated granite and minor granodiorite intrusions

Early to Late Ordovician

Pierre's Pond Plutonic suite:

Medium-grained, grey gabbro and/or diorite; some troctolite, pyroxenite and biotite granite

Biotite granite and granodiorite

Early to Middle Ordovician

Snowshoe Pond granite: Medium-grained, grey, pink or red, biotite granite and granodiorite

Early Ordovician

Annieopsquotch Complex: Basaltic pillow lava and minor red chert; diabase dykes, gabbro

Early Cambrian to Late Ordovician

Victoria Lake Supergroup

Tulks Hill Volcanics: Intermediate flows, and pyroclastic volcanic rocks and pillow lavas; some sedimentary rocks

Tulks Hill Volcanics: Felsic volcanic rocks; some pyroclastic volcanic rocks, pillow lavas and sedimentary rocks

Tulks Hill Volcanics: Volcanic marine rocks and associated siliclastic marine rocks

Stanley Waters Formation: Greywacke, siltstone, shale and associated volcanic rocks

Harbour Round Formation: Basalt and associated siliclastic marine rocks

Ediacaran

Valentine Lake Quartz Monzonite

Felsic quartz-porphyritic quartz monzonite, granodiorite and quartz diorite

Mafic quartz-porphyritic quartz monzonite, granodiorite and quartz diorite

Neoproterozoic to Early Ordovician

Fleur de Lys Supergroup: Metaclastic schists with interlayered amphiboilite and greenschist

Figure 3. *Bedrock geology of the study area (mostly from Geological Survey Resources atlas http:// gis.geosurv.gov.nl.ca/), including till sample locations.*

Tulks East prospect and 3 other VMS showings. Subsequent exploration by BP Canada Ltd., and Noranda Mining and Exploration discovered and defined several VMS-rich deposits, although none were brought to the final stages of development. Surging metal prices in the early 2000s refocused exploration efforts, with Messina Minerals discovering the Boomerang VMS deposit in 2004, and subsequently the associated Domino and Hurricane deposits (Hinchey, 2007). Delineation of the Boomerang cluster of deposits continues.

REGIONAL TILL-GEOCHEMISTRY PROGRAM

Sediment sampling was on a rough grid of 1 sample per 1 km^2 where access was good and a spacing of 1 sample per 4 km^2 where helicopter support was required. Samples were usually taken of the C- or BC-soil horizon, at a depth of about 0.5 m from hand-dug test pits or 0.5 to 1.0 m in road-cuts, quarries, and natural exposures along lake shorelines (Plate 3) or rivers. Sediment matrix samples (~1 kg) were collected in kraft-paper bags and submitted to the Geological Survey laboratory for geochemical analysis, including a suite of elements determined from AA and ICP techniques. Samples will be sent for external analysis for other elements, including gold, by INAA techniques. A total of 439 samples (including duplicates) were collected during this initial phase using a combination of road (truck and ATV) and helicopter-supported sampling (Figure 3). Data release is anticipated in mid to late 2008.

Plate 3. *Till sampling was made easier by the low levels of the Victoria Lake reservoir.*

REVIEW OF QUATERNARY HISTORY

The Quaternary history of central Newfoundland was summarized by Grant (1989) and Vanderveer and Sparkes (1982), although details of the sequence and timing of events and the relationship of separate ice flows to Quaternary stratigraphy remain largely unresolved. More recently Shaw *et al.* (2006) described the sequence of deglacial events following the late glacial maximum, based mostly on striation and landform data. These show a first-order ice divide along the axis of the Long Range Mountains, extending eastward through central Newfoundland to the Avalon Peninsula (Figure 4). This divide remained roughly in place through much of the late Wisconsinan, eventually collapsing during regional disintegration of the Newfoundland Ice Cap some time after 12 ka radiocarbon years (*ca.* 14 ka calendar years).

