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GLACIAL STRATIGRAPHY OF THE SOUTHWEST RED INDIAN LAKE BASIN, NEWFOUNDLAND: PRELIMINARY RESULTS

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ABSTRACT

This paper presents the third-year results of a multi-year program of till sampling, ice-flow and regional surficial mapping in the Red Indian Lake Basin, Newfoundland. The program was initiated to assist the increased mineral exploration in the Red Indian Lake Basin by better understanding its Quaternary geology. Preliminary results from the southwest part of the basin and along the north side of Red Indian Lake are presented. The stratigraphy of the Red Indian Lake Basin is complex. Three distinct diamictons were identified at three separate locations. Glaciofluvial deposits, made up of varying thicknesses of sand and gravel, are typically found in valley bottoms. Glaciolacustrine deposits include both fine- and coarse-grained sediments. The fine-grained sands and silts were identified up to 346 m above sea level; the coarse-grained sediments form deltas at 200 m and 300 m asl on the south and north side of Red Indian Lake, respectively. The spatial distribution of glaciolacustrine sediments indicates at least three phases of proglacial lake development; however, the extent and timing of these lakes remains unknown.

INTRODUCTION

This paper presents the results from the third year of field work of a multi-year program on the Quaternary geology of the Red Indian Lake Basin (RILB). The first two years focused on regional ice-flow history and geochemical sampling, the results of which were presented by Batterson and Taylor (2008), Smith (2009) and Smith *et al.* (2009). The 2009 field program comprised two small sampling programs, partly based on encouraging geochemical results from earlier programs and partly with the aim of expanding the sampling area, although the focus was on surficial mapping, stratigraphy and ice-flow history of the southwest end of Red Indian Lake. This paper describes the Quaternary sediments (diamicton, glaciofluvial and glaciolacustrine) that comprise the RILB stratigraphy, and provides evidence for proglacial lake development. An understanding of the basin stratigraphy, and how it relates to the ice-flow history and surficial landforms, will be an important contribution to the future development of a comprehensive strategy for drift-exploration programs in the area.

LOCATION, ACCESS, PHYSIOGRAPHY AND BEDROCK GEOLOGY

The study area includes NTS map area 12A/10 and parts of NTS map areas 12A/4, 5, 6, 7, 11 and 15, with an area of 3,570 km^2 (Figure 1). It extends from Tally Pond southwest to Wood Lake, and from Snowshoe Pond northward to the north end of the Star Lake access road.

The field area can be reached from the east by Route 370 off the Trans-Canada Highway, or by the woods road that extends south of the Exploits River from Grand Falls–Windsor. In the west, Route 480 (Burgeo Highway) provides access to the woods road that extends through the Lloyds River valley. Being within 100 km of a recently active pulp and paper mill, the RILB has an extensive forestry road network; however, remote sampling sites were accessed by helicopter.

The study area lies within the Dunnage Zone of the Newfoundland Appalachians (Figure 2). Sedimentary and volcanic rocks within this zone are the remnants of continental, intra-oceanic area, back-arcs and ophiolites deposited within the Iapetus Ocean during the Cambro-Ordovician (Evans and Kean, 2002; Hinchey, 2008). The Red Indian Line, which lies along the south shore of Red Indian Lake, separates the rocks of the Red Indian Lake and Buchans groups of the Notre Dame Subzone from the Victoria Lake supergroup of the Exploits Subzone. These subzones formed on the North American continent side and the Gondwanan side of Iapetus, respectively. A detailed description of the bedrock geology of the area is given in Evans and Kean (2002) and Hinchey (2007, 2008).

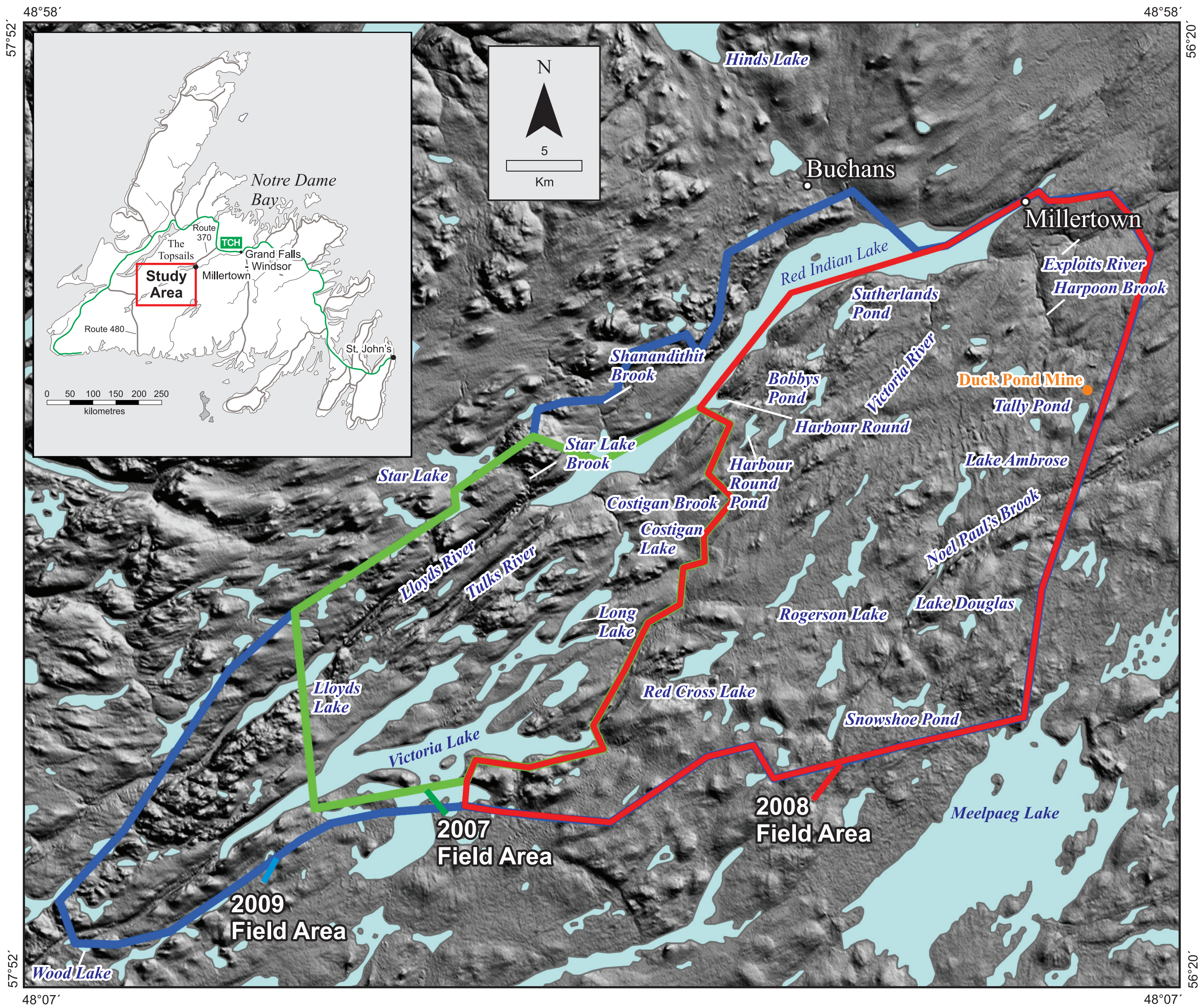

Figure 1. *Location of Red Indian Lake in central Newfoundland. Map identifies the location of the 2007 (green polygon, Batterson and Taylor, 2008), 2008 (red polygon) and 2009 (blue polygon) field areas. Note: Tulks River is also known as Tulks Brook. TCH – Trans-Canada Highway.*

QUATERNARY GEOLOGY

BACKGROUND

During the late Wisconsinan glacial maximum, Newfoundland was covered by a series of coalescent ice caps, which formed the Newfoundland Ice Cap (Grant, 1989; Shaw *et al.*, 2006). Ice divides extended down the Long Range Mountains through central Newfoundland and eastward to the Avalon Peninsula (Figure 3a). This configuration remained stable throughout much of the late Wisconsinan (Shaw *et al.*, 2006), until sometime after 13 ka BP as deglaciation became terrestrial, leading to the disintegration of the Newfoundland Ice Cap into a number of small isolated ice caps (Figure 3b). One of these was postulated to lie over Red Indian Lake (Grant, 1974; Figure 4). The complex ice-flow history recorded by many researchers in central Newfoundland (Vanderveer and Sparkes, 1982; Sparkes, 1985; Klassen, 1994; Klassen and Murton, 1996) reflects the shifting ice divides during the collapse of the Newfoundland Ice Cap. Central Newfoundland has also been suggested as one of the few places where there is evidence of multiple phases of glacial and deglacial deposition (Klassen and Murton, 1996), and was one of the last areas in Newfoundland to become ice free, sometime after 10 ka BP (Shaw *et al.*, 2006). Marine limit is 40 m asl at Stephenville and 75 m asl at Springdale (*cf.*, Liverman *et al.*, 1995; Batterson, 2003), which is well below the minimum elevation recorded for the study area (152 m asl).