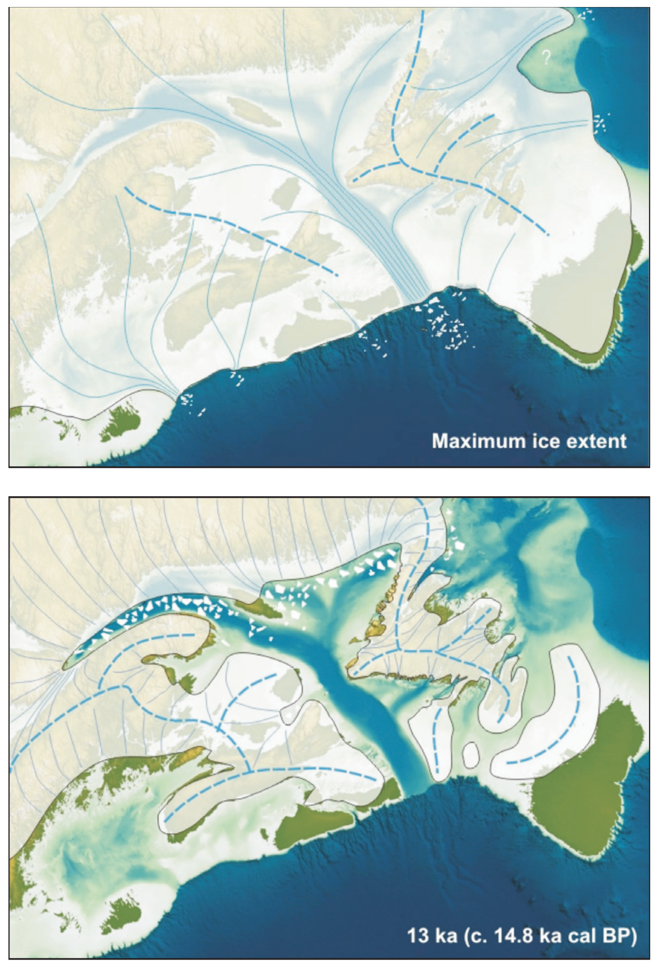


Figure 4. *Pattern of glaciation in Newfoundland (from Shaw* et al.*, 2006).*

Several directions of paleo-ice flow have been recorded on the basis of crosscutting striations and streamlined landforms (Murray, 1955; Graham and Grant, 1991; Klassen and Murton, 1996; Grant and Tucker, 1976; Sparkes, 1984). The earliest flow was a regionally extensive southward ice-flow event from a source in the Topsails, based on striations and the dispersal of Topsails Intrusive Suite granites from The Topsails plateau across the Red Indian Lake basin (Klassen, 1994; Klassen and Murton, 1996). Earlier suggestions of ice flow originating from a source in the Labrador sector of the Laurentide Ice Sheet (Murray, 1955) are inconsistent with regional striation patterns described from the Humber basin area to the north (Batterson, 1999, 2003; Taylor, 2001).

This early southward flow was followed by flow from an ice divide that extended northwest–southeast in the area between Lake Ambrose and Snowshoe Pond (Sparkes, 1984; Taylor, 1994). North of the divide, ice flow was northeastward toward Grand Falls (Klassen and Murton, 1996). This ice-flow event produced glacial landforms oriented parallel and perpendicular to glacial flow (Sparkes, 1984; Graham and Grant, 1991), as well as northeastward clast dispersal of amygdaloidal volcanic rocks from the Buchans Group (Klassen, 1994). South of the ice divide, ice flow was westward to southwestward along the Lloyds River valley and Victoria Lake basin. This flow produced a striation record, as well as ice-parallel glacial landforms (Sparkes, 1984; Taylor, 1994).

The pattern of ice-flow events provides a relative chronology of the sequence of events. Correlation with the glacial stratigraphy is problematic. In the southwest Red Indian Lake basin and around Victoria Lake, Sparkes (1984) and Vanderveer and Sparkes (1982) described basal till deposited by the early southward ice flow overlain by till derived from the westward flow. Around Red Indian Lake and in the Lloyds River valley these tills were separated by proglacial lake sediments produced by a glacial lake that reached about 59 m above present lake levels, and informally named 'glacial Lake Shananditihit' (Mihychuk, 1985). Thus, the glacial stratigraphy suggested 2 phases of glaciation separated by a non-glacial period. Some support for this argument was presented by Grant (1989), who argued that preservation of iron staining on striated bedrock outcrops indicated chemical weathering during an ice-free period. Klassen and Murton (1996) described a similar stratigraphy at Buchans to that presented by Sparkes (1984) and Vanderveer and Sparkes (1982), with diamictons separated by proglacial lake sediments, although at Buchans the upper diamicton ('till') was interpreted as subaqueous debris-flow deposits. This interpretation, if applicable to the similar stratigraphy described in other areas of the Red Indian Lake basin, indicates that the complete sediment package could have been deposited during the late Wisconsinan.