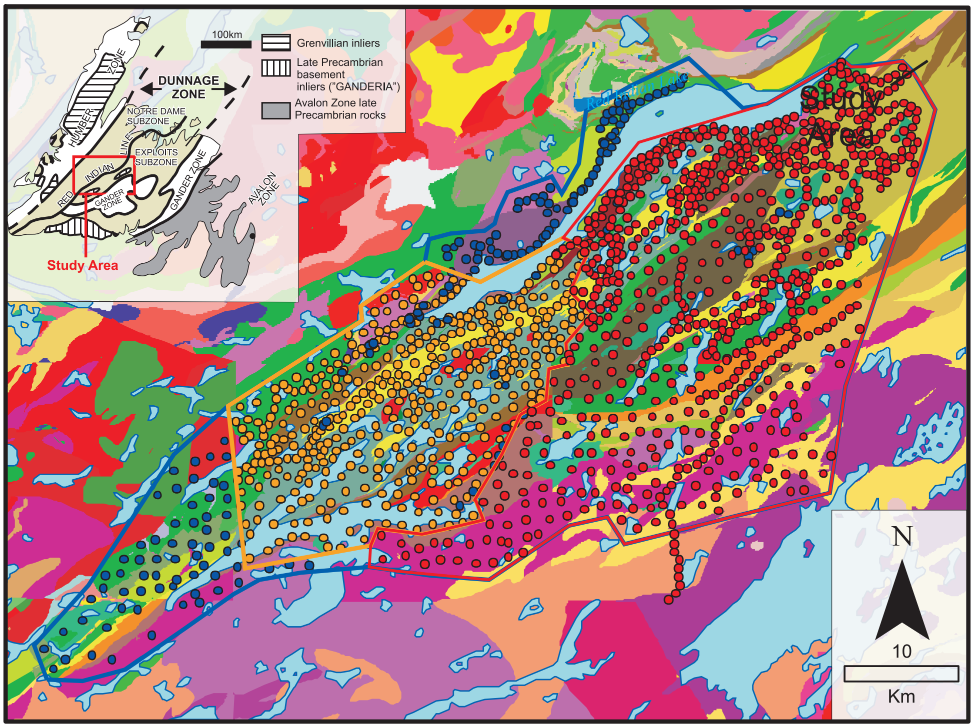

Figure 2. *Bedrock geology map of the RILB showing location of samples collected within the 2007 (orange polygon), 2008 (red polygon) and 2009 (blue polygon) field areas (bedrock geology map taken from the Geological Survey Resource Atlas http://gis.geosurv.gov.nl.ca, Colman-Sadd and Crisby-Whittle, 2005).*

ICE-FLOW HISTORY

The ice-flow history of the RILB has been described in detail by Smith (2009), and comprises two main late Wisconsinan ice-flow events (Figure 5). The earliest ice flow was south to southeast from a source in The Topsails (Figure 5; Phase 1, red arrows). In the southwest of the RILB, the Phase 1 ice flow was predominantly southward, while in

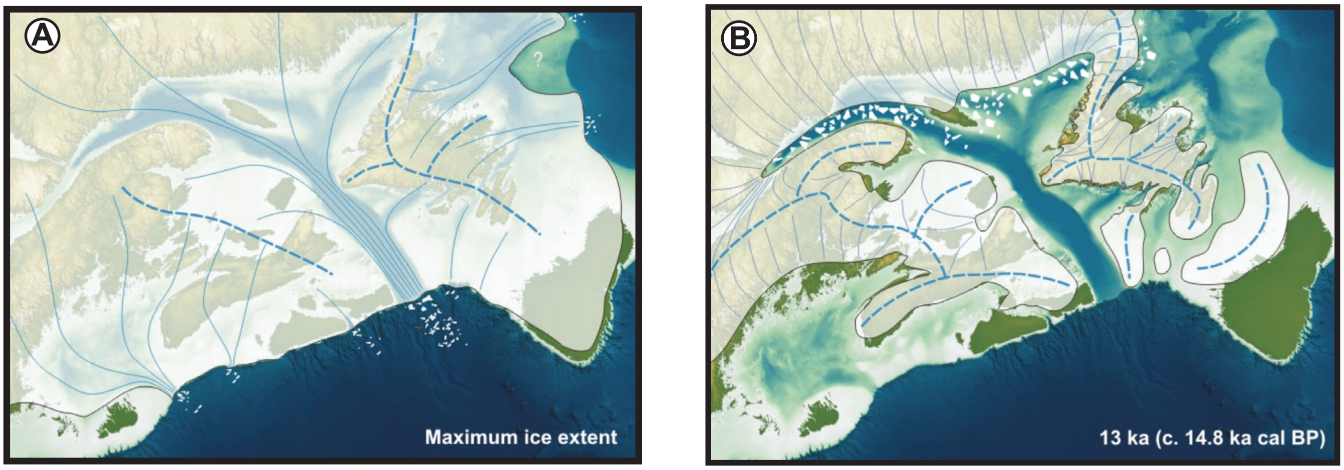

Figure 3. *Pattern of deglaciation for Atlantic Canada. Note the pattern for the Island of Newfoundland for (A) the maximum ice extent and (B) at 13 Ka BP. Dotted lines indicate approximate location of ice divides (Shaw* et al.*, 2006).*

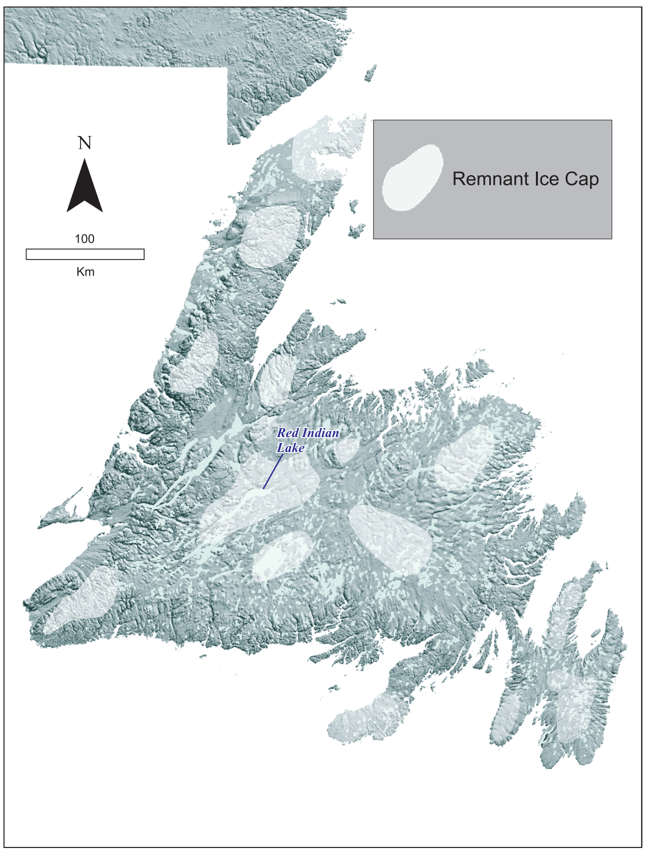

Figure 4. *Map of Newfoundland showing the approximate location of remnant ice caps as the Newfoundland ice cap disintegrated (modified after Grant, 1974).*

the northeast part, it was southeastward. The Phase 1 flow was followed by the development of an ice divide between Harbour Round Pond and Costigan Lake, where ice flow diverged toward the northeast and southwest (Figure 5; Phase 2, yellow arrows). A north-northwest flow was identified from several sites near Harbour Round Pond, northeast of Bobby's Pond and along the road at Lake Douglas; however its age relative to other flows is not known.

SURFICIAL GEOLOGY AND STRATIGRAPHY

Quaternary sediments within the RILB are commonly thick, exceeding 50 m near Buchans and represent several genetic environments, including glacial, glaciofluvial, glaciolacustrine and modern fluvial and organic sediments (Vanderveer and Sparkes, 1982; Klassen and Murton, 1996).

The stratigraphy of the basin was described by Vanderveer and Sparkes (1982), Sparkes (1984, 1985), Mihychuk (1985) and Klassen and Murton (1996). In the southwest part of Red Indian Lake, Vanderveer and Sparkes (1982) and Sparkes (1984, 1985) described a lowermost till in the Tulks River valley and near Costigan Lake as having been deposited during the earliest southward ice flow because it contains gabbro clasts derived from a bedrock source to the north (Sparkes, 1984). Sparkes (1984) also described a repetitive sequence of sand and silt, which he termed the Lloyds River rhythmites, and interpreted them as having been deposited in a proglacial lake whose formation was synchronous with the separation of the southward glacial flow into smaller local ice centres. This area was interpreted to have been covered by a local readvance from an ice centre situated between Victoria Lake and Lake Ambrose, from which ice flowed northeast and southwest (Sparkes, 1985). Simultaneously, ice flowed from a centre at Hinds Lake and occupied the RILB, including the Lloyds and Tulks River valleys, depositing till on top of the rhythmites (Sparkes, 1985). Vanderveer and Sparkes (1982) suggested that the elevation of the proglacial lake was at least 59 ± 5 m above Red Indian Lake (*i.e.*, 216 m asl); however no explanation was given for this estimation. Mihychuk

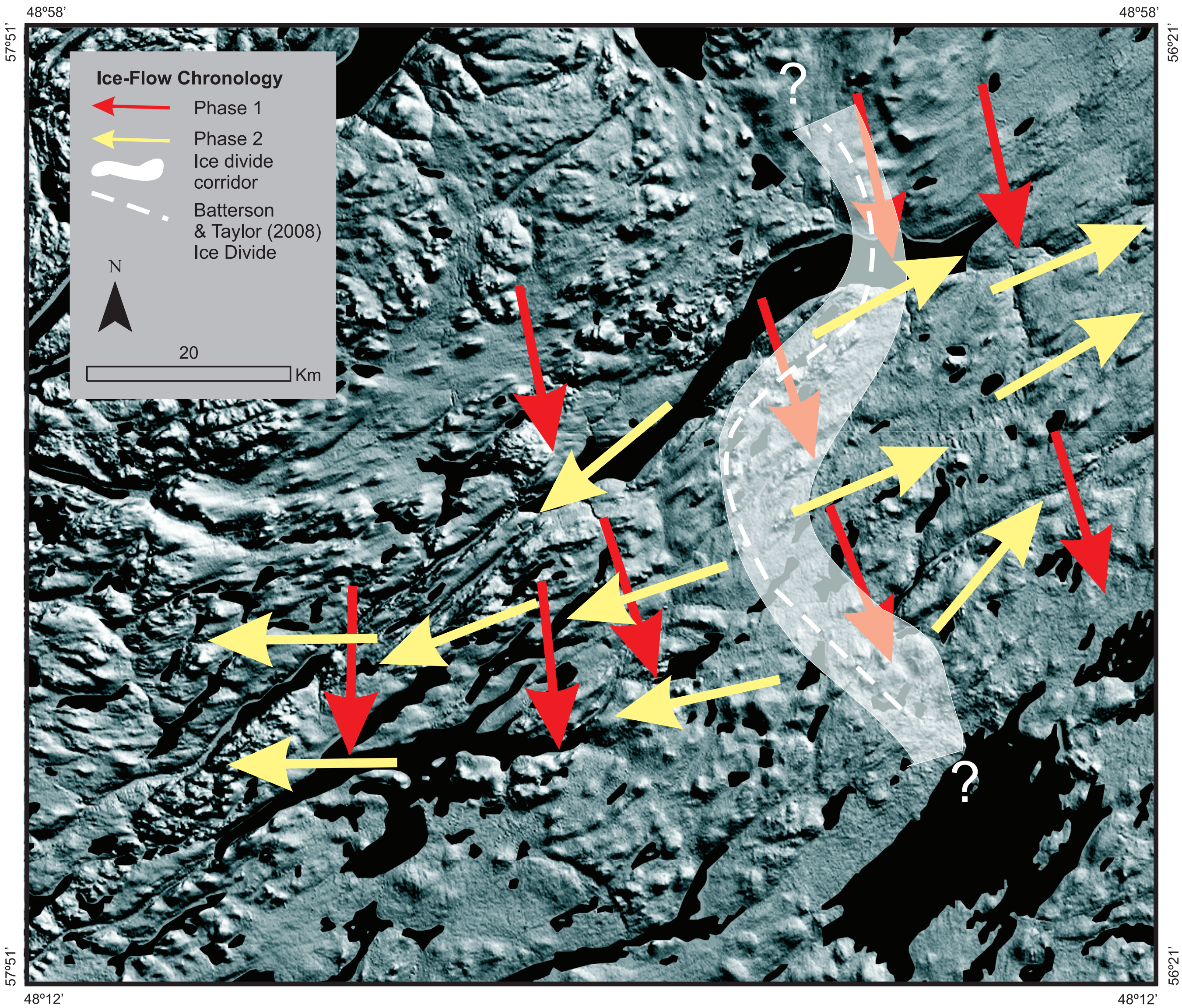

Figure 5. *Map showing the ice-flow chronology for the RILB.*

(1985) described a well-developed strandline at 212 m asl in the Victoria River area and suggested it was related to the proglacial lake described by Vanderveer and Sparkes (1982). Mihychuk (1985) informally named this lake, glacial Lake Shananditit. Proglacial lake sediments deposited in a lake with a maximum surface elevation of 300 m asl were also described by Klassen and Murton (1996) in the Buchans area, which they argued to be the result of ice damming in the RILB.

METHODS

CLAST FABRICS

The field component involved measuring the orientation and plunge of 25 elongate pebbles having a length:breath ratio of greater than 3:2. Clasts were measured within a small area (<1 m^2), away from contacts and large boulders. Collected data were entered into GEOrient ver. 9.4.4 (Holcombe, 2009) and plotted on an equal area stereonet. Using statistical analysis within GEOrient, the shape (K) and strength (C) of the clast fabric can be calculated following the methods of Woodcock (1977). Eigenvectors (V1, V2, and V3) show the direction in which the maximum clustering of clast orientations occur, while eigenvalues (S1, S2, and S3) describe the degree of clustering around eigenvectors.

Clast fabric measurements provide a three-dimensional view of clasts within a diamicton. These measurements are used in conjunction with sedimentological data to aid in determining if diamictons represent primary (*e.g.*, meltout, lodgement) or secondary tills (*e.g.*, gravity flow deposits). The fabrics measured in primary basal tills (S1>0.6, K>1.0) provide data on potential ice-flow direction.

Clast fabrics can be classified through statistical and graphical methods to relate specific clast fabric characteristics to depositional environments (Woodcock, 1977; Rappol, 1985). A graphical method (Woodcock, 1977) is shown in Figure 6. It uses the natural logarithms of the ratio between the S1 and S2 (y-axis) and that between the S2 and S3 (x-axis) to identify the strength and degree of cluster. Fabrics plotting in the upper left of the diagram are strongly clustered and may represent undisturbed basal meltout and lodgement tills, whereas those in the lower right represent weak, girdle fabrics that may indicate resedimented tills and debris flows (Woodcock, 1977). A similar approach is used by Woodcock (1977) and Dowdeswell and Sharp (1986), in a plot of S1 *versus* S3 eigenvalues (Figure 7). Although overlapping envelopes of potential depositional environments are presented, clast fabric is only one of multiple indicators, including lateral and vertical association with other sedimentary units, sedimentary structures, and stratigraphy that are used to interpret sediment genesis (Batterson, 2003).