There are no radiocarbon dates to constrain a chronology, and the lack of detailed sedimentology on exposures in the southwest Red Indian Lake basin makes it difficult to compare descriptions and subsequent interpretations with other exposures in the area.

ICE-FLOW PATTERNS

STRIATION RECORD

Thirty-six (36) ice-flow indicators (striations) were measured from bedrock outcrops across the study area, to supplement the measurements from previous studies. Data are interpreted to show that two regional ice-flow events affected the area (Figure 5). The earliest was predominantly southward and crossed the entire area. This is consistent with Event I of Klassen (1994) that was interpreted as having been derived from an ice centre in The Topsails. This southward event was succeeded by a southwestward to westward flow and is consistent with descriptions of Sparkes (1984) and Taylor (1994). All the striations were fresh and unweathered, and on this basis, along with correlations with regional ice flows, are tentatively assigned a late Wisconsinan age.

SRTM IMAGE

The Shuttle Radar Topography Mission (SRTM), flown in 2000, aimed to map the Earth's surface topography using synthetic aperture radar. Data from the mission are freely available online, and has been used for interpreting glacial landforms (*e.g.*, Campbell, 2005). Liverman *et al.* (2006) provided a preliminary interpretation of a digital elevation model (DEM) from the SRTM data that provide additional data on the ice-flow and glacial history of the Island. In the Red Indian Lake area, the SRTM image shows streamlined glacial landforms (flutes and drumlins), and moraines oriented perpendicular to flow throughout the area. The SRTM image and interpreted landforms are shown in Figure 6. Streamlined landforms are common north of the Lloyds River valley, and are consistent with the orientation of striations in the area indicating westward to southwestward ice flow. This area contains numerous bedrock outcrops, indicated by the rough texture of the image. The area between Lloyds River and the western edge of Victoria Lake is bedrock dominated and constructional features are rare. Small moraine ridges and some southwest–northeast-oriented flutes are found between the Victoria River and Costigan Lake. East of Victoria River and Victoria Lake, moraine ridges are common, and is reflected by the smoother texture of the terrain shown on the SRTM image. In all areas the orientation of the moraine ridges is consistent with the glacial erosional record showing deposition from southwestward ice flow.

SUMMARY OF QUATERNARY HISTORY

Although the relative sequence of ice-flow events across the southern part of the Red Indian Lake basin appear