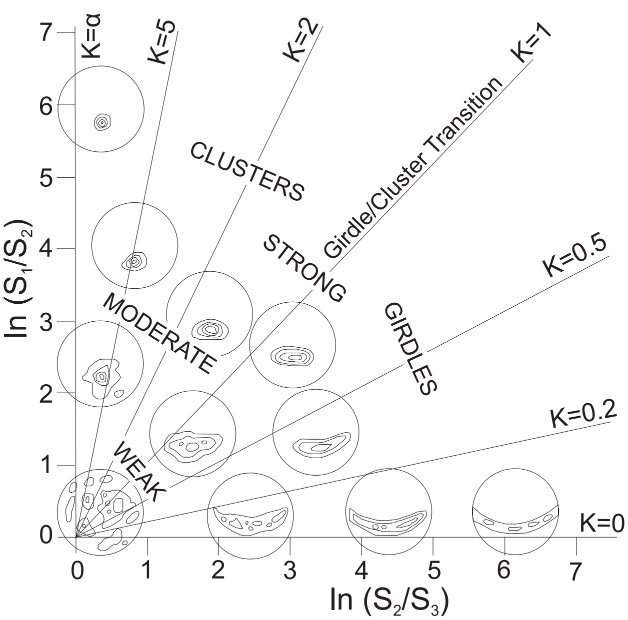

Figure 6. *Description of fabric shape for 2009 clast fabric data (after Woodcock, 1977).*

RESULTS

SURFICIAL GEOLOGY

Data from 2009 indicate that the surficial geology of the southwest part of RILB contains glacial diamicton, sand, gravel, silt and clay. Overburden thickness ranges from 1 to

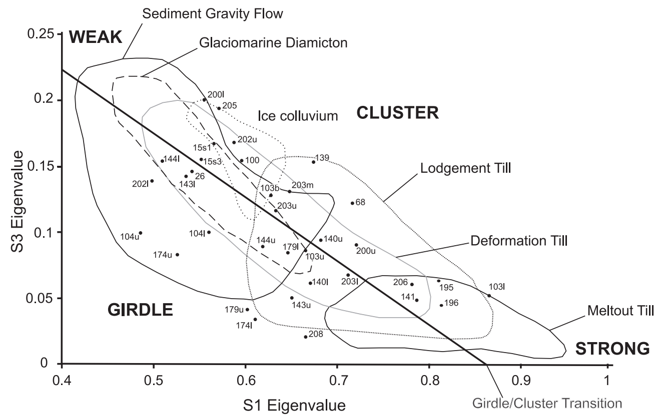

Figure 7. *Plot of S1* versus *S3 eigenvalues from diamictons deposited in different environments (modified from Dowdeswell and Sharp, 1986). The letters l, m, and u refer to lower, middle and upper for sites where more then one diamicton was identified.*

55 m, thicker at the southwest end of Red Indian Lake. Naturally exposed sections or excavated sites in areas of thick overburden commonly contain more than one sediment type (*e.g.*, sand, gravel, silt, diamicton). Individual sediment types are described below.

1. Diamicton

In the southwest part of RILB, diamicton is typically thick (2 to 6 m), and is composed of locally derived sediment that commonly forms a blanket over the underlying terrane; northeast of Costigan Brook, diamicton is up to 4 m thick.

The texture and colour of the surface diamicton vary considerably throughout the field area, and is the result of up-ice changes in bedrock geology. The surface diamicton is typically dark brown (Munsell 7.5YR 4/4), but ranges from reddish brown (5YR 4/4) to dark yellowish brown (10YR 4/4). The matrix is silty sand to sandy silt. Clast content within the diamicton is 25–30%; clast sizes average 2 cm, up to a maximum of 3.5 m. Clasts are very angular to subrounded (median of subangular), and are commonly striated and faceted; most comprise local rock types, however, peralkaline granites from the Topsails Plateau are also common.

In section, more than one diamicton unit is commonly exposed. Between Tulks Brook and Harbour Round, a distance of 15 km, three separate excavated pits (sites 200, 203, 204; Figure 8) each contained three diamicton units, with similar sedimentary characteristics. A generalized description of the three diamicton units at site 203 is given below.

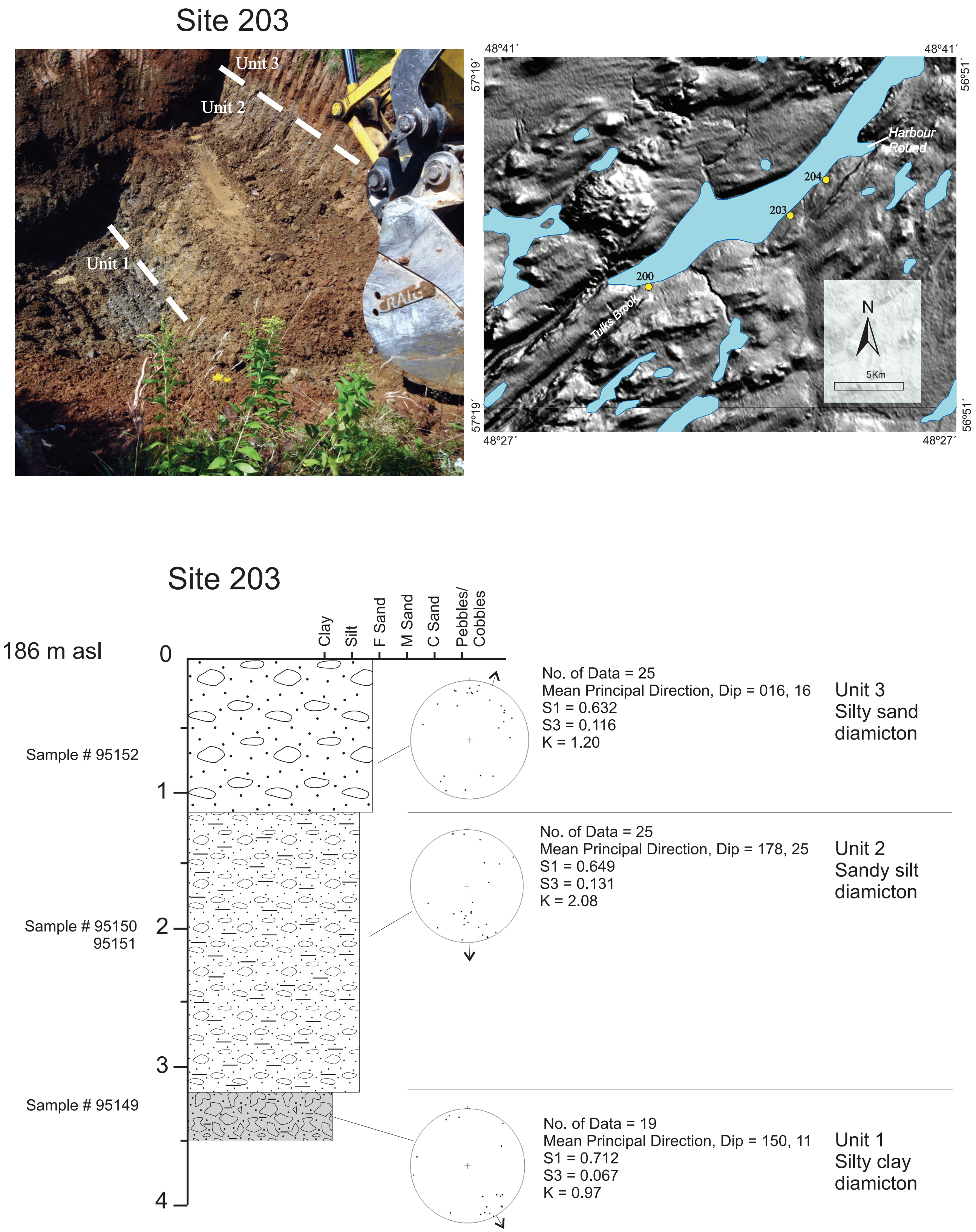

Figure 8. *Map showing location of sites with 3 diamictons. Photograph showing three diamictons identified at site 203. Sample locations are given by the sample numbers on the left of the stratigraphic column. Mean principal direction is marked by the arrow on the clast fabric diagram.*

Unit 1

The lowest diamicton (Unit 1) is a compact, light brownish-red (2.5Y 6/2) sediment, with a silty clay matrix containing minor fine sand. The unit contains 15–20% clasts, which are angular to subangular (median of subangular), commonly striated, and range from 0.2 to 30 cm diameter with a mean of 3 cm. The unit is generally structureless, except for well-sorted, randomly distributed, irregularly shaped silty clay inclusions. The size of the inclusions was not noted. Due to continuous slumping, only 19 pebble were measured for clast fabric. They provided a strong S1 (0.71), and a K value of 0.97, with a mean principal direction (mpd) of 150º.