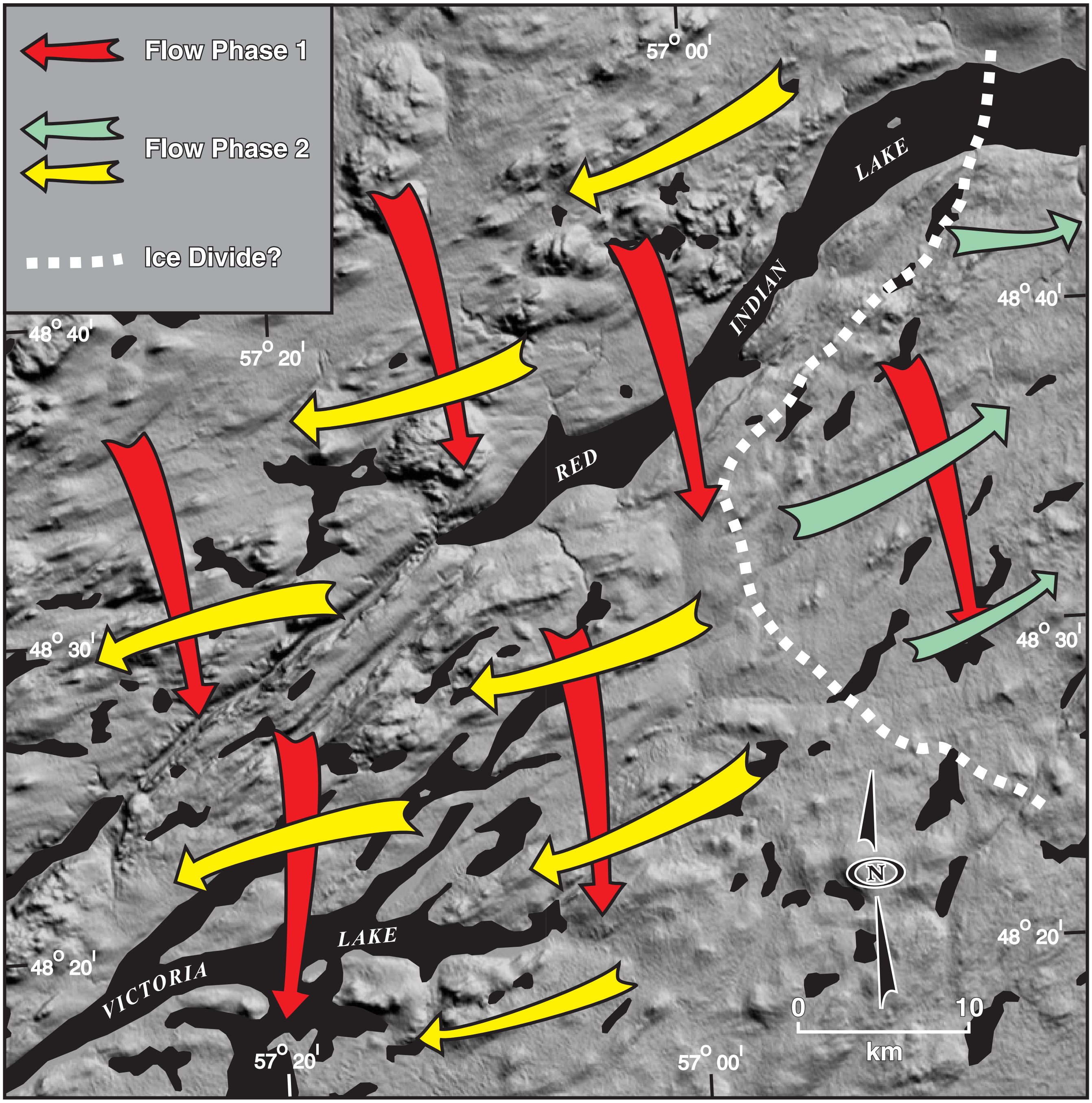


Figure 5. *Ice-flow patterns overlain on the SRTM image. At least 2 major ice-flow events affected the area. The first (Flow Phase 1) was a regionally extensive southward flow from a likely source in The Topsails. This was followed by divergent flow (Flow Phase 2) from an ice divide south of Red Indian Lake that produced westward flow at the western end of the Red Indian Lake and Victoria Lake basins. The SRTM image shows numerous glacial landforms in the Victoria Lake basin, which support the proposed ice-flow history (see text).*

clear, the absolute chronology and the relationship of ice flow to the glacial stratigraphy exposed through the area is far from resolved. The earliest ice flow was southward, and is correlated with Event I of Klassen (1994) and the earliest flow of Sparkes (1984). This flow direction is not reflected in the reconstructions of Shaw *et al.* (2006), and suggests that if the model is an accurate depiction of deglacial events, this flow must have occurred prior to the glacial maximum. This was followed by a westward to southwestward flow event, which correlates to the later flow described by Sparkes (1984) and Taylor (1994). It is likely contemporaneous with the northeastward Event II flow described by