Unit 1 is interpreted as a basal till, likely lodgement. This is supported by its poor sorting, compaction, clast angularity, striated clasts and strong clustered fabric (Woodcock, 1977; Dreimanis, 1988; Bennett and Glasser, 1996). The clast fabric for this unit also falls within the meltout envelope on Figure 7; however, the lack of sedimentary structures (*e.g.*, sorted lenses) does not support this interpretation. The clustered fabric, with dip angles greater than ten degrees, is typical of a basal till (Woodcock, 1977; Dowdeswell and Sharp, 1986; Dreimanis, 1988; Bennett and Glasser, 1996).

Unit 2

This diamicton is overlain (contact not observed due to slumping), by a 110-cm-thick yellowish brown (10YR 5/4), structureless, fine sandy silt diamicton. It contains approximately 30% clasts that range from 0.2 to 100 cm diameter, with a mean of 5 cm. Clasts are of local rock types, and are angular to subrounded (median of subangular). Clast fabric data produce a moderately clustered fabric with S1 of 0.65, and K values of 2.08, with an mpd of 178º.

Unit 2 is interpreted as a basal till, similar to Unit 1. This is supported by its compaction, poor sorting, angular clasts and the moderately strong clustered clast fabric (Woodcock, 1977; Dreimanis, 1988; Bennett and Glasser, 1996). The lack of sedimentary structures does not support a meltout till interpretation.

Unit 3

Unit 2 is overlain across a sharp and undulating contact by a very compact, fissile, yellowish red (5YR 4/6) sediment with a silty sand matrix. This unit contains 15% clasts, ranging in size from 0.2 to 5 cm diameter (mean 2 cm). Clasts are angular to subrounded (median of subangular). The clast fabric is moderately clustered with S1 and K values of 0.63 and 1.2, respectively, with an mpd of 016º.

Unit 3 is interpreted as a basal till. This is supported by its poor sorting, compaction and fissility (Woodcock, 1977; Dreimanis, 1988; Bennett and Glasser, 1996). The moderately clustered clast fabric and moderate dip are suggestive of a lodgement till (Dowdeswell and Sharp, 1986).

Relation to Ice Flow

Diamictons exposed at sites 103, 141, 195, 196, 203 (lower diamicton) and 206 (Figure 9) contain local clasts, are very compact, exhibit a moderate to strong fissility, and are also associated with strong S1 eigenvalues (>0.72) and K values greater than 1.28. These are interpreted as basal tills. Mean principal directions range from 124 to 148º. The stratigraphically lowest diamictons and/or those directly overlying bedrock had an mpd parallel to the earliest, southeastward, ice-flow direction (Phase 1) of Smith (2009).

Other Diamicton Units

Diamicton units with characteristics not consistent with deposition within a basal glacial environment are also common throughout the southern part of the RILB. Site 104 is located in a road cut immediately east of Star Lake Brook on the north side of Red Indian Lake (Figure 10). The section is approximately 5 m thick and is in contact with bedrock to the east, and is composed of a structureless diamicton having a loose sandy silt matrix, containing 30% clasts ranging in size from 0.5 to 25 cm. Clasts are striated and are very angular to rounded (median of subangular). Two clast fabrics taken from the upper and lower parts of the exposure show similar weak, girdle distributions with S1 values of 0.49 and 0.56, and K values of 0.11 and 0.41 respectively.

This diamicton is interpreted as a sediment gravity flow deposit. This is supported by the weak, girdle fabrics (Figure 7). Although sediment gravity flows typically display a range of sedimentary structures, it is not uncommon for them to be massive and structureless (Dreimanis, 1988).

Diamictons identified at sites 26, 103b, 144, 174, 200 and 202 are typically structureless and have a silty sand matrix with clast content ranging from 15–25%. Clasts are subangular to subrounded and are commonly striated. The girdle distributions observed in clast fabrics measured at these sites (Figure 9) suggest that these diamictons are also the result of sediment gravity flow. Clast orientations at sites 103b and 174 are upslope, suggesting deposition by gravity-induced sediment movement initiated from an ice margin.

2. Glaciofluvial

Glaciofluvial deposits, comprising sand and gravel, are typically found in the bottoms and sides of river valleys,

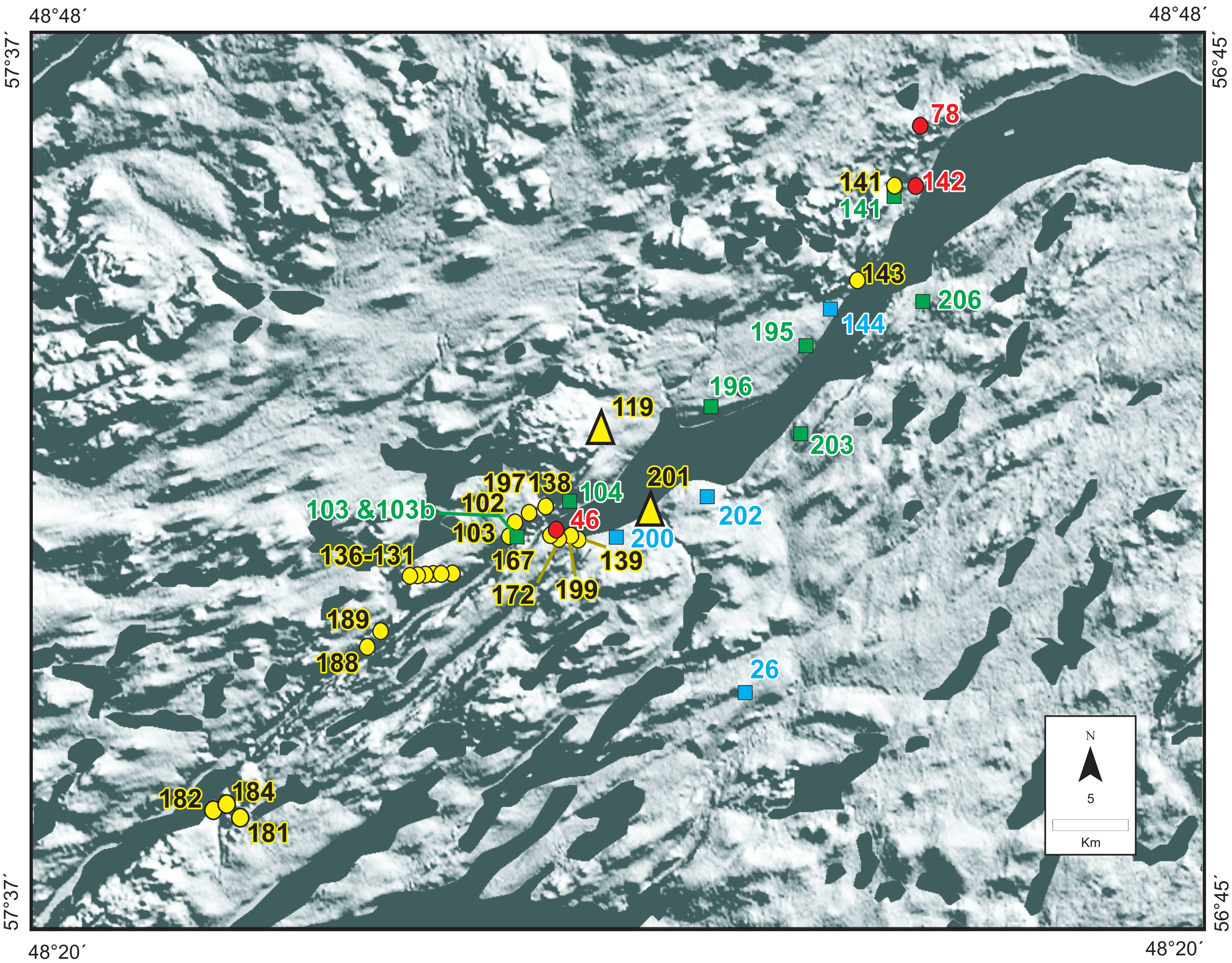

Figure 9. *Map showing the location of diamictons, glaciolacustrine sediments and shoreline features mentioned in the text. Yellow dots represent fine-grained glaciolacustrine sediments, red dots represent coarse-grained glaciolacustrine sediments and yellow triangles the location of deltas. Green and blue squares show the locations of diamictons interpreted as basal till and sediment gravity flow, respectively.*

e.g., Lloyds River, Tulks Brook, and Costigan Brook; however, they are also found in isolated areas away from modern river valleys (sites 78 and 119).

There is considerable intra- and inter-site variability in the composition of glaciofluvial material, which may be clast- or matrix-supported. The matrix varies from fine sand to granule gravel, and contains little to no silt–clay. Clast-supported beds are typically moderately to well-sorted, granule gravel to pebble gravel. Matrix-supported beds are moderately- to well-sorted, fine sand to granule gravel. Beds may be horizontal or crossbedded, and are 1 to 10 cm thick. Glaciofluvial deposits can form veneers (less than 1.5 m thick) or blankets (more than 1.5 m thick). They overlie fine sand and silt interpreted as glaciolacustrine deposits and are, in places, overlain by remobilized till.

3. Glaciolacustrine

Deposits interpreted as glaciolacustrine include both fine- and coarse-grained sediments and have been identified between 167–346 m asl within the RILB.

Fine-grained Sediments

Seventeen sites containing fine-grained sediments (medium- to very fine-sand and silt) were found on the north side and at the southwest end of Red Indian Lake, along the Lloyds River valley and in the Lloyds Lake area (Figure 9). Many of these deposits were found adjacent to brooks or rivers emptying into Red Indian Lake. Typical exposures, illustrated by sites 141 and 103, are described below.

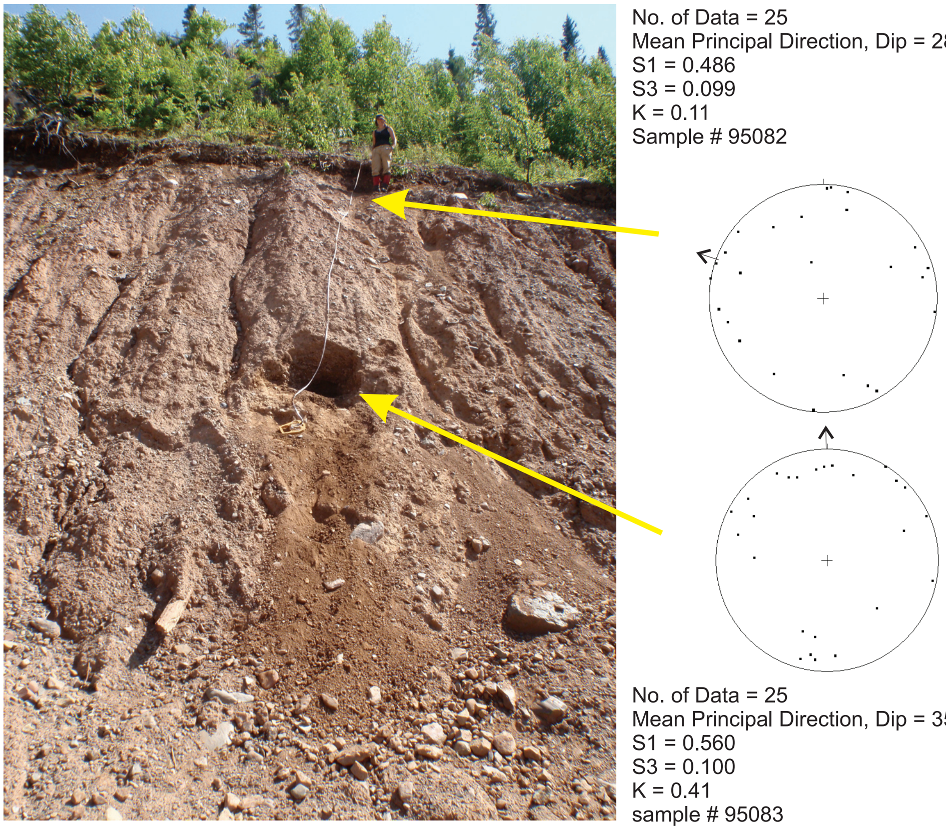

Figure 10. *A 5 m section interpreted as a sediment gravity flow from site 104 on the north side of Red Indian Lake. Sample and clast fabric locations are noted.*

Site 141

Site 141 is located on the north side of Red Indian Lake at 206 m asl (Figure 11). The lowermost unit is interpreted as a basal till that overlies bedrock (*see* above). This is overlain across a sharp and irregular contact by a 7-cm-thick bed of clayey silt that contains nodules of fine- to medium-sand. This is overlain by a 1.23-m-thick unit of laminated to bedded, fine sand, medium sand and silt (Figure 11). Medium-sand beds typically grade upward to silt and contain ripples and crosslaminations. Contacts between beds are sharp. Beds range in thickness from 0.5 to 4 cm and are convolute. Ripples, crosslaminations, loading structures and rip-up clasts were identified. The upper 80 cm is composed of predominantly medium-grained sand, with laminations of fine sand and silt.

These fine-grained sediments are interpreted to have been deposited in a proglacial lake. The lack of coarser material suggests deposition was distal from the input source. Convolute laminations, rip-up clasts and loading structures indicate deposition by turbulent underflow currents as sediment entered the basin, whereas the silt and clay fraction is an indication of deposition as a result of suspension settling between underflow currents (Boggs, 1995; Benn and Evans, 1998).

Site 103

Site 103 is located close to the mouth of Lloyds River at Red Indian Lake (Figure 12). It is a 19 m section, of which only the upper 7.10 m is exposed due to slumping. The lowest 1.05 m exposure consists of fine- to coarse-sand that contains rare fine sand and silt laminations. Randomly distributed, subangular cobble clasts are present, but rare. This is overlain by 10 cm of fine sand with convolute silt laminations. A 40 cm bed with a medium- to coarse-sand matrix, containing 0.5-20-cm-diameter clasts, overlies a sharp contact with the fine sand bed. The thickest unit (1.85 m) is an interbedded medium sand and silt-fine sand. Medium-sand beds are 1 to 10 cm thick, whereas those of silt-fine sand are 5 to 17 cm thick. Contacts between beds are sharp, irregular, and commonly contain flame structures. The upper 3.70 m is a pebble cobble to silty sand diamicton.

These sediments are interpreted to have been deposited in the distal part of a proglacial lake, similar to site 141. The fine-grained convolute laminations suggest that these sedi-