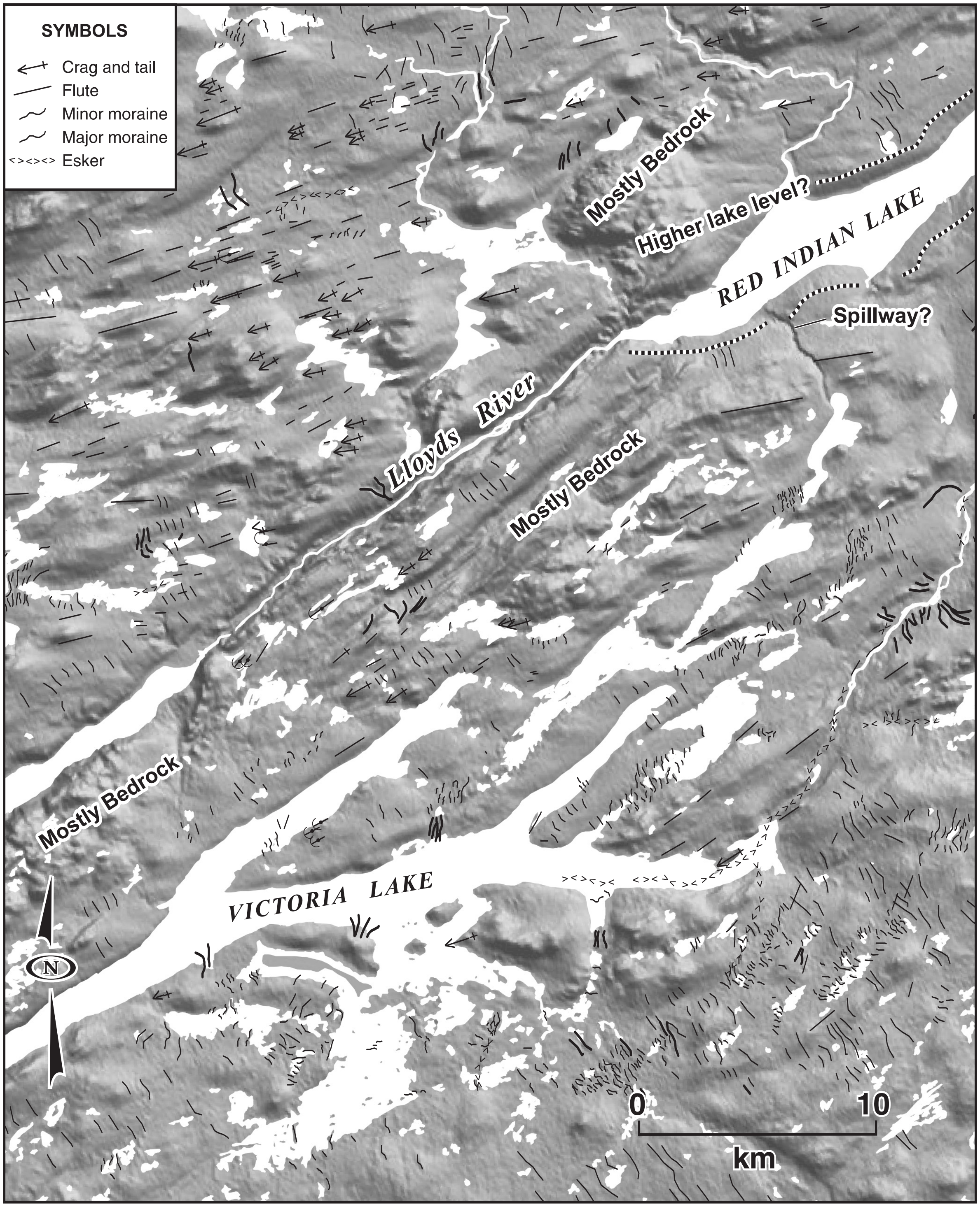


Figure 6. *SRTM image of the study area showing glacial landforms (modified from unpublished map by D. Liverman, GSNL, 2007). The area north of Lloyds River contains numerous features oriented parallel to glacial flow and indicate westward to southwestward ice flow. Bedrock is common in this area. Eskers and small moraines oriented perpendicular to ice-flow record the pattern of retreat across the area. The area south and east of Victoria Lake contains numerous small moraines oriented perpendicular to ice flow, but relatively few features oriented parallel to flow. Till is thicker in this area compared to areas to the north. This shows broad patterns of retreat across the area. Areas of dissected sediment cover around the margins of Red Indian Lake may suggest higher lake levels, and a possible spillway from Costigan Lake may show drainage from an ice-marginal proglacial lake.*

Klassen (1994) and represents flow from an ice divide that extended through the central part of the Red Indian Lake basin.

During deglaciation, proglacial lakes occupied the Red Indian Lake basin at elevations up to about 300 m, or 148 m above present lake levels (Sparkes, 1984; Mihychuk, 1985; Klassen and Murton, 1996). The largest lake, which occupied the Red Indian Lake basin up to 212 m asl was informally named 'glacial lake Shananditit by Mihychuk (1985). Glacial lakes are represented by strandlines and glaciolacustrine sediments (mostly debris-flow diamictons with some rhythmites and other associated fine-grained sediments). The relationship between the proglacial lakes described by Klassen and Murton (1996) and Mihychuk (1985), and thus the pattern of glacial retreat in the Red Indian Lake basin, is uncertain. Mihychuk (1985) and Klassen and Murton (1996) suggest the glacial lakes were deglacial features, based on stratigraphic evidence, whereas Vanderveer and Sparkes (1982) argue for a pre-late Wisconsinan age, based on the interpretation of overlying diamicton as till. Further detailed stratigraphic work will be required to resolve this issue.

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