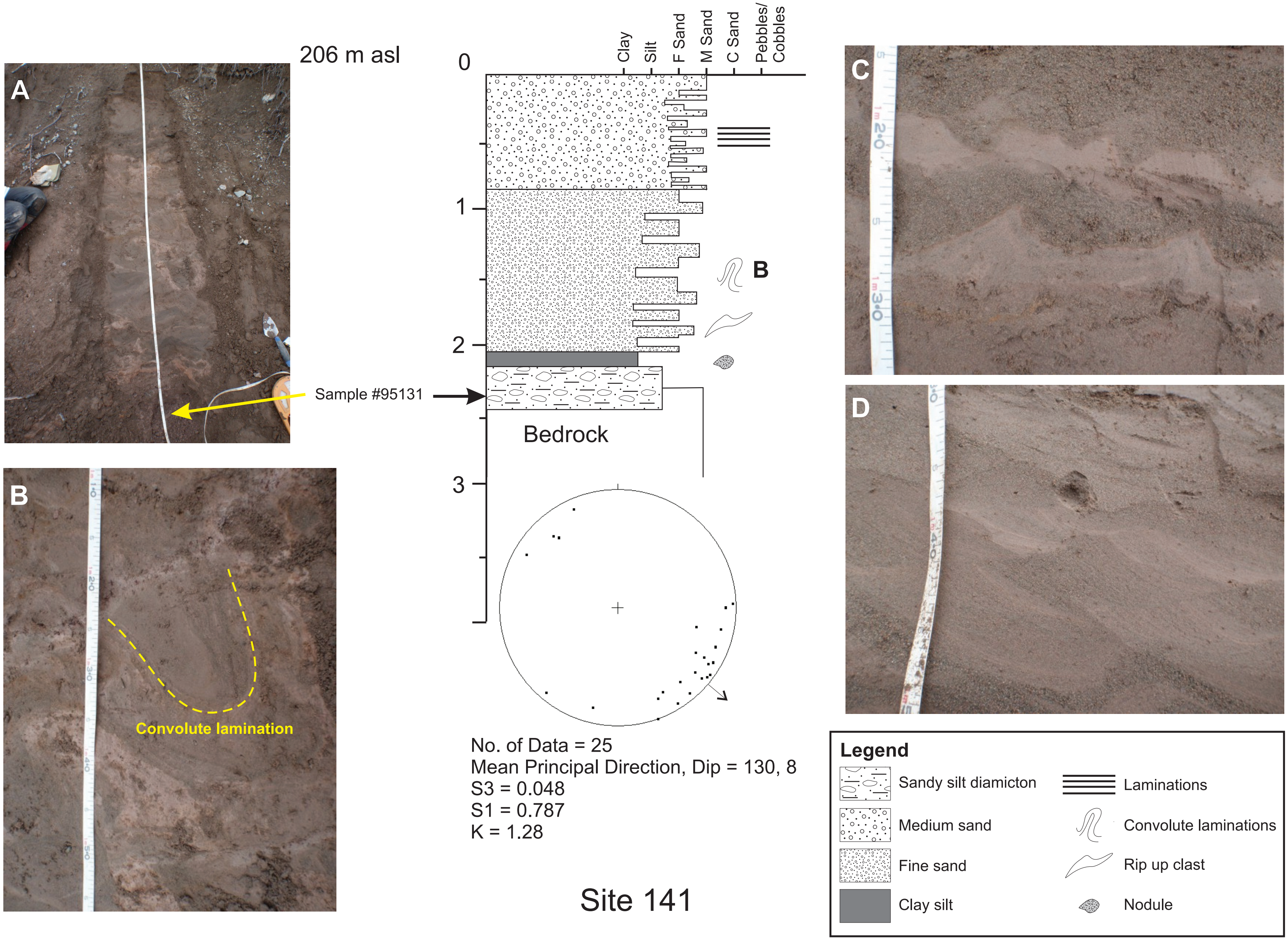

Figure 11. *Photograph (A) and section describing fine-grained sediments at site 141. Photograph B, is an example of convolute laminations. Photographs C and D are taken from sections on either side (2 m) of the one shown here and show load casts and cross-laminations, respectively.*

ments were waterlain, and that deposition occurred quickly as underflow currents carried sediments to distal parts of the basin (Boggs, 1995; Benn and Evans, 1998). The randomly distributed clasts within the interbedded medium sand and silt-fine sand are interpreted as ice-rafted dropstones. The interbedded medium sand and silt-fine sand are the result of underflow currents and suspension settling forming a repetitive sequence interpreted as rhythmites. Typically, rhythmites are indicative of seasonal fluctuations in sediment discharge from glacial ice (Boggs, 1995); however, considering the steep valley slope on which these sediments are found, it is likely that slope instability was critical in their formation. Irregular sand beds and loading structures within the silt are indicative of rapid deposition (Benn and Evans, 1998). The repetitive sequence identified would have been formed by multiple underflow currents and suspension settling events.

Coarse-grained Sediments

Coarse-grained sediments were found at site 119 located approximately 3 km from the shoreline on the north side of Red Indian Lake between Shanandithit Brook and Star Lake Brook at 300 m asl (Plate 1). The 50-m-wide exposure is found in a small borrow pit on an east-facing slope, away from any modern stream environment. The top of the pit has been grubbed off, leaving a 3.4 m section. The lower 0.65 m is interbedded fine to coarse sand that contains less than 5% pebbles and dips 15 to 24º, toward 125º. Contacts between beds are typically sharp. Clasts are subrounded to subangular, and are typically less than 3 cm diameter. This unit is overlain by 0.95 m of pebble gravel and fine- to coarse-sand beds that dip about 5º toward 130º. Contacts between beds are gradational. The pebble gravel is clast-supported in places and contains rare cobbles. Clasts are subangular to subrounded, and are 1 to 10 cm diameter. The upper 1.8 m is composed of horizontally bedded, clast-supported pebble- to cobble-gravel, with a medium-sand matrix. Clasts are 0.2 to 50 cm diameter, and are subangular to rounded.

Sediments within the section are interpreted as having been deposited in the delta of a proglacial lake with a surface elevation of 300 m asl. This is supported by the morphology of the section on a hillside, and the presence of dipping beds (interpreted as foreset bedding) overlain by horizontal beds (interpreted as topset beds). Foreset and topset beds are features of a classic Gilbert-type delta (Benn and Evans, 1998). An alternative interpretation as a kame is rejected because of the lack of internal folding and faulting, which would result from melting of supporting ice (Benn and Evans, 1998).

The thickest coarse-grained glaciolacustrine deposit (7 m) is found on the east side of Costigan Brook, approximately 500 m upstream of the Red Indian Lake shoreline (site 201; Plate 2). The lower 5 m is loose, coarse sand to granule gravel, containing clasts up to 35 cm diameter. The clasts are commonly contained within steeply dipping beds (~30º toward ~220º). The upper 2 m is composed of horizontally bedded, medium- to coarse-sand that contains 35–45% clasts. Sediment is clast-supported in places and clasts are typically subangular to rounded, ranging from 0.2 to 70 cm diameter (Plate 2). The steeply dipping beds are interpreted as foreset beds overlain by horizontal topset beds, representative of a classic Gilbert–type delta (Benn and Evans, 1998). Beds dipping toward Red Indian Lake were also measured in an exposure 100 m downstream and at 10 m lower elevation, and suggest that the water and sediment source was down Costigan Brook.

Plate 1. *Delta identified at site 119, which is at an elevation of 300 m asl.*

EVIDENCE FOR PROGLACIAL LAKE DEVELOPMENT IN THE RED INDIAN LAKE BASIN

The presence of both distal and proximal glaciolacustrine sediments, raised deltas and strandlines are all evidence for proglacial lakes. Although raised deltas and stran-

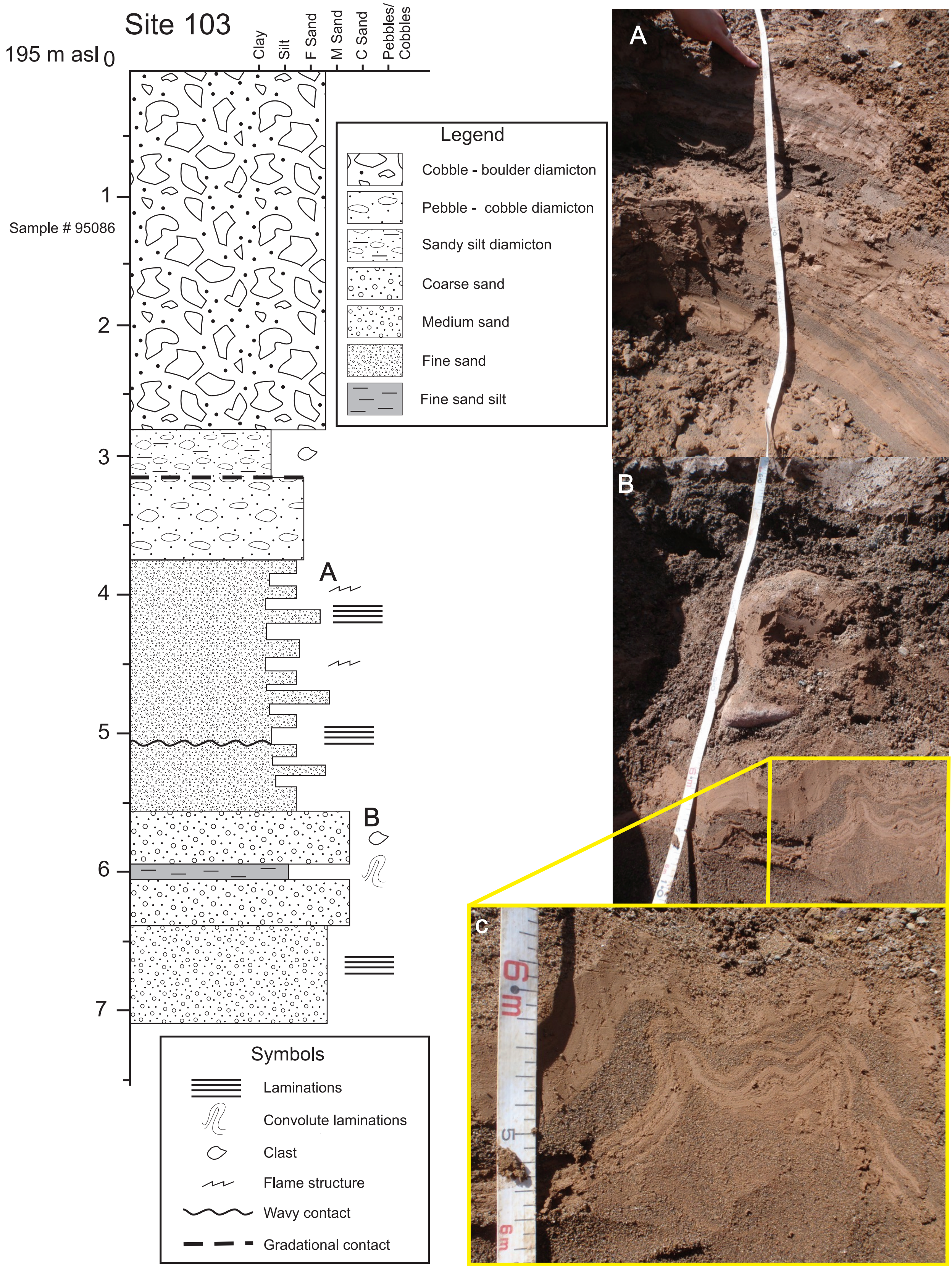

Figure 12. *Photograph and section describing fine-grained sediments at site 103. Photo A shows interbedded medium sand with fine sand to silt. B) A subangular cobble clast interpreted as a dropstone. C) Convolute laminations of fine sand to silt.*

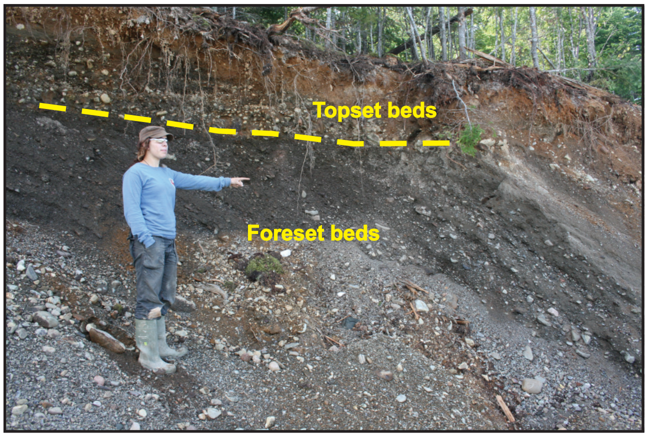

Plate 2. *Delta at Costigan Brook (site 201) at an elevation of 200 m asl.*

dlines provide data on lake level, the presence of silt and interbedded sand only indicate that water levels were higher. Figure 13 is a plot of the elevations of sites containing glaciolacustrine sediments or features, projected on a line along the central axis of the RILB extending from the end of Lloyds Lake to the northeast end of Red Indian Lake.

Eleven of the sites are found at the southwest end of Red Indian Lake, 8 in the Lloyds River valley, 3 near Lloyds Lake and 4 found 15 km southwest of Buchans. On the south side of Red Indian Lake, sites containing glaciolacustrine sediments are common between Lloyds River and Costigan Brook. Similarly, Mihychuk (1985) described a well-developed strandline in the Victoria River area at 212 m asl. The distribution of glaciolacustrine sediment–features is discontinuous on the north side of Red Indian Lake; no data is recorded between site 119 and 143. The discontinuous nature of glaciolacustrine sediment was noted by Klassen and Murton (1996) who provided evidence for a 300-m asl proglacial lake of unknown dimensions at Buchans, based on exposures of fine-grained sand and silt.

Based on observations during the 2009 field season and previous research, three phases of proglacial lake development are identified for the southwest part of Red Indian Lake.

Phase 1

The highest (and earliest) phase of proglacial lake development is identified by interbedded silts and very fine sand found between 303 m asl and 346 m asl (sites 131 to 136) above the Lloyds River valley. These sediments indicate proglacial lake(s) above these elevations. No correlative sediment has been identified on the south side of the valley, and thus it is assumed that the lake was impounded by ice in the Lloyds River valley. The presence of rare dropstones and lack of coarse material associated with the rhythmites indicate that the contribution of debris was distal to the main area of inflow.

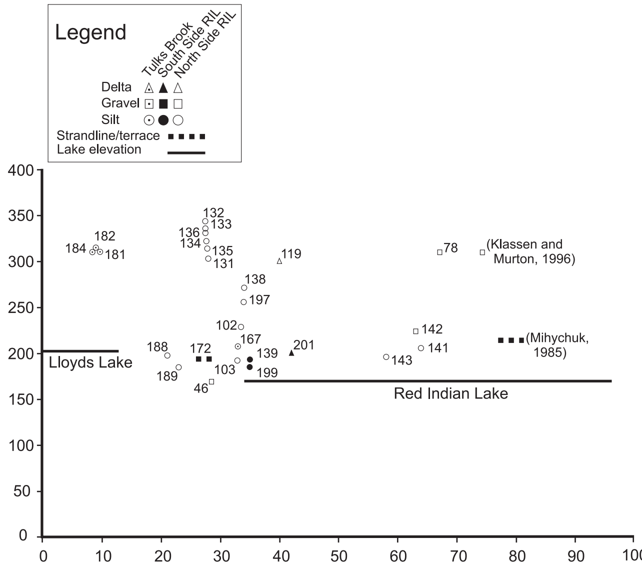

Figure 13. *Elevation of glaciolacustrine sediment, and shoreline features against distance along RILB.*

Phase 2

The delta at 300 m asl (site 119) provides a surface level of the proglacial lake associated with the delta (Phase 2). Sites 138 (272 m asl), 197 (256 m asl) and 141 (224 m asl) record the deposition of finer-grained sediment via suspension settling in areas of deeper water, *i.e.*, 28-44 m, which may be associated with this phase. Glaciolacustrine sediment at Buchans described by Klassen and Murton (1996) may be related to that identified in the southwest part of Red Indian Lake. The lack of evidence for a 300-m asl proglacial lake on the south side of Red Indian Lake suggests that this area was ice covered during Phase 2. Elevation was controlled by outflow through Lloyds River valley.

Phase 3

The Costigan Brook delta identified at 200 m asl represents the lowest phase of proglacial lake development in the RILB. Silt and fine-sand deposition was identified at 4 sites between Costigan Brook delta and Lloyds River, which may be associated with this phase. The Exploits River likely was the drainage outlet for the 200-m asl proglacial lake, as its outlet is at a lower level than Lloyds River, and indicates that deglaciation had exposed this lower outlet.

Although separate phases of proglacial lake development can be identified from the features and sediments in the RILB, the extent, and timing of formation and drainage of proglacial lakes are yet to be resolved. Data collected by Vanderveer and Sparkes (1982) from the Lloyds River area suggest that the proglacial lake formed after the southward flow and before the northeast-southwestward flow. Klassen and Murton (1996) suggested that the timing of deposition of glaciolacustrine sediments at Buchans occurred after the northeast-southwestward flow. However, neither of these interpretations has been substantiated by the dating of buried organics and these therefore represent relative ages only. Further mapping along the 200 and 300 m contours within the RILB, and additional backhoe work, should provide the evidence needed to determine the extent of these phases of proglacial lake development.

CONCLUSIONS

The stratigraphy of southwest RILB comprises diamicton, sand, gravel, silt and clay. These sediments represent deposition by glacial ice, modification by meltwater, and deposition within proglacial lakes.

Diamictons identified in the field are all interpreted as late Wisconsinan. Using sedimentary structures and clast fabrics, diamictons were classified as lodgement till, meltout till or sediment gravity flows. The mean principal directions of strongly clustered fabrics commonly corresponded to the ice-flow chronology of Smith (2009).

During deglaciation, meltwater deposited gravel and sand in valleys, that was later modified by modern fluvial processes. Proglacial lakes were identified on the basis of raised deltas identified at 300 m and 200 m asl, strandlines at ~212 m asl, and fine-grained sediments deposited by suspension settling or underflows. These data suggest that there were three phases of proglacial lake development:

- Phase 1: This represents the highest lake level, the minimum elevation of which is indicated by deposition of interbedded silt and very fine sand at 303-346 m asl (sites 131 to 136).
- Phase 2: Records the formation of the delta at 300 m asl (site 119) on the north side of Red Indian Lake.
- Phase 3: Records the formation of the delta at 200 m asl (site 201) on the south side of Red Indian Lake.

Further mapping of the 200 and 300 m contours around Red Indian Lake and examination of additional sections should provide more evidence needed to determine if these lake phases were contiguous or the result of a series of small, unrelated ice-marginal ponds.

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